Carnegie Mellon University
SPACE ARCHITECTURE

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

Kriss J. Kennedy
Architect
Building an Atmosphere

Building Inflatables/ Inflatable Construction: Planning and Details
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 Lunar Habitat

DESIGNED 1992
Mars Base & Mission Planning 1996
Mars Surface Hab/Combo Lander

DESIGNED 2000

MARS SURFACE HABITAT CROSS SECTION
Mid-Expandable Habitat Concept

Designed 2008
TransHAB Inflatable Prototype Module
Space Architecture
NASA TransHab Concept

- TransHab was a lightweight inflatable habitation module for space applications.
- Original 1997 concept for lightweight 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

DESIGNED 1997
Transportation Constraints

- TransHab Launch Package
- Inflated TransHab
- Robotic Arm Removal & Installation on ISS
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

Level 4: Pressurized Tunnel

Level 3: Crew Health Care

Level 2: Crew Quarters and Mechanical Room

Level 1: Galley and Wardroom

Hatch Door
Inflatable Shell
Central Structural Core
20” Window (2)
Integrated Water Tank
Soft Stowage Array
Wardroom Table
TransHab Specs

- Overall Length = 10.5 m
- OA Deployed Width = ~8.3 m
- Internal Diameter = 7.6 m
- Packaged volume = 342 m³
- Deployed volume = ~161 m³

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 = 446 ft³ (12.63 m³)  
 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 Overview

- Pressurized Cone
- Multi-Layer Inflatable Shell
- Mid Section
- Un-Pressurized Cone
Deployed Internal Structure Overview

- Inflatable Compression Ring
- Composite Longerons
- Composite Shear Panels / Shelves
- Composite Deployable Beams
- Fabric Tension Floors
- Inflatable Stiffeners
Subsystems Packaged in Core

- Avionics Packages
- Life Support Systems
- Longerons
- Area for Packaged Consumables and Outfitting Systems
- Core Panel Shelves
- Core Panel Shelves (Sheer Panels-Stiffeners)
Multi-Functional Layered Inflatable Pressure Shell

- MOD Shielding
- Structural Restraint Layer: Kevlar or Vectran
- Redundant Bladders
- External Thermal Blanket
- Internal Scuff Barrier
- 2 Windows
Multi-Layer Shell Configuration Overview

MLI Layer

AO Cover

TransHab Exterior

Deployment System

MMOD Shielding

Restraint Layer

TransHab Interior

Inner Liner

Redundant Bladders
Inflatable Restraint Layer

“basket weave” manufacturing approach. Manually labor intensive and many opportunities for human error.
Packaging & Folding

Fold Over each Gore
Folded Shell Gores x 7

Bulkhead

Tunnel

Push in every third Gore

Fixture needed to push fabric to fold line
Notional Shell Structural Interface

- Clevis (1 of 310)
- Bladder attach ring
- Bladder peel guard

Layers:
- Restraint Layer
- Silicone
- Bladder
- Bleeder Cloth
- RTV Bond Line

Top Bulkhead
Notional Window Detail

- Bladder Ring
- Exterior Cover
- Load Frame, Clevises, Hand Holds
- Interior Cover
- Scratch Pane
- Pressure Panes
- Debris Pane
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.
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

- MMOD
- Tunnel Fairing
- Restraint Layer
- Triple Redundant Bladder
- Core Fairing
- Support Stands
- Tunnel Fairing and Support Spacer
- Core Structure
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
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
Galley / Wardroom Area

Key Plan

- ISS Rack
- Wardroom
- Galley
- ISS Rack
- Refrig/Freezer
- Soft Stowage
- Table
- Wardroom Area
- Galley Area
- Hand Wash Utility
- CHASE 'A'
- CHASE 'B'

Integrated Floor Strut into Fabric Floor Above
Leave Floor Open for Return Air to Mech Rm. Above

Soft Stowage System

Wardroom Table
Leave Floor & Clg. Open for Return Air to Mech Rm.

Integrated Floor Strut into Fabric Flooring

MECHANICAL ROOM

CQ #1
CQ #5
CQ #4
CQ #6

Pass Thru to Below

Door

ISS Rack

Inflatable Outfitting

Compression Ring

OPEN TO WARD-ROOM BELOW
OPEN TO WARD-ROOM BELOW
OPEN TO WARD-ROOM BELOW
OPEN TO WARD-ROOM BELOW
OPEN TO WARD-ROOM BELOW
OPEN TO WARD-ROOM BELOW

42" Passage to Galley

WATER TANK

FLOOR STRUT

INFLATABLE OUTFITTING

COMPRESSION RING

 zenith

nadir

forward

aft

LEVEL 2

LEVEL 2

Leave Floor & Clg. Open for Return Air to Mech Rm.
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

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

SOUND ABSORBENT & FIRE RETARDANT FABRIC CEILING

SOUND ABSORBENT & FIRE RETARDANT FABRIC FLOORING

MECHANICAL ROOM
Crew Health Care Area

EXERCISE AREA

Tread mill
Ergometer

Level 4: Pressurized Tunnel to ISS

Soft Stowage System

Sound Absorbent & Fire Retardant Fabric Flooring

CHECS

KEY PLAN

EXERCISE AREA

Sound Absorbent & Fire Retardant Fabric Flooring