National Aeronautics and Space Administration

NASA's Moon to Mars Architecture

Planetary Advisory Committee

Strategy and Architecture Office

Exploration Systems Development Mission Directorate

Introductions

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Office of the Associate Administrator
NASA Headquarters

Strategy and Architecture Office
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Moon to Mars Program Office
NASA Headquarters

ESDMD Business Office
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Programs

Gateway Program
NASA’s Johnson Space Center

Human Landing System Program
NASA’s Marshall Space Flight Center

xEVA and Human Surface Mobility Program
NASA’s Johnson Space Center

Orion Program
NASA’s Johnson Space Center

Space Launch System Program
NASA’s Marshall Space Flight Center

Exploration Ground Systems
NASA’s Kennedy Space Center

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Safety and Mission Assurance Office
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Systems Engineering and Integration Office
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Exploration Operations
NASA’s Johnson Space Center

Program Planning and Control Office
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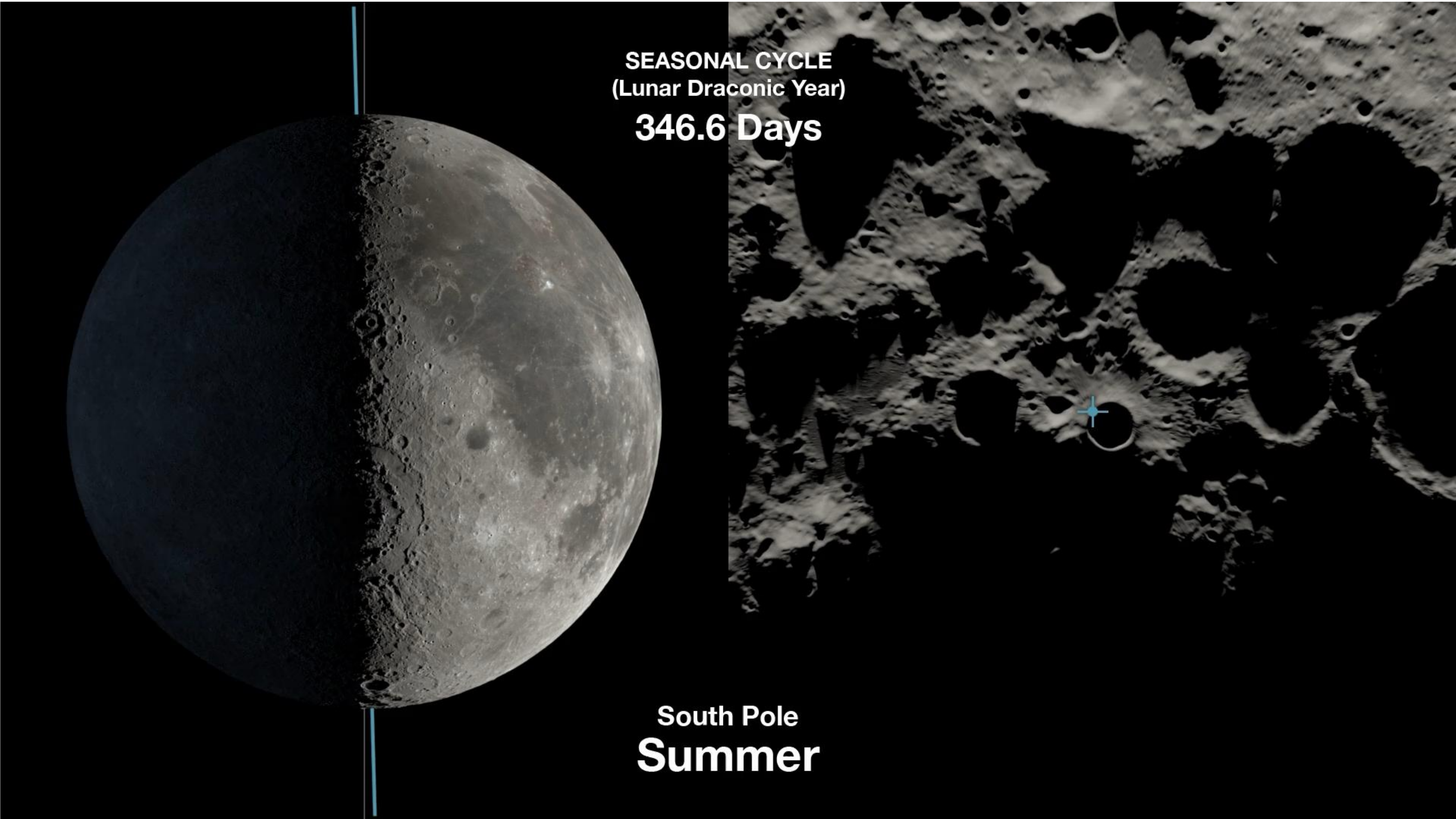
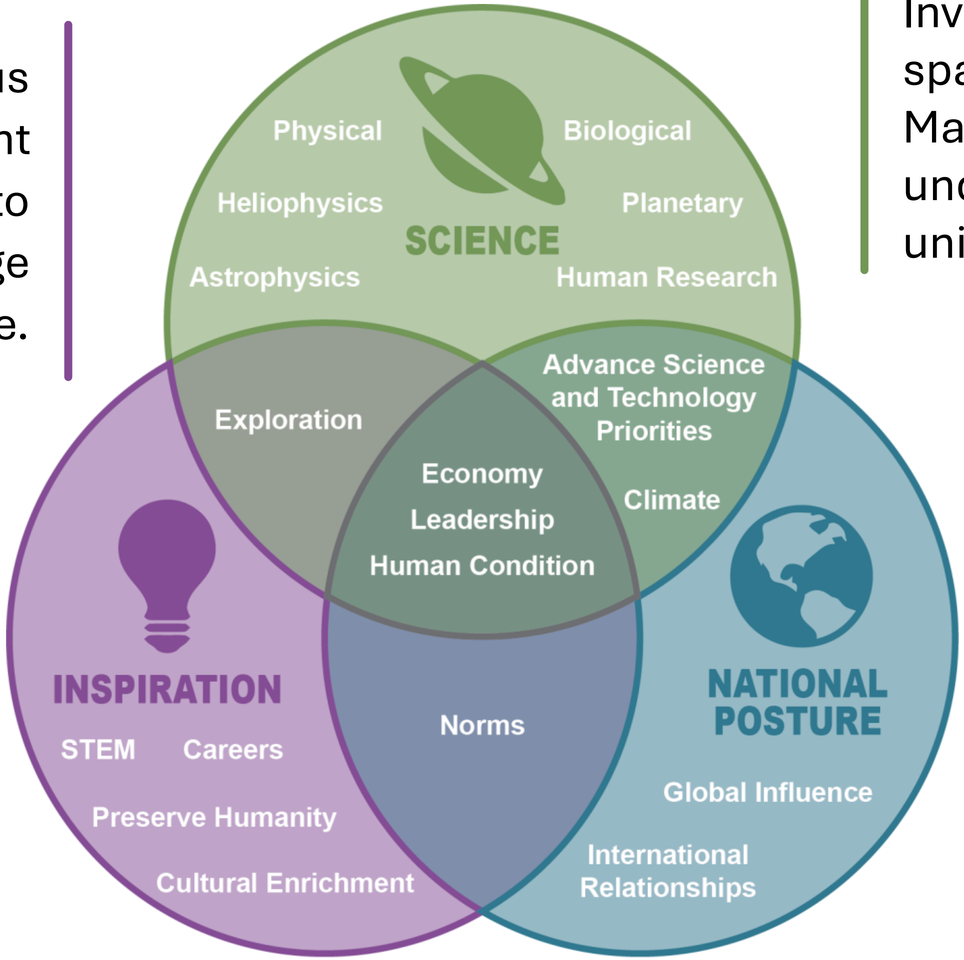

SEASONAL CYCLE
(Lunar Draconic Year)
346.6 Days
South Pole
Summer

Why We Explore...

