Evolvable Mars Campaign & SKGs

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Human Exploration and Operations Mission Directorate
“Fifty years after the creation of NASA, our goal is no longer just a destination to reach. Our goal is the capacity for people to work and learn and operate and live safely beyond the Earth for extended periods of time, ultimately in ways that are more sustainable and even indefinite. And in fulfilling this task, we will not only extend humanity’s reach in space -- we will strengthen America’s leadership here on Earth.”

- President Obama, April 2010
NASA Strategic Plan Objective 1.1

Expand human presence into the solar system and to the surface of Mars to advance exploration, science, innovation, benefits to humanity, and international collaboration.
Strategic Principles for Sustainable Exploration

• Implementable in the **near-term with the buying power of current budgets** and in the longer term with budgets commensurate with economic growth;

• **Exploration enables science and science enables exploration**, leveraging robotic expertise for human exploration of the solar system

• Application of **high Technology Readiness Level** (TRL) technologies for near term missions, while focusing sustained investments on technologies and capabilities to address challenges of future missions;

• **Near-term mission opportunities** with a defined cadence of compelling and integrated human and robotic missions providing for an incremental buildup of capabilities for more complex missions over time;

• Opportunities for **U.S. commercial business** to further enhance the experience and business base

• **Multi-use, evolvable** space infrastructure, minimizing unique major developments;

• Substantial **international and commercial participation**, leveraging current International Space Station and other partnerships.
Global Exploration Roadmap: Common Goals and Objectives

- **Develop Exploration Technologies and Capabilities**
  Develop the knowledge, capabilities, and infrastructure required to live and work at destinations beyond low-Earth orbit through development and testing of advanced technologies, reliable systems, and efficient operations concepts in an off-Earth environment.

- **Engage the Public in Exploration**
  Provide opportunities for the public to engage interactively in space exploration.

- **Enhance Earth Safety**
  Enhance the safety of planet Earth by contributing to collaborative pursuit of planetary defense and orbital debris management mechanisms.

- **Extend Human Presence**
  Explore a variety of destinations beyond low-Earth orbit with a focus on continually increasing the number of individuals that can be supported at these destinations, the duration of time that individuals can remain at these destinations, and the level of self-sufficiency.

- **Perform Science to Enable Human Exploration**
  Reduce the risks and increase the productivity of future missions in our solar system, characterizing the effect of the space environment on human health and exploration systems.

- **Perform Space, Earth, and Applied Science**
  Engage in science investigations of, and from, solar system destinations and conduct applied research in the unique environment at solar system destinations.

- **Search for Life**
  Determine if life is or was present outside of Earth and understand the environments that support or supported it.

- **Stimulate Economic Expansion**
  Support or encourage provision of technology, systems, hardware, and services from commercial entities and create new markets based on space activities that will return economic, technological, and quality-of-life benefits to all humankind.
Evolvable Mars Campaign Goal:

Define the pioneering strategy and operational capabilities required to extend and sustain human presence in the solar system including a journey towards the Mars system in the mid-2030s.
Mars Vicinity Options Provide the “Pull”

**Mars Orbit**
- Opportunities for integrated human-robotic missions:
  - Real time tele-operation on Martian surface
  - Mars sample return
  - Other science objectives
  - Technology demonstrations
- Demonstrate sustainable human exploration split-mission Mars concept
- Validate transportation and long-duration human systems
- Validate human stay capability in zero/micro-g

**Mars Moons**
- Opportunities for integrated human-robotic missions:
  - Real time tele-operation on Martian surface
  - Mars & moons sample return
  - Other science objectives
  - Technology demonstrations
- Demonstrate sustainable human exploration split-mission Mars concept
- Moons provides additional radiation protection
- In-situ resource utilization
- Validate human stay capability in low-g

**Mars Surface**
- Opportunities for integrated human-robotic missions:
  - Search for signs of life
  - Comparative planetology
  - Understanding Mars climate changes
  - Geology/geophysics
- Planet provides radiation protection
- Entry, descent, landing
- EVA surface suits
- In-situ resource utilization
- Validate human stay capability in partial-g
Using SEP for pre-emplacement of cargo and destination systems enables sustainable Mars campaign

