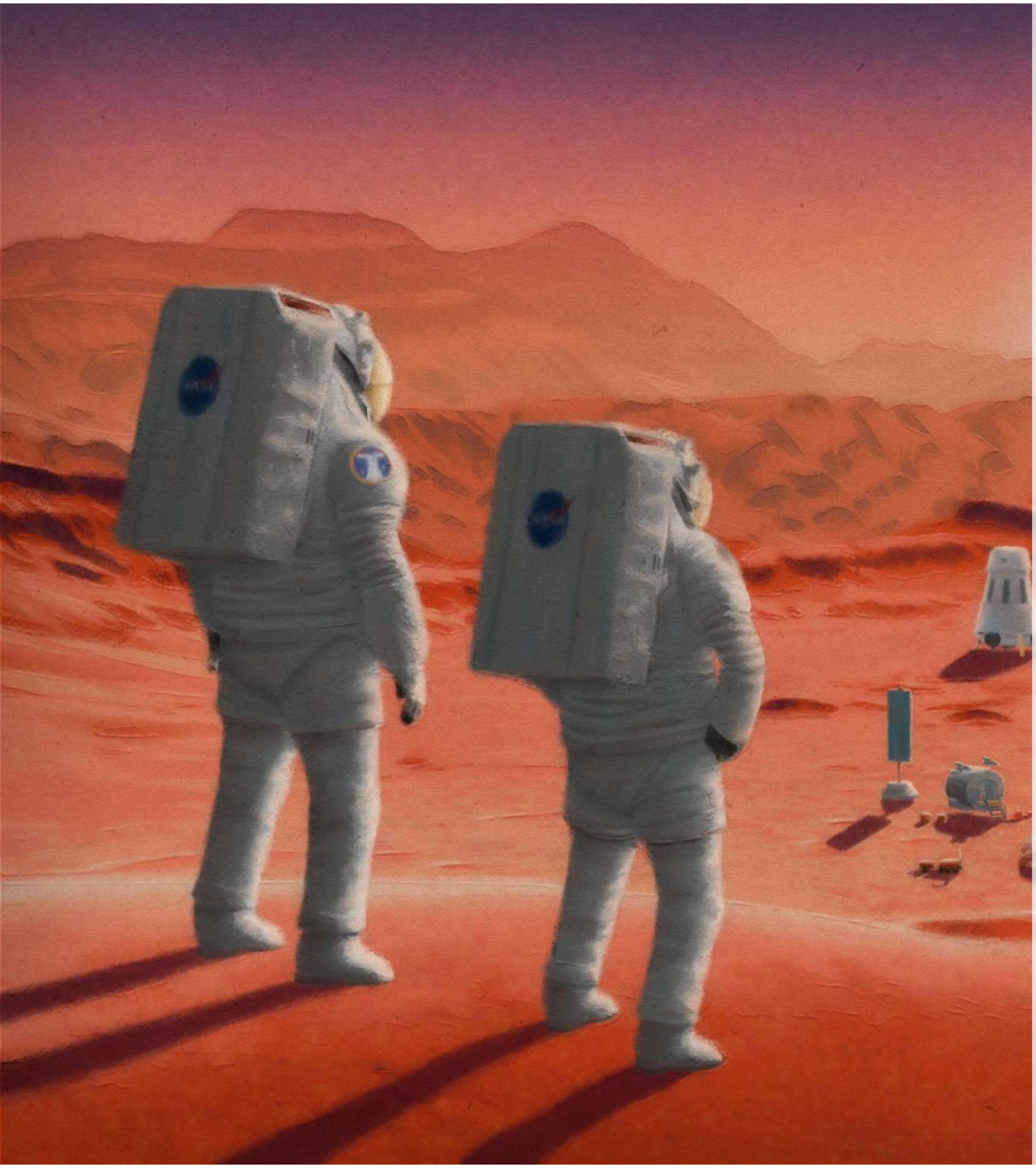


National Aeronautics and Space Administration

NASA's

Moon to Mars Architecture

National Academies

Arnold and Mabel Beckman Center | Irvine, California

December 17, 2024

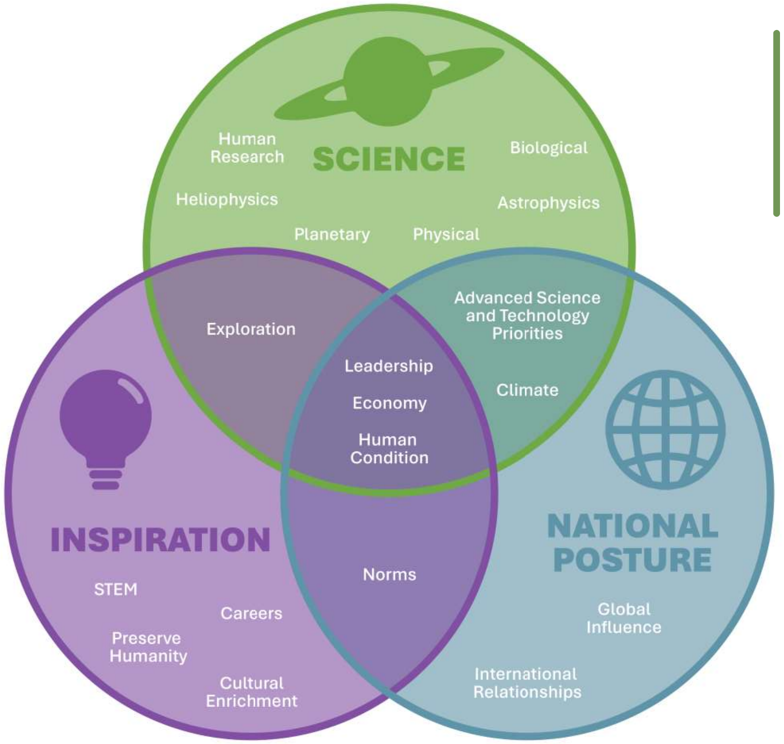
Dr. Jacob Bleacher

Chief Exploration Scientist

Strategy and Architecture Office

Exploration Systems Development Mission Directorate

Why We Explore…



SCIENCE
Investigations in deep space, on the Moon, and on Mars will enhance our understanding of the universe and our place in it.

INSPIRATION
Accepting audacious challenges motivates current and future generations to contribute to our voyage deeper into space.

NATIONAL POSTURE
What is done, how it's accomplished, and who participates affect our world, quality of life, and humanity's future.

