National Aeronautics and Space Administration

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

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Agenda

01 Study Request and Background

02 Key Mars Architecture Decisions

03 Key Definitions

04 Task Descriptions and Thoughts

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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

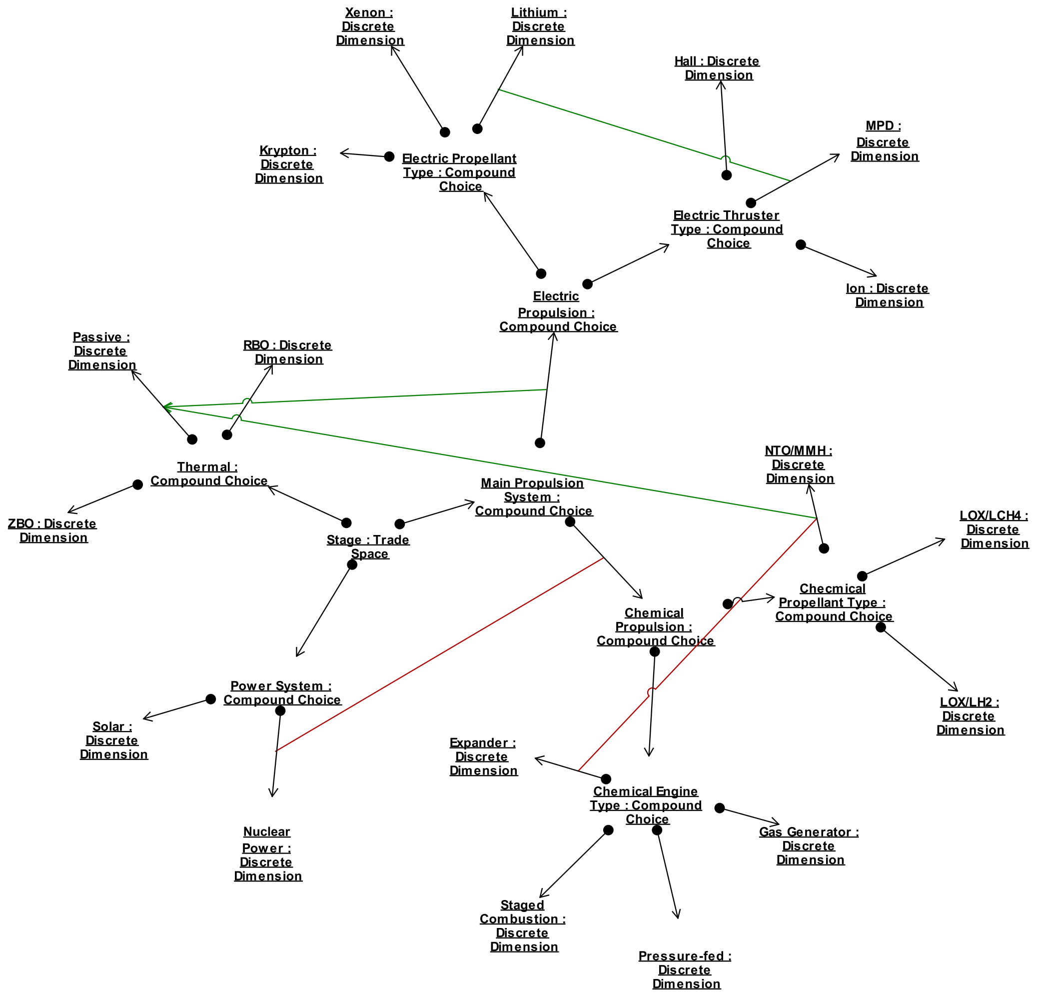
Key Mars Architecture Decisions

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

CREWED MARS MISSION
PRIORTY ARCHITECTURE
DECISIONS