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



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

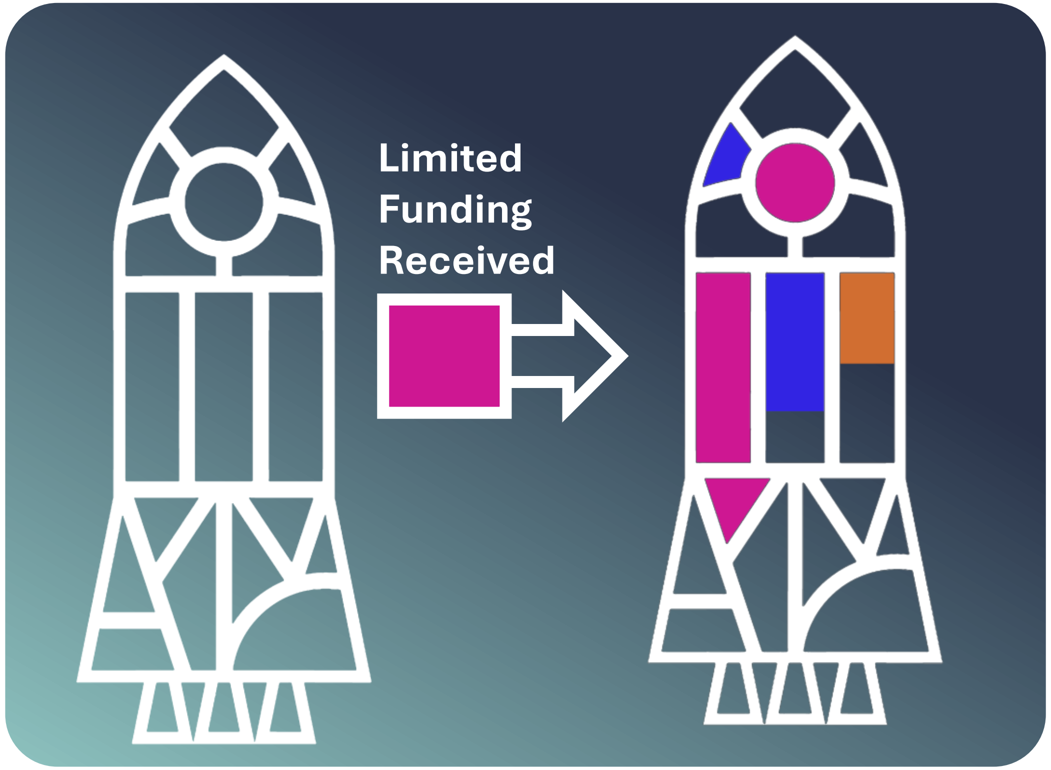
What is done, how it's accomplished, and who participates affect our world, quality of life, and humanity's future.

Historical Context

We need an objective-based approach

We must think **strategically** with **resilience and flexibility** in mind and **enhance our communications** to better achieve **unity of purpose**

- We've been on a 30+ year roller-coaster ride for Moon to Mars development
- We've experienced widespread and enduring uncertainty in the wake of Constellation cancellation
- A capability-based approach does not fully support a long-term strategy to Mars



Attempts to "stick with the plan" behind the scenes

- Initially, prioritized and prepared for more fruitful days
- Led to decentralized efforts
- Over time, lose clarity on overall plan

Moon to Mars Objectives

NASA's Moon to Mars Objectives document a systems engineering approach to crewed deep space exploration.

In contrast to a capabilities-based approach, an objectives-based approach focuses on the big picture, the "what" and "why," before prescribing the "how."

The methodology for the Moon to Mars Objectives is guided by five interrelated principles:

- Objectives-based Approach
- Constancy of Purpose
- Enhanced Communication and Engagement
- Unity of Purpose
- Architect from the Right Execute from the Left

Recurring Tenets

International Collaboration

Partner with international community to achieve common goals and objectives.

Crew Time

Maximize crew time available for science and engineering activities within planned mission durations.

Interoperability

Enable interoperability and commonality (technical, operations, and process standards) among systems, elements, and crews throughout the campaign.

Industry Collaboration

Partner with U.S. industry to achieve common goals and objectives.

Maintainability and Reuse

When practical, design systems for maintainability, reuse, and/or recycling to support the long-term sustainability of operations and increase Earth independence.

Leverage Low-Earth Orbit

Leverage infrastructure in low-Earth orbit to support Moon to Mars activities.

Crew Return

Return crews safely to Earth while mitigating adverse impacts to crew health.

Responsible Use

Conduct all activities for the exploration and use of outer space for peaceful purposes consistent with international obligations and principles for responsible behavior in space.

Commerce and Space Development

Foster the expansion of the economic sphere beyond Earth orbit to support U.S. industry and innovation.

Science Objectives

Lunar/Planetary Science

Lunar/Planetary Science (LPS) Goal: Address high priority planetary science questions that are best accomplished by on-site human explorers on and around the Moon and Mars, aided by surface and orbiting robotic systems.

Physics and Physical Science

Physics and Physical Science (PPS) Goal: Address high priority physics and physical science questions that are best accomplished by using unique attributes of the lunar environment.

Heliophysics Science

Heliophysics Science (HS) Goal: Address high priority heliophysics science and space weather questions that are best accomplished using a combination of human explorers and robotic systems at the Moon, at Mars, and in deep space.

Science-Enabling

Science-Enabling (SE) Goal: Develop integrated human and robotic methods and advanced techniques that enable high-priority scientific questions to be addressed around and on the Moon and Mars.

Human & Biological Science

Human and Biological Science (HBS) Goal: Advance understanding of how biology responds to the environments of the Moon, Mars, and deep space to advance fundamental knowledge, support safe, productive human space missions and reduce risks for future exploration.

Applied Science

Applied Science (AS) Goal: Conduct science on the Moon, in cislunar space, and around and on Mars using integrated human and robotic methods and advanced techniques, to inform design and development of exploration systems and enable safe operations.

Exploration Objectives

Lunar Infrastructure

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.

Transportation & Habitation

Transportation and Habitation Goal: Develop and demonstrate an integrated system of systems to conduct a campaign of human exploration missions to the Moon and Mars, while living and working on the lunar and Martian surface, with safe return to Earth.

Mars Infrastructure

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

Operations

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.

