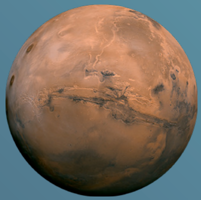
National Aeronautics and Space Administration

Mars Crew Complement Considerations



2024
Moon to Mars Architecture

white paper

Introduction

Crew complement — or the number of astronauts on a mission to accomplish set responsibilities — is a key driver for human exploration architectures, with flow-down impacts on most elements and sub-architectures. As such, it was identified by NASA as a priority decision in the 2023 Moon to Mars Architecture white paper, "Key Mars Architecture Decisions."[1]

The number of astronauts an architecture must accommodate has direct implications for a habitable element's volume, performance of associated environmental control and life support systems, power needs, crew support system considerations, and logistics needs (e.g., for utilization, food, clothing, medical supplies, etc.). The number of crew that an architecture must support also drives the necessary capabilities for human-rated ascent and descent vehicles and all other exploration systems at the destination. In determining crew complement, it is important to look beyond just the first mission towards what the desired end state for the architecture is. For example, the first Space Shuttle flight only carried two astronauts, but the vehicle was designed to accommodate more.

Operationally, crew complement must account for the skills necessary to carry out planned tasks. The number of astronauts enables crew time available to accomplish the functions necessary to achieve mission objectives. These activities include utilization for science, outreach, and instrument deployment, as well as mission overhead for systems monitoring, maintenance, and troubleshooting.

Additionally, the number of astronauts has implications for the range of crew expertise available on a given mission. This consideration is particularly relevant for deep space missions, where the operational paradigm differs from spaceflight in low-Earth orbit. At destinations like Mars, a crew must operate with communications delays and potential disruptions that prevent real-time communication with flight controllers and subject matter experts back on Earth.[2]

Historically, crew complement has been a secondary consideration defined by the capabilities of pre-selected exploration elements. As such, crew complement has been determined based on a limited set of capabilities or more general qualitative statements.

The process of architecting from the right — as outlined in "NASA's Moon to Mars Strategy and Objectives Development" document[3] — allows a more holistic and integrated approach. NASA architects can evaluate the drivers and flow-down impacts of crew complement to identify the number of crew needed to achieve Moon to Mars objectives[4] during a human Mars mission.

This methodology for deriving the number of crew to Mars vicinity and the Martian surface — which may be different values — will identify architectural characteristics that have the most significant impacts to the decision. **Due to inherent flow-down impacts for most aspects of mission planning, it is critically important that NASA establishes crew complement early in the stages of architecture development.**

Crew Health and Performance Considerations

Unlike purely robotic missions, human exploration missions must consider both the physical and psychological health of the crew. A mission architecture must accommodate crew health and performance needs with an appropriately sized crew complement and prevent or mitigate scenarios where health issues could affect mission goals or, more importantly, jeopardize safe return of the crew.

The unique challenges of a Mars mission require an architecture to consider human system risks. Some of these risks include crew behavioral health, team dynamics, probability of crew medical conditions (and duration of associated care), and integration of the human system with other exploration systems.

