S3-39

O4C142

Habitats and Surface Construction Technology and Development Roadmap

Marc Cohen
NASA Ames Research Center
Moffett Field, CA

and

Kriss J. Kennedy
Johnson Space Flight Center
Houston, TX

Habitats & Surface Construction Technology & Development Roadmap

Presented to the
AIAA Structures Technical Committee
Hampton, VA

September 4, 1997

Marc Cohen / NASA ARC
mcohen@mail.ARC.nasa.gov
Kriss J. Kennedy / NASA JSC
kriss.j.kennedy1@jsc.nasa.gov

Top Level Strategy for Habitats & Surface Construction

- GOAL: Sustain human presence on Mars.
- TARGET: Provide habitation and surface infrastructure to support humans on Mars on a long term basis.
- PLAN: Provide the capability to produce and construct habitats and surface facilities using indigenous resources.
- RATIONALE: Open Mars to long-term planetary exploration by humans with the eventual settlement of humans on Mars.
- INITIAL PRODUCTS: Initial human mission using relevant habitation technologies. ISRU resource demonstrations, i.e. material extraction and benefaction for processing.

Executive Summary

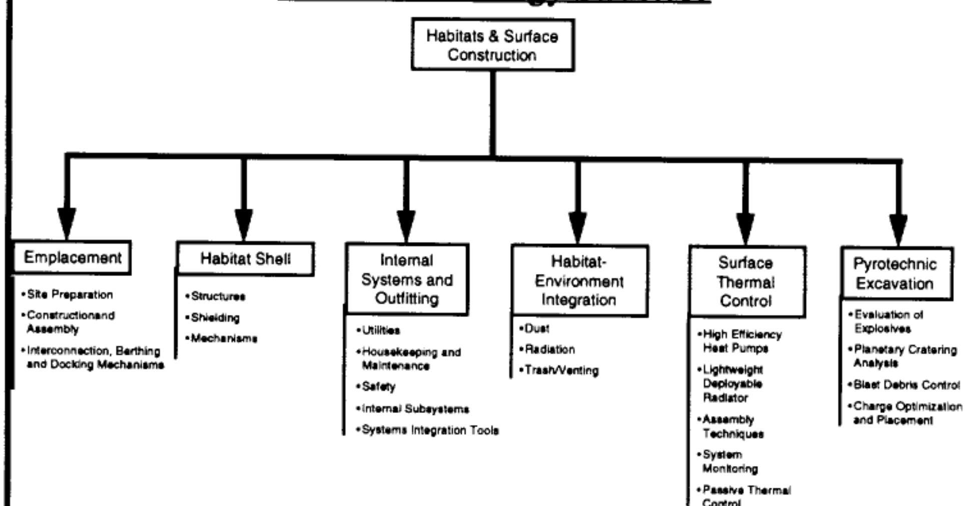
- Vision

  Provide the capability for automated delivery and emplacement of habitats and surface facilities.
- Benefits
  - Composites and Inflatables: 30 - 50% (goal) lighter than Al Hard Structures
  - Capability for Increased Habitable Volume, Launch Efficiency
  - Long Term Growth Potential
  - Supports initiation of commercial and industrial expansion.
- Key H&SC Technology Issues
  - Habitat Shell Structural Materials
  - Seals and Mechanisms
  - Construction and Assembly: Automated Pre-Deploy Construction Systems
  - ISRU Soil/Construction Equipment: Lightweight and Lower Power Needs
  - Radiation Protection (Health and Human Performance Tech.)
  - Life Support System (Regenerative Life Support System Tech.)
  - Human Physiology of Long Duration Space Flight (Health and Human Performance Tech.)
  - Human Psychology of Long Duration Space Flight (Health and Human Performance Tech.)
- What is Being Done?
  - Use of composite materials for X-38 CRV, RLV, etc.
  - TransHAB inflatable habitat design/development
  - Japanese corporations working on ISRU-derived construction processes.
- What Needs to be Done for 2004 Go Decision
  - Characterize Mars Environmental Conditions: Civil Engineering, Material Durability, etc.
  - Determine Credibility of Inflatable Structures for Human Habitation
  - Determine Seal Technology for Mechanisms and Hatches, Life Cycle, Durability

H&SC Team 09/02/97

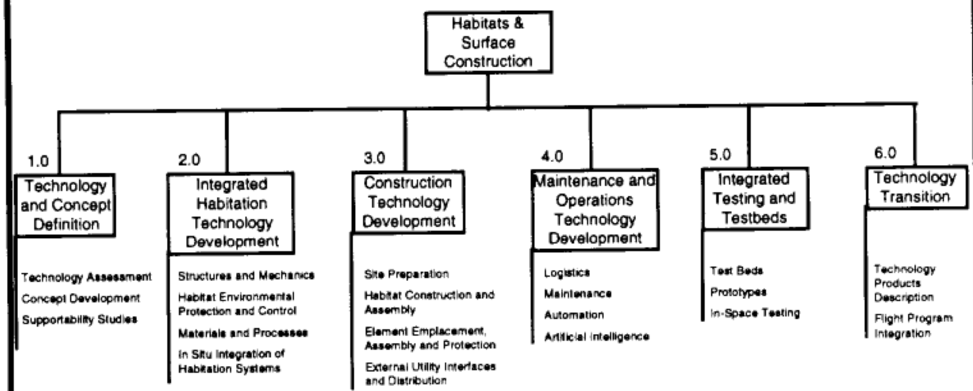
HEDS Technology Planning — Habitats & Surface Construction

H&SC Technology Structure



H&SC Team 09/02/97

H&SC WBS



H&SC Team 09/02/97

WBS 2.0 Integrated Habitation Technology Development

- Develop Habitat Technologies
  - Materials
  - Processes
  - Structures
  - Mechanisms
  - Radiation Protection
  - Passive Thermal Control
  - Dust Control
  - Habitat Internal Subsystem In-Situ Integration
- This Technology Development Area Addresses Items Such As:
  - Inflatable and Composite/Carbon Structures
  - Constructible Habitats
  - Water Jacket Radiation Shielding
  - Natural and Artificial Lighting
  - Joining Processes and Interfaces
  - Interior Utility Interfaces

