Habitats and Surface Construction
Technology and Development Roadmap

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Habitats & Surface Construction
Technology & Development Roadmap

Presented to the
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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 Technology Structure

- Emplacement
  - Site Preparation
  - Construction and Assembly
  - Interconnection, Barring, and Docking Mechanisms
- Habitat Shell
  - Structures
  - Anchoring
  - Mechanisms
- Internal Systems and Outfitting
  - Utilities
  - Housekeeping and Maintenance
  - Safety
  - Internal Subsystems
  - Systems Integration Tools
- Habitat Environment Integration
  - Dust
  - Radiation
  - Thermal Venting
- Surface Thermal Control
  - High Efficiency Heat Pump
  - Lightweight Deployable Radiator
  - Assembly Techniques
  - System Monitoring
  - Passive Thermal Control
- Pyrotechnic Excavation
  - Evaluation of Explosives
  - Kinematics/Grating Analysis
  - Blasting Control
  - Charge Optimization and Placement
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/Caarbon Structures
  - Constructible Habitats
  - Water Jacket Radiation Shielding
  - Natural and Artificial Lighting
  - Joining Processes and Interfaces
  - Interior Utility Interfaces
### WBS 2.0 Integrated Habitation Technology Development

#### Typical Products

<table>
<thead>
<tr>
<th>Category</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pressure Shell</strong></td>
<td>- Rigid Pressure Shell Components</td>
</tr>
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<td></td>
<td>- Flexible/Inflatable Pressure Shell Components</td>
</tr>
<tr>
<td>- ISRU Product Pressure Shell Components</td>
<td></td>
</tr>
<tr>
<td><strong>Habitat Structures</strong></td>
<td>- Deployable Trusses</td>
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<td>- Deployable Columns</td>
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<td>- Quick Connect Bracing</td>
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<td></td>
<td>- Quick Release Structural Connectors</td>
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<td></td>
<td>- Mechanical Fastening Materials and Devices</td>
</tr>
<tr>
<td><strong>Ejecta Protection</strong></td>
<td>- Loose Regolith/Soil Shielding</td>
</tr>
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<td></td>
<td>- Constructed Basalt Shields</td>
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<td></td>
<td>- Sintered/Cast Basalt Shielding</td>
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<td></td>
<td>- Prefabricated Shielding</td>
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<tr>
<td><strong>Thermal Control</strong></td>
<td>- Internal Thermal Insulation</td>
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<td>- Reflective Coverings and Coatings</td>
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<td>- Integral Shielding</td>
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<tr>
<td><strong>Lighting</strong></td>
<td>- Natural Lighting Techniques and Equipment</td>
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<td>- Artificial Lighting</td>
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<tr>
<td><strong>Vibration Control</strong></td>
<td>- Vibration Isolation Techniques and Components</td>
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<td>- Vibration Damping/Reduction Techniques and Components</td>
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<td></td>
<td>- Noise Prevention Techniques and Components</td>
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<tr>
<td></td>
<td>- Noise Reduction Techniques and Components</td>
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<tr>
<td><strong>Radiation Protection</strong></td>
<td>- Loose Regolith/Soil Shielding</td>
</tr>
<tr>
<td></td>
<td>- Pressure Shell Integrated Shielding</td>
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<td></td>
<td>- Sintered/Cast Basalt Shielding</td>
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<td>- Prefabricated Shielding</td>
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<tr>
<td><strong>Micrometeoroid Protection</strong></td>
<td>- Loose Regolith/Soil Shielding</td>
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<td>- Pressure Shell Integrated Shielding</td>
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<td>- Sintered/Cast Basalt Shielding</td>
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<td></td>
<td>- Prefabricated Shielding</td>
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### 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.
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.

- **Reduce Cost**
  - Lower Launch Mass
  - Lower Logistics

- **Expand Human Presence**
  - Commonality
  - Transit Habitats/Vehicles
  - Surface Infrastructure & Habitats

- **Reduce Risk**
  - Ensure Crew Safety
  - Increase Autonomy
  - Increase Self-Sufficiency
  - Increase Reliability

- **Technology Spin-Offs**
  - Smart Structures/Habitats
  - Automated Construction
  - Entertainment & Tourism
HEDS Technology Planning

