Preparing for Humans at Mars, MPPG updates to Strategic Knowledge Gaps and Collaboration with Science Missions

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Abstract

The Mars Program Planning Group (MPPG) was an agency wide effort, chartered in March 2012 by the NASA Associate Administrator for Science, in collaboration with NASA's Associate Administrator for Human Exploration and Operations, the Chief Scientist, and the Chief Technologist. NASA tasked the MPPG to develop foundations for a program-level architecture for robotic exploration of Mars that is consistent with the President's challenge of sending humans to the Mars system in the decade of the 2030s and responsive to the primary scientific goals of the 2011 NRC Decadal Survey for Planetary Science. The Mars Exploration Program Analysis Group (MEPAG) also sponsored a Precursor measurement Strategy Analysis Group (P-SAG) to revisit prior assessments of required precursor measurements for the human exploration of Mars. This paper will discuss the key results of the MPPG and P-SAG efforts to update and refine our understanding of the Strategic Knowledge Gaps (SKGs) required to successfully conduct human Mars missions.

I. Introduction

Future robotic science missions to Mars provide opportunities to reduce uncertainties of environmental parameters, allow advanced concept teams to make better informed architectural and technology investment choices, and to support overall risk reduction planning. NASA has conducted numerous robotic missions since the Viking spacecraft first surveyed and landed on Mars in 1976. Recent missions, including the 2001 Mars Odyssey orbiter and the 2011 Mars Science Laboratory rover (landed August 6, 2012) carried dedicated payloads for making specific measurements to address the knowledge gaps relevant to human exploration. While a significant amount of data and knowledge has been acquired over the past decades of Mars exploration, significant gaps, large uncertainties, or large variability of key environmental parameters remain. Additional payloads on future robotic missions could further address these gaps as well as enrich our scientific knowledge of Mars.

Operationally, similar mission phases exist between human mission concepts and robotic science missions. This creates potential opportunities and synergy for introducing new technologies in all of the mission phases.

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1. Capturing into Mars Orbit
2. Getting to the surface, referred to as Entry Descent and Landing (EDL)
3. Mobility on the surface
4. Ascending from the surface
5. Returning to Earth

Each of these phases poses technological and engineering challenges and risks for a human Mars mission. Based on numerous prior assessments, the most difficult seem to be EDL and the ascent phase. For getting to the surface, the scale and required mass of human systems/payloads is considerably larger (≈40 metric tons) versus the current capability as recently demonstrated by the Mars Science Laboratory (≈1 metric ton). The two major options being considered to solve this problem are a lifting body design that has more lifting capability than the traditional 70° rotated cone heat shield used by robotic missions today. The rotated cone heat shield shape was initially developed by the Viking robotic missions in the early 1970's and continues to be used for landed missions today. Another option being considered for entry is a large inflatable decelerator, which has similar geometry to the heat shield geometry used today but is much larger and would also enable larger payloads to be landed on the surface of Mars. Each of these options have unique engineering challenges related to structural stiffness and guidance, navigation and control. Both options would also benefit, even when flown at subscales, future science missions due to the increased landed mass performance.

A robotic Mars sample return mission requires ascent from the Martian surface. While both human and robotic systems have returned from the lunar surface, robotic ascent has not yet been performed from Mars. Trade studies have shown that the performance of solid rockets would enable robotic systems to deliver small payloads/samples to Mars orbit where a return vehicle could rendezvous, capture and then depart for Earth.

II. Strategic Knowledge Gap Filling Activities

The environmental knowledge gained from future robotic science missions will be essential for improving crew safety, designing more capable systems, and for conducting operations of human missions on the surface of Mars. NASA has conducted numerous robotic missions since the Viking missions first surveyed and landed on Mars in 1976. The Mars Science Laboratory mission (landed August 6, 2012) carried heat shield instrumentation on the entry vehicle and the rover carries a radiation measurement instrument. These instruments specifically addressed critical knowledge gaps; the data will assist in reducing design margins and improve crew protection systems. While the existing body of knowledge about Mars' surface is growing daily, some measurements are needed to characterize crew chemical or biological hazards, and to understand future operational constraints and issues on the Martian surface. The measurements needed are broken up into three categories as follows:

<u>Architecture drivers</u> – measurements that allow us to design spacecraft and the mission more efficiently

1. **Atmospheric density and winds**: current uncertainty is large due to limited flight data and diurnal/seasonal variability, and when dust storms are active.
   IMPACT: Landed mass, available landing sites (lower altitude), EDL design
2. **Resources**: allows for ISRU, dependent on the strategy.
   IMPACT: Landed mass (consumables and propellant required to transport from Earth and for use by the crew)

<u>Crew Safety/hazards</u> – measurements that allow us to keep the crew safe.