H&SC Team 09/02/97

HEDS Technology Planning *Habitats & Surface Construction*

WBS 2.0 Integrated Habitation Technology Development Typical Products

- Pressure Shell
  - Rigid Pressure Shell Components
  - Flexible/Inflatable Pressure Shell Components
  - ISRU Product Pressure Shell Components
- Habitat Structures
  - Deployable Trusses
  - Deployable Columns
  - Quick Connect Bracing
  - Quick Release Structural Connectors
  - Mechanical Fastening Materials and Devices
- Interior Structures and Mechanisms
  - Bulkheads
  - Rack Support Structure and Components
  - Subsystem Equipment Support Structure and Components
  - Floor Support Structure
  - Foldable Decking
  - Deployable Stairs, Ramps and Elevators
- Radiation Protection
  - Loose Regolith/Soil Shielding
  - Pressure Shell Integrated Shielding
  - Sintered/Cast Basalt Shielding
  - Prefabricated Shielding
- Micrometeoroid Protection
  - Loose Regolith/Soil Shielding
  - Pressure Shell Integrated Shielding
  - Sintered/Cast Basalt Shielding
  - Prefabricated Shielding
- Ejecta Protection
  - Loose Regolith/Soil Shielding
  - Constructed Blast Shields
  - Sintered/Cast Basalt Shielding
  - Prefabricated Shielding
- Thermal Control
  - Internal Thermal Insulation
  - Reflective Coverings and Coatings
  - Integral Shielding
- Lighting
  - Natural Lighting Techniques and Equipment
  - Artificial Lighting
- Vibration Control
  - Vibration Isolation Techniques and Components
  - Vibration Dampening/Reduction Techniques and Components
  - Noise Prevention Techniques and Components
  - Noise Reduction Techniques and Components

H&SC Team 09/02/97

HEDS Technology Planning *Habitats & Surface Construction*

Robotic Construction Technology (WBS 2.5)

- Survey existing approaches to robots and their capabilities - automobile assembly, housing, etc.
- Evaluate potential for adapting construction components for robotic assembly.
- Use CAD/VR to experiment with simulated robotic construction.
- Determine appropriate levels of modularity, assembly and component packaging.
- Develop virtual user interface for directing robotic/teleoperated construction.
- Build experimental construction system with components.
- Conduct integrated robotic construction ops tests.

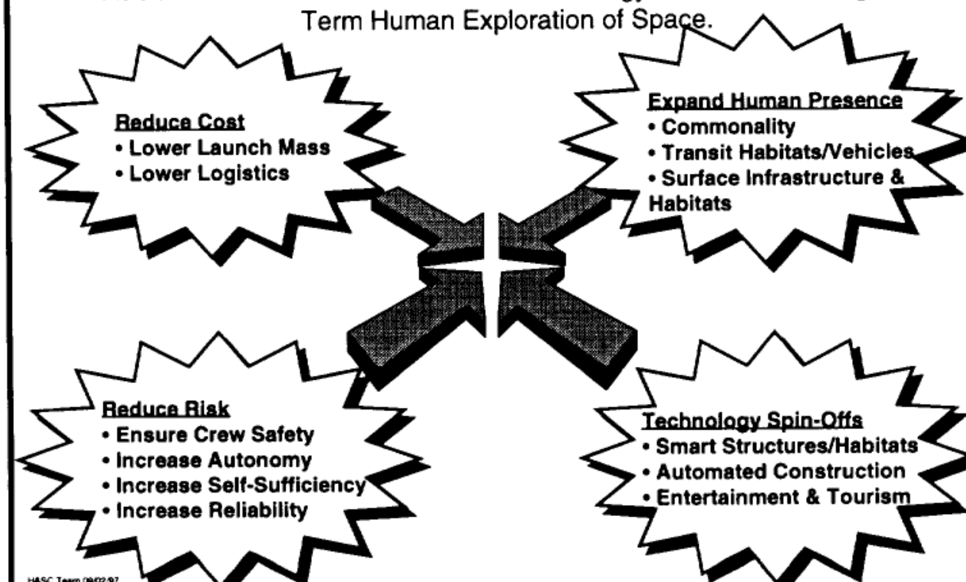
H&SC Team 09/02/97

Robotic Construction Technology Products (WBS 2.5)

- System studies of approaches to robotic/teleop construction techniques.
- Evaluation of potential for robotic methods to assemble a Lunar/Mars base.
- Develop requirements for capabilities, software, expert systems, user interface, training, hardware, end effectors, and construction components such as grapple fixtures, hard points, joints, connectors, etc.
- Design experimental prototype robotic construction system.
- Adapt hardware and software for robotic construction field testing.

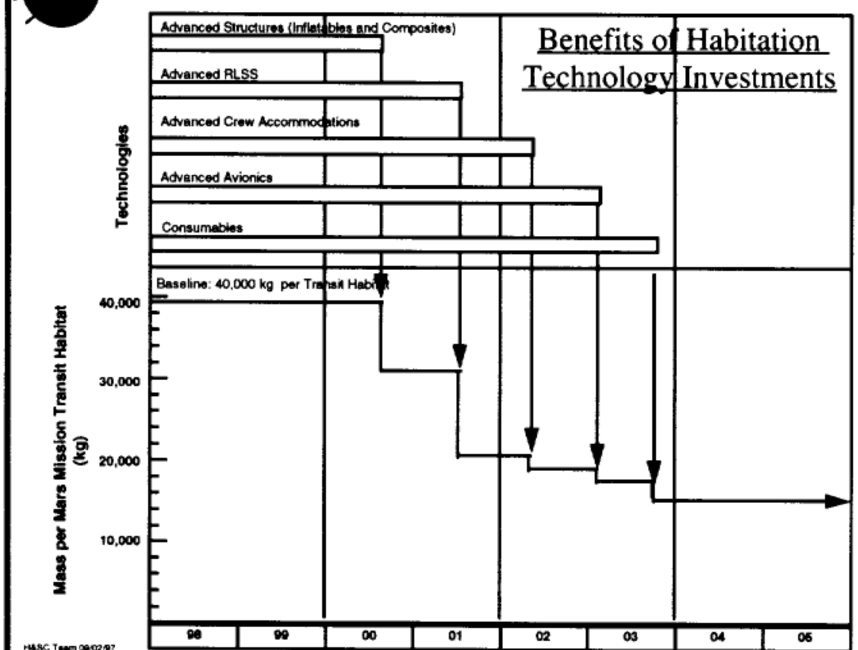
Purpose and Benefits of H&SC

Habitats and Surface Construction Technology is Crucial for Long-Term Human Exploration of Space.



