NASA’s Plans for Human Exploration Beyond Low Earth Orbit

NASA Office of Inspector General

https://oig.nasa.gov/docs/IG-17-017.pdf
Introduction

• Human exploration of Mars has been long-term goal for NASA for more than 50 years
• Change in national priorities in the 1970s shifted the Agency’s focus from Mars to low Earth orbit
• NASA is once again pursuing human exploration beyond low Earth orbit, announcing its Journey to Mars in 2015
• Vital to this goal is the successful development of NASA’s new spaceflight system
  • Heavy lift rocket—Space Launch System (SLS)
  • Crew capsule—Orion Multi-Purpose Crew Vehicle (Orion)
  • Ground processing and launch facilities—Ground Systems Development and Operations (GSDO)
  • Since 2012, NASA has invested more than $15 billion on these three programs
• In 2017, NASA’s near-team goals included an uncrewed flight of the integrated SLS/Orion systems in November 2018 and a first crewed flight as early as 2021
  • Exploration Mission 1 (EM-1)
  • Exploration Mission 2 (EM-2)
• NASA’s plans beyond EM-1 and EM-2 are less clear
Audit Objectives

• Assess NASA’s plans for and progress towards its first flights of the integrated SLS/Orion systems in the next 2 to 5 years

• Examine the challenges in executing a sustainable and affordable plan to send a crewed mission to Mars in the 2030s or 2040s

• Assess strategies to help reduce the costs associated with the Agency’s human exploration efforts
Audit Risks and Challenges

• Large and complex scope

• Lack of established criteria beyond three major systems

• Lack of cost estimates

• Fluctuating and uncertain space policy

• Working with a large number of “pre-decisional” documents
Background
NASA’s Plans for the Journey to Mars

<table>
<thead>
<tr>
<th>Earth Reliant (low Earth orbit)</th>
<th>Proving Ground (cislunar space)</th>
<th>Earth Independent (Mars orbit/surface)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission Duration</td>
<td>6 to 12 months</td>
<td>2 to 3 years</td>
</tr>
<tr>
<td>Return to Earth</td>
<td>hours</td>
<td>days</td>
</tr>
<tr>
<td>Time Period</td>
<td>2016 to 2024</td>
<td>mid-2020s to early 2030s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>early 2030s to mid-2040s</td>
</tr>
</tbody>
</table>

**Phase 0**
- ISS testing
- Commercial crew
- Commercial cargo

**Phase 1**
- EM-1
- EM-2
- Asteroid Redirect Robotic Mission

**Phase 2**
- Cislunar exploration missions and development of deep space systems

**Phase 3**
- Mars orbit
- Exploration of Mars’ moons
- Transport system between high and low Mars orbits

**Phase 4**
- Mars surface
- Phase 4a: robotic and preparatory (non-human) missions
- Phase 4b: crewed Mars landing (human missions)
Space Launch System (SLS)

- SLS will transport cargo and crew into space for missions in cislunar and Mars orbits
- Leverages technologies from previous programs
- NASA plans to incrementally increase SLS performance capabilities through a series of upgrades to the system’s boosters and second stage
<table>
<thead>
<tr>
<th></th>
<th>SLS Block 1 (322 feet)</th>
<th>SLS Block 1B</th>
<th>SLS Block 2 (365 feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch readiness date</td>
<td>2020</td>
<td>2024</td>
<td>no earlier than 2028</td>
</tr>
<tr>
<td>Vehicles needed</td>
<td>3 to 4</td>
<td>approximately 7</td>
<td>unknown</td>
</tr>
<tr>
<td>Upgrades</td>
<td>n/a</td>
<td>Exploration Upper Stage</td>
<td>Advanced Boosters</td>
</tr>
<tr>
<td>Cargo payload fairing size</td>
<td>n/a</td>
<td>8.4 meters by 27.4 meters</td>
<td>10 meters by 27.4 meters</td>
</tr>
<tr>
<td>(width by height)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co-manifested payload for</td>
<td>n/a</td>
<td>6 to 10 metric tons</td>
<td>10+ metric tons</td>
</tr>
<tr>
<td>crew version</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upmass to low Earth orbit</td>
<td>70 metric tons</td>
<td>105 metric tons</td>
<td>130 metric tons</td>
</tr>
<tr>
<td>Upmass to trans-lunar</td>
<td>25 metric tons</td>
<td>41 metric tons</td>
<td>45 metric tons</td>
</tr>
<tr>
<td>injection (cargo)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upmass to trans-lunar</td>
<td>25 metric tons</td>
<td>37 metric tons</td>
<td>41 metric tons</td>
</tr>
<tr>
<td>injection (cargo)</td>
<td></td>
<td></td>
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</tbody>
</table>
Orion Multi-Purpose Crew Vehicle (Orion)

