National Aeronautics and Space Administration

NASA's

Moon to Mars Architecture

In-Space Manufacturing Workshop

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Exploration Systems Development Mission Directorate

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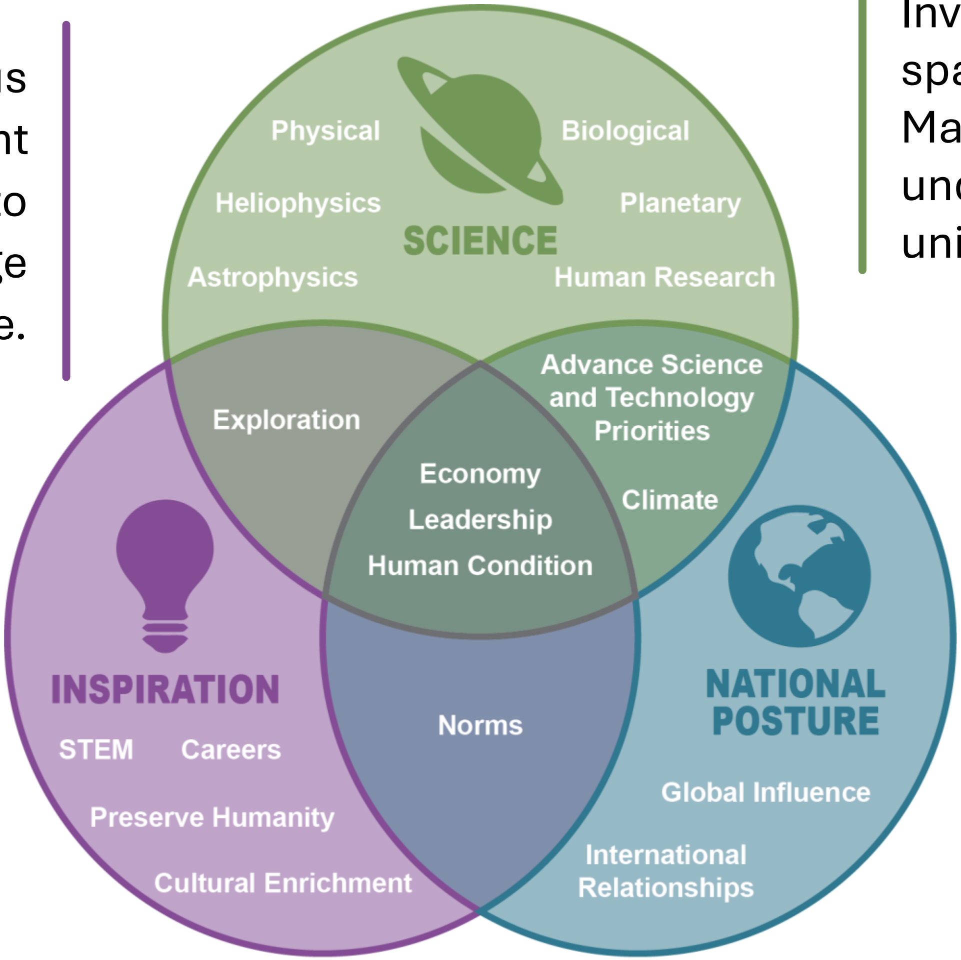
Why We Explore...

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.

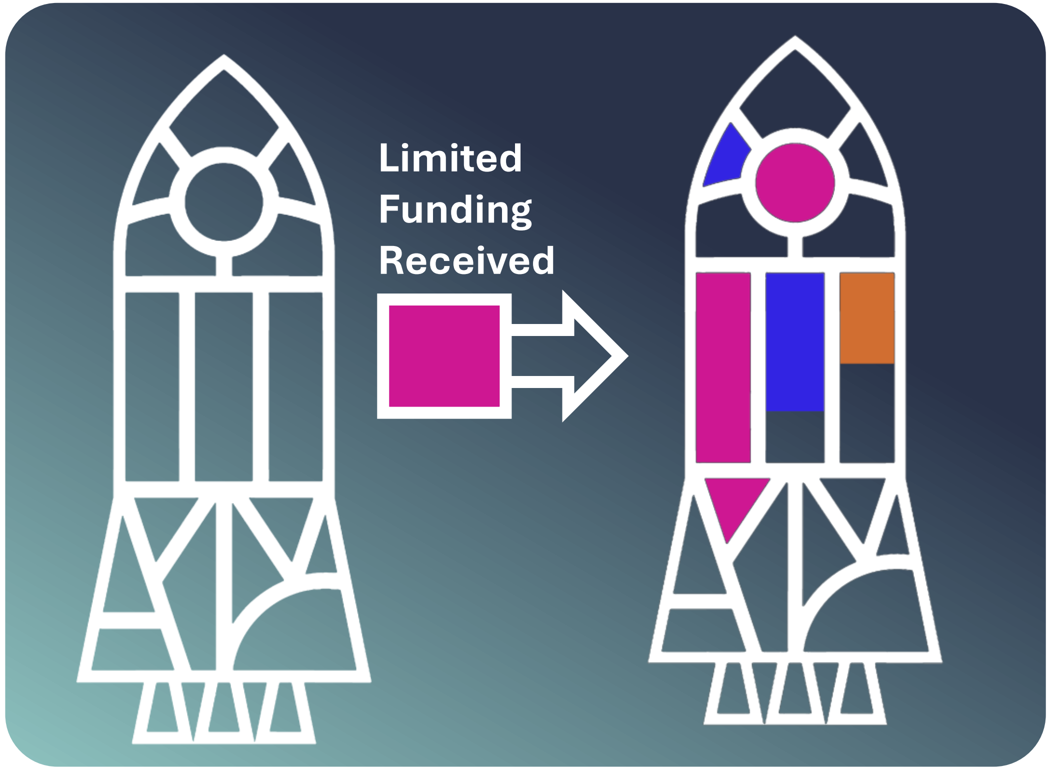
What is done, how it's accomplished, and who participates affect our world, quality of life, and humanity's future.

