National Aeronautics and Space Administration

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

The Apollo Program serves as a cautionary tale for Mars: if the focus is on "when?" as an anchoring decision (architecting from the right in Figure 2), and the answer is a date that doesn't permit enough time to develop new technologies, then the answer to "how?" will default to heritage or heritage-derived systems. If the specified date is too soon to develop and certify both a new transportation system and new descent, ascent and surface systems, then the schedule compromise may be an orbital-only or fly-by first mission, followed by surface missions in later years. This affects not just "how?" but cascades to "what?" and "why?" If instead of a particular date, "when?" is indexed to another event—for example, the timeline of a particular technology development or an agency funding profile—then certain technologies or assets from other Programs may be prescribed, again influencing both "how?" and "what?" If the answer to "when?" specifies both a "boots on Mars" date and a "boots back on Earth" date (in other words, a total crewed mission duration) that will define whether new high-tech, high energy transportation systems capable of shorter mission durations must be developed. As shown in Figure 2, architecting from the right by starting with "when?" potentially makes the answers to "why?" "where?" and "who?" reliant on the answers to "how?" and "what?"

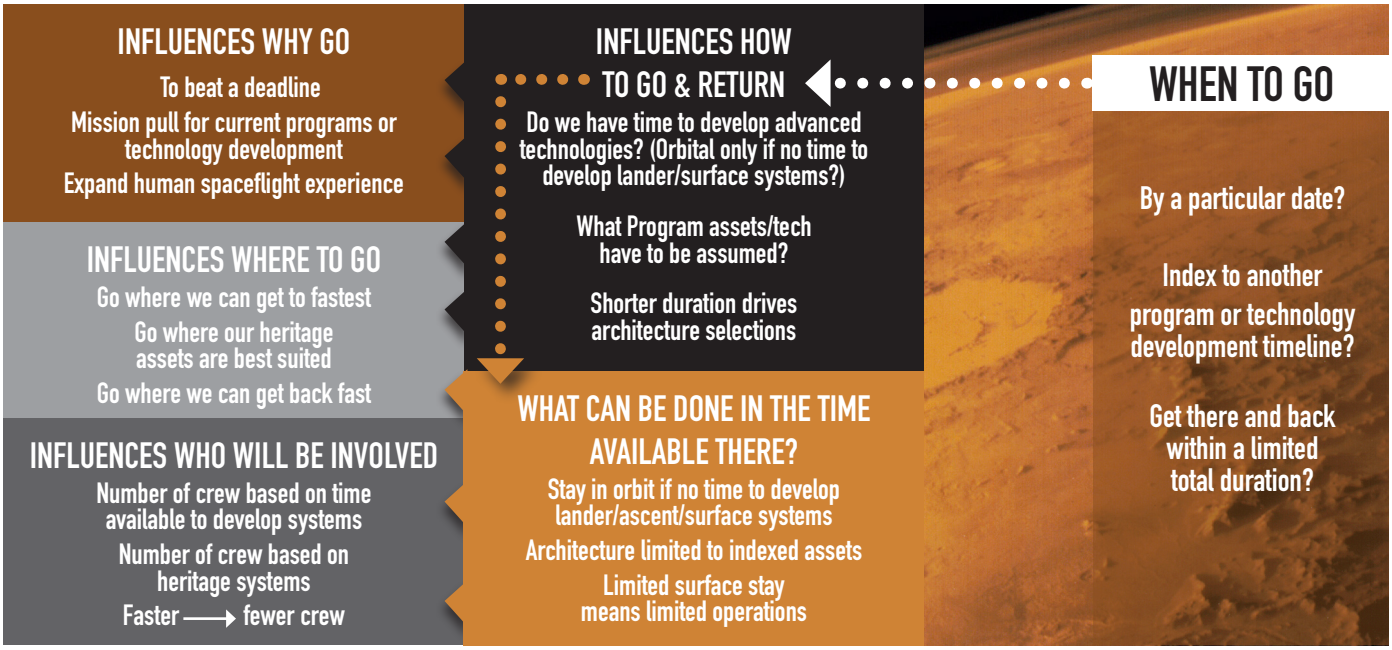

Figure 2. Architecture decision flow if starting with "when?"

With few architecture decisions mandated thus far, human Mars exploration offers a unique opportunity to take an objectives-based exploration architecture development approach.
NASA's new Moon to Mars Blueprint Goals and Objectives for Exploration initiative1 provides such a framework. In contrast to a capabilities-based approach, an objectives-based approach focuses on the big picture, the "what?" and "why?" of what NASA should be doing in terms of deep space exploration before prescribing the "when?" or "how?"

