National Aeronautics and
Space Administration

NASA's Moon to Mars Architecture Overview

National Academy of Sciences

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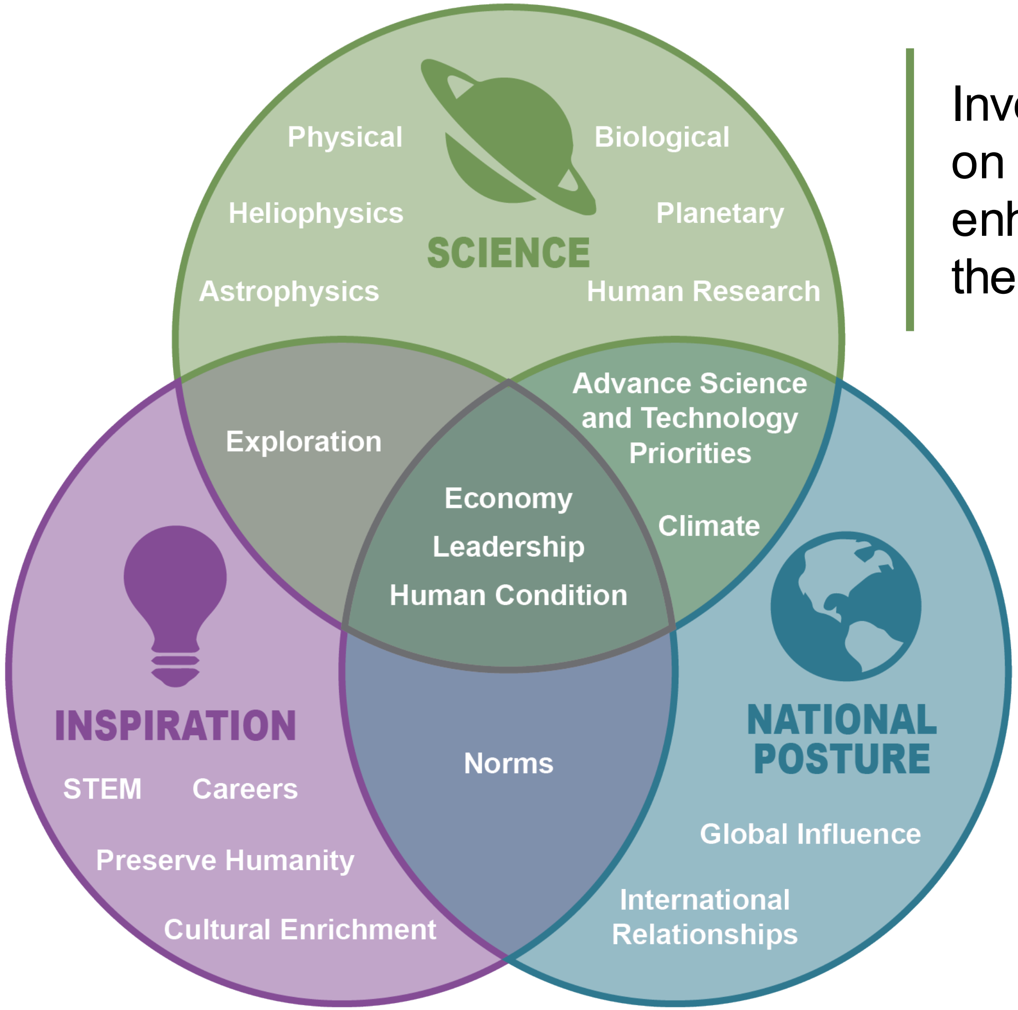
Why Go?

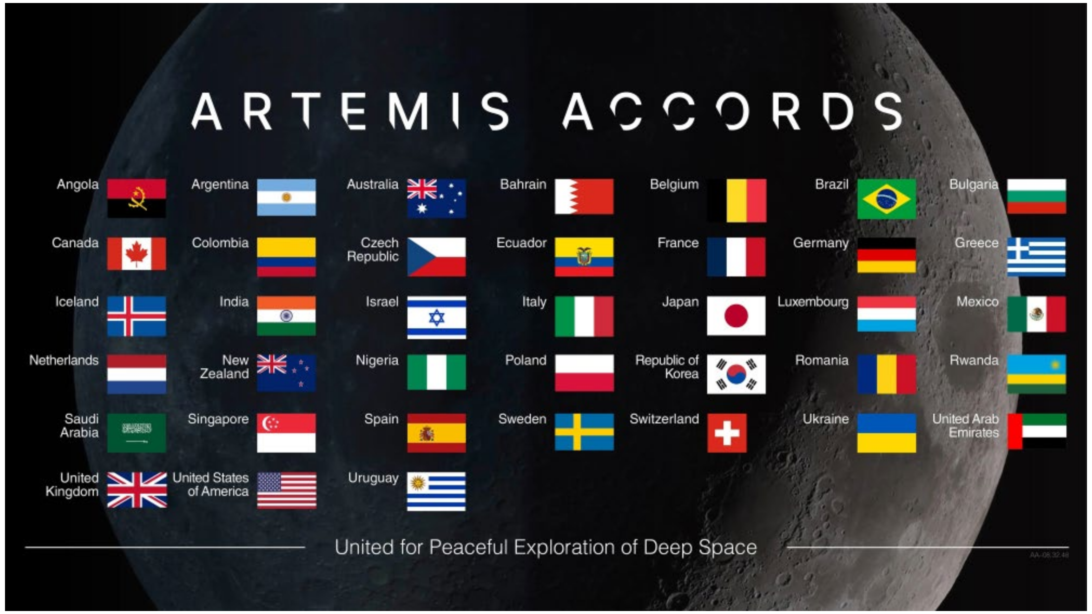
Accepting audacious challenges motivates current and future generations to contribute to our voyage deeper into space.



