National Aeronautics and Space Administration

Alternative Strategies for Exploring Mars and the Moons of Mars

Bret G. Drake / NASA Johnson Space Center, USA

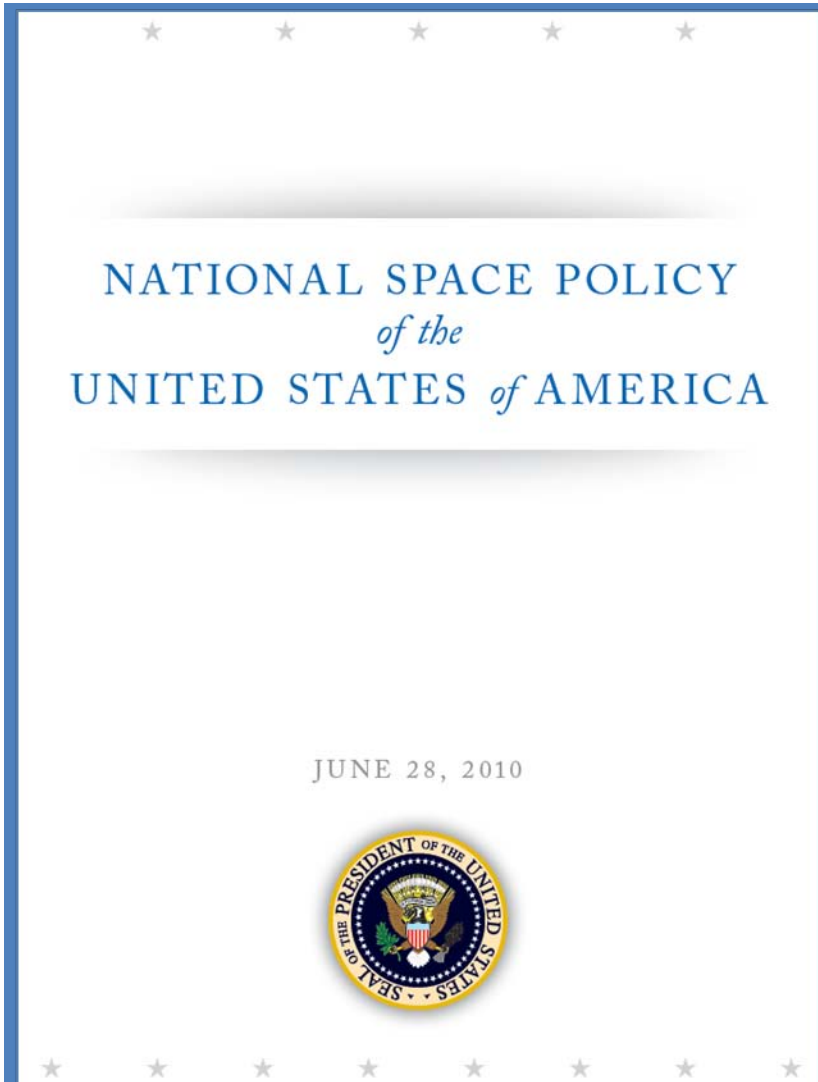
John D. Baker / Jet Propulsion Laboratory, California Institute of Technology, USA

Stephen J. Hoffman, PhD. / Science Applications International Corporation, USA

Damon Landau, PhD. / Jet Propulsion Laboratory, California Institute of Technology, USA

Stephen A. Voels, PhD. / Science Applications International Corporation, USA

2010 National Space Policy


NATIONAL SPACE POLICY
of the
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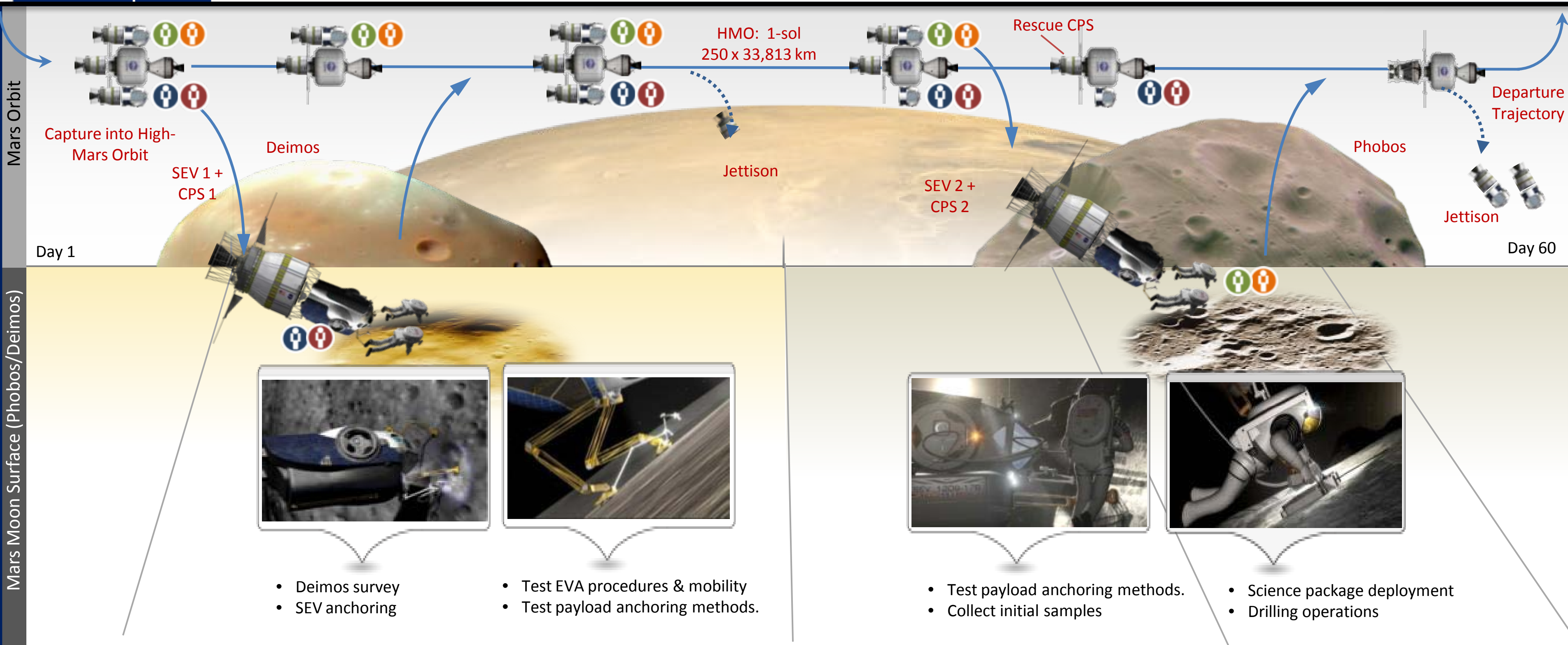
"Set far-reaching exploration milestones. By 2025, begin crewed missions beyond the moon, including sending humans to an asteroid. By the mid-2030s, send humans to orbit Mars and return them safely to Earth"