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

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

Candidate Key Mars Architecture Decision

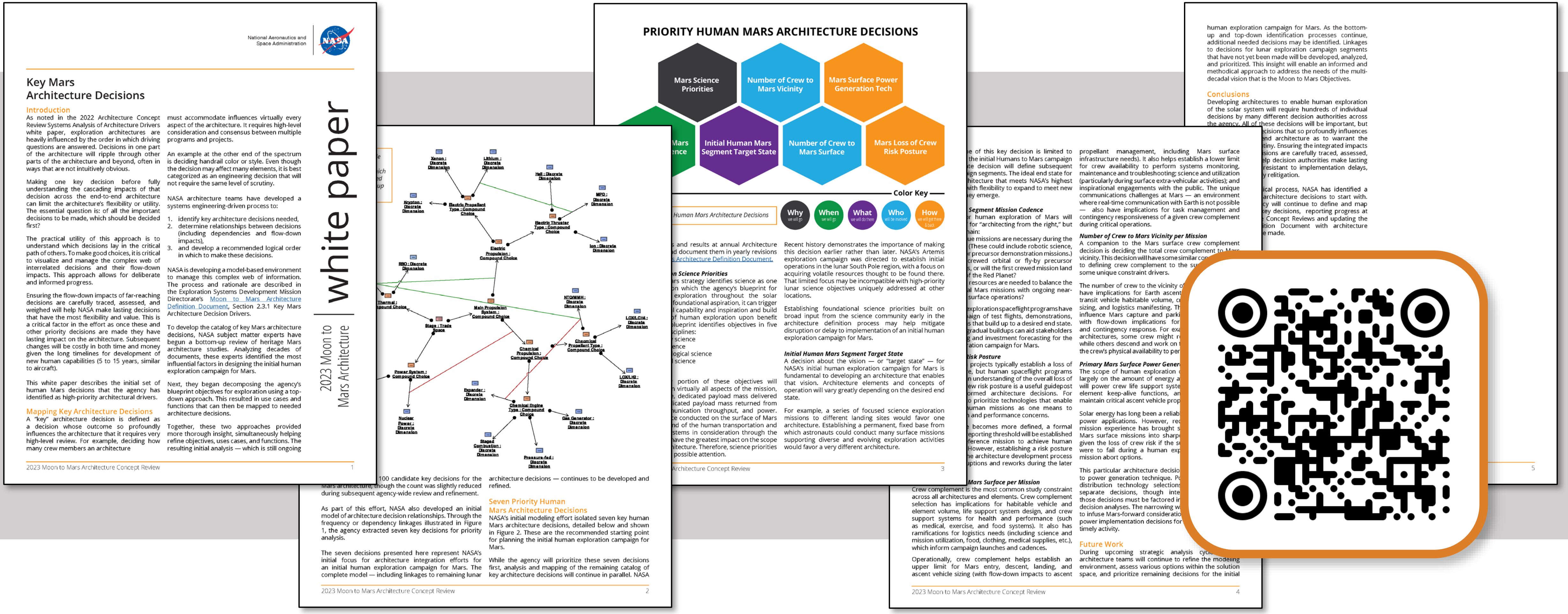
Science Priorities for Initial Human Mars Segment

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

Key Mars Architecture Decisions White Paper



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

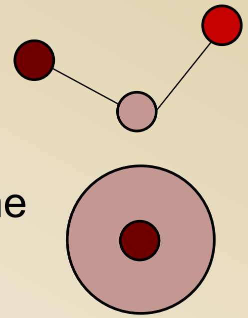
Key Definitions

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^{o} 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