NASA's Moon to Mars Objectives

Lunar and Planetary Science | Answer questions about the formation of our solar system, the geology and chemistry of planetary bodies, and the origins of life.

Heliophysics | Advance our study of the Sun and our ability to observe, model, and predict space weather.

Human and Biological Science | Grow our understanding of how the lunar, Martian, and deep space environments affect living things.

Physics and Physical Sciences | Investigate space, time, and matter in the unique environments of the Moon, Mars, and deep space.

Science Enabling | Realize integrated human and robotic techniques that address high-priority scientific questions around and on the Moon and Mars.

Applied Science | Carry out science utilizing integrated human and robotic techniques to inform the design of exploration systems.

Lunar Infrastructure | Enable government, industry, academia, and international partners to participate in a robust lunar economy and facilitate science.

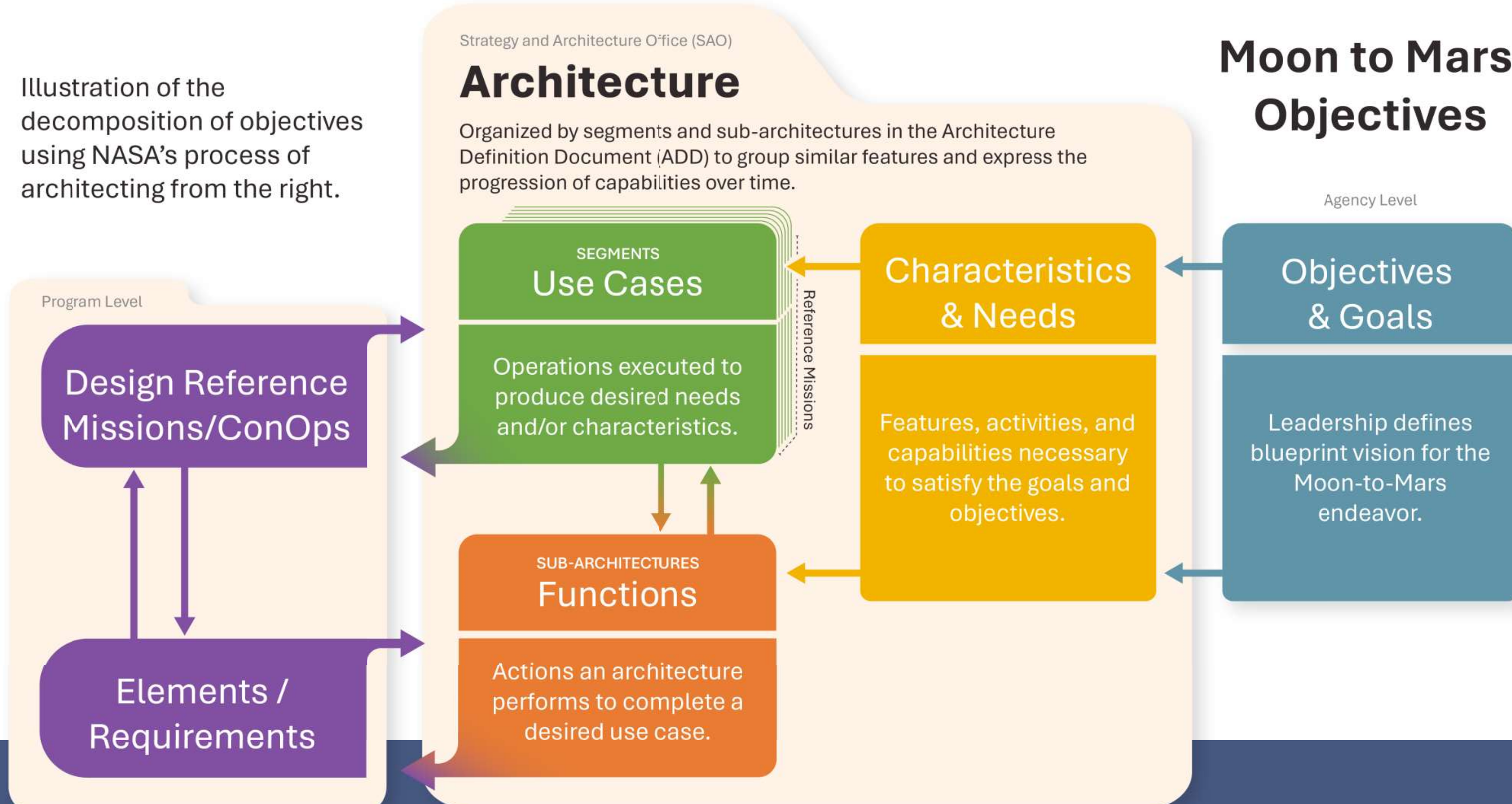
Mars Infrastructure | Develop the power, communications, navigation, and resource utilization capabilities to support initial human Mars exploration.

Transportation and Habitation | Create the systems necessary for humans to travel to the Moon and Mars, live and work there, and return to Earth safely.

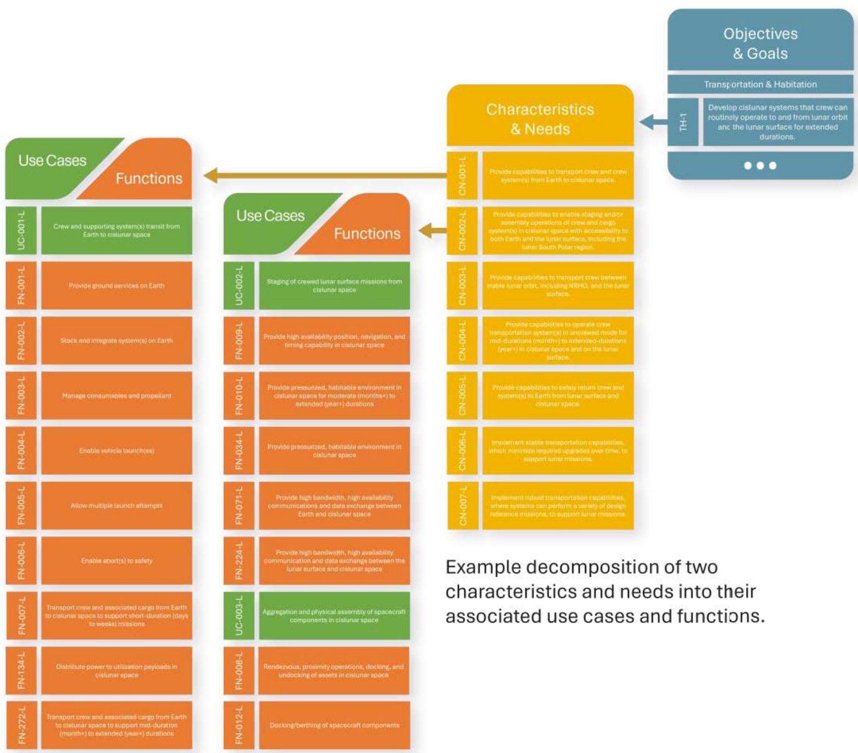
Operations | Conduct crewed missions to gradually build technologies and capabilities to live and work on planetary surfaces other than Earth.

