

National Aeronautics and
Space Administration

An artistic illustration of three astronauts on the surface of Mars. The landscape is reddish-orange with rolling hills and mountains in the background. A large American flag is being planted in the ground by one astronaut. Another astronaut is using a tool on the surface, and a third is in the background pointing towards the horizon. In the sky, there is a large sun, a smaller planet (Mars), and the Earth in the distance.

NASA's Moon to Mars Architecture

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Exploration Systems Development Mission Directorate

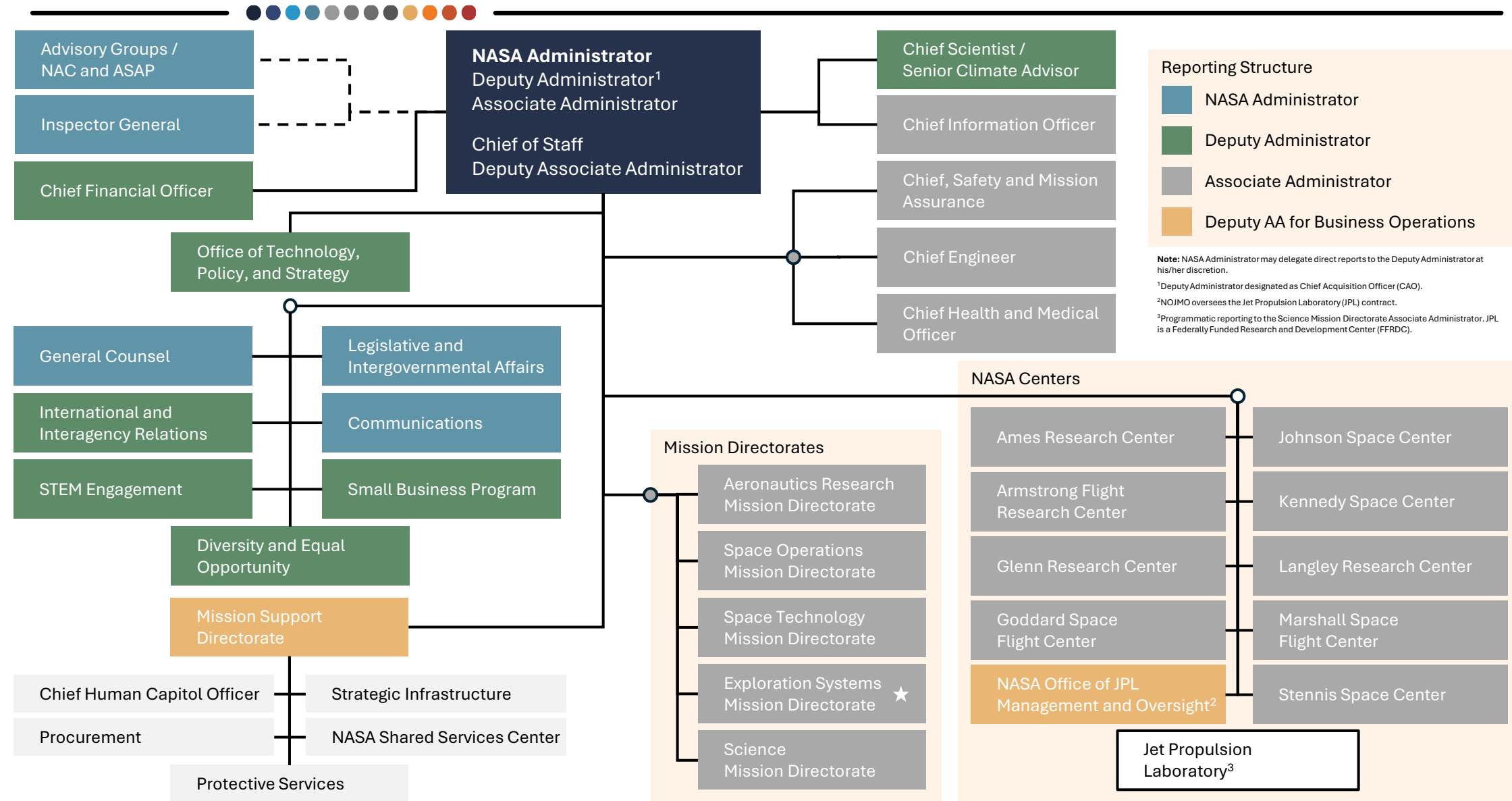


December 13, 2024

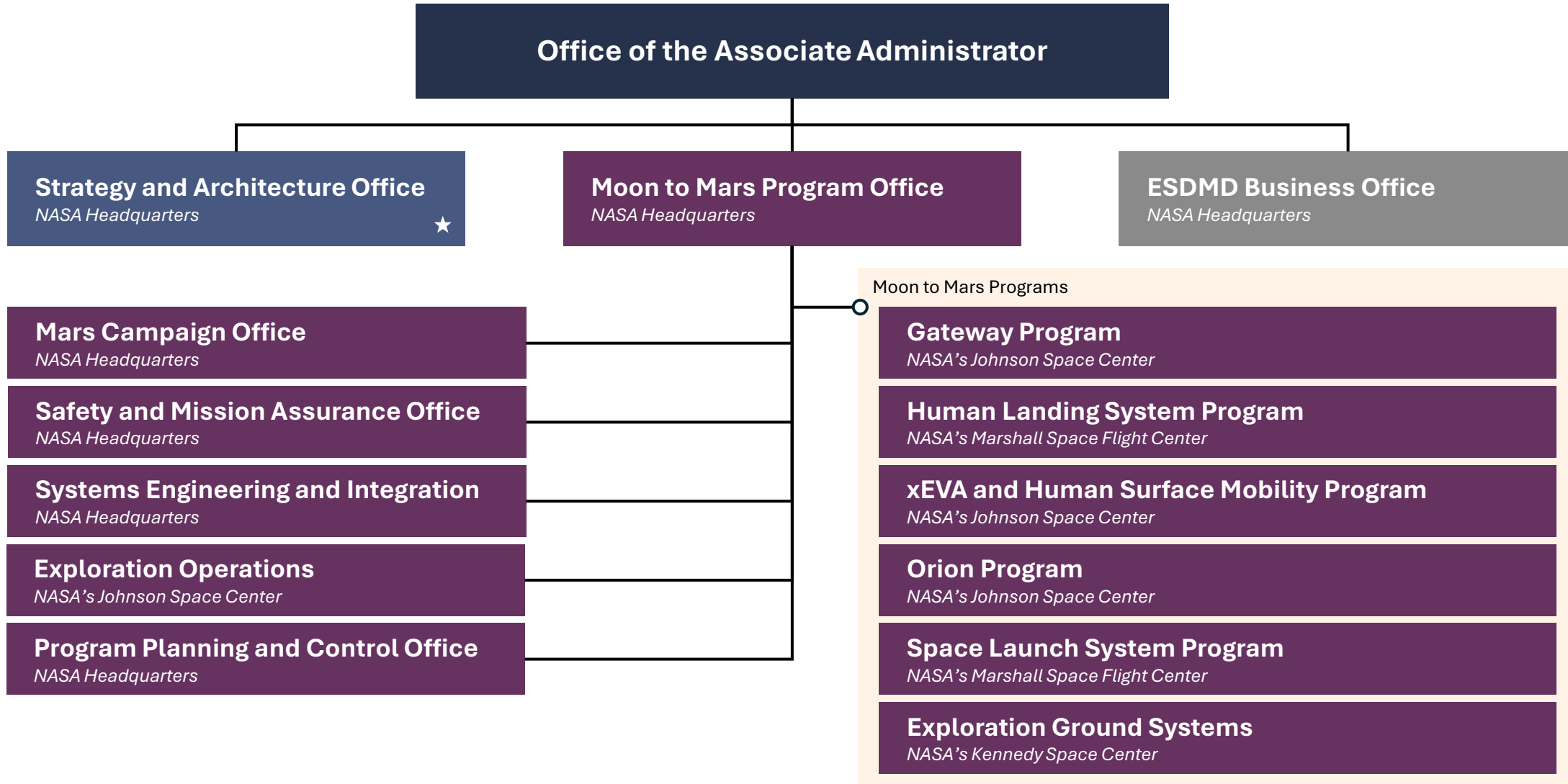
NASA Organizational Chart



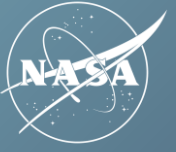
Architecture 101



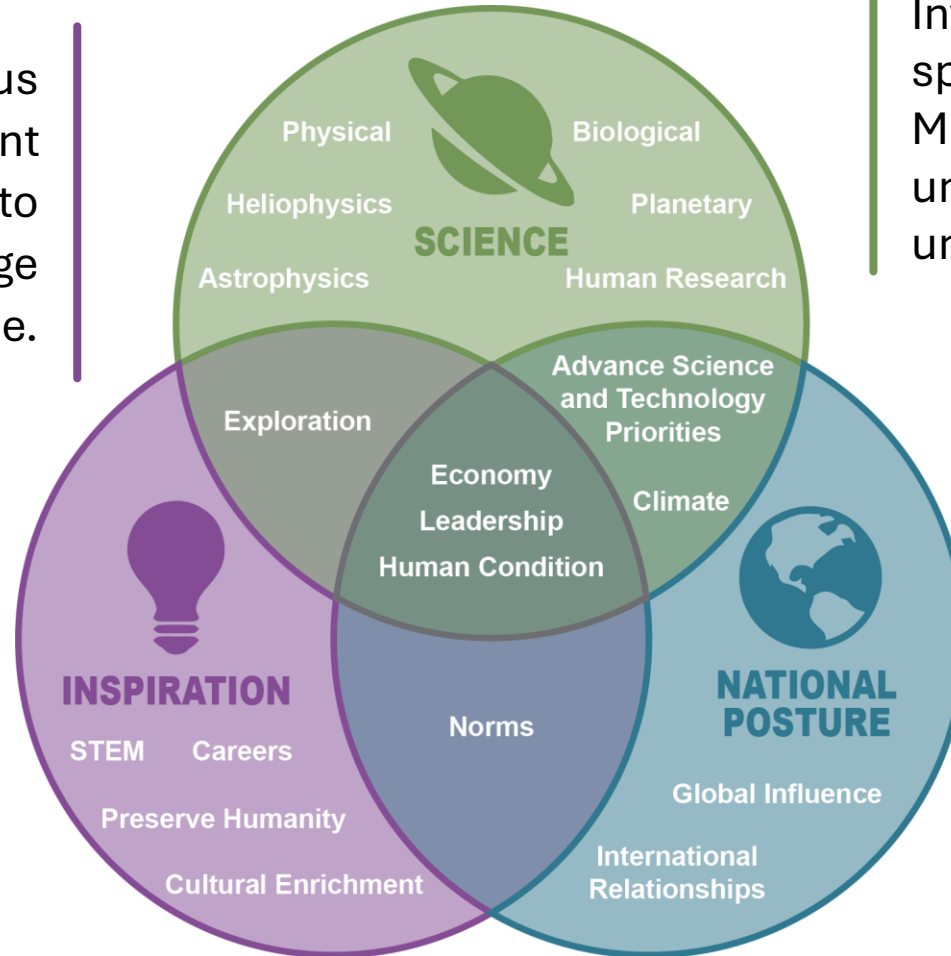
Exploration Systems Development



Why We Explore...



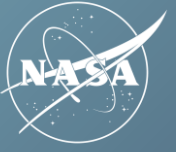
Accepting audacious challenges motivates current and future generations to contribute to our voyage deeper into space.



