National Aeronautics and
Space Administration

M2M Architecture White Papers
Mars Challenges

Mars Missions Are Different

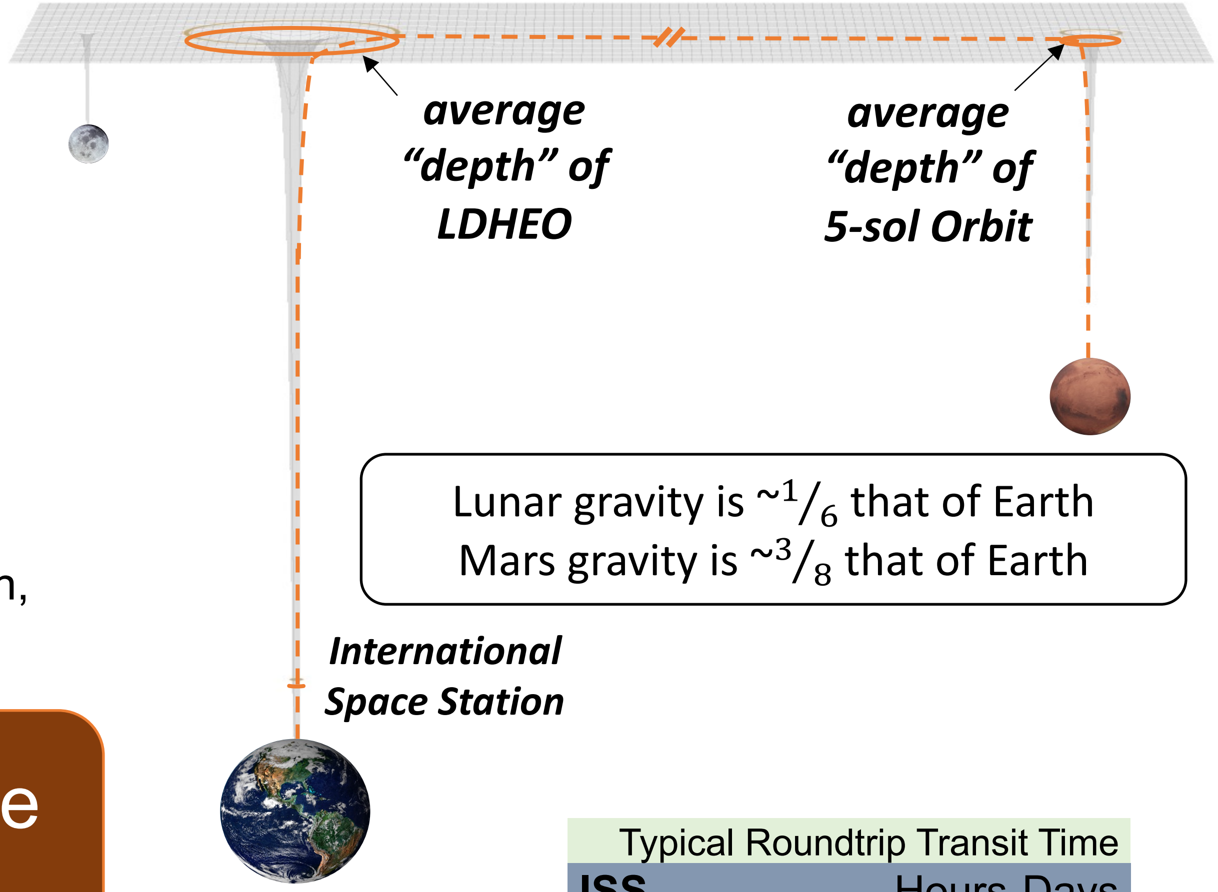
Mars is <u>much farther</u> than the Moon

	Closest Approach to Earth	Farthest Distance from Earth	Typical Round-Trip “Odometer” Reading
Moon	360,000 km	405,000 km	2,000,000 km
Mars	54,600,000 km	400,000,000 km	2,000,000,000 km