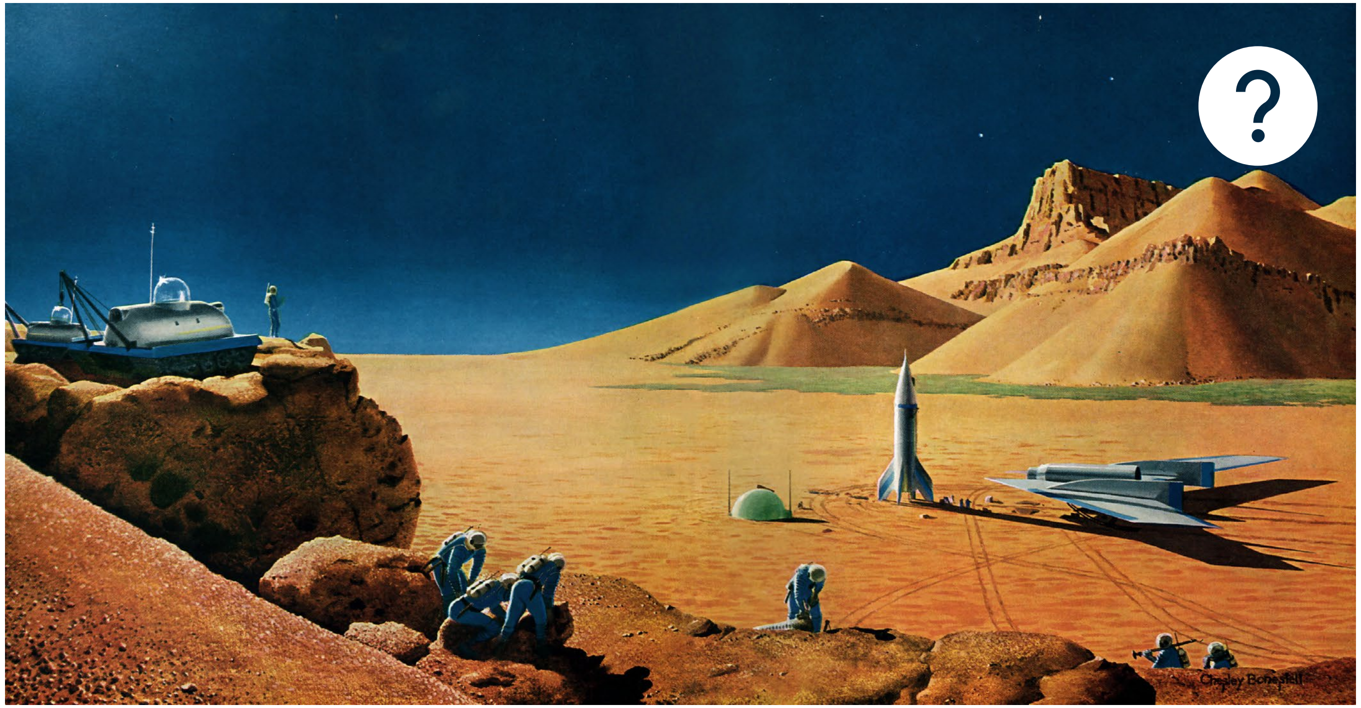
Initial Human Mars Segment Target State

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)

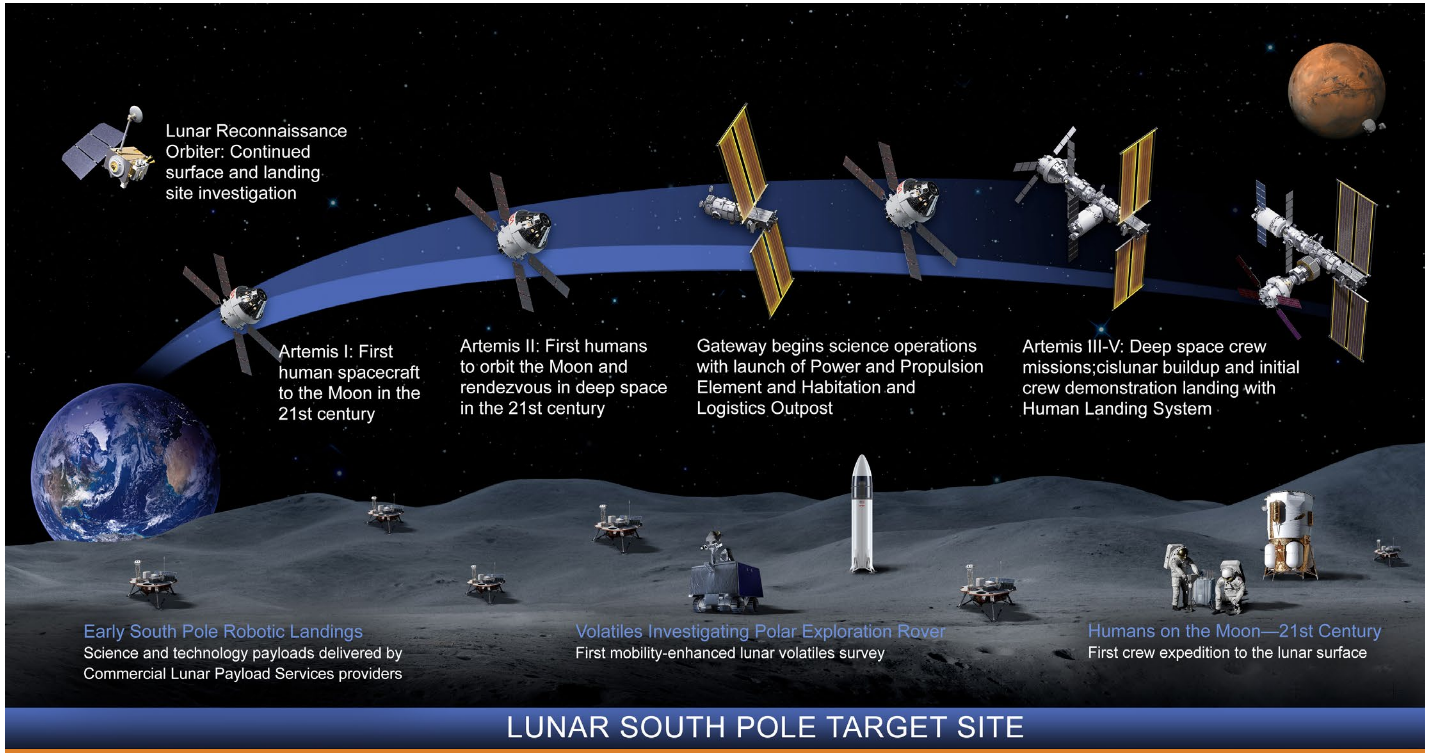
Candidate Key Mars Architecture Decision

