National Aeronautics and
Space Administration

NASA's Moon to Mars Architecture Workshop

ESDMD ACR23 Progress

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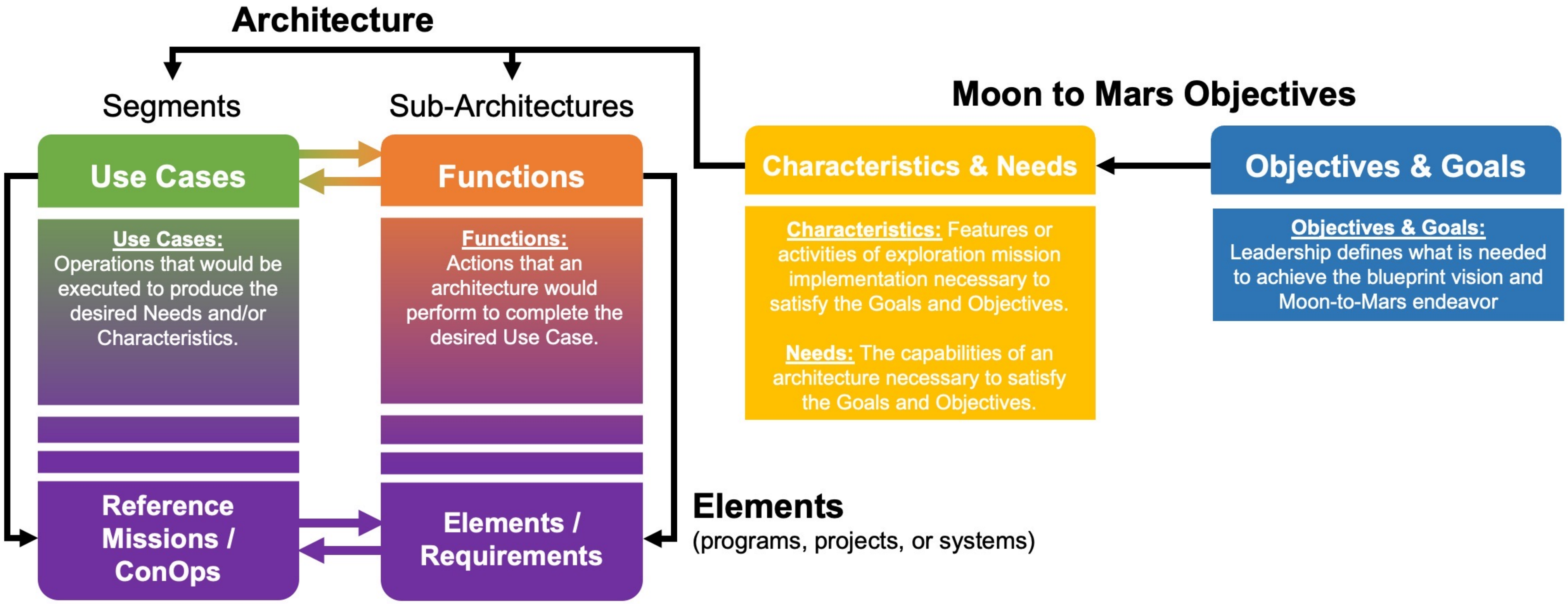
Architecting from the Right



Architecture organized by Segments and Sub-architectures in the ADD to group similar features and express progression of capabilities over time.

The Architecture process requires a decomposition of Moon to Mars Objectives to element functions and mission use cases to complete the process of “architecting from the right.” This establishes the relationship of executing programs and projects to the driving goals and objectives.

Architecture Concept Review

The purpose of an Architecture Concept Review (ACR) is to help unify the agency, promote advocacy for the architecture, and generate inputs from across NASA.

- The specific purpose of the Architecture Concept Review 22 (ACR22) was to:
  - Concur on the newly established yearly ACR process
  - Concur on disposition of key issues from ESDMD-001 Moon to Mars (M2M) Architecture Definition Document (ADD) Change Request
    - Human Lunar Return segment focus
  - Concur on priority tasks for the next ACR

ARCHITECTURE CONCEPT REVIEW (ACR22)
Participation included representation from Mission Directorates, Agency Leadership, NASA Centers, Tech Authorities, ESDMD Leadership, Program Managers, and the Architecture Team