Mars gravity well is "deeper" than that of the Moon

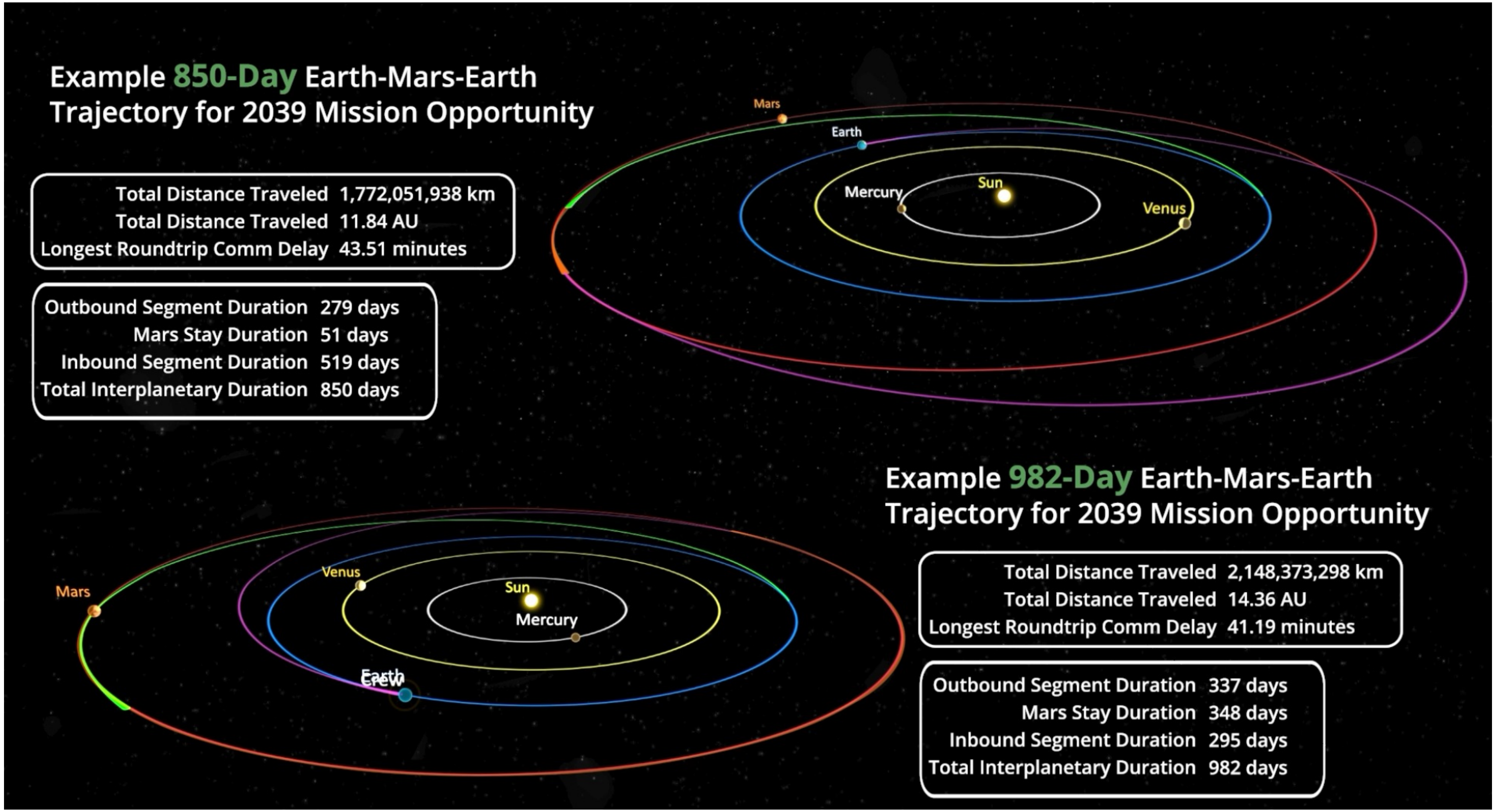
- Gravity wells help visualize gravitational pull
- Mars's gravitational pull is stronger than that of the Moon, requiring more energy to escape