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?*



What does a Mars-equivalent campaign look like?

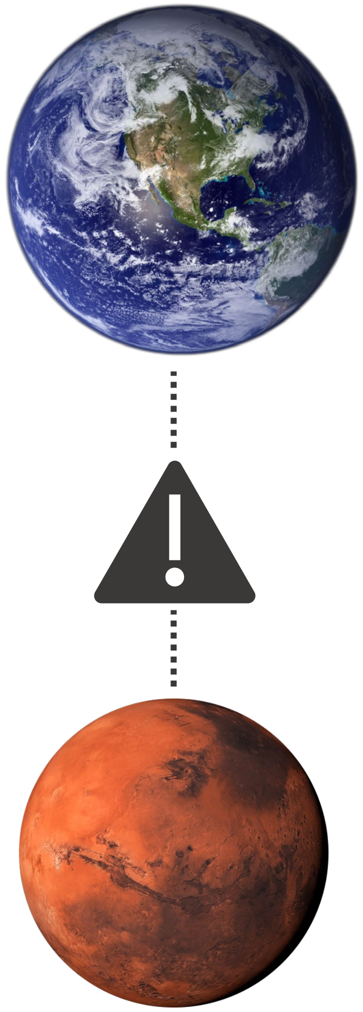
MARS LOSS OF CREW RISK POSTURE

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.