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.

Artemis Accords



PRINCIPLES FOR A SAFE, PEACEFUL, AND PROSPEROUS FUTURE

PEACEFUL PURPOSES
Conduct activities for peaceful purposes, per the Outer Space Treaty

TRANSPARENCY
Publicly describe space polices and plans in a transparent manner

INTEROPERABILITY
Use open international standards and support interoperability

EMERGENCY ASSISTANCE
Provide emergency assistance to those in need

REGISTRATION OF SPACE OBJECTS
Register space activities to avoid harmful interference

RELEASE OF SCIENTIFIC DATA
Make data public, ensuring all benefit from space exploration

SPACE RESOURCES
Use space resources under the auspices of the Outer Space Treaty

DECONFLICTION OF ACTIVITIES
Provide information about lunar activities to inform scope of ‘safety zones’

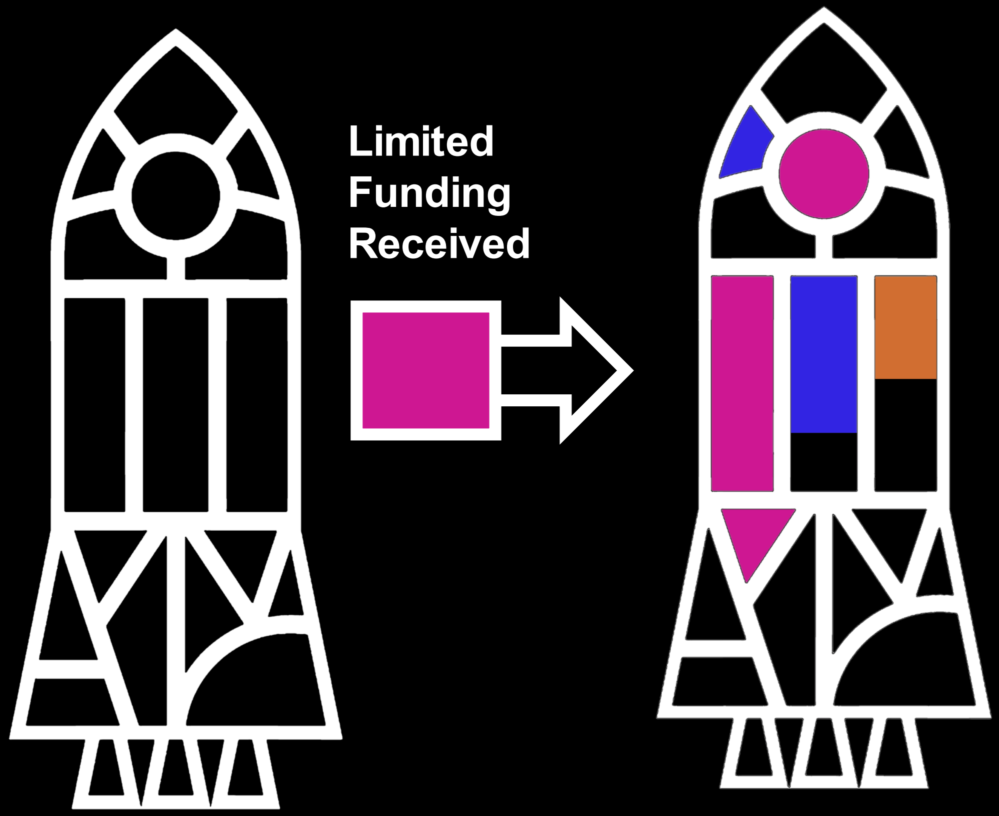
ORBITAL DEBRIS AND SPACECRAFT DISPOSAL
Plan for the mitigation of orbital debris

