National Aeronautics and Space Administration

NASA's Moon to Mars Architecture Updates

NASA Advisory Council

Nujoud Merancy
Deputy Associate Administrator
Strategy and Architecture

STRATEGY AND ARCHITECTURE OFFICE
EXPLORATION SYSTEMS DEVELOPMENT MISSION DIRECTORATE

NASA Headquarters – April 26, 2024

Agenda

2024 Architecture Workshops

Pre-Formulation Process

Mars Priority Decisions

2024 SAO Priorities

Credit: NASA

2024 Architecture Workshops

Credit: NASA/Keegan Barber

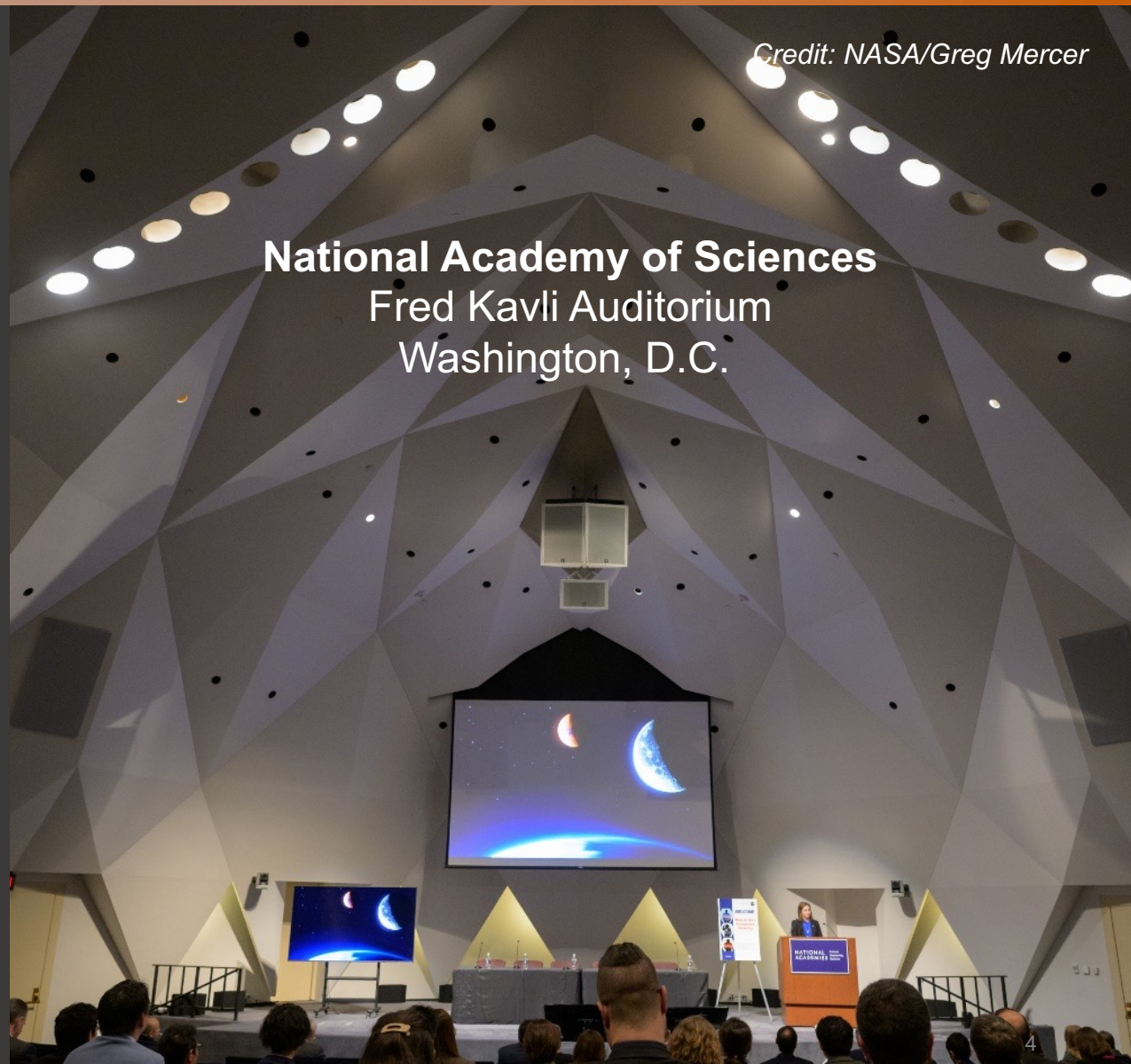
2024 Architecture Workshops

February 20–22 – Washington, DC

The workshops remain a great forum for **receiving feedback** from stakeholders and **answering questions**.