Mars mission is unlike anything we’ve ever done for human spaceflight



Typical Roundtrip Transit Time	
ISS	Hours-Days
Moon	Days-Weeks
Mars	Years

Example Mission Trajectory



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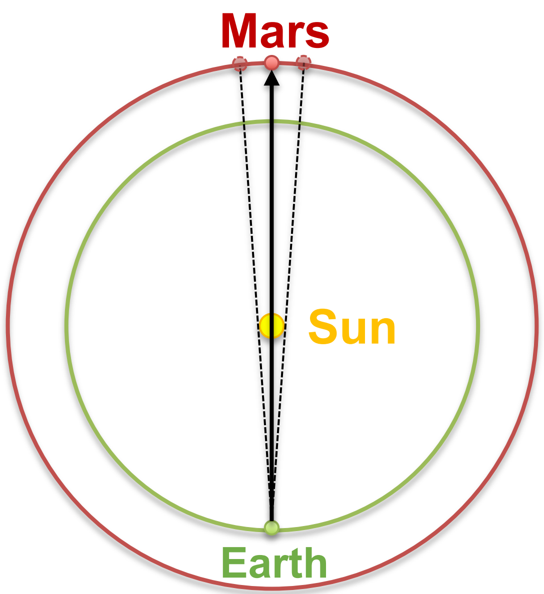
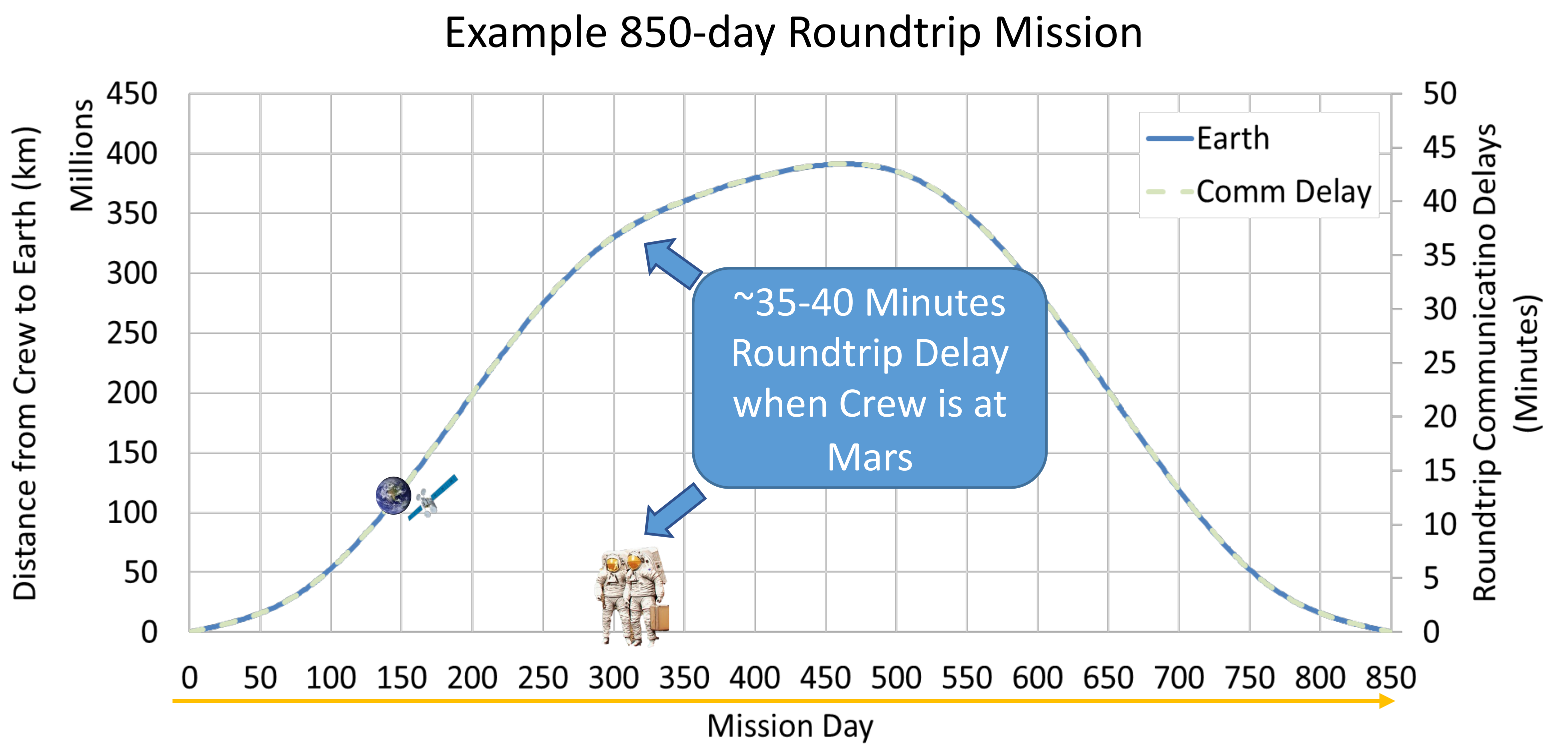
Communication Challenges