Architecture Strategy

ARCHITECTURE

Iterate and evolve through annual Architecture Concept Reviews

Goals and Objectives

RECURRING TENETS

SCIENCE	TRANSPORTATION AND HABITATION
LUNAR AND MARS INFRASTRUCTURE	OPERATIONS

Requested feedback on these objectives in summer 2022 from the following key stakeholders:

NASA workforce: our greatest asset

International partners: our key current and future, anticipated collaborators

U.S. Industry, Academia, OGAs: our national leaders in space research and capabilities

Architecture Approach

An Evolutionary Architecture Process

Formulating an Architecture and Exploration Strategy Based on Objectives

TRACEABILITY

Decomposition of Blueprint Objectives to executing Architecture elements

ARCHITECTURE FRAMEWORK

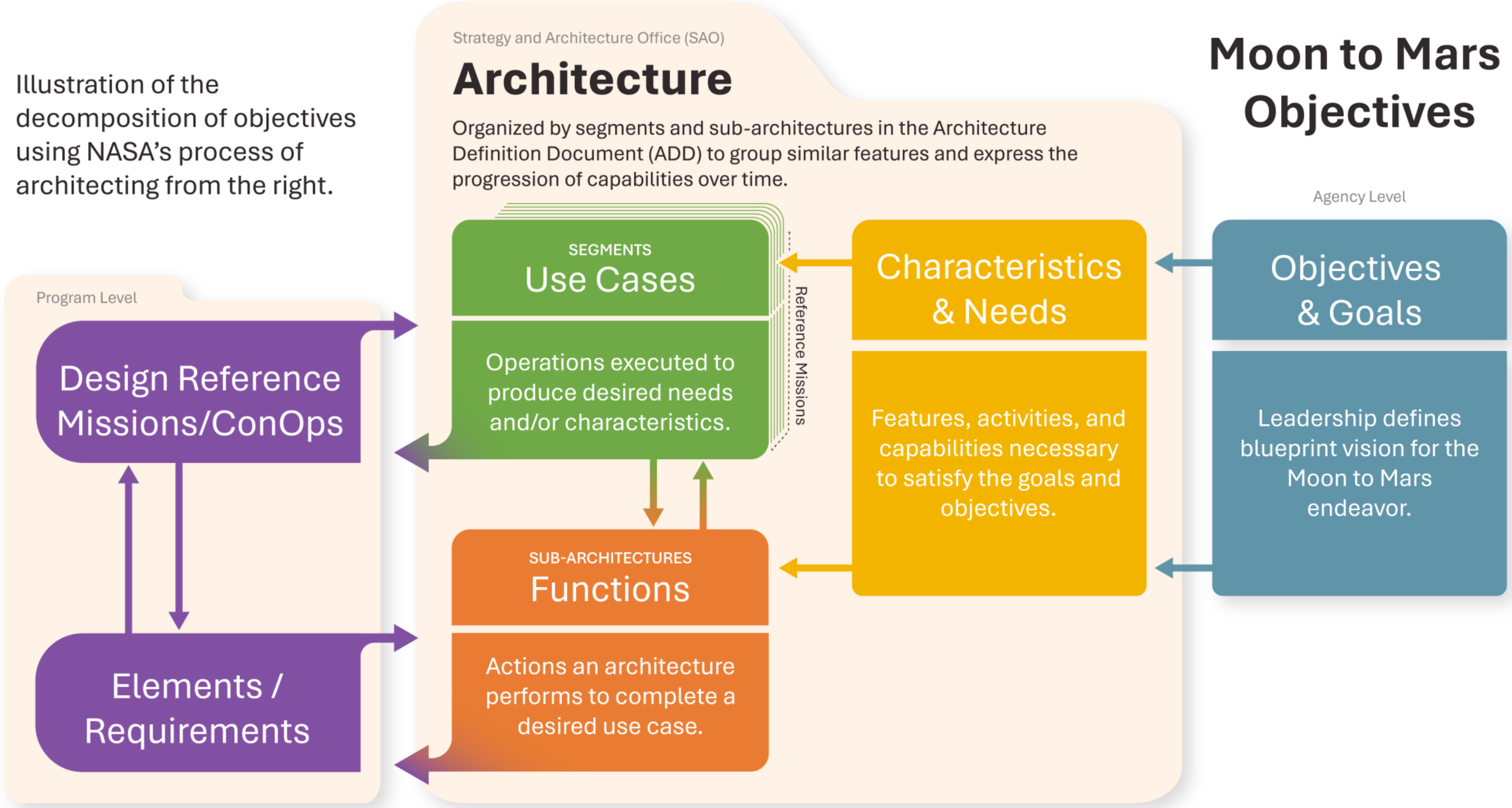
Organizational construct to ensure system/element relationships are understood and gaps can be identified

PROCESS & PRODUCTS

Clear communication and review integration paths for stakeholders

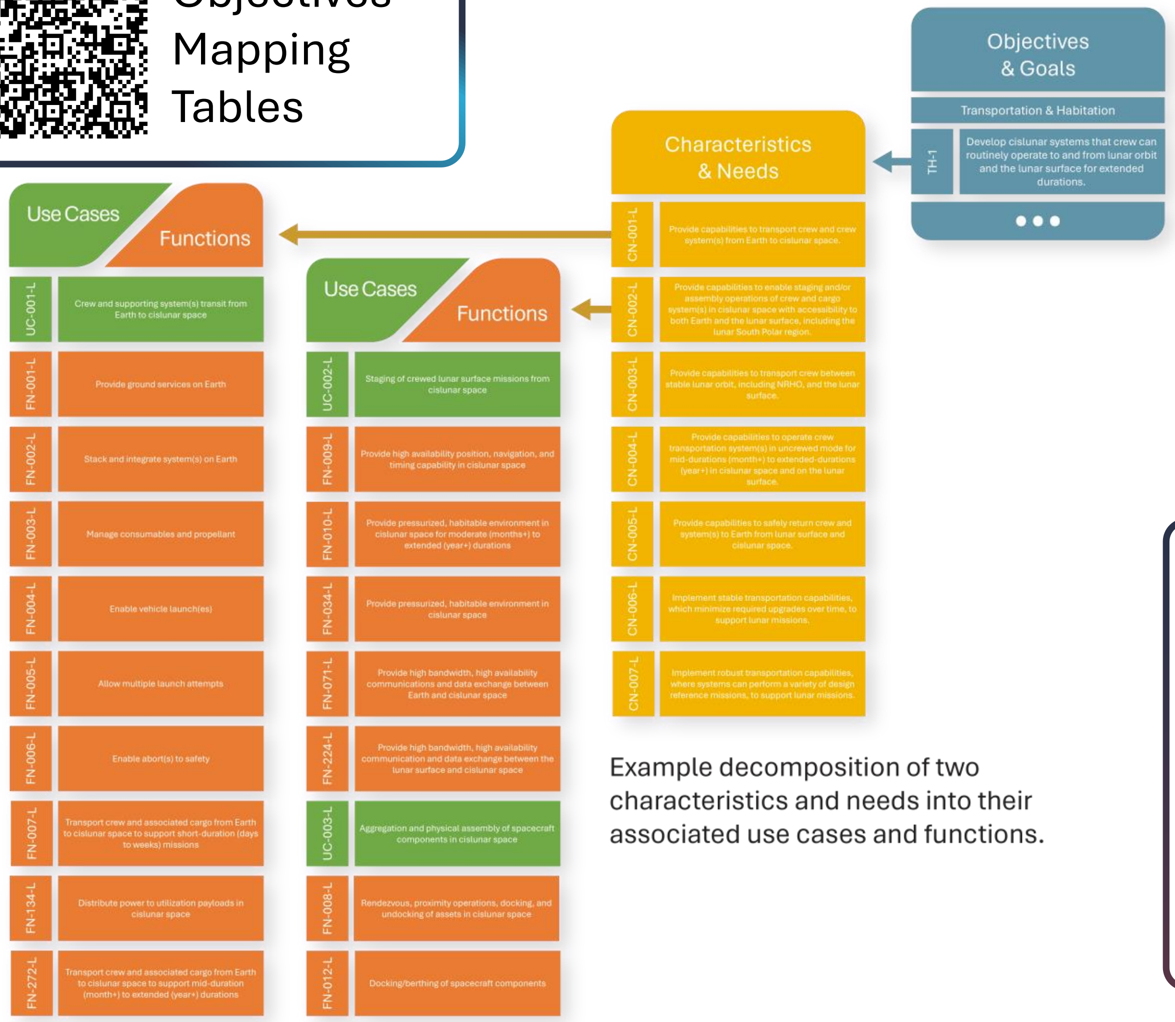
Architecting from the Right

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



Decomposition of Objectives

Objectives Mapping Tables



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.