Benefits of Habituation Technology Investments

2004 Go Decision Criteria

<table>
<thead>
<tr>
<th>Technology</th>
<th>2004 Go/No Go Criteria</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflatable Structures</td>
<td>Meet Human-Rating Standards</td>
<td>Habitats: In Space and Surface</td>
</tr>
<tr>
<td>Advanced Composite Structures</td>
<td>Maintain Pressure Integrity</td>
<td>Must Maintain Integrity and Long-Life in Lunar/Mars Environmental Conditions</td>
</tr>
<tr>
<td>Seals/Mechanisms</td>
<td>Capability to Maintain Seal in Dust Environment</td>
<td>Support Mars Mission with ISRU Capability</td>
</tr>
<tr>
<td>ISRU-Derived Structures</td>
<td>Prove ISRU Structural Technology</td>
<td>Support Humans as Habitats: In Space and Surface</td>
</tr>
<tr>
<td>Artificial Intelligent Structures (Smart Structures)</td>
<td>Proven Ability to Integrate AI Nano Technology into Pressure Shell Skin/Structure</td>
<td>Habitats: In Space and Surface</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Technology</th>
<th>Justification/Value</th>
<th>Criticality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflatable Structures</td>
<td>• Unproven Technology for Habitat Space Structures</td>
<td>• Longer lead Time and funding to meet 2005 Go Time to answer critical technology issues about materials and shell integration</td>
</tr>
<tr>
<td>Seals</td>
<td>• Critical Link of Providing Contamination Control</td>
<td>• Health: Provides the Habitability Volume Required for Long Duration Spaceflight: Crew Psychological Health, Spaceflights: Crew Psychological Health</td>
</tr>
<tr>
<td>Advanced Composites</td>
<td>• Unproven Technology for Habitat Space Structures</td>
<td>• Time and funding to meet 2005 Go Time to answer critical technology issues about materials and shell integration</td>
</tr>
<tr>
<td>Soil Moving Machinery</td>
<td>• Requires High Power and Energy Efficient Equipment</td>
<td>• Ensures Clear Site for Landing, Habitat Emplacement, and Surface Mobility</td>
</tr>
<tr>
<td>Mass Handling Equipment</td>
<td>• Required for Loading and Unloading of Payloads, and Moving/Connecting Elements</td>
<td>• Ensures Clear Site for Landing, Habitat Emplacement, and Surface Mobility</td>
</tr>
</tbody>
</table>

### Enabling H&SC Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>Enables</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflatable Structures</td>
<td>• Larger HAB Volume</td>
<td>• Smaller ETO Launch Vehicles</td>
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<tr>
<td></td>
<td>• Inflatable Aerobrake</td>
<td>• No LEO Assembly Ops</td>
</tr>
<tr>
<td></td>
<td>• Inflatable Airlock</td>
<td>• Save HAB Vol and Packaging Vol</td>
</tr>
<tr>
<td>Seals</td>
<td>• Integrity of Connections</td>
<td>• Pressurized Integrity of Connections</td>
</tr>
<tr>
<td></td>
<td>• Long Life Connections, Hatches, and Mechanisms</td>
<td>• Ensures Clear Site for Landing, Habitat Emplacement, and Surface Mobility</td>
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<tr>
<td></td>
<td>• Contamination Control</td>
<td>• Protection of Lubricants and Mechanisms</td>
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<tr>
<td>Shell Materials</td>
<td>• Tolerant of Environment</td>
<td>• Protect Humans from Dust</td>
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<tr>
<td>Advanced Composites</td>
<td>• Lightweight Strong Structures</td>
<td>• Tolerant of Long Duration Exposure to Space and Mars Environment</td>
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<tr>
<td>Soil Moving Machinery</td>
<td>• Site Preparation and Clearing</td>
<td>• Lower Initial Mass in LEO</td>
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<tr>
<td></td>
<td>• Habitat Emplacement</td>
<td>• Ensures Clear Site for Landing, Habitat Emplacement, and Surface Mobility</td>
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<td></td>
<td>• Radiation/Blaze Ejecta Berthing</td>
<td>• Protection of Lubricants and Mechanisms</td>
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<tr>
<td>Mass Handling Equipment</td>
<td>• Loading and Unloading of Payloads</td>
<td>• Required for Base Assembly</td>
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<tr>
<td>Self-Deploying and Automated Systems</td>
<td>• Moving/Connecting Elements</td>
<td>• Limit EVA Crew Time for Construction Assembly Operations</td>
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<td></td>
<td>• External Shelters/Facilities</td>
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### Breakthrough H&SC Technology

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

**Timeline**

- **1997**: Mars TransHAB Skunkworks Activity
- **1999**: Mars TransHAB Project Go/No Go
- **2001**: Prototype Habitat (Ground Based)
- **2003**: Place TransHAB on ISS
- **2005**: Ground Test Surfaces Equip. and Seals
- **2007**: Integration, Assembly and Checkout Flight Hardware

