Analysis of the Mars Feedforward Value of Possible Lunar Objectives

Prepared on behalf of MEPAG by the Mars Forward Lunar Objectives Science Analysis Group (MFLO-SAG)

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INTRODUCTION

- NASA's formal statement of its strategic goal linking Mars and the Moon is to "**establish a lunar return program having the maximum possible utility for later missions to Mars and other destinations**".
- A draft set of “themes” and “objectives” for the lunar program has been prepared by the NASA synthesis team, with subsequent updates by the Lunar Architecture Team*.
- The purpose of this analysis is to evaluate the Moon-Mars linkages from a Mars perspective.

**The master spreadsheet has evolved through time, and the final version used in this analysis is the one presented in Houston on Dec. 5, 2006.*

MEPAG's Analysis

- This analysis was prepared from the perspective of a Mars stakeholder: **IF** our objective were to optimize the exploration of Mars, what is the relevance of the multiple possible lunar objectives?
- The draft lunar objectives were prioritized from a Mars perspective in two ways:
  - Relevance to "PREPARE FOR HUMANS TO MARS"
    - Assume that the objective we are preparing for is achieving the first human landing on Mars.
    - Mars design reference mission being worked in 2007.
  - Relevance to "ADVANCE MARS SCIENCE"
    - Scientific relevance of lunar investigations to Mars was assessed in a relative sense. NOTE—these were not prioritized against doing the same investigations directly at Mars.

Level of Confidence

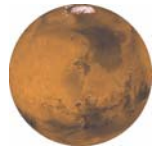
For some types of lunar objectives, the degree of relevance to Mars depends on future implementation decisions and context, and MEPAG's evaluation is more uncertain.

Mars priority more confident	In these categories, many NA and N ratings
• Geology • Human health • Environmental characterization • Environ. hazard mitigation • Op. Environment Monitoring • Life support & habitat • Operations, test, verification • Communications • Surface mobility	• Historic preservation • Public engagement, inspiration • Transportation • Commercial Opportunities • Development of Lunar Commerce • Power • General infrastructure • Materials science

Humans to Mars and Moon: Primary Similarities

- **Life Support**. Need for self-sustained life support system. Neither environment has required human essentials in water, air, or food. It is possible the Moon could use a system involving resupply and disposable elements (like ISS), rather than a closed-loop recycling system, but that seems extremely unlikely to be viable for Mars.
- **Human Health Hazards**. For example, prolonged low gravity exposure, radiation exposure, dust exposure, psychological isolation and medical needs --differ in degree, but not in kind.
- **Infrastructure**. Need for surface EVA/Suit and mobility, and habitats; need for greater capacity space transportation systems capabilities; need for a power-rich environment.
- **Human-related scientific exploration**. There will be commonalities in process (although the specific scientific questions will be largely different).

Humans to Mars and Moon: Primary Differences (1 of 2)



- **EDL (Entry, Descent, and Landing)**. EDL technology is very different at Mars, because of its atmosphere (e.g. aerobraking and parachutes are both key elements for Mars, but not Moon), with more similarity during the terminal landing phase, such as hazard avoidance.
- **Mission length and opportunity to abort**. At the Moon a crew is 3 days away from a can of beans; at Mars one-way travel time is (at best) about 6 months. Nominal round-trip Mars mission lengths are 1.5-2.5 years, and the opportunity to abort a mission that is having difficulties is severely limited.
- **ISRU (In-Situ Resource Utilization)**. The ISRU needs/opportunities are probably rather different on the two bodies.
- **Planetary Protection**. Mars may have indigenous biology, and because of that it is a protected planet. The Moon is sterile.

Humans to Mars and Moon: Primary Differences (2 of 2)

- **Communications**: The round-trip light travel time to Mars is 8-40 minutes (depending on orbital position), and for the Moon it is 3 seconds. There will likely be a significantly higher need for autonomy at Mars.
- **Environmental conditions (examples)**.
  - Thermal environments are significantly different. The lunar surface has temperature swings to +120 C and -170 C (less for the poles), far larger ranges than for the martian surface. Because the Moon is in vacuum, multi-layer insulation (MLI) works very well there, but on Mars, different insulation approaches are required.
  - Dust, when disturbed on the moon, travels in ballistic trajectories. On Mars, dust devils and artificial (man-made) events will raise dust clouds that slowly disperse. Mars dust is finer, oxidizing. Martian global-scale dust storms are a significant issue.
  - Mars has local low bearing-strength soils (e.g., both MER Rovers have had trafficability problems) because it is an environment influenced by aeolian activity.