Solar Conjunction Causing Communications Disruption

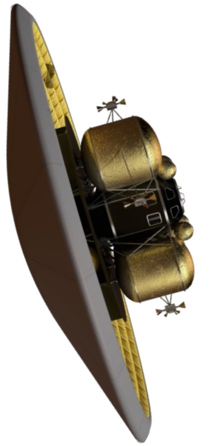


Need a new paradigm on HOW we communicate with crew

How to Get to the Surface?

	Viking 1&2	Pathfinder	Spirit & Opportunity	Phoenix	Curiosity	InSight	Perseverance
Diameter (m)	3.505	2.65	2.65	2.65	4.5	2.65	4.5
Entry Mass (kg)	930	585	840	602	3,151	606	3,369
Landed Mass (kg)	603	360	539	364	899	375	1,026

Human Class Lander Concept
16-19
47,000-65,000
36,000-40,000



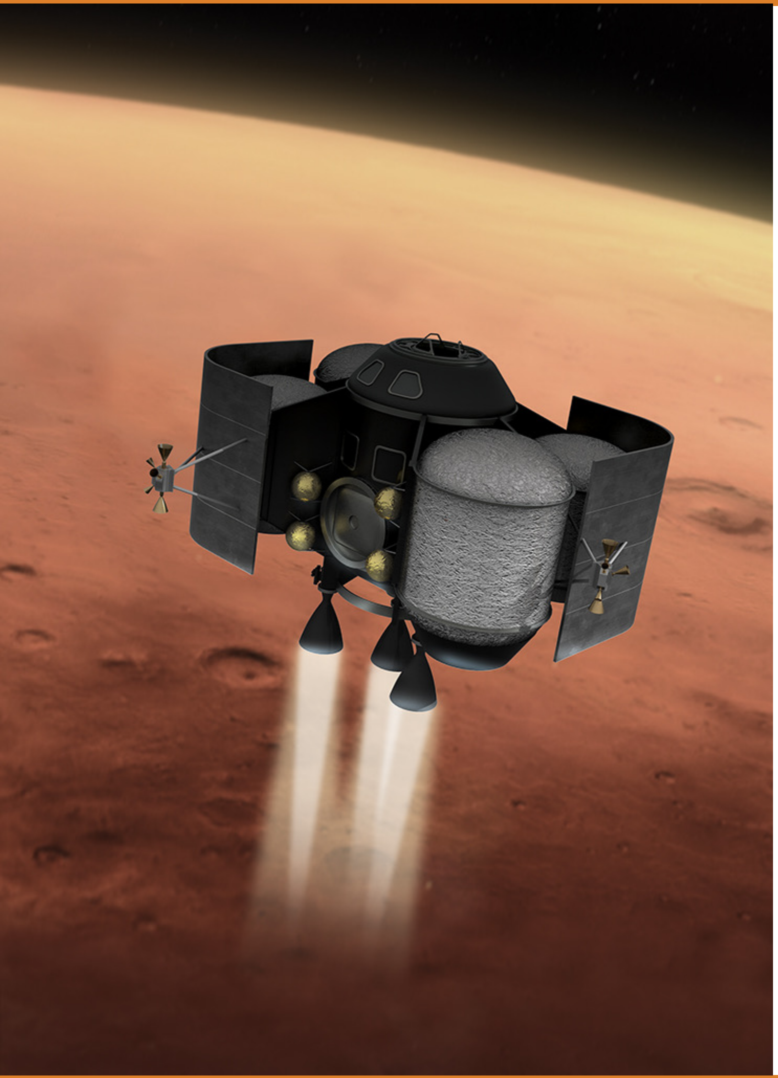
Steady Progression of "in family" Entry, Descent, Landing

