Future Homes in Space: Development of Concepts for Exploration Space Habitats

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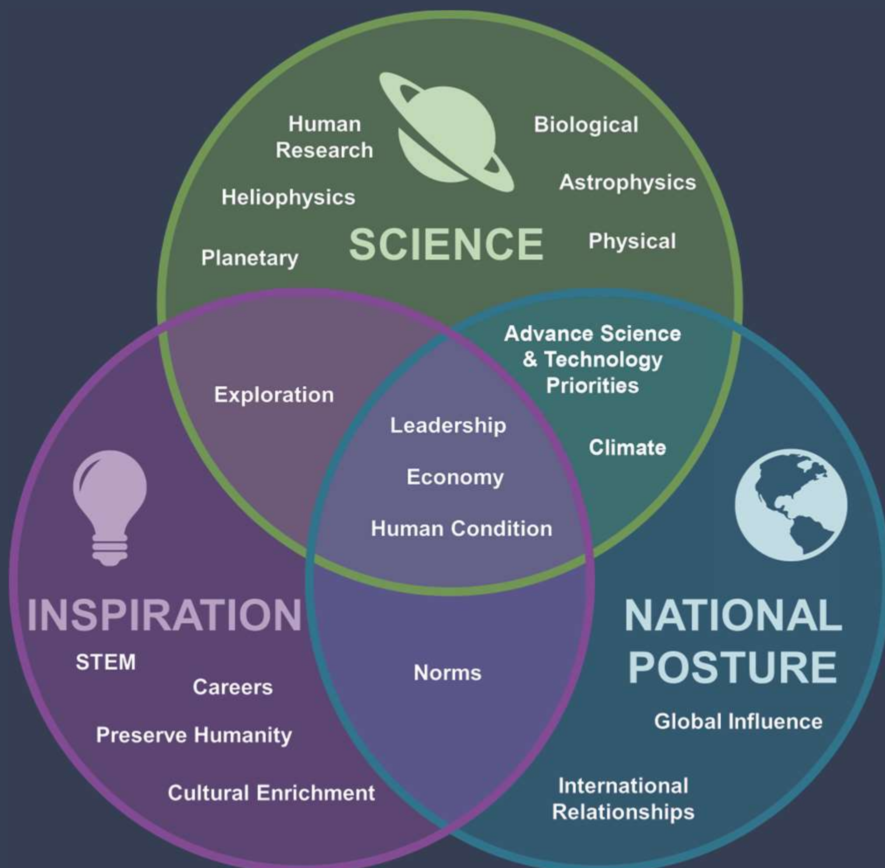
Benefits to Humanity: Why We Explore



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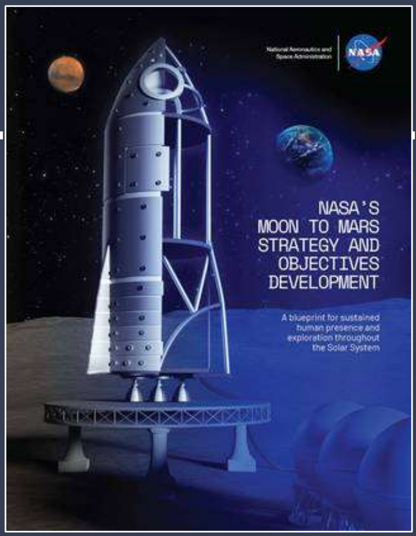
NASA's Moon to Mars Strategy and Objectives: A Blueprint for Human Exploration (Architecting from the Right)

ARCHITECTURE

Iterate and evolve through annual Architecture Concept Reviews

Goals and Objectives

- **SCIENCE**
- **TRANSPORTATION AND HABITATION**
- **LUNAR AND MARS INFRASTRUCTURE**
- **OPERATIONS**



go.nasa.gov/3zzSNhp

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Architecture Concept Review Products