As shown in Figure 3, NASA's exploration blueprint identifies many answers to the question of "Why?" Any single answer is unlikely to satisfy all stakeholders, but each answer is important to one or more stakeholders. Starting with "why?" will help anchor the development process, but architecture choices may still vary widely depending on how the many different answers to "why?" are prioritized. Must the first human Mars mission check off every item in the "Why?" Venn diagram, shown in Figure 3, or is it sufficient to establish a first-mission architecture that meets the highest priority items, and is extensible to meet lower priorities during subsequent missions.

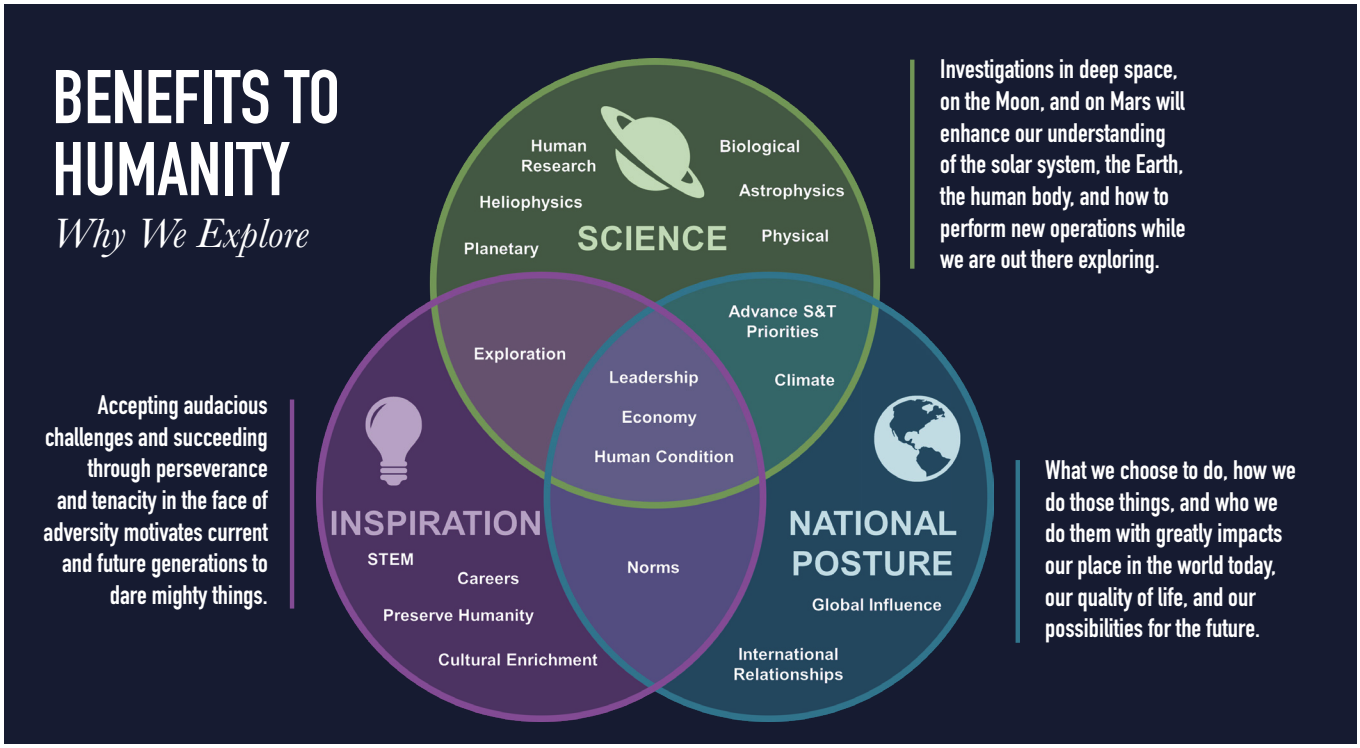

Figure 3. "Why?" Explore

For example, prioritizing Science on the first human Mars mission will influence "where?" the landing site is selected if the specific science objective of interest requires access to a particular region or feature; this may require mission elements (the "how?") tailored to that particular science discipline. If that priority science location is difficult to reach or lacks the resources for sustained human presence, a lighter exploration footprint may be desired for the first mission, and crew selection may be heavily influenced by science expertise. Conversely, if Inspiration, in the form of sustained human presence is the priority goal, then a landing site offering abundant resources or ease of access may be desired, with the first mission elements laying the groundwork for a heavier, permanent infrastructure at a single location, able to support a larger number of crew, possibly selected for their engineering expertise. As shown in Figure 4, again architecting from the right, different priorities within "why?" will cascade through the other questions.

