



National Aeronautics and
Space Administration



A Science Strategy for the Human Exploration of Mars: Task Overview

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NAS Open Meeting
April 25, 2024

Agenda

01 Study Request
and Background

02 Key Mars
Architecture
Decisions

03 Key Definitions

04 Task Descriptions
and Thoughts

05 Additional
Considerations



Study Request and Background

- Associate Administrator for Science Nicky Fox and Associate Administrator for Exploration Systems Development Jim Free request the National Academies of Sciences, Engineering, and Medicine to address the topic:

A Science Strategy for the Human Exploration of Mars

- NASA requests that a consensus study report be produced.

Study Request and Background

- Expected Use
 - “Mars Science Priorities” is an anchoring decision that will influence all subsequent architecture decisions
 - This report will inform decisions on human exploration architecture capabilities that will enable NASA to achieve identified science objectives during the initial human exploration campaign to Mars
- Goal for this requested study: Define the highest priority science for humans to address at Mars and consider how those priorities can be addressed in the first three human-scale missions to Mars
 - Leverage previously completed community studies and analyses as much as warranted
 - Implementation of the identified science objectives is not in the scope of this study
- Why is this study needed when we have other studies?
 - Consensus on prioritization of objectives across science disciplines
 - Provide information we need to make the “Mars Science Priorities” decision

Three astronauts in silhouette are shown from the waist up, facing away from the viewer. The astronaut on the left is overlaid with a blue-toned image of a Mars landscape featuring a rocket launch. The middle astronaut is overlaid with a black-toned image of a lunar or Martian surface with a rover. The astronaut on the right is overlaid with a red-toned image of a Mars landscape with a rover. A dark blue horizontal bar is centered across the image, containing the title text.