Key discussion areas included next steps in the process for **technology and systems definitions**.

NASA continues to engage **partners of all types**: emerging and established space agencies, small and large companies, and academia and the science community.



International Partner

Credit: NASA/Greg Mercer

National Academy of Sciences
February 20, 2024

50 attendees *from* **18** countries

Key Themes:

- The community aspect of the day was integral.
- Partners want to engage domestic stakeholders and build support for space.
- Some emerging space agencies are struggling to identify where they can engage in the ADD process.
- There is confusion between the Artemis Accords, Artemis campaign, and the Moon to Mars Architecture.

Industry and Academia

140 attendees *from* **110** organizations

85 companies, 25 academic institutions

Key Themes:

- Communication has improved.
- Stakeholders appreciate transparency regarding decisions and decision-making.
- Industry desires more clarity on investment priorities.
- Industry and academia would appreciate opportunities to engage in the architecture process earlier.

Subscribe to Updates

Subscribe to the Moon to Mars Architecture email list at the link below:

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

Credit: NASA

Pre-Formulation Process

Credit: NASA

Element Initiation Purpose

- Overt integration point based for an identified gap in the Moon to Mars Architecture coordinated with partner mission directorates.
- Indicates a commitment to formulate element with approval at a Directorate Program Management Council (DPMC).
- Affirms strategic alignment and coordination of architecture need and implies *intent* to apply necessary resources for element formulation.
- Applied to large elements or systems that need to integrate across programs and projects and not intended for small payloads, utilization, etc.
- Element initiation may include:
  - Architecture Use Cases & Functions
  - A Preliminary Concept
  - Potential International Partner Contributions
  - Schedule, Planning, and Pre-project Team

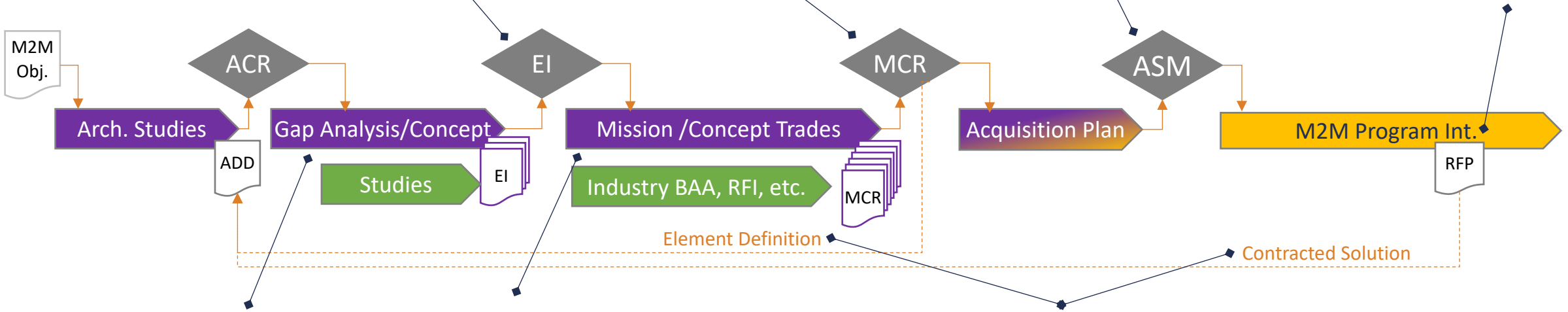
Credit: NASA

ESDMD Pre-Formulation for Industry

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 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