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 stress and anxiety 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 inter-related principles:

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

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

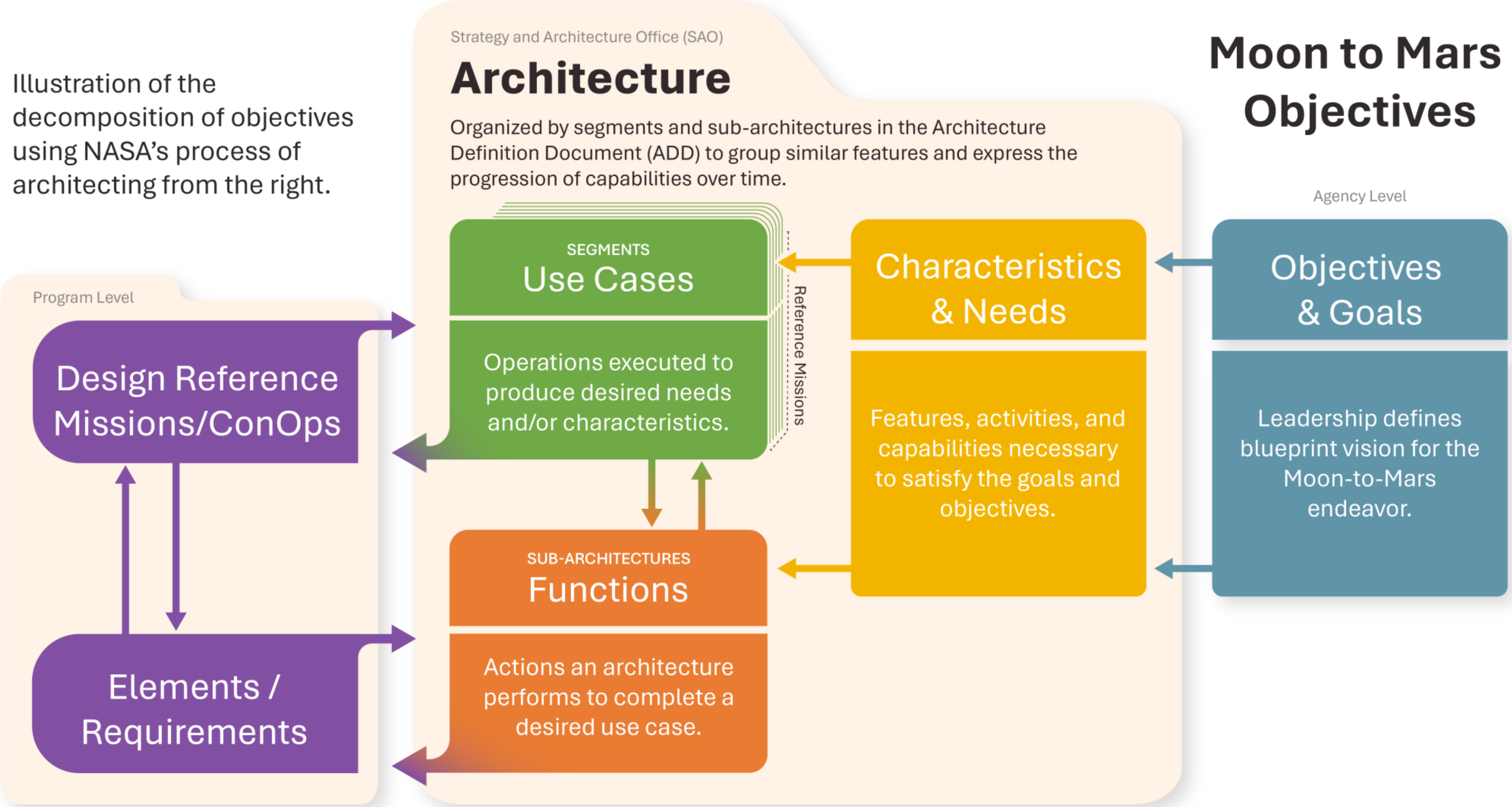
Organizational construct to ensure system/element relationships are understood and gaps can be identified