Key Mars Architecture Decisions

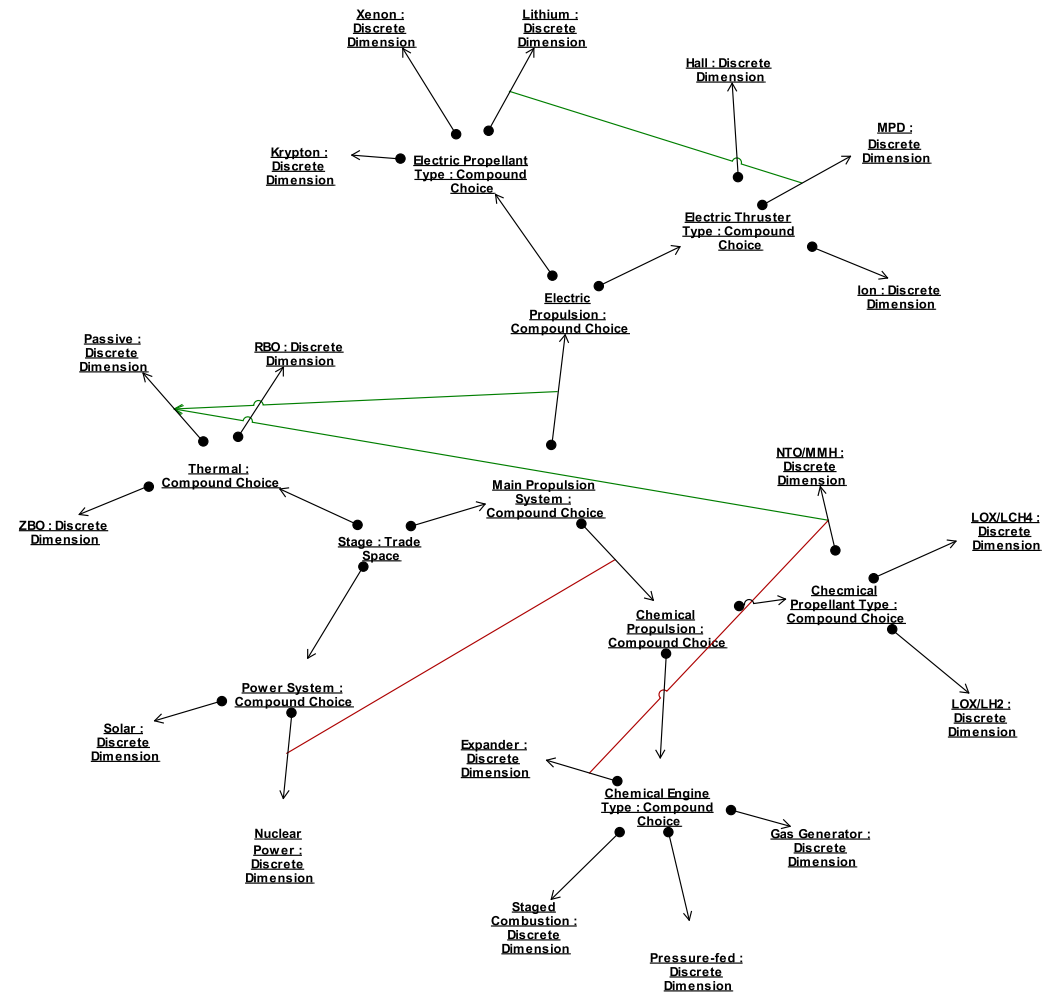
Decision Space Modeling



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.*

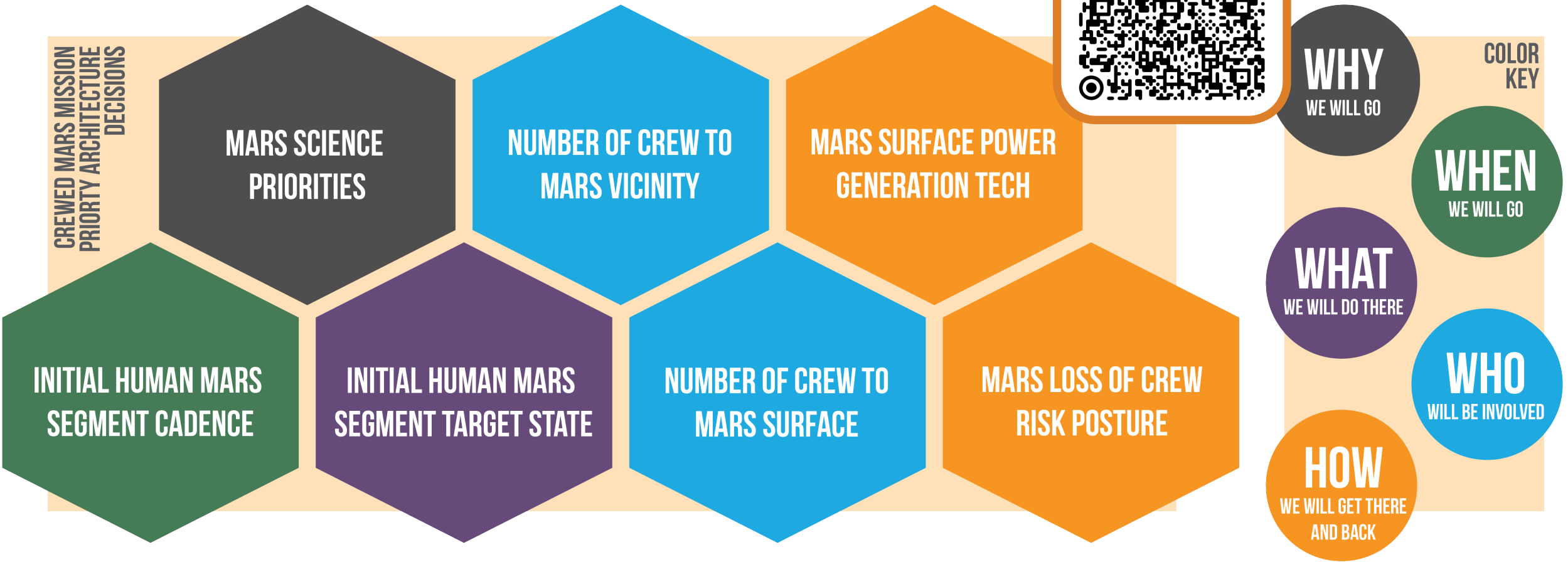
Seven key decisions recommended for priority analysis in the 2024 analysis cycle.



Decision Time Criticality



Mars Priority Architecture Decisions



Candidate Key Mars Architecture Decision

Science Priorities for Initial Human Mars Segment



Needed Decision Outcome:

Identify the highest science priorities *for the initial human Mars segment*

— *Includes both planetary and biological science priorities*

Context: Picking where before considering why may force us to revisit our how decisions



Science priorities are why and what decisions, not how (implementation) decisions — but they can anchor the how



Key Mars Architecture Decisions White Paper



Key Mars Architecture Decisions

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's 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



National Aeronautics and Space Administration

white paper

2023 Moon to Mars Architecture Concept Review

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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

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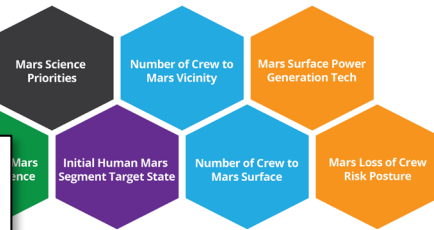
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Seven Priority Human Mars Architecture Decisions

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

PRIORITY HUMAN MARS ARCHITECTURE DECISIONS



Human Mars Architecture Decisions

Why we need it, When we need it, What we need it, Who we need it, How we need it

Results and annual Architecture Definition Document in yearly revisions

Science Priorities

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.

Architecture Concept Review

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of this key decision is limited to the initial Humans to Mars campaign. The decision will define subsequent design segments. The ideal end state for architecture that meets NASA's highest with flexibility to expand to meet new crew emerge.

Segment Mission Cade

of human exploration of Mars will for "architecting from the right," but

are necessary during the (These could include robotic science, precursor demonstration missions.)

crewed orbital or fly-by precursor, or will the first crewed mission land

resources are needed to balance the al Mars missions with ongoing near-surface operations?

Exploration spaceflight programs have

sign of test flights, demonstrations, is that build up to a desired end state, gradual buildups can aid stakeholders and investment for recasting for the

mission campaign for Mars.

Risk Posture

projects typically establish a loss of re, but human spaceflight programs in understanding of the overall loss of

low risk posture is a useful guidepost

formed architecture decisions. For

to prioritize technologies that enable

human missions as one means to

and performance concerns.

becomes more defined, a formal

reporting threshold will be established

reference mission to achieve human

however, establishing a risk posture

the architecture development process

options and reworks during the later

Mars Surface per Mission

Crew complement is the most common study constraint across all architectures and elements. Crew complement 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

2023 Moon to Mars Architecture Concept Review

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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 that so profoundly influences

and architecture as to warrant the

ity. Ensuring the integrated impacts

ions are carefully traced, assessed,

help decision authorities make lasting

resistant to implementation delays,

ly reiteration.

ical process, NASA has identified a

architecture decisions to start with,

ty will continue to define and map

key decisions, reporting progress at

Concept Reviews and updating the

Architecture Definition Document with architecture

made.

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 consequences to defining crew complement to the surface, but some unique constraint drivers.