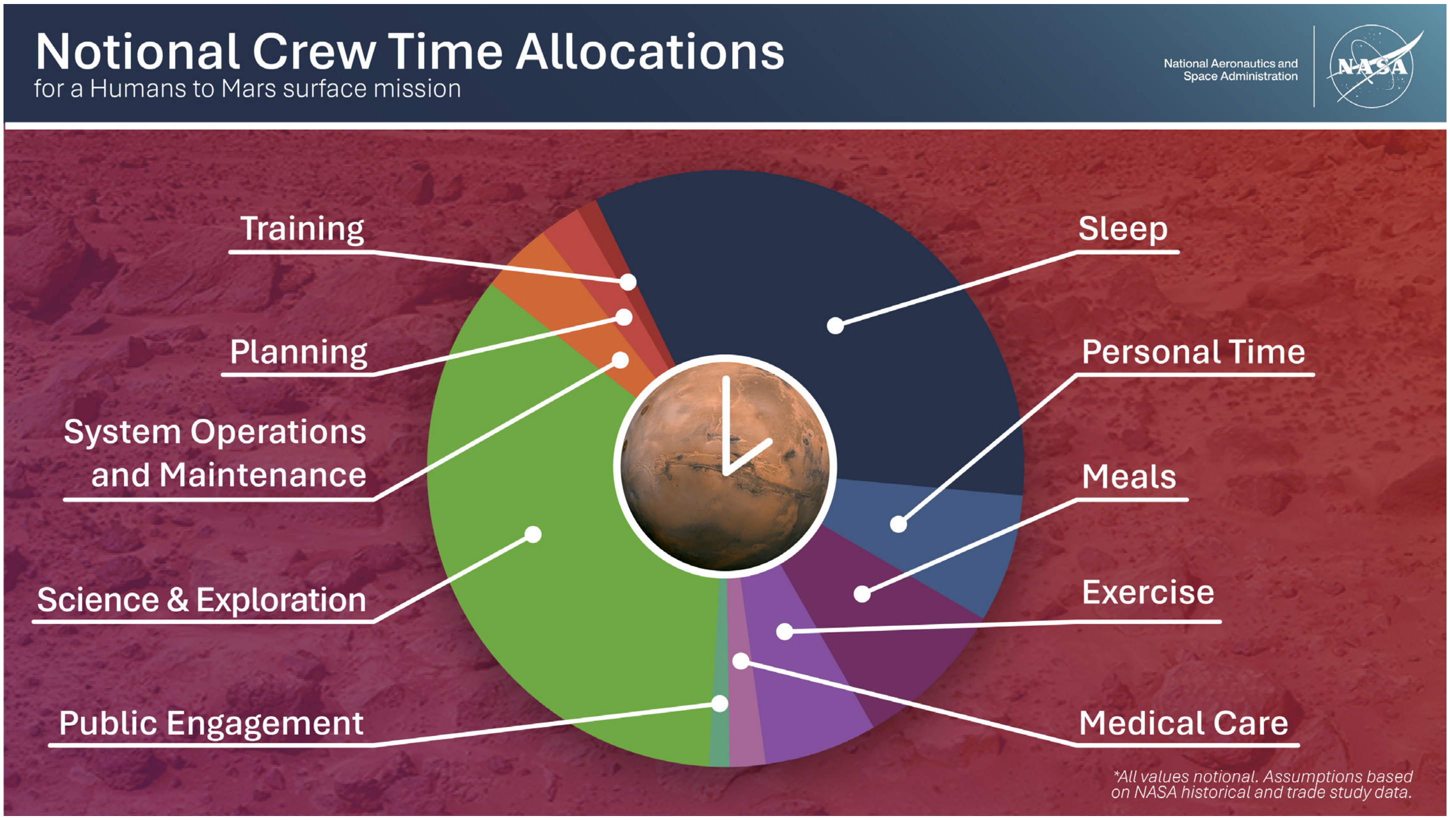


Figure 1: *Notional crew time allocations for a Humans to Mars segment surface mission. (NASA)*

Human systems integration is perhaps the most complex of these risks. These risks are intrinsically linked with crew task load, system design, and human interactions with exploration systems.

Additionally, the demands on astronauts may change throughout the mission. Deviations in environmental, communication, or mission phase–related stressors can have deleterious effects on crew physical and psychological health.

For more details, read the 2023 Moon to Mars Architecture white paper, "Human Health and Performance: Keeping Astronauts Safe & Productive On a Mission to Mars."[5]

Crew Responsibility Considerations

Each crew member will have defined responsibilities and proficiency levels to support a Mars mission. Specific expertise may be leveraged across an entire mission (e.g., for vehicle monitoring and maintenance, medical care, etc.) or called upon during specific mission-critical phases (e.g., for launch or landing preparation, in-space docking, surface exploration, etc.).

There are practical limitations on how many in-mission responsibilities a single crew member can support. Extended periods where a mission requires intense mental strain or burden on crew ability — whether during nominal operations or critical events — can result in burnout and significantly degrade health and performance. The more crew on a mission; the more that duties may be shared and stressors may be minimized.

Due to the distances and communications delays associated with a Mars mission;[2] the crew must also have the capability to operate independently, particularly during mission critical events. Crew members will need to accomplish many responsibilities traditionally performed by terrestrial mission control during low-Earth orbit or lunar missions.

In establishing a crew complement, NASA must consider the complement of astronauts needed to ensure needed skills and expertise to accomplish nominal tasks, time-critical contingency operations, and mission utilization objectives.

Crew Workload Considerations

Understanding a crew's day-to-day workload and ensuring a healthy work-life balance are key aspects of selecting the number of crew. Daily, the crew must maintain mission systems; conduct science, technology utilization, and public engagement activities; plan for upcoming mission milestones; and keep up with necessary training — all while meeting the physical and cognitive requirements of specific tasks.

Each day must also include sufficient time for meals, exercise, hygiene, sleep, relaxation, and other crew health and performance activities. Successful mission design for crew workload will fall within reasonable human limitations. An excessive workload can increase the rate of human error during task execution, result in a failure to complete tasks, and degrade response time during critical or contingency operations.

Many tasks performed on the International Space Station (e.g., during extravehicular activity (EVA)) rely on significant coordination and support from Earth-based personnel. During a Mars mission, much of that real-time support will need to be provided by members of the crew instead because of communications delays, disruptions, and limitations.