1. **Radiation:** Determine surface and/or orbital radiation levels and directionality (e.g. MSL RAD). This can affect the surface vehicle configuration if additional neutron shielding is needed and also surface operations during solar particle events (SPEs).
2. **Biohazards:** Determine if extant life is present on the surface and poses a hazard to the crew and public.
3. **Toxicity:** Determine if there are chemicals with known toxic effects on humans and the levels of toxicity.

<u>Operational</u> – measurements that allow us to operate safely on the surface.

1. **Trafficability**: Determine surface hazards at the landing site (limits site selection) as well as the load bearing strength of surface to handle larger vehicles (as compared to smaller robotic vehicles, i.e. MER and MSL/Curiosity).
2. **Dust effects on systems**: Determine mechanical properties of airborne and surface dust (drives ISRU/lander/rover/EVA suit/equipment dust tolerance and operations).
3. **Forward Planetary Protection**: Determine how organisms from Earth may survive and possibly contaminate special regions on Mars (landing site selection and operations).
4. **Atmospheric electricity**: Characterize the electric field magnitude and frequencies, atmospheric and surface conductivity (drives lander/rover/suit/equipment grounding design and operations).

The PSAG results both confirmed prior efforts by the MEPAG, captured in the Goal IV update of 2010, which reviewed measurements made to date and also prioritized the measurements. MEPAG Goals I, II and III are science investigation areas and Goal IV covers human precursor mission measurements. The Goal IV information can be found on-line at: http://mepag.jpl.nasa.gov/Goal4/index.html

P-SAG (2012) organized their thinking around the definition of a set of "Strategic Knowledge Gaps", that represent information missing to achieve one of four objectives:

A. Achieve the first human mission to Mars orbit
B. Achieve the first human mission to the martian surface
C. Achieve the first human mission to the surface of Phobos and/or Deimos
D. Sustained human presence on Mars

Overall, 17 SKGs were identified, although not all of them are relevant to each of the above four objectives. For each of these knowledge gaps, the work needed to fill the gap (referred to as GFA, or Gap-Filling Activity) was described. Although it was recognized that the knowledge to be generated by GFA work could be produced in several different ways (using the Mars flight program, using ISS, using labs or computer models on Earth, using terrestrial Mars analogs, etc.), P-SAG limited its scope to the data that needs to be generated by the Mars flight program. In this category alone there are about 60 GFAs, of significantly differing priority and degree of urgency (time phasing). The instruments needed to collect the data related to the flight-related GFAs can then be evaluated, and the missions needed to deliver and operate the instruments can be envisioned.

Table 1 below shows a matrix comparing MEPAG science investigation areas (goals 1-3) and human precursor measurement areas (goal 4). The cells marked with 'E' indicate that there is excellent overlap where making measurements. The cells marked 'S' indicate that there is some overlap. While the purpose of the measurements is quite different, overall, the matrix indicates that there are quite a few areas where excellent overlap exists in life sciences, climatology and geophysics.

P-SAG (2012) concluded that the high-priority gaps for a human mission to Mars orbit relate to a) atmospheric data and models for evaluation of aerocapture, and b) technology demonstrations. The early robotic precursor program needed to support a human mission to the martian surface would consist of <u>at least</u>:

- One orbiter
- A surface sample return mission (the first mission element of which would need to be a sample-caching rover)
- A lander/rover-based in situ set of measurements (which could be made from the sample-caching rover)
- Certain technology demonstrations

Human Precursor Measurement Areas (Goal IV)