- Recent discussions have focused on the prospect of conducting a human mission to Mars orbit as a validation test prior to the surface mission
- These strategies are drawn from the historical precedence of the Apollo test missions
- Apollo 8 and 10 flew very similar mission profiles to the eventual surface missions
- But this Apollo analogy may not apply for much harder and longer Mars orbital missions

- **Careful examination of the required capabilities and knowledge needed is necessary to fully understand the key issues and applicability of a human mission to Mars orbit prior to a surface mission**

Short Stay Mars Vicinity Operations

Mission Sequence



Mission Summary

Assumed Mars Orbit Strategy

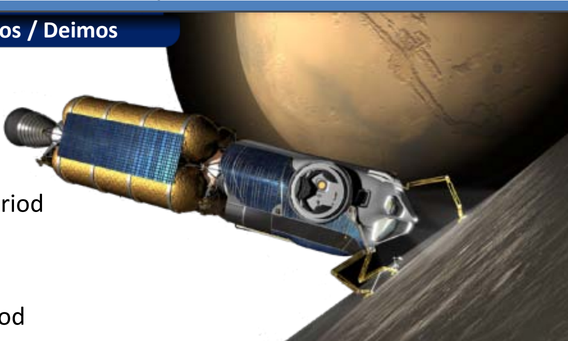
1. Capture into a 1-sol parking orbit with proper plane change to match departure asymptote
2. Leave Mars Transfer Vehicle in 1-sol parking orbit
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Deimos for 14 days (1,370-2,770 m/s delta-v required)
5. Utilize SEV-2 to explore Phobos for 14 days (1,700-3,170 m/s delta-v required)
6. Prepare for Mars departure
7. Trans-Earth Injection

Mission Site: Phobos / Deimos

Crew: 4

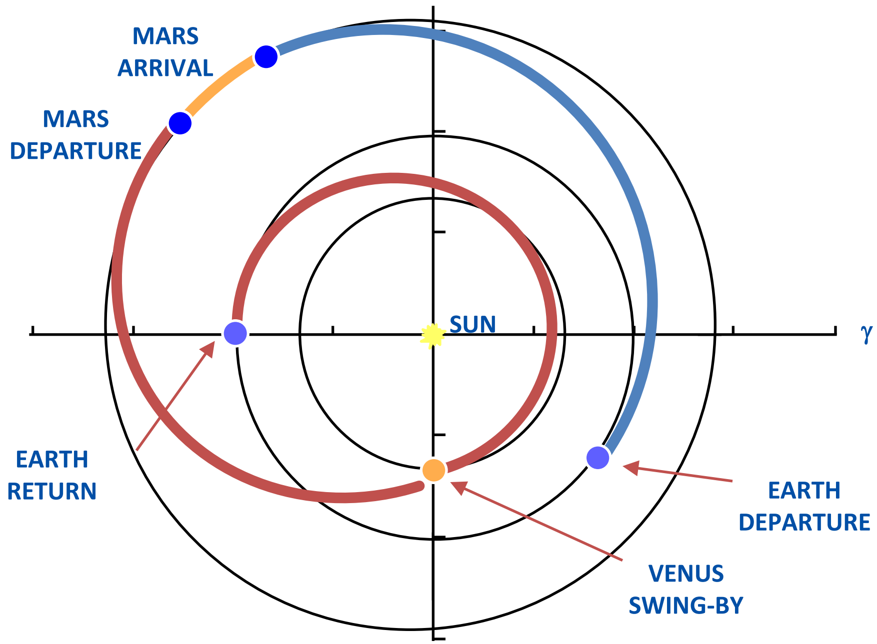
Deimos:
20,063 km circular
0.9 deg, 1.26 day period