Architecting from the Right

Illustration of the decomposition of objectives using NASA's process of architecting from the right.



Objective Decomposition



Example decomposition of two characteristics and needs into their associated use cases and functions.

The process of "architecting from the right" decomposes Moon to Mars Objectives into element functions and mission use cases.

This establishes the relationship of executing programs and projects to the driving goals and objectives.

Defining Terms

Architecture: The unified structure that defines a system, providing rules, guidelines, and constraints for constituent parts and establishing how they fit and work together.

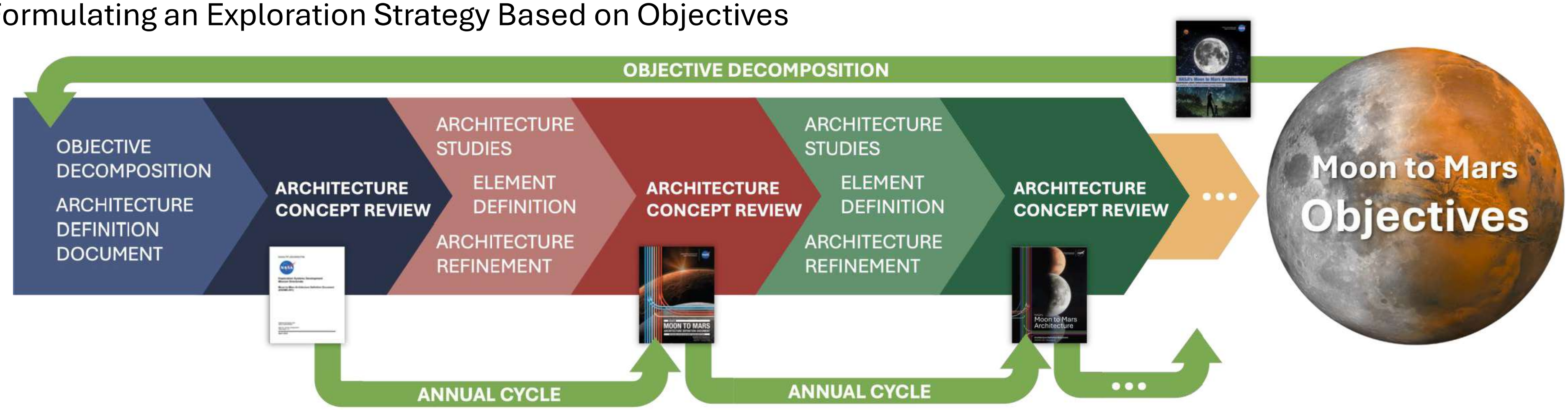
Characteristics and Needs: Features, activities, and capabilities necessary to satisfy goals and objectives.

Use Case: An operation that would be executed to meet desired characteristics and needs.

Function: One of the actions necessary to satisfy a use case.

NASA's Moon to Mars Architecture

An Evolutionary Architecture Process:
Formulating an Exploration Strategy Based on Objectives



TRACEABILITY

Decomposition of Blueprint Objectives to executing Architecture elements

ARCHITECTURE FRAMEWORK

Organizational construct to ensure system/element relationships are understood and gaps can be identified

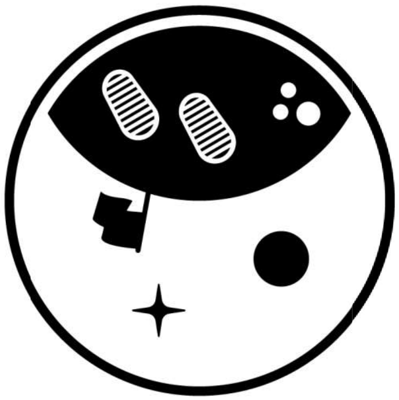
PROCESS & PRODUCTS

Clear communication and review integration paths for stakeholders

NASA's Moon to Mars Architecture Website
nasa.gov/architecture

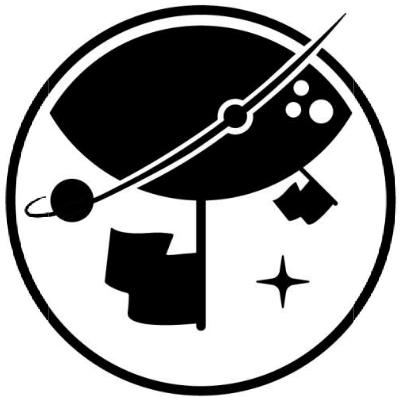
Architecture Segments

Future Segments



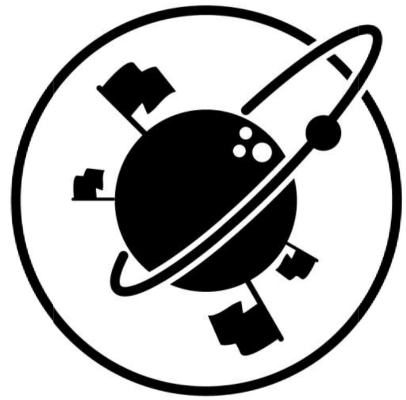
Human Lunar Return

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



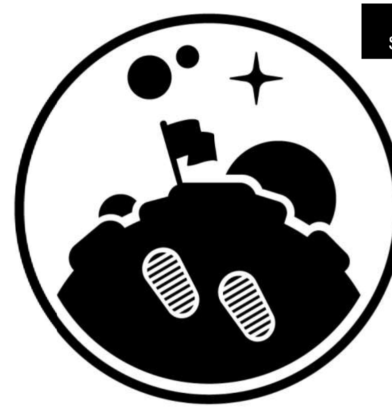
Foundational Exploration

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



Sustained Lunar Evolution

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



Humans to Mars

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

Segment | A portion of the architecture that integrates sub-architectures and progressively increases in complexity and objective satisfaction.