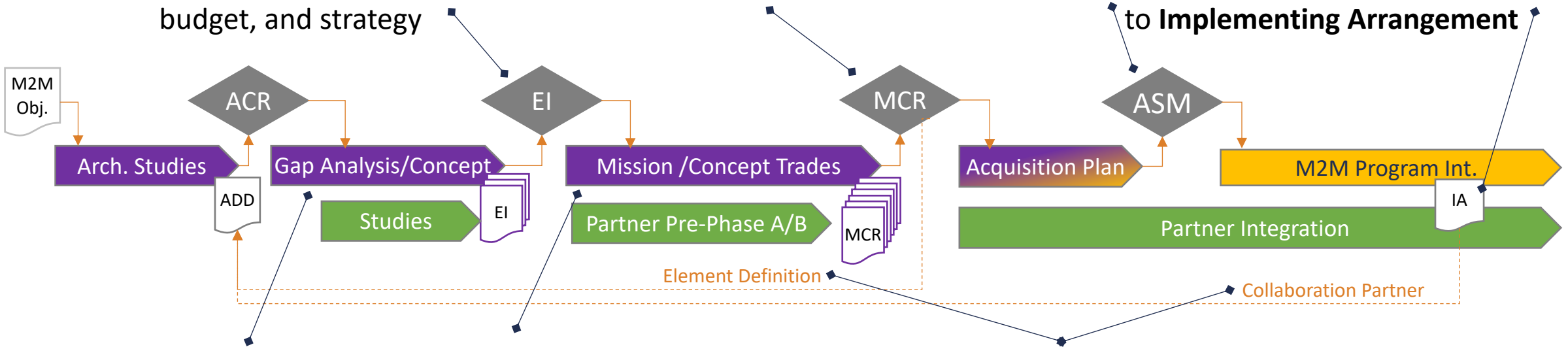
Document(s) | NASA Milestone | ESDMD Strategy & Architecture Office | ESDMD Moon to Mars Program | Collaboration Partner

ESDMD Pre-Formulation for International 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**



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Upcoming Pre-Formulation Milestones

Pre-Phase A Tailored 7120 Approach				
Element Initiation	Decision Framing Meeting	Mission Concept Review	Acquisition Strategy Meeting	Key Decision Point A
EI	**DFM**	**MCR**	**ASM**	**KDP-A**

- **Forecast elements for FY24-25 are assessed to inform PPBE26 planning. Element Initiations will only occur if assessed as supportable with budget and programmatic planning.**
- Elements must be approved through MCR to be formally included in the Architecture Concept Review (ACR) and Architecture Definition Document (ADD) update.

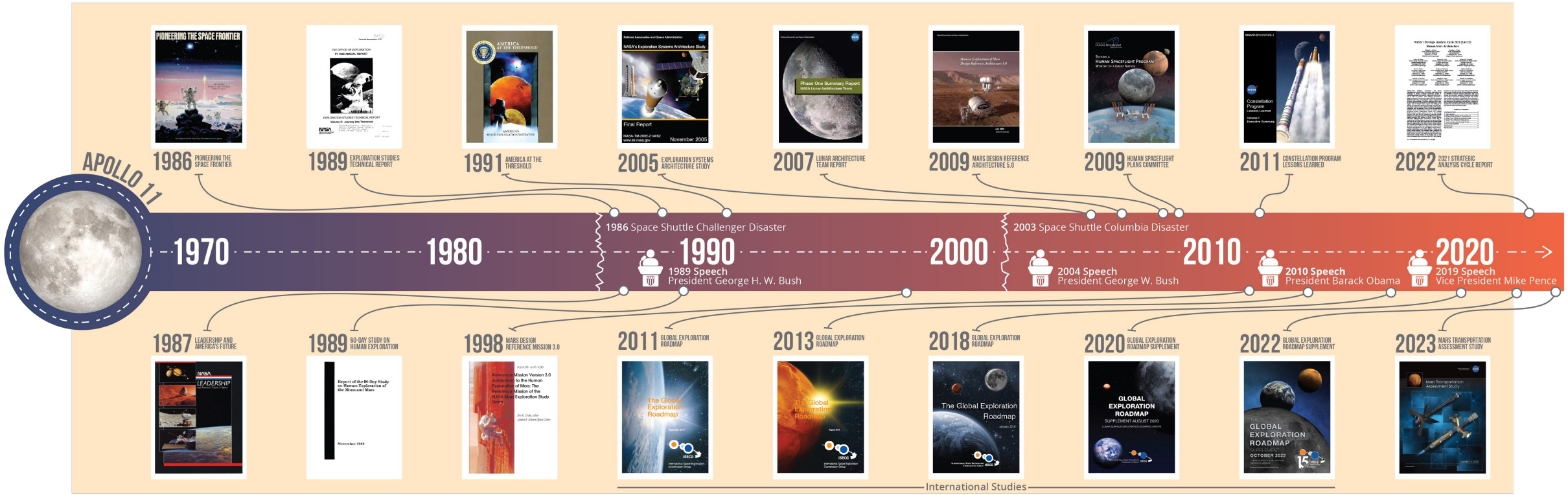
	FY24				FY25
Element	**QTR1**	**QTR2**	**QTR3**	**QTR4**	
Initial Surface Habitation	✓ **EI** (1/10)	✓ **DFM** (1/18) ✓ **MCR Phase 1** (1/31)	• **MCR Phase 1 Closeout** (04/29)	• **MDR (ASI)** (July) • **MCR Phase 2** (Sept)	• **ASM**
Small Cargo Lander	✓ **EI** (11/27)	✓ **DFM** (4/4)	• **MCR Board** (Jun/Jul)	• **ASM** (TBD)	• **Payload EI** • **Payload MCR**
Utility Rover			• **EI** (Jun)	• **DFM** (TBD)	• **MCR** • **ASM**