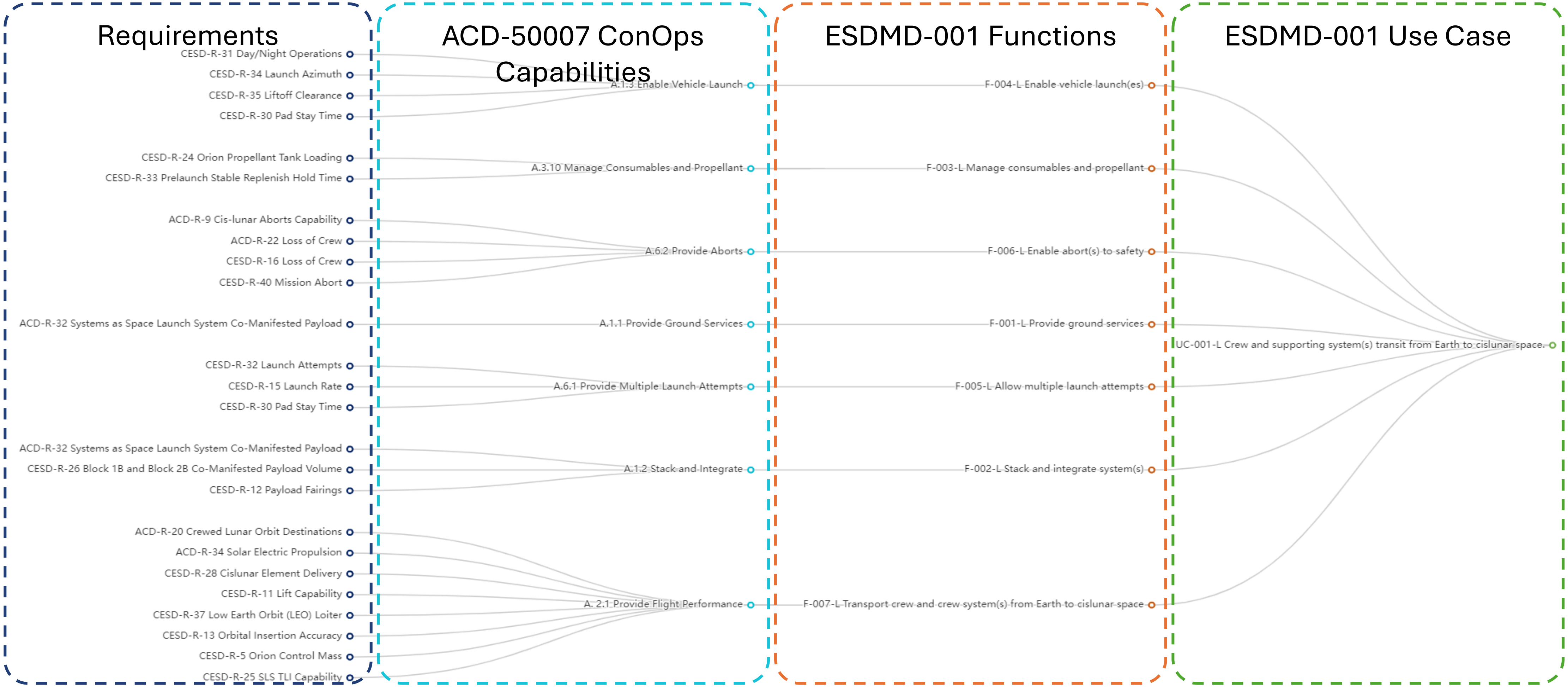
Characteristics and Needs: Features, activities, and capabilities necessary to satisfy goals and objectives.

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.

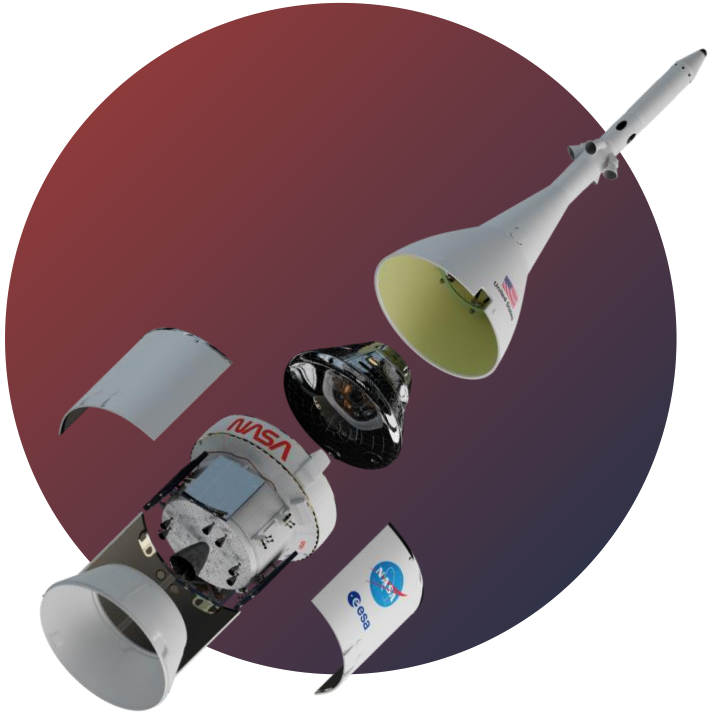
Requirements Flowdown

Requirements Flow Down for Use Case 001:
Crew and supporting system(s) transit from Earth to cislunar space



Architecture Overview

Architecture Components



Segments

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

Sub-Architectures

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

Elements

A notional exploration system that enables a set of functions.

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

Future Segments

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

Sub-Architectures

Communications, Navigation, Positioning, and Timing Systems
enable transmission and reception of data, determination of location and orientation, and acquisition of precise time.

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

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.

New for ADD Rev-A

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

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

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

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

Elements

Space Launch System

Commercial Lunar Payload Services

Exploration EVA Systems

Human Landing System

Human-class Delivery Lander

Lunar Terrain Vehicle

Pressurized Rover

Human Lunar Return → **Foundational Exploration**

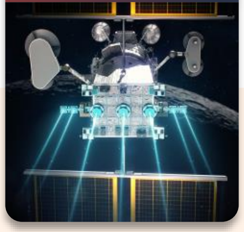
notional timeline

Exploration Ground Systems

Orion Spacecraft

Deep Space Logistics

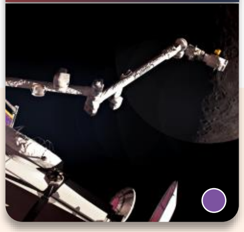
Power and Propulsion Element



Lunar View Module

International Habitat

Extra-vehicular Robotics System



Crew and Science Airlock

Gateway

Element Partnerships

- Canadian Space Agency
- United Arab Emirates
- European Space Agency
- Japan Aerospace Exploration Agency

Empowering Partnerships

Moon to Mars **Architecture Definition Document (ADD)** Revision A

Unallocated Use Cases and Functions:
All use cases and functions *not* mapped to current systems express existing architectural needs for large systems or elements available for partnerships

Open Questions and Gaps:
Human Lunar Return and Foundational Exploration segment descriptions include lists of open questions and integrated capabilities identified by the architecture team

Utilization (Science and Technology) Opportunities:
2024 Architecture Concept Review updates will more clearly articulate areas and scenarios where smaller or emerging partners can contribute to fulfill objective needs through payloads or experiments