- Orion is designed for human exploration beyond low Earth orbit
- Crew module accommodates up to four astronauts for 21 days in 316 cubic feet—similar to the size of a minivan
- Orion will be used in combination with habitation modules and other systems to extend stay and broaden access to Mars or other deep space location
Ground Systems Development and Operations (GSDO)

- SLS launches will use the Kennedy Space Center’s processing and launch facilities managed by GSDO
  - Vehicle Assembly Building
  - Mobile Launcher
  - Crawler-Transporter
  - Launchpad 39B

- NASA is also developing command and control software
Additional Systems Required for Journey to Mars

- NASA has identified additional systems beyond SLS, Orion, and GSDO that will be required for Journey to Mars

- These systems are still being conceptualized and have yet to enter official project planning
  - In-space propulsion
  - Long-duration deep space transit habitat
  - Mars orbital transport vehicle
  - Mars lander and ascent vehicle
  - Mars surface habitat
Challenges with NASA’s Near-Term Missions Illustrate Difficulty of Deep Space Exploration
• Three separate programs with similar challenges
  • Increasing costs and schedule delays
  • Technical challenges
  • Lack of monetary and schedule reserve

• Spaceflight system software is behind schedule and may affect EM-1 launch date

• NASA’s integration plans for EM-2 are incomplete

• Feasibility of crewed flight on EM-1

• Agency commitments do not capture all SLS, Orion, and GSDO costs
- Green Run—test fire of Core Stage engines
- No schedule margin or funding reserves
- Block 1B will have a new second stage (Exploration Upper Stage)
• Delays with service module
• Updates to heat shield after test flight in 2014
• Crewed EM-2 will use life support without a test flight
• Modifications to Vehicle Assembly Building and Mobile Launcher
• Schedule concerns due to changing requirements from Orion and SLS
Program Cost and Schedule Commitments

<table>
<thead>
<tr>
<th>Program Agreements</th>
<th>EM-1</th>
<th>EM-2</th>
<th>Beyond EM-2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated Life Cycle Costs</td>
<td>Launch Readiness Date</td>
<td>Estimated Life Cycle Costs</td>
</tr>
<tr>
<td>SLS</td>
<td>$9.3 billion</td>
<td>September 2018</td>
<td>Outside the scope of Agency Baseline Commitment&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>$9.7 billion</td>
<td>November 2018</td>
<td></td>
</tr>
<tr>
<td>Orion</td>
<td>Internal&lt;sup&gt;a&lt;/sup&gt;</td>
<td>No separate metrics; part of EM-2 program agreement</td>
<td>$10.8 billion</td>
</tr>
<tr>
<td></td>
<td>External</td>
<td></td>
<td>$11.3 billion</td>
</tr>
<tr>
<td>GSDO</td>
<td>Internal&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$2.7 billion</td>
<td>September 2018</td>
</tr>
<tr>
<td></td>
<td>External</td>
<td>$2.8 billion</td>
<td>November 2018</td>
</tr>
</tbody>
</table>

- Commitments for each program are not coordinated or combined
- Exceeding costs/schedule requires notifying Congress
- SLS Program external cost commitment of $9.7 billion
  - Assumes November 2018 launch date
  - Does not include costs for EM-2 and beyond
SLS Program Spending Outside Cost Commitments

- Estimated funding through fiscal year 2018: **$12.1 billion**
  - Compared to $9.7 billion cost commitment (EM-1 only, November 2018)
- Estimated funding through fiscal year 2021: **$19.1 billion** (EM-2)
- Through fiscal year 2022, $17 billion will be spent outside cost commitments (Orion, SLS, and GSDO programs)
NASA Challenged to Develop Realistic Cost and Schedule Estimates for Mars Missions Beyond EM-2
NASA Lacked Long-term Requirements and Cost Estimates

- NASA has established requirements only through EM-2

- No NASA cost estimates for missions beyond EM-2
  - No long-term estimates for total costs or key systems
  - NASA said budget funding assumptions were adequate for Mars missions

- Jet Propulsion Laboratory (JPL) feasibility study shows funding deficit in the early 2020s
  - The Aerospace Corporation reviewed estimates based on NASA OIG inputs to more closely match NASA planning
  - JPL Study showed funding deficit in the early 2020s for critical technology development
## Comparison of JPL and NASA Architectures