PROCESS & PRODUCTS

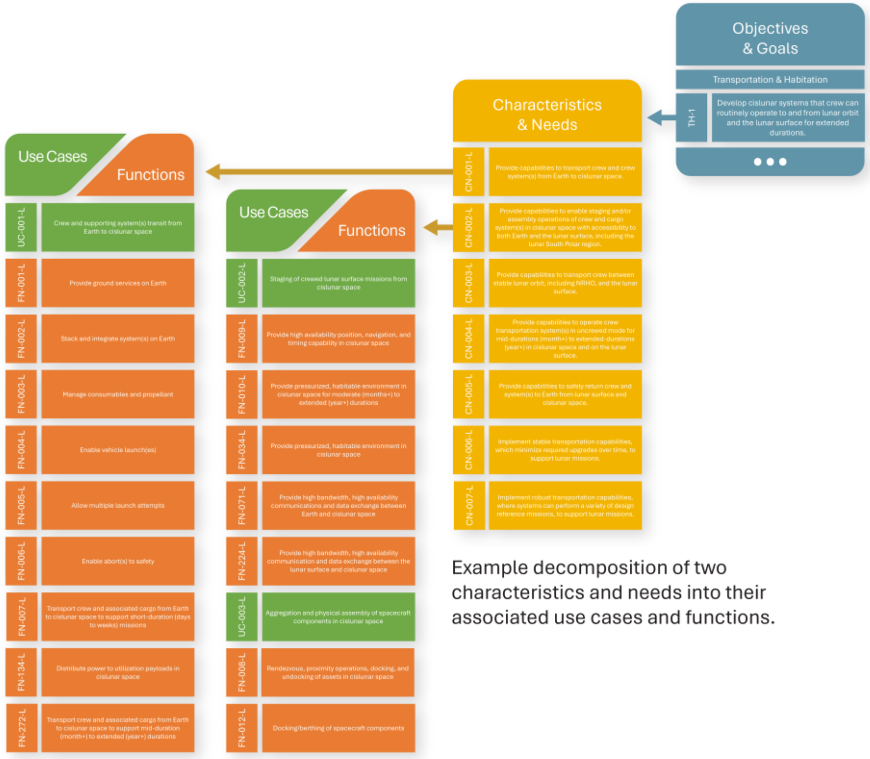
Clear communication and review integration paths for stakeholders

Architecting from the Right

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



Decomposition of Objectives



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

Objectives Mapping Tables

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.