Autonomous technologies and systems could reduce crew burden and, ergo, the minimum crew complement needed to support exploration systems and functions. However, an architecture must identify opportunities for the implementation of automation and autonomy early enough in the mission design process to allow for the design, integration, and testing of new systems.

Mission Concept of Operations Considerations

Crew allocation decisions result in differing concepts of operations, with flow-down impacts on exploration systems design and many other aspects of an architecture. Mission objectives or constraints may lead to splitting a crew between different locations. Some crew members may remain aboard a spacecraft in the vicinity of Mars while the rest descend to the surface. If the entire crew lands on the surface, any vehicles remaining in space would need to remain uncrewed and may increase vehicle autonomy needs in the design.

In the event of a divided crew, each group must be appropriately sized to safely complete their respective responsibilities and mission objectives. Mars mission architects must consider operational needs for tasks and activities specific to both the vicinity and the surface of the Red Planet. For example, surface EVAs have significant safety and operational support requirements. Sending a crew member on an EVA alone or leaving a crew member alone in a habitation element while others are on EVA may result in unacceptable risks.

Mission Complexity and Value Considerations

Crew complement can affect the overall complexity of a mission. The scale and complexity of vehicles and systems may vary based on crew complement, although increasing crew complement may also provide opportunities for economy of scale.

The number of crew an architecture must support can also drive the development of new technologies and systems. This is particularly true for Earth-independent systems needed to overcome the constraints of a more limited crew complement. A decision about crew complement may reveal a need for precursor missions to demonstrate certain integrated systems that enable a specific crew complement to achieve mission science and exploration objectives.

To support a larger number of crew, NASA may need to modify or expand crew training and Earth reconditioning facilities. Finally, programmatic, administrative, budgetary, and schedule constraints can also influence crew complement for a human mission to Mars.

Summary and Forward Work

NASA's Moon to Mars architecture allows for the opportunity for a holistic analysis on crew complement. NASA architects must carefully balance crew workload, skills, health, and safety with their need to achieve NASA's Moon to Mars Objectives. They must also consider the current state of the art, prioritizing the development of the autonomous systems needed to empower a given crew complement. Further, they must weigh the costs associated with a given crew complement against budgetary constraints.

Decisions about crew complement are enormously important and must be made early in the process of architecture development. The many flow-down impacts of the number of astronauts included on a Mars mission can shape all aspects of mission planning.

In the coming years, NASA will continue to analyze the Mars crew complement trade space, considering data and insights from its mission directorates, centers, technical authorities, and stakeholders. Ultimately, NASA will develop an integrated decision package that includes analyses and recommendations for review and approval by agency leadership as part of the annual Architecture Concept Review process.

For an example of a key driving decision made using this process, see the 2024 Mars Initial Surface Power Decision white paper published concurrently to this paper.

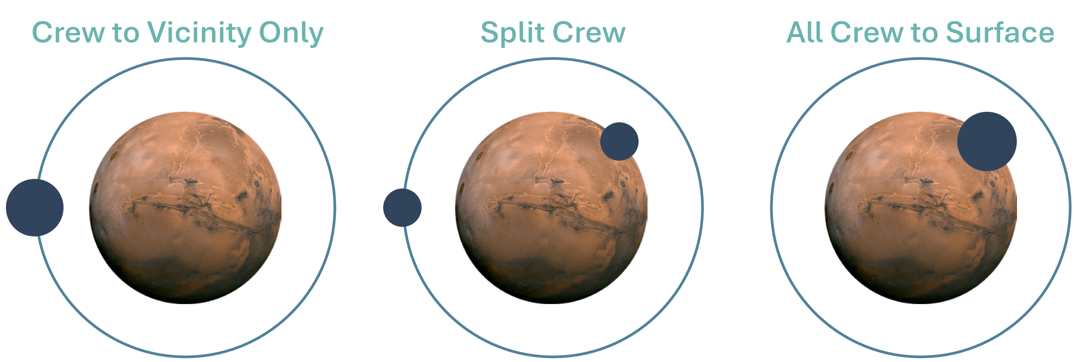


Figure 2: *Three crew concepts of operations for a Humans to Mars segment mission. (NASA)*

Key Takeaways

The number of crew an architecture must support has flow-down impacts on most sub-architectures and elements, with profound implications for key exploration systems, including launch vehicles, transit systems, ascent vehicles, communications infrastructure, and power generation.

Splitting a crew between locations (e.g., in space, inside habitat, on EVA, etc.) significantly impacts the architecture necessary to support them.

Key considerations for establishing the number of crew to the vicinity and the surface of Mars include balancing crew health, performance, operations, safety, utilization, technology integration, and exploration objectives.

Due to these flow-down impacts, it is critically important that NASA makes a decision regarding crew complement early in the stages of architecture development.

NASA will continue to analyze the trade space in support of a decision on crew complement, developing a decision package for review by agency leadership.

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