Science Investigation Areas	Objective	#	Investigation (from 2010 MEPAG Goals Document)	A1 Upper Atmosphere	A2 Atm. Modeling	A3 Orbital Particulates	A4 Technology: To/from Mars System	B1 Lower Atmosphere	B2 Back PP	B3 Crew Health and Performance	B4 Dust Effects	B5 Forward PP	B6 Atmospheric ISRU	B7 Landing Site and Surface Hazards	B8 Technology: Mars Surface	C1 Phobos/Deimos Science	C2 Phobos/Deimos surface Ops	C3 Technology: Phobo/Deimos	D1 Water Resources	D2 Technology: Sustained Presence
I. Life	A. Past habitability/life	1	PRIOR HABITABILITY OF SURFACE ENVIRONMENTS				Not addressed.								Not addressed.			Not addressed.	S	Not addressed.
		2	PRESERVATION POTENTIAL																	
		3	EVIDENCE OF PRIOR HABITABILITY OR BIOSIGNATURES																	
	B. Present habitability/life	1	PRESENTLY HABITABLE ENVIRONMENTS						E			E							S	
		2	DEGRADATION OF LIFE SIGNATURES						S			E								
		3	SEARCH FOR EXTANT LIFE						E			S								
	C. Evolution of habitability	1	CHARACTERIZE HYDROLOGICAL CYCLE																S	
		2	BIOESSENTIAL ELEMENTS																	
		3	POTENTIAL ENERGY SOURCES																	
		4	OXIDATIVE / RADIATION HAZARDS						E	E	S			S						
II. Climate	A. Present	1	WATER, CO2, AND DUST PROCESSES	E	E			E		S	S		E	S					S	
		2	PHOTOCHEMICAL SPECIES	S	S			S	E		S		E							
		3	VOLATILE AND DUST EXCHANGE	S	S			S			S		E							
		4	SEARCH FOR MICROCLIMATES						S		S	S	S							
	B. Recent	1	ISOTOPIC, NOBLE, & TRACE GAS CHANGES W/ OBLIQUITY																	
		2	STRATIGRAPHIC RECORD--PLD																	
		3	PERIGLACIAL PROCESSES																	
	C. Ancient	1	RATES OF ESCAPE OF KEY SPECIES																	
		2	PHYS AND CHEM RECORDS																S	
		3	ISOTOPIC, NOBLE, AND TRACE GAS EVOLUTION																	
III. Geology/ Geophysics	A. Crust	1	MINERALOGY OF GEOLOGIC UNITS							S	E			E					E	
		2	SEDIMENTARY PROCESSES AND EVOLUTION							S	S			S					S	
		3	ABSOLUTE AGES																	
		4	HYDROTHERMAL ENVIRONMENTS						E										S	
		5	IGNEOUS PROCESSES AND EVOLUTION																	
		6	SURFACE-ATM INTERACTIONS								S			S					S	
		7	TECTONIC HISTORY OF CRUST																	
		8	PRESENT STATE AND CYCLING OF WATER																E	
		9	CRUSTAL MAGNETIZATION																	
		10	EFFECTS OF IMPACTS																	
	B. Interior	1	STRUCTURE AND DYNAMICS OF INTERIOR																	
		2	ORIGIN AND HISTORY OF MAGNETIC FIELD																	
		3	CHEMICAL AND THERMAL EVOLUTION																	
	C. Phobos / Deimos	1	ORIGIN													E	S			
		2	COMPOSITION													E	E			
		3	INTERNAL STRUCTURE													E	E			

Table 1.0 P-SAG Summary Table

Measurements can be obtained using two primary types of spacecraft: orbiters and surface vehicles (i.e. landers/rovers). Orbiters allow for global observations and reconnaissance and landers/rovers enable local in-situ surface measurements as well as enabling simultaneous measurements in conjunction with orbiters for measurements such as columnar atmospheric density characterization or atmospheric radiation transport.

Orbiters can be used to make the following types of moderate- to high-priority measurements:

1. Upper and lower atmospheric densities to inform aerocapture and EDL designs, respectively
2. Radiation Transport —simultaneous orbital and surface measurements for characterizing moderate-energy solar energetic particle events.
3. High resolution imaging and mineral mapping for:
   - Forward Planetary Protection assessments
   - Landing site identification, selection and certification
   - Resource identification

Precursor Landers/Rovers can be used to make the following types of moderate to high priority measurements as well:

1. EDL profiles of atmospheric state (e.g. MEDLI – MSL Entry, Descent and Landing Instrumentation). While an impressive data set was gathered to improve our knowledge and modeling capability, more than one data set is required to reduce uncertainties prior to a human landed mission. Additionally, atmospheric pressure data at a range of altitudes is required to determine the descent engine design for ignition and operation. See figure 1, which is a picture of the back of the MSL heat shield shortly after separation, showing the MEDLI sensors and wiring.