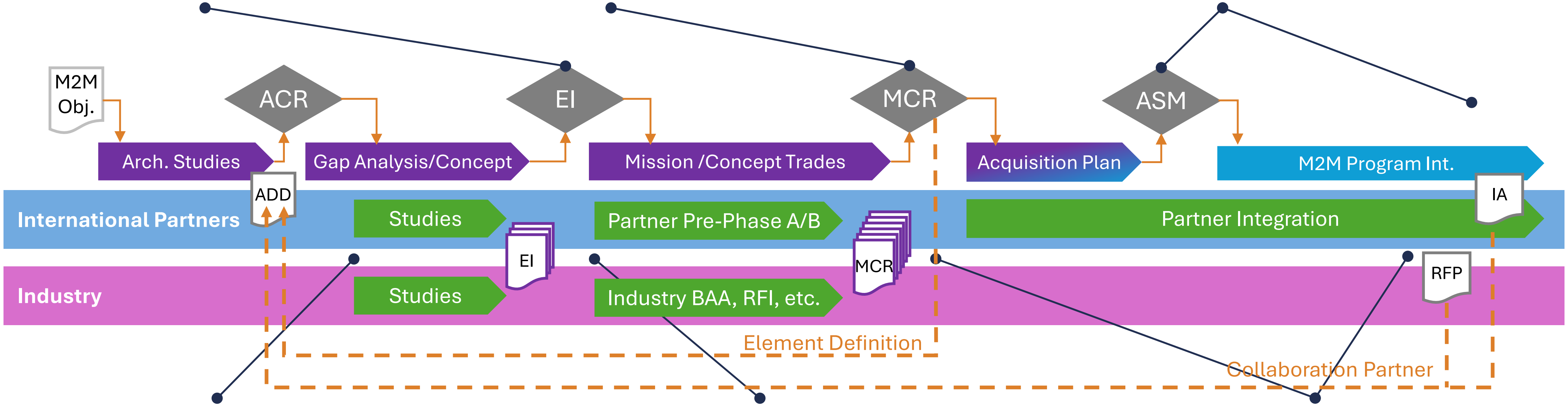
Moon to Mars Architecture products enable strategic conversations where NASA's needs and partner strategies align.

Partner Pre-formulation Process

Element Initiation: Overt decision to proceed with maturation of concept assessed for Arch. priority, budget, and strategy

Mission Concept Review: To evaluate the feasibility of the proposed mission concept(s) and its fulfillment of the Architecture needs and objectives

Acquisition Strategy Meeting: Transition to Moon to Mars Program for implementation, completion of project roles & responsibilities leading to Implementing Arrangement (IA) or to to contracting process (e.g. RFP)



Feasibility studies and collaboration identify potential concept

Mission refinement to optimize for strategic value and functional achievement, use of study mechanisms to better inform planning

Feedback incorporated into Architecture products as milestones occur

Document(s) | NASA Milestone | ESDMD Strategy and Architecture Office | ESDMD Moon to Mars Program Office | Collaboration Partner

Progress Under this Approach

Traceability

- ✓ Assigned functions to all Human Lunar Return segment and initial Foundational Exploration segment elements
- ✓ Implemented full digital traceability to Moon to Mars program requirements, identifying areas for further integration
- ✓ Demonstrated process through incorporation of the United Arab Emirates Gateway Airlock and JAXA Pressurized Rover

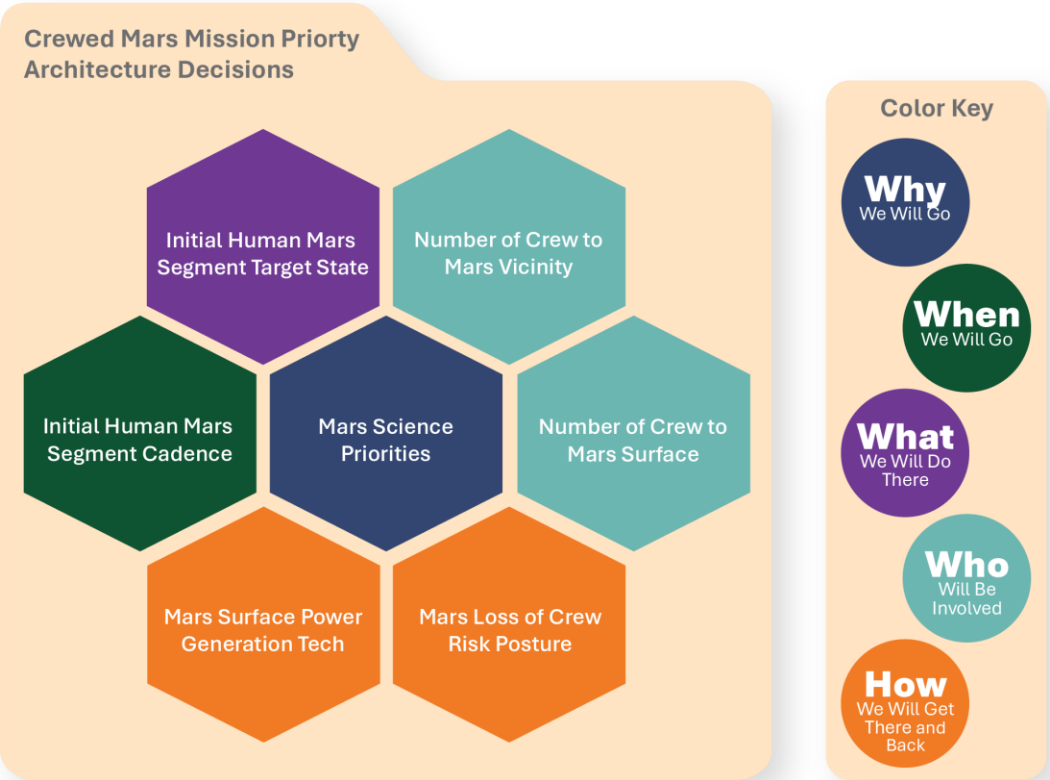
Framework

- ✓ Identified architecture gaps for large cargo return, logistics demand, and surface docking
- ✓ Aligning international partner strategic planning efforts to articulated gaps
- ✓ Enabling industry studies and logistics investments to meet needs, including for mobility and surface cargo capabilities
- ✓ Informing the work of industry partners, as shown by the alignment of portfolios to architecture needs and gaps

Process & Products

- ✓ Tracing architecture gaps to science and technology portfolio for greater coordination
- ✓ Prioritized CubeSat selections for the Artemis II mission using identified gaps in the architecture
- ✓ Leveraged segment use cases to inform Artemis III mission objectives

Mars Decision Mapping



In 2024, NASA began analyses needed to allow for informed decision-making by agency leadership, beginning with the seven priority decisions identified.

