National Aeronautics and Space Administration

2025
Moon to Mars Architecture

white paper

Architecture Definition

NOTE This white paper supersedes two previous Moon to Mars Architecture white papers: **Systems Analysis of Architecture Drivers** (2022) and **Key Mars Architecture Decisions** (2023). It reflects updates to NASA's approach for defining the Moon to Mars Architecture.

Introduction

An exploration architecture, such as NASA's Moon to Mars Architecture, must answer a set of **guiding questions**: *Why we go? Who is involved? Where we go? What we do there? When do we go? How we go?*

Figure One: *Six guiding questions. (NASA)*

NASA's answers to those questions shape the **trade space**, the range of options for exploration missions. There are numerous more specific questions or trades beneath each of the six guiding questions, and many of the **trades** are interrelated such that the answer to one will impact the next, which will impact the next, and so on.

NASA establishes a recommended sequence for answering the guiding questions via **key definition tasks** in the **architecture roadmapping process**. Through key definition tasks, NASA converts its Moon to Mars Objectives[1] into elements and assets that can achieve those objectives.

The **outcome** of a key definition task could include a decision, down-select, ground rule, or other determination that narrows the architecture trade space. Therefore, decision-makers must understand how the possible outcomes of key definition tasks relate to one another.

Selecting one option within the architecture trade space can preclude or require other options in ways both expected and unexpected. Laying out the trade-offs and relationships between definition tasks in the roadmapping process helps the agency understand the impact of narrowing the trade space in one area on other areas of the architecture. It also enables the agency to respond to technological advances and industry developments — as technologies emerge or mature, they can open up new architectural capabilities. Roadmapping empowers NASA leaders to make the right decisions at the right time.

This white paper examines how NASA undertakes architecture definition tasks to create an architecture that can achieve the agency's Moon to Mars Objectives. Whether planning future lunar exploration or preparing for the first human missions to Mars, NASA uses the same roadmapping process to logically order definition tasks so that the agency understands how definition outcomes impact the Moon to Mars Architecture.