<table>
<thead>
<tr>
<th>Architecture Assumptions</th>
<th>JPL Feasibility Study</th>
<th>HEOMD’s Journey to Mars Planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliance on new technologies</td>
<td>Relied on key systems already in development to reduce costs and schedule delays, such as hypergolic chemical propulsion to transport crewed missions to Mars orbit, and to and from the Mars surface.</td>
<td>Utilized underdeveloped new systems, such as 1. Fission power for habitation on Mars surface; 2. Oxygen production on the Mars surface; and 3. Liquid oxygen and methane for Mars ascent propulsion.</td>
</tr>
<tr>
<td>Scope of system capabilities for initial missions</td>
<td>Architecture limited to system capabilities needed only for initial missions.</td>
<td>Expanded focus on long-term capabilities, such as liquid oxygen and methane propulsion and oxygen production on Mars.</td>
</tr>
<tr>
<td>Development investments in the 2020s</td>
<td>Cost estimates were conducted on each system needed in order to achieve the designated Mars missions and showed a significant investment was needed for the development of these systems in the 2020s.</td>
<td>Assumed supportable with flat budgets with incremental increases based on inflation and economic growth.</td>
</tr>
<tr>
<td>Extension of ISS funding beyond 2024</td>
<td>Assumed a reduction of ISS funding after 2024.</td>
<td>No analysis related to key systems costs or impact of ISS funding beyond 2024.</td>
</tr>
</tbody>
</table>

- JPL assumed minimal architecture
  - Less technology development, less robust capabilities
  - Allowed for funding spikes in beginning

- NASA assumed long-term development needs
  - Oxygen production on Mars surface (using fission power plant)
  - New oxygen and methane propulsion engine (to and from Mars surface)
  - Flat budget profiles
HEOMD Budget Assumptions Compared to JPL Estimates

- HEOMD budget assumptions: **$545 billion** (optimistic) vs. **$410 billion** (realistic)
- JPL architecture with The Aerospace Corporation cost estimate: **$450 billion** through 2046
  - Deficit of $16 billion (fiscal years 2018 through 2026)
- Mars missions are feasible when comparing NASA budget assumptions to JPL/Aerospace cost estimates
Funding Critical System Development and the Impact of ISS Funding

- JPL/Aerospace analysis showed a need for early investment in critical systems (~$16 billion deficit in early 2020s)
- Ending the ISS in 2024: ~$16 billion funding wedge (mid- to late 2020s)
- NASA may need more money in the early 2020s and should make a decision on the ISS to determine mid-2020 funding or there could be delays of 3 years or more for Mars missions
NASA Pursuing Options to Make the Journey to Mars Less Costly
NASA Pursuing Options to Make the Journey to Mars Less Costly

• Program management strategies to reduce costs
  • Goal of reducing program costs to $2 billion a year from $3.5 billion
  • Integration approach using exploration systems development
  • Incremental development
  • Reusing systems
  • Acquisition strategy
  • Technology development

• Partnerships with other space agencies may provide opportunities for collaboration and cost savings

• Commercial partnerships may help defray costs
Commercial Launch Options

- NASA has adjusted its plans to include lunar missions—the size and scope are not finalized yet
- Commercial options are cheaper but less capable than the SLS
- Continued debate over government-run space system development versus commercial
Potential International Partners

- ISS partnerships provide a working model for human exploration beyond low Earth orbit
- Significant international partner interest in lunar missions
Recommendations

1. Complete an integrated master schedule for the SLS, Orion, and GSDO programs for the EM-2 mission. *(Concur)*

2. Establish more rigorous cost and schedule estimates for the SLS and GSDO programs for the EM-2 mission mapped to available resources and future budget assumptions and independently reviewed by the Office of the Chief Financial Officer *(Partially Concur)*

   • OIG response: “While we understand the challenges posed by the appropriations process and the difficulty of projecting long-range life-cycle costs, the Agency is currently spending significant amounts of money on EM-2 without an official cost estimate for these programs. [. . . ] In our judgment, a detailed EM-2 cost estimate would allow Agency officials and external stakeholders to better understand the mission’s progress and the full costs involved.”
Recommendations (cont.)

3. Establish objectives, need-by dates for key systems, and phase transition mission dates for the Journey to Mars. *(Concur)*

4. Include cost as a factor in NASA’s Journey to Mars feasibility studies when assessing various missions and systems. *(Concur)*

5. Design a strategy for collaborating with international space agencies in their cis-lunar space exploration efforts with a focus on advancing key systems and capabilities needed for Mars exploration. *(Concur)*

6. Incorporate into analyses of space flight system architectures the potential for utilization of private launch vehicles for transportation of payloads. *(Concur)*
Current Human Exploration Plans

- NASA Human Exploration Update Presentation from March 2018:
Conclusion

• Ongoing cost increases and schedule delays for EM-1 and EM-2
• NASA needs to set realistic expectations of the long-term funding needed for Mars missions (+$400 billion)
• Critical development needed in the 2020s for Mars missions
• Continuing the ISS could impact the schedule for Mars missions
• International and commercial partnerships could help defray these costs
Questions?
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