HEDS Technology Planning *Habitats & Surface Construction*

Benefits of Habitation Technology Investments



H&SC Team 09/02/97

HEDS Technology Planning *Habitats & Surface Construction*

2004 Go Decision Criteria

Technology	2004 Go/ No Go Criteria	Rationale
Inflatable Structures	• Meet Human-Rating Standards • Long-Duration Environmental Tests / Survivability • Maintain Pressure Integrity	• Habitats: In Space and Surface
Advanced Composite Structures	• Meet Human-Rating Standards • Long-Duration Environmental Tests / Survivability • Maintain Pressure Integrity	• Habitats: In Space and Surface
Seals/Mechanisms	• Capability to Maintain Seal in Dust Environment • No Leaks • Long Duration Service	• Must Maintain Integrity and Long-Life in Lunar/ Mars Environmental Conditions
ISRU-Derived Structures	• Prove ISRU Structural Technology • Prove Manufacturing Process • Prove Soil Moving & Mining Processing • Prove Construction Technique Under Simulated Conditions • Prove Autonomous/Telerobotic Equipment Capability • Prove Power Efficient Techniques/ Equipment	• Support Mars Mission with ISRU Capability • Support Humans as Habitats: In Space and Surface
Artificial Intelligent Structures (Smart Structures)	• Proven Ability to Integrate A.I. Nano Technology into Pressure Shell Skin/Structure • Proven Capability for Self Diagnostics and Repair	• Habitats: In Space and Surface • Alleviate Direct Human Activities

Assumes Human Factors and Radiation Shielding by Health & Human Performance Technology.

H&SC Team 09/02/97

Criticality of Technology

Technology	Criticality	Justification/Value
Inflatable Structures	• Unproven Technology for Habitat Space Structures • Requires longer lead time and funding to meet 2003 Go Time to answer critical technology issues about materials and shell integration	Save $ • Can reduce the number of ETO Launch Vehicles by 2-3 Launches: ~ $150 - 300 M √Health† • Provides the Habitability Volume Required for Long Duration Spaceflight: Crew Psychological Health Save $ • Does Not Require New HLLV /Shuttle C to meet Volume Capability Save $ • Lower IMLEO (mass) thus Mission Cost • Impact to Mission Architecture Design and Operations
Seals	• Critical Link of Providing Contamination Control • Crew Health • System Life-Cycle, Failures	√System† • Pressure Integrity of Connections √System† • Ensures Life Cycle of Pressure Connections, Hatches & Mechanisms √System† • Protection of Lubricants and Mechanisms √Health† • Protect Humans from Dust
Advanced Composites	• Unproven Technology for Habitat Space Structures • Requires time and funding to meet 2003 Go Time to answer critical technology issues about materials and shell integration	Save $ • Can reduce the mass of a HAB by ~ 30%, thus IMLEO Save $ • Lower IMLEO (mass) thus Mission and Transportation Cost
Soil Moving Machinery	• Requires High Power and Energy Efficient Equipment • Required for Site Preparation and Clearing, Habitat Emplacement, and Radiation/ Blast Ejecta Berming	• Ensures Cleared Site for Landing, Habitat Emplacement, and Surface Mobility • Mission Failure Due to Inability to Land or Link Surface Facilities due to surface conditions • Support Long-Term Objectives of Sustained Human Presence
Mass Handling Equipment	• Requires High Power and Energy Efficient Equipment • Required for Loading and Unloading of Payloads, and Moving/Connecting Elements	• Ensures Cleared Site for Landing, Habitat Emplacement, and Surface Mobility • Mission Failure Due to Inability to Land or Link Surface Facilities due to surface conditions • Support Long-Term Objectives of Sustained Human Presence

H&SC Team 09/02/97

HEDS Technology Planning — Habitats & Surface Construction

Enabling H&SC Technology

Technology	Enables	Rationale
Inflatable Structures	• Larger HAB Volume • Inflatable Aerobrake • Inflatable Airlock	• Smaller ETO Launch Vehicles • No LEO Assembly Ops • Save HAB Vol and Packaging Vol
Seals	• Integrity of Connections • Long Life Connections, Hatches, and Mechanisms • Contamination Control	• Pressure Integrity of Connections • Ensures Life Cycle of Pressure Connections, Hatches and Mechanisms • Protection of Lubricants and Mechanisms • Protect Humans from Dust
Shell Materials	• Tolerant of Environment	• Tolerant of Long Duration Exposure to Space and Mars Environment
Advanced Composites	• Lightweight Strong Structures	• Lower Initial Mass in LEO
Soil Moving Machinery	• Site Preparation and Clearing • Habitat Emplacement • Radiation/Blast Ejecta Berming	• Ensures Cleared Site for Landing, Habitat Emplacement, and Surface Mobility
Mass Handling Equipment	• Loading and Unloading of Payloads • Moving/Connecting Elements	• Required for Base Assembly
Self-Deploying and Automated Systems	• External Shelters/Facilities • Internal System Assembly • Unmanned Cargo Pre-deployment	• Limit EVA Crew Time for Construction/ Assembly Operations