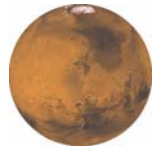
Prioritization Summary

Lunar Objective Category	Prepare for Humans to Mars						Advance Mars Science					
	E	H	M	L	N	NA	E	H	M	L	N	NA
Astronomy & Astrophysics					9						9	
Heliophysics					8						8	
Earth Observation					12						12	
Geology			1	2	13			3	3	6	4	
Materials Science					2	1					3	
Human Health		2	1	5							8	
Environmental Characterization			1	1	8	2				1	11	
Environmental Hazard Mitigation		1	2	2							5	
Operational Environ Monitoring		1	1	1							3	
Life Support & Habitat		3	5			1					9	
General Infrastructure			1		1	2					4	
Operations, Test & Verification		2	2	4		1			1		8	
Power			1			2					3	
Communication				5							5	
Position, Navigation & Timing			2	4							6	
Transportation		1		1		2					4	
Surface Mobility			3								3	
Crew Activity Support			2	3							5	
Lunar Resource Utilization			7			4				1	10	
Historic Preservation					3						3	
Development of Lunar Commerce					5						5	
Commercial Opportunities					14						14	
Global Partnership		1	1	1		1					4	
Public Engagement & Inspiration		5				12					17	
TOTAL	**0**	**16**	**30**	**29**	**75**	**28**	**0**	**3**	**4**	**8**	**163**	**0**
	0%	**9%**	**17%**	**16%**	**42%**	**16%**	**0%**	**2%**	**2%**	**4%**	**92%**	**0%**

Top 7 Objectives for Mars Science

mGEO1	Determine the internal structure and dynamics of the Moon to constrain the origin, composition, and structure of the Moon and other planetary bodies.	**H**
mGEO7	Characterize impact cratering over the Moon's geologic history, to understand early solar system history.	**H**
mGEO9	Study the lunar regolith to understand the nature and history of solar emissions, galactic cosmic rays, and the local interstellar medium.	**H**
mGEO2	Determine the composition and evolution of the lunar crust and mantle to constrain the origin and evolution of the Moon and other planetary bodies.	**M**
mGEO3	Characterize the lunar geophysical state variables to constrain the origin, composition, and structure of the Moon and other planetary bodies.	**M**
mGEO16	Provide sample analysis instruments on the Moon to analyze lunar samples before returning them to Earth.	**M**
mOPS7	Evaluate astrobiology protocols and measurement technologies that will be used to test for life on other planets.	**M**

Priority of Lunar Investigations
to Mars Science (from MEPAG, 2004)



RELATIVE PRIORITY

HIGHER

PRIORITY GROUP 1:

A5: Impactor Flux vs. Time

A9: Exogenous Volatiles

PRIORITY GROUP 2:

A3: Thermal and Magmatic Evolution

A10: Interpreting Geologic Environments

A6: Regolith History

A8: Endogenous Volatiles

PRIORITY GROUP 3:

A1: Interior Planetary Structure

A4: Planetary Asymmetry

A2: Early Planetary Differentiation

A7: Energetic Particle History

LOWER

Prioritization Criteria:

- The intrinsic scientific value of each theme for advancing our understanding of Mars if the investigation was first carried out on the Moon.
- Degree of criticality of the possible lunar activity to one or more future Mars missions (or surface measurement activities)
- Degree of alignment with MEPAG's priority system for Mars exploration

Note: Differences in priority within priority groups are not judged to be significant.

Resource and Demo. Priorities
(from MEPAG, 2004)

Test crucial instrument or strategy, or establish test bed under the proviso that (*i*) Activity cannot be done satisfactorily on Earth, or (*ii*) Moon provides a unique (or vastly superior) martian analog than does the Earth.

RELATIVE PRIORITY

HIGHER

PRIORITY GROUP #1:

C1: In-situ sample selection & anal.
C7: Sample Return
C3: Drilling technologies

PRIORITY GROUP #2:

C4: Seismic technologies/Studies
B1: Water as a Resource
B2: In-situ fuel resources
C5: Assess Bio-Organic Cont.

PRIORITY GROUP #3:

C6: ISRU Technology Demos.
C2: Comm. and ranging systems
B3: Other resource issues

LOWER

Prioritization Criteria:

1. If successfully carried out at the Moon, the value to our ability to correctly plan and successfully implement the future Mars exploration program.
2. Timing: Importance that these measurements/demonstrations be carried out by the lunar robotic program prior to 2020.
3. Cost: General affordability of these measurements/ demonstrations.
4. Technology readiness: Our technical ability to carry out these measurements/ demonstrations within the time frame specified in #2 above.