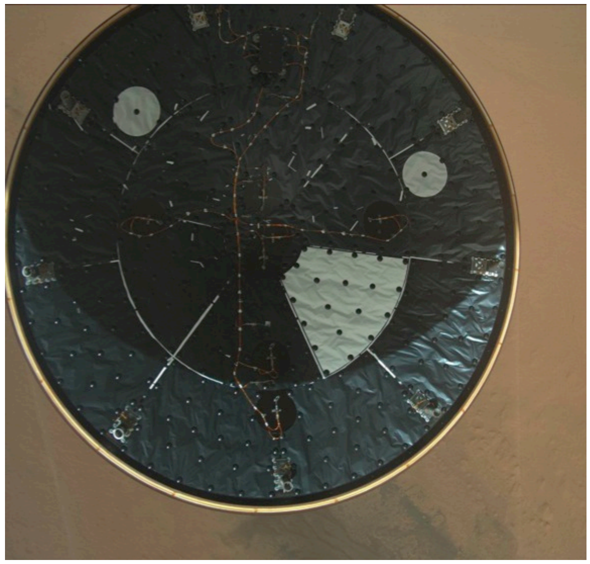

Figure 1. MSL Heatshield post separation with MEDLI shown

2. Dust properties, regolith composition, regolith structure
3. Atmospheric electrical characteristics
4. Atmospheric and climate measurements to obtain time dependent density profiles (simultaneous with orbital measurements).
5. Radiation measurements (simultaneous with orbital measurements).

III. Mars Sample Return

Given what we know about the Martian environment, there is debate about whether the return of a sample from Mars to Earth is required prior to human exploration of the surface. The answer to this question depends on the level of risk tolerance. Though most of these risks would be borne by the flight crew, some of these risks would need to be shared by the citizens of Earth. We do not currently have the ability to assess all of these risks using the robotic exploration program, however, it is well-accepted (e.g. P-SAG, 2012) that accurate assessments could be done by returning samples from Mars.

Near to mid-term human missions beyond low Earth orbit offer strategic benefits as well to Mars exploration. One of the major technical concerns for a Mars sample return mission has been planetary protection. A crewed mission activity to retrieve a sample in a long term stable lunar orbit could improve both planetary protection and improve the overall safety of the return vehicle by providing intelligent inspection and assessment of the sample return canister and then additional protection and increased safety during the return to Earth due to the higher systems reliability for human-rated systems.

For a Mars sample return mission, proven and commercially available solar electric propulsion using Hall thrusters could enable a lower cost sample return mission architecture. The preliminary sample return scenario goes as follows:

- SEP enabled robotic vehicle delivers samples to cislunar space, possibly a long term stable Lunar distant retrograde orbit for a crew based retrieval.
  - Cislunar capability planned after 2021

- Sample canister could be captured, inspected, encased and retrieved tele-robotically
  - The Orion MPCV crew vehicle does a rendezvous with the robotic sample return spacecraft.
  - Prior to retrieval, the sample canister would be inspected
  - The canister could then be retrieved using Orion vehicle or by using a crew piloted robotic

retrieval vehicle.

- Finally, the canister could be cleaned and enclosed in a stowage case in the airlock and finally stowed for Earth return in the cabin.

A Mars sample return mission conducted in this fashion would accomplish high priority national science, be accomplished more safely and would also lead to a safer human mission to Mars in the future.

IV. Low Cost Mission Approaches to making Precursor Measurements

As launch performance allows, lower cost missions could be enabled by using the heavy lift Space Launch System (SLS) to launch fully capable planetary spacecraft as secondary payloads. These spacecraft, when equipped with solar electric propulsion, can fly to Mars and conduct missions with instrumentation that are relevant both scientifically and for human exploration.

Commercially available hall thrusters, when combined by innovative lunar gravity assist trajectories, can provide inner solar system planetary exploration capabilities with adequate thrust and a high Isp. An example is shown in the figure below of two small Mars telecom relay orbiters attached to the inter-stage adapter with a relevant human precursor and science payload for high-resolution mineral mapping. Two spacecraft are also shown to maintain the launch vehicle center of gravity (CG) during ascent. If only one vehicle were to be flown, additional ballast would likely be required. Shown below, the conceptual spacecraft are stowed in the volume between the upper stage and the Orion Service Module (full length nozzle shown). Other types of small spacecraft could also be accommodated including CubeSats.