H&SC Team 09/02/97

HEDS Technology Planning *Habitats & Surface Construction*

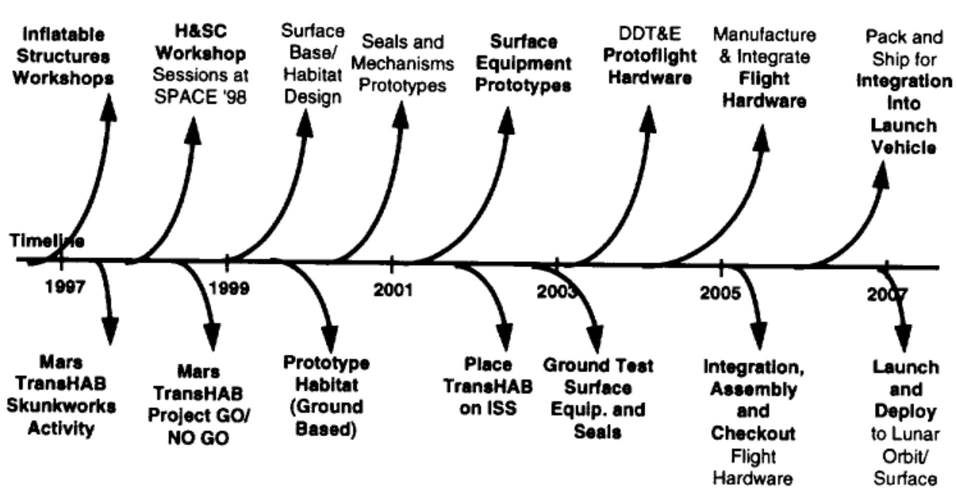
Breakthrough H&SC Technology

Technology	Enables	Rationale
A.I. Smart Structure	• Integrated and Self Diagnostics • Self Repair	• Alleviate Crew Maintenance and Repair Time • Automation and Several Yrs Unmanned
ISRU-LSS Living Shell	• Process CO2 Through Shell to Produce O2 for Interior Use • Integration of Nano Life Support System into Skin	• Self Sufficiency, Lower Weight • Applicable to Hostile Terrestrial Environments
Bio-Structure	• Bio-Technology Integration with Shell Skin Enables Self-Healing Capability	• Alleviate Crew Servicing and Maintenance
Tunneling/ Mining Mole	• Enables Underground Habitation Facilities Analogous to Oil Industry Siberia (Hostile Environment) Facilities	• Create Underground Facilities for Mars Evolution/Civilization • Constant Thermal Environment • Radiation Protection
ISRU-Derived Structure	• Use of In-Situ Materials to Process, Manufacture and Assemble Structures	• Supports Long-Term Plan for Human Expansion into Solar System • Breaks Dependency of Earth Supplies

H&SC Team 09/02/97

HEDS Technology Planning *Habitats & Surface Construction*

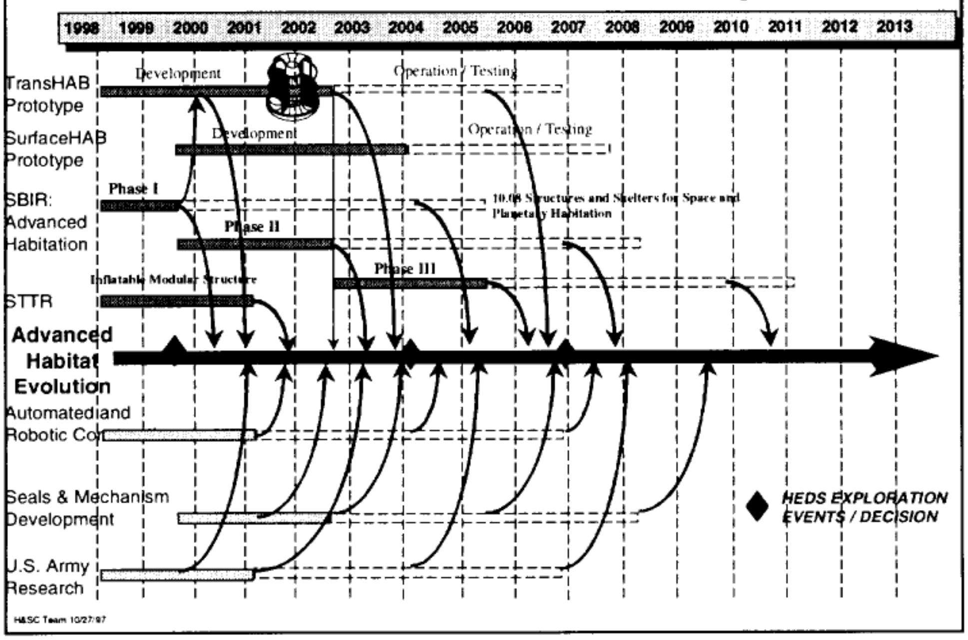
Habitats and Surface Construction Roadmap



H&SC Team 09/02/97

HEDS Technology Planning | Habitats & Surface Construction

Habitats & Surface Construction Roadmap

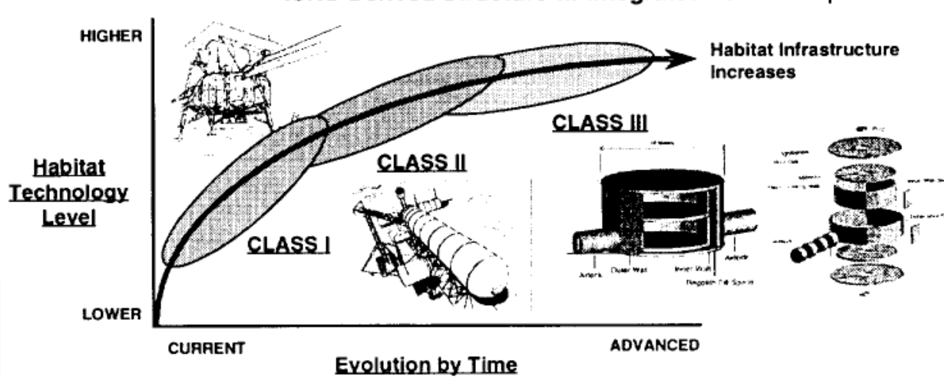


H&SC Team 10/27/97

HEDS Technology Planning | Habitats & Surface Construction

Habitation Technology Strategy (Options)

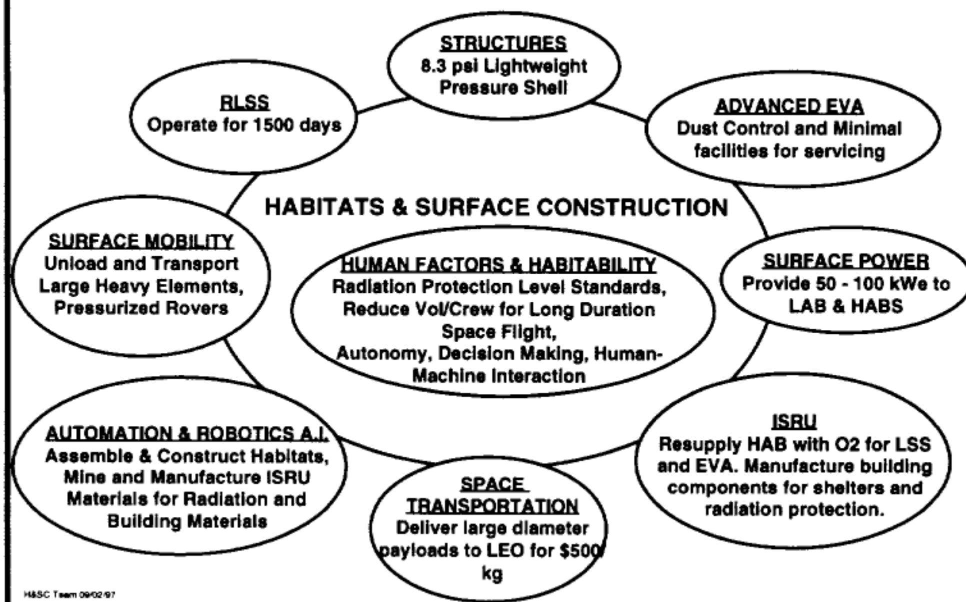
- **CLASS I:**
  - **Preintegrated, Hard Shell Module**
- **CLASS II:**
  - **Prefabricated, Surface Assembled**
- **CLASS III:**
  - **ISRU Derived Structure w/ Integrated Earth components**