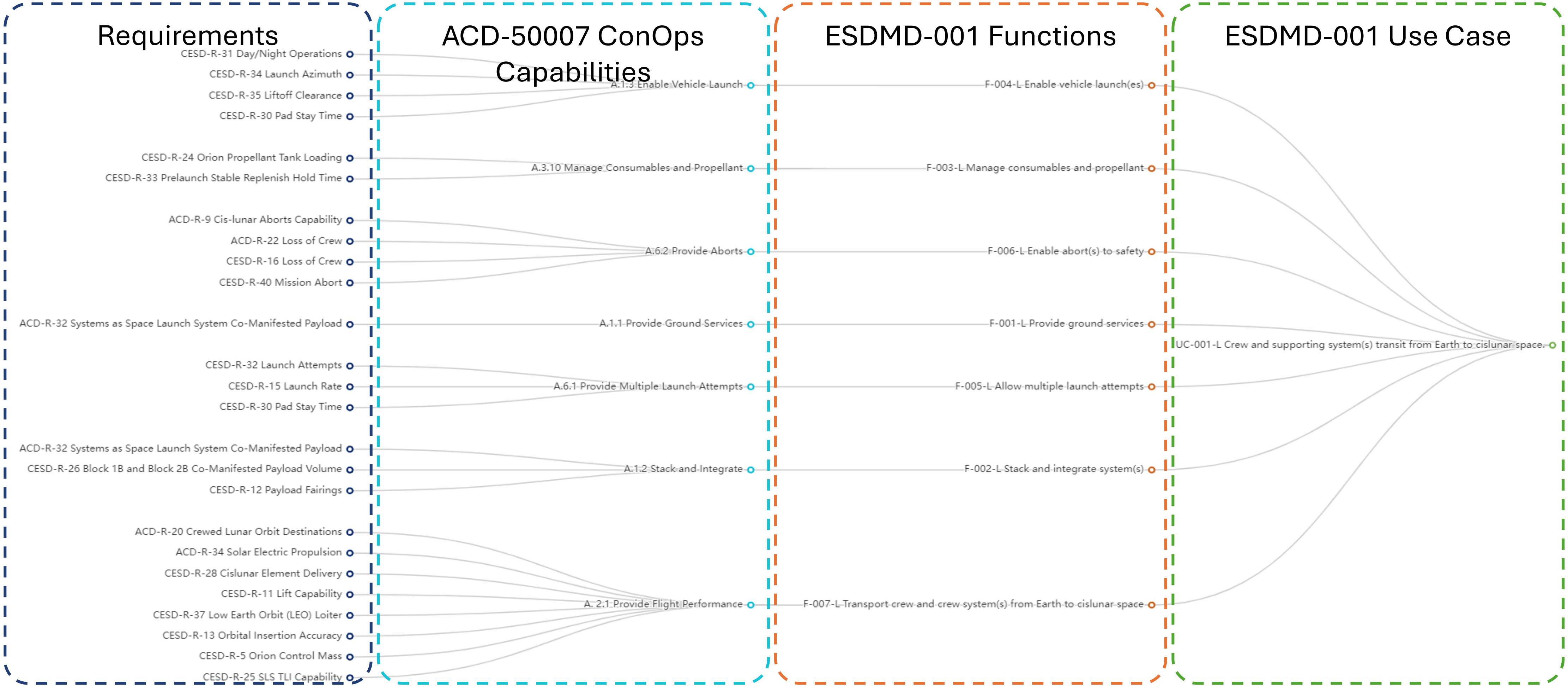
Characteristics and Needs: Features, activities, and capabilities necessary to satisfy goals and objectives.

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.