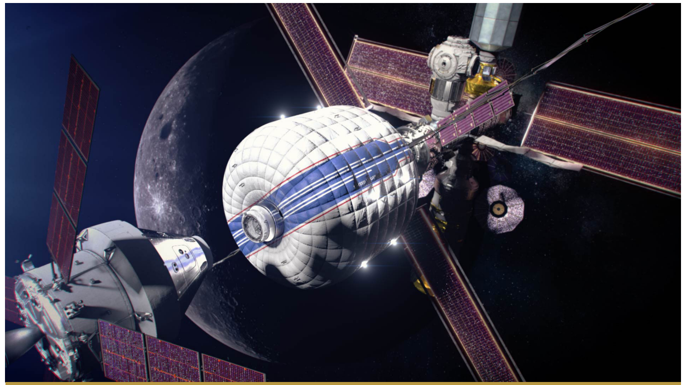
Future ACRs will be conducted annually in November to continue refining the architecture based on evolving policy, budget, partner contributions, and development schedules. Annual ACRs shifted to align with the NASA budget cycle.

FY23 Architecture Iteration

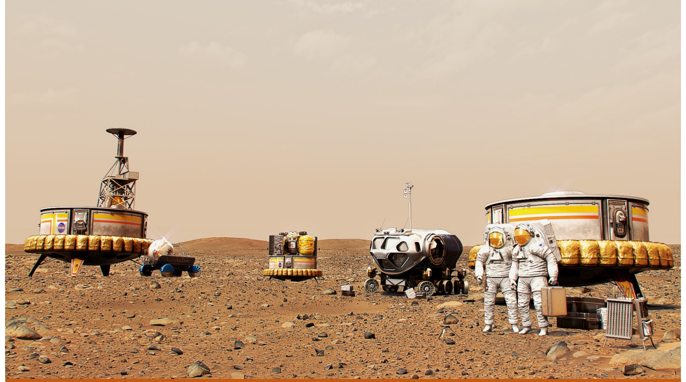
- NASA's architecture team is currently working Strategic Analysis Cycle 23.
- There are two priorities for shortened cycle:
  - Near-term needs for further Foundational Exploration segment definition
  - Humans to Mars objectives decomposition and expansion of detail for long term arch planning
- The team will conduct on-going assessments of feedback from events, which will influence ACR23 content and processes for the next year.