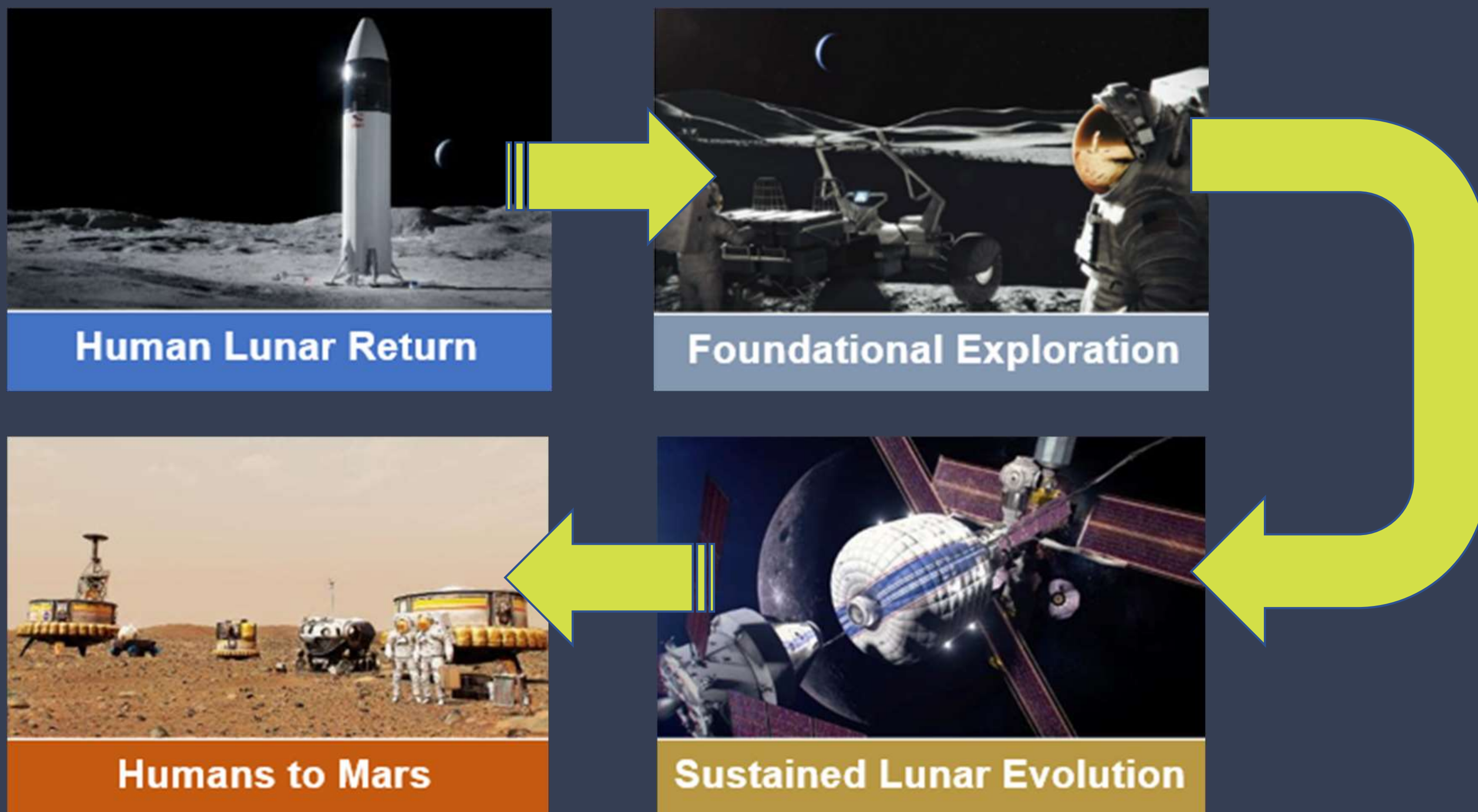
www.nasa.gov/MoonToMarsArchitecture

Architecture Definition Document
Detailed documentation snapshot of NASA's human spaceflight architecture and exploration strategy

Moon to Mars Architecture Summary
High-level overview of NASA's Moon to Mars architecture and exploration strategy

White Papers
Six papers on architecture study details for frequently discussed topics

Executing from the Left: Segments and Sub-architectures



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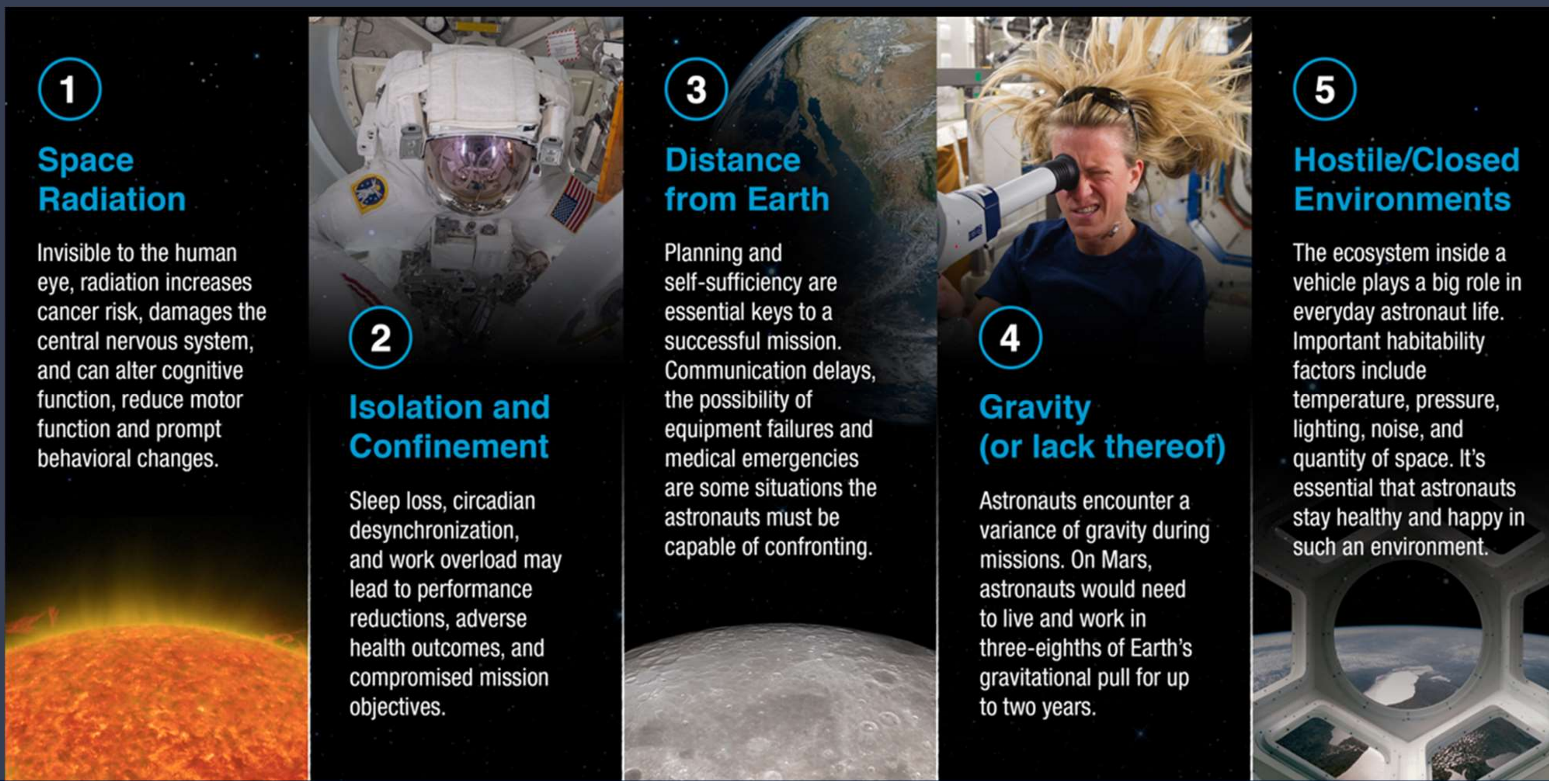
The Five Hazards of Human Spaceflight