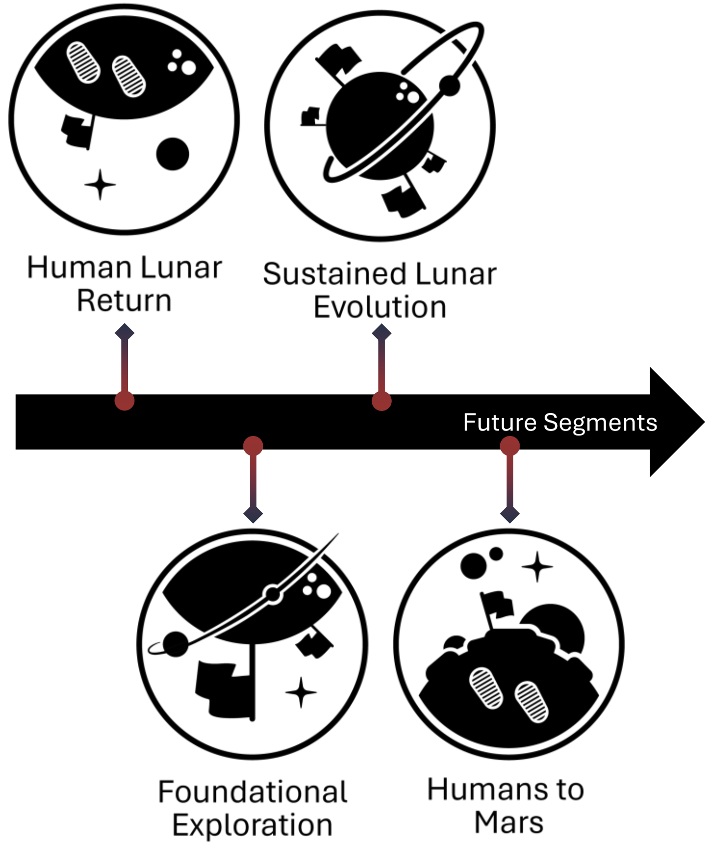
Requirements Flowdown

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



Architecture Overview

Architecture Components

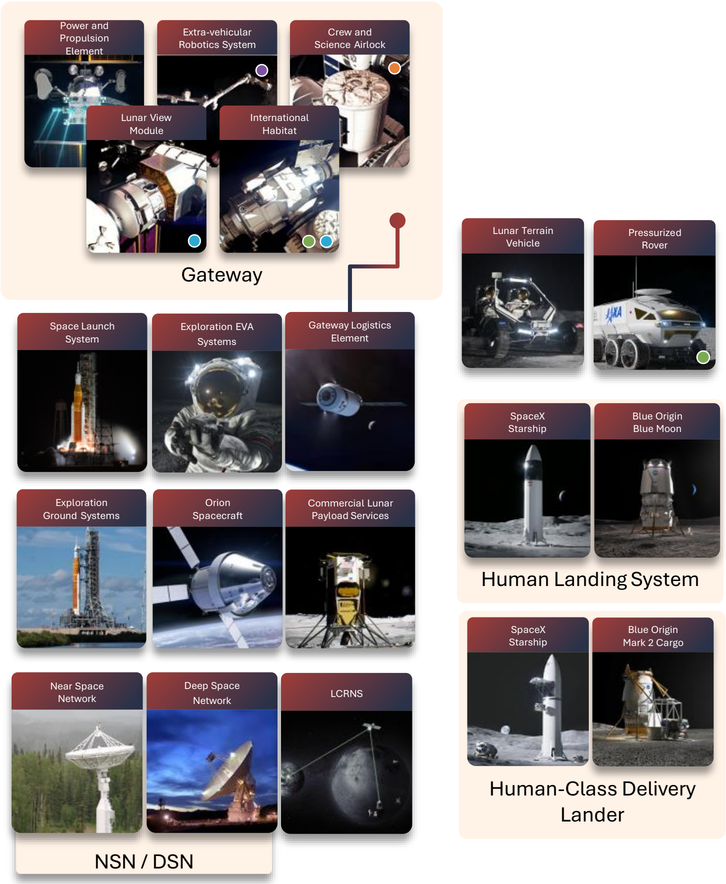


Segments

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.

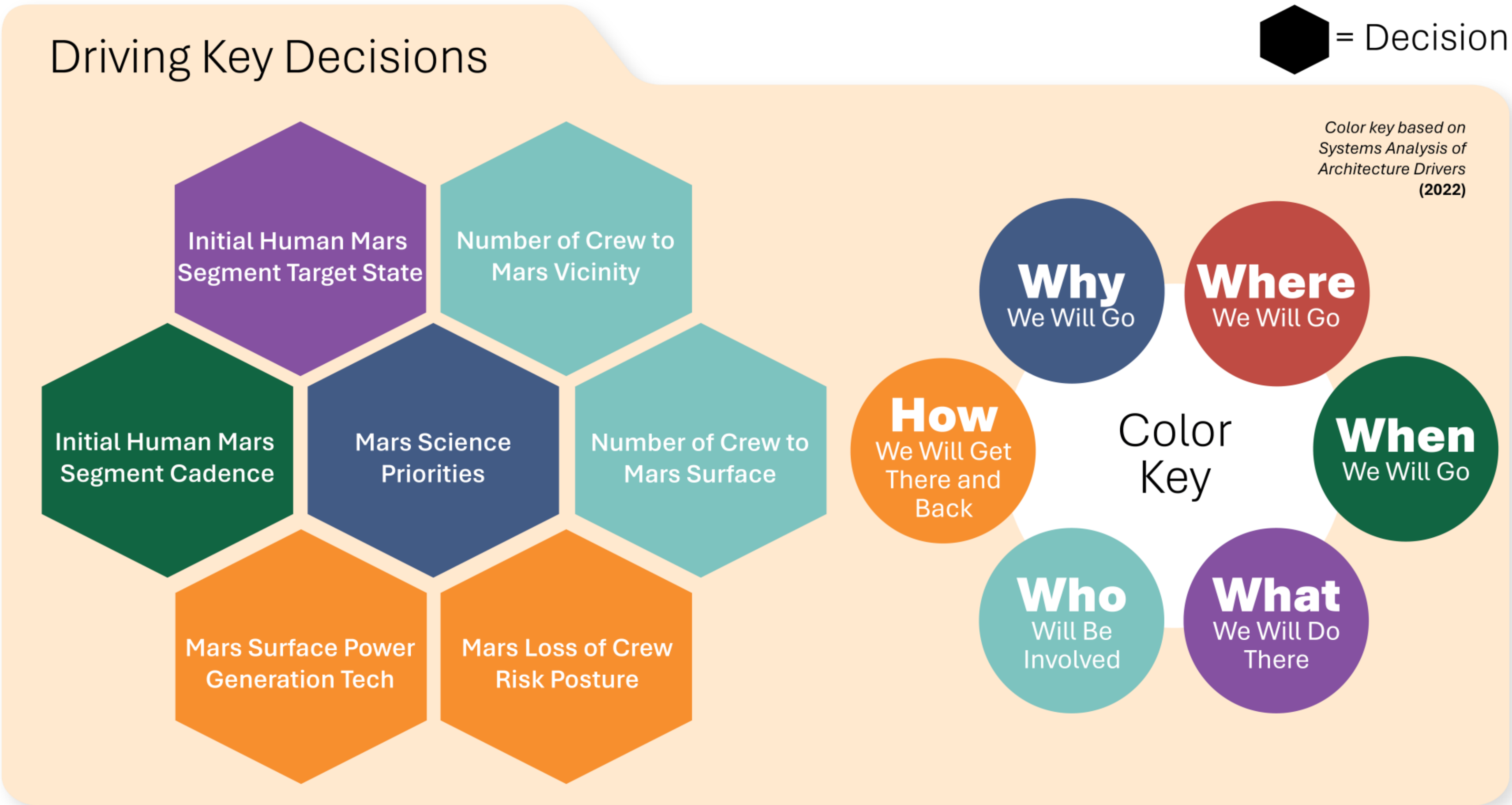


Elements

A notional exploration system that enables a set of functions.

