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Selecting a Trajectory for Human Missions to Mars

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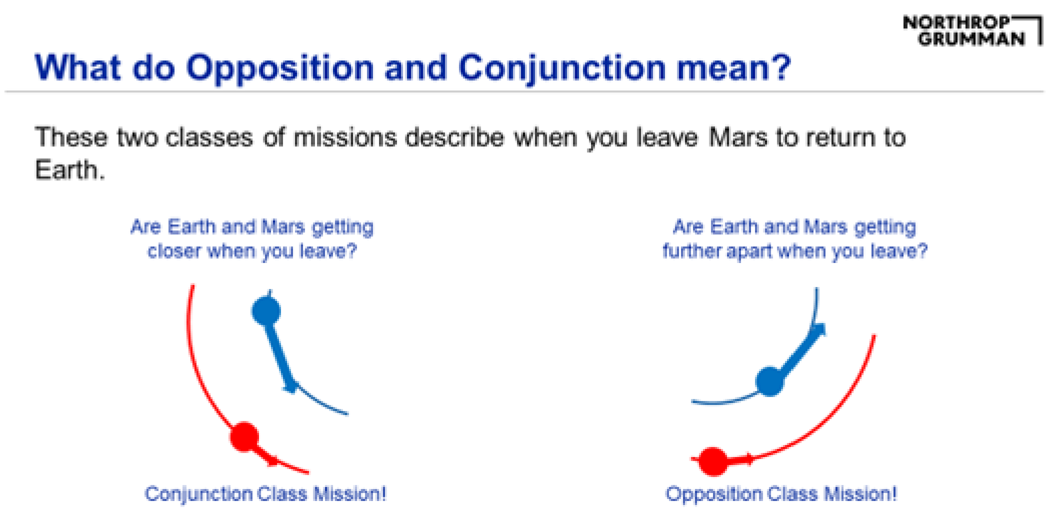
This paper summarizes the trades being considered for human missions to Mars in the 2030s, which is the stated goal of the United States space program. Missions that involve relatively longer stays on the martian surface are often referred to as “Conjunction-class missions”. Short-stay surface missions are often referred to as “Opposition-class missions”.

The figure below shows a simplified way to distinguish Conjunction-class missions from Opposition-class.



The overall trade space is complex, but fundamentally

- Shorter-stay missions use an alternative trajectory to minimize total time away from Earth, but are a challenge for propulsion technologies, in-space radiation protection, and long-duration microgravity exposure.
- Longer-stay missions are a challenge for other human health issues and require additional consumables and infrastructure to support the mission.
- A variant on the long-stay missions is a Conjunction-class fast transit mission, which employs additional propulsive capability to reduce the transit times between Earth and Mars. Essentially this requires additional propellant mass to reduce the total transit time by approximately 10 – 30 % depending on the departure year.

Below we summarize the features of the two types of human Mars missions, as well as those of a third type, which is a variation on the long-stay mission: (1) Long-Stay, (2) Fast-Transit Long-Stay, and (3) Short-Stay. There is no single option that addresses all issues and eliminates all risks. Discussions should center around which of these risks and challenges can be mitigated (and to what extent and at what relative cost) and how the Artemis Program can be used to best advantage to mitigate each risk and challenge.

CONJUNCTION: LONG-STAY

BENEFITS

- Shorter crew transit time between Earth and Mars: 160 – 180 days, same duration or shorter than typical International Space Station (ISS) crew rotation
- Over 500 days at Mars, allowing crews to conduct significant science and to thoroughly test equipment such as in-situ resource utilization (ISRU) that is required to sustain astronauts during future missions.
- Crew health can be maintained better on the surface of Mars than during long periods in deep space.
- More frequent launch windows: Approximately every 2 years
- Fewer technical challenges: Specifically, can be achieved with existing propulsion technology or with reasonable incremental developments.
- Long-stay missions will require less propellant mass for crew transport and will not require advanced propulsion or overcoming other major technical challenges that are necessary for short-stay missions.