Architecture Sub-Architectures

Communications and Positioning, Navigation, and Timing Systems (C&PNT) enable transmission and reception of data, determination of location and orientation, and acquisition of precise time.

Autonomous Systems & Robotics employ software and hardware to assist the crew and operate during uncrewed periods.

Data Systems and Management transfer, distribute, receive, validate, secure, decode, format, compile, and process data and commands.

Habitation Systems ensure the health and performance of astronauts in controlled environments.

Infrastructure Support includes facilities, systems, operations planning and control, equipment, and services needed on Earth, in space, and on planetary surfaces.

In-situ Resource Utilization (ISRU) Systems extract resources in space or on the Moon or Mars to generate products.

Human Systems execute human and robotic missions; this includes crew, ground personnel, and supporting systems.

Logistics Systems package, handle, transport, stage, store, track, and transfer items and cargo.

Mobility Systems move crew and cargo around the lunar and Martian surfaces.

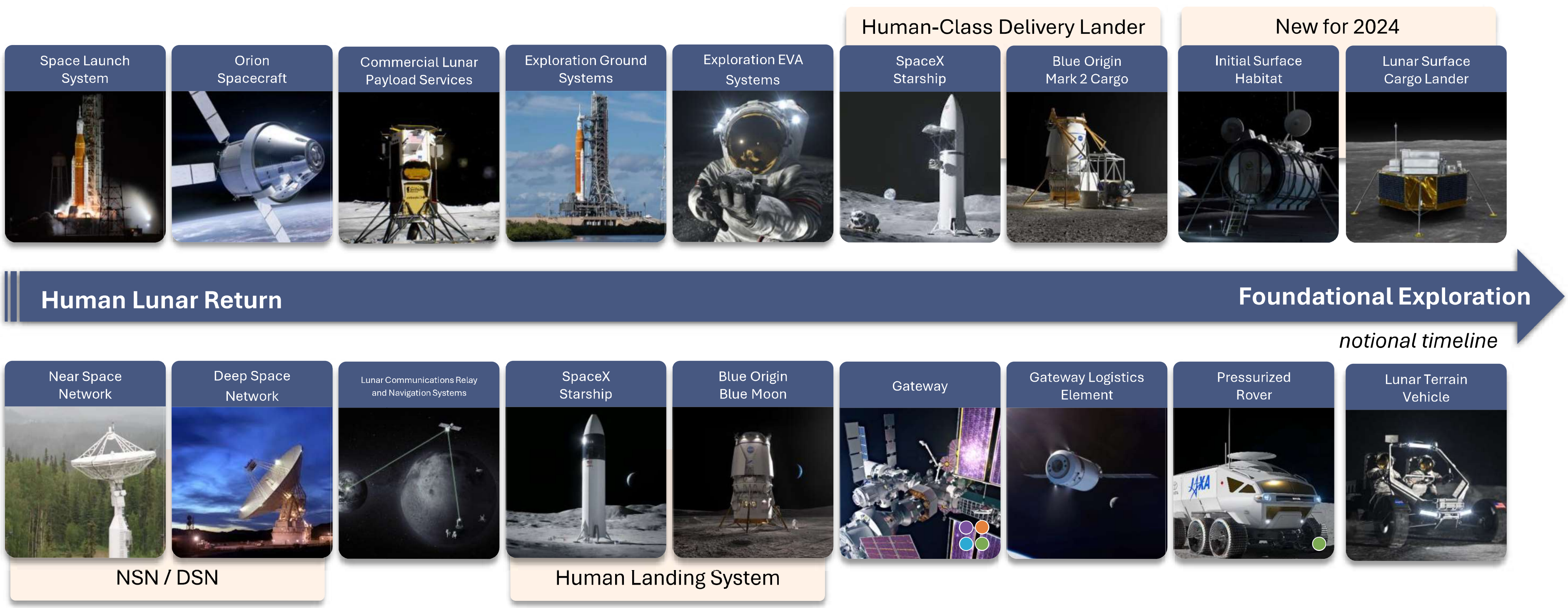
Power Systems generate, store, condition, and distribute electricity for architectural elements.

Transportation Systems convey crew and cargo to and from Earth to the Moon and Mars.

Utilization Systems enable science and technology demonstrations.

Sub-Architecture | A group of tightly coupled elements, functions, and capabilities that work together to accomplish one or more objectives.