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Lunar Surface Habitat Key Challenges

- Delivery mass
- Dust contamination
- Long dormancy
- Survive the night/thermal power
- Logistics transfer and loading

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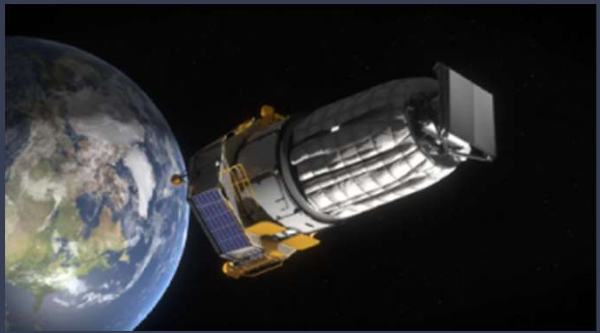
Lunar Surface Habitat Concept



The Surface Habitat is a concept being traded within NASA's Moon to Mars architecture

Mars Transit Challenges

- No spares resupply chain
- Logistics storage capacity
- Reliability/Maintainability
- Communication delays/blackouts
- Earth Independent Operation
- Human health & performance

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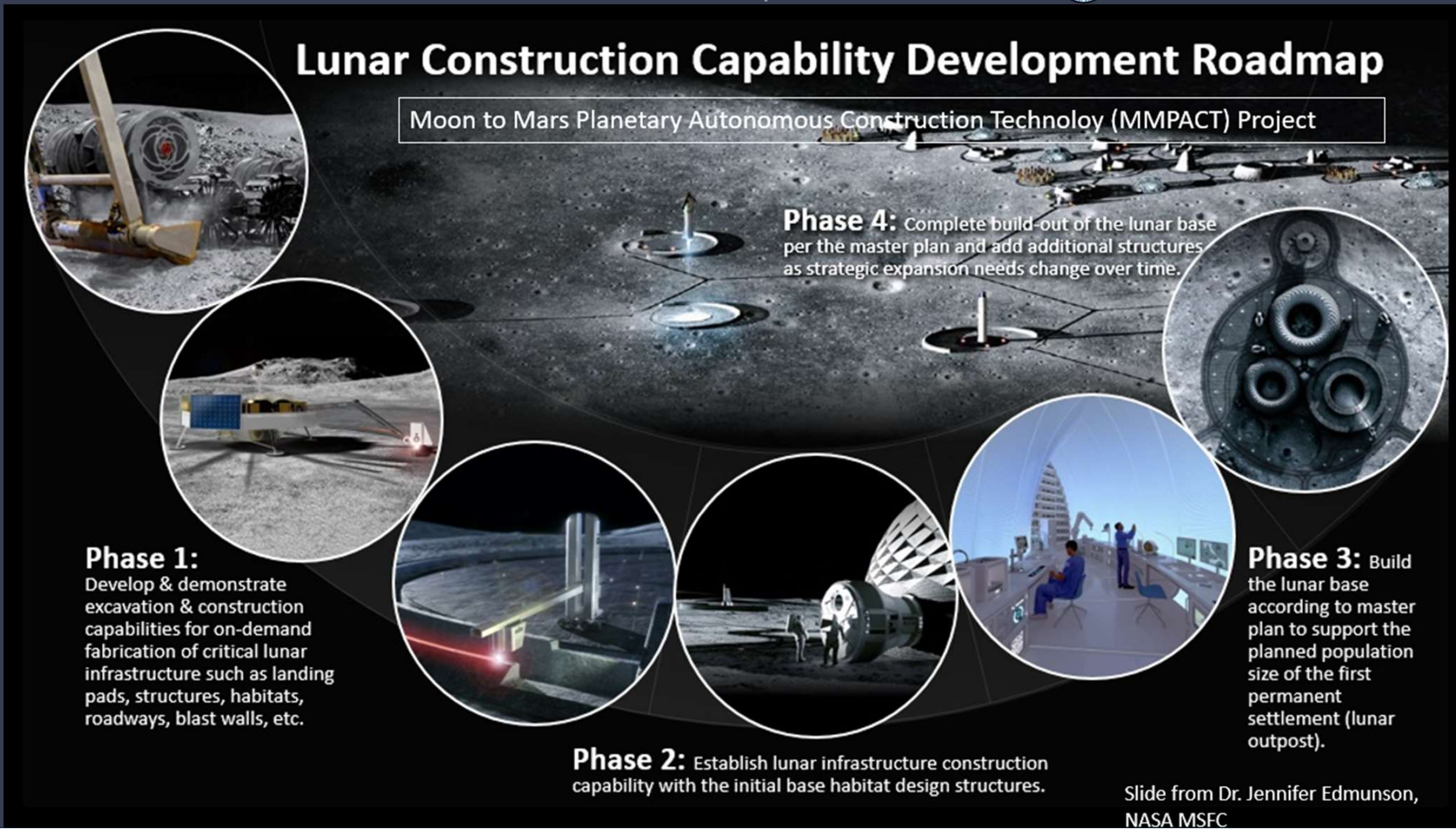
Mars Surface Habitation Challenges