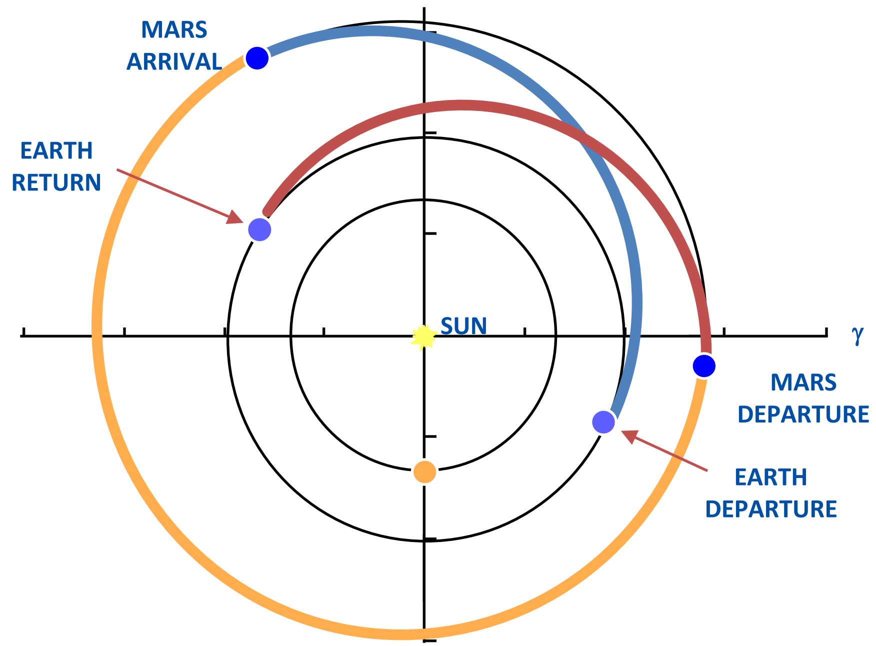
Phobos:
5981 km circular
1 deg, 0.32 day period