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



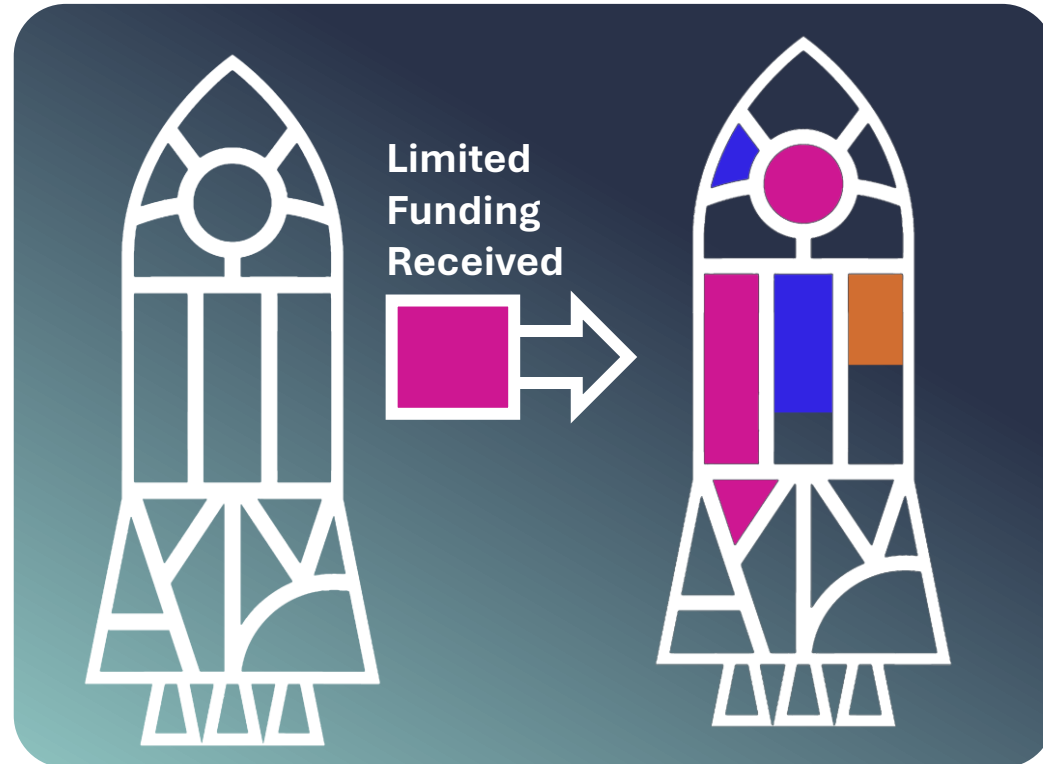
We need an objective-based approach.

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

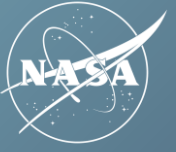
A capability-based approach does not fully support a long-term strategy to Mars