Historical Context: Moon to Mars Plan

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

Architecture Approach

An Evolutionary Architecture Process

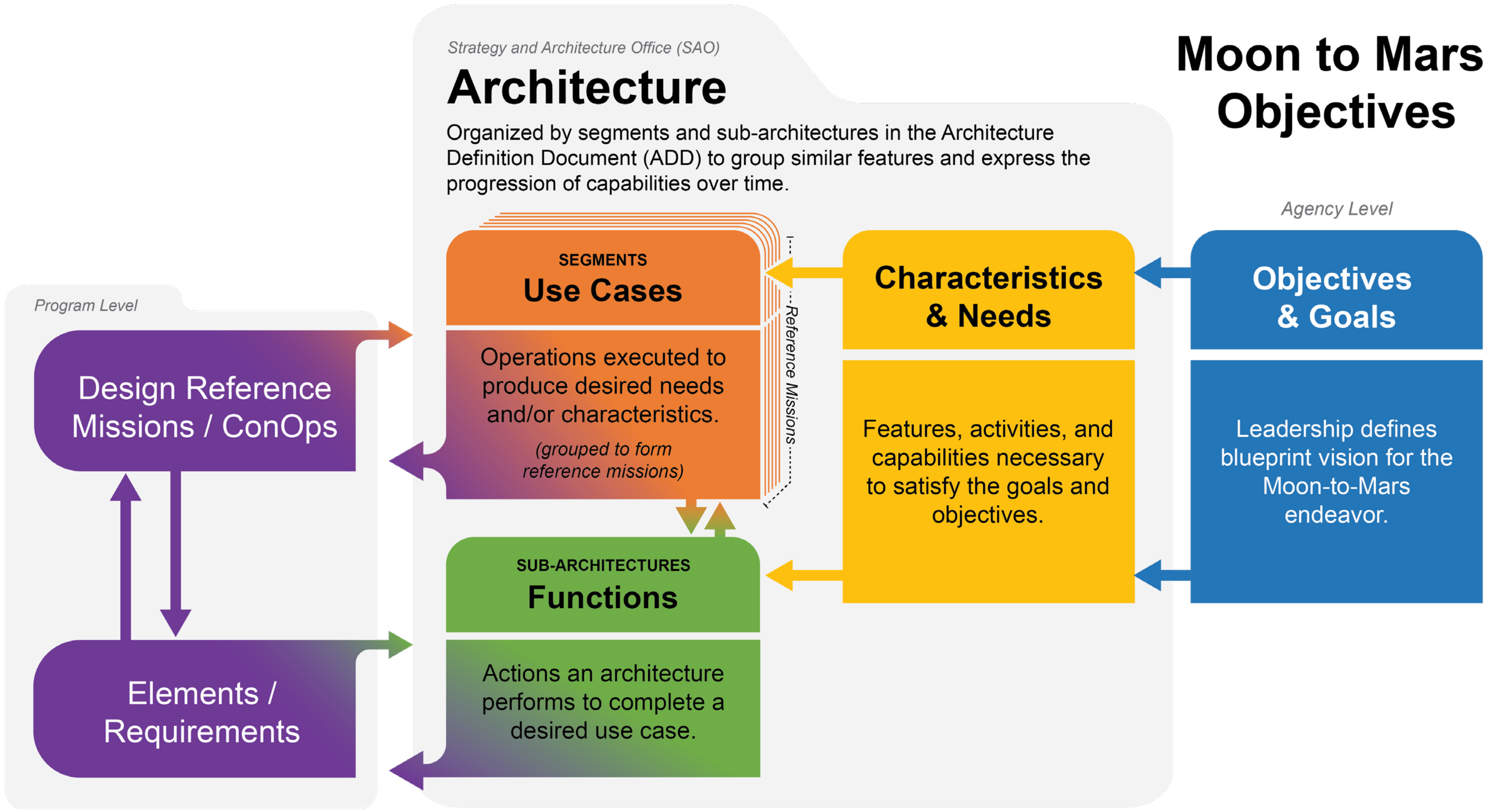
Formulating an Architecture and Exploration Strategy Based on Objectives

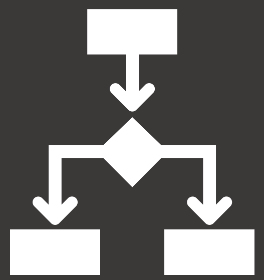
TRACEABILITY
Decomposition of Blueprint Objectives to executing Architecture elements