- Habitat landing and activation
- Planetary protection
- Maintenance and sparing
- Martian dust management
- Radiation and thermal protection


Lunar Construction Capability Development Roadmap
Moon to Mars Planetary Autonomous Construction Technoloy (MMPACT) Project
Phase 4: Complete build-out of the lunar base per the master plan and add additional structures as strategic expansion needs change over time.
Phase 1: Develop & demonstrate excavation & construction capabilities for on-demand fabrication of critical lunar infrastructure such as landing pads, structures, habitats, roadways, blast walls, etc.
Phase 2: Establish lunar infrastructure construction capability with the initial base habitat design structures.
Phase 3: Build the lunar base according to master plan to support the planned population size of the first permanent settlement (lunar outpost).
Slide from Dr. Jennifer Edmunson, NASA MSFC

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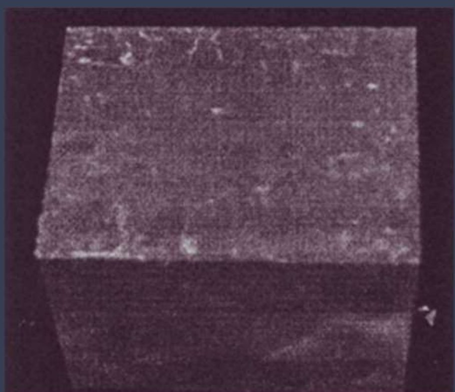
Regolith Concrete



Example of waterless lunar simulant from H.A. Toutanji and R.N. Grugel. "Performance of Waterless Concrete."

- Lunar and Martian regolith could each serve as aggregates for concrete
- Cement and water will either need to be brought, extracted in-situ, or replaced in the mixture
- Sieving lunar & Martian regolith simulant to <1 mm diameter particles improves regolith concrete's compressive strength [1]
- Embedded fibers and mixture additives using in-situ materials offer more viable near-term reinforcement solutions [2]

References: [1] Heemskerk, M.V., van Westrenen, W., and Foing, B.H., "Lunar and Martian Regolith Based Concrete as Building Blocks for Future Human Settlements," *51st Lunar and Planetary Science Conference*, Universities Space Research Association, The Woodlands, TX, 2020.

[2] Empelmann, M., Hack, N., Herrmann, E., Kloft, H., and Lowke, D., "Reinforcement Strategies for 3D-Concrete-Printing," *Civil Engineering Design*, Vol. 2, Issue 4, 2020, pp. 131-139

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Slide 12

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Prater, Tracie {she, her} (MSFC, 2024-01-05T16:31:39.478

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PAUL KESSLER, 2024-01-05T19:57:46.249

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Prater, Tracie {she, her} (MSFC, 2024-01-05T20:08:49.772

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Commercial Partners

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NextSTEP Appendix A: Habitation Systems

Phase 1 – 2015-2016: Concept Designs and Operations

Phase 2 – 2016-2019: Prototype Development and Testing

Phase 3 – 2019-present: Concept maturation and focus on long-duration, in-space and surface habitats

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Partnership Mechanisms

- **Cooperative Agreement Notification (CAN)**
  - Step-1 white paper solicitation now open and due on March 13th, 2024
- **Small Business Innovative Research (SBIR)**
  - Subtopic on sensing/structural health monitoring for inflatable softgoods
- **XHab**
  - University grant program
- **Space Act Agreements**
  - Allows external partner to use NASA expertise, facilities, equipment
- **Tipping Points and Announcements of Collaborative Opportunity (ACO)**
  - Partnerships for technology development; targeted solicitations on specific technologies released periodically