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

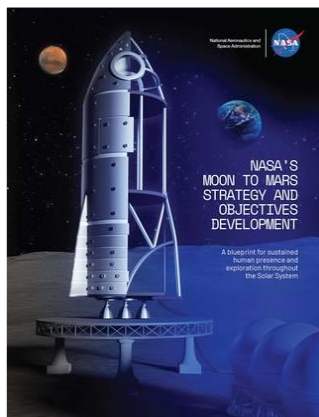
Architecture Overview



Moon to Mars Architecture

Evolves through annual Architecture Concept Reviews

Objectives and Strategy



RECURRING TENETS

SCIENCE

TRANSPORTATION
AND HABITATION

LUNAR AND MARS
INFRASTRUCTURE

OPERATIONS



Architecture Approach

An Evolutionary Architecture Process

Formulating an Exploration Strategy Based on Objectives

Moon to Mars Objectives

- PRODUCT REVIEW
- ARCHITECTURE DEFINITION DOCUMENT
- REVISED ARCHITECTURE



- ARCHITECTURE CONCEPT REVIEW



- ARCHITECTURE CONFIRMATION



- PRODUCT DEVELOPMENT REVIEW
- ARCHITECTURE DEFINITION DOCUMENT EXPANSION
- REFINED/EXPANDED ARCHITECTURE

- ARCHITECTURE CONCEPT REVIEW



ANNUAL CYCLE TO MATURE ARCHITECTURE

Architecting from the Right

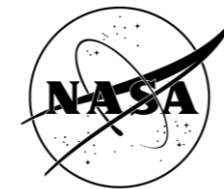
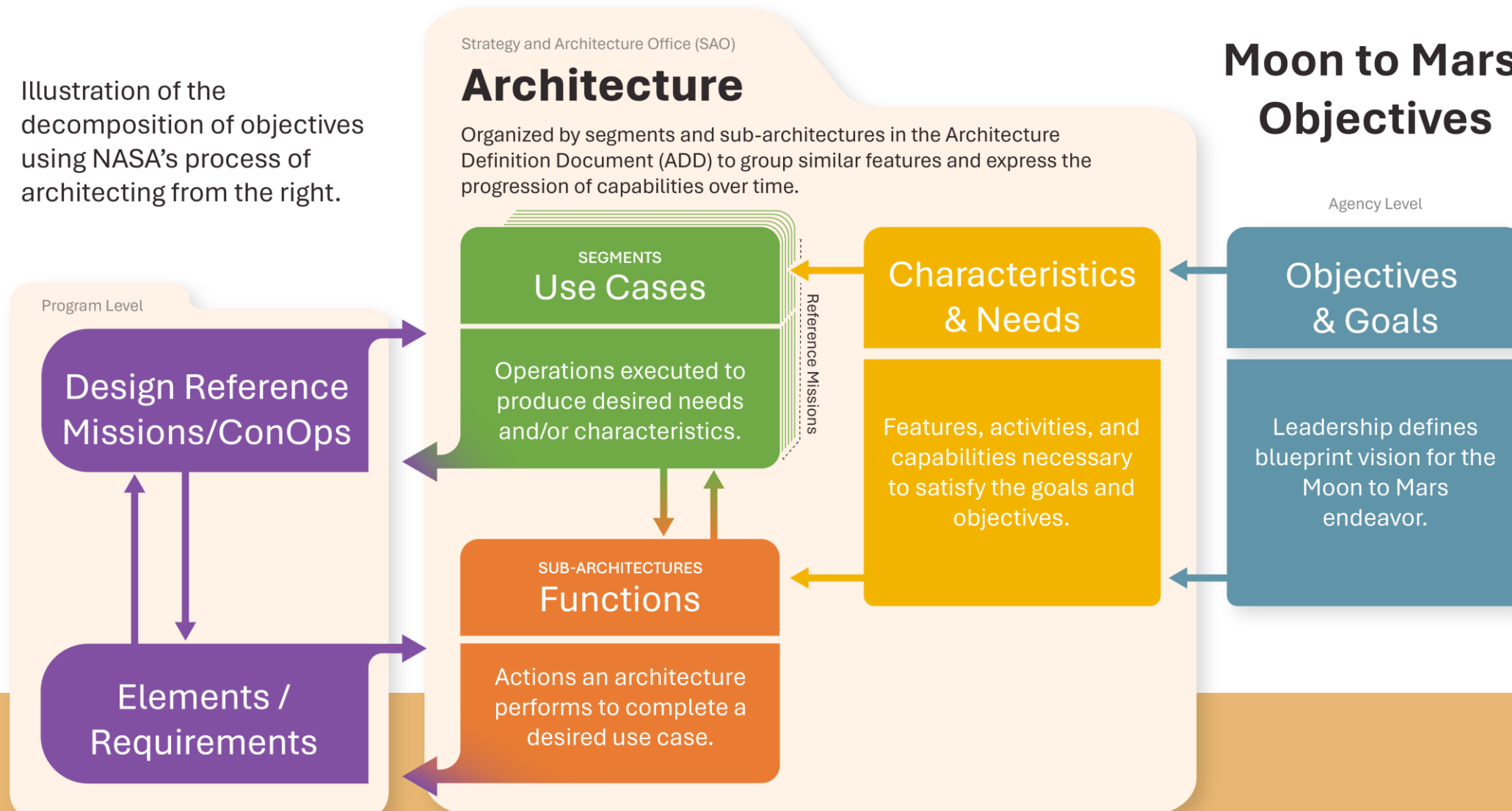
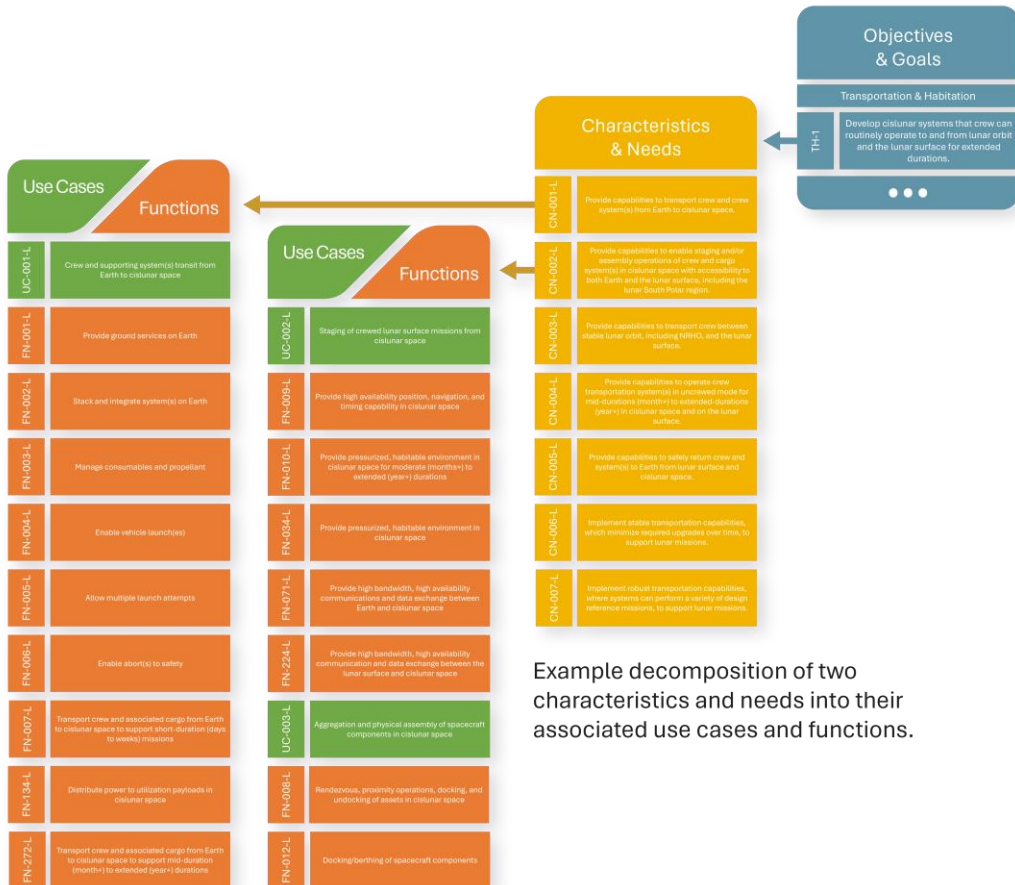


Illustration of the decomposition of objectives using NASA's process of architecting from the right.



Decomposition of 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.