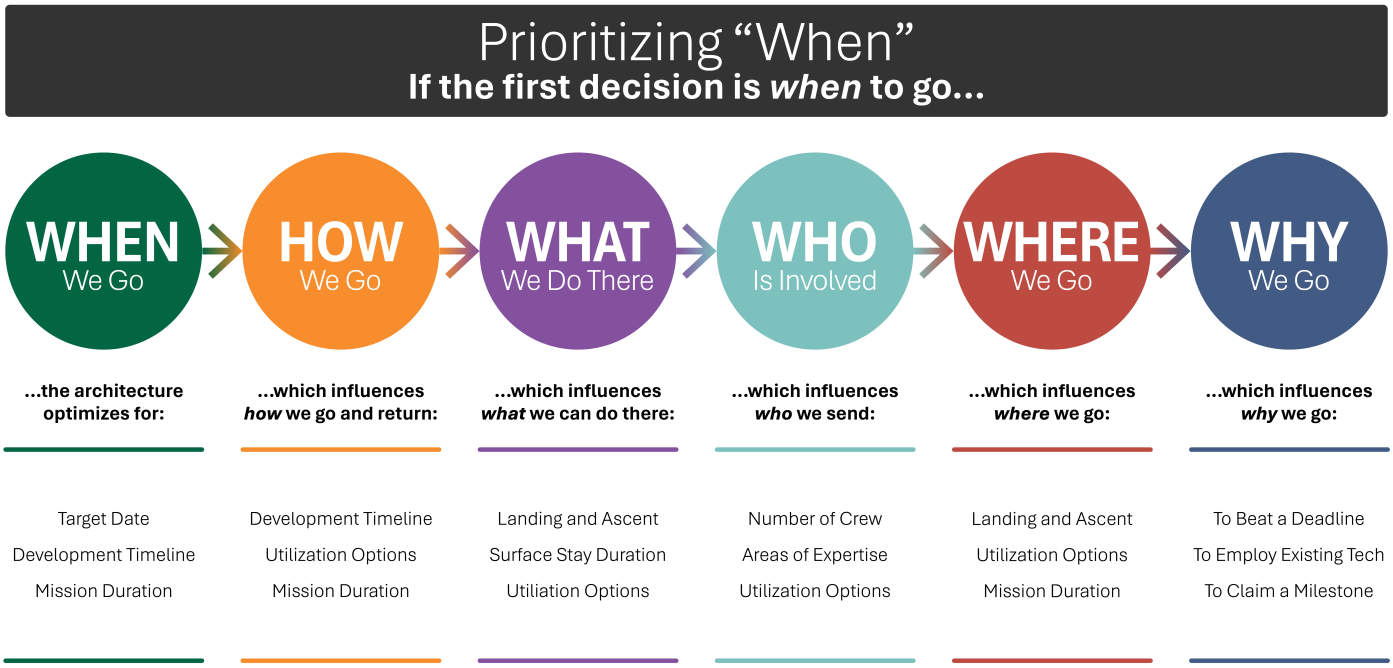

Figure Two: *Architecture question flow, prioritizing "When." (NASA)*

Impacts of Guiding Questions

The architecture must address the six guiding questions defined above: Who, What, Where, When, Why, and How. However, these questions do not exist independent of one another; the order in which the architecture addresses them significantly affects their answers.

For example, consider the Apollo Program. Apollo famously responded to the mandate of "landing a man on the Moon and returning him safely to the Earth" before the end of the decade,[2] establishing "When" as the priority. NASA successfully achieved that goal, but because the resulting architecture was optimized to meet a tight implementation schedule, it was not a particularly extensible architecture, which had profound implications for the sustainability of human exploration of deep space.

As shown in Figure Two, taking the same approach for Mars and foregrounding "When" would result in an architecture that prioritizes speed above all else, with impacts cascading through other areas of the architecture. Prioritizing "When" might dictate reliance on heritage systems rather than new technologies that take time to develop; it could favor Mars stay durations that can be achieved faster, rather than stay durations that achieve more of NASA's exploration objectives.

Instead, beginning with "Why?" — as in Figure Three — foregrounds NASA's Moon to Mars Objectives and the agency's pillars of exploration. This flow ensures that answers to the questions that follow from "Why?" address the agency's exploration objectives, rather than targeting a specific constraint, like a mission deadline. In this paradigm,

KEY TERMS	
Guiding Questions	Questions that determine the purpose and scope of an exploration architecture (i.e., Who, What, Where, When, Why, and How?)
Trade Space	A range of possible options for implementation for a particular area of the architecture.
Trade Studies	Analyses that examine sets of options to better understand the impacts and benefits of individual options. Colloquially referred to as "trades."
Architecture Definition Task	An examination of a question within the architecture, typically to shape or reduce the trade space (e.g., trade studies in ser-vice to Moon to Mars Architecture definition).
Roadmapping	The process of ordering definition tasks in a manner that maximizes opportunities and minimizes risk.
Definition Outcome	The result of an architecture definition task, which could include a decision, down-select, ground rule, methodology, or other narrowing of the trade space.

Figure Three: *Architecture question flow, prioritizing "Why." (NASA)*

architectural trades (e.g., transportation technology) aren't limited by timeline, enabling NASA to send the right people to the right destinations at the right time, rather than constraining the trade space.

As these examples show, the priority of the questions can constrain or widen specific parts of the trade space. However, in practice, developing the architecture is iterative, not linear, with NASA addressing many questions and trades simultaneously. A flexible, sustainable architecture that addresses these questions holistically reduces cost by minimizing disruption, re-work, and cost and schedule changes.

The answer to any one of these questions is less important than whether all six answers complement each another. When they do, NASA can establish an achievable, affordable, and adaptable architecture.

Architecture Definition

NASA answers the guiding questions and makes iterative updates to the architecture with architecture definition tasks. These definition tasks examine a particular topic and — once complete — enable NASA to set an architectural ground rule, make a decision, select a methodology, or otherwise shape the architecture.

Conducting architecture definition tasks enables the agency to examine open, undefined parts of the architecture, answer questions about the architecture, and narrow down the trade space. Architecture definition brings future exploration into focus.

Every definition task is important, but certain tasks (i.e., "key" definition tasks) significantly influence the end-to-end architecture and impact many flow-down topics. These warrant much more scrutiny and high-level review to balance a variety of priorities and demands.

For example, deciding how many crew members an architecture must accommodate influences virtually every other aspect of the architecture. It requires high-level consideration and consensus between multiple programs and projects. At the other end of the spectrum, the number of windows on a specific habitat module — though it may affect many aspects of element design — is an engineering decision that does not require the same scrutiny.

NASA's architecture roadmapping approach identifies and tracks **key definition tasks** within the Moon to Mars Architecture. It only includes definition tasks that significantly influence the architecture and/or require collaboration between multiple, cross-agency authorities to answer an agency-level question. Identifying and sequencing these key definition tasks ensures that NASA works efficiently and remains a smart buyer of capabilities and services.