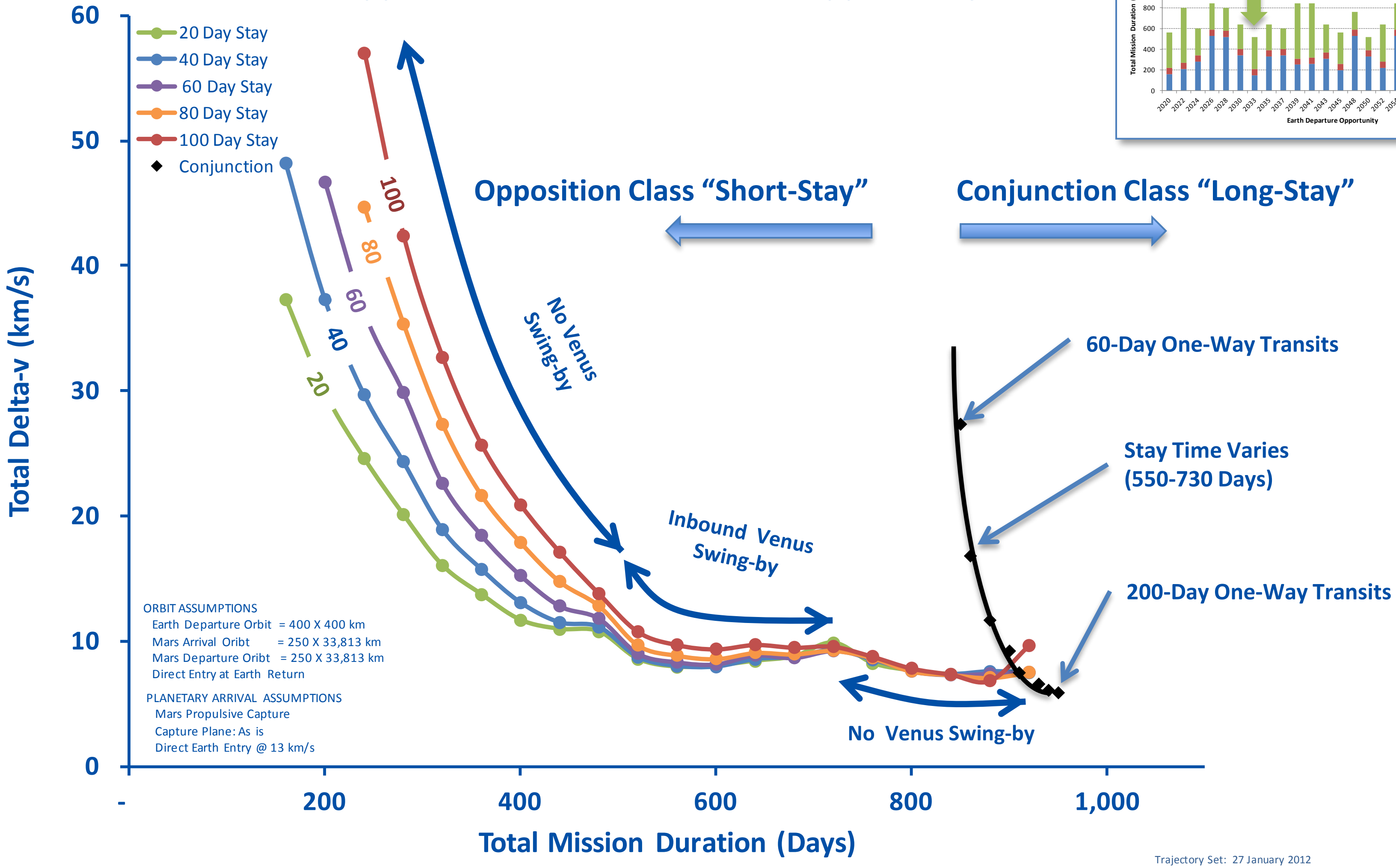
Mars Ballistic Trajectory Classes

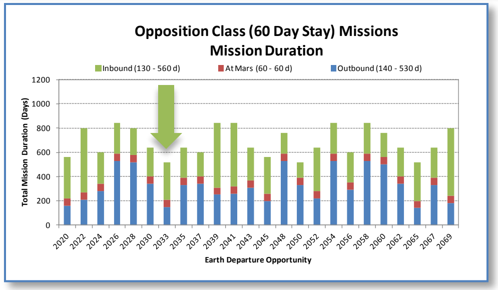
- **Short-Stay Missions (Opposition)**
  - Variations of missions with short Mars surface stays (20-60 days) and may include Venus swing-by
  - Total mission duration typically 540-840 days
- **Long-Stay Missions (Conjunction)**
  - Variations about the minimum energy mission
  - Long-stays at Mars (~500 days) and long overall duration (900-1000 days)





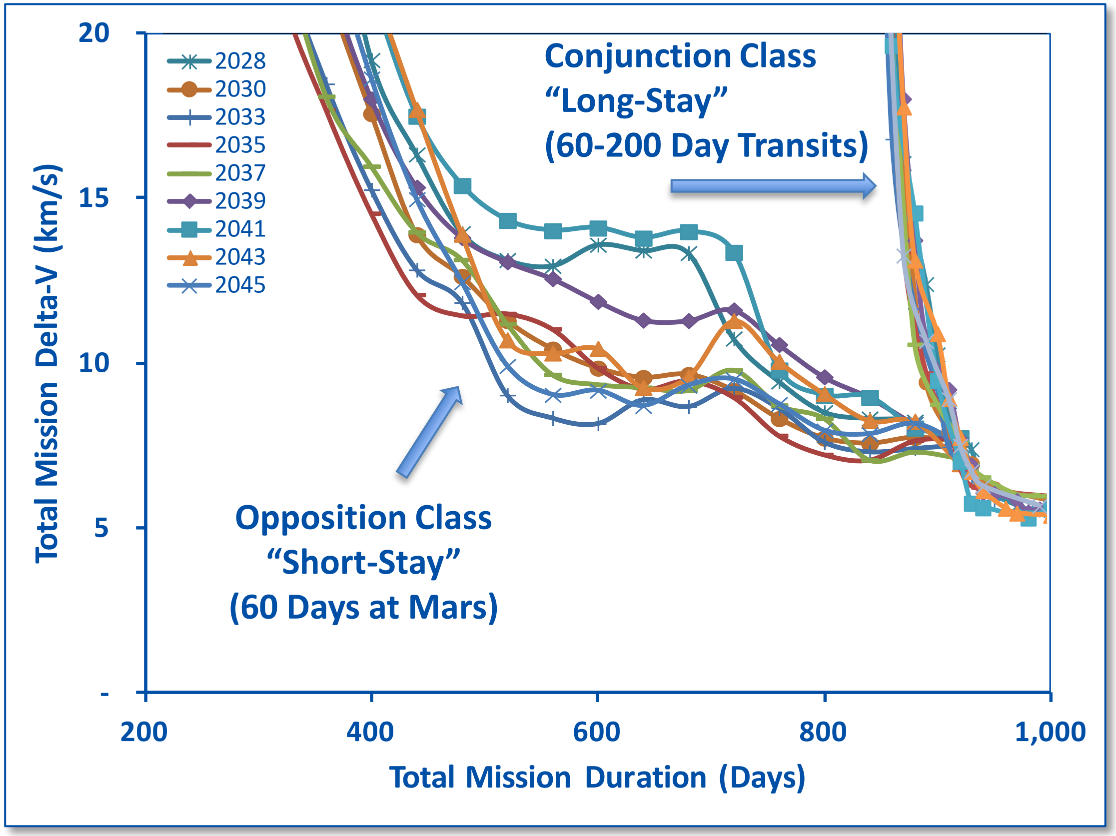
Example Delta-v versus Mission Duration





Total Crew Mission ΔV Sensitivity

Co-planar Trajectories



Mission Characteristics

- LEO: 400 km x 400 km
- HMO: 250 km x 33,813 km
- Direct Earth Entry: 13 km/s

- Mission opportunities (Earth departure date) occur approximately every 26 months
- Due to the difference in orbits of both the Earth and Mars, the required trajectories vary for each Earth departure date
- Short-stay (opposition) missions demonstrate significantly variation
- Less sensitivity occurs for long-stay (conjunction) missions