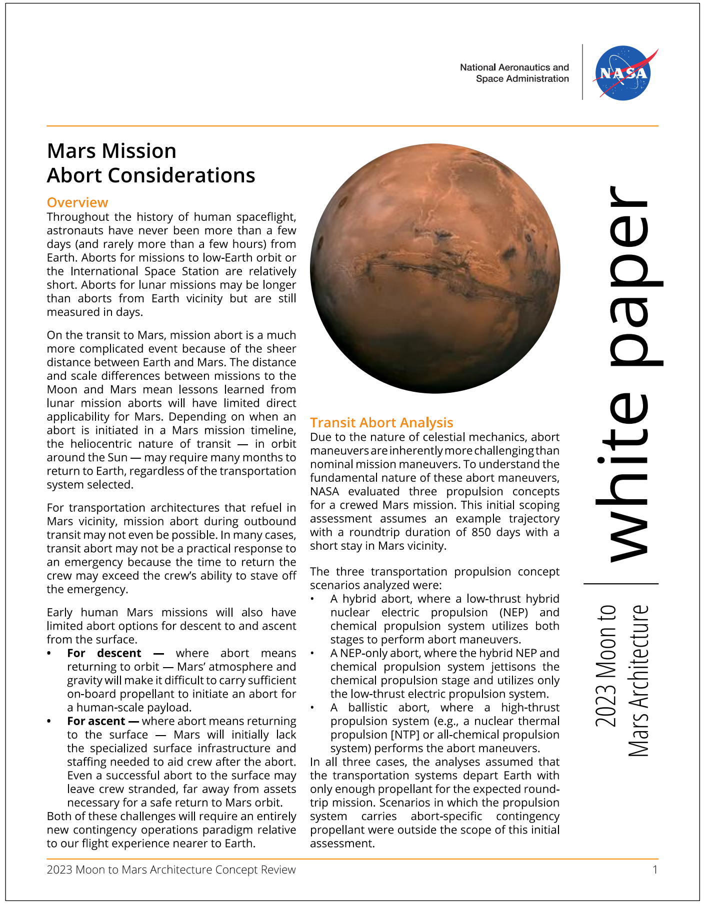
Decisions for Mars will inform lunar planning, development, and needs to demonstrate and ready systems and operations for eventual Humans to Mars segment missions.

Mars Decisions White Paper

Architecture Products

Architecture Definition Document
Revision A (ADD Rev-A)

Moon to Mars Architecture
Executive Overview


National Aeronautics and Space Administration

white paper

2023 Moon to Mars Architecture

Mars Mission Abort Considerations

Overview

Throughout the history of human spaceflight, astronauts have never been more than a few days (and rarely more than a few hours) from Earth. Aborts for missions to low-Earth orbit or the International Space Station are relatively short. Aborts for lunar missions may be longer than aborts from Earth vicinity but are still measured in days.

On the transit to Mars, mission abort is a much more complicated event because of the sheer distance between Earth and Mars. The distance and scale differences between missions to the Moon and Mars mean lessons learned from lunar mission aborts will have limited direct applicability for Mars. Depending on when an abort is initiated in a Mars mission timeline, the heliocentric nature of transit — in orbit around the Sun — may require many months to return to Earth, regardless of the transportation system selected.

For transportation architectures that refuel in Mars vicinity, mission abort during outbound transit may not even be possible. In many cases, transit abort may not be a practical response to an emergency because the time to return the crew may exceed the crew's ability to stave off the emergency.

Early human Mars missions will also have limited abort options for descent to and ascent from the surface.

- **For descent —** where abort means returning to orbit — Mars' atmosphere and gravity will make it difficult to carry sufficient on-board propellant to initiate an abort for a human-scale payload.
- **For ascent —** where abort means returning to the surface — Mars will initially lack the specialized surface infrastructure and staffing needed to aid crew after the abort. Even a successful abort to the surface may leave crew stranded, far away from assets necessary for a safe return to Mars orbit.

Both of these challenges will require an entirely new contingency operations paradigm relative to our flight experience nearer to Earth.

Transit Abort Analysis

Due to the nature of celestial mechanics, abort maneuvers are inherently more challenging than nominal mission maneuvers. To understand the fundamental nature of these abort maneuvers, NASA evaluated three propulsion concepts for a crewed Mars mission. This initial scoping assessment assumes an example trajectory with a roundtrip duration of 850 days with a short stay in Mars vicinity.

The three transportation propulsion concept scenarios analyzed were:

- A hybrid abort, where a low-thrust hybrid nuclear electric propulsion (NEP) and chemical propulsion system utilizes both stages to perform abort maneuvers.
- A NEP-only abort, where the hybrid NEP and chemical propulsion system jettisons the chemical propulsion stage and utilizes only the low-thrust electric propulsion system.
- A ballistic abort, where a high-thrust propulsion system (e.g., a nuclear thermal propulsion [NTP] or all-chemical propulsion system) performs the abort maneuvers.

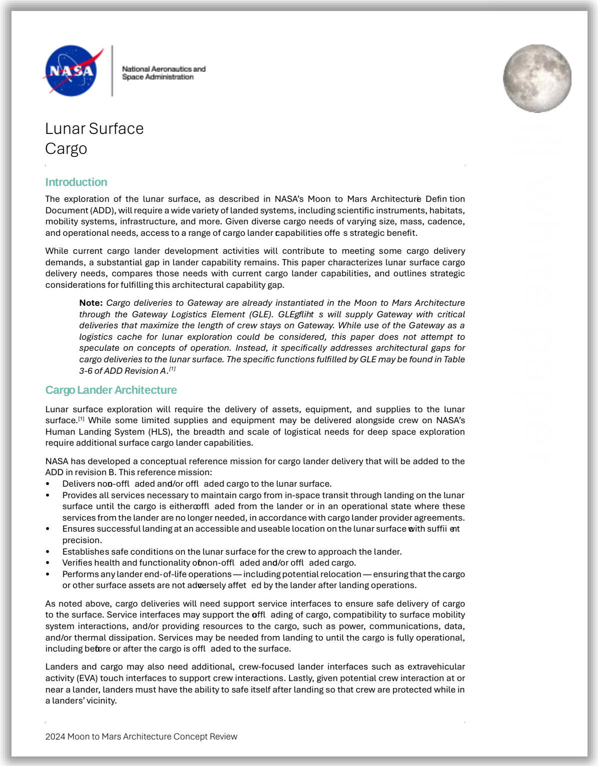
In all three cases, the analyses assumed that the transportation systems depart Earth with only enough propellant for the expected round-trip mission. Scenarios in which the propulsion system carries abort-specific contingency propellant were outside the scope of this initial assessment.

2023 Moon to Mars Architecture Concept Review 1

White Papers
(19 as of May 2024)

Architecture Progress

New White Papers



National Aeronautics and Space Administration

Lunar Surface
Cargo

Introduction

The exploration of the lunar surface, as described in NASA's Moon to Mars Architecture Defin tion Document (ADD), will require a wide variety of landed systems, including scientific instruments, habitats, mobility systems, infrastructure, and more. Given diverse cargo needs of varying size, mass, cadence, and operational needs, access to a range of cargo lander capabilities offe s strategic benefit.

While current cargo lander development activities will contribute to meeting some cargo delivery demands, a substantial gap in lander capability remains. This paper characterizes lunar surface cargo delivery needs, compares those needs with current cargo lander capabilities, and outlines strategic considerations for fulfilling this architectural capability gap.

> **Note:** *Cargo deliveries to Gateway are already instantiated in the Moon to Mars Architecture through the Gateway Logistics Element (GLE). GLEgflilt s will supply Gateway with critical deliveries that maximize the length of crew stays on Gateway. While use of the Gateway as a logistics cache for lunar exploration could be considered, this paper does not attempt to speculate on concepts of operation. Instead, it specifically addresses architectural gaps for cargo deliveries to the lunar surface. The specific functions fulfilled by GLE may be found in Table 3-6 of ADD Revision A.*[1]

Cargo Lander Architecture

Lunar surface exploration will require the delivery of assets, equipment, and supplies to the lunar surface.[1] While some limited supplies and equipment may be delivered alongside crew on NASA's Human Landing System (HLS), the breadth and scale of logistical needs for deep space exploration require additional surface cargo lander capabilities.

