Human Missions to Mars

Key Challenges

Bret G. Drake
NASA Lyndon B. Johnson Space Center

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Why Do We Want To Explore Mars?

- Long-standing curiosity, particularly since it appears that humans could one day visit there
- A NASA chartered group, Mars Exploration Program Analysis Group, has organized a set of four primary goals:
  - Determine if life ever arose on Mars
  - Understand the processes and history of climate on Mars
  - Determine the evolution of the surface and interior of Mars
  - Prepare for human exploration
- Two additional goals considered as well:
  - Preparing for sustained human presence
  - Ancillary science such as heliophysics, space weather, astrophysics

Goals and Objectives Summary Implications

- The first three human missions to Mars should be to three different geographic sites
- Maximize the amount of time that the astronauts spend exploring the planet
- Maximize mobility to extend the reach of human exploration beyond the landing site
- Provide subsurface access
- Return a minimum of 250 kg of samples to Earth
A trip to Mars with a return back to Earth is a double rendezvous problem

- Mars round-trip missions are flown in heliocentric space
- Relative planetary alignment is a key driver in the mission duration and propulsion required

**Example “Short-Stay” Opposition Class Mission**

**Example “Long-Stay” Conjunction Class Mission**
Example Delta-v versus Mission Duration

Crew Vehicle Total Delta-V
Opposition Class - 2033 "Good" Opportunity

Opposition Class “Short-Stay”
Conjunction Class “Long-Stay”

Total Delta-v (km/s)

Total Mission Duration (Days)

Orbit Assumptions:
- Earth Departure Orbit = 400 x 400 km
- Mars Arrival Orbit = 250 x 33,813 km
- Mars Departure Orbit = 250 x 33,813 km
- Direct Entry at Earth Return

Planetary Arrival Assumptions:
- Mars Propulsive Capture
- Capture Plane: As is
- Direct Earth Entry @ 13 km/s

Opposition Class (60 Day Stay) Missions
Mission Duration
- 200-Day One-Way Transits
- 200-Day One-Way Transits
- 60-Day One-Way Transits
- Earth Departure Opportunity

Trajectory Set: 27 January 2012
The difference in orbits of the Earth and Mars influence the mission delta-v and timing

- Earth departure opportunities occur approximately every 26 months
- The Earth departure “window” lasts a few weeks and is highly dependent on the propulsion system choice
- The round-trip mission delta-v varies over a 15-year cycle (the Synodic Cycle)

Although “good” opportunities occur in 2018, 2033, and 2047, the ability to conduct missions in any opportunity across the Synodic Cycle will reduce programmatic risk

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Example Variation in Total Delta-V

- Conjunction Class - Long Stay (~500 Days) at Mars
- Opposition Class - 560 Total with 60 Days at Mars

Earth Departure Opportunity
Advanced In-Space Transportation
Options, options, options....

**High Thrust: Chemical Propulsion**

**Advantages:**
- More “state of the art”
- Multiple destinations

**Challenges:**
- High Mass / Lots of Launches
- Long-term storage of cryogenic propellants, particularly H\(_2\)
- Configuration and integration challenges
- Long-stay missions only

**Low Thrust: Solar Electric Propulsion (SEP)**

**Advantages:**
- Low architectural mass
- Multiple destinations

**Challenges:**
- Limited to long-stay missions
- Configuration and integration challenges (large solar arrays)
- Long operating times (spirals)

**High Thrust: Nuclear Thermal Propulsion (NTP)**

**Advantages:**
- Good combination of high thrust and high efficiency (Isp)
- Low architectural mass
- Both long and short stay missions
- Has been demonstrated (NERVA)

**Challenges:**
- Long-term storage of cryogenic H\(_2\)
- Large launch volume (due to H\(_2\))
- Nuclear regulatory compliance/testing

**Low Thrust: Nuclear Electric Propulsion (NEP)**

**Advantages:**
- Low architectural mass
- Both long-stay and short-stay (if power is high) missions

**Challenges:**
- No experience base for space based high power, high efficiency, nuclear reactors
- Configuration and integration challenges (large radiators)
- Nuclear regulatory compliance/testing
- Long operating times (spirals)
Propulsion Technology Comparisons
Crew Vehicle Mass as a Function of Trip Time – Short Stay Opposition Missions