Human Lunar Return

Foundational Exploration



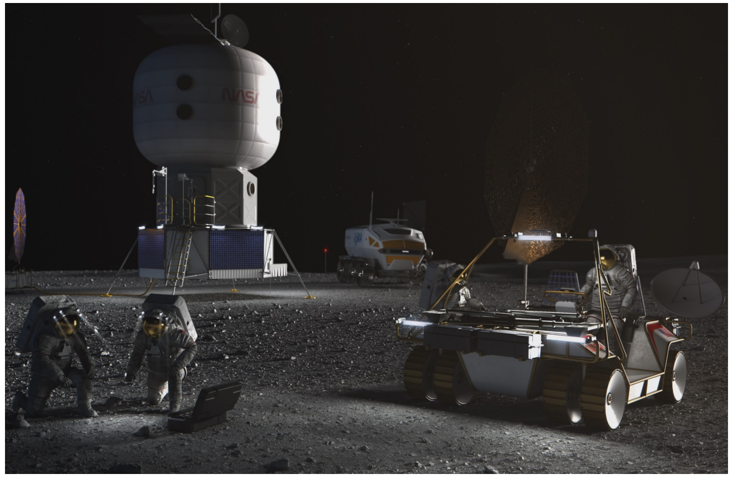
Sustained Lunar Evolution



Humans to Mars

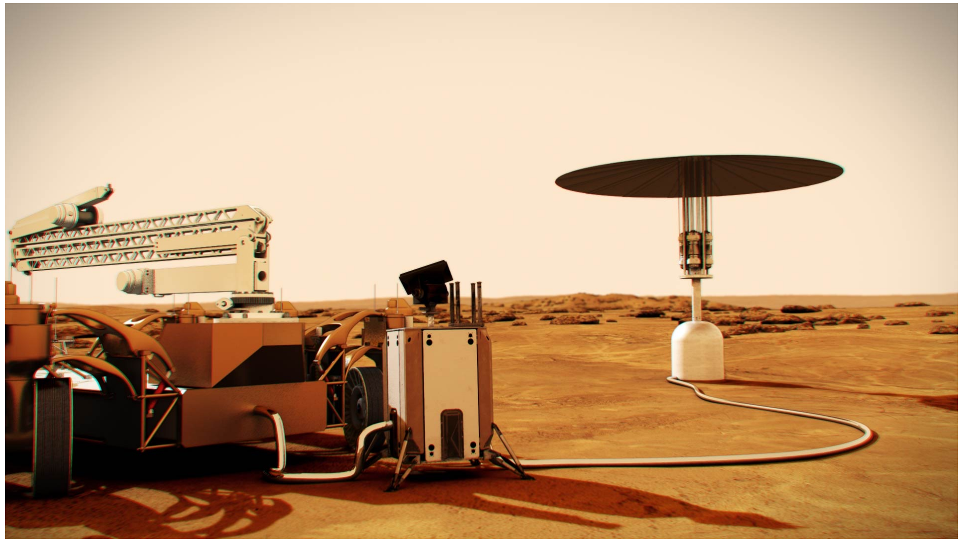
ACR23 Foundational Exploration Growth

- Anticipate three additional sub-architectures that were not driven in the Human Lunar Return segment or emerged from feedback:
  - Infrastructure (including In-Situ Resource Utilization)
  - Command and Data Handling
  - Robotics
- Will include Architecture Definition Document element definition for programs and/or projects after they pass NASA Mission Concept Review milestone:
  - Lunar Terrain Vehicle
  - Pressurized Rover
  - Human-class Delivery Lander (HDL)
  - Gateway Extra-Vehicular Robotic System (GERS)
  - ESPRIT Refueling Module (ERM)
- Foundational Exploration use case and functions
  - Plan to expand content for sub-architectures for future element needs



ACR23 Humans to Mars Focus

- Objective decomposition for Mars objectives
  - Deferred from ACR22 for schedule
  - Additional content as is traces to lunar supporting needs
- Initial list of major Mars decisions that are needed
- Expanded content in the Mars trades and studies
- Mars White Papers:
  - Mars Communication Challenges
  - Mars Mission Abort Challenges
  - Mars “Gear Ratios”
  - Mars Surface Power Considerations



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Science Objectives Progress

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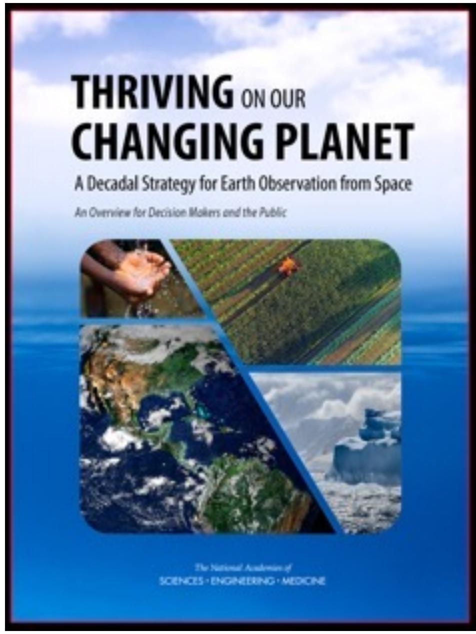
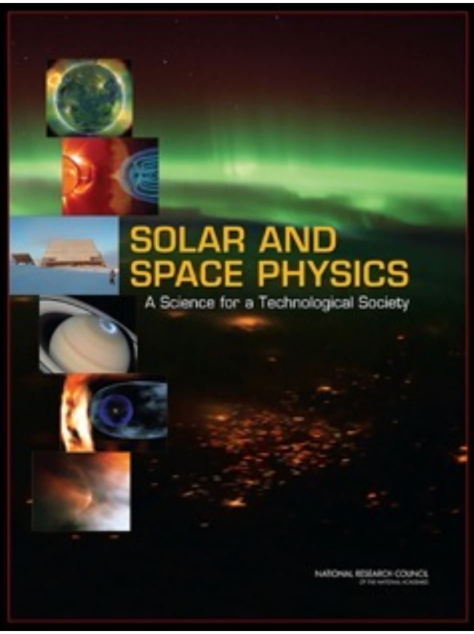
Who, What, When, Where, Why, and How?

When addressing the classic six questions, each drives different architectural decisions, but all must be answered to arrive at a complete exploration strategy.