NUMBER OF CREW TO MARS SURFACE

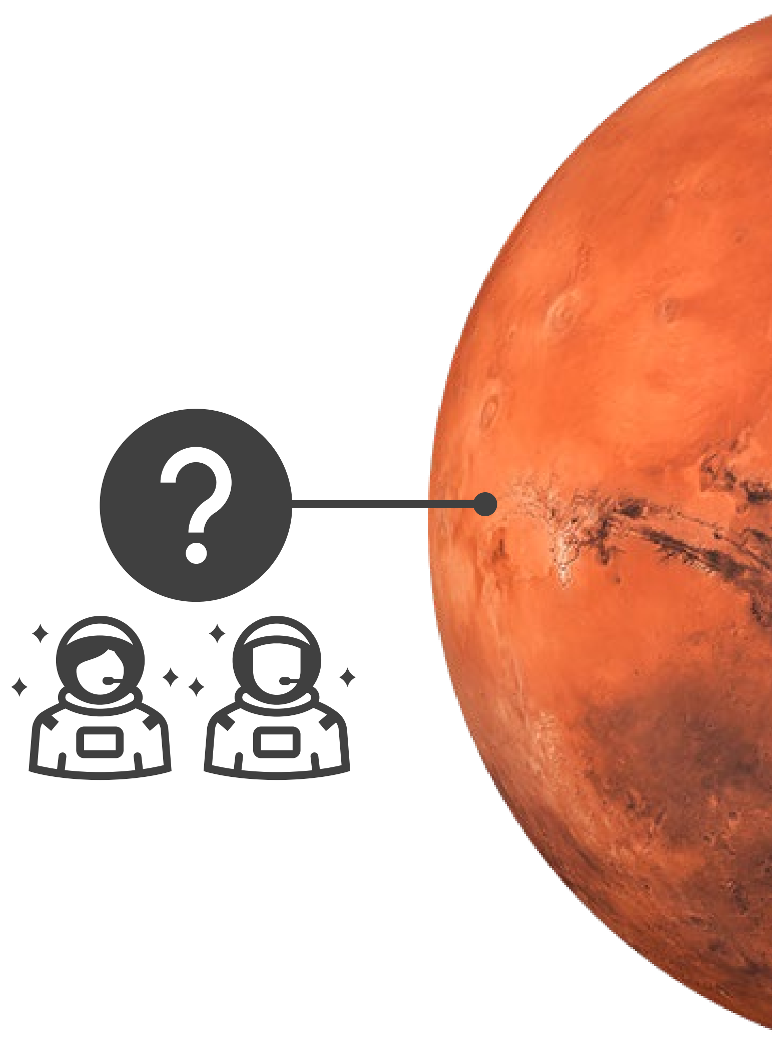
Candidate Key Decision

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.



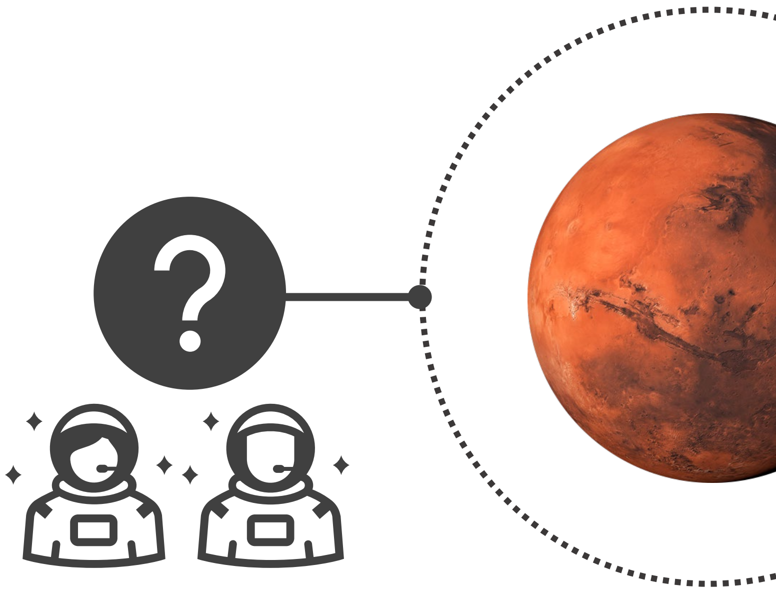
Candidate Key Mars Architecture Decision

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.