These sample decision structures illustrate an important point: the Mars architecture depends on which decisions are prioritized, and which are allowed to "float" to enable the highest priorities first. In practice, the Mars architecture decision flow is likely to be iterative rather than linear. To minimize disruption, rework and cost or schedule changes, understanding the minimum goals and priorities for the first mission, as well as the longer-term goals for subsequent missions, can aid in establishing a flexible and sustainable architecture. The answer to any one of these questions is less important than whether the answers to all six complement one another as a set and can be balanced to establish an architecture that is achievable, affordable, and adaptable.

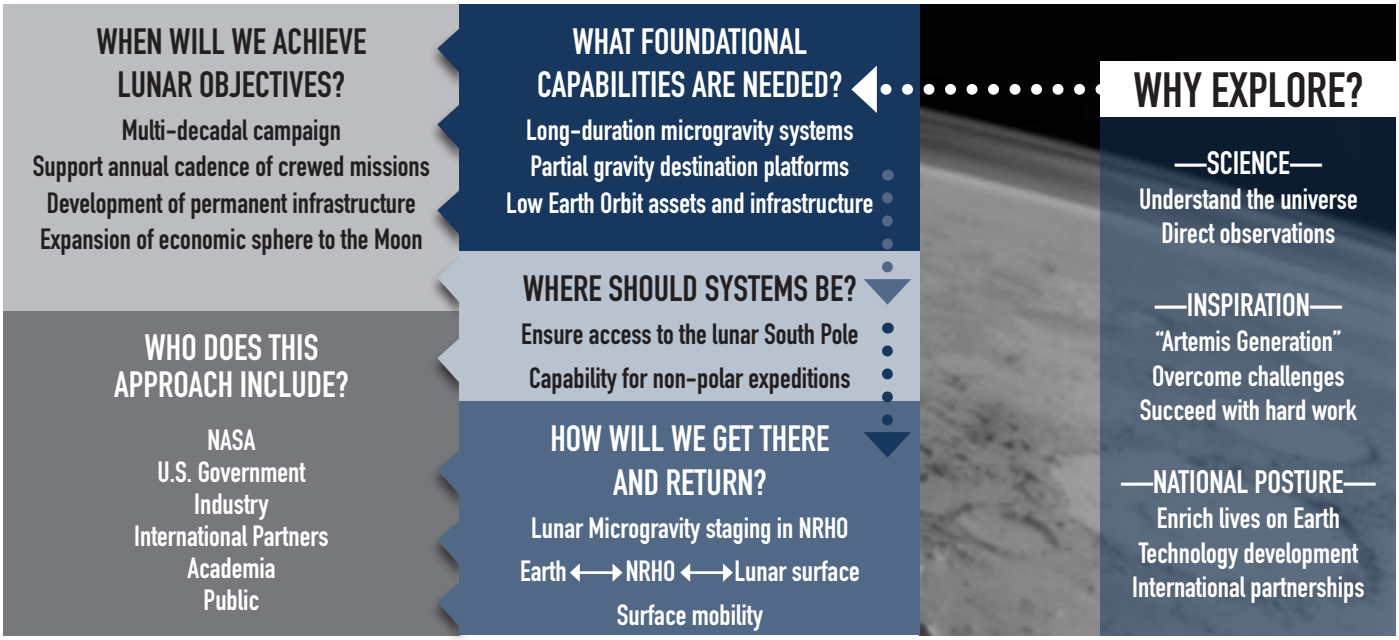

Figure 4. Architecture decision flow from "why?"

KEY TAKE-AWAYS

Mars architecture will be shaped by the answers to six questions: Who, What, Where, When, Why, and How? It is critically important for decision-makers to understand how these key decisions relate to each other and how the architecture varies depending on the order in which these decisions are made, or how different facets are prioritized within a given aspect. The answer to any one of these questions is less important than whether the answers to all six complement one another as a set and meet the agency's overall exploration objectives.

This white paper was developed as part of NASA's 2022 strategic analysis cycle to address topics of frequent discussion. For the latest white papers or other architectural documents related to human missions to the Moon and Mars, please visit: www.nasa.gov/MoonToMarsArchitecture.