TRANSLATING ΔV TO MASS

Transportation and Exploration Systems Assumptions

Space Exploration Vehicle

- Primary purpose is for exploration of the moons
- Crew of 2 for 14 days
- Nominal mass = 6.7 t
- CH_4 Stage when needed:
  - Stage Fraction: 15%
  - Isp: 355 s

Multi Purpose Crew Vehicle

- Crew delivery to Earth orbit and high-energy Earth return
- CM inert = 9.8 t
- SM inert = 4.5 t
- SM specific impulse = 328 s

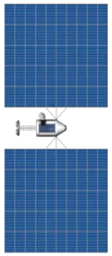
Deep Space Habitat

- Support a crew of 4-6 from 365 – 1100 days
- Mass Range : 28-65 t
- Consumables loaded based on crew size & mission duration

Chemical Propulsion Stage

- High-thrust propulsive stage
- Parametric design with each stage optimized
- Zero-boiloff cryo management
- Stage fraction ~ 23%
- Specific impulse = 465 s

Solar Electric Propulsion



- Low-thrust with solar power
- Spacecraft alpha ~30 kg/kw
- Specific impulse = 1800-4000 s
- Xe tank fraction = 5%
- Total power varies

Nuclear Electric Propulsion

- Low-thrust with nuclear power
- Spacecraft alpha ~20 kg/kw
- Specific impulse = 1800-4000 s
- Xe tank fraction = 5%
- Total power varies

Nuclear Thermal Propulsion

- High-thrust nuclear propulsion
- NERVA-derived common core propulsion (20 t core)
- 3 x 111 kN engines
- Specific Impulse = 900 s
- All LH2 fuel with zero boil-off
- Drop tanks @ 27% tank fraction

Space Launch System

- Gross Performance ~ 130 t
- Net Performance ~ 120.4 t
- Performance estimates to negative perigee conditions: (-87 km x 241 km)

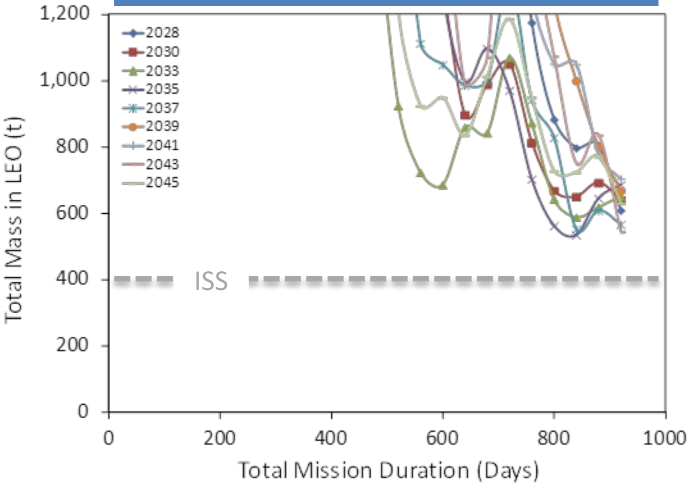
Mars Landers

- Parametric sizing of entry and landing systems
- Inflatable (HIAD) entry system assumed
- Wet lander mass: 89-113 t

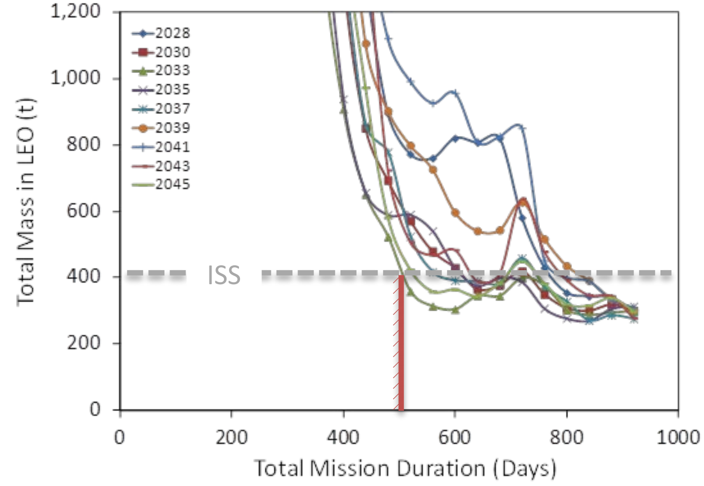
Opposition Class Missions Crew Vehicle Mass