Mars Priority Decisions

Credit: NASA/JPL-Caltech/ASU/MSSS

To Send Humans to Mars…

WE NEED TO MOVE BEYOND STUDIES…



…AND START MAKING DECISIONS

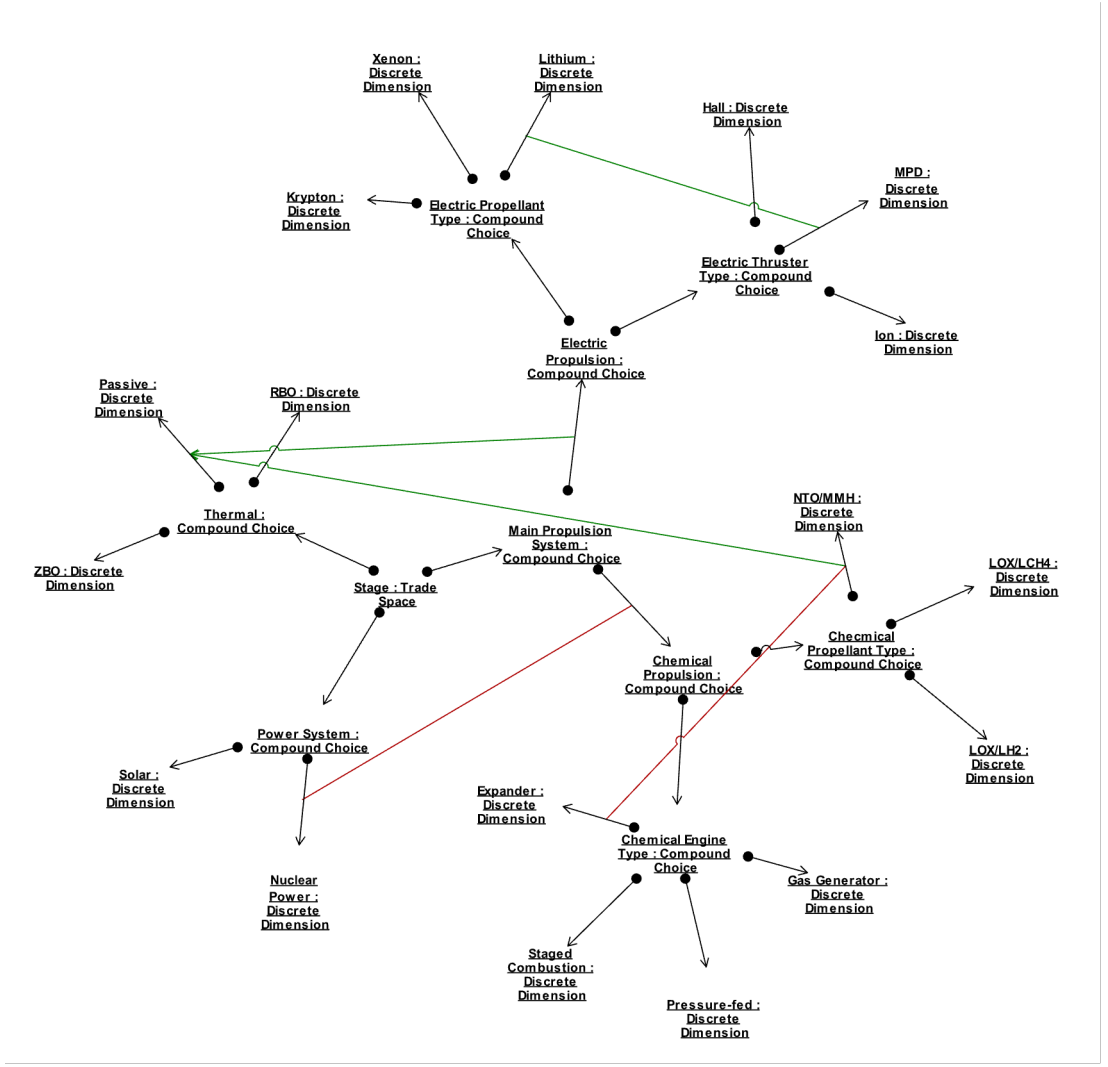
Decision Time Criticality

Mars Decision Modeling