The number of crew to the vicinity of Mars will have implications for Earth ascent transit vehicle habitable volume, crew

sizing, and logistics manifesting. The

influence Mars capture and parking

with flow-down implications for

and contingency response. For ex

architectures, some crew might v

while others descend and work on

the crew's physical availability to per

Primary Mars Surface Power Generation

The scope of human exploration is largely on the amount of energy a

will power crew life support system

element keep-alive functions, ar

maintain critical ascent vehicle prop

Solar energy has long been a reliable power applications. However, re

mission experience has brought a

Mars surface missions into sharp

given the loss of crew risk if the s

were to fail during a human ex

mission abort options.

Future Work

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

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What We Need to Make the Mars Science Priorities Decision

- Identify highest priority Mars Science Objectives among all relevant science disciplines to be addressed by humans on the surface of Mars
- Identify types of samples and Measurements needed to address Campaign Science Objectives
- Identify and prioritize several Mars Science Campaigns that would achieve a subset of the identified highest priority Mars Science Objectives
- Identify preliminary Landing Site Criteria, based on available data, that will enable Campaign Science Objectives to be met
- Identify any key Equipment needed for each Mars Science Campaign to address the identified Campaign Science Objectives

Key Definitions

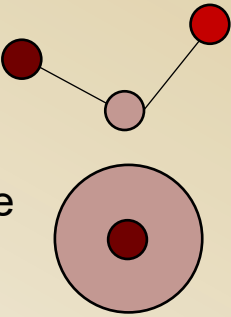


Key Definitions

- Moon to Mars Science Objectives – Agency level statements that define Moon to Mars goals more specifically and help achieve desired outcomes.
- Mars Science Objectives – Aspirational scientific endeavors that are part of a larger strategy to understand Mars. Mars Science Objectives trace to Moon to Mars Science Objectives and are broader than Campaign Science Objectives.
- Campaign Science Objectives – Focused scientific efforts that make progress towards addressing Mars Science Objectives. Campaign Science Objectives are achieved by a Mars Science Campaign.
- Measurements – Types of data needed to address one or more Campaign Science Objectives
- Equipment - Hardware, facilities, accommodations, etc. that support science and technology payloads and activities, such as storage and conditioning of sample containers, etc. but do not directly generate scientific data or samples
- Landing Site Criteria – Unique characteristics of terrain necessary to achieve site-specific science objectives. Specific landing sites are not requested as a part of this study.

Key Definitions: Mars Science Campaign

- A series of three human-class missions that achieve Campaign Science Objectives
- NASA suggests the Committee consider two different scenarios for the science campaigns:
 - 1) Three short missions (~30 sols each) with crew that may go to three different locations or to a single location of high interest; or
 - 2) Dedicate all three landings to the same location to achieve one short (~30 sol) crewed mission and one long (~300 sol) crewed mission, with the second landing in the sequence used as an uncrewed logistics delivery to enable the long stay.
- These scenarios are based on NASA's preliminary studies on constraints for human architecture to Mars
 - Systems Analysis of Architecture Drivers and Mars Transportation white papers
- These are suggestions not mandates; a different preferred sequence can be provided with accompanying justification
- Based on analyses from crew time allocations on ISS, as documented in Reference Surface Activities for Crewed Mars Mission Systems and Utilization, it is expected that ~20% of total surface time will be available for utilization activities.
- The intent is for other mission constraints (e.g., number of crew, mission cadence, mass and power constraints) to be determined based in part on the Mars Science Priorities that this report will inform



Seeds of a Science Campaign

- From Jakosky et al.'s MEPAG Tiger Team On Mars Human-Mission Science Objectives (more details will be briefed by Dr. Jakosky during this forum);

Mission Science Objectives

- Determine water chemistry, water sources, past climate over 1st Gyr of Mars history
- Search for evidence of life in water-formed rocks and mineral deposits from multiple types of habitable environments
- Examine lavas and potential pyroclastic deposits
- Establish the absolute timing of water- and volcanic-related processes
- Understand the mineral resources of Mars
- Additional science objectives achievable from other disciplines

Criteria for Landing Sites

Noachian Fe/Mg and Al clay-bearing terrain

Deep lake beds with sulfate deposits

Recent lavas

Access to Amazonian/Hesperian chloride-bearing deposits

Unique Capabilities Required

High elevation

Long traverse distances enable science (20-40 km drives)

Access in and out of deep craters (>2 km deep, ~15-20° slopes)

Converting to a Campaign:

Expand or revise from mission objectives to campaign objectives

Discuss crew role in achieving objectives

Identify relevant measurements

Identify key equipment needed to enable measurements

Prioritize amongst other campaigns

Task Descriptions and Thoughts



Task 1: Mars Science Objectives

- Identify the highest priority science objectives among all relevant science disciplines to be addressed by humans on the surface of Mars.
 - Specify how each identified science objective maps to the respective Decadal report or discipline roadmap as well as to one or more of the objectives identified in NASA's Moon to Mars Science Objectives.
 - Identify any objectives missing in NASA's Moon to Mars Objectives that are relevant to this objectives mapping task.
 - Explain how the objectives change or the priority order is altered by the number of crew or the duration of the surface mission.
 - This includes noting if crew size or surface duration are factors for prioritization.

Task 1: Mars Science Objectives

- Mars Science Objectives for human explorers should be identified first before key elements of architecture can be appropriately scoped
 - Several studies have addressed this topic already – but without clear prioritization
 - MEPAG “Tiger Team Report” MHMSOTT – Oct 2023, to be briefed here by Dr. Jakosky
 - HSO-SAG Task #3 – Jul 2015
 - Previous studies did not account for duration of surface mission or # crew available on surface
- Mars Science Objectives for potential human missions should be given clear priority
- Question: Does surface duration or # crew change the priority of any objective? (This is relevant when considering Campaign prioritization, Task 3)
 - Propose considering short duration (~30 sols) vs. long duration (~300 sols)
 - Propose considering 2 crew vs 4 crew vs 6 crew at surface
- A separate follow-on study will investigate what science objectives are highest priority for in-space phases of crewed missions to Mars.