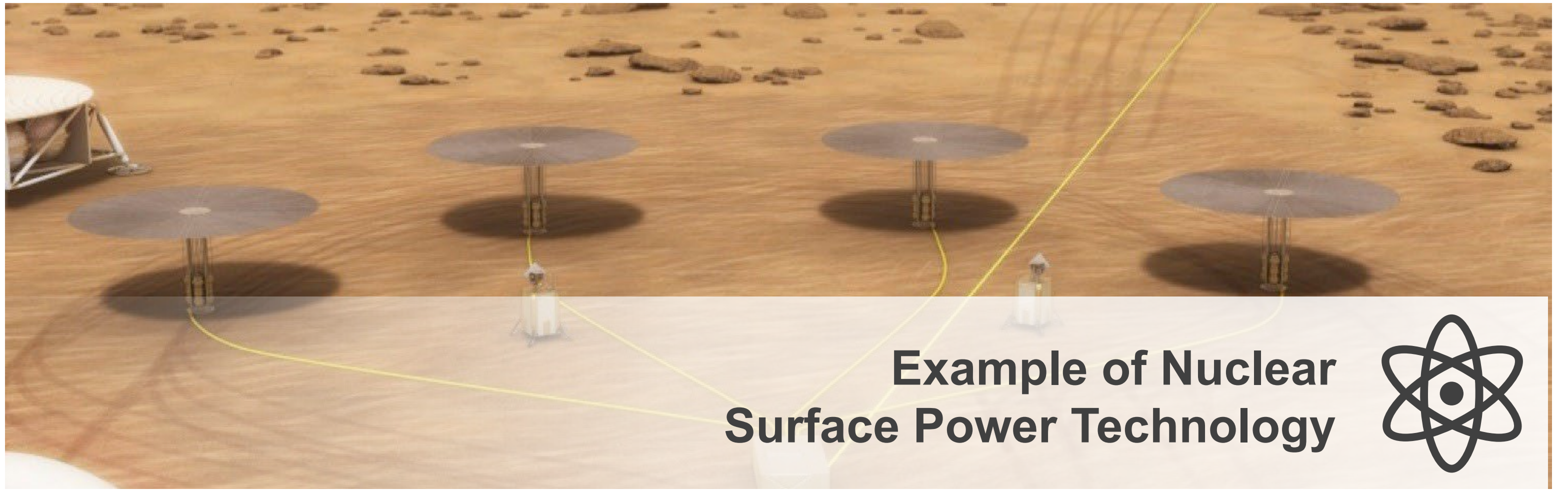


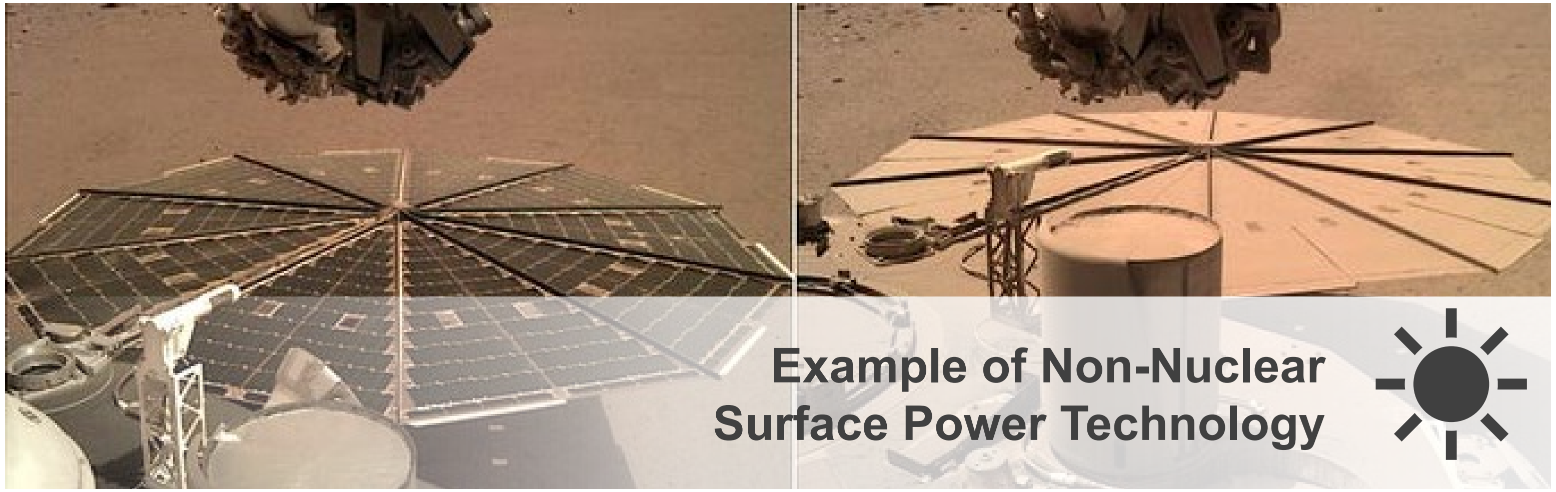
Candidate Key Mars Architecture Decision

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.