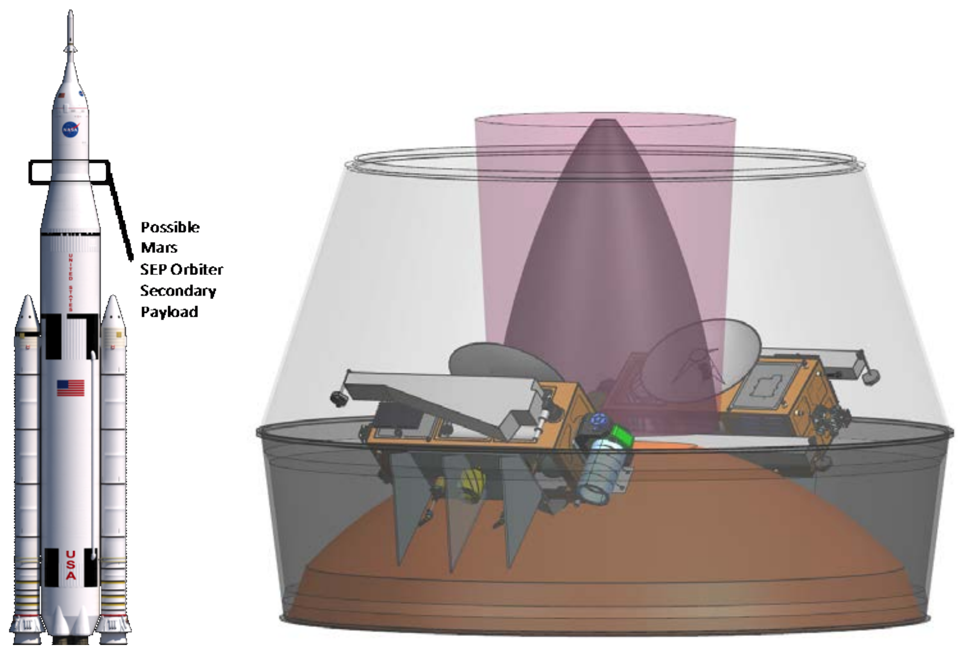

Figure 2. SLS Secondary Payload Accommodation Concept

The spacecraft would then be jettisoned after Orion separation and prior to the upper stage disposal burn. The current SLS upper stage has secondary payload capabilities, which would be utilized to initiate separation. Access ports (not shown) on the side of the vehicle, would be used for inspection, removal of safing plugs and possibly for spacecraft battery charging during an extended launch delay.

V. Summary

Our knowledge of the Martian environment is fairly limited considering there have been 15 successful US robotic missions to date since 1965. Current orbiting and surface assets tell us more everyday, but there are many unanswered questions that once addressed, would reduce the cost and risk of a human mission to Mars' surface. The recent P-SAG assessment showed excellent overlap between science and human precursor measurements. We can now say that considerable synergies and opportunities exist between the current robotic Mars Exploration Program efforts to accomplish high priority national science and efforts to address SKGs in support a future human Mars mission.

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VII. References

[1]Figueroa, O., et al, "Summary of the Final Report", Mars Program Planning Group, NASA Report, September 25, 2012, http://www.nasa.gov/pdf/691580main_MPPG-Integrated-v13i-Summary%20Report-9-25-12.pdf

[2]National Research Council (U.S.). Committee on the Planetary Science Decadal Survey. and National Research Council (U.S.). Space Studies Board. *Vision and Voyages for Planetary Science in the Decade 2013-2022*. Washington, D.C.: National Academies Press, 2011p 6-24

[3]P-SAG (2012) Analysis of Strategic Knowledge Gaps Associated with Potential Human Missions to the Martian System, TBD pp., posted July, 2012, by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag.jpl.nasa.gov/reports/

[4]Mars Design Reference Architecture 5.0, NASA/SP–2009–566, July 2009

[5]NASA's Joint Robotic Precursor Activity: Providing Strategic Knowledge to Inform Future Human Exploration, 5th Wernher von Bruan Memorial Symposium, October, 16, 2012. Victoria P Friedensen, Dr. Michael J. Wargo, http://www.astronautical.org/sites/default/files/attachment/WARGO%20v4%20-%202012%20VB.pdf