Task 2: Samples and Measurements

- Identify types of samples and measurements needed to address science objectives.
 - Specify key measurements, if any, that need to be made before human arrival using pre-placed assets, either in orbit or on the surface.
 - Specify key measurements, if any, that must be made in situ or on the Martian surface before return needed to achieve the identified science objectives.
 - Justify why the measurements need to be made on the Martian surface rather than in terrestrial laboratories.
 - Specify key measurements, if any, that must be made in terrestrial labs on returned samples to achieve the identified science objectives.
 - Include estimates of mass of returned sample(s) required to make identified measurements, and justify why the measurements need to be made in terrestrial laboratories rather than on the Martian surface.
 - Specify whether analyses of any surface-collected samples are needed to be performed during the return trip, and justify why measurements must be made in transit rather than on the Martian surface or in terrestrial laboratories.

Task 2: Samples and Measurements

- Understanding how each science objective is best carried out is vital to successfully creating an architecture that enables success
- Measurements should be identified generically, as in:
 - Elemental composition vs mineralogy, not specific absorption bands detected
- The intent is to identify science needs, for example:
 - Field portable instrumentation vs deployed instrumentation vs surface laboratories
 - Sample return vs in situ/surface measurements

Task 3: Science Campaigns

- Identify and prioritize several science campaigns that would achieve a subset of the identified highest priority science objectives, where each campaign encompasses the first 3 landings of human-scale landers on Mars.
 - For each science campaign, describe a science “roadmap” (e.g., Science Traceability Matrix) that includes the highest priority science objective(s) addressed, secondary science objectives that are also achievable, measurements needed to address the objectives, and key assets and major equipment emplaced at each phase of the campaign (before, during, between, or after crew missions).
 - Provide a rationale for the prioritization of the identified science campaigns. Include a discussion of the crew’s role in achieving the science objectives.
 - If applicable, specify and justify any variations in the provided guidance for campaigns needed to achieve the highest priority science objectives (for example, more than 3 missions).

Task 3: Science Campaigns

- Campaign Science Objectives vs. Human Mars Science Objectives
 - It may be necessary to craft more specific Campaign Science Objectives from the broader Mars Science Objectives identified in the first task
 - These should be equivalent to typical Level 1 science objectives
 - The objectives should be:
 - Achievable by the campaign
 - Implementation agnostic
 - “Measurable” – we should be able to track progress and successful achievement of these objectives

Task 3: Science Campaigns

- A Science Campaign is defined by a “**subset**” of science objectives
 - MEPAG “Tiger Team Report”: “No single site can address all of the high-priority science goals”
 - Any realistic human Mars mission or campaign must focus on a subset of the Mars Science Objectives
 - Types of terrain on Mars suggest that certain objectives may be logically grouped together
 - Specific types of landing sites will address specific science objectives
 - Some science objectives can be done at any landing site
- Each science campaign should contain the following elements:
 - A list of primary and secondary Campaign Science Objectives to be achieved (within 3 landings; more specific than the Mars Science Objectives identified in Task 1; achievable within the Science Campaign)
 - A list of measurements needed to address those objectives (Task 2)
 - A list of key assets and major equipment (Task 4)
- How many science campaigns should be identified?
 - As many as needed to ensure highest priority campaigns are identified
 - Propose: 10-20?

Tasks 3-5: Criteria for Landing Site and Prioritization, Equipment

- For the highest priority science campaigns, identify preliminary criteria for appropriate landing sites, based on available data, that will enable science objectives to be met.
 - Examples of criteria that might be considered include: 1) ice within a certain surface depth, 2) salt-bearing materials accessible to crew, or 3) caves with accessible entrance points for human explorers.
 - Discussion of specific landing sites is not requested.
- Identify any key equipment needed for each science campaign to address the identified science objectives.
- Include a discussion of the criteria used to assign prioritization for science campaigns.

Tasks 6-7: Moon Commonalities and Synergies with Exploration

- Describe commonalities with Moon exploration.
 - For example, discuss equipment and capabilities for each campaign that could also be developed and used for upcoming human exploration missions to the Moon, Gateway, or ISS.
 - If relevant and straightforward, note any equipment/capabilities developed for the Moon, Gateway, or ISS is relevant to Mars exploration.
 - Identifying areas where high priority science investigations on Mars can be applied to the Moon, or where activities on the Moon could directly prepare for exploration on Mars, could enhance the overall Moon to Mars science return
- Identify key synergies with Moon to Mars Goals.
 - Specifically, discuss how science activities in each campaign synergize with NASA's Moon to Mars Strategy and Objectives Development report.

Additional Considerations



Additional Considerations

- Planetary Protection – Use current NASA guidance:
 - NID 8715.129: Biological Planetary Protection for Human Missions to Mars:
https://nodis3.gsfc.nasa.gov/OPD_Docs/NID_8715_129_.pdf
 - As Mars Science Campaigns are developed, identify risks to Planetary Protection
 - These risks will help guide identification of any new knowledge gaps for Planetary Protection
 - Existing Planetary Protection knowledge gaps are documented in Spry et al., 2024 in *Astrobiology*: <https://www.liebertpub.com/doi/abs/10.1089/ast.2023.0092?journalCode=ast>
 - Additional inputs that may be relevant to the Committee's work will be provided after an upcoming Planetary Protection workshop that will be shared in the next talk.