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





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

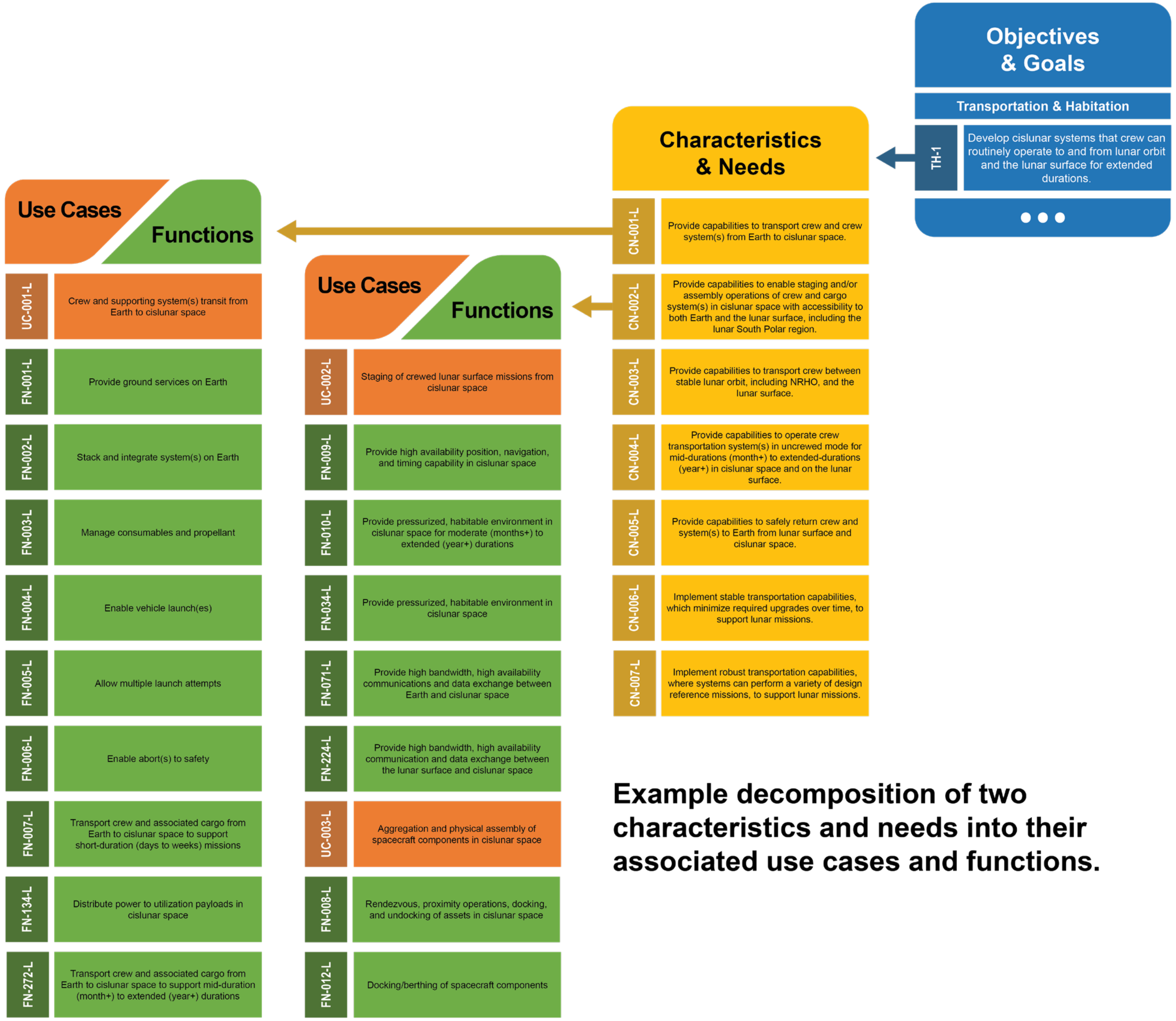
Architecting from the Right

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.

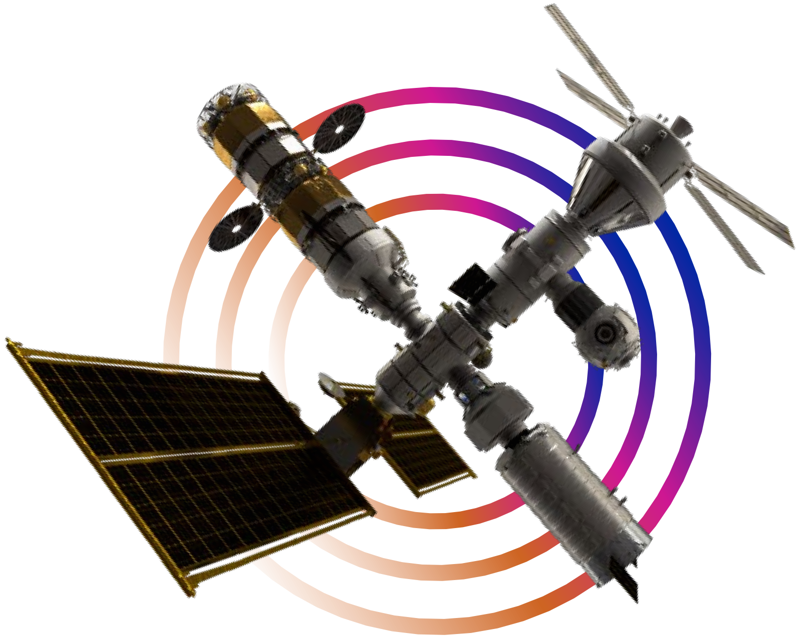
Use Case: An operation that would be executed to meet desired characteristics and needs.

