National Aeronautics and
Space Administration

white paper
2023 Moon to
Mars Architecture

Mars Communications Disruption and Delay

Overview

The communications disruption and delay profile for a Mars mission will depend on the trajectory profile of the mission, though some generalizations can be made. While several factors can contribute to communications disruption and delay, this paper addresses the unique physical characteristics of Mars transit and Mars-vicinity operations.

Assuming nominal operation of communications systems, disruption occurs when the Sun or other planetary objects are directly between Earth and a spacecraft, rover, or other element. This obstruction severs the line of sight as the signal travels between Earth and Mars and results in a communications blackout. Interference from solar radiation can also degrade that signal without full obstruction.

The duration of a blackout depends on the communications protocol and signal strength. For any crewed, roundtrip mission to Mars, direct spacecraft-to-Earth communications blackouts are inevitable and can last weeks. Depending on the mission profile, these blackout periods can occur while the crew is in transit or the vicinity of Mars. NASA analyses show that blackout periods generally occur while the crew is at Mars for long-stay missions, and during transit for higher energy, short-stay missions.

For communications delays, the time required for signal to travel from Earth to a Mars element and back is a function of the distance separating the two. Communications signals travel at the speed of light in a vacuum, so signal transit time is the element's distance from Earth divided by the speed of light.

The exact profile of the delay will depend on trajectory, but the one-way communications delay for a crewed Mars mission can be upward of 21–23 minutes, with the longest delays occurring while the crew is at Mars or just after Mars departure.

Communications disruptions and delays for crewed Mars missions necessitate significant crew and system autonomy from Earth-based mission control, which drives certain system and operational requirements. Communications relay assets could potentially provide some relief from communications blackouts but would not eliminate delays, as the signal must still travel the same distance or farther to reach its destination.

Background

Approximately every 26 months, Earth and Mars are on exact opposite sides of the Sun. Astronomers call this celestial phenomenon — where all three celestial bodies are in a straight line — "conjunction." Figure 1 illustrates this feature that results from the relative orbits of planets.

Conjunction presents a challenge to any Mars mission in that it results in a communications disruption. This is because communications signals cannot pass through the Sun directly. The Sun also distorts any signals that pass too close due to the interference of solar energy.

For robotic missions, operations during these conjunctions are typically managed to reduce impacts on science objectives and increase spacecraft safety. Operating robotic platforms in safe mode and standing down of any operational activities reduces risk during a conjunction. However, those options are not available to a crewed mission, as crew activities must continue even in the absence of direct communications with mission control.

The extent of any communications disruption or blackout depends on communications equipment and sensitivity to interference from solar energy. A graphical representation of that angle, θ, can be seen in Figure 1. Communications equipment highly sensitive to solar interference would experience communications disruption with a higher value of θ.

Figure 1. *This diagram illustrates Earth-Sun-Mars conjunctions creating line-of-sight disruption between Earth and Mars (left) and the angle definition for communications disruption analysis (right).*

For the initial assessment of the blackout period during Mars missions, NASA assumed a θ value of 2° based on the current understanding of communications protocols and their susceptibility to signal disruptions. However, higher bandwidth communications protocols may have higher sensitivity to disruptions and could have a higher θ value.

Example 850-Day Short-Stay Roundtrip Mission to Mars

Figure 2 shows the communications disruption and delays for a representative, 850-day, short-stay mission to Mars. The top chart shows the Sun-Earth-spacecraft angle, and the bottom chart shows the one-way communications delay profile for this representative trajectory.

A 2° θ angle results in a communications disruption of three weeks of blackout around 450 days into the mission, about 100 days after the crew departs Mars from their surface mission. This three-week period of communications disruption and blackout would require significant crew and system autonomy from mission control. This drives certain system capabilities, redundancies, and operational needs for mission design and/or the addition of communications relays.

Example 1000-Day Long Mars Stay–Class Roundtrip Mission

Figure 3 shows the communications disruption and delays for a representative, 1,000-day mission typically associated with a minimum-energy roundtrip mission to Mars. Assuming an Earth-Sun-spacecraft angle threshold of 2°, the trajectory results in a communications blackout period of approximately 13 days during the phase of the mission in the vicinity of Mars.

Depending on the surface concept of operations, the crew could be on the surface of Mars performing exploration duties. This blackout period occurs about 100 days into the 300-day stay in the vicinity of Mars. This means critical events related to planetary arrival and departure should not be impacted by the disruption. For delays in communications, the blackout period coincides with the longest delay period of just over 20 minutes one-way, 100 days after Mars arrival.