Final Product

- NASA requests a final report for NASA-internal use and made available to all interested parties, that includes (but is not limited to):
 - List of the highest priority Mars Science Objectives with tracing to the Moon to Mars Science Objectives and respective Decadal reports, with justification for the objectives included
 - Types and locations of samples and measurements needed to address identified Mars Science Objectives
 - This can be presented in any format deemed appropriate
 - Prioritized list of Mars Science Campaigns identified, including descriptions of each campaign
 - Discussion of the criteria used to assign prioritization to the Mars Science Campaigns
 - For the top ~3-4 Mars Science Campaigns, include extended discussions of
 - Preliminary criteria for landing sites, including visualizations as appropriate
 - Primary and secondary Campaign Science Objectives addressed in each Science Campaign
 - Key assets and equipment needed to support the Campaign Science Objectives
 - Crew role in achieving Campaign Science Objectives
 - Moon to Mars synergies and commonalities with Moon to Mars Goals

Backup



Candidate Key Mars Architecture Decision

Initial Human Mars Segment Target State

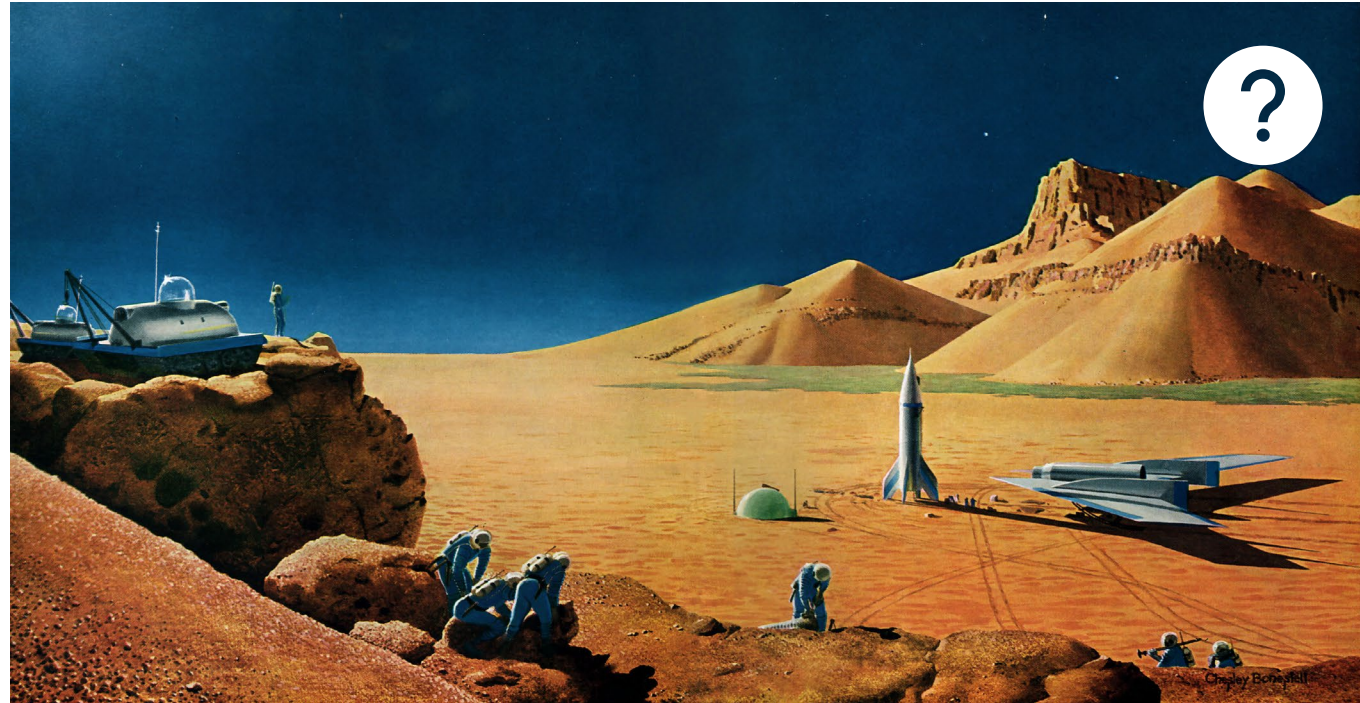


Needed Decision Outcome: What is the target state ("vision") for the *initial human Mars segment*?

- *Science missions to different sites, excursions from an established base at one site, or something else?*

Context: Segment scope should focus on the target state, not just a first mission

- *Apollo focused on getting to the Moon and back, so architecture wasn't suited for more crew, longer stays, larger exploration radii, or ambitious infrastructure*



Chesley Bonestell, *The Exploration of Mars*, 1953, oil on board.
(Chesley Bonestell, Smithsonian Institution)