NASA has developed a conceptual reference mission for cargo lander delivery that will be added to the ADD in revision B. This reference mission:

- Delivers non-offl aded and/or offl aded cargo to the lunar surface.
- Provides all services necessary to maintain cargo from in-space transit through landing on the lunar surface until the cargo is either offl aded from the lander or in an operational state where these services from the lander are no longer needed, in accordance with cargo lander provider agreements.
- Ensures successful landing at an accessible and useable location on the lunar surface with suffii ent precision.
- Establishes safe conditions on the lunar surface for the crew to approach the lander.
- Verifies health and functionality of non-offl aded and/or offl aded cargo.
- Performs any lander end-of-life operations — including potential relocation — ensuring that the cargo or other surface assets are not adversely affet ed by the lander after landing operations.

As noted above, cargo deliveries will need support service interfaces to ensure safe delivery of cargo to the surface. Service interfaces may support the offl ading of cargo, compatibility to surface mobility system interactions, and/or providing resources to the cargo, such as power, communications, data, and/or thermal dissipation. Services may be needed from landing to until the cargo is fully operational, including before or after the cargo is offl aded to the surface.

Landers and cargo may also need additional, crew-focused lander interfaces such as extravehicular activity (EVA) touch interfaces to support crew interactions. Lastly, given potential crew interaction at or near a lander, landers must have the ability to safe itself after landing so that crew are protected while in a landers' vicinity.

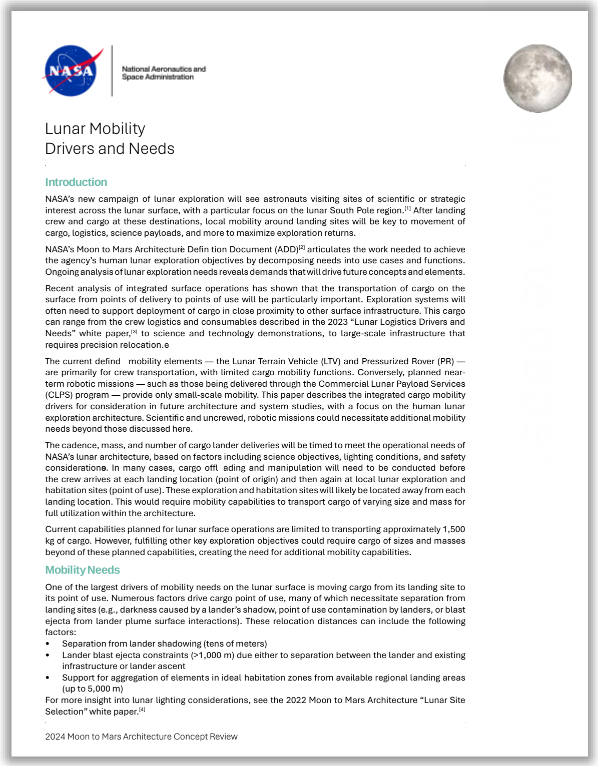
2024 Moon to Mars Architecture Concept Review

Lunar Surface Cargo

This paper characterizes lunar surface cargo delivery needs, comparing them with current cargo lander capabilities, and outlining strategic considerations for filling capability gaps.

Lunar Mobility Drivers and Needs

This paper outlines current lunar mobility capabilities expressed in the Moon to Mars Architecture and characterizes gaps where future demand for mobility services exist.



National Aeronautics and Space Administration

Lunar Mobility
Drivers and Needs

Introduction

NASA's new campaign of lunar exploration will see astronauts visiting sites of scientific or strategic interest across the lunar surface, with a particular focus on the lunar South Pole region.[1] After landing crew and cargo at these destinations, local mobility around landing sites will be key to movement of cargo, logistics, science payloads, and more to maximize exploration returns.

NASA's Moon to Mars Architecture Defin tion Document (ADD)[2] articulates the work needed to achieve the agency's human lunar exploration objectives by decomposing needs into use cases and functions. Ongoing analysis of lunar exploration needs reveals demands that will drive future concepts and elements.

Recent analysis of integrated surface operations has shown that the transportation of cargo on the surface from points of delivery to points of use will be particularly important. Exploration systems will often need to support deployment of cargo in close proximity to other surface infrastructure. This cargo can range from the crew logistics and consumables described in the 2023 "Lunar Logistics Drivers and Needs" white paper,[3] to science and technology demonstrations, to large-scale infrastructure that requires precision relocation.e

The current defind mobility elements — the Lunar Terrain Vehicle (LTV) and Pressurized Rover (PR) — are primarily for crew transportation, with limited cargo mobility functions. Conversely, planned near-term robotic missions — such as those being delivered through the Commercial Lunar Payload Services (CLPS) program — provide only small-scale mobility. This paper describes the integrated cargo mobility drivers for consideration in future architecture and system studies, with a focus on the human lunar exploration architecture. Scientific and uncrewed, robotic missions could necessitate additional mobility needs beyond those discussed here.

The cadence, mass, and number of cargo lander deliveries will be timed to meet the operational needs of NASA's lunar architecture, based on factors including science objectives, lighting conditions, and safety considerations. In many cases, cargo offl ading and manipulation will need to be conducted before the crew arrives at each landing location (point of origin) and then again at local lunar exploration and habitation sites (point of use). These exploration and habitation sites will likely be located away from each landing location. This would require mobility capabilities to transport cargo of varying size and mass for full utilization within the architecture.

Current capabilities planned for lunar surface operations are limited to transporting approximately 1,500 kg of cargo. However, fulfilling other key exploration objectives could require cargo of sizes and masses beyond of these planned capabilities, creating the need for additional mobility capabilities.

Mobility Needs

One of the largest drivers of mobility needs on the lunar surface is moving cargo from its landing site to its point of use. Numerous factors drive cargo point of use, many of which necessitate separation from landing sites (e.g., darkness caused by a lander's shadow, point of use contamination by landers, or blast ejecta from lander plume surface interactions). These relocation distances can include the following factors:

- Separation from lander shadowing (tens of meters)
- Lander blast ejecta constraints (>1,000 m) due either to separation between the lander and existing infrastructure or lander ascent
- Support for aggregation of elements in ideal habitation zones from available regional landing areas (up to 5,000 m)

For more insight into lunar lighting considerations, see the 2022 Moon to Mars Architecture "Lunar Site Selection" white paper.[4]

2024 Moon to Mars Architecture Concept Review

Read the White Papers Here:
https://www.nasa.gov/moontomarsarchitecture-whitepapers/

Coming Soon…

Two New Elements Entering the Architecture

2024 Architecture Concept Review (ACR24)

Architecture Definition Document Rev-B

ACR24 White Papers

ACR24 Executive Overview

One Priority Mars Decision Completed

Artemis I Science Payloads

Science and technology investigations and demonstrations paving the way for future, deep space human exploration

Moonikin Campos

The Moonikin is a male-bodied manikin previously used in Orion vibration tests. Campos occupied the commander's seat inside and wore an Orion Crew Survival System suit

Crew Interface Technology Payload (CITP)

Creates an interactive experience between Orion and the public during the mission

Bio-Experiment-1

Battery-powered life sciences payload for biology research beyond low-Earth orbit (LEO)

MARE

Radiation shielding Personal Protection Equipment (radiation vest) for astronauts

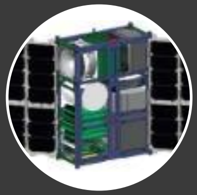
Radiation Sensors

Artemis I carried three types of sensors, including the ESA Active Dosimeters, Hybrid Electronic Radiation Assessor, and the Radiation Area Monitor

SECONDARY PAYLOADS

INTERNATIONAL COLLABORATION

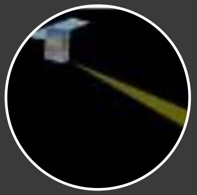
Team Miles



CuSP

LunaH-Map

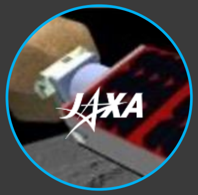
NEA Scout



LunIR

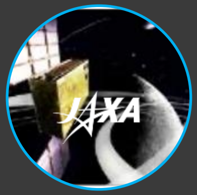
Lunar IceCube

BioSentinel



OMOTENASHI

ArgoMoon

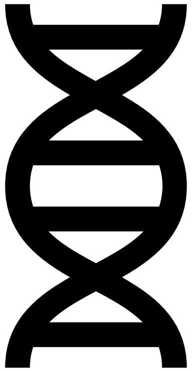


EQUULEUS

Artemis II Science

Human Research

Biological and Physical Sciences



Earth and Planetary Science

Science & Technology

Artemis III Science

NASA has chosen the first science instruments designed for astronauts to deploy on the surface of the Moon. Once installed near the lunar South Pole, the three instruments will collect valuable scientific data about the lunar environment, the lunar interior, and how to sustain a long-duration human presence on the Moon.