International Partnerships: Canadian Space Agency; European Space Agency; United Arab Emirates; Japan Aerospace Exploration Agency

Our First Seven Decisions for Mars



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

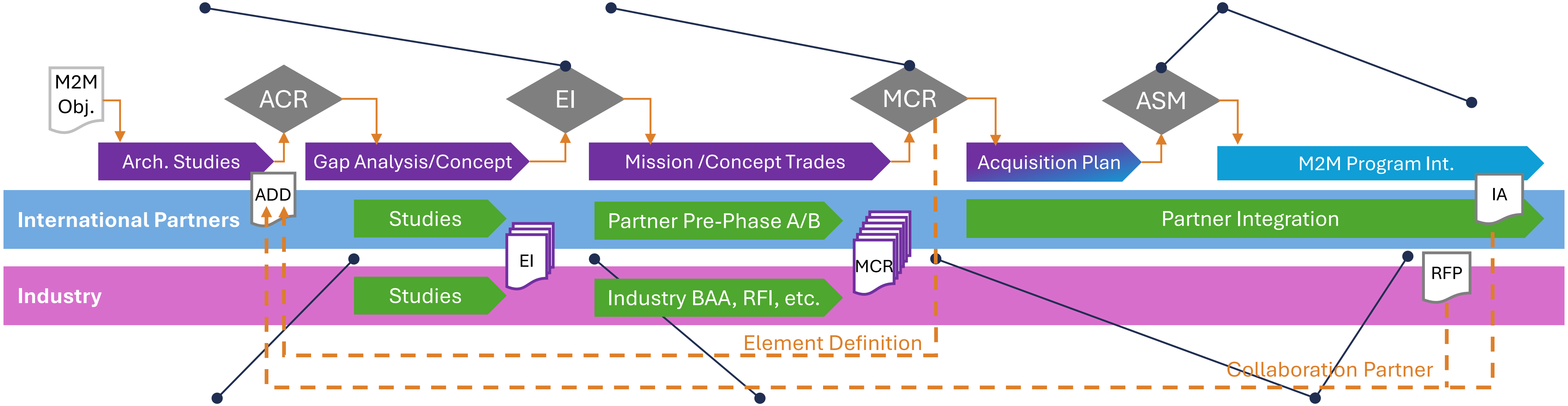
Moon to Mars Architecture products enable strategic conversations where NASA's needs and partner strategies align.

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

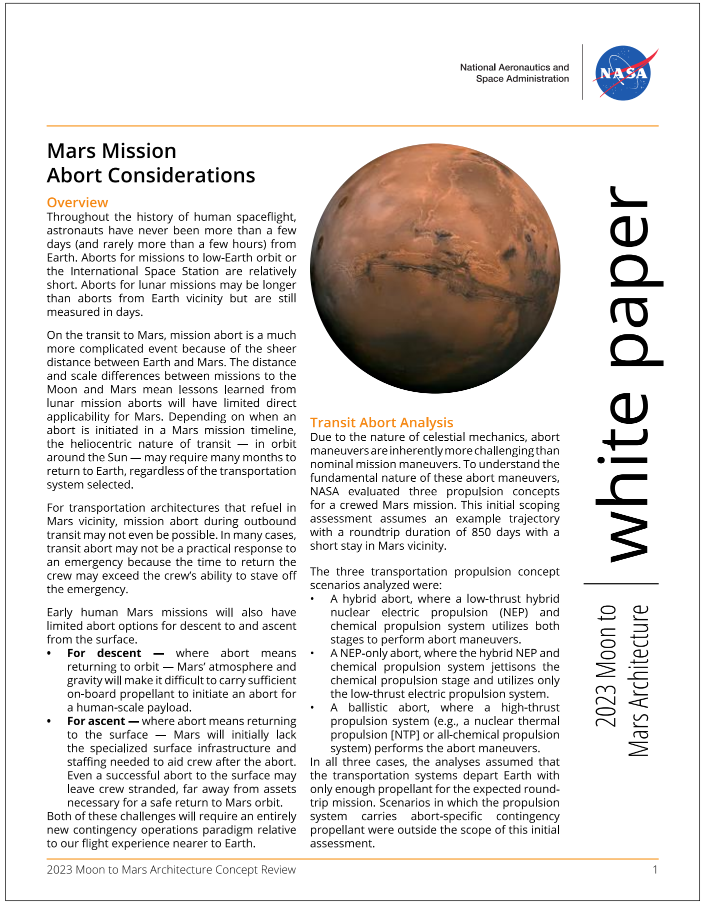
Process & Products

- ✓ 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

Architecture Products

Architecture Definition Document
Revision A (ADD Rev-A)