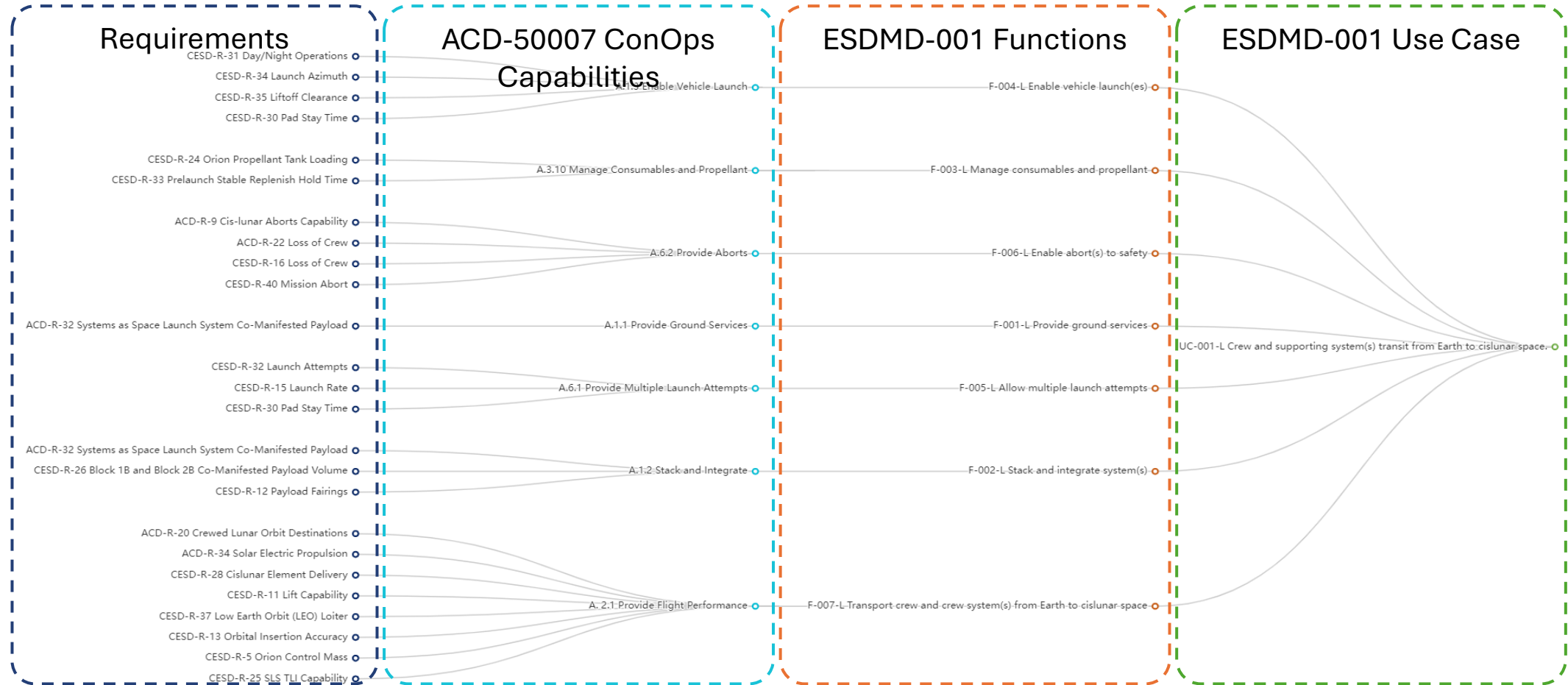
Characteristics and Needs: Features, activities, and capabilities necessary to satisfy goals and objectives.

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.

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.

Requirements Flow Down

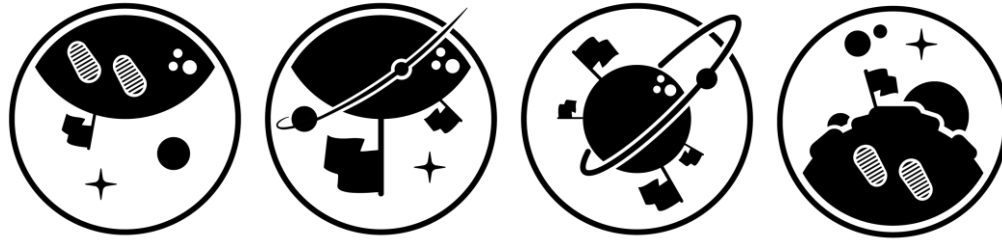


Requirements Flow Down for Use Case 001:
Crew and supporting system(s) transit from Earth to cislunar space

Architecture Components



Segments



Human Lunar Return

Foundational Exploration

Sustained Lunar Evolution

Humans to Mars

Future Segments

Sub-Architectures



Autonomous Systems and Robotics

Communications, Positioning, Navigation, and Timing Systems

Data Systems and Management

Habitation Systems

Human Systems

Infrastructure Support



In-situ Resource Utilization (ISRU) Systems

Logistics Systems

Mobility Systems

Power Systems

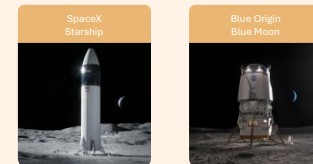
Transportation Systems

Utilization Systems

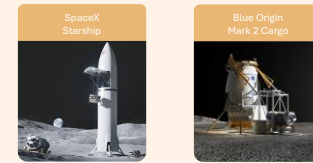
Elements



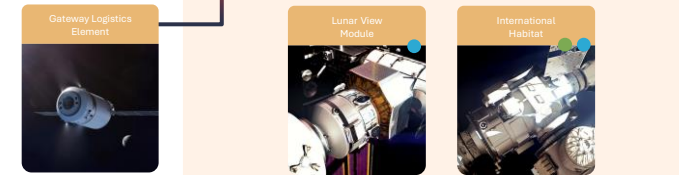
NSN/DSN



Human Landing System



Human-Class Delivery Lander



Gateway

International Partners

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

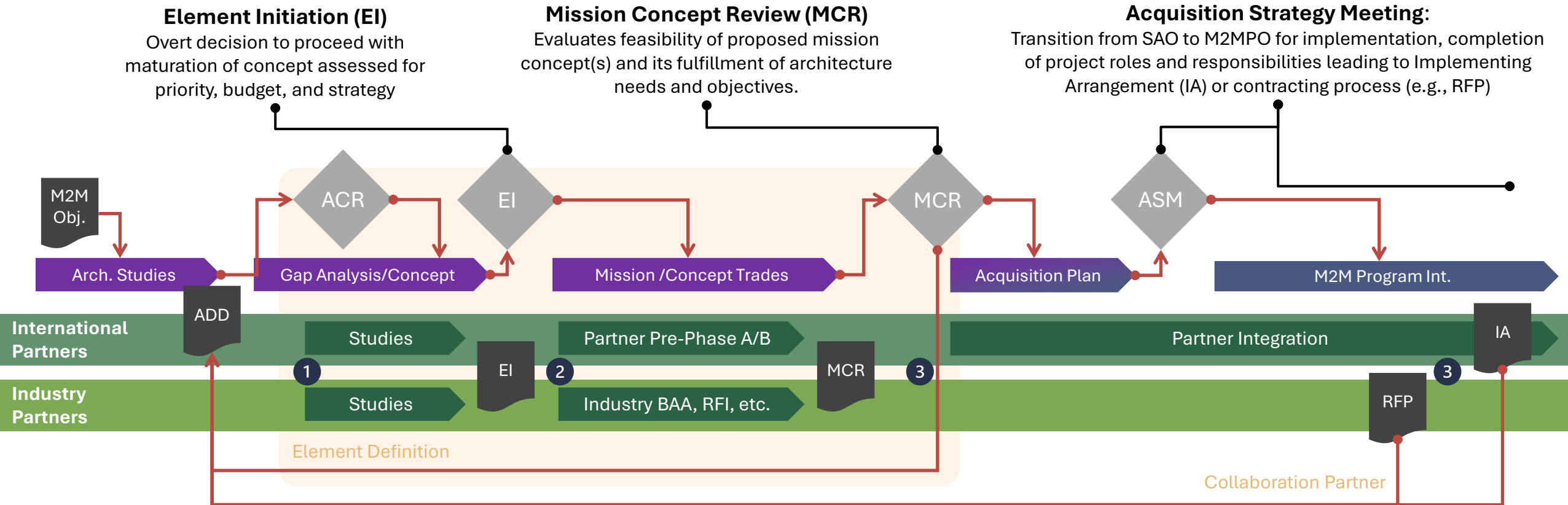
Segments are portions of the architecture that integrate sub-architectures and progressively increase in complexity and objective satisfaction.