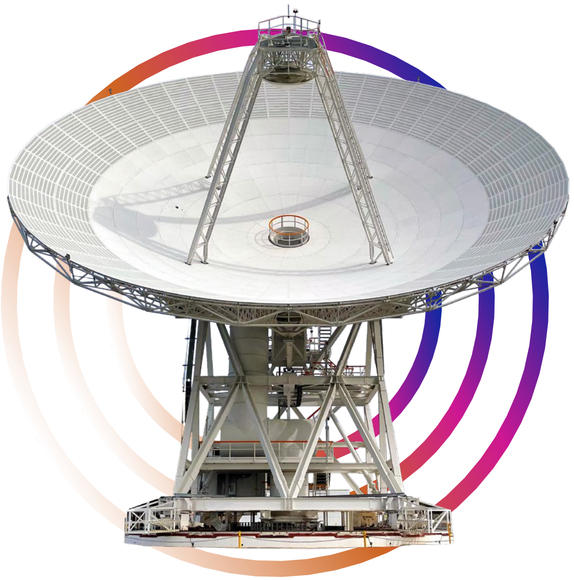
Function: One of the actions necessary to satisfy a use case.

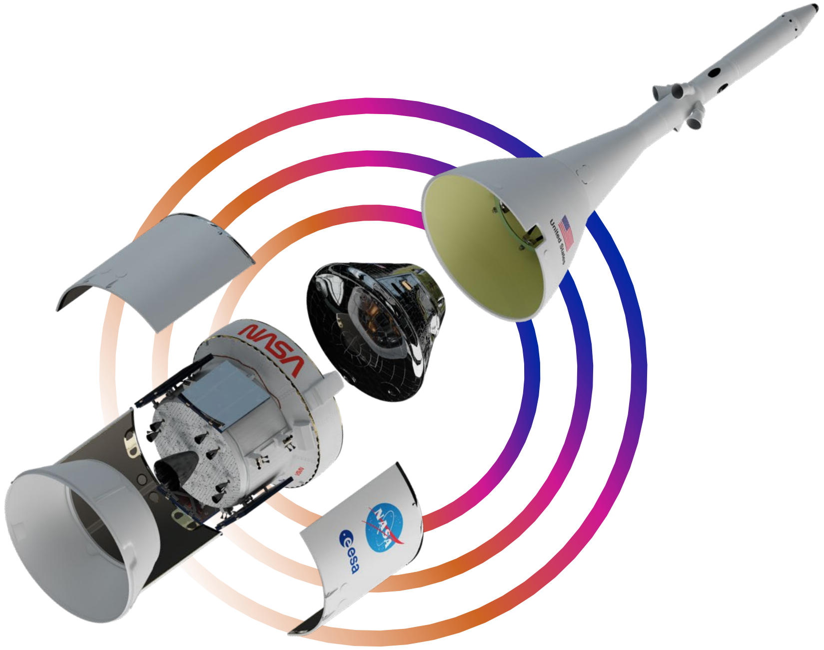


Example decomposition of two characteristics and needs into their associated use cases and functions.

Architecture Components





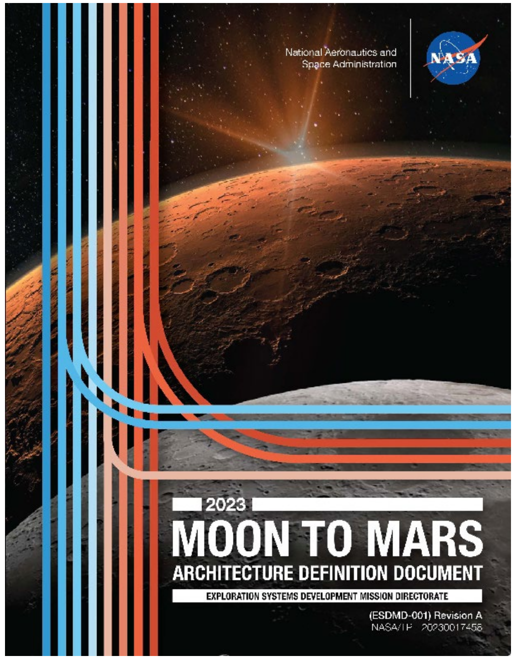


Segments
A portion of the architecture that integrates sub-architectures and progressively increases in complexity and objective satisfaction.

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

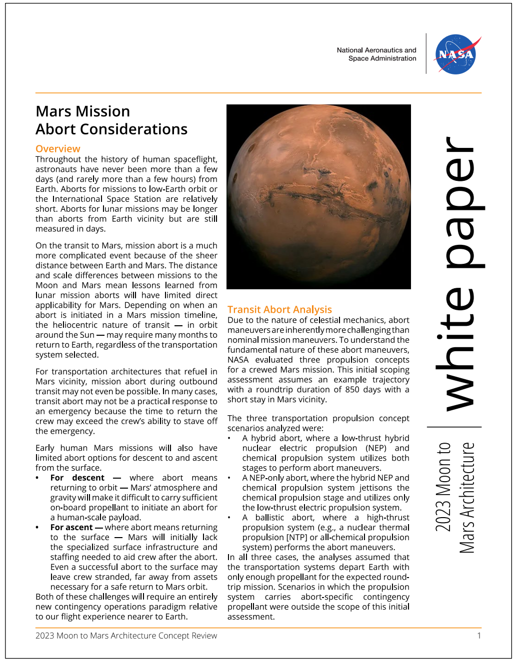
Elements
A notional exploration system that enables a set of functions.