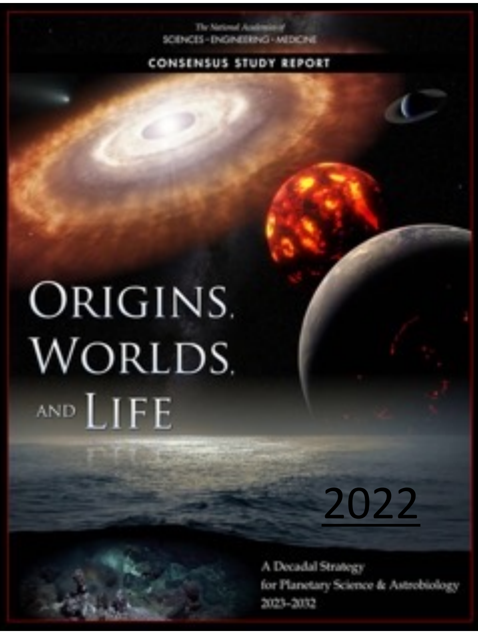
In the case at the right, the driving question is "Why," which informs the What, Where, How, When, and Who.

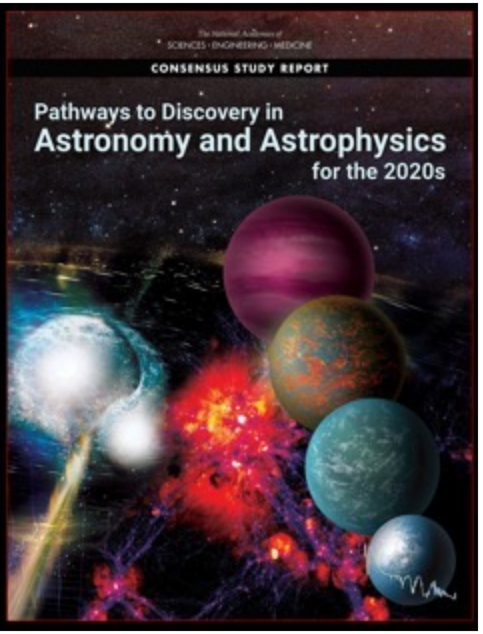
Strategic Research and Priorities from Decadal Surveys

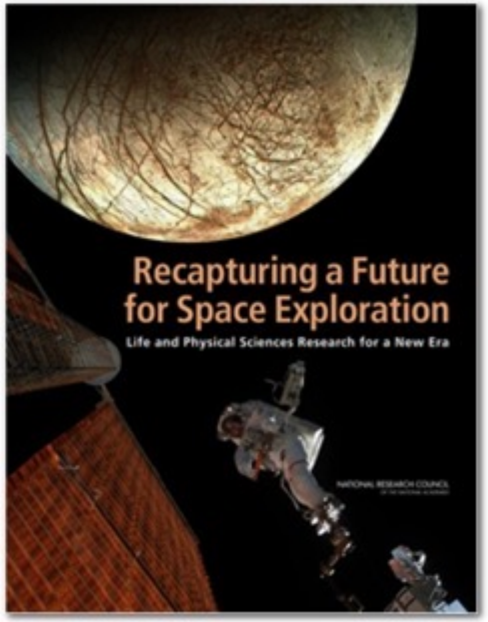




to be updated in 2024

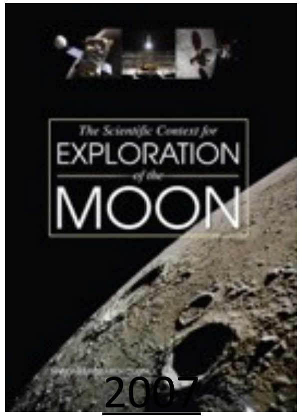


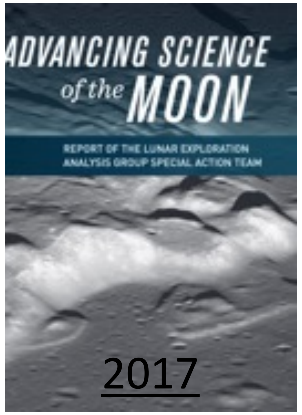


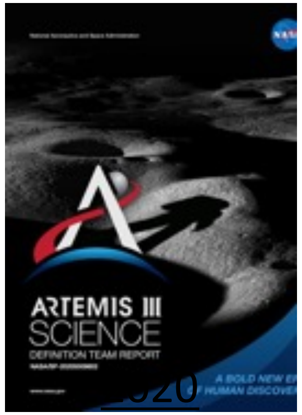


to be updated in 2023

Planetary Science Community reports







NASA reports

Suggested Questions to be Addressed

Image Credit: Gene and Cell Magazine

Image Credit: NASA

Image Credit: Journal of Petroleum Technology

1. Are the functions, needs, characteristics, and use cases appropriate to accomplish the defined Science Objectives or are there some required to support the objectives that are not yet in the ADD?