Candidate Key Mars Architecture Decision

Initial Human Mars Segment Mission Cadence

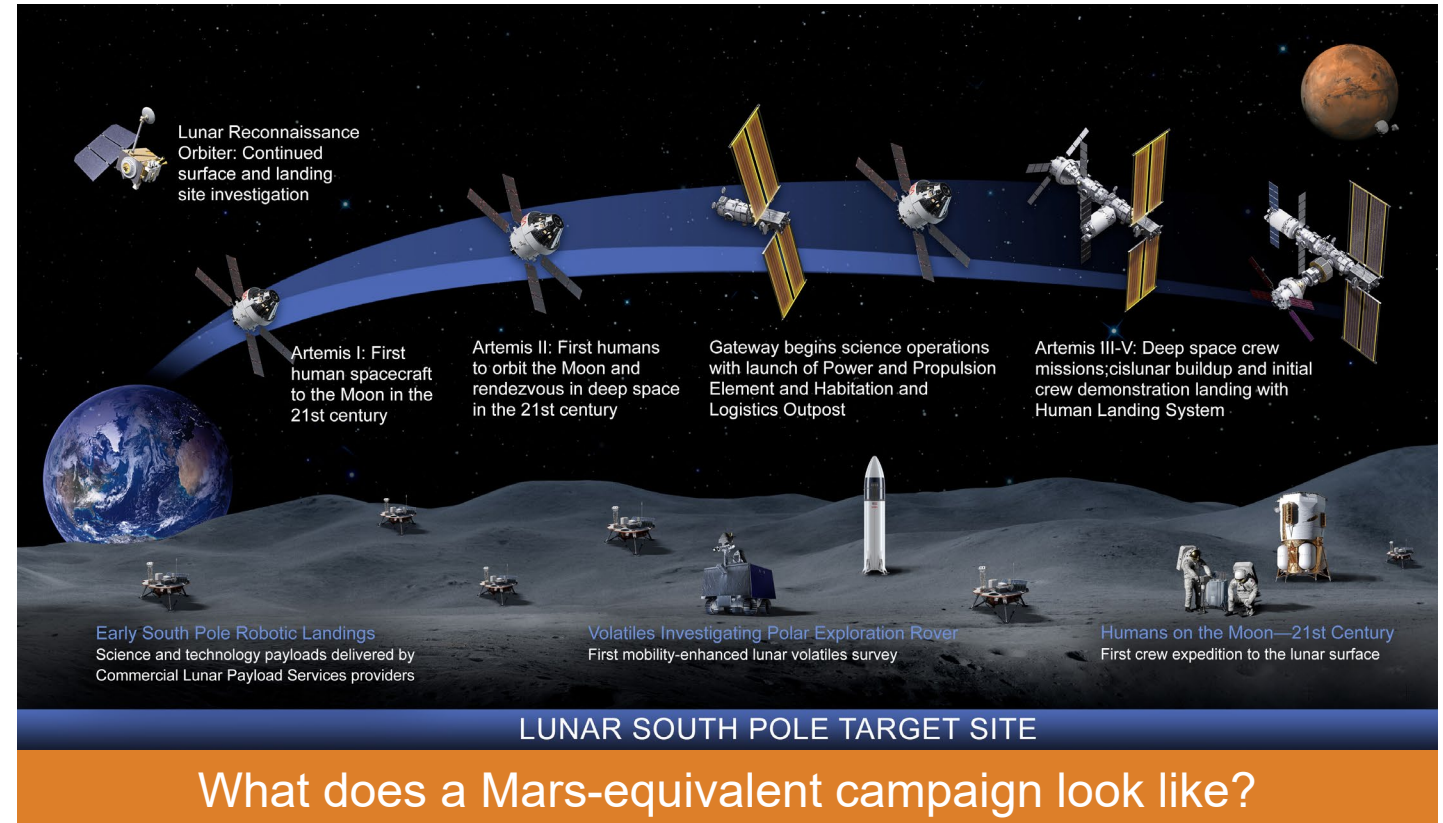


Needed Decision Outcome:

What is the cadence of missions for the *initial human Mars segment*?

Context: Initial Mars Segment Target State key decision will establish the segment scope

- *How many unique missions (including robotic precursors, cargo, and demonstrations) are necessary to achieve desired scope?*



Candidate Key Mars Architecture Decision

Mars Architecture Loss of Crew (LOC) Risk Posture



Needed Decision Outcome: Define probability LOC risk posture for a Mars mission.

Context: Human spaceflight programs typically develop an understanding of the overall LOC risk for the candidate operations and define a minimum level of acceptable risk (i.e., safety threshold) for the mission.



Candidate Key Decision

Crew Complement to Mars Surface per Crewed Mission



Needed Decision Outcome: How many crew will descend and land on the Mars surface per crewed mission?

- *Minimum number for first mission and upper limit for subsequent missions in the initial segment*
- *Note that number of crew to surface is not necessarily the same as number of crew to Mars vicinity*

Context: Crew complement is the most common study constraint across all architectures and elements, with implications for virtually every crewed element, plus logistics and operations.



Candidate Key Mars Architecture Decision

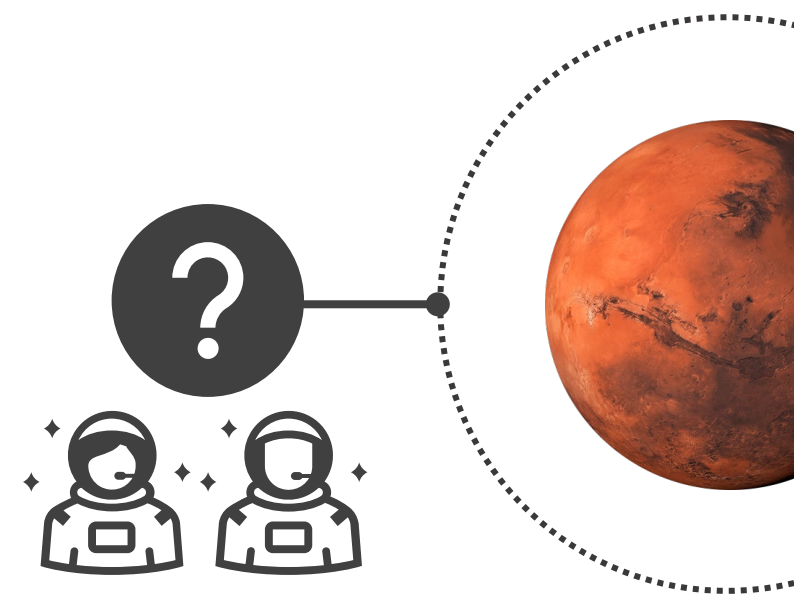
Crew Complement to Mars Vicinity per Mission



Needed Decision Outcome: How many crew will travel to Mars vicinity per crewed mission?