Sub-Architectures are a group of tightly coupled elements, functions, and capabilities that work together to accomplish one or more objectives.

Elements are notional exploration systems that enable a set of functions.

Partner Pre-formulation Process

Exploration Systems Development Mission Directorate



Document(s)
 NASA Milestone

- 1 Feasibility studies and collaboration identify potential concept.
- 2 Mission refinement to optimize for strategic value and functional achievement, using study mechanisms to better inform planning.
- 3 Feedback incorporated into architecture products as milestones occur.

Collaboration Partner
Strategy and Architecture Office (SAO)
Moon to Mars Program Office (M2MPO)

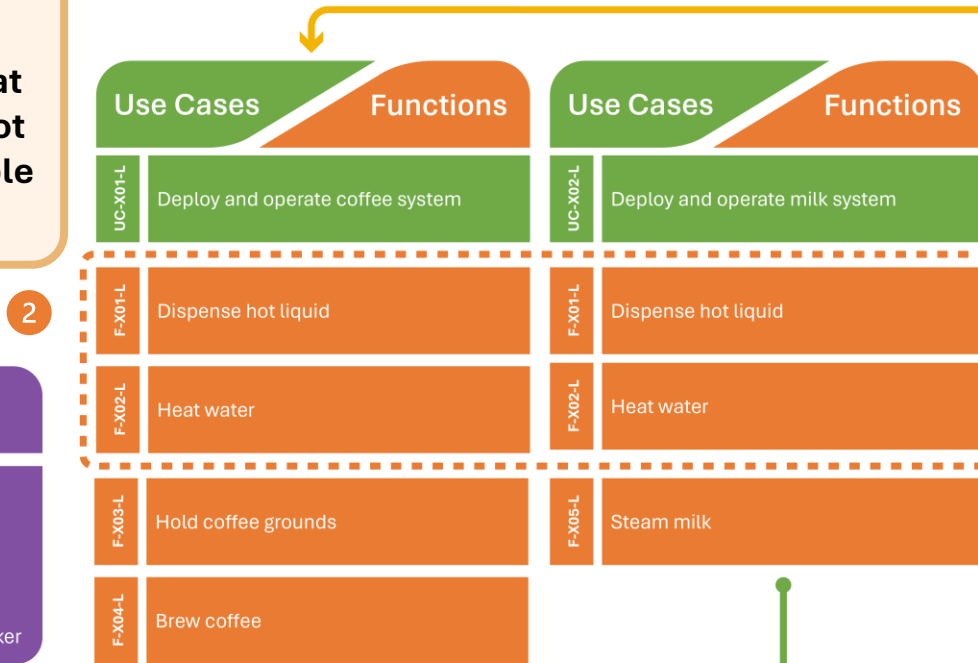
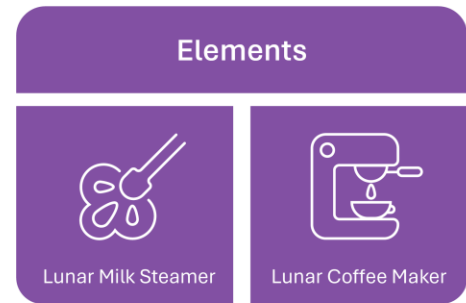
Fictional Decomposition

Presented for Illustrative Purposes Only



Decomposition of
imaginary objective
CC-1^{LM}

**“Develop system(s) that
enable crew to make hot
coffee drinks in habitable
surface volumes.”**



- 1 Characteristics and needs associated with the delivery of the coffee systems and associated consumables to habitable volumes on the lunar surface are met by existing elements already instantiated within the architecture.
- 2 Function F-X01-L and F-X02-L are shared by use cases UC-X01-L and UC-X02-L and the elements that fulfill them. However, implementation of functions may look different for each element.
- 3 NASA maps elements to the use cases and functions they fulfill and documented in the agency's Architecture Definition Document. The Moon to Mars Program Office develops requirements for and manages implementation of elements.