Moon to Mars Architecture
Executive Overview



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). GLEgfliht 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/

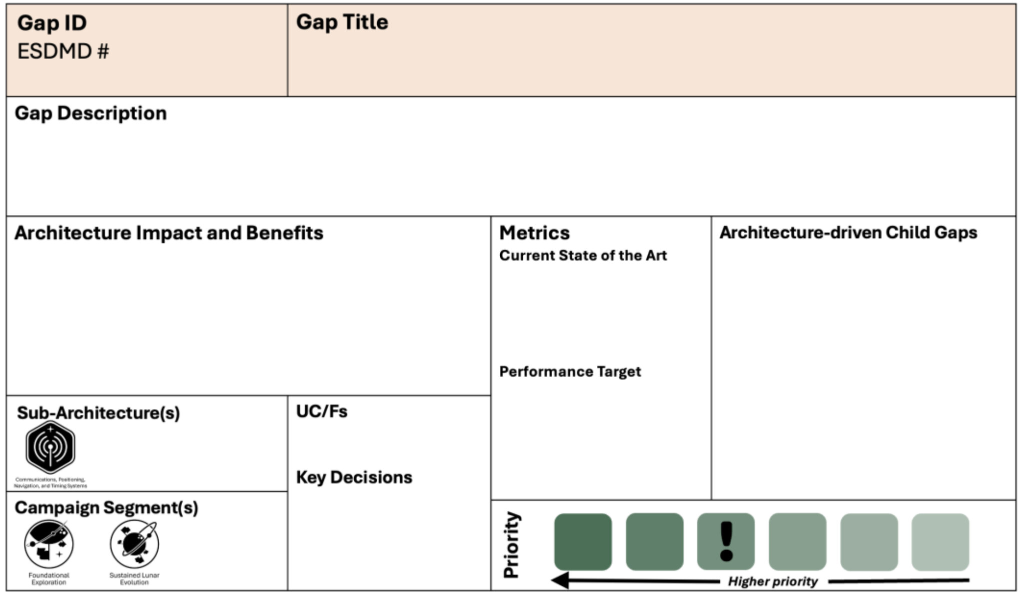
Technology Gaps

Technology Gaps

- Distinct from the Space Technology Mission Directorate's technology shortfalls, though there is overlap
- Identifies needed technologies and capabilities to realize future segments of the architecture
- Organizes gaps by associated sub-architecture and architecture segment

Associated Segment(s)

Foundational Exploration | Sustained Lunar Evolution | Humans to Mars



Tech Gap Template

Science & Technology

Architecture Workshops

Get Involved

2024 Industry and Academia Workshop
National Academy of Sciences

2024 International Partner Workshop
National Academy of Sciences

Yearly Architecture Workshops

2025 workshops tentatively scheduled for February 11 to 13 in Washington, D.C.

https://socialforms.nasa.gov/Architecture-Updates

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Get Involved

Questions?

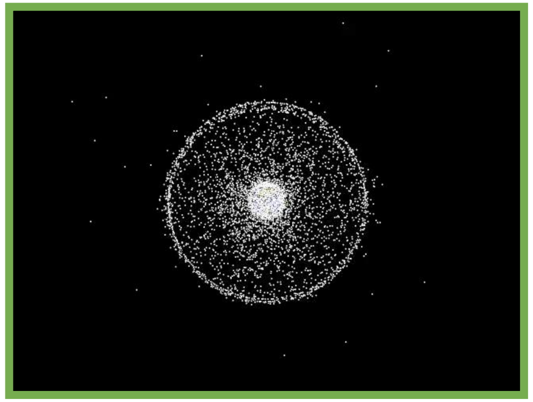
nasa.gov/architecture

What is ISAM?

Changing the "One and Done" Paradigm

In-space Servicing, Assembly, and Manufacturing (ISAM)

Robots are poised to make what was once thought to be impossible in space a reality. From extending the lifespan of satellites, to assembling massive telescopes in space, to refueling and repairing spacecraft on journeys to distant locations, the possibilities are endless.



Servicing...

Covers activities meant to fix, improve, or revive satellites and refers to work to refuels, repairs, replaces, or augments an existing asset in space. Servicing allows for satellite life-extension and upgradability as technology evolves.

Assembly...

Gathers two or more parts together in space into a single, functional aggregate structure. Assembly allows for separate launches of individual spacecraft parts separately, thereby overcoming rocket fairing size constraints.

