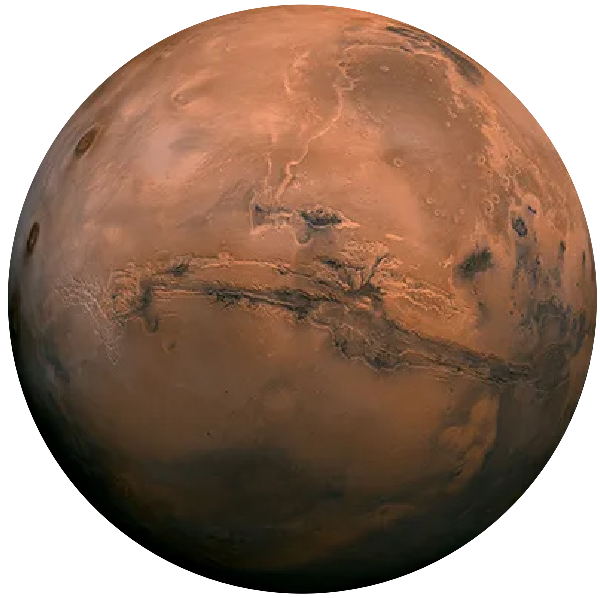
Mars Mission Abort Considerations



Overview

Throughout the history of human spaceflight, astronauts have never been more than a few days (and rarely more than a few hours) from Earth. Aborts for missions to low-Earth orbit or the International Space Station are relatively short. Aborts for lunar missions may be longer than aborts from Earth vicinity but are still measured in days.

On the transit to Mars, mission abort is a much more complicated event because of the sheer distance between Earth and Mars. The distance and scale differences between missions to the Moon and Mars mean lessons learned from lunar mission aborts will have limited direct applicability for Mars. Depending on when an abort is initiated in a Mars mission timeline, the heliocentric nature of transit — in orbit around the Sun — may require many months to return to Earth, regardless of the transportation system selected.

For transportation architectures that refuel in Mars vicinity, mission abort during outbound transit may not even be possible. In many cases, transit abort may not be a practical response to an emergency because the time to return the crew may exceed the crew's ability to stave off the emergency.

Early human Mars missions will also have limited abort options for descent to and ascent from the surface.

- **For descent —** where abort means returning to orbit — Mars' atmosphere and gravity will make it difficult to carry sufficient on-board propellant to initiate an abort for a human-scale payload.
- **For ascent —** where abort means returning to the surface – Mars will initially lack the specialized surface infrastructure and staffing needed to aid crew after the abort. Even a successful abort to the surface may leave crew stranded, far away from assets necessary for a safe return to Mars orbit.

Both of these challenges will require an entirely new contingency operations paradigm relative to our flight experience nearer to Earth.

Transit Abort Analysis

Due to the nature of celestial mechanics, abort maneuvers are inherently more challenging than nominal mission maneuvers. To understand the fundamental nature of these abort maneuvers, NASA evaluated three propulsion concepts for a crewed Mars mission. This initial scoping assessment assumes an example trajectory with a roundtrip duration of 850 days with a short stay in Mars vicinity.

The three transportation propulsion concept scenarios analyzed were:

- A hybrid abort, where a low-thrust hybrid nuclear electric propulsion (NEP) and chemical propulsion system utilizes both stages to perform abort maneuvers.
- A NEP-only abort, where the hybrid NEP and chemical propulsion system jettisons the chemical propulsion stage and utilizes only the low-thrust electric propulsion system.
- A ballistic abort, where a high-thrust propulsion system (e.g., a nuclear thermal propulsion [NTP] or all-chemical propulsion system) performs the abort maneuvers.

In all three cases, the analyses assumed that the transportation systems depart Earth with only enough propellant for the expected round-trip mission. Scenarios in which the propulsion system carries abort-specific contingency propellant were outside the scope of this initial assessment.