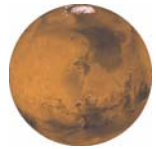
Backup

Finding #1: Need for a multi-venue program

- Because of the significant differences between Mars and Moon, preparation for sending humans to Mars will involve programs of activity to be carried out at multiple venues:
  - Those that require robotic precursor flight missions to Mars (described in MEPAG Goal IV).
  - Those that can be achieved on the Moon (this study).
  - Those that can be achieved at LEO or on Earth (not yet described).

<u>FINDING.</u> Preparing for crewed missions to Mars will involve a Mars robotic precursor portion (described as MEPAG Goal IV), as well as preparation work at other venues, including the Moon, at LEO, and/or on the Earth.

Finding #2: Relevance of Lunar Objectives to Mars



- About 25% of the lunar objectives under consideration were judged to have HIGH or MEDIUM relevance to "Preparing for Humans to Mars".
- None of the objectives were considered ESSENTIAL.
- No significant missing Mars-relevant objectives were recognized.
- For many of the lunar objectives, the degree of relevance to Mars depends on how they are carried out at the Moon, the structure of martian human planning, and the context of the space program.

<u>FINDING.</u> The presently-considered lunar objectives have relevance to Mars, and this relevance could be increased with lunar implementation decisions.

Finding #3: ISRU Linkages

- Lunar ISRU is subject to major uncertainties regarding the range of resources present, their accessibility, potential future supply/demand relationships, and technical/economic factors involved in extraction, production, storage and utilization.
- Similar uncertainties exist regarding martian ISRU. Because of its greater distance, martian ISRU may be more compelling (some would say enabling), and two key raw materials (water, CO_2) are widely present.
- The value of lunar ISRU experience to future Mars application depends to a significant degree on resolution of the above details.

<u>FINDING.</u> There is an uncertain but potentially important relationship between lunar ISRU and martian ISRU that needs further study to enhance the potential of Mars ISRU.

Finding #4.
Science linkages between Mars-Moon

- Lunar planetary science investigations are not required to prepare for human explorers at Mars.
- However, NASA's goal is to "maximum possible utility for later missions to Mars", and we interpret this as including usefulness to our scientific understanding of Mars as a planet.
  - Mars-Moon science linkages recently analyzed by MEPAG (2004).
  - Those linkages reviewed, updated in this study.

<u>FINDING.</u> The primary scientific linkages between Mars and the Moon were recently evaluated by MEPAG, and those linkages are still valid.

Finding #5.
Relationship to MEPAG Goal IV

- MEPAG Goal IV describes the preparation activities that are thought to <u>require</u> robotic Mars flight missions. At the time Goal IV was written, it was assumed that any work that could be done elsewhere would be.
- A re-check was made to see if there are any aspects of MEPAG Goal IV that can be instead carried out on the Moon. **Answer: NO**
- Certain of the lunar objectives can, however, enhance the preparation work being carried out at Mars.

<u>FINDING.</u> Carrying out the lunar investigations under consideration will not lead to a reduction in the requirements in MEPAG Goal IV (Preparation for Human Explorers).

Finding #6.
Full Preparation for Mars

- The relationships between the Mars, Moon, and Earth portions of a complete program of preparation for human exploration of Mars have not yet been mapped out.
  - A more complete, integrated systematic study that examines the full set of validations and measurements from a risk-reduction perspective required for Human Mars Missions, as well as determining the most effective means to achieve these goals - whether by Earth Analogs, LEO, in-space, Moon, and Mars is needed.
  - The goal of such a study would be to determine the most cost effective means to achieve the fidelity required to meet these objectives (representative system in a relevant environment).

<u>FINDING.</u> An analysis of the complete program required to prepare for human missions to Mars has not yet been planned in sufficient detail, and should be carried out.

Prioritization Scale: "Prepare for Humans to Mars"

- **Essential** => An activity that must be performed on the Moon as a precondition to human exploration of Mars.
- **High Relevance** => An activity for which there is a high correspondence between the activity at the Moon and a capability that is needed at Mars.
- **Medium Relevance** => An activity that, while it could be performed on the Moon, might be more effectively accomplished by other means or at other venues. There is a less compelling rationale that these activities need to be demonstrated on the Moon.
- **Low Relevance** => If deleted from the lunar program would have a low impact on preparations for a later Mars mission.
- **No score** => No perceived relevance to Mars.
- **Not Assessed** => Dependent on information not available to MEPAG.