NASA is developing a decision modeling process and tools.

- 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.

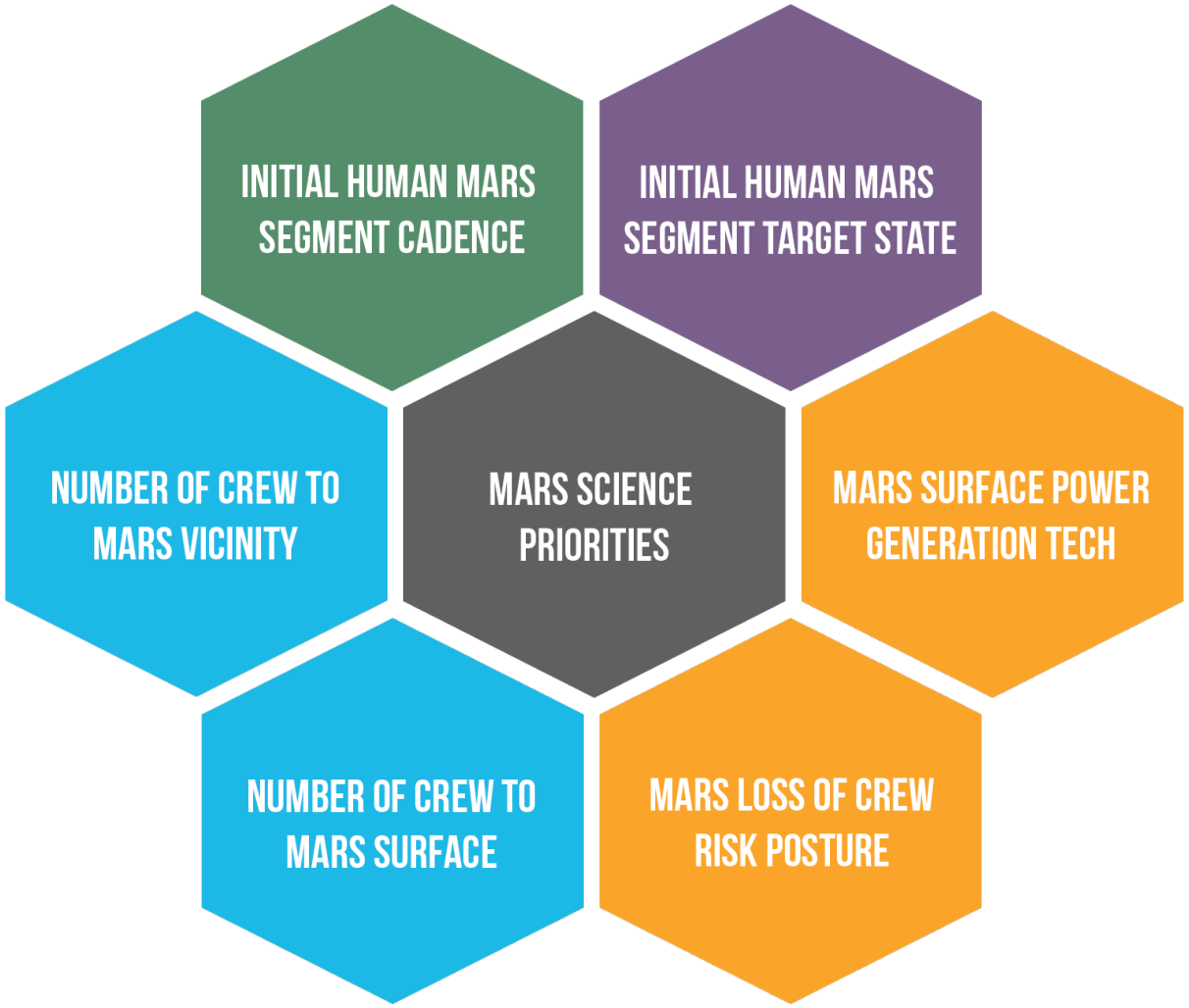
Seven key decisions recommended for priority analysis in the 2024 analysis cycle.