- *Minimum number for first mission and upper limit for subsequent missions*
- *Note that number of crew to surface is not necessarily the same as number of crew to Mars vicinity*

Context: Crew complement is the most common study constraint across all architectures and elements, with implications for transit and Earth launch/land vehicles.



Candidate Key Mars Architecture Decision

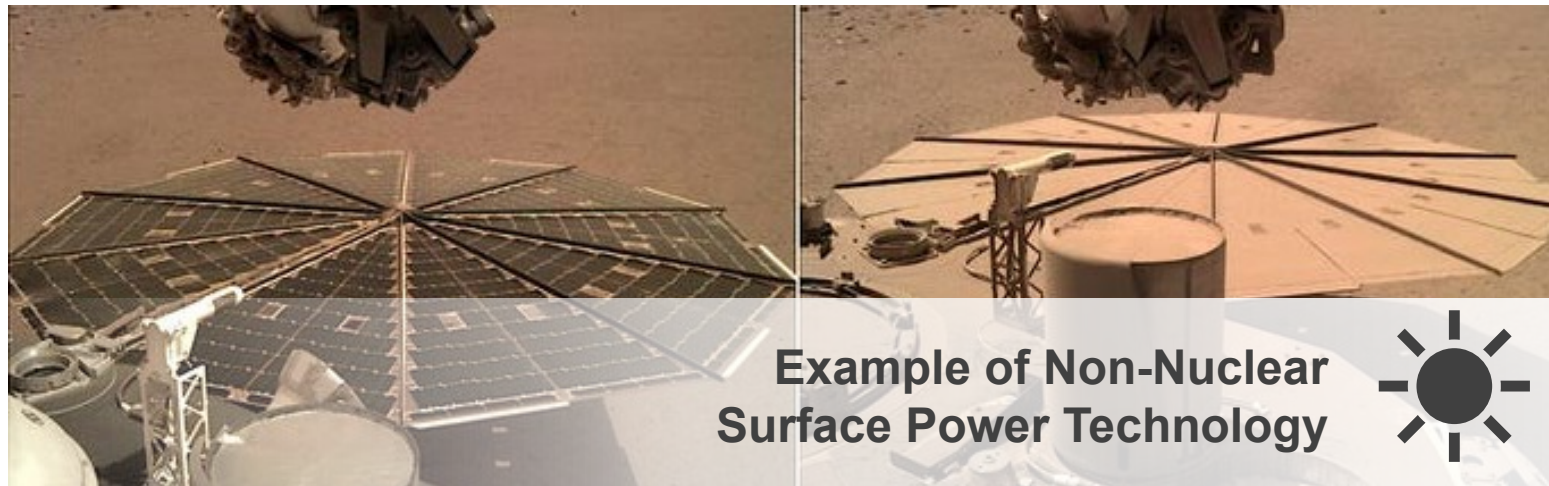
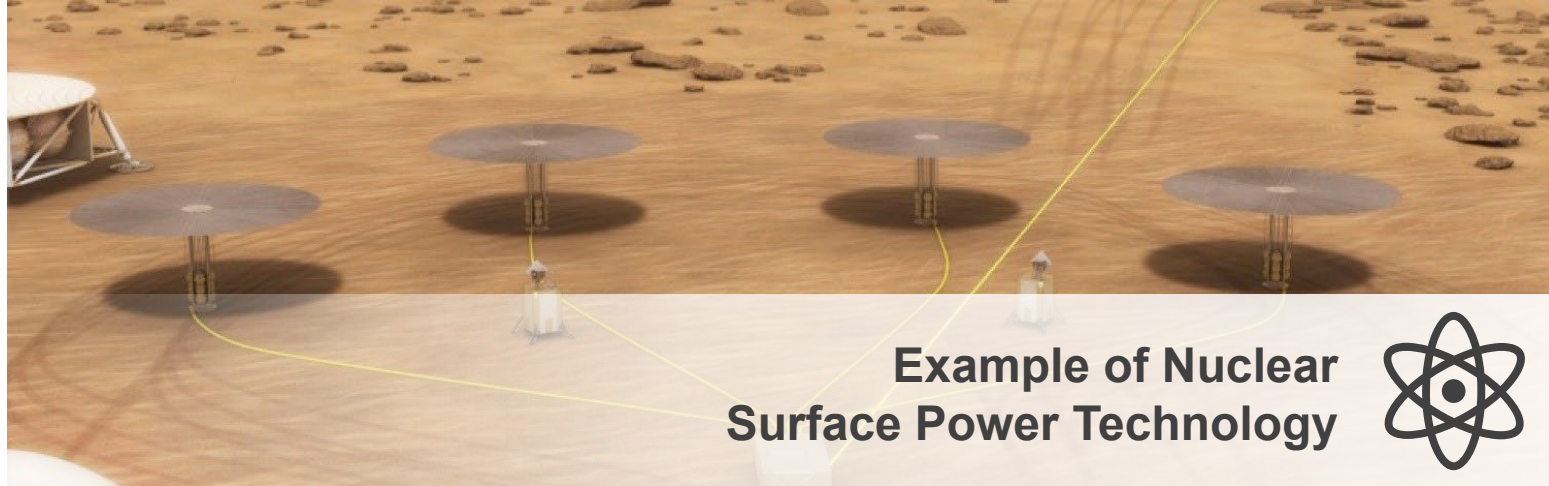
Mars Primary Surface Power Generation Technology



Decision Outcome Needed:

Select primary surface power generation technology.

Context: Extensive robotic mission experience has made clear that reliable surface power is mission critical in Mars' challenging environment. Primary power source selected will be a scalability driver for human Mars missions.



Key Take-Aways



The **order in which key decisions are made** heavily influences exploration architectures.