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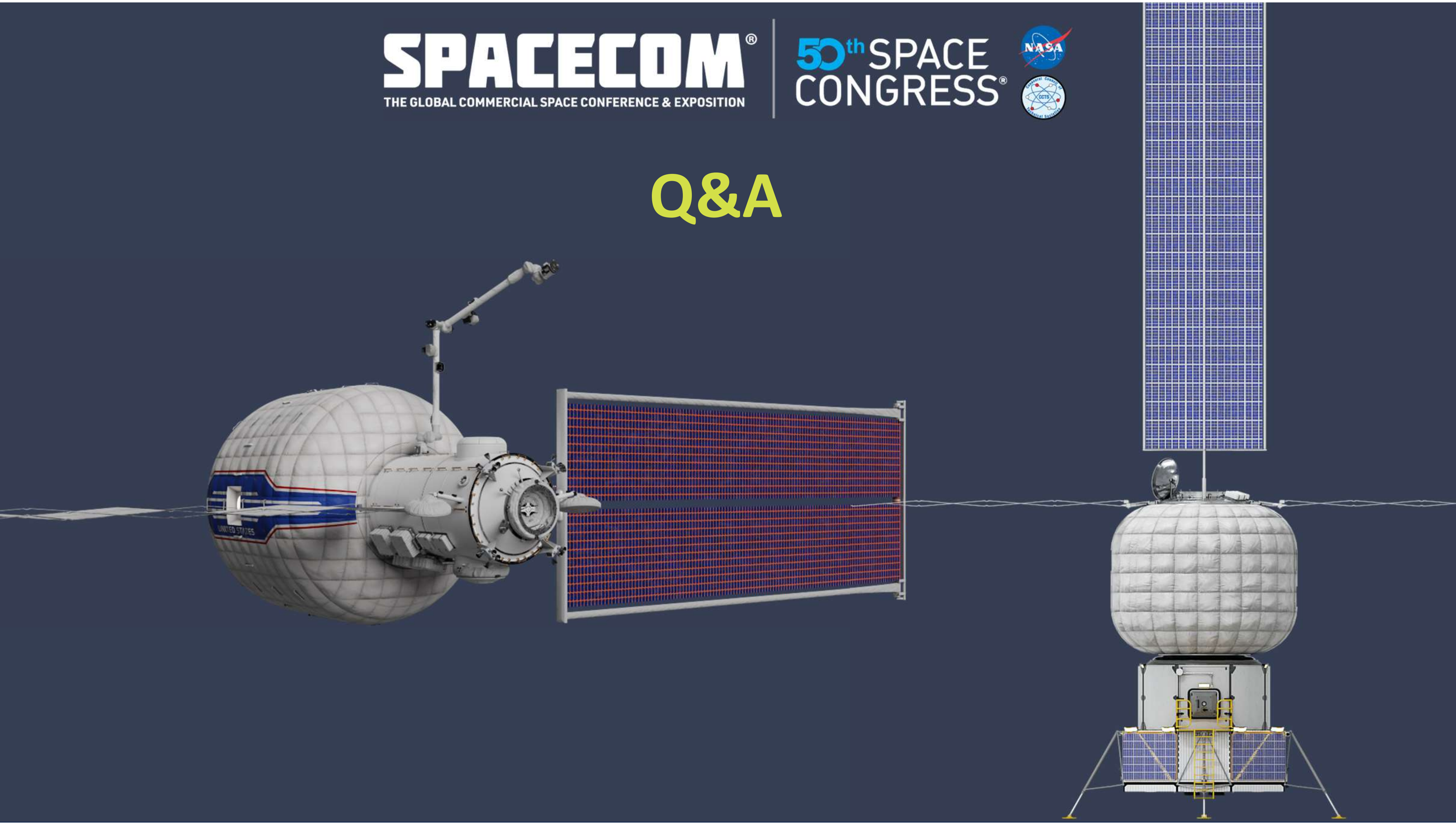
Q&A



Backup charts

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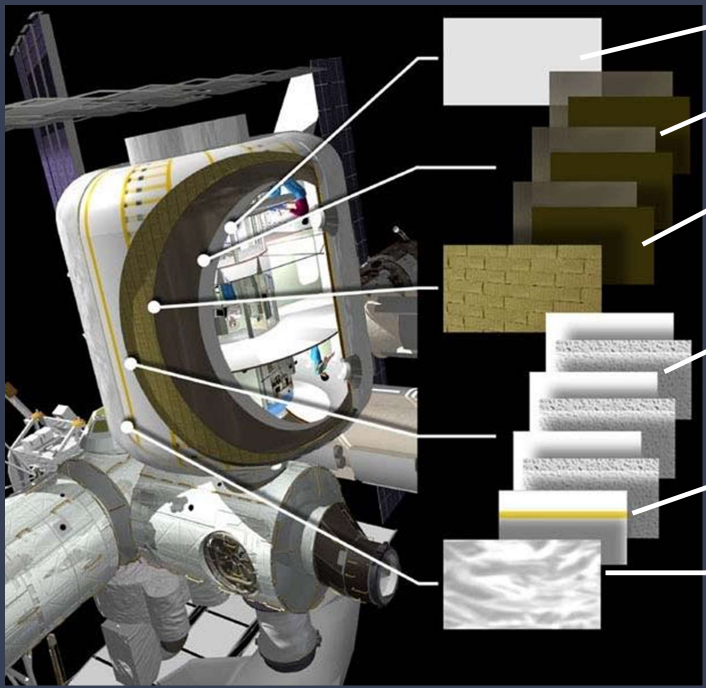
Types of Space Habitats