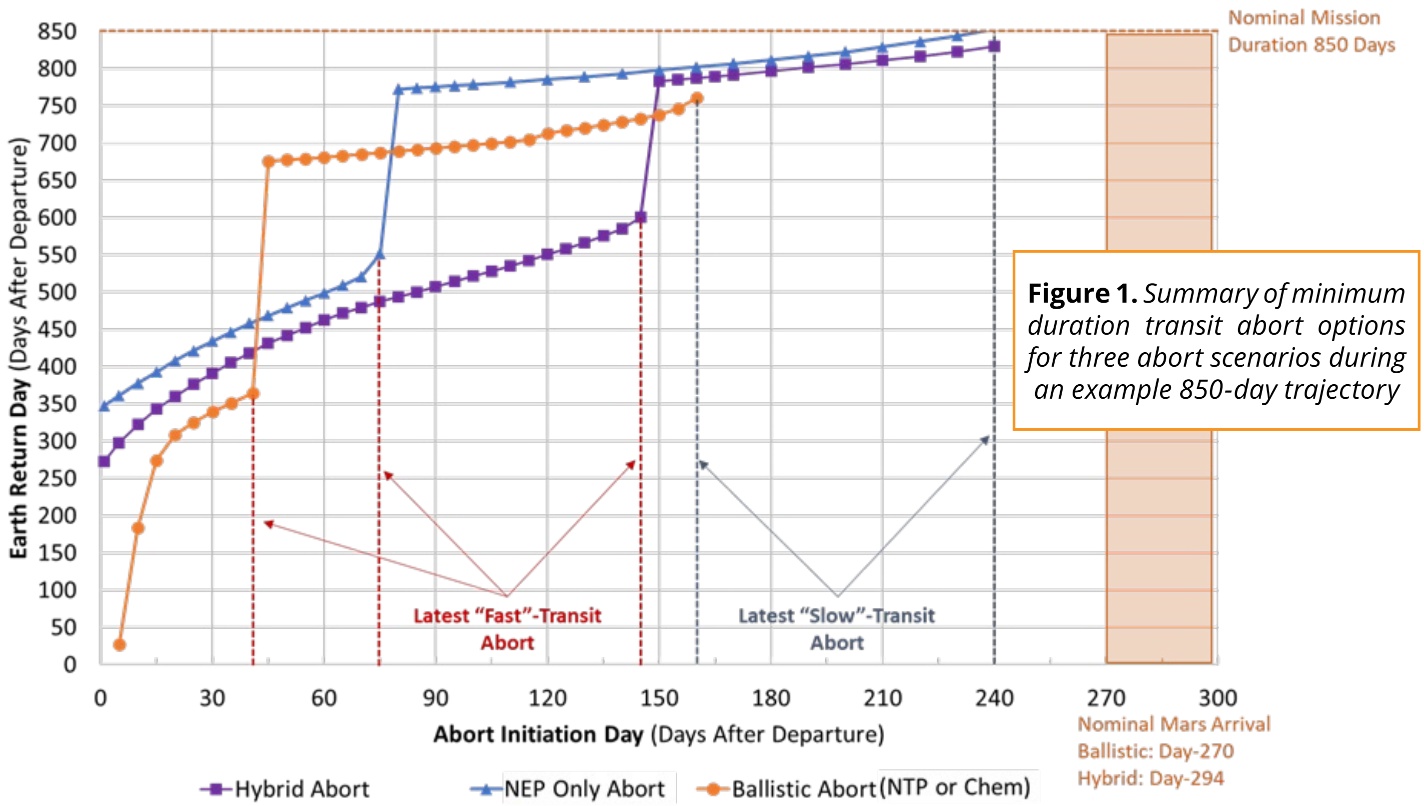
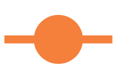
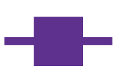


Figure 1. *Summary of minimum duration transit abort options for three abort scenarios during an example 850-day trajectory*

Figure 1 summarizes the minimum duration abort utilizing all remaining propellant as a function of the day abort is initiated for the three scenarios.



High-thrust, ballistic aborts using NTP or all-chemical systems provide an advantage if abort is initiated within a few days of departing Earth.



An abort using hybrid low-thrust systems can enable faster Earth return if initiated after 45 days.

A low-thrust hybrid system operating only on electric propulsion could still enable a faster return to Earth than high-thrust systems if abort is initiated between mission days 45 and 75, even with the loss of its chemical stage.

However, these differences may be inconsequential. An abort initiated beyond about 30 days of Earth departure will require a year or more to return to Earth in all cases. If a mission initiates an abort due to a life-threatening emergency like a failure of critical life support systems, a loss of crew is likely regardless of whether their transportation system is capable of returning to Earth by day 310 versus day 390.

To better understand these performance curves, it is necessary to understand the two classes of abort trajectories available:

- In a fast-transit abort, the spacecraft flies closer to the Sun to increase its relative velocity to Earth for a faster rendezvous.
- In a slow-transit abort, the spacecraft increases its distance from the Sun to reduce its relative velocity to Earth, allowing Earth to catch up for the rendezvous.

In this case, "fast" and "slow" are relative; even just a few weeks after departing Earth, the time required to return to Earth increases dramatically. An abort initiated on day 30 of a Mars mission would result in a return to Earth nearly a year later — on mission day 300+ — regardless of propulsion system. This fundamental shift in abort definition from previous crewed exploration campaigns is one of the primary findings of this analysis.

A ballistic abort utilizing high-thrust maneuvers and fast transit can return to Earth earlier than a hybrid propulsion abort. However, the availability of fast-transit abort is limited to about the first 40 days of the mission. After mission day 40, a ballistic abort is limited to slow-transit, while a hybrid propulsion system may pursue a fast-transit abort through day 75 if NEP-only and through day 140 if NEP and chemical.

These estimates only consider this specific mission trajectory and these transportation system conceptual designs. They may vary with other mission trajectories or concepts. The analysis shown here is not meant to generalize all abort scenarios. Abort capabilities are specific to a given scenario, with both abort availability window and return to Earth duration dependent on the exact situation that necessitated the abort.