Every decision is important, but not every decision can be first.

NASA endeavors to identify a **logical order for decision making** by modeling the decision trade space for human Mars exploration.

Methodology allows decision makers to understand the integrated impacts of each individual decision on the overarching architecture.

Application of the new process and tools resulted in **seven key Mars architecture decisions** to focus on in the current analysis cycle.

These decisions affect every subsequent decision.

Mars serves as a **test case** for this approach.

Lessons will inform future decisions for the Moon and subsequent exploration.

As architecture decisions are made, updates will be reflected in NASA's **Moon to Mars Architecture Definition Document**.

The Architecture Definition Document is updated annually.

White Paper



Key Mars Architecture Decisions

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?

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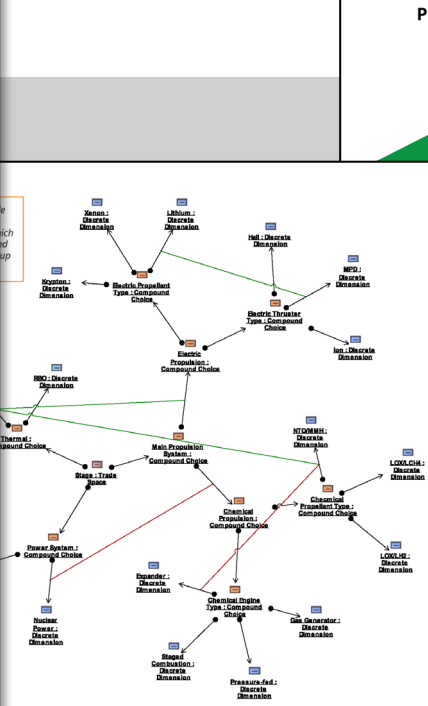
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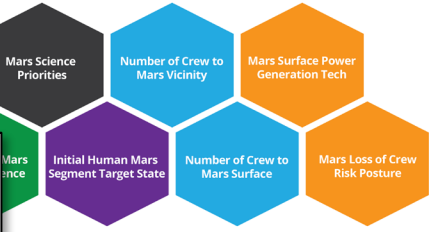
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white paper

Mars Architecture



PRIORITY HUMAN MARS ARCHITECTURE DECISIONS



Human Mars Architecture Decisions

Why we need it? When we need it? What we need it for? Who we need it for? How we need it for?

of this key decision is limited to the initial Humans to Mars campaign. The decision will define subsequent design segments. The ideal end state for architecture that meets NASA's highest with flexibility to expand to meet new crew emere.

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.

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 decisions that so profoundly influence the architecture as to warrant the Agency. Ensuring the integrated impacts of decisions are carefully traced, assessed, and weighed will help decision authorities make lasting decisions resistant to implementation delays, and costly reiteration.

As part of this process, NASA has identified a set of key architecture decisions to start with. These decisions will continue to define and map the architecture, reporting progress at the Architecture Concept Reviews and updating the Architecture Definition Document with architecture decisions made.

Segment Mission Capabilities

Human exploration of Mars will require "architecting from the right," but 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 consequences to defining crew complement to the surface, but some unique constraint drivers.

The number of crew to the vicinity of Mars will have implications for Earth ascent, transit vehicle habitable volume, communications, and logistics manifesting. The influence Mars capture and parking orbit with flow-down implications for contingency response. For example, architectures, some crew might not be able to descend and work on the surface while others descend and work on the surface while others descend and work on the surface.

Primary Mars Surface Power Generation

The scope of human exploration of Mars largely on the amount of energy available. Power will power crew life support systems, element keep-alive functions, and maintain critical ascent vehicle propulsion systems.

Solar energy has long been a reliable power applications. However, recent mission experience has brought a new perspective on Mars surface missions into sharp focus. The loss of crew risk if the surface were to fail during a human exploration mission is a high-stakes decision.

This particular architecture decision to power generation technique. Power distribution technology selection, separate decisions, though interrelated, these decisions must be factored into decision analyses. The narrowing window to infuse Mars-forward considerations into power implementation decisions for timely activity.

Future Work

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



100 candidate key decisions for the 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

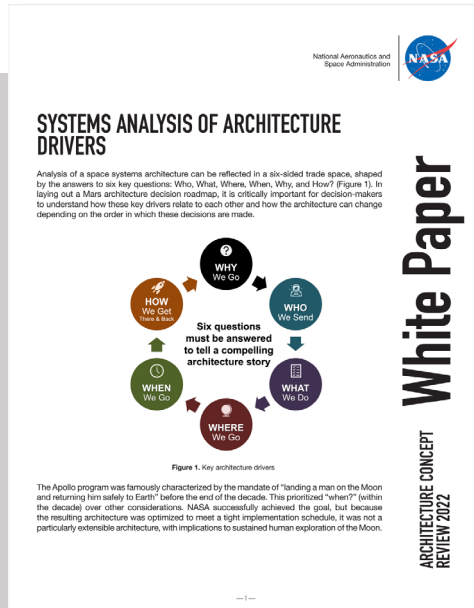
architecture decisions — continues to be developed and refined.

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

White Papers



Systems Analysis of Architecture Drivers:

Analysis of a space systems architecture are shaped by answers to six key questions: Who, What, Where, When, Why, and How? In laying out a Mars architecture decision roadmap, it is critically important for decision-makers to understand how these key drivers relate to each other and how the architecture can change based on the order of these decisions. (PDF)

Mars Transportation:

One of the most visible portions of the Mars architecture is the Earth to Mars transportation system. Four propulsion systems are currently under consideration: nuclear thermal, hybrid nuclear electric/chemical, hybrid solar electric/chemical, and all chemical. This paper orients the greater community to their breadth, variations, and associated risks. (PDF)