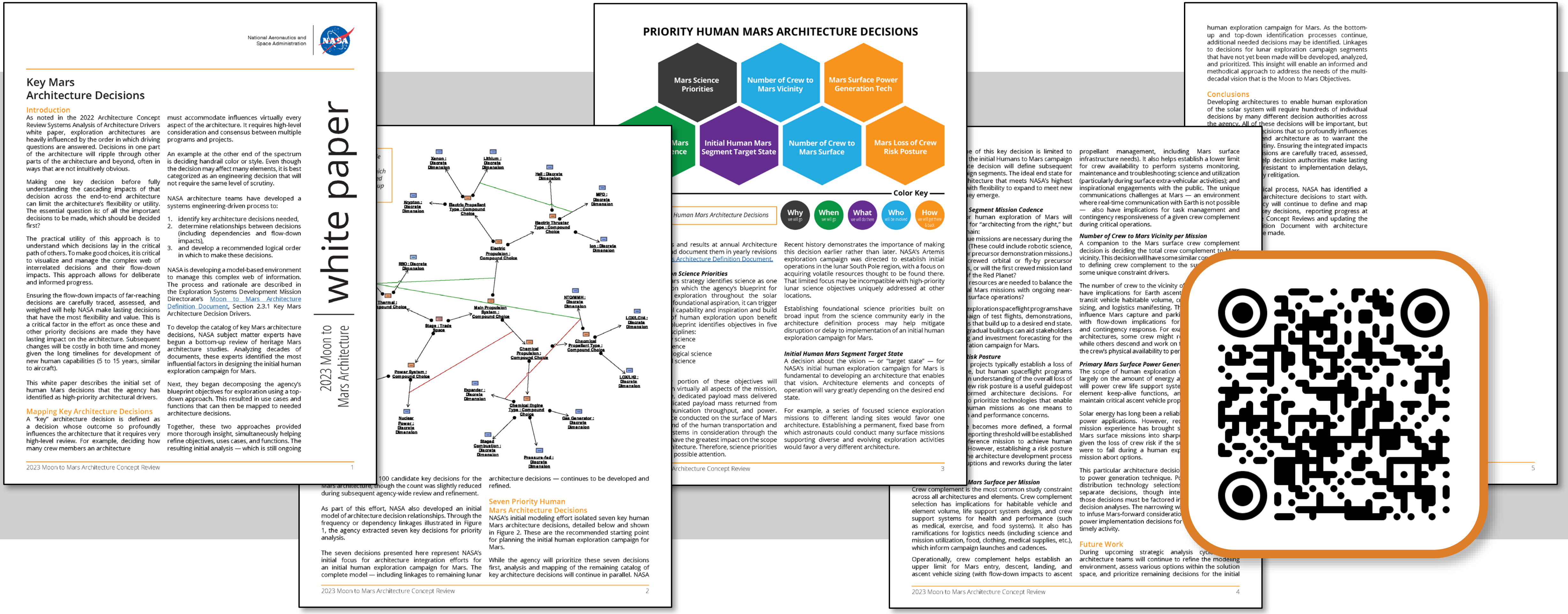
Mars serves as a **test case** for this approach.

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


National Aeronautics and Space Administration
Key Mars Architecture Decisions
Introduction
Mapping Key Architecture Decisions
white paper
2023 Moon to Mars Architecture
2023 Moon to Mars Architecture Concept Review
PRIORITY HUMAN MARS ARCHITECTURE DECISIONS
Mars Science Priorities
Number of Crew to Mars Vicinity
Mars Surface Power Generation Tech
Initial Human Mars Segment Target State
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Mars Loss of Crew Risk Posture
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Why
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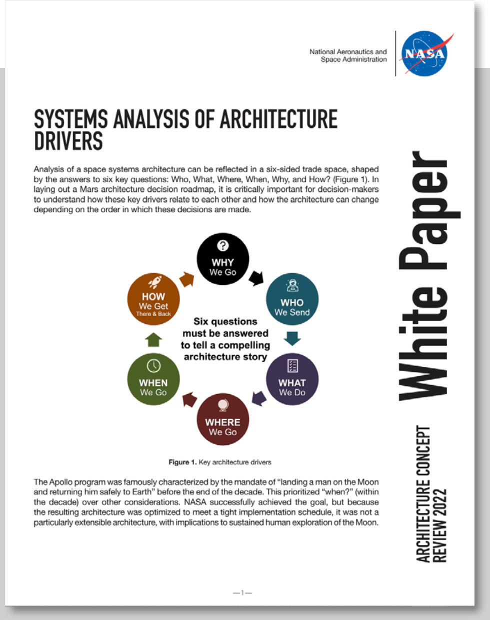
Seven Priority Human Mars Architecture Decisions
Conclusions
Future Work

White Papers



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SYSTEMS ANALYSIS OF ARCHITECTURE DRIVERS

Analysis of a space systems architecture can be reflected in a six-sided trade space, shaped by the answers to six key questions: Who, What, Where, When, Why, and How? (Figure 1). 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 depending on the order in which these decisions are made.