Architecture Elements

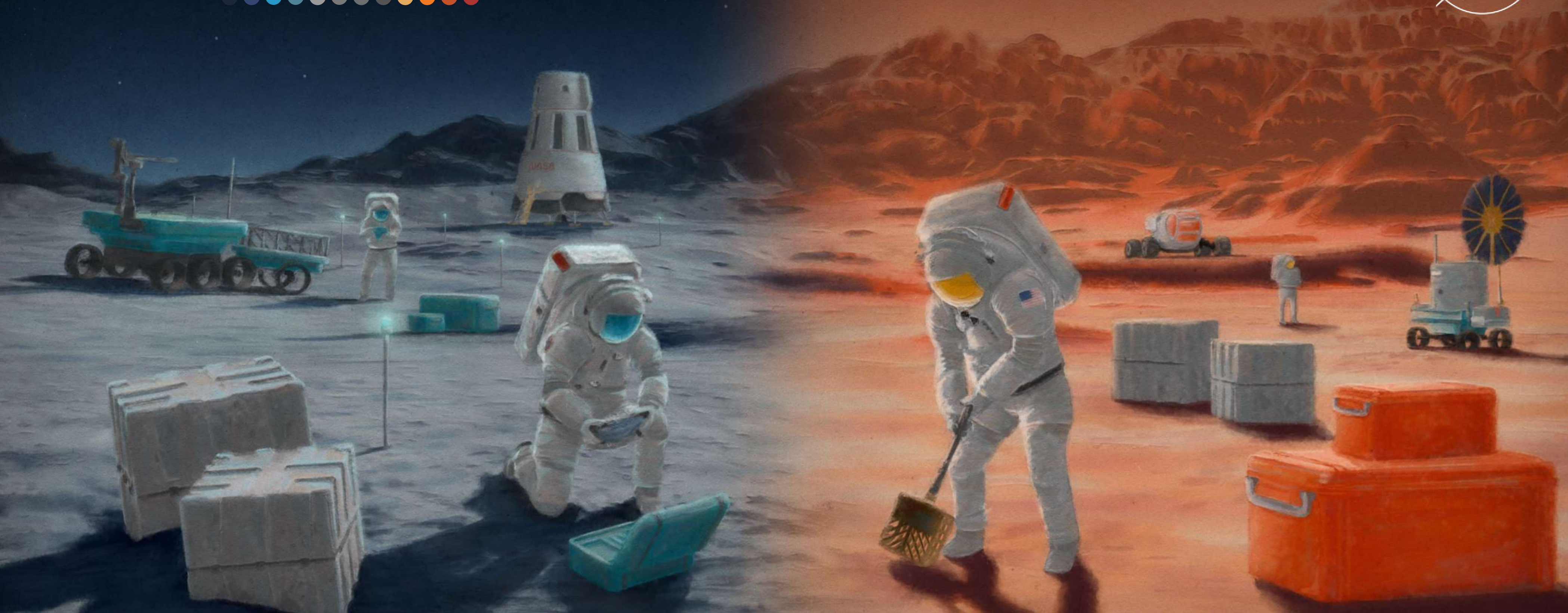


International Partnerships

- Canadian Space Agency
- European Space Agency
- Mohammed Bin Rashid Space Centre
- Japan Aerospace Exploration Agency

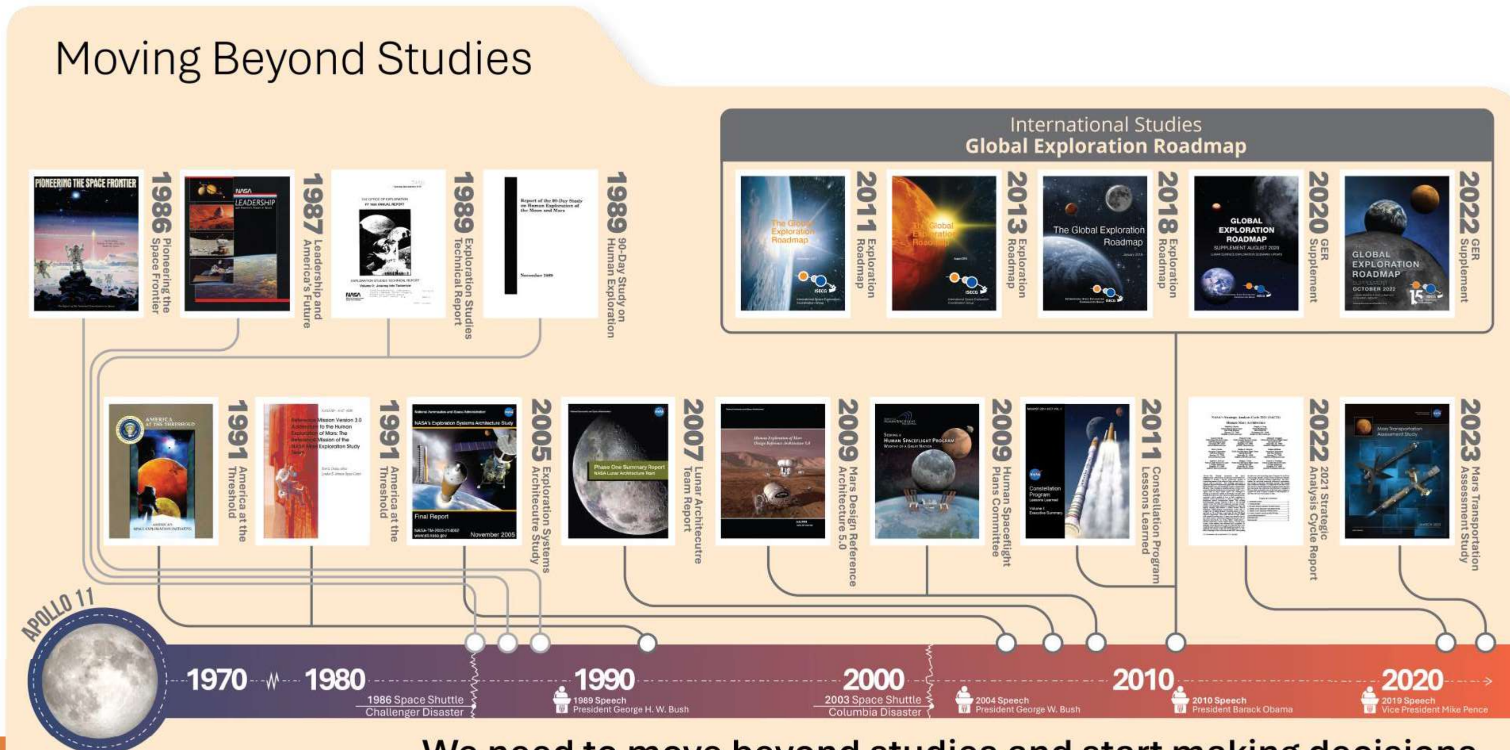
Element | A notional exploration system that enables a set of functions.

Why Moon *to* Mars?



Lunar exploration gives NASA the opportunity to prove the systems, capabilities, and operational paradigms needed for a successful human Mars exploration campaign.

Mars-Forward Planning

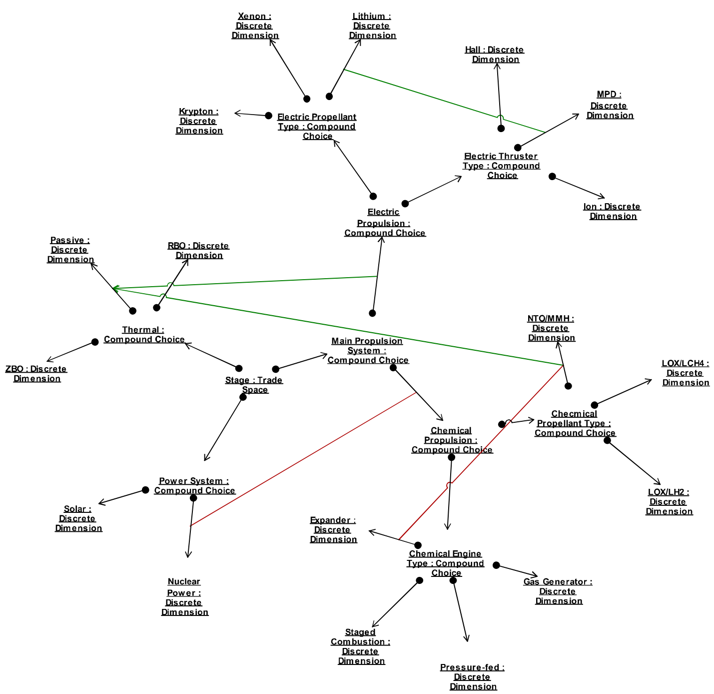


We need to move beyond studies and start making decisions.