H&SC Team 10/27/97

HEDS Technology Planning *Habitats & Surface Construction*

H&SC Technology Requirements



H&SC Team 09/02/97

HEDS Technology Planning *Habitats & Surface Construction*

Key Structural Issues

- Metal Alloy Structures
  - Environmental Degradation, Manufacturability, $ to Manuf., Achieve tbd% weight savings, robustness, maintainability and repair.
- Composite Structures
  - Environmental Degradation, Manufacturability, $ to Manuf., Achieve 30% weight savings, robustness, maintainability and repair.
- Inflatable Structures
  - Environmental Degradation, Manufacturability, $ to Manuf., Achieve weight savings, robustness, reliability, deployability: automated/robotic assisted surface deployment, maintainability and repair.
- ISRU-Derived Structures
  - Environmental Degradation, Manufacturability, $ to Manufacture HAB units, Complexity of mining, benefaction and processing ISRU material to make structures, robustness, reliability, automated/robotic assisted manufacturing, maintainability and repair.

H&SC Team 09/02/97

Habitats and Surface Construction

Man-Rated Pressure Structure

- Technology: Advanced Structures
- Application: In-Space and Planetary Pressurized Structures for Human Exploration
- Benefits:
  - 30-50% (goal) lighter than Al Hard Structures
  - Capability for Increased Habitable Volume, Launch Efficiency
  - Long Term Growth Potential
  - Compatible with Technology Developments for Current Space Craft.
- Current Technology Status:

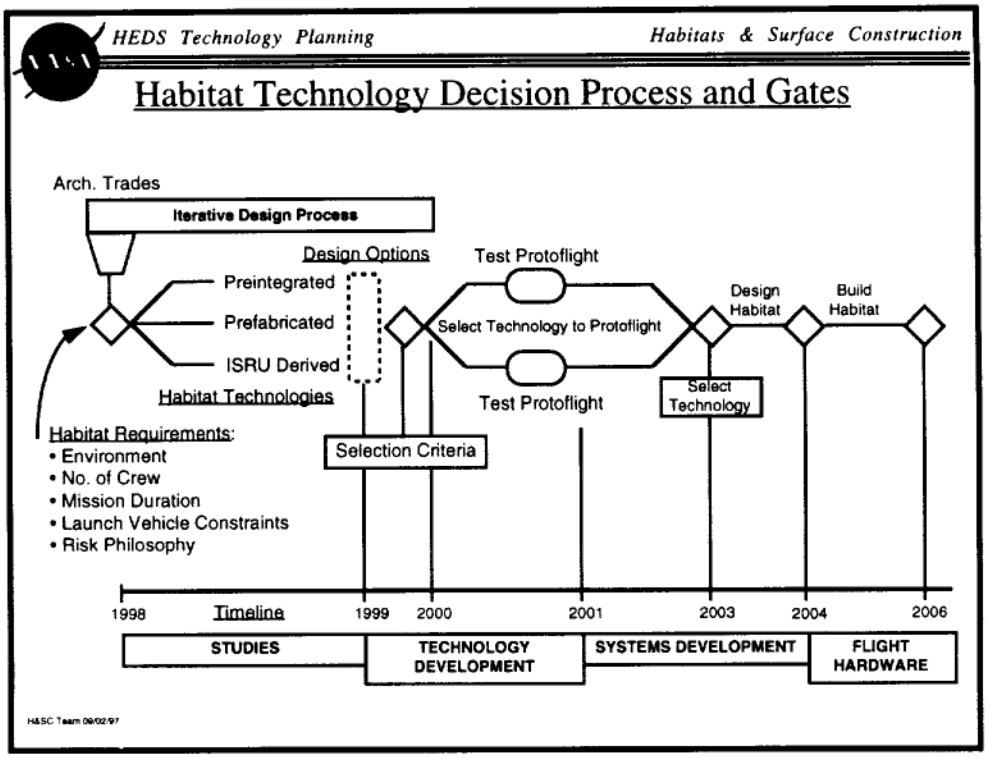
Composites: TRL 6-7
- Used for pressure tanks: DC-X
- Incorporated into X-33 Demonstration
- Incorporated into X-38 CRV
- Planned for Space Craft Upgrades

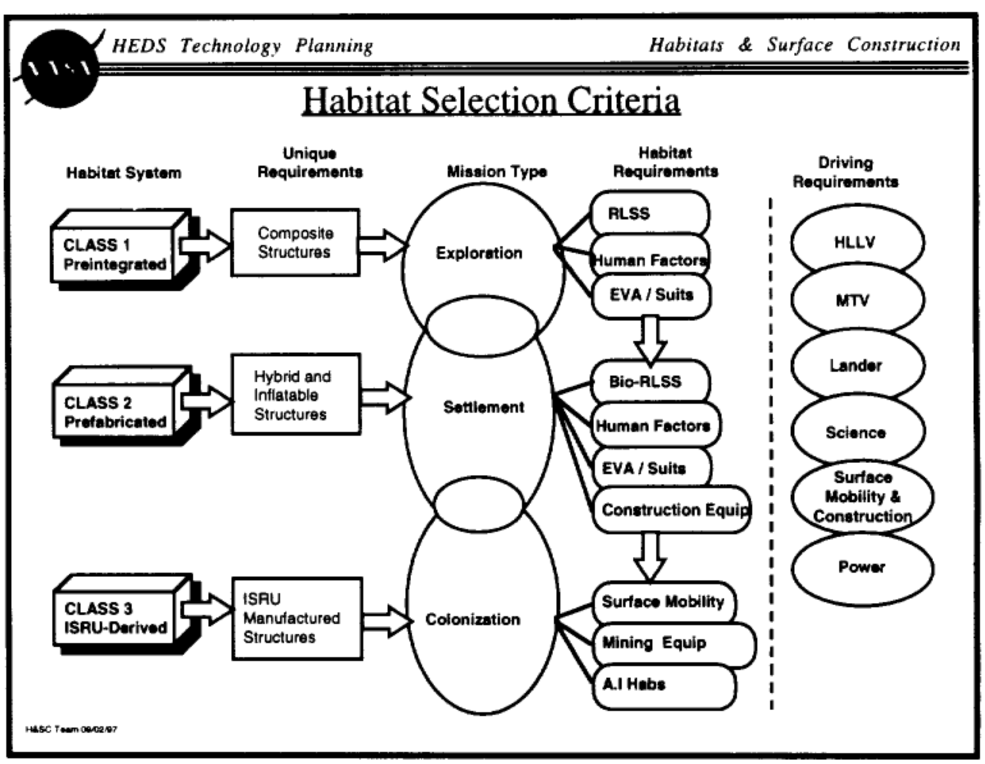
Inflatables: TRL 4-5
- Concepts Developed
- Impediment Defined
- EMU Suit Materials
- Materials Selection for HAB
- Full-Scaled Prototype Planned FY98-99
- '96 Space Demo of IAE