- Minimizes the cargo needed to be transported with the crew on future launches
- Enables a more sustainable launch cadence
- Pre-positions assets for crew missions allows for system checkout in the Mars vicinity prior to committing to crew portion of mission
DRO as an aggregation point for Mars habitation systems
- Provides a stable environment and ease of access for testing Proving Ground capabilities
- Allows for Mars transit vehicle build-up and checkout in the deep-space environment prior to crew departure
- Able to transfer Mars Transit Vehicle from DRO to High Earth Orbit with small amount of propellant to rendezvous with crew in Orion – HEO is more efficient location to leave Earth-moon system for Mars vicinity
Returning from Mars, the crew will return to Earth in Orion and the Mars Transit Habitat will return to the staging point in cis-lunar space for refurbishment for future missions.
VALIDATE
• SLS and Orion in deep space
• Solar Electric Propulsion (SEP) systems
• Long duration, deep space habitation systems
• Mitigation techniques for crew health and performance in a deep space environment
• In-Situ Resource Utilization
• Operations with reduced logistics capability

CONDUCT
• EVAs in deep space, micro-g environments
• Human and robotic mission operations
• Capability Pathfinder and SKG missions
Mission concepts with Universal Stage Adaptor (includes additional payload capability)

Orion with EAM
total mission volume = ~ 400m³

Orion with ARV
total mission volume = ~ 400m³

5m fairing with Robotic Lunar Lander & EAM
total mission volume = ~ 600m³

8m fairing with ATLAST
total mission volume = ~ 1200m³

10m fairing with notional Mars payload
total mission volume = ~ 1800m³
• Global Exploration Roadmap (GER) outlines multi-agency plan for human exploration
  – Includes consensus principles, notional mission scenarios, preparatory activities

• Two scenarios: Asteroid Next, Moon Next
1. **Strategic Knowledge Gap (SKG):** The Gaps in Knowledge Needed to Achieve a Human Spaceflight Capability.

2. **Gap-Filling Activity (GFA):** Work that contributes to closing an SKG.

**GFA areas**
- Mars flight program
- Flights to other places
- Non-flight work (models, lab experiments, field analogs, etc.)
- Technology demos

Total knowledge needed to achieve a goal
SB SKGs can be organized into several themes, which can be further divided into categories:

I. **Human mission target identification (NEOs).** The identification of multiple targets for human exploration is fundamental.

II. **Understand how to work on or interact with the SB surface.** Human presence may disturb the environment in non-intuitive ways. We need to understand how best to perform sample acquisition and handling, instrument placement, and proximity operations.

III. **Understand the SB environment and its potential risk/benefit to crew, systems, and operational assets.** The small body environment may include dust emitted periodically (for instance via levitation) or episodically (after impact or spin-up events). It may enhance or screen solar radiation. It may be gravitationally metastable.

IV. **Understand the SB resource potential.** ISRU is considered a “game changer” in how humans explore the Solar System by enabling an infrastructure that allows a sustainable human presence in space. The short-stay missions likely to be in the first wave of NEO or Phobos/Deimos visits may test or prepare that infrastructure but are unlikely to take advantage of it.
<table>
<thead>
<tr>
<th>SKG Themes</th>
<th>SKG Categories</th>
<th>Examples of SKGs</th>
</tr>
</thead>
</table>
| **I. Human mission target identification (NEOs)** | A. Constraints on targets  
B. NEO orbit distribution  
I-A-2. Reachable objects within planned architecture  
I-B-1. Long-synodic period NEOs having multiple mission opportunities.  
I-B-2. Number of available targets at a given time.  
I-C-1. NEO size-frequency distribution.  
I-C-2. NEO albedos.  
I-C-3. NEO rotation state. |
<table>
<thead>
<tr>
<th>Venue/Context</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R&amp;A</strong></td>
<td>Research and Analysis Programs that support basic research, field work, and mission data analysis supported by PSD and HEOMD but in a broad programmatic context.</td>
</tr>
<tr>
<td><strong>Earth-based</strong></td>
<td>Terrestrial location for specific development and testing, including ground-based telescopes.</td>
</tr>
<tr>
<td><strong>ISS</strong></td>
<td>International Space Station</td>
</tr>
<tr>
<td><strong>Robotic</strong></td>
<td>Space-based robotic missions which can be telescopic or a precursor mission to a small body target.</td>
</tr>
</tbody>
</table>
### Venue/Context Relevancy