Program Office
Requirements



Functions



Use
Cases



Characteristics
& Needs



Objectives
& Goals

Lunar Coffee Maker Element

Implementation by International Partner - Presented for Illustrative Purposes Only

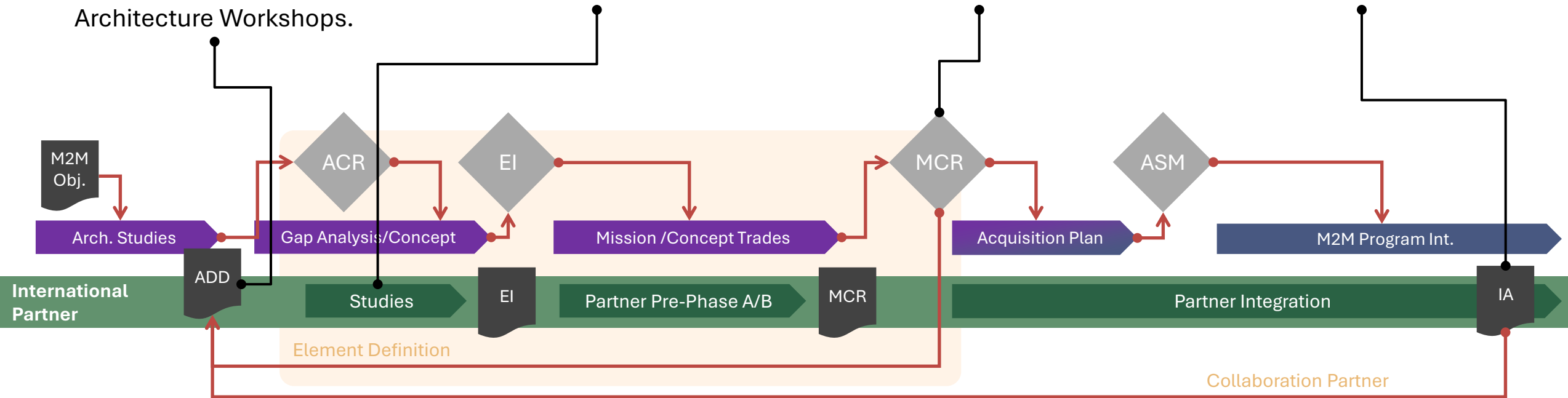


NASA and international partner discuss architectural gap identified in the Architecture Definition document at Moon to Mars Architecture Workshops.

NASA and international partner execute a bi-lateral study agreement for a partner-developed lunar coffee maker concept.

After iterating, NASA and the international partner conduct mission concept reviews for the lunar coffee maker concept.

The U.S. and the international partner nation sign an implementing arrangement, proceeding to formulation and implementation.



Document(s)
NASA Milestone

Collaboration Partner
Strategy and Architecture Office (SAO)
Moon to Mars Program Office (M2MPO)

Lunar Milk Steamer Element

Implemented by Industry - Presented for Illustrative Purposes Only

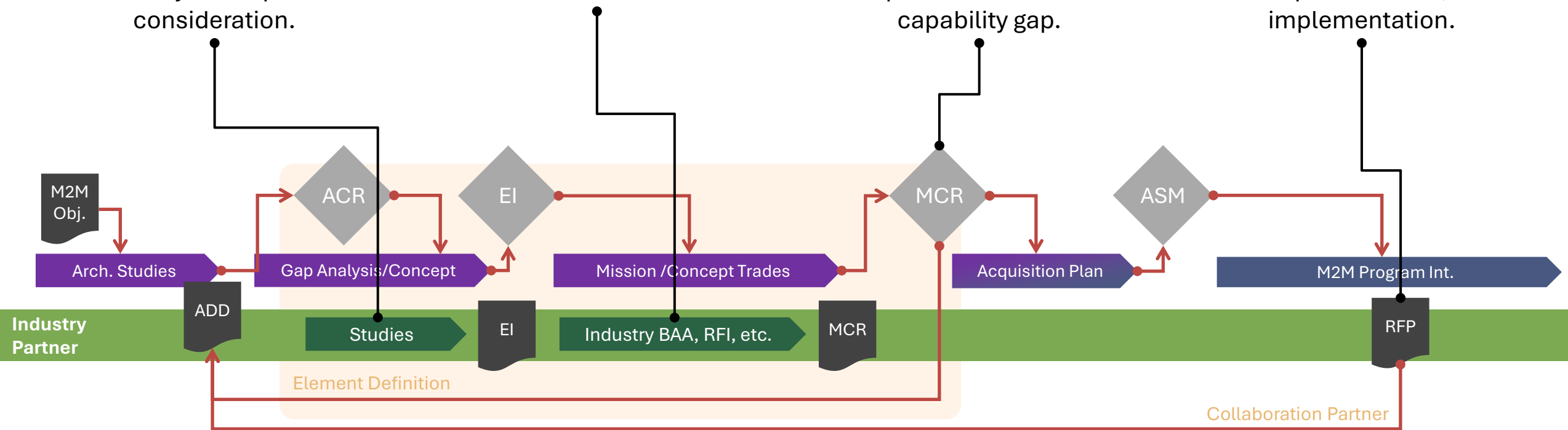


While examining the lunar milk steamer trade space, the agency decides to seek industry concepts for consideration.

NASA issues a request for information (RFI) seeking industry approaches to a lunar milk steamer element.

After considering industry approaches, NASA conducts a mission concept review for a concept that would close the capability gap.

The element transitions to formulation, competitive industry selection through a NASA procurement, and implementation.



Document(s)
NASA Milestone

Collaboration Partner
Strategy and Architecture Office (SAO)
Moon to Mars Program Office (M2MPO)