**study list representative, not comprehensive.*

[redacted]

Mars Decision Mapping



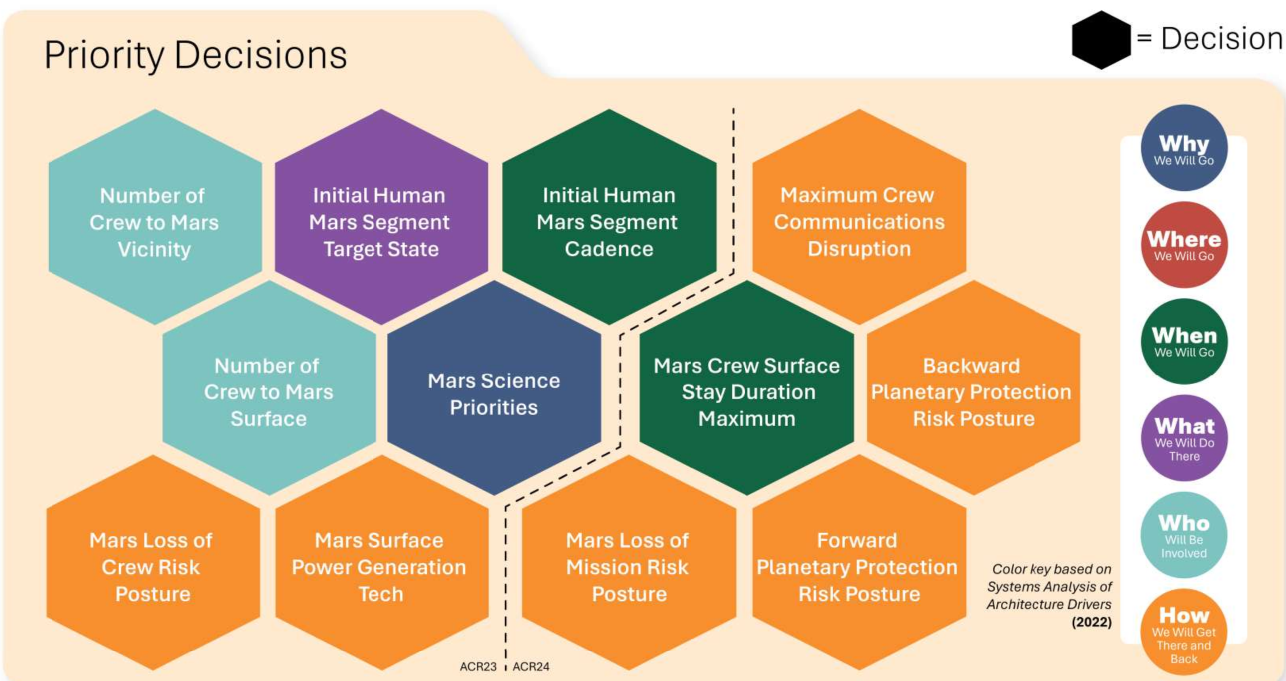
- Developing an exploration architecture requires innumerable decisions; every decision must be made, but not every decision must be made first.
- The order in which decisions are made heavily influences the ultimate architecture; the flow down implications and precedence relationships of decisions must be understood.
- **NASA has developed modelling tools to ensure the agency makes the right decision at the right time.**

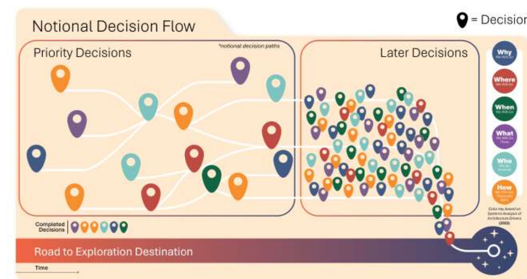
2022 White Paper
Systems Analysis of Architecture Drivers
https://go.nasa.gov/4giTrTT

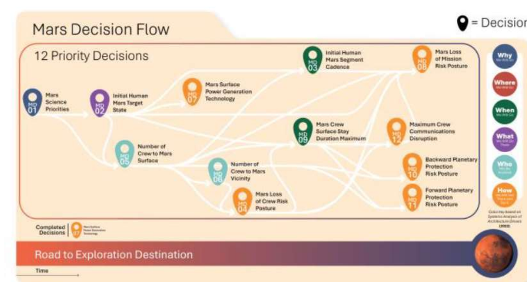
2023 White Paper
Key Mars Architecture Decisions
https://go.nasa.gov/3BclsgX

In 2023, NASA began analyses needed to allow for informed decision-making by agency leadership. **As a result the agency debuted its first seven priority decisions.**

Mars Decisions and First Decision



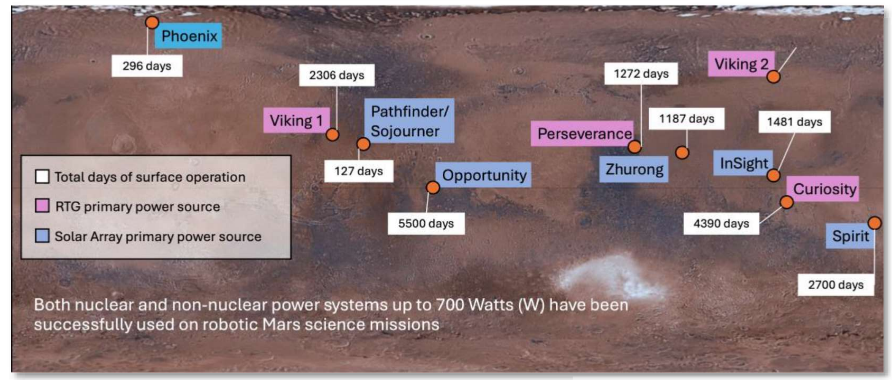




As part of the 2024 Architecture Concept Review, NASA added 5 additional priority decisions to the 7 the agency debuted in the 2023 Architecture Concept Review.

Mars Surface Power Decision

- The minimum power required for a modest, short duration, human Mars surface mission with a limited crew complement is about 10 kW. More complex architectures leveraging significant in-situ resource utilization could require MW-class power systems.
- The Mars surface power generation technology selected for the initial crewed missions to Mars must accommodate anticipated operational needs and the unique challenges of the Mars environment, with limited repair or replacement options.
- The Artemis campaign offers an opportunity to test safety-critical Mars surface power generation technologies and operations on the Moon to reduce risk for later Mars missions.