LEMS	**Lunar Environment Monitoring Station**
LEAF	**Lunar Effects on Agricultural Flora**
LDA	**Lunar Dielectric Analyzer**

Additionally, NASA will conduct integrated, crewed science on the lunar surface and collect at least one sample.

Initial Gateway Science Instruments

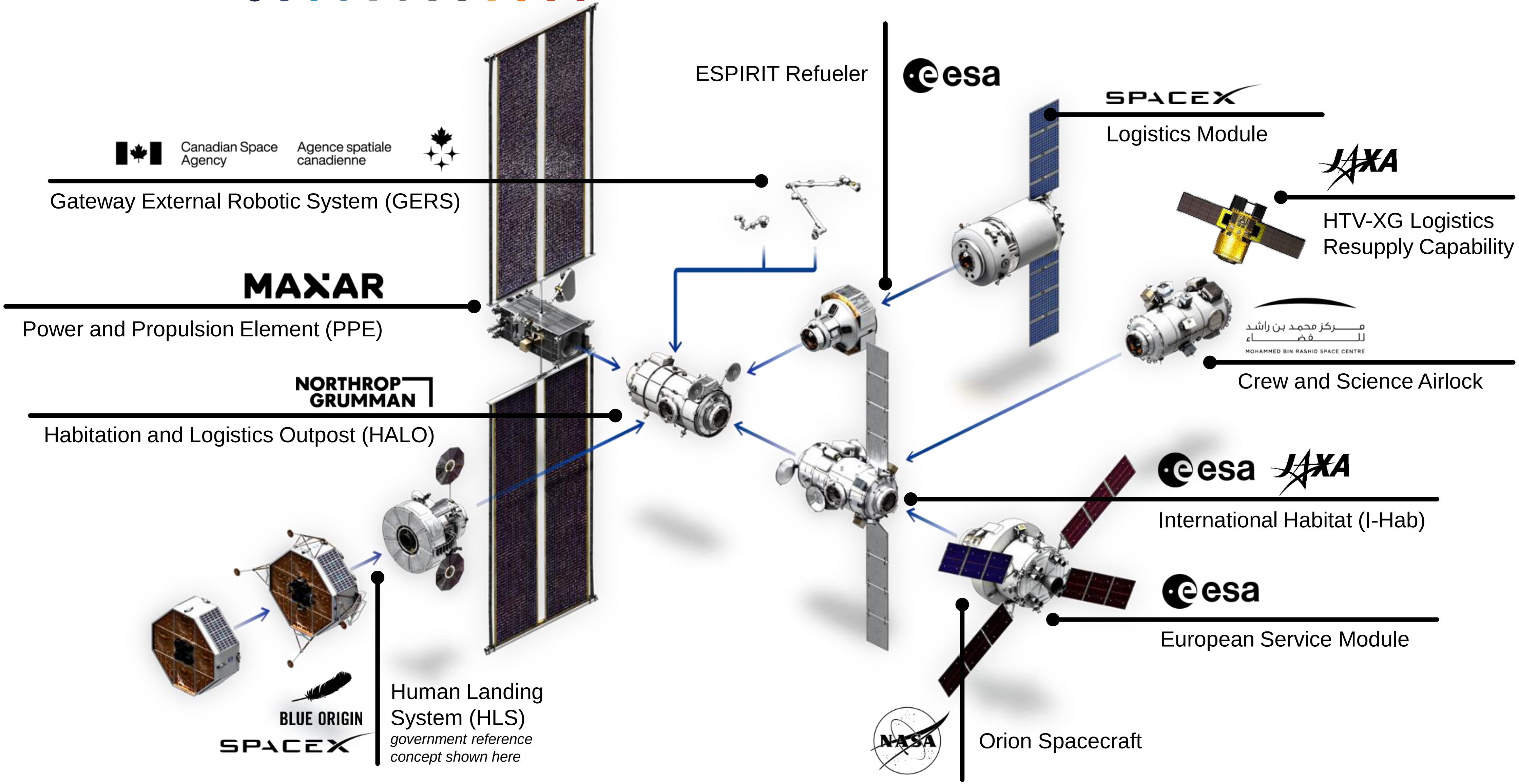
European Radiation Sensors Array (ERSA): The European Space Agency's (ESA's) radiation instrument package will help provide an understanding of how to keep astronauts and hardware safe by monitoring the radiation at higher energies with a focus on space weather

ESA's Internal Dosimeter Array (IDA): Instruments including those provided by Japan Aerospace Exploration Agency (JAXA) will inform for improvements in radiation physics models for cancer, cardiovascular, and central nervous system effects, helping assess crew and hardware risk on exploration missions

Heliophysics Environmental Radiation Measurement Experiment Suite (HERMES): NASA's space weather instrument suite will observe lower energy solar particles critical to scientific investigations of the Sun, including the solar winds *[pictured left]*

Gateway's polar orbit will offer unique opportunities for **heliophysics, human health research, space biology and life sciences, astrophysics,** and **fundamental physics investigations**. As new modules are added, science capability will increase.

Gateway Partnerships



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National Aeronautics and Space Administration
Questions?
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Sample Return: Historical Context

Lunar Samples

Apollo 11	Apollo 12	Apollo 14	Apollo 15	Apollo 16	Apollo 17
21.8 kg	34.3 kg	42.3 kg	77.3 kg	95.7 kg	110.5 kg

With Lunar Roving Vehicle

Other Deep Space Sample Return Missions

Genesis	Stardust	Hayabusa (JAXA)	Hayabusa 2 (JAXA)	OSIRIS-REx
n/a particles	≥7 particles	micrograms	0.005 kg	0.1216 kg
Of the Solar Wind	Of Comet Wild 2	Of S-type Asteroid 25143 Itokawa	Of C-type Asteroid 162173 Ryugu	Of Asteroid 10955 Bennu

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Sample Return: Architectural Gaps

Human Lunar Return Segment

3.1.7 - Open Questions, Ongoing Assessments, and Future Work

- What options are available to increase sample return and conditioned cargo from the lunar surface to Earth?

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Foundational Exploration Segment

3.2.7 - Open Questions, Ongoing Assessments, and Future Work

- What options are available to significantly enhance sample return and conditioned/cryogenic cargo from the lunar surface to Earth?

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Sample Return: Questions for Discussion

What measurements can be made effectively in-situ instead of through sample return?

How much returned sample mass does NASA need to achieve each of our scientific objectives?

What is the most effective way for the science community to those aggregated and mapped sample return needs?