2. What science is necessary to be conducted on the Moon to be ready for humans to perform science on Mars?

3. Which science is best achieved through human exploration vs. robotic missions? Or a combination?

4. Are there any science-focused white papers that would help the community understand why certain decisions have been made?

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STMD ACR23 – Infrastructure Goals Progress

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Architecture Segments and Sub-Architectures

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.

Human Lunar Return

Initial capabilities, systems, and operations necessary to re-establish human presence on the Moon.

Foundational Exploration

Expansion of operations, capabilities, and systems supporting complex orbital and surface missions to conduct utilization and Mars forward analogs.

Sustained Lunar Evolution

Enabling operations, capabilities, and systems to support regional and global utilization, economic opportunity, and a steady cadence of human missions on and around the Moon.

Humans to Mars

Initial capabilities, systems, and operations necessary to establish human presence on Mars and continued exploration.

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 • Logistics • Mobility Systems • Power • Transportation • Utilization Systems

Lunar Infrastructure Goal and Objectives

Lunar Infrastructure (LI) Goal: Create an interoperable global lunar utilization infrastructure where U.S. industry and international partners can maintain continuous robotic and human presence on the lunar surface for a robust lunar economy without NASA as the sole user, while accomplishing science objectives and testing for Mars.

LI-1[L]: Develop an incremental lunar power generation and distribution system that is evolvable to support continuous robotic/human operation and is capable of scaling to global power utilization and industrial power levels.

LI-2[L]: Develop a lunar surface, orbital, and Moon-to-Earth communications architecture capable of scaling to support long term science, exploration, and industrial needs.

LI-3[L]: Develop a lunar position, navigation and timing architecture capable of scaling to support long term science, exploration, and industrial needs.

LI-4[L]: Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.

LI-5[L]: Demonstrate precision landing capabilities in support of continuous human lunar presence and a robust lunar economy.

LI-6[L]: Demonstrate local, regional, and global surface transportation and mobility capabilities in support of continuous human lunar presence and a robust lunar economy.

LI-7[L]: Demonstrate industrial scale ISRU capabilities in support of continuous human lunar presence and a robust lunar economy.

LI-8[L]: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.

LI-9[L]: Develop environmental monitoring, situational awareness, and early warning capabilities to support a resilient, continuous human/robotic lunar presence.

Superscripts indicate applicability to Lunar (L), Martian (M), or both (LM)

Mars Infrastructure Objectives

Mars Infrastructure (MI) Goal: Create essential infrastructure to support initial human Mars exploration campaign.

- MI-1^{M}: Develop Mars surface power sufficient for an initial human Mars exploration campaign.
- MI-2^{M}: Develop Mars surface, orbital, and Mars-to-Earth communications to support an initial human Mars exploration campaign.
- MI-3^{M}: Develop Mars position, navigation and timing capabilities to support an initial human Mars exploration campaign.
- MI-4^{M}: Demonstrate Mars ISRU capabilities to support an initial human Mars exploration campaign.

Superscripts indicate applicability to Lunar (L), Martian (M), or both (LM)

Example: Power Systems Decomposition

Sustainable Living and Working Further from Earth

Developing sustainable power sources and other surface utilities to enable continuous Lunar and, ultimately, Mars surface operations.

Power Generation

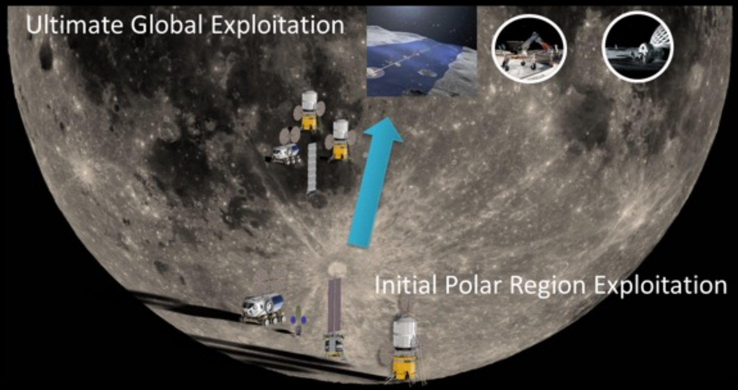
- Up to 50 kW_e-class modular Earth-sourced Photovoltaic Arrays for Lunar Polar surface outposts and ISRU prospecting/production plants.
- 40 kW_e-class mobile Fission Power Systems to support Lunar Polar operations, bootstrap a global Lunar surface power grid to support Lunar industrialization at lower latitudes, and support Mars surface exploration