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.



White Paper

National Aeronautics and Space Administration

Key Mars Architecture Decisions

white paper

2023 Moon to Mars Architecture

Introduction

As noted in the 2022 Architecture Concept Review Systems Analysis of Architecture Drivers white paper, exploration architectures are heavily influenced by the order in which driving questions are answered. Decisions in one part of the architecture will ripple through other parts of the architecture and beyond, often in ways that are not intuitively obvious.

Making one key decision before fully understanding the cascading impacts of that decision across the end-to-end architecture can limit the architecture's flexibility or utility. The essential question is: of all the important decisions to be made, which should be decided first?

The practical utility of this approach is to understand which decisions lay in the critical path of others. To make good choices, it is critical to visualize and manage the complex web of interrelated decisions and their flow-down impacts. This approach allows for deliberate and informed progress.

Ensuring the flow-down impacts of far-reaching decisions are carefully traced, assessed, and weighed will help NASA make lasting decisions that have the most flexibility and value. This is a critical factor in the effort as once these and other priority decisions are made they have lasting impact on the architecture. Subsequent changes will be costly in both time and money given the long timelines for development of new human capabilities (5 to 15 years, similar to aircraft).

This white paper describes the initial set of human Mars decisions that the agency has identified as high-priority architectural drivers.

Mapping Key Architecture Decisions

A "key" architecture decision is defined as a decision whose outcome so profoundly influences the architecture that it requires very high-level review. For example, deciding how many crew members an architecture must accommodate influences virtually every aspect of the architecture. It requires high-level consideration and consensus between multiple programs and projects.

An example at the other end of the spectrum is deciding handrail color or style. Even though the decision may affect many elements, it is best categorized as an engineering decision that will not require the same level of scrutiny.

NASA architecture teams have developed a systems engineering-driven process to:

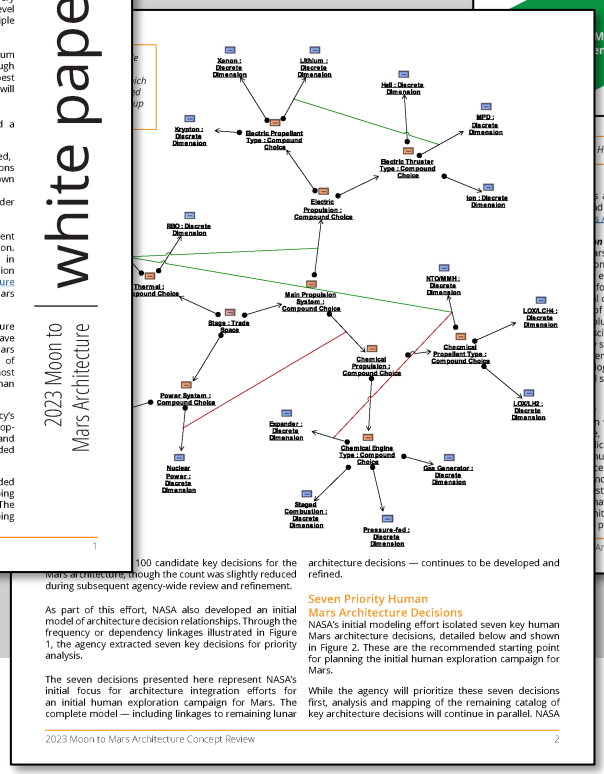
1. identify key architecture decisions needed,
2. determine relationships between decisions (including dependencies and flow-down impacts),
3. and develop a recommended logical order in which to make these decisions.