<table>
<thead>
<tr>
<th>Relevance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preferred Location/Context:</strong></td>
<td>Provides the best location or context to obtain knowledge, including actual or flight-like conditions, environments, or constraints for testing operational approaches and mission hardware.</td>
</tr>
<tr>
<td><strong>Highly Relevant:</strong></td>
<td>Provides highly relevant location/context to obtain knowledge, including flight-like conditions, environments, or constraints for testing operational approaches and mission hardware. This venue can serve as a good testing location with less difficulty and/or cost than anticipated for the preferred location.</td>
</tr>
<tr>
<td><strong>Somewhat Relevant:</strong></td>
<td>Provides some relevant testing or knowledge gain (including basic analytical research and computational analysis). Conditions are expected to be not flight-like or of sufficient fidelity to derive adequate testing or operational performance data.</td>
</tr>
<tr>
<td><strong>Not Relevant:</strong></td>
<td>Not an adequate location/context for testing or knowledge gain.</td>
</tr>
</tbody>
</table>
### IV. Understand the SB resource potential

<table>
<thead>
<tr>
<th>SKG</th>
<th>R&amp;A</th>
<th>Earth-Based</th>
<th>ISS</th>
<th>Robotic Missions</th>
<th>Specific Target?</th>
<th>Narrative</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-3. Knowledge of extracting and collecting water in zero-g.</td>
<td>![Red]</td>
<td>![Blue]</td>
<td>![Red]</td>
<td>![Black]</td>
<td>![No]</td>
<td>Techniques can be developed and tested on Earth preparing and heating meteorite analog and simulants, then optimally tested in the microgravity of ISS.</td>
</tr>
<tr>
<td>A-5. Refining, storing, and using H &amp; O in micro-g.</td>
<td>![Red]</td>
<td>![Blue]</td>
<td>![Red]</td>
<td>![Black]</td>
<td>![No]</td>
<td>Refinement testing starting with extracted water from meteorite analogs and simulants to test processes on Earth, then deploy for testing at ISS. In-situ demonstration needed.</td>
</tr>
</tbody>
</table>
Determining a Timeline

### Ranking Priorities

<table>
<thead>
<tr>
<th>Rank</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical</td>
<td>Human exploration cannot proceed without closing of SKG.</td>
</tr>
<tr>
<td>High</td>
<td>Important for maximizing human safety and/or meeting mission objectives.</td>
</tr>
<tr>
<td>Enhancing</td>
<td>Enhances mission objective return.</td>
</tr>
</tbody>
</table>

### Timeframe

<table>
<thead>
<tr>
<th>Time</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near</td>
<td>Needs to be addressed immediately or in the near-term: A target cannot be chosen without it.</td>
</tr>
<tr>
<td>Mid</td>
<td>Needs to be addressed in the mid-term: Must be completed before launch to human mission target,</td>
</tr>
<tr>
<td>Long</td>
<td>May be addressed in the longer term: May be completed after first launch.</td>
</tr>
</tbody>
</table>
### 4 potential HEO Goals in the Martian system

**SKGs can only be defined w.r.t. a specific goal.**

**Goals evaluated, this study**

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Goal</th>
<th>MEPAG</th>
<th>Linkage</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Achieve the first human mission to Mars orbit</td>
<td>Goal IV-</td>
<td>Group A SKGs also needed</td>
</tr>
<tr>
<td>B.</td>
<td>Achieve the first human mission to the martian surface</td>
<td>Goal IV</td>
<td>Group A SKGs also needed</td>
</tr>
<tr>
<td>C.</td>
<td>Achieve the first human mission to the surface of Phobos and/or Deimos</td>
<td>Goal IV+</td>
<td>Group A, B, (C?) SKGs also needed</td>
</tr>
<tr>
<td>D.</td>
<td>Sustained human presence on Mars</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SKGs and Decomposition