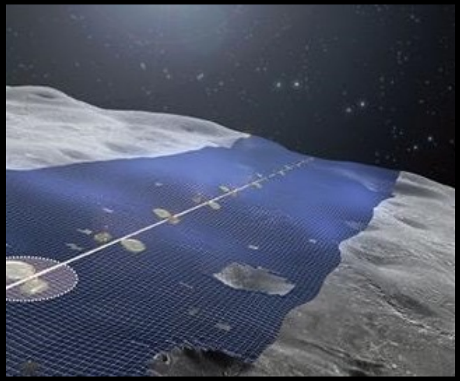
Energy Storage

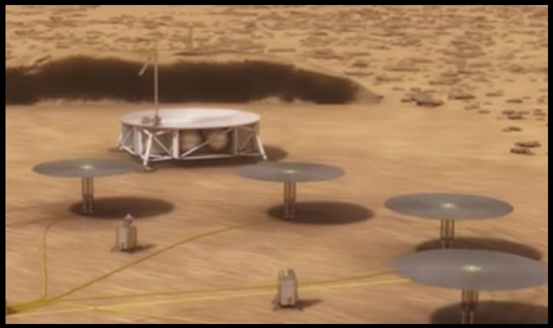
- Up to 50 kW_e-hr Secondary Batteries for mobility
- Up to 1 MW_e-hr Regenerative Fuel Cells for Polar Outpost/ISRU energy storage
- Large scale energy storage systems gathered from Lunar-sourced minerals

Power Distribution

- 1000 V, radiation-hard, high reliability power electronics
- Up to 10 kW_e–class low mass Cables and spools for multi-km power distribution grids
- Up to 10 kW_e-class Power Beaming for up to 5 km line-of-sight.
- High power, long distance transmission lines printed from Lunar-sourced aluminum.







EXPLORE: Develop Next Generation Communications and Navigation Technologies

Develop communications, navigation, and sensing infrastructure capable of handling high data volumes with near real-time communication (cislunar), and increased onboard navigation and time-keeping autonomy

QUANTUM COMMUNICATIONS

- High-quality, high-rate entangled photon sources
- Entanglement swapping
- Quantum memory
- Non-demolition measurement
- Networking: repeater, error correction, etc.

CISLUNAR AND MOON

- LunaNet framework for interoperable and resilient communication and navigation
- 1-10+ Gbps coherent optical links direct-to-Earth
- Multi-Gbps optical links to lunar surface
- Weak-signal, fast-acquisition multi-GNSS receiver for cislunar and lunar users
- High-performance atomic frequency standards for improved onboard navigation and timing
- 3GPP/5G+ for lunar surface
- Metric tracking data from available communication links

OTHER CELESTIAL BODIES AND DEEP SPACE

- Extension of LunaNet framework beyond Earth-Moon for interplanetary and deep space network
- High Photon Efficiency optical links for 100s Mbps direct-to-Earth downlink
- High-performance atomic frequency standards enabling one-way metric tracking data
- GPS-like autonomous onboard navigation and timing through observation of X-ray emitting millisecond pulsars
- Metric tracking data from available communication links

NEAR-EARTH

- 200+ Gbps low-Earth orbit direct-to-Earth optical downlink for smallsats
- 1-100s Gbps optical inter-satelite links
- Metric tracking data from optical links for alternative position, navigation, and timing
- Multi-lingual, cognitive, wideband terminals
- Weak-signal, fast-acquisition multi-GNSS smallsat compatible receiver for above GNSS constellation users
- Metric tracking data from available communication links

Example: Autonomous Lunar Excavation, Construction, & Outfitting

targeting landing pads, structures, habitable buildings utilizing in-situ resources

Excavation for ISRU-based Resource Production

- Site surveying, resource prospecting
- Ice mining & regolith extraction for 100s to 1000s metric tons of commodities per year

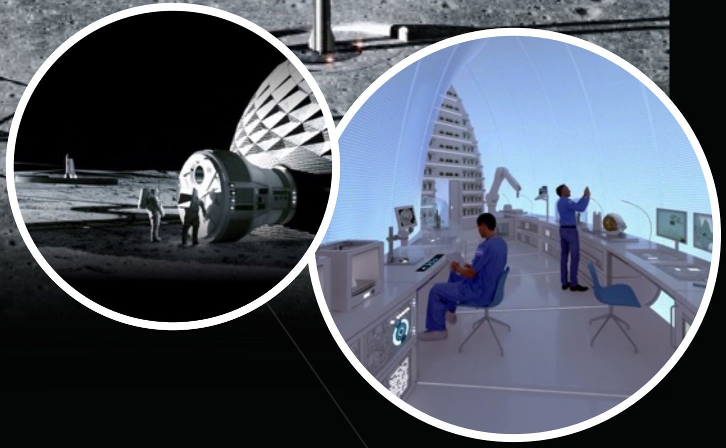
Excavation for Construction

- Site preparation for construction: obstacle clearing, leveling & trenching
- Construction materials production utilizing in-situ resources
  - 100s to 1000s metric tons of regolith-based feedstock for construction projects
  - 10s to 100s metric tons of metals and binders