A class I habitat is a pre-integrated habitat, manufactured and integrated prior to launch	Example: ISS	
A class II habitat is pre-fabricated prior to delivery, but deployed in space or on a planetary surface	Example: Inflatable ISS BEAM module	
A class III habitat is built in situ using local resources	Example: 3D Printed Habitat on planetary surface	 Image from ICON and SEArch+.

Marc Cohen and Kriss Kennedy, *"Habitats and Surface Construction Technology and Development Roadmap". Sept 4, 1997*

Inflatable Softgoods Material System



Internal scuff layer

Bladder

Restraint layer

Micrometeoroid Orbital Debris (MMOD) shield

Thermal blanket

External shield

Represents one possible structural material option for future habitation systems

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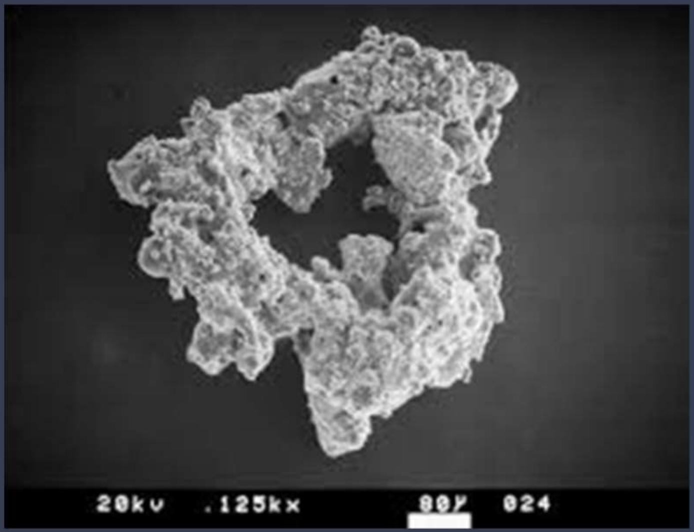
Lunar regolith

- Composed of very fine debris particles (a majority between 40-130 microns in diameter) of crystalline rocks, fragments of minerals, meteorite fragments, and underlying sub-particles (such as breccias and agglutinates)

- Relatively high cohesion due to factors such as electromagnetic forces and the jagged nature of its particles

- Bulk density, shear strength, and compactness of regolith increases rapidly after the first few surface centimeters, making it incredibly difficult to dig and drill into given the moon's 1/6th gravity



Lunar agglutinate from Apollo 11 (NASA photo S87-38812)

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IN ORBIT

DEEP SPACE AGGREGATION
Assembling a complex ship in deep space

MARS TRANSIT HABITAT
Round the clock, years-long operations of a Mars-class habitat and life support system

ORBIT TO SURFACE OPERATIONS
Operating an orbiting outpost that deploys a lander and its crew to a planetary surface

COMMERCIAL RESUPPLY AND REFUELING
Leveraging the space logistics supply chain for industry provided cargo deliveries

CREW HEALTH & PERFORMANCE
Studying how the human body and mind adapt to deep space hazards

A roundtrip mission to Mars will take about two years—and once the ship's course is set, there's no turning back.

As much as is possible, lunar systems will be designed for dual Moon-Mars operations.

Integrated missions in the lunar vicinity prepare us for successful Mars missions

ON THE SURFACE

SPACESUIT ADVANCEMENTS
Improving spacesuit design across Artemis missions with astronaut input and private sector innovation

MOBILE OPERATIONS
Living and working 'on the go' inside a mobile habitat for weeks at a time

PLANETARY PROTECTION
Mitigating dust transfer and establishing pristine sample curation protocols

HUMAN ROBOTIC EXPLORATION
Robots pre-positioning surface assets and conducting reconnaissance for astronauts

HUMAN RESILIENCE
Learning how humans can survive and thrive in a partial gravity environment

Moon to Mars Planetary Autonomous Construction (MMPACT) Materials

- Binder-based materials
  - Ordinary Portland cement
  - Magnesium oxide-based cements
  - Sodium silicate
  - Calcium sulfo-aluminate
  - Geopolymers
  - Polymers
  - Sulfur concrete
- 100% Regolith-based materials
  - Microwave sintering
  - Laser vitreous material transformation (VMX)
  - Molten extrusion
  - Molten casting