- We have identified 17 SKGs associated with the four HEO goals.
  - Full statements of the knowledge gaps are listed in Appendix I.
- About 60 Gap-Filling Activities (GFAs) have been identified that would address the 17 SKGs.
  - Detailed analysis of the GFAs is in Appendix II.
  - The GFAs have different priorities and degrees of urgency (see GFA Analysis on Slides #11-12)
  - Only about half of the GFAs would require use of the Mars flight program.
## Strategic Knowledge Gaps

<table>
<thead>
<tr>
<th>SKG Themes</th>
<th>SKG Categories</th>
<th>Examples of SKGs</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Understand the lunar resource potential.</td>
<td>A. Solar Resources</td>
<td>I-A Solar illumination mapping</td>
</tr>
<tr>
<td></td>
<td>B. Regolith Resources 1</td>
<td>I-B Regolith volatiles, Apollo samples</td>
</tr>
<tr>
<td></td>
<td>C. Regolith Resources 2</td>
<td>I-C Regolith volatiles, in situ</td>
</tr>
<tr>
<td></td>
<td>D. Polar Resources</td>
<td>I-D Extent, magnitude and age of cold traps</td>
</tr>
<tr>
<td></td>
<td>E. Pyroclastic Deposit Resources</td>
<td>I-E Pyroclastic deposit volatiles, in situ</td>
</tr>
<tr>
<td></td>
<td>F. Lunar ISRU production efficiency 1</td>
<td>I-F ISRU production efficiency, Earth testing</td>
</tr>
<tr>
<td></td>
<td>G. Lunar ISRU production efficiency 2</td>
<td>I-G ISRU production efficiency, Moon testing</td>
</tr>
<tr>
<td>II. Understand the lunar environment and its effects on human life.</td>
<td>A. Solar Activity</td>
<td>II-A Solar Event Prediction</td>
</tr>
<tr>
<td></td>
<td>B. Radiation at the lunar surface</td>
<td>II-B Radiation shielding effect of lunar materials</td>
</tr>
<tr>
<td></td>
<td>C. Biological impact of dust</td>
<td>II-C Biological effects of lunar dust. Earth-based testing</td>
</tr>
<tr>
<td></td>
<td>D. Maintaining peak human health</td>
<td>II-D Maintain peak human health and performance in dusty, high-radiation, partial gravity environments</td>
</tr>
<tr>
<td>III. Understand how to work and live on the lunar surface.</td>
<td>A. Resource production</td>
<td>III-A Excavation of lunar resources</td>
</tr>
<tr>
<td></td>
<td>B. Geodetic grid &amp; navigation</td>
<td>III-B Lunar Geodetic Control</td>
</tr>
<tr>
<td></td>
<td>C. Surface trafficability</td>
<td>III-C Trafficability: Modeling</td>
</tr>
<tr>
<td></td>
<td>D. Dust and Blast Ejecta</td>
<td>III-D Lunar Dust Remediation</td>
</tr>
<tr>
<td></td>
<td>E. Plasma environment and charging</td>
<td>III-E Plasma Environment and charging</td>
</tr>
<tr>
<td></td>
<td>F. Energy production and storage</td>
<td>III-F Propellant scavenging</td>
</tr>
<tr>
<td></td>
<td>G. Radiation shielding</td>
<td>III-G Radiation shielding technology</td>
</tr>
<tr>
<td></td>
<td>H. Micrometeorite shielding</td>
<td>III-H Micrometeorite shielding technology</td>
</tr>
<tr>
<td></td>
<td>I. Lunar mass contribution and distribution</td>
<td>III-I Lunar mass contribution</td>
</tr>
<tr>
<td></td>
<td>J. Habitat, life support and mobility</td>
<td>III-J Semi-closed life support</td>
</tr>
</tbody>
</table>

Black text = SKG are identical or similar to those identified by HAT analysis.

Red text = SKG are added or significantly modified from HAT analysis.
SKG Path Forward

- All three documents are comprehensive

- Goal is to revisit

- Are the same questions being asked by the Human Architecture Teams?

- Have any of the SKGs been closed by recent data analysis?

- Make all three SKGs consistent in format/depth