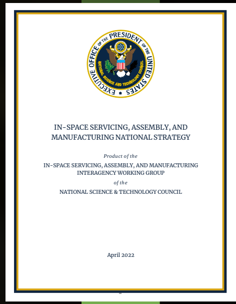
Manufacturing...

Is the fabrication of components in space. Manufacturing offers greater adaptability to unforeseen challenges, reduces the number of components needed at launch, and enables production of large, monolithic structures.

ISAM: A National Priority

Science & Technology

ISAM National Strategy

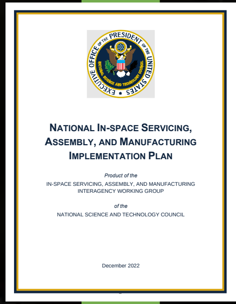

IN-SPACE SERVICING, ASSEMBLY, AND MANUFACTURING NATIONAL STRATEGY

Product of the
IN-SPACE SERVICING, ASSEMBLY, AND MANUFACTURING INTERAGENCY WORKING GROUP
of the
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

April 2022

The United States government has identified ISAM as key to continued American leadership in space. In April 2022, the White House Office of Science and Technology Policy (OSTP) released their ISAM National Strategy, which provides an interagency strategy guiding U.S. Government (USG) direction for and investments in ISAM capabilities and services.

ISAM Implementation Plan


NATIONAL IN-SPACE SERVICING, ASSEMBLY, AND MANUFACTURING IMPLEMENTATION PLAN

Product of the
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of the
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

December 2022

In December 2022, the White House OSTP released their ISAM Implementation Plan, organized around the realization of six goals:

- advancing ISAM research and development,
- prioritizing the expansion of scalable infrastructure, accelerating the emerging ISAM commercial industry,
- promoting international collaboration and cooperation to achieve ISAM goals,
- prioritizing environmental sustainability as we move forward with ISAM capabilities, and
- inspiring a diverse workforce as a potential outcome of ISAM innovation.

Vice President Kamala Harris tours NASA Robotics Facilities | **2022**

Key Moments in ISAM History

SKYLAB
1973

Just 10 days after the initial launch of the Skylab, the crew executed a series of Extravehicular Activities to replace a thermal shield and restore the orbiting laboratory to acceptable performance limits.

SOLAR MAXIMUM
1984

The Solar Maximum Mission is repaired by space shuttle astronauts. The mission possessed a modular design that made servicing possible and set the stage for more ambitious shuttle servicing missions.

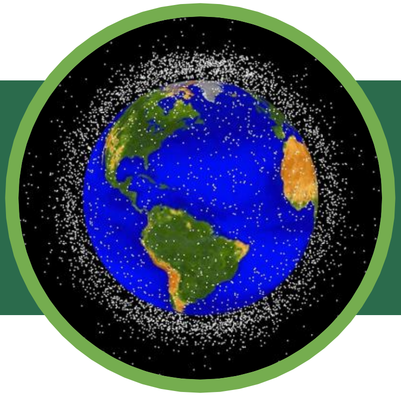
HUBBLE SERVICING
1993-2009

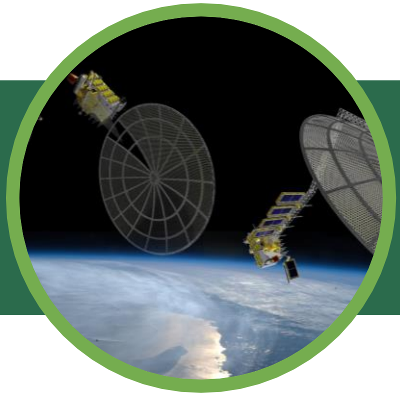
Over the five Hubble servicing missions, space shuttle astronauts corrected a mirror aberration, installed new instruments, replaced solar panels, and demonstrated the power of servicing capabilities.

BUILDING STATION
1998-Today

The International Space Station has been the largest, most complex international construction project. Assembly of the orbiting laboratory has greatly advanced ISAM technologies and capabilities.

ISAM Capability Futures


Debris
Mitigation

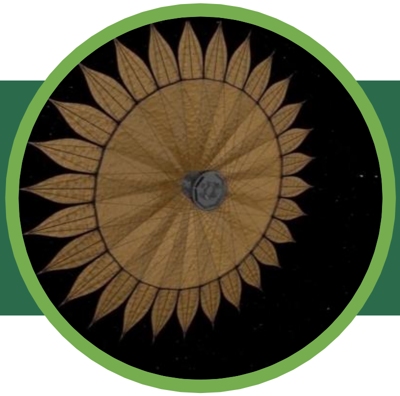

Persistent
Platforms


Observatory
Construction


Exploration
Systems


Astronaut
Tools


Space
Tugs


Telescope
Starshades


Orbital
Factories


Servicing
Fleets

Science & Technology