NASA is developing a model-based environment to manage this complex web of information. The process and rationale are described in the Exploration Systems Development Mission Directorate's Moon to Mars Architecture Definition Document, Section 2.3.1 Key Mars Architecture Decision Drivers.

To develop the catalog of key Mars architecture decisions, NASA subject matter experts have begun a bottom-up review of heritage Mars architecture studies. Analyzing decades of documents, these experts identified the most influential factors in designing the initial human exploration campaign for Mars.

Next, they began decomposing the agency's blueprint objectives for exploration using a top-down approach. This resulted in use cases and functions that can then be mapped to needed architecture decisions.

Together, these two approaches provided more thorough insight, simultaneously helping refine objectives, uses cases, and functions. The resulting initial analysis — which is still ongoing



100 candidate key decisions for the Mars architecture, though the count was slightly reduced during subsequent agency-wide review and refinement.

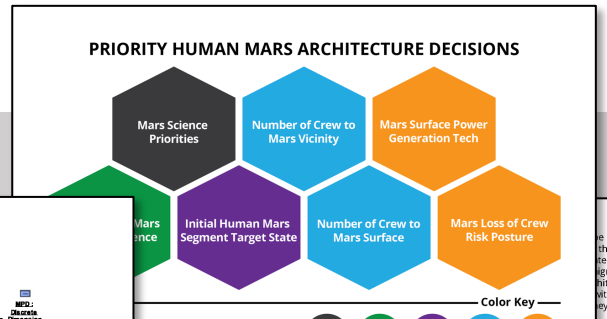
As part of this effort, NASA also developed an initial model of architecture decision relationships. Through the frequency or dependency linkages illustrated in Figure 1, the agency extracted seven key decisions for priority analysis.

The seven decisions presented here represent NASA's initial focus for architecture integration efforts for an initial human exploration campaign for Mars. The complete model — including linkages to remaining lunar architecture decisions — continues to be developed and refined.

Seven Priority Human Mars Architecture Decisions

NASA's initial modeling effort isolated seven key human Mars architecture decisions, detailed below and shown in Figure 2. These are the recommended starting point for planning the initial human exploration campaign for Mars.

While the agency will prioritize these seven decisions first, analysis and mapping of the remaining catalog of key architecture decisions will continue in parallel. NASA



Human Mars Architecture Decisions

and results at annual Architecture
document them in yearly revisions
Architecture Definition Document.

Science Priorities

strategy identifies science as one
on which the agency's blueprint for
exploration throughout the solar
foundational aspiration, it can trigger
capability and inspiration and build
human exploration upon benefit
blueprint identifies objectives in five
ciplines:
science
ence
logical science
science

portion of these objectives will
virtually all aspects of the mission,
dedicated payload mass delivered
licated payload mass returned from
unication throughput, and power.
conducted on the surface of Mars
nd of the human transportation and
stems in consideration through the
ave the greatest impact on the scope
itecture. Therefore, science priorities
possible attention.

Recent history demonstrates the importance of making this decision earlier rather than later. NASA's Artemis exploration campaign was directed to establish initial operations in the lunar South Pole region, with a focus on acquiring volatile resources thought to be found there. That limited focus may be incompatible with high-priority lunar science objectives uniquely addressed at other locations.

Establishing foundational science priorities built on broad input from the science community early in the architecture definition process may help mitigate disruption or delay to implementation of an initial human exploration campaign for Mars.

Initial Human Mars Segment Target State

A decision about the vision — or "target state" — for NASA's initial human exploration campaign for Mars is fundamental to developing an architecture that enables that vision. Architecture elements and concepts of operation will vary greatly depending on the desired end state.