Architecture Roadmapping

NASA uses a systems engineering–driven process to:

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

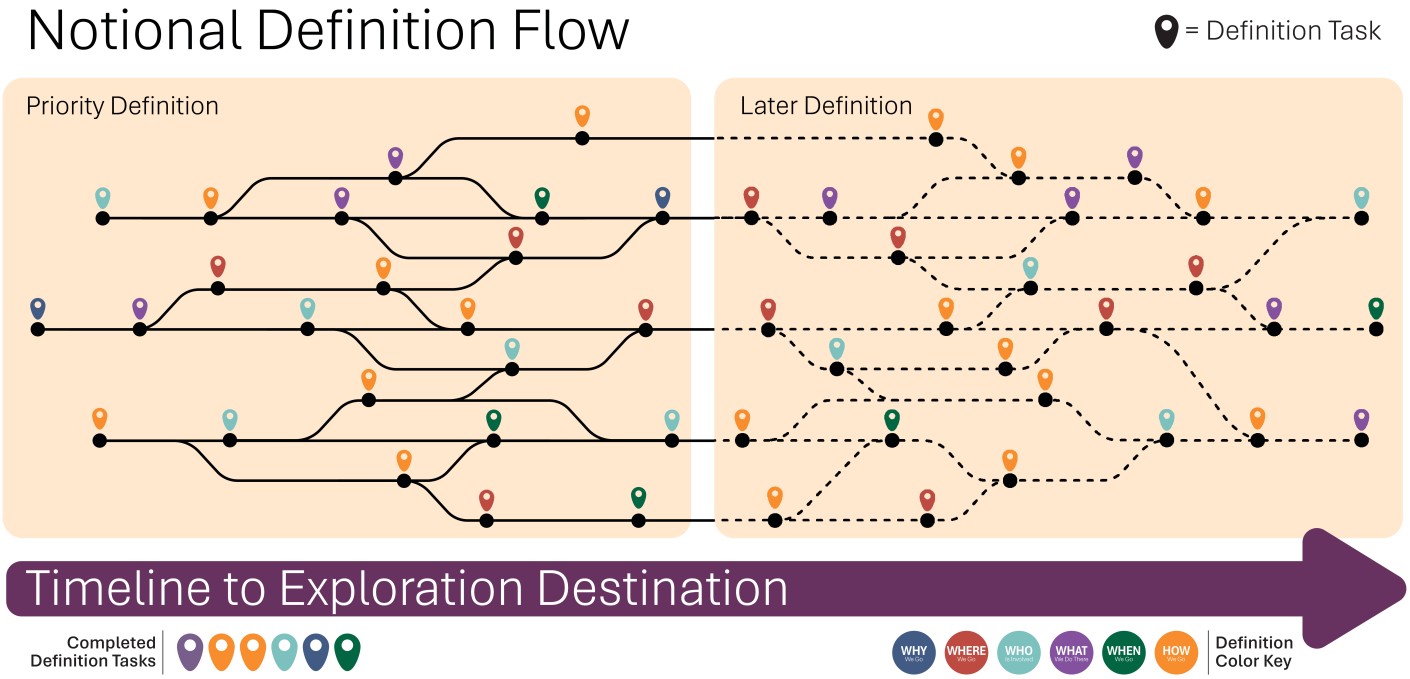

Figure Four: *Notional definition flow. (NASA)*

NASA maintains a digital modeling environment to manage this complex web of information. The model tracks the possible options that NASA is studying through definition tasks (i.e., the definition trade space) and the flow-down relationships between them.

To develop the catalog of Mars architecture definition tasks, NASA subject matter experts conducted 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 decomposed the agency's blueprint objectives for exploration using a top-down approach. This produced use cases and functions that must be performed by yet-undefined elements and assets, which revealed needed definition tasks.

The resulting analysis — which is still ongoing — identified nearly 100 candidate definition tasks for the Mars architecture. NASA has since further refined this list, examined the possible definition outcomes for each, and identified flow-down relationships (i.e., dependencies) between the possible outcomes.

The flow-down relationships are used as a key input in creating recommendations for the sequence in which the definition tasks should be conducted — this is the **roadmapping**. Several other considerations influence the sequence, including the level of resources that constrain how many definition tasks the agency could conduct in a given year, needs that inform technology development investments, the impact of a given definition outcome on the remaining trade space, and more.

Based on these considerations, NASA established a partial roadmapping sequence and adds to it each year. This is represented by the "priority" key definition tasks, which should be made early in the architecting process.