ISRU Derived: TRL 1-2
- Resources Identified
- Extraction Techniques Defined
- Material Processing and Manufacturing Defined
- Structural Concepts

Material Requirements for Habitats

- Large Volumes, i.e. 300-500 m^3
- High Strength Materials
  - Internal Operating Pressure 8.3 psia
- Durability
  - 10-15 Years
- Reliability
  - Fail Op/Fail Safe
- Low Cost
  - Orders of Magnitude Less ($M NOT $B)
- Low Mass
  - Orders of Magnitude Less (100s kg NOT 10s Mt)
- Autonomous Deployment
- Low Vibration
- Withstand Radiation: GCR and SPE
- No Off-gassing to Internal HAB
- Withstand Debris/Micrometeoroid Hits
  - 1/4" d @ 7 km/s, Self-repair?
- Low Risk
  - Deployment
  - Pressure Integrity
  - Puncture/Tear Resistant
  - No Off-gassing
- Pre-integrated Support Systems
  - Life Support, Communications
  - Deployable Floors and Walls
  - Smart Structures: self diagnostic
- Human Support
  - Radiation Shelters
  - Medical Treatment
  - EVA Support
  - Living and Working Facilities
  - Autonomous Operations


HEDS Technology Planning
Habitats & Surface Construction
Habitat Technology Decision Process and Gates
Arch. Trades
Iterative Design Process
Design Options
Preintegrated
Prefabricated
ISRU Derived
Habitat Technologies
Test Protoflight
Select Technology to Protoflight
Test Protoflight
Design Habitat
Build Habitat
Select Technology
Habitat Requirements:
• Environment
• No. of Crew
• Mission Duration
• Launch Vehicle Constraints
• Risk Philosophy
Selection Criteria
1998
Timeline
1999
2000
2001
2003
2004
2006
STUDIES
TECHNOLOGY DEVELOPMENT
SYSTEMS DEVELOPMENT
FLIGHT HARDWARE
H&SC Team 09/02/97


HEDS Technology Planning
Habitats & Surface Construction
Habitat Selection Criteria
Habitat System
Unique Requirements
Mission Type
Habitat Requirements
Driving Requirements
CLASS 1 Preintegrated
Composite Structures
Exploration
RLSS
Human Factors
EVA / Suits
HLLV
MTV
Lander
Science
Surface Mobility & Construction
Power
CLASS 2 Prefabricated
Hybrid and Inflatable Structures
Settlement
Bio-RLSS
Human Factors
EVA / Suits
Construction Equip
CLASS 3 ISRU-Derived
ISRU Manufactured Structures
Colonization
Surface Mobility
Mining Equip
A.I Habs
H&SC Team 09/02/97

HEDS Technology Planning — Habitats & Surface Construction

Interaction Between H&SC and Other Technologies

ISRU: - Development of ISRU processes - ISRU processing technologies - Mining technologies - Development of ISRU structural materials	ISRU and H&SC: - Dust control technologies - Regolith movement technologies	H&SC: - Construction technologies - Excavation technologies - Maintenance technologies - Assembly of ISRU structural materials
Planetary Rover: - Rover technologies - Sample collection technologies - Navigation technologies	Planetary Rover and H&SC: - Vehicle chassis utilization	H&SC: - Robotic construction technologies - Robotic maintenance technologies - Robotic surveying technologies
BLSS: - Life support technologies - Plant growth technologies	BLSS and H&SC: - Artificial lighting technologies - Radiation filtering materials	H&SC: - Greenhouse construction technologies - Natural lighting technologies

H&SC Team 09/02/97

HEDS Technology Planning — Habitats & Surface Construction

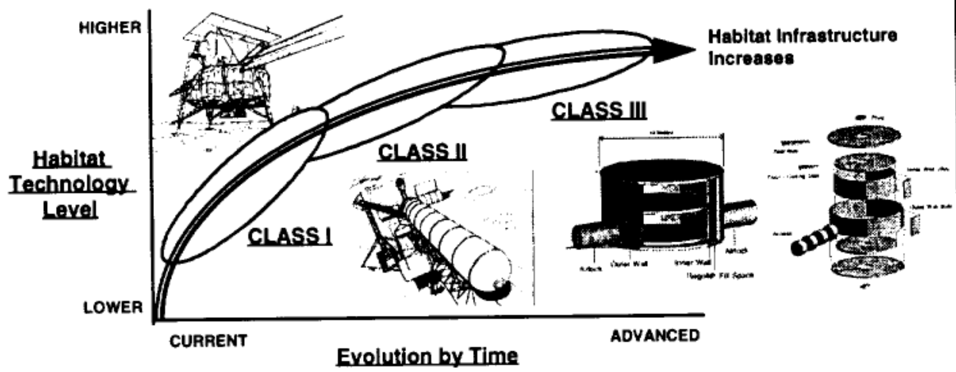
Summary

- Need Advanced Structures Research
- SBIR/STTR Innovative Technology Opportunities
- Technology Development Strategy
- Return-on-Investment Potential is Enormous
- Paradigm Shift from "Traditional" Habitat Concepts
- Need to Move Technology from Earth Applications to Space Applications
- Need Continued Material Testing for Human Spaceflight Use

H&SC Team 09/02/97

Habitation Technology Strategy (Options)

- **CLASS I:**
  - **Preintegrated, Hard Shell Module**
- **CLASS II:**
  - **Prefabricated, Surface Assembled**
- **CLASS III:**
  - **ISRU Derived Structure w/ Integrated Earth components**



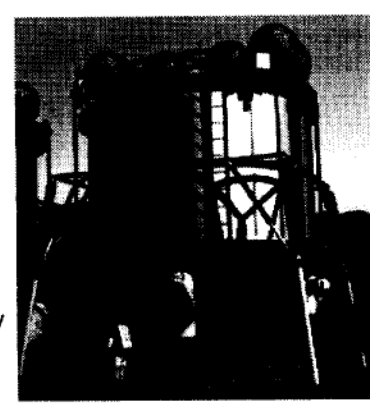
Class 1: Preintegrated Habs

Vision

- A **composite structure** that can be autonomously predeployed and operated on the Moon and Mars surface. Fully integrated. The capability for A.I. smart hab for failure detection, analysis and self repair.