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
(13 Total)

- Analytical Capabilities In-situ vs. Returned
- Safe and Precise Landing at Lunar Sites
- Lunar Site Selection
- Lunar Communications and Navigation Architecture
- Lunar Logistics Drivers and Needs
- Surface EVA Architectural Drivers
- Mars Mission Abort Considerations
- Mars Communications Disruption and Delay
- Mars Surface Power Generation
- Mars Priority Decisions
- Round Trip Mars Mission Mass Challenges
- Human Health and Performance for Mars Missions
- Exploration Lessons Learned from the Space Station

Suggestion from 2023 Architecture Workshops
White paper added after ACR23 Concurrence

Moon to Mars
Architecture Products
www.nasa.gov/architecture

Architecture 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.

Future Segments

Humans to Mars

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 2023

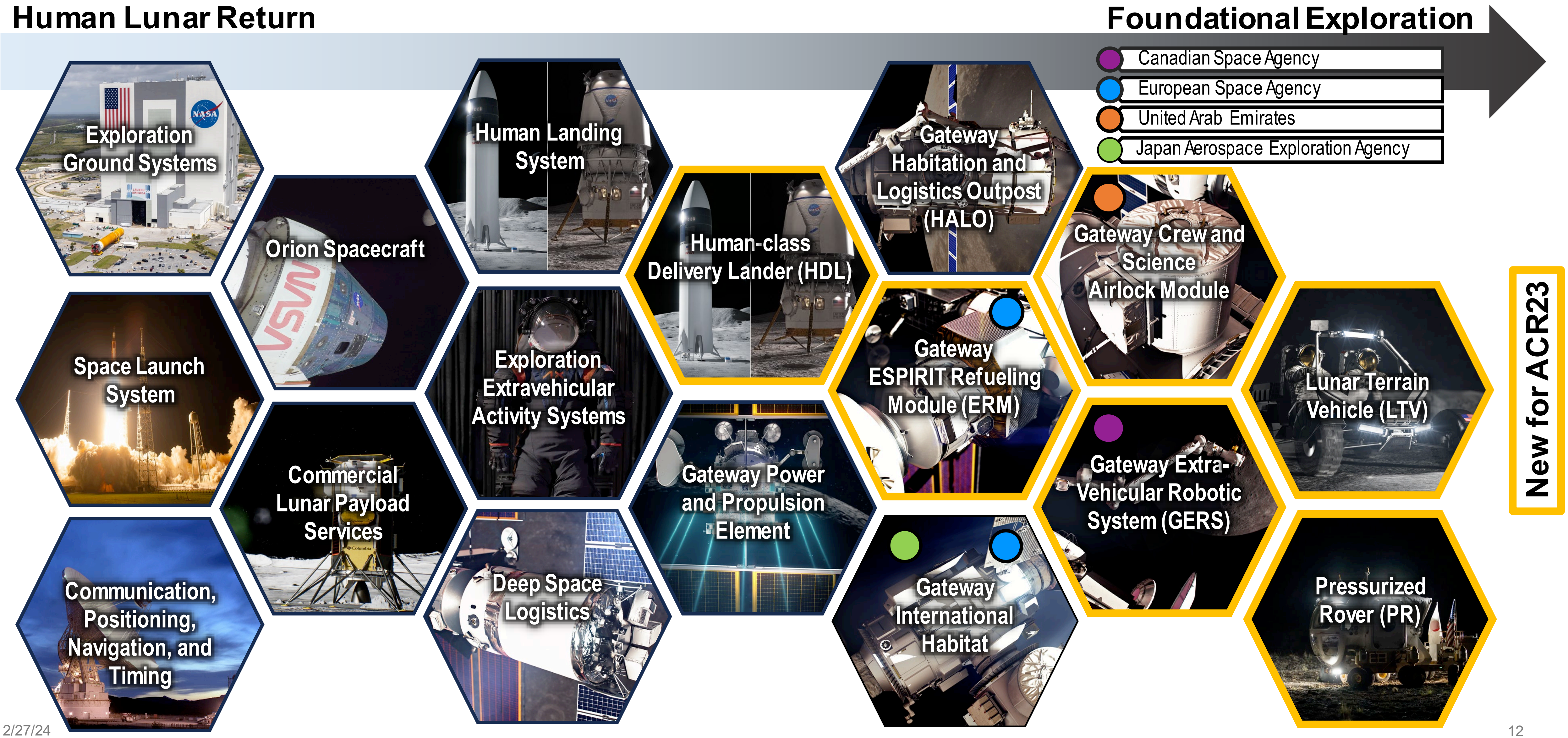
Data Systems and Management
transfer, distribute, receive, validate, secure, decode, format, compile, and process data and commands.