Priority Definitions

From the overall list of definition tasks, NASA has identified priority areas with many flow-down impacts. The agency brings these definition tasks to the annual Architecture Concept Review for concurrence from agency stakeholders. Once approved, the agency prioritizes resources for these definitions.

While these priority definitions represent the most important topics that the agency must address early on, they do not follow a linear order. NASA addresses multiple tasks in parallel. Figure Four visualizes this order.

The list below represents a snapshot of the current state of architecture roadmapping. This list will evolve as NASA identifies new priority topics and completes existing definition tasks. Through these iterations, the agency shapes the Mars exploration architecture.

Note that identification numbers and order in the table do not imply prioritization. NASA pursues multiple definition tasks in parallel.

For a complete list of identified definition tasks, refer to the latest revision of the Architecture Definition Document.[3] NASA updates this document annually to capture the latest progress in the Moon to Mars Architecture.

Definition Task Outcomes

A completed definition task results in a definition outcome. These outcomes can take a variety of forms, though all reduce the trade space or have implications for architecture implementation.

In some cases, these outcomes are tangible decisions about aspects of the architecture, as was the case for the primary surface power generation technology for initial human missions to Mars (see the case study below.) In other cases, the outcome can be a reduction of the trade space to a viable or plausible range, as was the case in the selection of the number of crew to Mars surface. The outcome can also be the selection of a methodology or approach, as was the case for the Mars architecture loss-of-crew risk methodology task.

CASE STUDY

Mars Surface Power Generation Decision

For an example of a completed key definition task, consider NASA's 2024 decision to select nuclear fission power as the primary surface power generation technology for initial human missions to Mars. This definition task examined the full range of power generation technologies that could enable human missions to Mars.

NASA engineers examined a range of power sources, including solar power, nuclear fission power, and other sources (e.g., geothermal power, fuel cells). The agency weighed each technology's mass, power output, safety, suitability to the Martian environment, and other factors, and ultimately decided upon nuclear fission power, which offered the best balance across these factors.

This selection offers an example of a key definition outcome that will inform subsequent architectural work. With a technology selected, NASA can begin developing power generation and distribution systems, as well as surface infrastructure (e.g., habitation systems) that takes advantage of nuclear fission power's continuous output.

This documented mission pull helps inform industry investments and future partnerships. By communicating its selection of nuclear power, NASA offers a demand signal for technology developers and positions itself as a future customer and partner. Industry and international partners can prioritize their technology development efforts, while NASA can focus its own resources on the areas with the most impact.

For more information about this key definition task, refer to the associated 2024 white paper.[4]

Conclusion

NASA's Moon to Mars Architecture is a multi-decadal campaign of space exploration that will return the agency to the lunar surface and take humanity to the Red Planet. The analysis supporting these definition tasks helps the agency to narrow the trade space into an implementable architecture. The architecture's roadmapping approach logically orders definition tasks to maximize opportunities to achieve the agency's Moon to Mars Objectives.

This thoughtful, systems engineering approach will power continued American leadership in space as NASA explores the unknown for the benefit of all.

Table One:
Snapshot of priority key definition tasks. Shaded rows indicate that NASA has closed a key definition task with a definition outcome.

ID	DEFINITION TASK
MD-01	Initial Human Mars Segment Science Objectives Priorities
MD-02	Initial Human Mars Segment Target State
MD-03	Initial Human Mars Segment Mission Cadence
MD-04	Mars Architecture Loss of Crew Risk Methodology
MD-05	Number of Crew to Mars Surface
MD-06	Number of Crew to Mars Vicinity Per Mission
MD-07	Primary Mars Surface Power Generation Technology
MD-08	Mars Architecture Loss of Mission Risk Methodology
MD-09	Maximum Mars Crew Surface Stay Duration
MD-10	Mars Forward Contamination Planetary Protection Risk Posture
MD-11	Mars Backward Contamination Planetary Protection Risk Posture
MD-12	Maximum Allowable Crewed Communications Disruption

Key Takeaways

The Moon to Mars Architecture must answer a series of overarching questions: Who, What, When, Why, and How?

To address these guiding questions and develop the architecture, NASA conducts architecture definition tasks.

Some tasks have major impacts on the end-to-end architecture. The agency tracks these "key definition tasks" to capture their relationships and flow-down impacts and establishes a priority order to maximize efficiency and minimize re-work.

Completed key definition tasks can result in a ground rule, decision, methodology, or other definition outcome that shapes the architecture.

NASA's Architecture Definition Document captures the latest list of ongoing key definition tasks and the results of completed key definition tasks.

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