With 60-Days at Mars

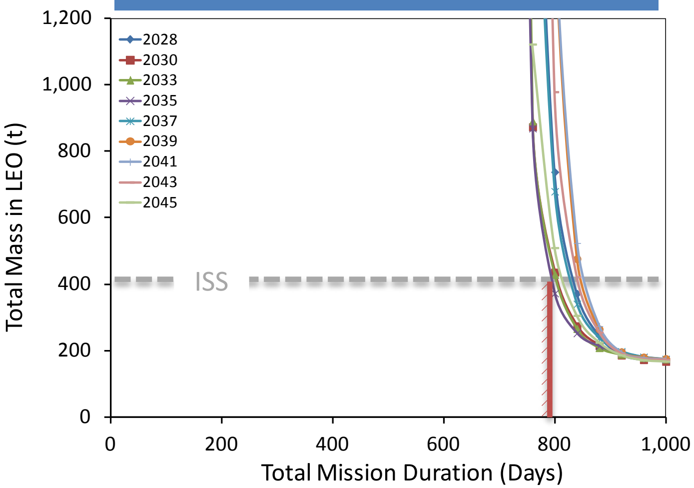
Chemical



Nuclear Thermal



Solar Electric



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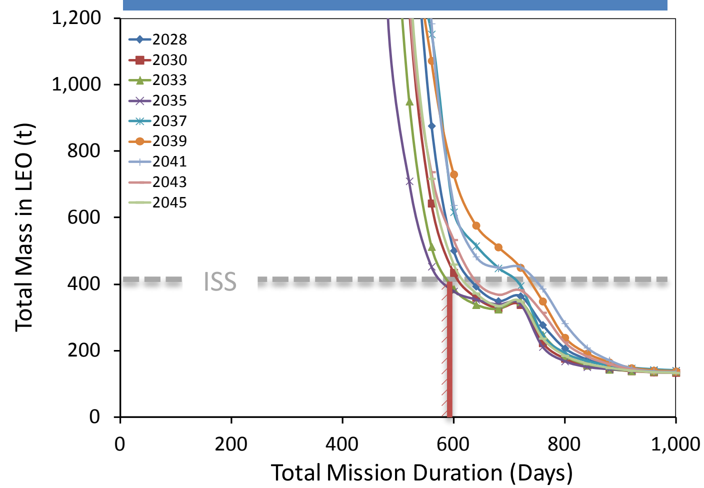
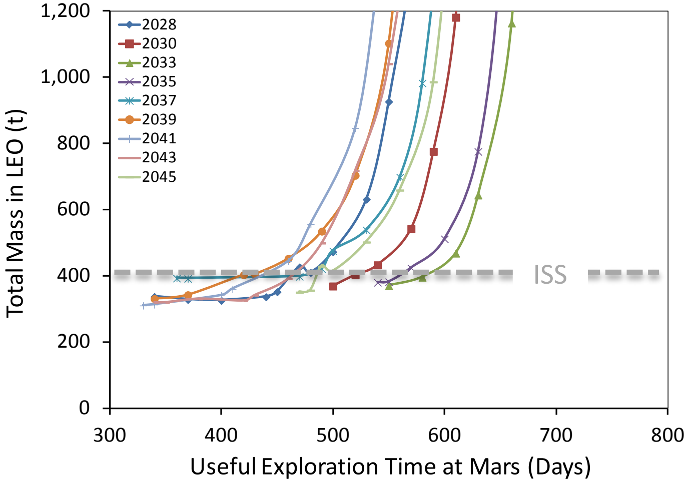


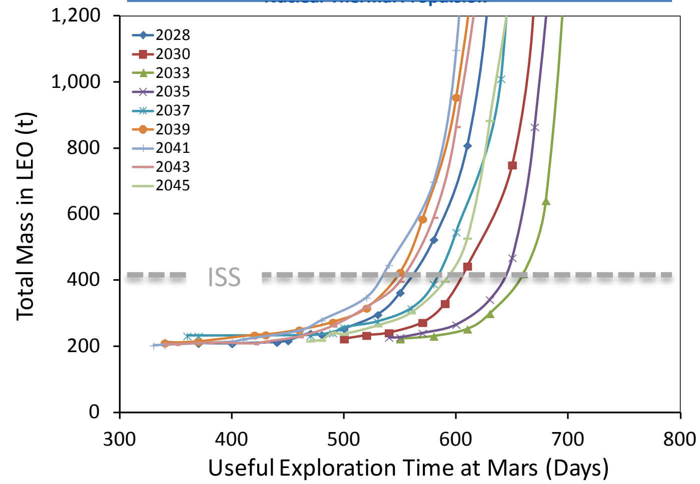
Conjunction Class Missions Crew Vehicle Mass