Figure 1. Key architecture drivers

The Apollo program was famously characterized by the mandate of "landing a man on the Moon and returning him safely to Earth" before the end of the decade. This prioritized "when?" (within the decade) over other considerations. NASA successfully achieved the goal, but because the resulting architecture was optimized to meet a tight implementation schedule, it was not a particularly extensible architecture, with implications to sustained human exploration of the Moon.

White Paper

ARCHITECTURE CONCEPT REVIEW 2022

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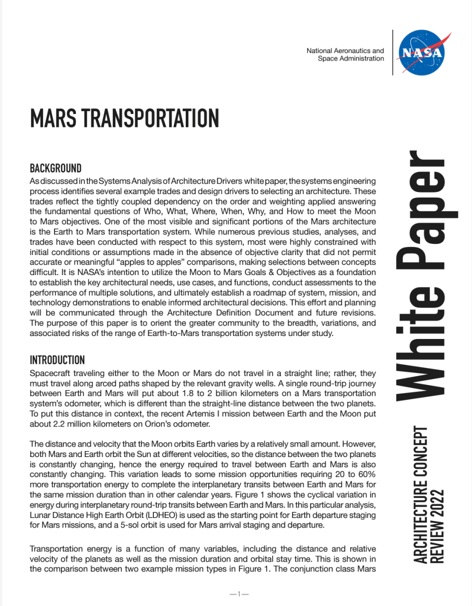
Systems Analysis of Architecture Drivers:

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)



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MARS TRANSPORTATION

BACKGROUND

As discussed in the Systems Analysis of Architecture Drivers white paper, the systems engineering process identifies several example trades and design drivers to selecting an architecture. These trades reflect the tightly coupled dependency on the order and weighting applied answering the fundamental questions of Who, What, Where, When, Why, and How to meet the Moon to Mars objectives. One of the most visible and significant portions of the Mars architecture is the Earth to Mars transportation system. While numerous previous studies, analyses, and trades have been conducted with respect to this system, most were highly constrained with initial conditions or assumptions made in the absence of objective clarity that did not permit accurate or meaningful "apples to apples" comparisons, making selections between concepts difficult. It is NASA's intention to utilize the Moon to Mars Goals & Objectives as a foundation to establish the key architectural needs, use cases, and functions, conduct assessments to the performance of multiple solutions, and ultimately establish a roadmap of system, mission, and technology demonstrations to enable informed architectural decisions. This effort and planning will be communicated through the Architecture Definition Document and future revisions. The purpose of this paper is to orient the greater community to the breadth, variations, and associated risks of the range of Earth-to-Mars transportation systems under study.

INTRODUCTION

Spacecraft traveling either to the Moon or Mars do not travel in a straight line; rather, they must travel along arced paths shaped by the relevant gravity wells. A single round-trip journey between Earth and Mars will put about 1.8 to 2 billion kilometers on a Mars transportation system's odometer, which is different than the straight-line distance between the two planets. To put this distance in context, the recent Artemis I mission between Earth and the Moon put about 2.2 million kilometers on Orion's odometer.

The distance and velocity that the Moon orbits Earth varies by a relatively small amount. However, both Mars and Earth orbit the Sun at different velocities, so the distance between the two planets is constantly changing, hence the energy required to travel between Earth and Mars is also constantly changing. This variation leads to some mission opportunities requiring 20 to 60% more transportation energy to complete the interplanetary transits between Earth and Mars for the same mission duration than in other calendar years. Figure 1 shows the cyclical variation in energy during interplanetary round-trip transits between Earth and Mars. In this particular analysis, Lunar Distance High Earth Orbit (LDHEO) is used as the starting point for Earth departure staging for Mars missions, and a 5-sol orbit is used for Mars arrival staging and departure.

Transportation energy is a function of many variables, including the distance and relative velocity of the planets as well as the mission duration and orbital stay time. This is shown in the comparison between two example mission types in Figure 1. The conjunction class Mars

White Paper

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