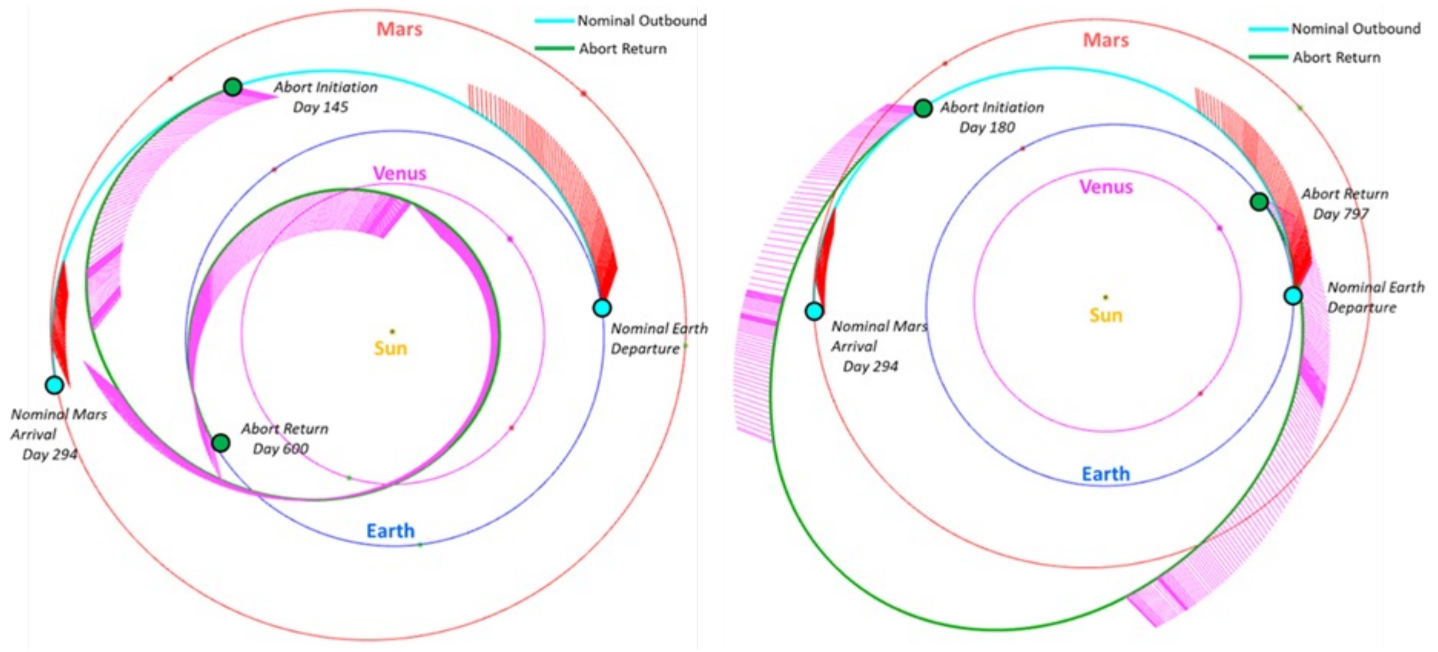


Figure 2. *Example "fast" transit (left) vs. "slow" transit (right) abort trajectories for an example 850-day short Mars vicinity stay–class roundtrip mission to Mars*

Fast-transit aborts would present significant challenges in thermal and radiation management, as the trajectory would push a mission significantly closer to the Sun than the expected mission trajectory. Spacecraft systems would need design modifications for these contingency scenarios to ensure crew safety.

Hybrid propulsion systems have wider abort windows for slow-transit aborts compared to the ballistic option. However, these aborts are significantly longer in duration and may mitigate less risk to a crew.

Risk mitigation for abort scenarios is a complex problem with many competing metrics. Without a holistic view of the integrated problem, it would be misleading to use abort as a discriminating factor between different transportation system options.

Additional details of this analysis may be found in the NASA-authored technical publication referenced below.

Key Take-Aways

A Mars transit abort will not mean an immediate return to Earth, regardless of the chosen propulsion system. Mission aborts will be measured in months, not days.

At Mars, there will be limited ascent or descent abort options for early human exploration missions.

Abort planning for crewed Mars missions requires a fundamental shift in thinking regarding reliability, crew risk, contingency planning, and mission operations.

To meet NASA's Moon to Mars Objectives, mission planners must develop a new operational paradigm. Mission abort alone will not be useful for crew risk mitigation.

Abort considerations will have flow-down impacts on vehicle design, redundancy and sparing strategies, and contingency planning. Understanding the complex interplay of these factors is the first step in developing a safe, reliable transportation system for crewed missions to Mars.

Reference

Chai, P. and M. Qu, H*uman Mars Mission Transit Abort Options for Ballistic high Thrust and Hybrid Transportation Systems*, AIAA 2022-4374, AIAA ASCEND, October 15, 2022. https://doi.org/10.2514/6.2022-4374