Summary

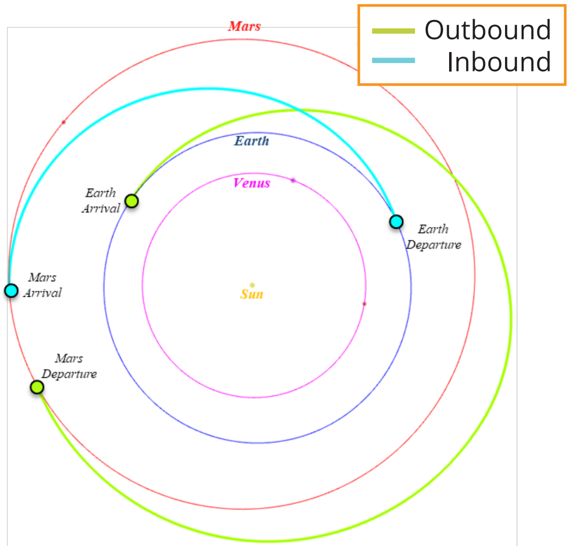
Communications blackouts and delays are unavoidable for crewed missions to Mars, though blackouts could be mitigated with communications relay elements. The design of crewed Mars missions must reflect this shift in communications paradigm when compared to low-Earth-orbit or lunar missions.

System and crew autonomy should be a significant focus in Mars mission design. NASA analyses can provide representative mission profiles, with estimated communications delays and blackout periods to inform those design parameters.

References

McBrayer, K., Chai, P., Judd, E., Communication Delays, Disruptions, and Blackouts for Crewed Mars Missions, AIAA ASCEND, 2022

Figure 2. *Communications disruption and delay for an 850-day, short-stay, roundtrip Mission to Mars with a communications blackout of about 21 days and maximum one-way communications delay of 22 minutes. Both blackouts occur during the inbound leg of interplanetary transit.*



Deep Space Duration: **850 days**
Mars Vicinity Duration: **51 days**
Solar Distance: **~1.0AU to ~1.8AU**

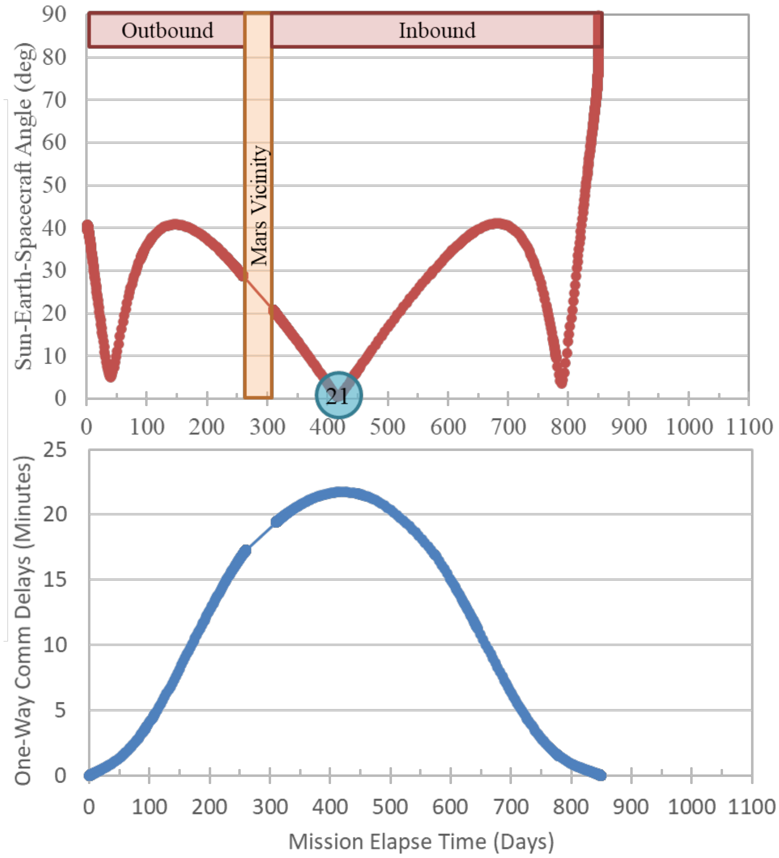
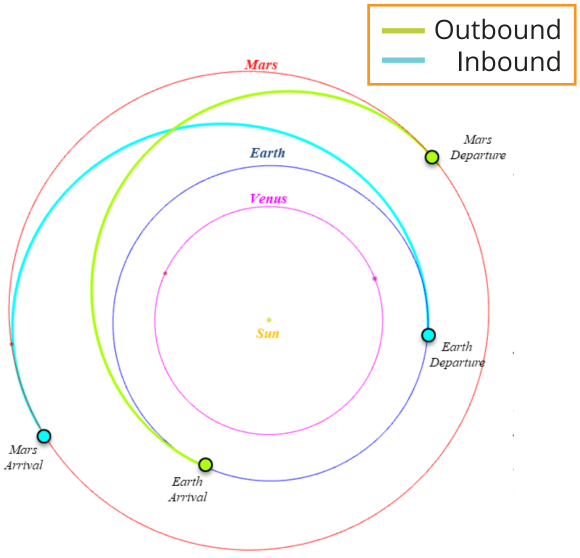


Figure 3. *Communications disruption and delay profile of a representative minimum energy, approximately 1,000-day stay, roundtrip mission to Mars with a communications blackout of about 13 days and a maximum one-way communications delay of 21 minutes. Both occur while the crew is in Mars orbit or on the surface of Mars.*



Deep Space Duration: **985 days**
Mars Vicinity Duration: **~300 days**
Solar Distance: **~1.0AU to ~1.6AU**