Total Mission Durations Approximately 1,100 Days

Chemical



Nuclear Thermal



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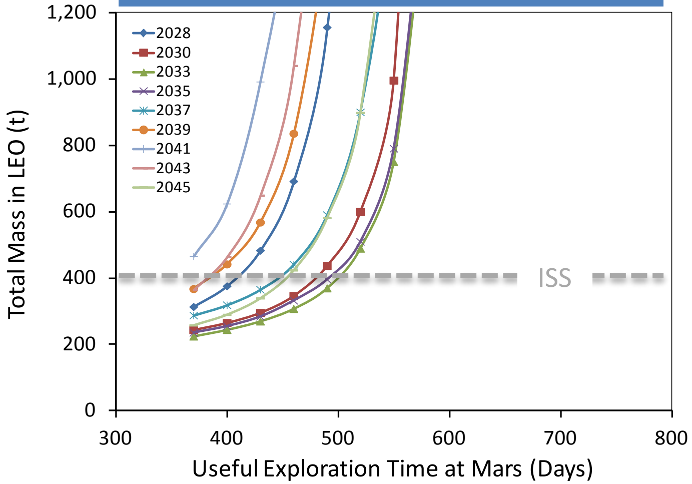
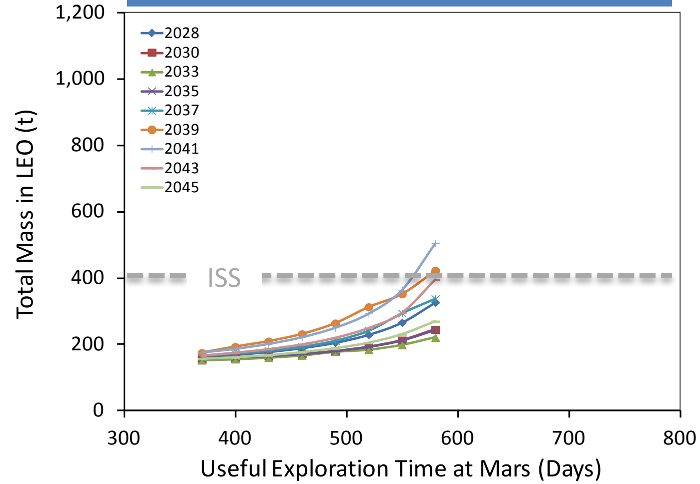
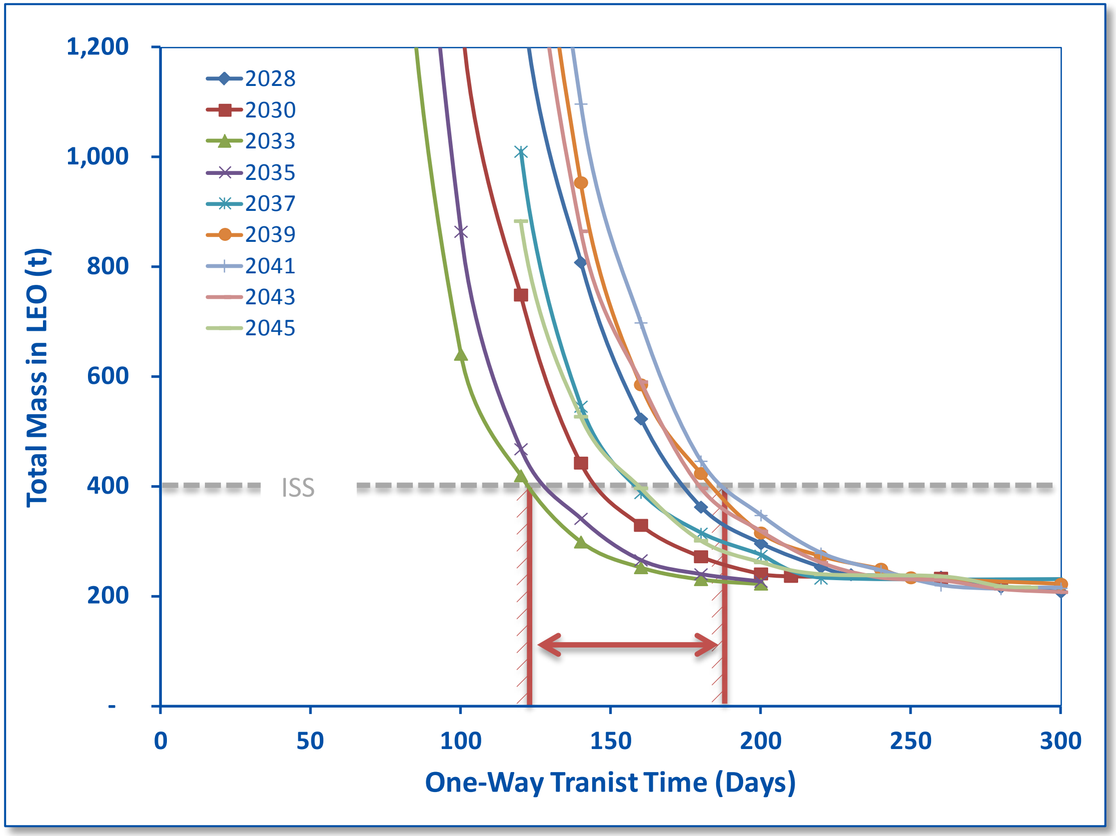