Benefits

- Low mass.
- High reliability and easy to repair.
- Near-current technology.
- Add larger modules to ISSA and Lunar Orbit.



Current Status

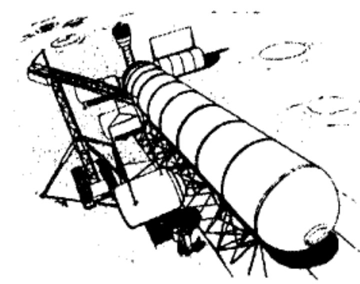
- Technology demonstrated to TRL 6-7.
- Manufacturing techniques being perfected by aircraft and launch vehicle industry.
- Incorporated into CRV skin.

HEDS Technology Planning — Habitats & Surface Construction

Class 2: Prefabricated Habs

Vision

- An **Inflatable structure** that can be autonomously predeployed and operated on the Moon and Mars surfaces. Partially integrated and flexible. The capability for A.I. smart hab for failure detection, analysis and self repair.



Benefits

- Larger usable habitable volume
- Lower mass
- Higher crew productivity
- Higher crew moral and quality of life (lower stress)
- High reliability and easy to repair
- Taking the steps toward building new civilizations

Current Status

- Technology demonstrated to TRL 4-5 by NASA-LaRC and DoD/U.S. Army.
- Industry established "smart" houses and integrated systems.
- Workshops on Space Inflatable Structures are planned (2 in '96).
- Shannon Lucid's experience of 6 months in space (Zero G).
- Long term habitability studies completed by ARC & JSC.
- Early Human Testbed preparing for 90 day test.

H&SC Team 09/02/97

HEDS Technology Planning — Habitats & Surface Construction

Impediments of Inflatable Structures

- Technical
- High Strength Material
- Seaming/Stress Points
- Connection Points
  - Hard Points for Internal/External Connections
- Reliable and Autonomous Deployment
- Material Degradation
  - Radiation, Dust, Thermal, Atomic O2, Micrometeoroid
- Hatches and Interconnects
- Off-gassing
- Durability/Life Span
- Flexibility/Packaging
- Human Rating

Social

- In-Space/Surface Flight Experience
- "Unknown" Factor
- Lack of Skilled Work Force at NASA with Inflatable Structures
  - Understanding not Building
- Balloon (Pop) Theory
- Cost is so low compared to hard space structures, no one believes it.
- Credibility
- Confidence
  - Comes from in-space demonstrated experience
- Complexity Factor

H&SC Team 09/02/97

Class 3: ISRU-Derived Habs

Vision

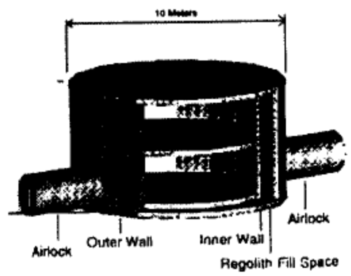
- An **ISRU-derived structure** that is manufactured using indigenous resources and constructed autonomously. It is autonomously operated and maintained utilizing A.I. and V.R. The capability for A.I. for failure detection, analysis and self-repair.

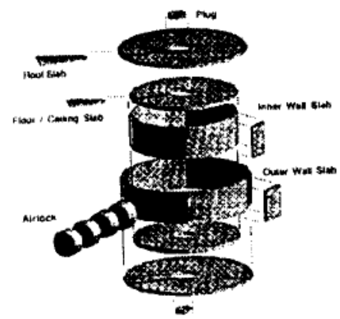
Benefits

- Larger usable habitable volumes.
- Can build colony infrastructure to support sustained human presence and evolution.
- Self sufficiency from Earth.
- Higher level of society.
- Ability to manufacture, service and repair.

Current Status

- Technology demonstrated to TRL 2-3 for Lunar-crete. Other technologies possible.