Construction and Outfitting

- Landing pad construction demo scaling to human lander capable landing pads
- Unpressurized structure evolving to single and then multi-level pressurized habitats
- Outfitting for data, power & ECLSS systems
- 100-m-diameter landing pads, 10s km of roads, 1000s m^3 habitable pressurized volume

Sustainable Off-Earth Living & Working



- Commercial autonomous excavation and construction of landing pads, roads and habitable structures
- Fully outfitted buildings to support a permanent lunar settlement and vibrant space economy
- Extensible to future SMD missions and Mars settlement

Discussion and Questions for the Infrastructure Breakouts:

1. Any questions or comments on the Lunar or Mars Infrastructure Goal Rationales or objectives?

2. NASA is engaging with U.S. industry partners and asking for feedback on sustainable business cases. How are other Agencies engaging their industries?

3. Which infrastructure objectives align with your Agency's interests?

National Aeronautics and Space Administration

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SOMD Operations Objectives Progress

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Operations Objectives

Operations Goal: Conduct human missions on the surface and around the Moon followed by missions to Mars. Using a gradual build-up approach, these missions will demonstrate technologies and operations to live and work on a planetary surface other than Earth, with a safe return to Earth at the completion of the missions.

- OP-1[L]: Conduct human research and technology demonstrations on the surface of Earth, low Earth orbit platforms, cislunar platforms, and on the surface of the moon, to evaluate the effects of extended mission durations on the performance of crew and systems, reduce risk, and shorten the timeframe for system testing and readiness prior to the initial human Mars exploration campaign.
- OP-2[LM]: Optimize operations, training and interaction between the team on Earth, crew members on orbit, and a Martian surface team considering communication delays, autonomy level, and time required for an early return to the Earth.
- OP-3[LM]: Characterize accessible resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable use of resources on successive missions.
- OP-4[LM]: Establish command and control processes, common interfaces, and ground systems that will support expanding human missions at the Moon and Mars.
- OP-5[LM]: Operate surface mobility systems, e.g., extra-vehicular activity (EVA) suits, tools and vehicles.
- OP-6[L]: Evaluate, understand, and mitigate the impacts on crew health and performance of a long deep space orbital mission, followed by partial gravity surface operations on the Moon.
- OP-7[LM]: Validate readiness of systems and operations to support crew health and performance for the initial human Mars exploration campaign.
- OP-8[LM]: Demonstrate the capability to find, service, upgrade, or utilize instruments and equipment from robotic landers or previous human missions on the surface of the Moon and Mars.
- OP-9[LM]: Demonstrate the capability of integrated robotic systems to support and maximize the useful work performed by crewmembers on the surface, and in orbit.
- OP-10[LM]: Demonstrate the capability to operate robotic systems that are used to support crew members on the lunar or Martian surface, autonomously or remotely from the Earth or from orbiting platforms.
- OP-11[LM]: Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.
- OP-12[LM]: Establish procedures and systems that will minimize the disturbance to the local environment, maximize the resources available to future explorers, and allow for reuse/recycling of material transported from Earth (and from the lunar surface in the case of Mars) to be used during exploration.

Superscripts indicate applicability to Lunar (L), Martian (M), or both (LM)

Decomposition of OP-1^{L}

Conduct human research and technology demonstrations on the surface of Earth, low Earth orbit platforms, cislunar platforms, and on the surface of the moon, to evaluate the effects of extended mission durations on the performance of crew and systems, reduce risk, and shorten the timeframe for system testing and readiness prior to the initial human Mars exploration campaign.