Slide from Dr. Jennifer Edmunson, MSFC

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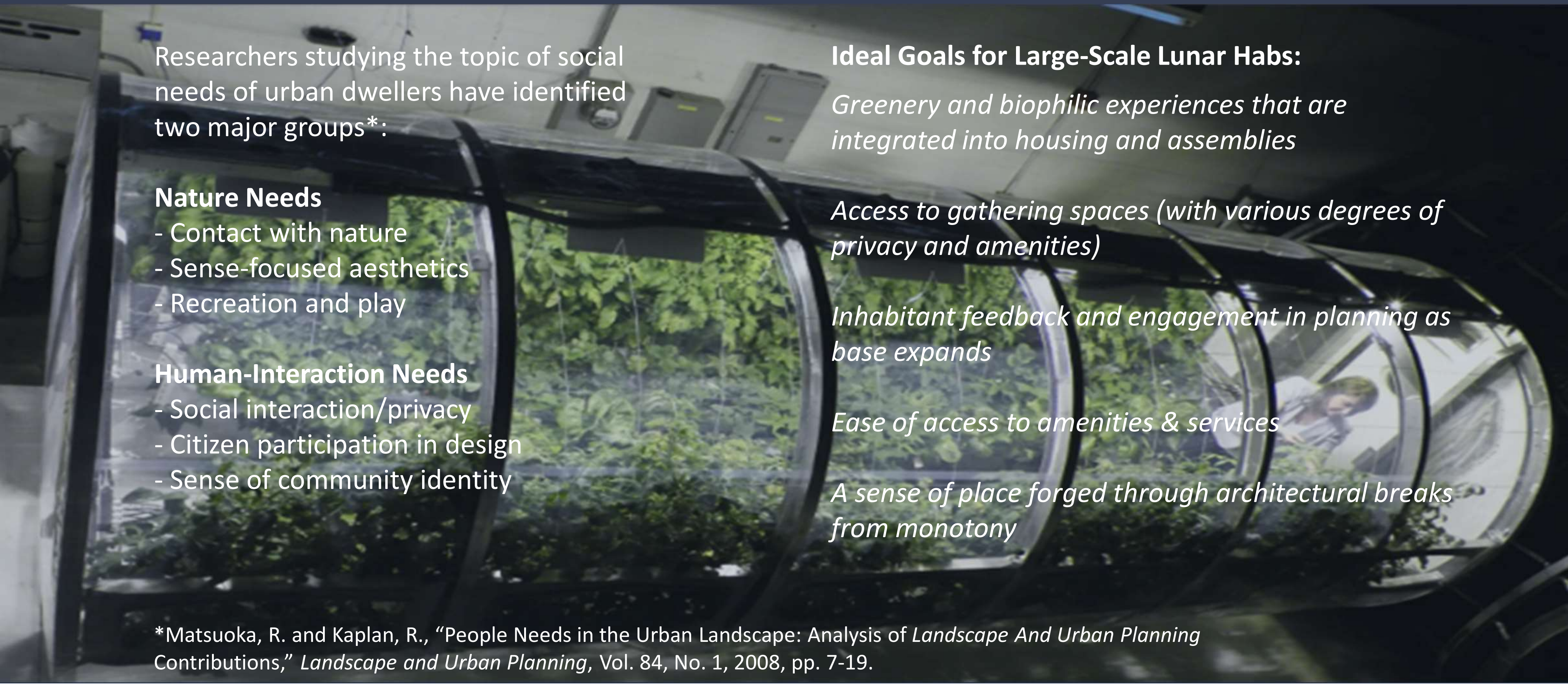
Psychological and Social Considerations



Researchers studying the topic of social needs of urban dwellers have identified two major groups*:

Nature Needs
- Contact with nature
- Sense-focused aesthetics
- Recreation and play

Human-Interaction Needs
- Social interaction/privacy
- Citizen participation in design
- Sense of community identity

Ideal Goals for Large-Scale Lunar Habs:

Greenery and biophilic experiences that are integrated into housing and assemblies

Access to gathering spaces (with various degrees of privacy and amenities)

Inhabitant feedback and engagement in planning as base expands

Ease of access to amenities & services

A sense of place forged through architectural breaks from monotony

*Matsuoka, R. and Kaplan, R., "People Needs in the Urban Landscape: Analysis of *Landscape And Urban Planning* Contributions," *Landscape and Urban Planning*, Vol. 84, No. 1, 2008, pp. 7-19.

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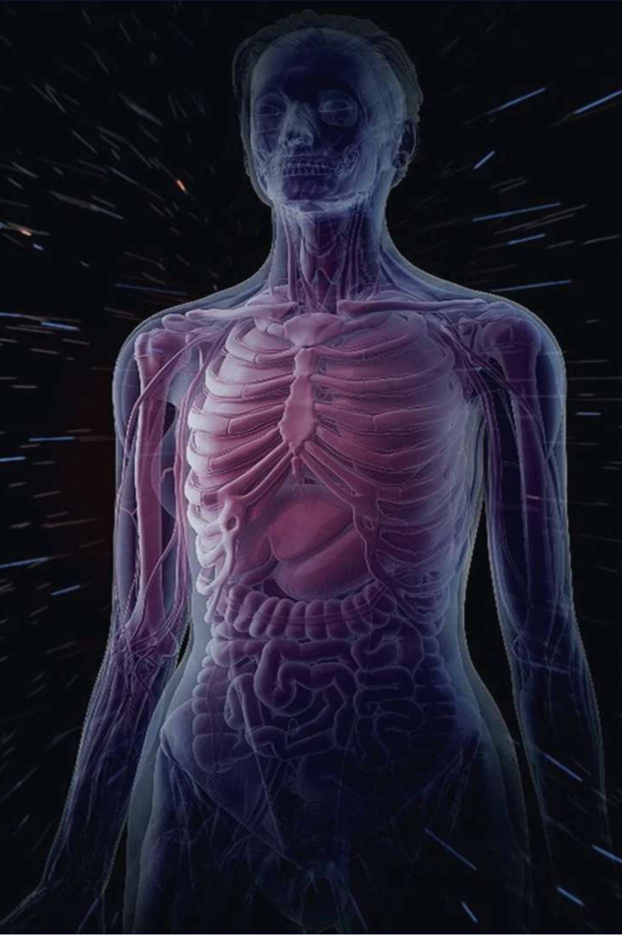
The Radiation Problem