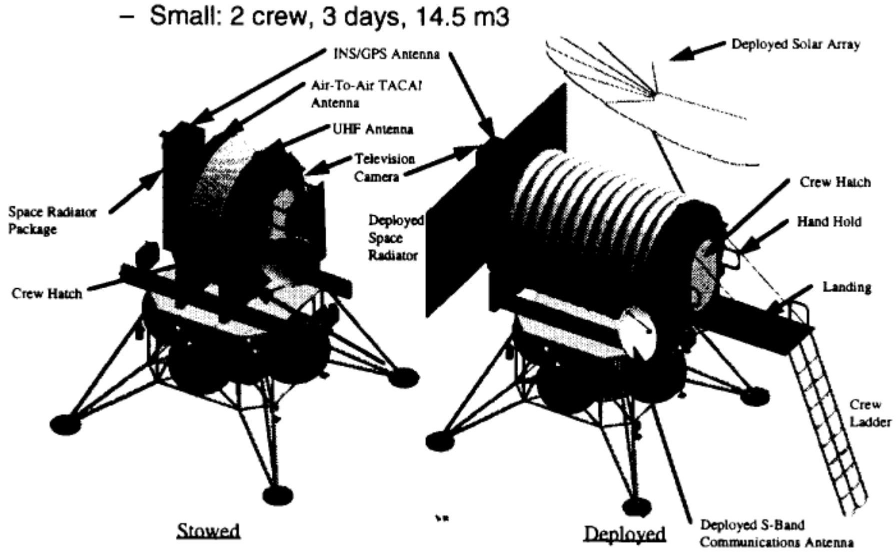


HASC Team 08/02/97

Concepts & Development

Inflatable Habitat Concept for Short Surface Mission Duration

- Small: 2 crew, 3 days, 14.5 m3

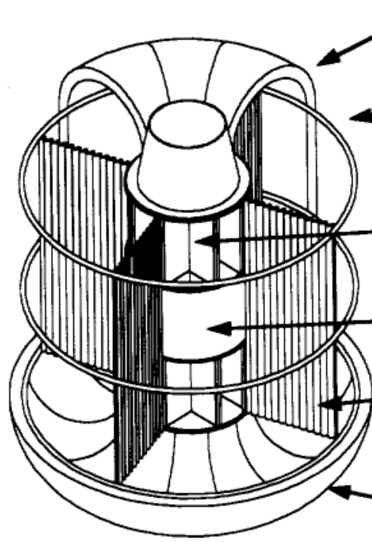


Human Lunar Return Concept

Hybrid Structure: Inflatable Mid-Section with Composite End Domes

Mars Transit Internal Configuration

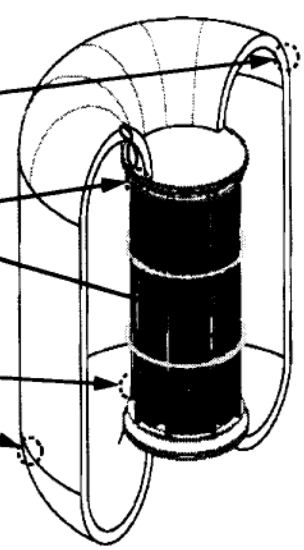
- **Section TransHAB into Four Quadrants**
- **Run Length of HAB**
- **Horizontal Orientation**
- **Deployable Core Fairing for Floor/ Partition System**



TransHAB Structural Configuration

Engineering Directorate
Horacio M. de la Fuente

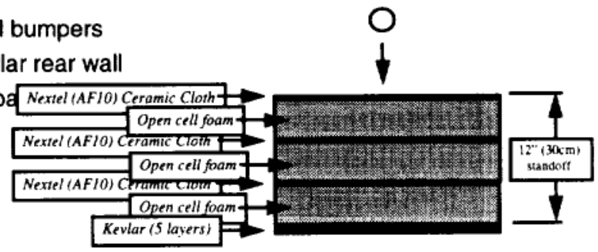
- Configuration Topics:
  - Multi-Layer Meteoroid/Orbital Debris Protection
  - Main Structural Attachments
    - Central Core - Inflatable Shell Interface
    - Central Core Shelves
  - Structural Optimization
    - Central Core Longerons
    - Inflatable Shell Aspect Ratio
  - Configuration Summary



Engineering Directorate
Horacio M. de la Fuente

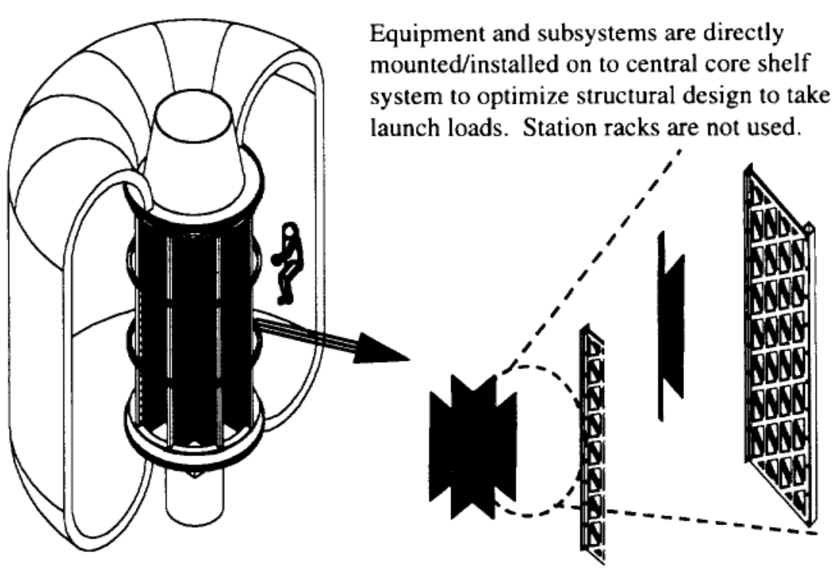
TransHAB
Main Structural Attachments

- **Meteoroid/Orbital Debris Protection**
  - JSC Hypervelocity Testing Results:
    - >98% No leak, while in Earth orbit for ~ 6Mths (threat is orbital debris driven)
    - >99.5% No leak, during to/from Mars transit (threat is meteoroid driven)
    - Impacts up to 0.25 in. (0.63cm) Dia. Aluminum projectile, V=~7 km/s, 0^0 impact angle
  - Main components:
    - Multi-shock Nextel bumpers
    - High-strength Kevlar rear wall
    - Large, open cell foa

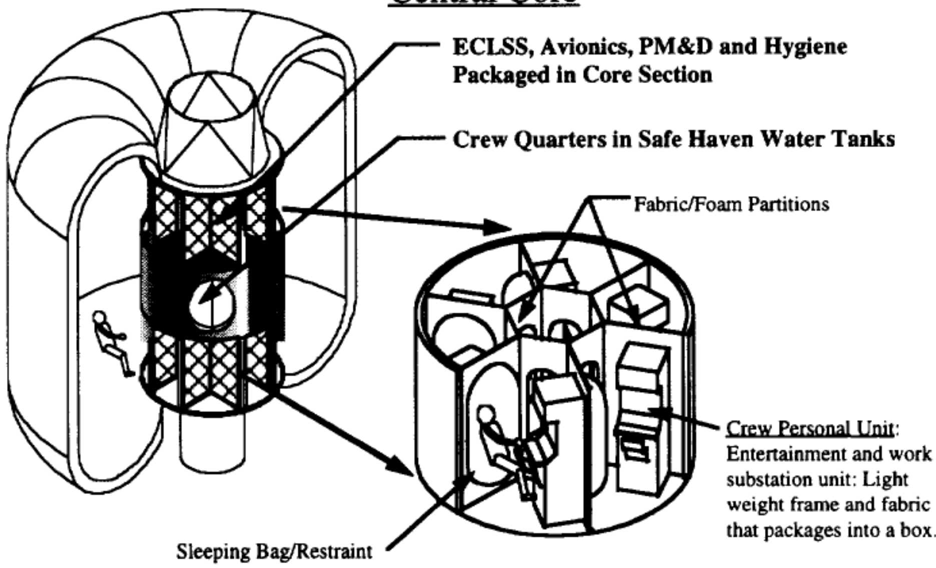


Central Core Shelf System

Equipment and subsystems are directly mounted/installed on to central core shelf system to optimize structural design to take launch loads. Station racks are not used.



Central Core



Typical Crew Quarter

H&SC Team 09/02/97