For example, a series of focused science exploration missions to different landing sites would favor one architecture. Establishing a permanent, fixed base from which astronauts could conduct many surface missions supporting diverse and evolving exploration activities would favor a very different architecture.

of this key decision is limited to
the initial Humans to Mars campaign
te decision will define subsequent
ign segments. The ideal end state for
hitecture that meets NASA's highest
ith flexibility to expand to meet new
ey emerge.

Segment Mission Cadence

r human exploration of Mars will
for "architecting from the right," but
ain:
ue missions are necessary during the
(These could include robotic science,
precursor demonstration missions.)
crewed orbital or fly-by precursor
s, or will the first crewed mission land
f the Red Planet?
resources are needed to balance the
l Mars missions with ongoing near-
surface operations?

exploration spaceflight programs have
aign of test flights, demonstrations,
s that build up to a desired end state.
gradual buildups can aid stakeholders
g and investment forecasting for the
ation campaign for Mars.

isk Posture

projects typically establish a loss of
e, but human spaceflight programs
n understanding of the overall loss of
ew risk posture is a useful guidepost
ormed architecture decisions. For
o prioritize technologies that enable
uman missions as one means to
and performance concerns.

becomes more defined, a formal
eporting threshold will be established
ference mission to achieve human
However, establishing a risk posture
e architecture development process
ptions and reworks during the later

propellant management, including Mars surface infrastructure needs). It also helps establish a lower limit for crew availability to perform systems monitoring, maintenance and troubleshooting; science and utilization (particularly during surface extra-vehicular activities); and inspirational engagements with the public. The unique communications challenges at Mars — an environment where real-time communication with Earth is not possible — also have implications for task management and contingency responsiveness of a given crew complement during critical operations.

Number of Crew to Mars Vicinity per Mission

A companion to the Mars surface crew complement decision is deciding the total crew complement to Mars vicinity. This decision will have some similar co
to defining crew complement to the su
some unique constraint drivers.

The number of crew to the vicinity o
have implications for Earth ascent
transit vehicle habitable volume, c
sizing, and logistics manifesting. Th
influence Mars capture and parki
with flow-down implications for
and contingency response. For ex
architectures, some crew might r
while others descend and work on t
the crew's physical availability to per

Mars Surface per Mission

Crew complement is the most common study constraint across all architectures and elements. Crew complement selection has implications for habitable vehicle and element volume, life support system design, and crew support systems for health and performance (such as medical, exercise, and food systems). It also has ramifications for logistics needs (including science and mission utilization, food, clothing, medical supplies, etc.), which inform campaign launches and cadences.

Operationally, crew complement helps establish an upper limit for Mars entry, descent, landing, and ascent vehicle sizing (with flow-down impacts to ascent

human exploration campaign for Mars. As the bottom-up and top-down identification processes continue, additional needed decisions may be identified. Linkages to decisions for lunar exploration campaign segments that have not yet been made will be developed, analyzed, and prioritized. This insight will enable an informed and methodical approach to address the needs of the multi-decadal vision that is the Moon to Mars Objectives.

Conclusions

Developing architectures to enable human exploration of the solar system will require hundreds of individual decisions by many different decision authorities across the agency. All of these decisions will be important, but
cisions that so profoundly influences
nd architecture as to warrant the
tiny. Ensuring the integrated impacts
sions are carefully traced, assessed,
lp decision authorities make lasting
resistant to implementation delays,
relitigation.

ical process, NASA has identified a
architecture decisions to start with.
y will continue to define and map
ey decisions, reporting progress at
Concept Reviews and updating the
tion Document with architecture
e made.

Future Work

During upcoming strategic analysis cyc
architecture teams will continue to refine the modeling environment, assess various options within the solution space, and prioritize remaining decisions for the initial

Progress Under ACR Approach

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

2024 SAO Priorities

- Integrate architectural decomposition process within other NASA mission directorates.
- Develop NASA's lunar surface exploration strategy.
- Deliver one Mars priority decision package for consideration by decisionmakers.
- Demonstrate element handoff from SAO to the Moon to Mars Program Office (M2MPO)
- Consolidate and document an architecture-derived list of prioritized technology gaps.
- Establish and integrate Model-Based Systems Engineering (MBSE) tools throughout the architecture process.

nasa.gov/architecture

Moon to Mars Architecture, Objectives, White Papers and More