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.

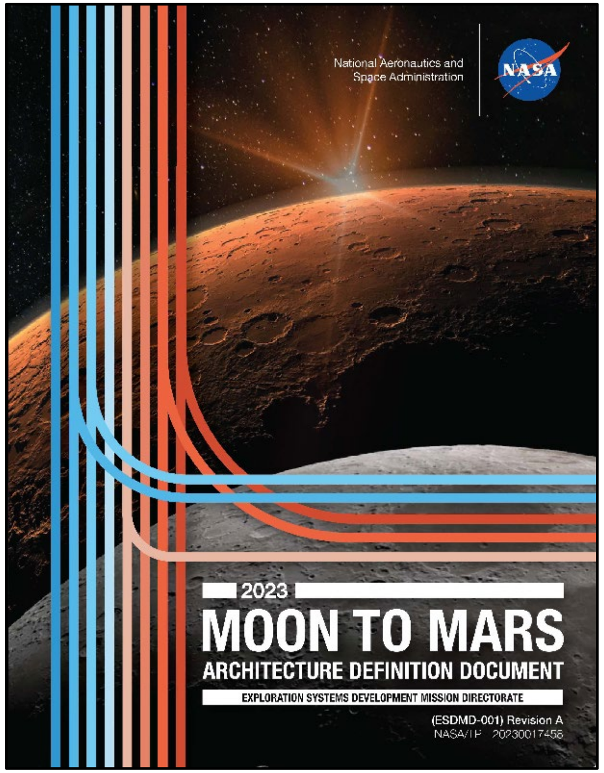
Autonomous Systems and Robotics
employ software and hardware to assist the crew and operate during uncrewed periods.

Elements



Human Lunar Return
Foundational Exploration
Canadian Space Agency
European Space Agency
United Arab Emirates
Japan Aerospace Exploration Agency
Exploration Ground Systems
Orion Spacecraft
Human Landing System
Human-class Delivery Lander (HDL)
Gateway Habitation and Logistics Outpost (HALO)
Gateway Crew and Science Airlock Module
Space Launch System
Exploration Extravehicular Activity Systems
Gateway ESPIRIT Refueling Module (ERM)
Lunar Terrain Vehicle (LTV)
Commercial Lunar Payload Services
Gateway Power and Propulsion Element
Gateway Extra-Vehicular Robotic System (GERS)
Communication, Positioning, Navigation, and Timing
Deep Space Logistics
Gateway International Habitat
Pressurized Rover (PR)
New for ACR23

Enabling Informed Exploration Partnerships



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 Definition Document (ADD)** Revision A

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

Integrated Approach to Partnership Development

- ESDMD established a routine process to support transparent communication in developing partnerships
- Leverage the Moon to Mars ADD to identify where partner strategic interests or capabilities align with architecture needs
- Process applied to large elements or systems that need to integrate across programs and projects and not intended for small payloads, utilization, etc.
- Milestone based to establish:
  - Architecture Use Cases & Functions
  - Preliminary Concept(s)
  - Potential International Partner Contributions or early Industry Engagement
  - Schedule, Planning, and Pre-project Team

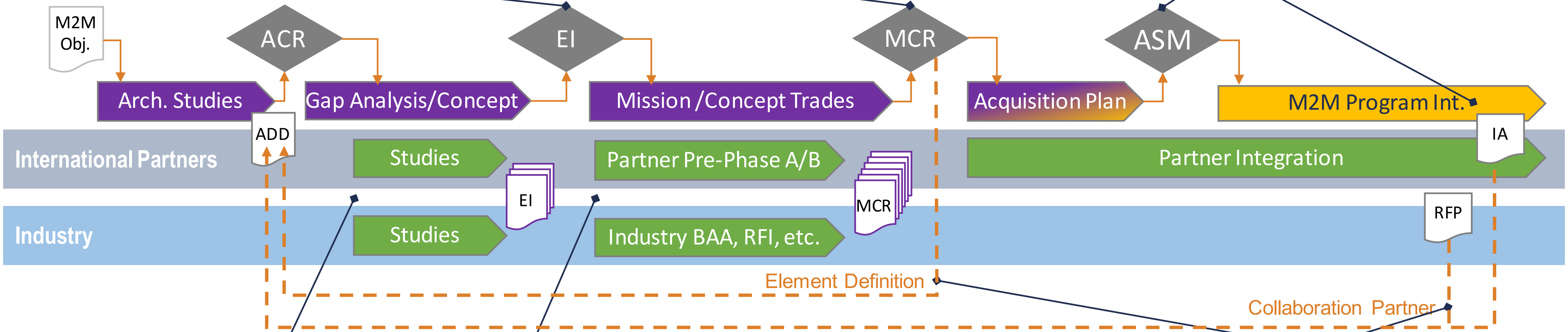
Credit: NASA

ESDMD Pre-Formulation for Partners

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 & Architecture Office | ESDMD Moon to Mars Program | Collaboration Partner