Upcoming ACR24 White Paper

Alternate Mid-L/D Concept

New paradigm needed for Human Class Landers

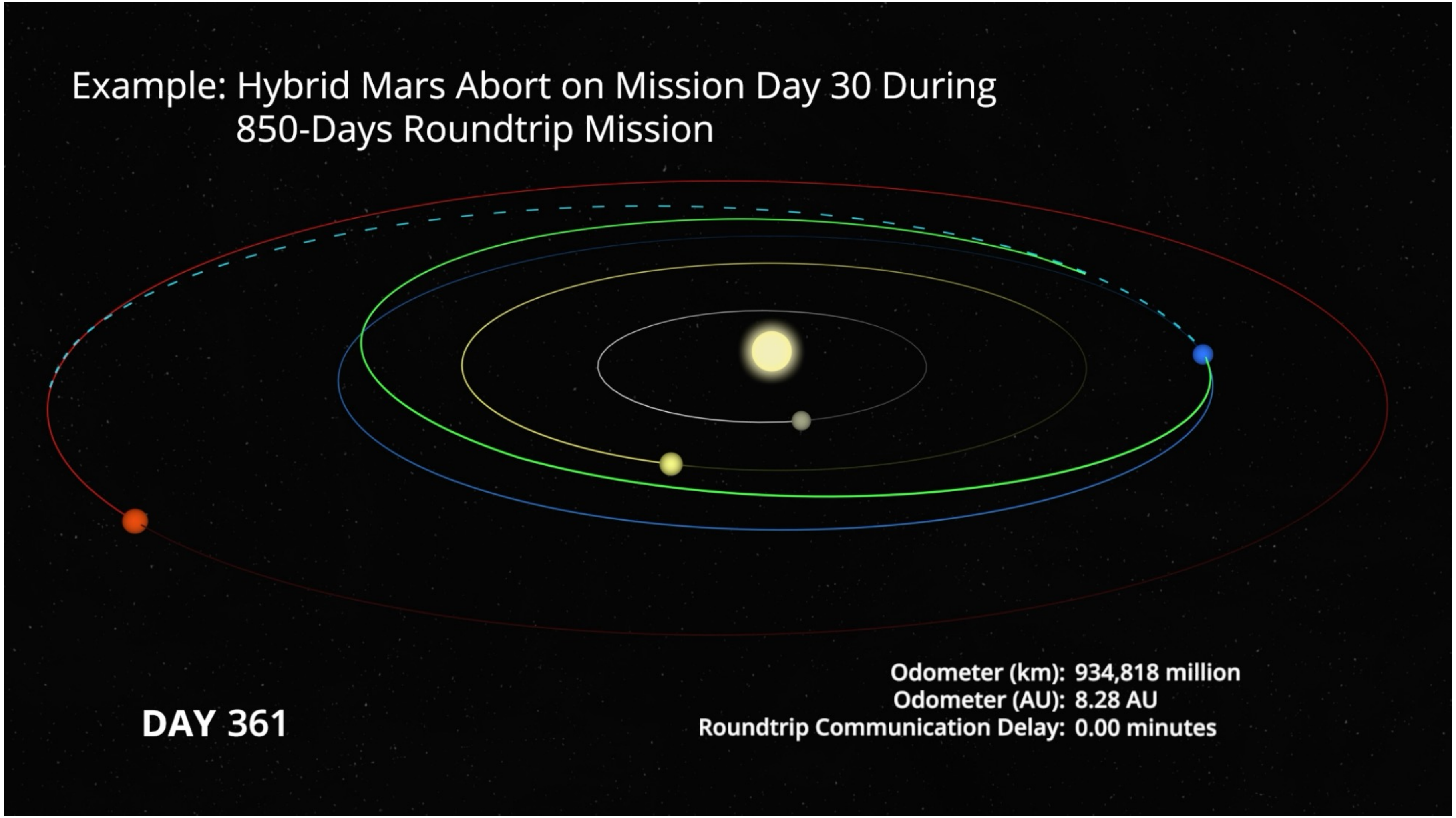
Getting Back Off the Surface



- Earth 100's human launches
  - Significant in-person ground support
  - Generous delay/abort capability
- Moon 6 human launches
  - Vehicle is delivered with crew prepared for ascent
  - Real-time ground support via coms
- Mars 0 launches
  - Little to no margin for delays
  - Little to no real-time ground support
  - Vehicle likely arrives unprepared for launch

Humans have ascended from only two celestial bodies to date, usually with significant support