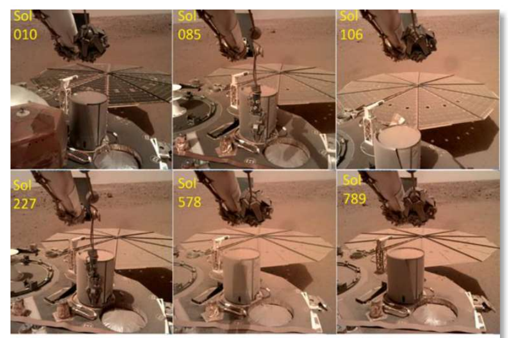
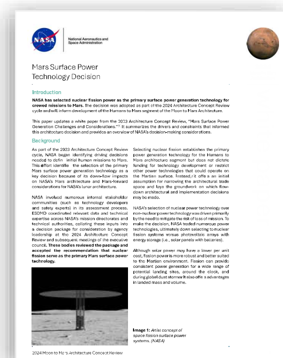


Fig. 1. Steady accumulation of dust on the InSight solar arrays (Lorenz et al., 2021).

See Associated **ACR24 White Paper**



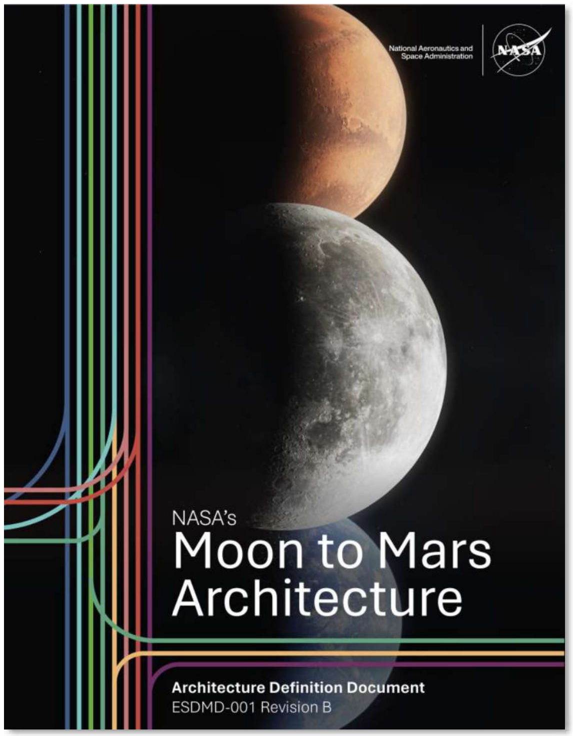
NASA approved nuclear fission as primary surface power generation technology for initial human Mars segment given stakeholder consensus that fission trades more favorably when compared to photovoltaic power with energy storage.

We Want to Understand…

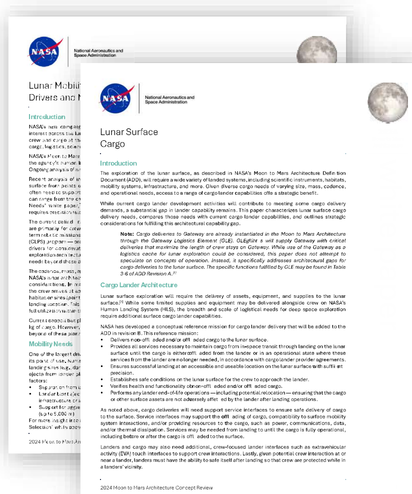
1. Can NASA accomplish the priority science objectives for initial human missions at one geographical location, or will the priority science require access to multiple geographic locations (i.e., landing sites)?
2. Which science priorities make sense grouped into a single mission? How should NASA group science priorities if split across multiple missions?
3. Which science investigations will require crew present? Do any investigations require shirt-sleeve crew support (inside the crew cabin) or are they all outside? Which science investigations could be set up, left, and revisited later?

The answers to these questions may have flow-down impacts on the architecture.

2024 Architecture Products



NASA's Architecture Definition Document



Architecture White Papers

Architecture Executive Overview

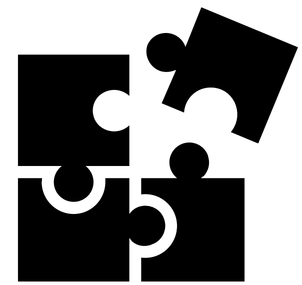
NASA's Moon to Mars Architecture Website

nasa.gov/architecture

New Technology Gaps

New Appendix C:
Architecture-Driven Technology Gaps

Included descriptions of architecture-driven technology gaps, the ranked gap list, 56 external facing one-pagers with descriptions and architectural mappings

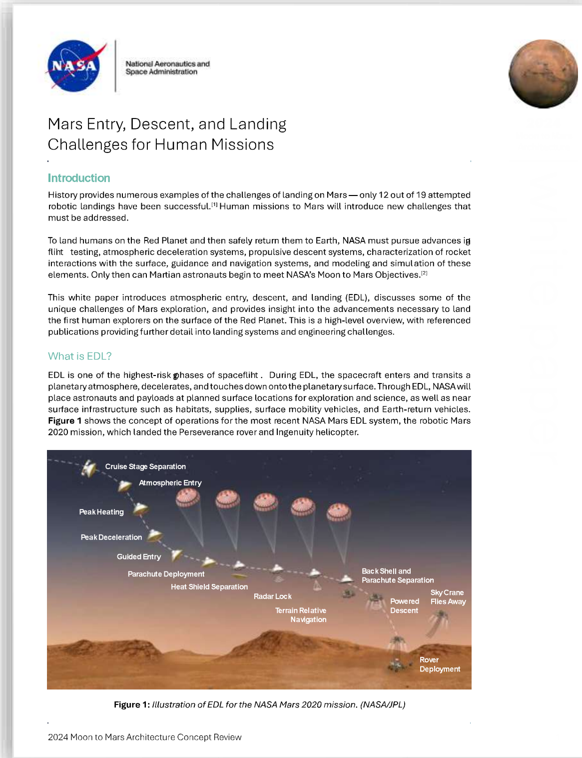


Example Technology Gaps (2024)
Lunar Dust Tolerant Systems and Dust Mitigation
Systems to Survive and Operate through Extended Periods of Lunar Shadow
High-bandwidth, High-reliability Surface-to-Surface Communications
Mars Transportation Propulsion
Extreme Environment Avionics