Concept Maturity Mapped to Process

For Fictional/Illustrative Lunar Coffee Maker Element



Area of Partner Interest

In-Space Food Systems

Architectural Gap

Provide coffee to lunar astronauts

Associated Sub-Architectures



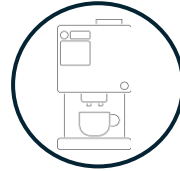
Human Systems



Habitation Systems



Logistics Systems



Espresso Machine



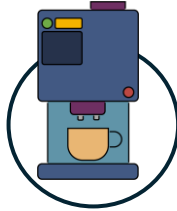
French Press



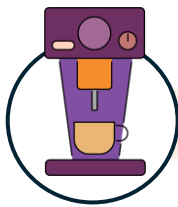
Drip Coffee



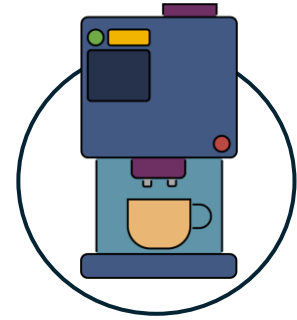
Espresso Concept 1



Espresso Concept 2



Espresso Concept 3



Lunar Coffee Maker Element

Joint Capability Studies

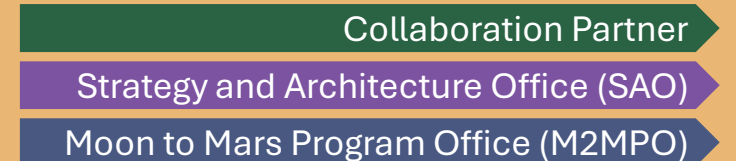
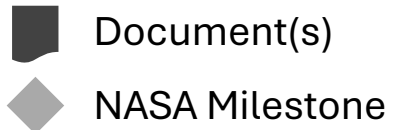
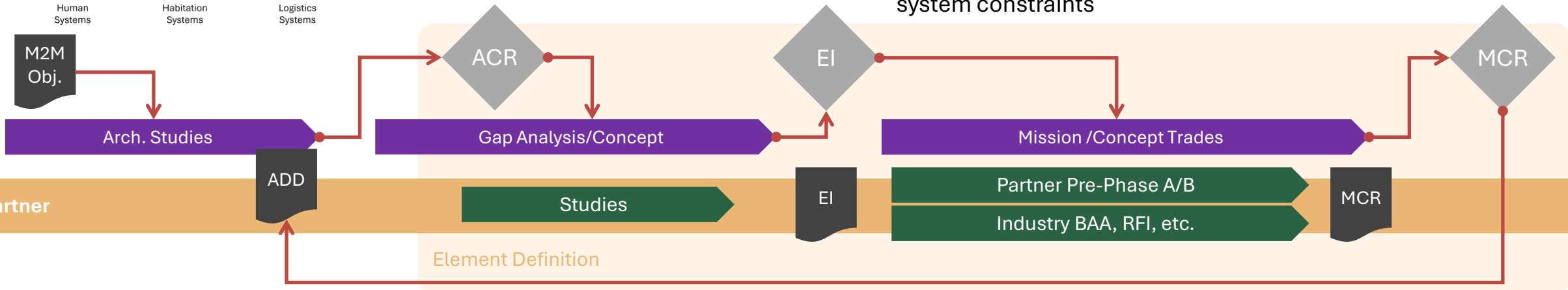
Examine the trade space while developing concepts.

Element Definition

Establish best solution to fulfil the architecture needs within partner and system constraints

Pre-Phase A

Select concept for formulation; prepare for mission concept review.



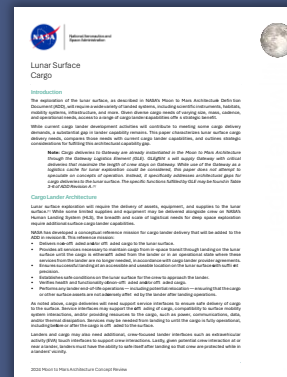
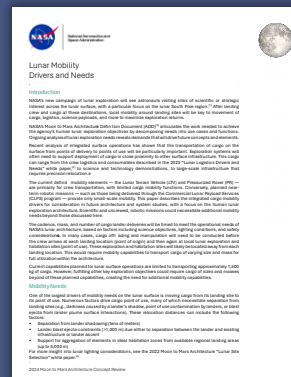
Logistics and Mobility Studies



Request for Proposals

NASA is asking U.S. industry to submit innovative architecture solutions that could help the agency land and move cargo on the lunar surface during future Artemis missions.

<https://www.nasa.gov/general/nasa-seeks-innovative-artemis-lunar-logistics-mobility-solutions/>

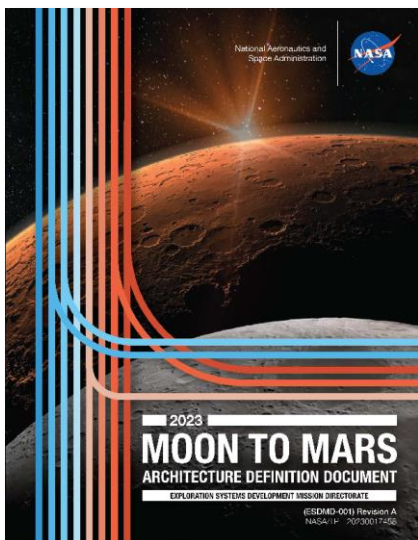
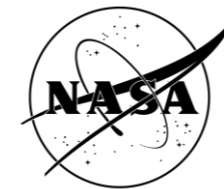


Associated White Papers:

- Lunar Logistics Drivers and Needs
- Lunar Mobility Drivers and Needs
- Lunar Surface Cargo

www.nasa.gov/architecture

Architecture Products



NASA will publish new revisions of the **Architecture Definition Document** and **Executive Summary** later this month alongside a new batch of **Architecture White Papers!**

Moon to Mars Architecture White Papers		
Focus	Year	Title and Link
lunar	ACR24	Lunar Surface Cargo
lunar	ACR24	Lunar Mobility Drivers and Needs
lunar	ACR23	Lunar Communications and Navigation Architecture
lunar	ACR23	Lunar Site Selection
lunar	ACR23	Analytical Capabilities In-situ vs. Returned
lunar	ACR23	Safe and Precise Landing at Lunar Sites
both	ACR23	Surface Extravehicular Activity Architectural Drivers
both	ACR23	Lunar Logistics Drivers and Needs
mars	ACR23	Mars Communications Disruption and Delay
mars	ACR23	Mars Mission Abort Considerations
mars	ACR23	Mars Surface Power Generation
mars	ACR23	Key Mars Architecture Decisions
mars	ACR23	Round-Trip Mars Mission Mass Challenges
mars	ACR23	Human Health and Performance for Mars Missions
both	ACR23	Exploration Lessons Learned from the Space Station
both	ACR22	Systems Analysis of Architecture Drivers
lunar	ACR22	Why NRHO: The Artemis Orbit
lunar	ACR22	Why Artemis will Focus on the Lunar South Pole Region
lunar	ACR22	Gateway: The Cislunar Springboard
	ACR22	Mars-Forward Capabilities to be Tested at the Moon
mars	ACR22	Mars Transportation



Moon to Mars
Architecture Website

<https://www.nasa.gov/moontomarsarchitecture/>



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Questions?

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