Mission Abort Example

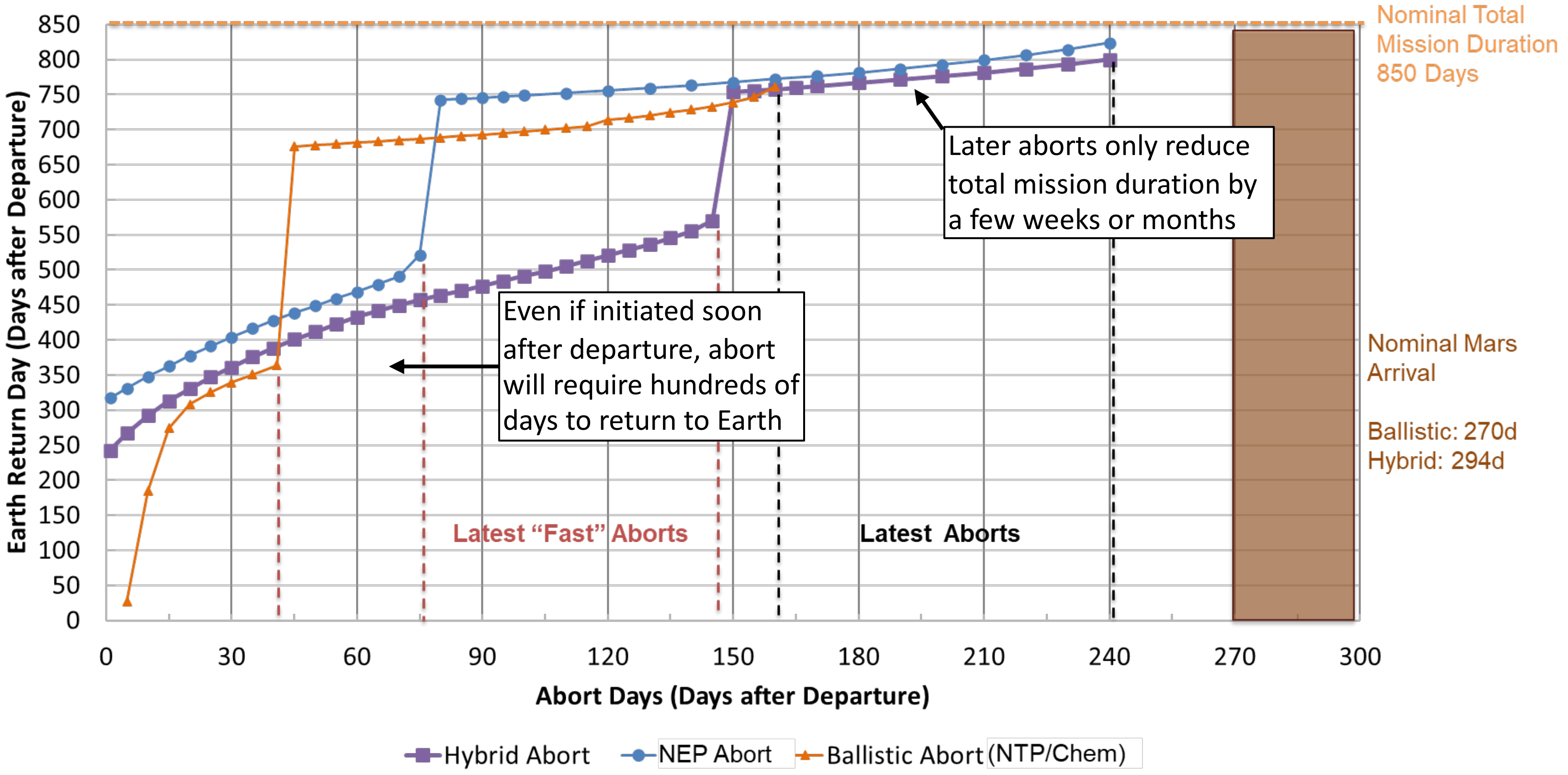


https://go.nasa.gov/4bVbqy4

What Does Mission Abort Mean?