Left: *Five high priority technology gaps identified in 2024. The initial list included 56 total gaps, but NASA will revise as developments and analysis occur. For the most up-to-date version of the gaps, see the current revision of the Architecture Definition Document.*

2024 White Papers

	White Paper Title	Org/Author
1	Mars Entry, Descent, and Landing Challenges	STMD
2	Humans in Space to Accomplish Certain Objectives	SMD
3	Artemis Accomplishing Decadal Recommendations	SMD
4	International Partnerships: Policies, Opportunities, & Engagement	OIIR
5	Responsible Exploration	OTPS
6	Mars Surface Power Tech Decision	SAO
7	Mars Crew Complement Considerations	SAO
8	Mars Ascent Propellant Considerations	SAO
9	Lunar Mobility Drivers and Needs	SAO
10	Lunar Surface Cargo	SAO
11	Lunar Reference Frame	SAO
12	Architecture-Driven Technology Gaps	SAO


National Aeronautics and Space Administration

Mars Entry, Descent, and Landing Challenges for Human Missions

Introduction

History provides numerous examples of the challenges of landing on Mars — only 12 out of 19 attempted robotic landings have been successful.[1] Human missions to Mars will introduce new challenges that must be addressed.

To land humans on the Red Planet and then safely return them to Earth, NASA must pursue advances in flight testing, atmospheric deceleration systems, propulsive descent systems, characterization of rocket interactions with the surface, guidance and navigation systems, and modeling and simulation of these elements. Only then can Martian astronauts begin to meet NASA's Moon to Mars Objectives.[2]

This white paper introduces atmospheric entry, descent, and landing (EDL), discusses some of the unique challenges of Mars exploration, and provides insight into the advancements necessary to land the first human explorers on the surface of the Red Planet. This is a high-level overview, with referenced publications providing further detail into landing systems and engineering challenges.

What is EDL?

EDL is one of the highest-risk phases of spaceflight. During EDL, the spacecraft enters and transits a planetary atmosphere, decelerates, and touches down onto the planetary surface. Through EDL, NASA will place astronauts and payloads at planned surface locations for exploration and science, as well as near surface infrastructure such as habitats, supplies, surface mobility vehicles, and Earth-return vehicles. **Figure 1** shows the concept of operations for the most recent NASA Mars EDL system, the robotic Mars 2020 mission, which landed the Perseverance rover and Ingenuity helicopter.

Figure 1: *Illustration of EDL for the NASA Mars 2020 mission. (NASA/JPL)*

2024 Moon to Mars Architecture Concept Review

2025 Architecture Workshops

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Washington, DC

International Partners
February 25-26, 2025
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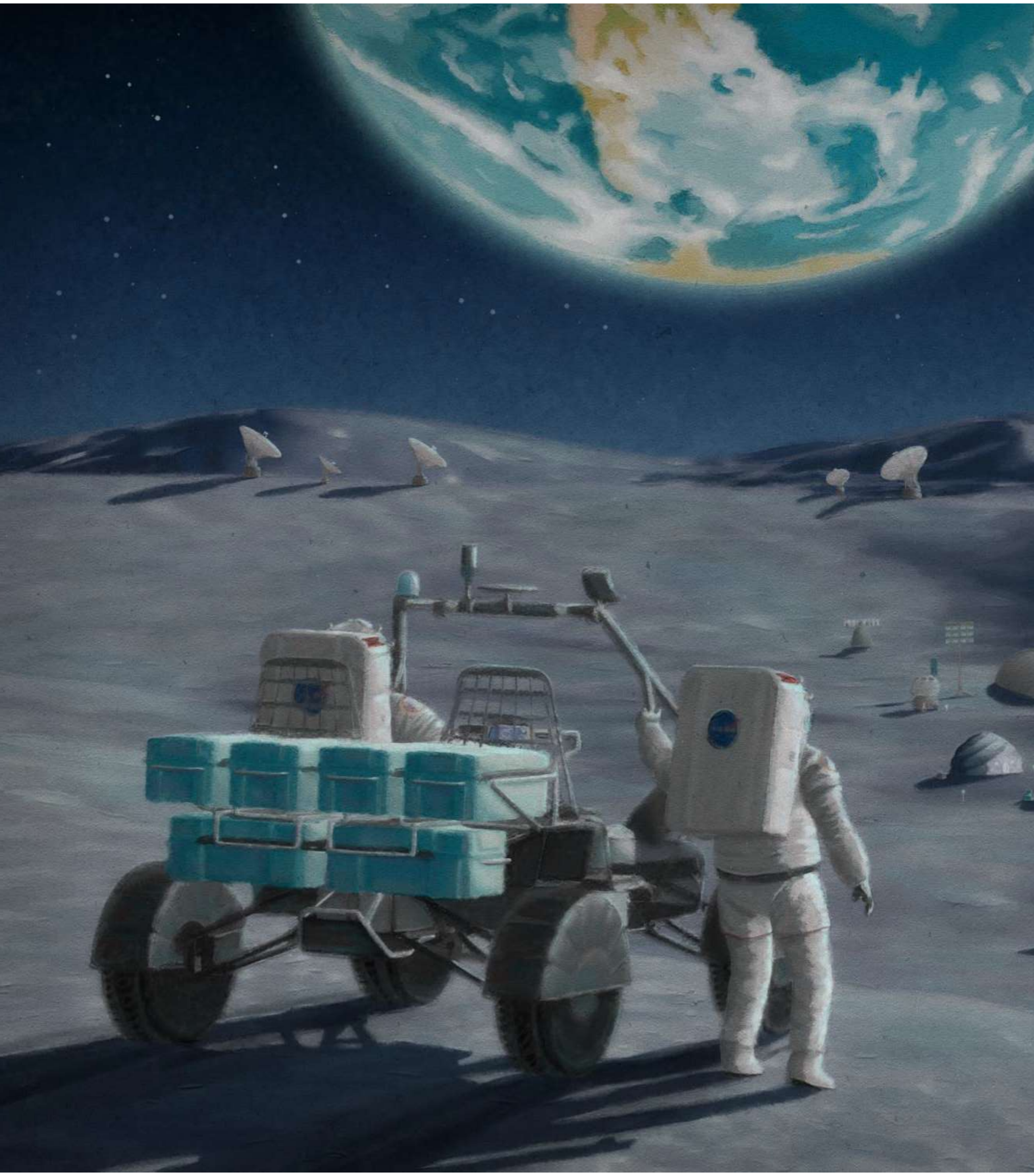

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