Progress Under ACR Approach


image credit: Toyota/JAXA


image credit: NASA


image credit: NASA

TRACEABILITY

Decomposition of Blueprint Objectives to executing Architecture elements

- ✓ 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

ARCHITECTURE FRAMEWORK

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

- ✓ 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

Clear communication and review integration paths for stakeholders

- ✓ 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

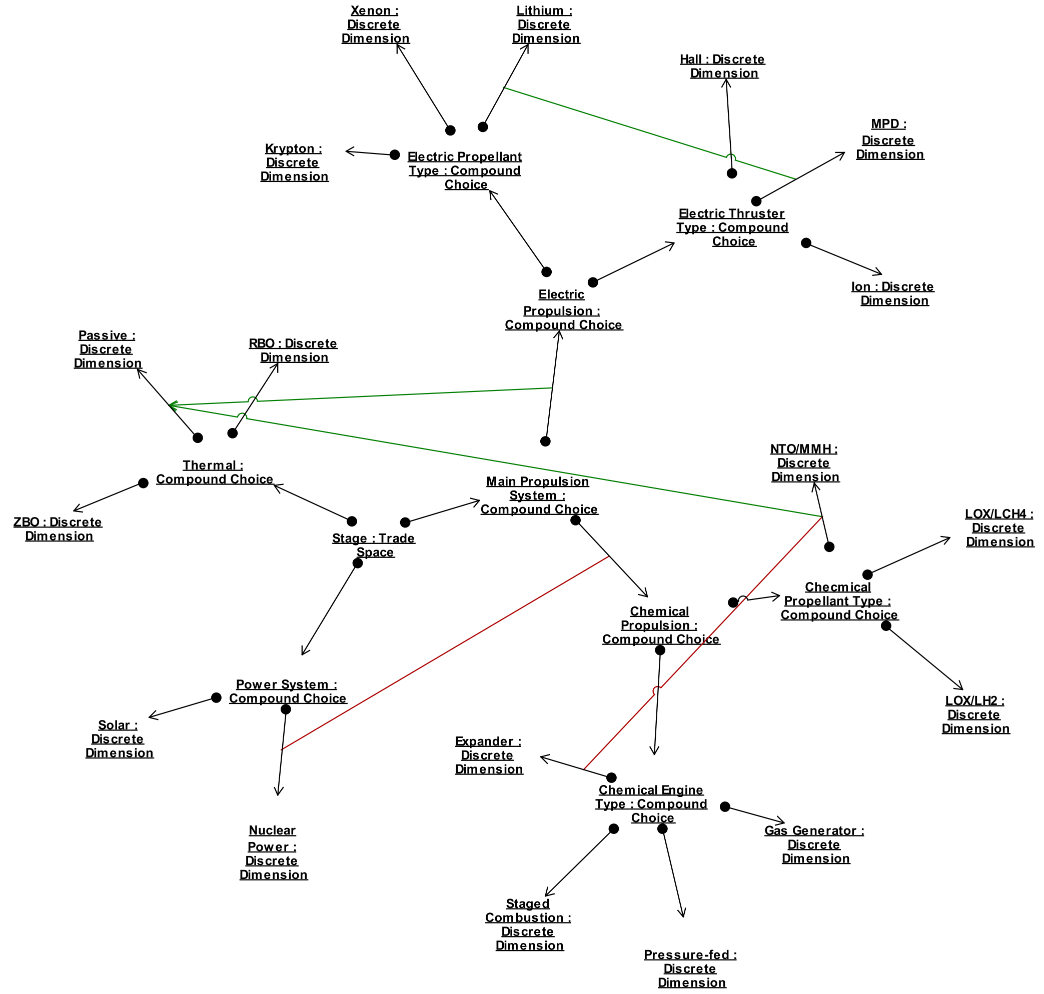
Architecture Progress Beyond the Moon

Mars Decision Modeling

NASA is developing a decision modeling process and tools to support planning for the Humans to Mars segment.

- Preliminary analysis identified nearly 100 key architecture decisions.
- NASA is currently refining the catalog of needed decisions and modeling in a decision trade space that maps linkages between decisions.

Seven key decisions recommended for priority analysis in the 2024 analysis cycle.



Priority Mars Decisions

In 2024, NASA has begun 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.

COLOR KEY

- WHY — WE WILL GO
- WHEN — WE WILL GO
- WHAT — WE WILL DO THERE
- WHO — WILL BE INVOLVED
- HOW — WE WILL GET THERE AND BACK

- INITIAL HUMAN MARS SEGMENT CADENCE
- INITIAL HUMAN MARS SEGMENT TARGET STATE
- NUMBER OF CREW TO MARS VICINITY
- MARS SCIENCE PRIORITIES
- MARS SURFACE POWER GENERATION TECH
- NUMBER OF CREW TO MARS SURFACE
- MARS LOSS OF CREW RISK POSTURE