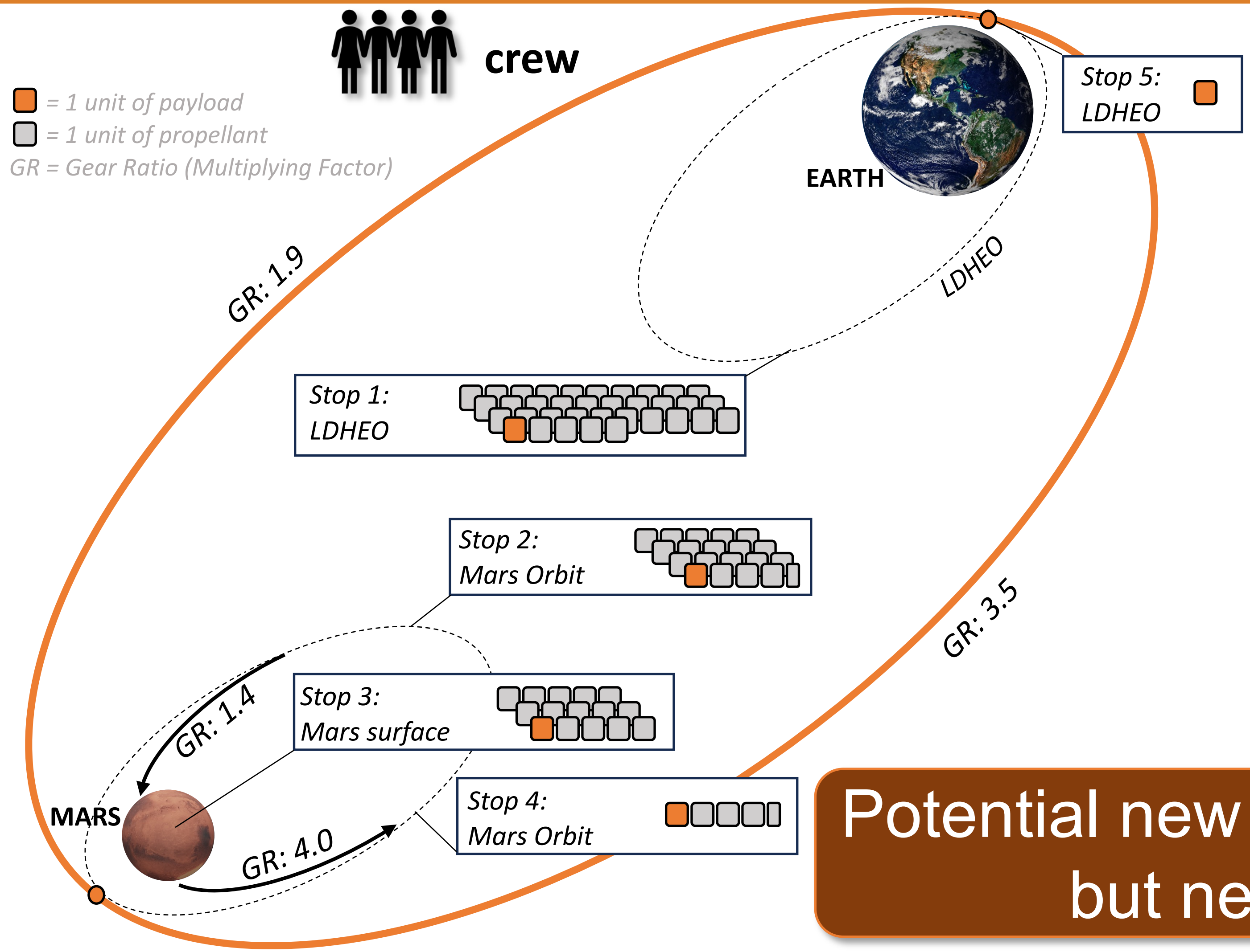
Mars mission aborts will be very different from past or current experience