**Pack and Ship for Integration into Launch Vehicle**

- **1998**: HASC Workshop Sessions at SPACE '98
- **2001**: Surface Design
- **2003**: Seals and Mechanisms Prototypes
- **2005**: Surface Equipment Prototypes
- **2007**: DDT&E Protolflight Hardware
- **2009**: Manufacture & Integrate Flight Hardware
- **2011**: Manned Mission to Mars
- **2013**: Mars表面 Exploration

**Launch and Deploy to Lunar Orbit/Surface**
Habitats & Surface Construction Roadmap

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<td>Operation</td>
<td>Testing</td>
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<td>Phase I</td>
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<td>Seals &amp; Mechanism</td>
<td>Development</td>
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HEDS Exploration Events / Decision

Habitation Technology Strategy (Options)

- **CLASS I:**
  - Preintegrated, Hard Shell Module

- **CLASS II:**
  - Prefabricated, Surface Assembled

- **CLASS III:**
  - ISRU Derived Structure w/ Integrated Earth components

Habitat Technology Level

Evolution by Time

CURRENT | ADVANCED
**H&SC Technology Requirements**

- **STRUCTURES**
  - RLSS Operate for 1500 days
- **ADVANCED EVA**
  - Dust Control and Minimal facilities for servicing
- **HABITATS & SURFACE CONSTRUCTION**
- **SURFACE MOBILITY**
  - Unload and Transport Large Heavy Elements, Pressurized Rovers
- **HUMAN FACTORS & HABITABILITY**
  - Radiation Protection Level Standards, Reduce Vol/Crew for Long Duration Space Flight, Autonomy, Decision Making, Human-Machine Interaction
- **SURFACE POWER**
  - Provide 50 - 100 kWe to LAB & HABS
- **ISRU**
  - Resupply HAB with O2 for LSS and EVA. Manufacture building components for shelters and radiation protection.
- **AUTOMATION & ROBOTICS A.I.I.**
  - Assemble & Construct Habitats, Mine and Manufacture ISRU Materials for Radiation and Building Materials
- **SPACE TRANSPORTATION**
  - Deliver large diameter payloads to LEO for $500 kg

**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.
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 m³
• 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

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Habitat Technology Decision Process and Gates

Habitat Technology Requirements:
- Environment
- No. of Crew
- Mission Duration
- Launch Vehicle Constraints
- Risk Philosophy

Habitat Technologies:
- Preintegrated
- Prefabricated
- ISRU Derived

Habitat Selection Criteria:

CLASS 1
Preintegrated
- Composite Structures
- Exploration
- Human Factors
- EVA / Suits

CLASS 2
Prefabricated
- Hybrid and Inflatable Structures
- Settlement
- Human Factors
- EVA / Suit

CLASS 3
ISRU-Derived
- ISRU Manufactured Structures
- Colonization
- Construction Equip
- Surface Mobility
- Mining Equip
- A.I Habs

Driving Requirements:
- HLLV
- MTV
- Lander
- Science
- Surface Mobility & Construction
- Power
### Interaction Between H&SC and Other Technologies

<table>
<thead>
<tr>
<th>ISRU</th>
<th>ISRU and H&amp;SC</th>
<th>H&amp;SC</th>
</tr>
</thead>
</table>
| - Development of ISRU processes  
- ISRU processing technologies  
- Mining technologies  
- Development of ISRU structural materials | - Dust control technologies  
- Regolith movement technologies | - Construction technologies  
- Excavation technologies  
- Maintenance technologies  
- Assembly of ISRU structural materials |

<table>
<thead>
<tr>
<th>Planetary Rover</th>
<th>Planetary Rover and H&amp;SC</th>
<th>H&amp;SC</th>
</tr>
</thead>
</table>
| - Rover technologies  
- Sample collection technologies  
- Navigation technologies | - Vehicle chassis utilization | - Robotic construction technologies  
- Robotic maintenance technologies  
- Robotic surveying technologies |

<table>
<thead>
<tr>
<th>RLSS</th>
<th>RLSS and H&amp;SC</th>
<th>H&amp;SC</th>
</tr>
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</table>
| - Life support technologies  
- Plant growth technologies | - Artificial lighting technologies  
- Radiation filtering materials | - Greenhouse construction technologies  
- Natural lighting technologies |

### 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
Habitation Technology Strategy (Options)

- **CLASS I:**
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  - 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.
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.

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
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.
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

- 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
**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° impact angle

  - Main components:
    - Multi-shock Nextel bumpers
    - High-strength Kevlar rear wall
    - Large, open cell foam

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**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

ECLSS, Avionics, PM&D and Hygiene Packaged in Core Section

Crew Quarters in Safe Haven Water Tanks

Fabric/Foam Partitions

Crew Personal Unit: Entertainment and work substation unit: Light weight frame and fabric that packages into a box.

Typical Crew Quarter

Sleeping Bag/Restraint