Earth Departure Dates from 2028 - 2045

ISS Reference:
~2,800 t for 31 Assembly Flights
~4,500 t to date, 131 Total Flights

Chemical
Isp=465 sec

SEP
Isp=4000 sec

NTP
Isp=900 sec

NEP
Isp=1800-4000 sec

Total Crew Vehicle Mass in Earth Orbit (t)

[Mass of Landers not Included]

Total Round-Trip Mission Duration (Days)

1 As of February 2013
SLS Architecture Block Upgrade Approach

Starting with Available Assets and Evolving the Design
Example Launch Packaging
Diameter and Volume are also Key

Landers and Other Payloads

Nuclear Thermal Propulsion

Solar Electric Propulsion

Nuclear Electric Propulsion

<table>
<thead>
<tr>
<th>Diameter and Volume</th>
<th>SLS 105 t</th>
<th>SLS 105 t</th>
<th>SLS 130 t</th>
<th>SLS 130 t</th>
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</thead>
</table>

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Humans 2 Mars
Example Relationship Between Launches and Reliability

Number of Launches and Launch & Assembly Reliability Versus Launch Vehicle Capacity

- "High" Assembly Rel. = 0.996/launch
- "Low" Assembly Rel. = 0.9897/launch

These results do not include any risk from MMOD, on-orbit failure, or missed departure window during the assembly period (ascent & assembly failures only) - relative risk will depend on time between launches for different launch vehicle capacities.

- 1200t Base Mass to LEO
- All Cases Assume that Propellant Flights Can be Replaced

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## Launch Campaign and Transportation Options

### Cargo Missions

### Crew Mission

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Chemical Propulsion</th>
<th>Nuclear Thermal</th>
<th>Nuclear Electric</th>
<th>Solar</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>“Stressing” (^1)</td>
<td>“Easy”</td>
<td>“Stressing” (^1)</td>
<td>“Easy”</td>
</tr>
<tr>
<td></td>
<td>Long-Stay</td>
<td>Short-Stay</td>
<td>Long-Stay</td>
<td>Short-Stay</td>
</tr>
<tr>
<td>Total Mass (mt)</td>
<td>~1,250</td>
<td>~1,460</td>
<td>~890</td>
<td>~860+</td>
</tr>
<tr>
<td># SLS Launches</td>
<td>~12</td>
<td>~13+</td>
<td>~9</td>
<td>~9+</td>
</tr>
<tr>
<td>SLS delivery to LEO (mt)</td>
<td>105 &amp; 130</td>
<td>105 &amp; 130</td>
<td>105</td>
<td>105</td>
</tr>
<tr>
<td>Launch Spacing (days)*</td>
<td>50-120</td>
<td>10-110+</td>
<td>70-150</td>
<td>70-150</td>
</tr>
</tbody>
</table>

\(^1\) “Stressing” Long-Stay - Represents most stressing conjunction class (2037 long-stay) mission. Typical mission values will be less for other opportunities.

\(^1\) “Easy” Short-Stay - Represents the easiest opposition class (2033 short-stay) mission. Values for other opportunities will vary greatly and will be much more stressing.

* Launch spacing lower/upper values represent spacing required for crew missions every opportunity (26 months) & every-other opportunity (52 months) respectively + 6 mo schedule margin.

**Depending upon SLS performance 1-2 ATV launches using a Ariane 5 class vehicle are required to provide consumables.
Orion Crew Transfer / Earth Return Vehicle

- **Crew Delivery to Earth Departure Point**
  - Provide safe delivery of 4-6 crew to Earth departure point for rendezvous with the Mars Transfer Vehicle
    - Delivery and return of checkout crew prior to the mission
    - Delivery of the mission crew

- **End of Mission Crew Return (Mars Block)**
  - Provide safe return of 4-6 crew from the Mars-Earth transfer trajectory to Earth at the end of the mission
    - 12 km/s entry speed (13+ km/s for short-stay mission)
    - 900 day dormant operations
    - 3 day active operations
    - Much smaller service module (~300 m/s delta-v) for re-targeting and Earth entry corridor set-up
Challenges of Landing on Mars