Nuclear Electric



Conjunction Class Missions Crew Vehicle Mass

Shortening the One-Way Transit Times – Nuclear Thermal Propulsion

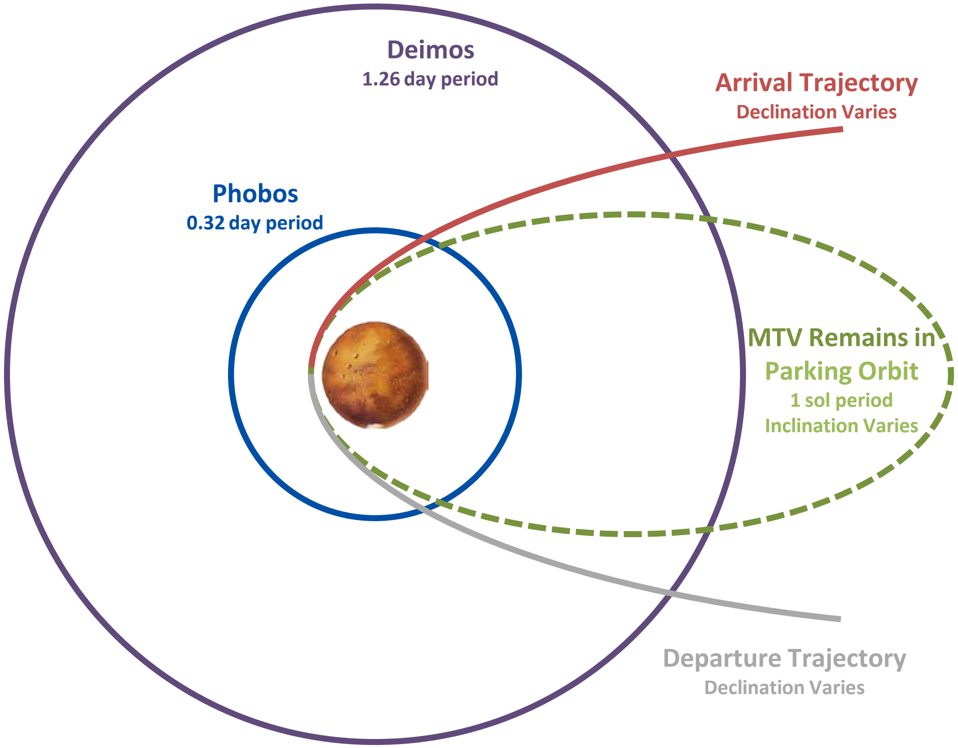


- For the Conjunction Class missions, the stay at Mars can be lengthened to allow faster one-way transits to and from Mars
- Practical limits exist, due to the physics of the trajectories
- The limits are dependent on the propulsion technology choice
- The range of practical transits for the Nuclear Thermal Propulsion depicted here
- Transit times also dependent on Earth departure year

ADDITIONAL MISSION DESIGN CONSIDERATIONS

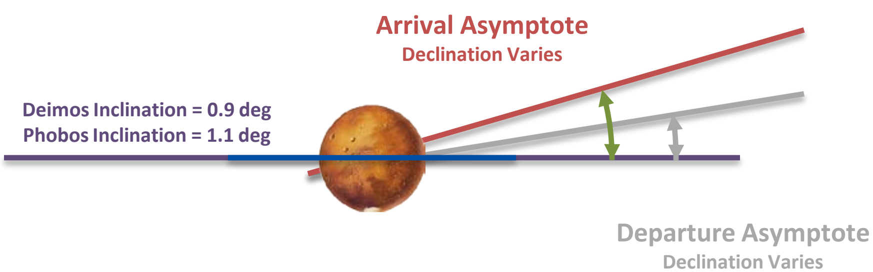
Short Stay Orbital Operations Concept

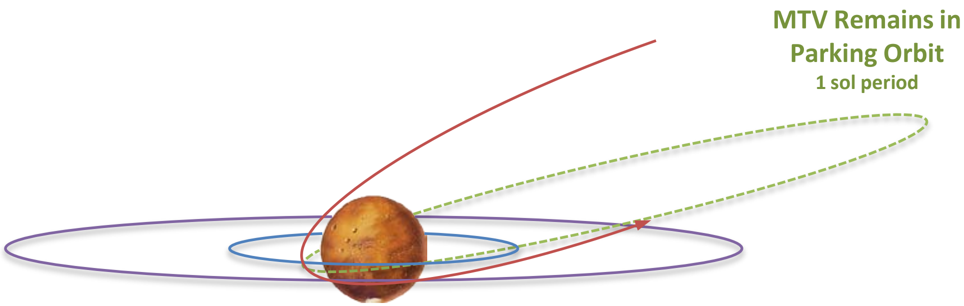
High-Thrust Missions



Assumed Mars Orbit Strategy

1. Cargo pre-deployed into high-Mars parking orbit
2. Crew captures into high-Mars parking orbit
3. Crew transfer vehicle remains in high-Mars parking orbit
4. Crew prepares for orbital operations
5. Space Exploration Vehicle #1 used to explore Deimos for 14 days (1,370-2,770* m/s delta-v required)
6. Space Exploration Vehicle #2 used to explore Phobos for 14 days (1,700-3,170* m/s delta-v required)
7. Prepare for Mars departure
8. Trans-Earth Injection



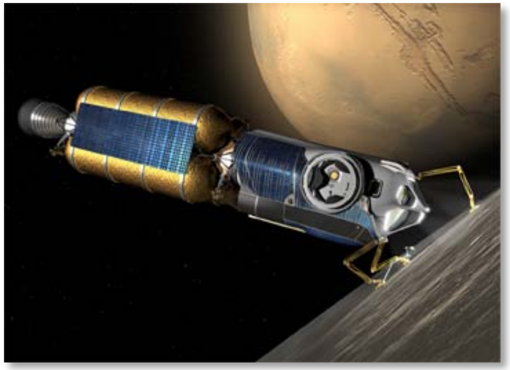


* These values still under review

Key Takeaways

Mars Orbital Missions

- Mars orbital missions, including exploration of the moons of Mars, are conducted entirely in deep-space
- Reducing the exposure of the mission crew to the hazards of deep-space is of prime concern for these missions
- Practical considerations (transportation technology and number of launches) will limit mission durations to not much less than 600 days. Thus, human health issues cannot be obviated by propulsion technology alone
- If there is no true difference between 600 and 900 days from a human health perspective, then long-stay (conjunction class missions) should be used



Mars Surface Missions

- Application of short-stay opposition class missions is not so clear
- Short-surface stay alone is insufficient to ameliorate the human health concerns (zero-g and radiation)
- It is anticipated, though yet to be confirmed, that the surface environment of Mars (partial gravity and radiation) may provide sufficient human health mitigation for long-stay missions
- Landing large payloads remains a key challenge for Mars surface missions, both short and long stay