- Provide capabilities to conduct crewed and uncrewed testing of surface habitable system(s)
- Provide capabilities to conduct short-duration (<1month) crew exploration missions(s) on the lunar surface
- Provide capabilities to conduct mid-duration (~1-3 months) crew exploration mission(s) on the lunar surface
- Provide capabilities to conduct long-duration (~1year+) crew exploration mission(s) in cislunar space
- Provide capabilities to transition crew from micro-gravity environment to partial gravity environment


National Aeronautics and Space Administration
NASA
Human Research Program
STEPS TO MARS
EARTH:
Simulated spaceflight hazards in Ground Analogs | :envihab | Antarctic Stations | NEK | HERA | Space Radiation Lab
LOW EARTH ORBIT:
International Space Station – A unique testbed to study micro-gravity and environment hazards, with varying mission durations
LUNAR MISSIONS:
Decreasing Earth-dependence around and on the lunar surface. Provides insight into deep space radiation, behavioral health, and gravity transitions
www.nasa.gov/hrp
NP-2020-11-020-JSC

Research Highlights: FY22 to FY23 Analog Missions

HERA Campaign 6 (Isolation & Confinement):
- Four 45-day missions: 15 HRP Studies
- **Primary research themes - Human Systems Integration Architecture (HSIA) & autonomy.**

SIRIUS 21 (Isolation & Confinement):
- 8 month mission with 6 crew residing in the **NEK habitat in Moscow, Russia** completed July 2022
- Multinational crew – 3 Russian, 2 US, and 1 UAE
- HRP research themes – **Team functioning, stress and resilience, autonomy, food acceptability**
- 70 total studies participated, **8 HRP studies**
- **Numerous real-life challenges in mission**

US SIRIUS 21 Crewmembers

:envihab (Bedrest) SANS Countermeasures:
- **6 HRP** and 6 DLR investigations
- **Campaigns 1-2 focus on Lower Body Negative Pressure**
- **Campaigns 3-4 focus on thigh cuff + exercise countermeasure**

DLR's :envihab Facility

Antarctic Stations (Isolation & Confinement):
- Palmer Station: **Immune Countermeasure study**
  - Data collection completed in 2022 winter-over and ongoing in 2023
- South Pole Stations: **VR Sensory Stimulation study**
  - Data collection began Aug. 2022 and continuing in 2023 winter-over.

Novespace Parabolic Flights:
- 0g **cardiovascular study** completed
- Upcoming **cardiovascular, sensorimotor and neurophysiological responses to 0-g & partial-g** in June

CHAPEA: One Year Analog at JSC
- Integrated suite of studies evaluating crew health and performance during a Mars mission with a notional Mars food system.
- 4 crew being a one year mission in June 2023

Decomposition of OP-4^{L,M}

Establish command control processes, common interfaces, and ground systems that will support expanding human missions at the Moon and Mars

Characteristics and Needs:

- Integrate networks and mission systems to exchange data between Earth based systems and exploration elements
- Utilize common data interface(s) for exchanges between Earth based systems and exploration elements
- Provide capabilities to store and protect data on exploration elements

Comm and Nav Architecture Solutions to Support Human Lunar Return Segment

DSN Lunar Exploration Upgrades (DLEU)

- Upgrades to two DSN antennas at each of the three complexes (totaling six upgraded antennas)
- Simultaneous operations – S+Ka-band or X+Ka-band, simultaneous Ka-band
- Increased data rates – greater than 100Mbps downlink in Ka-band

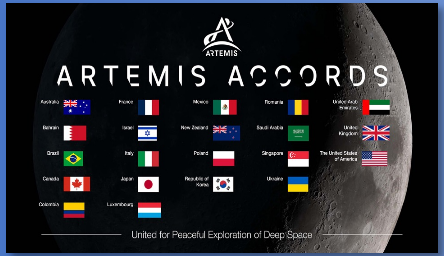
Lunar Exploration Ground Segment (LEGS)

(18-Meter Class Antenna Subnet)

- A dedicated new set of antennas, designed to support lunar missions, to help alleviate the user load on the DSN
- Minimum of three sites around the Earth for continuous coverage
- NASA pursuing build of LEGS sites #1-3
- Commercial services to add additional capacity – add assets as demand grows and to meet redundancy / resiliency needs

Lunar Communications and Navigation Relay Services

- Removes DTE line-of-sight comm constraint & reduces user burden
- Initial relay deployment targeted at South Pole and Far-Side
- Networking and PNT services
- Commercial service procurement approach for the relay



International Partnerships and Contributions

- SCaN seeking contributions for both Earth based and Lunar C&N assets
- Priority 1: Direct-to-Earth assets that meet or exceed LEGS performance
- Priority 2: Lunar relay comm and PNT services
- Priority 3: Lunar surface comm and PNT capabilities

SCaN Architecture For Human Lunar Return