- The Atmosphere of Mars
  - The Good: Mars has an atmosphere that can help slow the entry vehicle down
  - The Bad: The atmosphere is thick enough that it requires a heat shield, but not thick enough to provide substantial drag (density 1% of Earth’s)
  - Atmospheric dust may prohibit ability or timing of landing at designated landing sites

- The Current Mars Science Laboratory Landing Strategy is Limited
  - ~ 1 mt payload to the surface (target 40 mt)

- Key for Human Missions Challenge: Supersonic Transition

Technology Options

- Hypersonic Inflatable Aerodynamic Decelerator (HIAD)
- Rigid Aeroshells (mid L/D)
- Supersonic Retro-propulsion

Human Mars

Apollo LM

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Humans 2 Mars
Human missions to Mars are demanding from a human health and performance perspective

- **Long-Duration**: 600 days minimum, 900 days most probable
- **Deep-Space**: Micro-gravity and harsh environment
- **Remote**: No logistics train, no fast return aborts

**Categories of Key Human Support Challenges**

- **Ocular Syndrome**: Intercranial pressure
- **Toxicity**: Dust and other hazards
- **Autonomous Emergency**: Response to system emergencies (e.g. life support system failure)
- **Radiation**: Solar Proton (solutions exist), Galactic Cosmic Radiation (currently no standards for exploration)
- **Behavioral Health and Performance**: Remote isolated missions with no real-time communications.
- **Autonomous Medical Care**: Response to medical issues
- **Nutrition**: Food with adequate nutrition for long missions
- **Hypogravity**: Adjusting to the gravity of Mars
- **Musculoskeletal**: Muscle atrophy and bone decalcification
- **Sensorimotor**: Sensory changes/dysfunctions
Living off of the Land: In-Situ Resources

- **Atmosphere**
  - Atmospheric resources found globally with slight change in pressure/concentration
  - Primary product: oxygen ($O_2$) bound in carbon dioxide ($CO_2$)
  - Oxygen can be used for propulsion, life support, and extravehicular activity (EVA) applications
  - Production of $O_2$ only from $CO_2$ makes over 75% of ascent propellant mass
  - Production of $O_2$ and $CH_4$ (or other hydrocarbon fuel) possible with hydrogen ($H_2$) brought from Earth

- **Soil Processing for Water**
  - Water resources found globally with large variations in concentration, form, and depth.
  - Water can be used for life support, EVA, and radiation shielding
  - Water can be processed into $O_2$ and $H_2$ or with $CO_2$ to make fuels for propulsion and power
  - Production of $O_2$ and methane ($CH_4$) from $CO_2$ and $H_2O$ allows for 100% of ascent propellant mass

- **Leverage**
  - Producing oxygen from the atmosphere provides significant leverage in terms of mass (32%) and volume (lander packaging)
Surface Exploration and Discovery

- Long surface stays with visits to multiple sites provides scientific diversity thus maximizing science return
- Sustainability objectives favor return missions to a single site (objectives lend themselves best to repeated visits to a specific site on Mars)
- Mobility at great distances (100’s km) from the landing site enhances science return (diversity)
- Subsurface access of 100’s m or more highly desired
- Advanced laboratory and sample assessment capabilities necessary for high-grading samples for return
## Human Exploration of Mars Capability Needs

### Launch
- Multiple launches
- Short spacing
  - Large mass: 130 t
  - Large Volume 10 x 30 m

### Space Transportation
- Advanced propulsion to reduce mass
- Fast Transits for Crew (180 days)
- Limited / lack of quick aborts

### Entry Descent and Landing
- Large mass (40 t) / Large volume
- Abort to surface
- Precision landing

### Crew Surface Health and Support
- Crew acclimation post landing
- Human Support (radiation, hypogravity, dust, behavior)
- Planetary protection

### Operations
- Automated, rendezvous and docking
- Pre-deploy cargo
- No logistics
- Reliability, maintenance and repair
- Autonomous operations post landing
- Infrastructure emplacement (power)
- High continuous power (40 kWe)
- ISRU oxygen production - atmosphere
- Multiple EVAs, long-range roves, routine exploration
Human mission to Mars will be long and complex, but the round trip duration is within the experience of some of the past successful exploration missions with significantly far fewer crew.