- Galactic cosmic rays (GCRs) are omnipresent and omnidirectional high-energy particles that are the most concerning form of radiation and greatest shielding challenge in space exploration

- Solar particle events (SPEs) are much more predictable and can be more easily stopped than GCRs (which tend to decline in number during SPEs)



- Total permissible career dose for a crew member is 600 mSv (NASA-STD-3001, updated based on recommendation from National Academy of Sciences study on crew radiation limits in 2021)

- Short term SPE exposure limited to 250 mSv per event

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Executing from the Left: Segments and Subarchitectures

Human Lunar Return	Foundational Exploration	Sustained Lunar Evolution	Humans to Mars
Initial capabilities, systems, and operations necessary to re-establish human presence and initial utilization (science, etc.) on and around the Moon.	Expansion of lunar capabilities, systems, and operations supporting complex orbital and surface missions to conduct utilization (science, etc.) and Mars forward precursor missions.	Enabling capabilities, systems, and operations to support regional and global utilization (science, etc.), economic opportunity, and a steady cadence of human presence on and around the Moon.	Initial capabilities, systems, and operations necessary to establish human presence and initial utilization (science, etc.) on Mars and continued exploration.
Focus for ACR 22			**Focus for ACR 23**

Segment: A portion of the architecture, identified by one or more notional missions or integrated use cases, illustrating the interaction, relationships, and connections of the sub-architectures through progressively increasing operational complexity and objective satisfaction.

Sub-architecture: A group of tightly-coupled systems, functions, and capabilities that perform together to accomplish architecture objectives.

Communication, Positioning, Navigation, and Timing • Habitation • Human Systems • Mobility System and Logistics • Utilities and Services • Transportation • Utilization Systems

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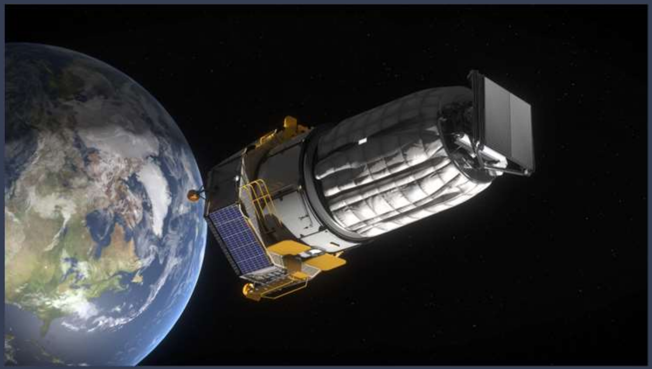
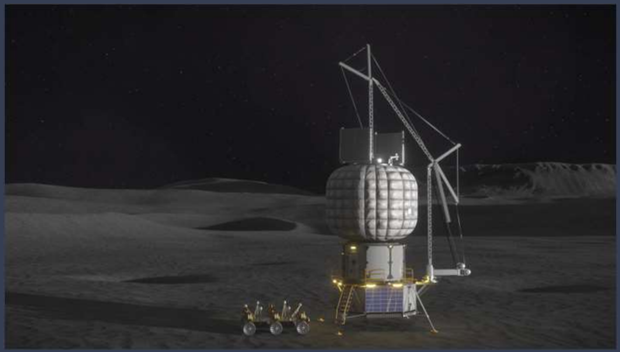
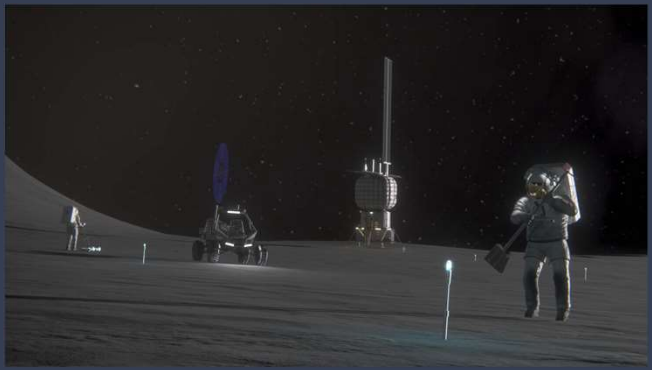
Lunar Surface Habitat







Lunar surface habitat is one concept under trade in the architecture

Mars Transit Habitat

Mars Transit Habitat is one concept under trade in the architecture.