CHALLENGES

- Longer total time away from Earth: Roughly 2.6 years.
- A longer mission requires more consumables and infrastructure mass.
  - More surface infrastructure, including power, environmental control and life support systems (ECLSS), and waste/trash management. Spare parts, and redundancy for critical systems and supplies, will also be needed. The impact of carrying more mass for these items may be offset by the lower propulsive needs of this mission type.
- Additional crew members may be needed to maintain the site.

CONJUNCTION: FAST-TRANSIT LONG-STAY

BENEFITS

- The transit times to and from Mars can be reduced by a month or more each way with less additional propellant mass than needed for Opposition-class missions.
- The trajectories never go inside the orbit of the Earth (i.e., 1 AU), reducing the thermal challenges, especially for cryogenic propellants, and reducing risk to the crew from solar radiation.
- The total time spent in microgravity and in deep-space radiation environments is lowest for this option.
- The surface times on Mars can be equivalent to the long-stay missions.

CHALLENGES

- Total mission length could be roughly 2.4 years, depending on the propulsion system used and the budgeted propellant mass.
- Similar issues with surface infrastructure and redundancy as long-stay missions
- Scenarios have been developed that require additional propellent, in-space staging, a “lean” transfer facility, and higher velocity re-entry at the Earth to reduce significantly the time in free space.

OPPOSITION: SHORT-STAY

BENEFITS

- Shorter total time away from Earth: Roughly 1.8 years (Note: If the mission were to be conducted in 2033, a particularly favorable launch window, the time away from Earth would be 1.6 years)
- Requires significantly less precursor infrastructure preparation on the martian surface than is required for the long-stay mission (see long-stay requirements above)
- A short-duration mission could increase understanding of the requirements for long-stay missions before committing to a specific site.
- A 2021 NASA/Baylor College of Medicine technical memorandum estimated that a short-stay mission could result in *decreased risk* as compared to the standard mission (i.e., long-stay). Most of the risks cited in the study are associated with the likelihood of a medical emergency arising during the time span of the trip. The 420-day trip time used in the Baylor study for the short-stay mission, however, would be very difficult to achieve, even with advanced propulsion systems. A more realistic trip time would be 650 days, offsetting much of this benefit.

CHALLENGES

- Less-frequent launch windows: as opposed to roughly every two years for the long-stay missions.
- Longer crew transit time: Total crew transit time would be approximately 650 days. In addition, their return trajectory would require the crew to travel much closer to the Sun, inside the orbit of Venus, increasing exposure to solar radiation and potentially solar storms (aka, coronal mass ejections).
- Larger propellant mass: required ΔV values average 3 times higher than long-stay.
- Probable need for advanced propulsion, such as nuclear thermal propulsion (NTP) or nuclear electric propulsion (NEP). These technologies are currently in the very early stages of research and development. Alternately, using conventional propulsion would require a substantially larger number of launches to position required fuel in space. The system complexity of advanced propulsion implementations may present development and mission reliability risks.
- Shorter surface time: 30 days, with only a small portion of this surface time dedicated to extra-vehicular activities (EVAs).
- Far less productivity: It is unknown how long it will take for crews to adapt to the martian gravity after many months at zero g. Even in the best-case scenario, only limited amount of science, EVAs, and technology demonstrations will be conducted.

OBSERVATIONS

The advantages and drawbacks of the short-stay missions are complex. It is not clear decreasing total mission duration by 27% - 30% is worth the near doubling of time spent in deep space, the significantly increased propulsive requirements, and the order of magnitude or more decrease in productive surface operations as compared to other mission options.

Advanced propulsion technology is important and should continue to be aggressively developed, but initiating safe and reliable crewed missions to Mars does not need to wait for advanced propulsion systems in order to proceed. Advanced technologies can be incorporated when they become available, human-rated, and proven to be more reliable, lower cost, and higher performance than current technologies.