- For LEO or Lunar operations, abort can return crew to Earth within hours or days
- For Mars missions, Earth return will be **months or years after abort initiation**
- <u>Abort may only shorten mission duration by a few weeks</u>



New paradigm needed for risk buy-down and contingency planning

A Mass-ive Challenge



The tyranny of the Rocket Equation

- Every kg added has multiplicative impact on the total mass required
- But mass is not EVERYTHING
- **Sometimes mass penalty can offset other challenge and be a net positive trade**

Potential new paradigm for launch mass / cost, but need to manage complexity

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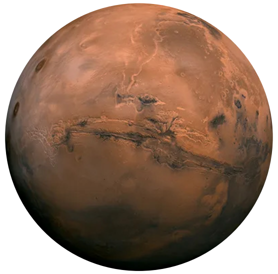
Mars Mission Abort Considerations



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.

white paper

2023 Moon to Mars Architecture

National Aeronautics and Space Administration

Round-Trip Mars Mission Mass Challenges

Introduction

As noted in the 2022 Architecture Concept Review "Mars Transportation" white paper, the distance between Earth and Mars changes constantly as the two planets revolve around the Sun. Regardless of their relative positions, traveling to Mars requires significantly more energy than lunar missions. However, the distance between the planets is only part of the story. This white paper explains how gravity wells, combined with the distance and desired transit duration between them, serve as a mass, and potentially cost, multiplier for a round-trip human Mars mission.

Escaping from a Gravity Well

A gravity well is one way to visualize the gravitational pull exerted by a large body in space. The "depth," or strength, of a given gravity well is a function of the planetary body's mass, with the bottom of the well terminating on the body's surface. For example, Mars is smaller and less massive than Earth, so Mars' gravity well is shallower than Earth's gravity well; the Moon is even less massive than Mars, so the Moon's gravity well is much shallower than either Earth's or Mars' gravity wells, as depicted in Figure 1.

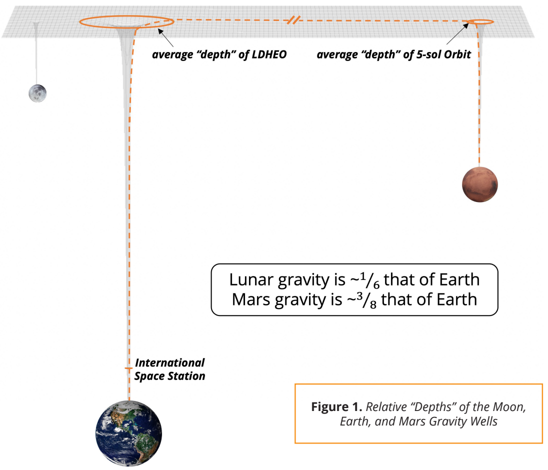


Figure 1. *Relative "Depths" of the Moon, Earth, and Mars Gravity Wells*

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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 t conjunctions are typically managed to r impacts on science objectives and in spacecraft safety. Operating robotic pla in safe mode and standing down o operational activities reduces risk du conjunction. However, those options a available to a crewed mission, as crew ac must continue even in the absence of communications with mission control.

The extent of any communications disr or blackout depends on communi equipment and sensitivity to interferenc solar energy. A graphical representation angle, θ, can be seen in Figure 1. Communic equipment highly sensitive to solar interf would experience communications disr with a higher value of θ.

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