IAC-13-A3.1.4

ASSESSMENT OF THE STRATEGIC KNOWLEDGE GAPS FOR EXPLORATION.

Michael Wargo †
NASA Headquarters, Washington D.C.

Sylvie Espinasse,
ESA ESTEC, Noordwijk, Netherlands, sylvie.espinasse@esa.int

Michelle Rucker
NASA-Johnson Space Center, Houston, USA, michelle.a.rucker@nasa.gov

François Spiero
CNES Headquarters, Paris, France, francois.spiero@cnes.fr

Kevin Watts
NASA-Johnson Space Center, Houston, USA, kevin.d.watts@nasa.gov

Satoh Naoki
Japan Aerospace Exploration Agency, JAXA, Japan, satoh.naoki1@jaxa.jp

† *This paper is dedicated to Michael J Wargo, Chief Exploration Scientist for NASA's Human Exploration and Operations Mission, who passed away in August 2013.*

In order to prepare for safe, effective, and efficient human exploration beyond Low Earth Orbit (LEO), system and mission planners will need access to data that characterizes the engineering boundary conditions of representative exploration environments, identifies hazards, and assesses resources. The knowledge developed from this data will inform the selection of future destinations, support the development of exploration systems, and reduce the risk associated with human exploration. Such data can be obtained on Earth or in space, by analogue, experimentation, or direct measurement by remote sensing, in situ or sample return. In order to accomplish this, it is necessary to identify the Strategic Knowledge Gaps (SKGs) associated with potential destinations for human exploration, what measurements or data are needed to fill those gaps, how the knowledge is best obtained, and for which missions and functional capabilities the knowledge is needed.

A Strategic Knowledge Gap Assessment Team has been formed within the International Space Exploration Coordination Group (ISECG) and charged with developing an internationally integrated set of SKGs to inform joint efforts at planning human and robotic precursor exploration of the Moon, asteroids, and Mars and its moons. The effort also includes articulating how currently planned robotic missions and ground based activities will contribute to filling the SKGs and elucidation of potential future missions and activities that complement those currently planned and could provide robust opportunities for international cooperation.

These observations/measurements will directly support engineering design and also assist in numerical model validation.

This paper will present the outcome of the analysis performed by the ISECG SKG Assessment Team to document the internationally integrated set of highly relevant gaps, as well as information on how planned robotic mission and ground based activities fill these gaps.

I. INTRODUCTION

Since Project Apollo, robotic missions have served as the precursors to human exploration missions. Beginning with Ranger, Surveyor, and Lunar Orbiter, the data collected have defined the boundary conditions and provided information on the environment that was needed to inform the first human missions to the Moon. Agencies are planning a number of robotic missions to destinations reachable by humans. Almost all are done through international partnership. Most of these robotic missions are driven by scientific objectives; some have originated as human precursor missions. In each case, information is gathered which is useful for meeting science and human exploration goals. Increasingly, science missions in the formulation phase are creating opportunities to gather information and demonstrate technologies needed to prepare future human missions.

To facilitate coordination among space agencies and support definition and planning of future missions, the International Space Exploration Coordination Group (ISECG) has set up the Strategic Knowledge Gaps Assessment Team (SKGAT) and tasked it to identify the Strategic Knowledge Gaps (SKGs) related to the ISECG Global Exploration Roadmap (GER)[1] destinations. These SKGs have been discussed by ISECG representatives of the participating agencies, mapped against past, current and future robotic missions and ground based activities. In addition, an assessment of the priority level of these SKGs with respect to the ISECG GER Design Reference Missions (DRMs) is currently on-going.

II. STRATEGIC KNOWLEDGE GAPS: DEFINITION AND ASSESSMENT

In order to prepare for safe, effective, and efficient human exploration beyond Low Earth Orbit (LEO), system and mission planners need access to data that characterizes the engineering boundary conditions of representative exploration environments, identifies hazards, and assesses resources. The knowledge developed from this data will inform the selection of future landing sites, inform the design and support the development of exploration systems, and reduce the risk associated with human exploration. While some data can be obtained through ground-based activities (e.g. analogue campaigns, experimentation, modelling, laboratory analysis, etc.) others data can only be collected in space by remote sensing, in situ measurements or sample return.

In order to accomplish this, it is necessary to identify the SKGs associated with potential destinations for human exploration, what measurements or data are needed to fill those gaps, how the knowledge is best obtained, and for which missions and functional capabilities the knowledge is needed.

In preparation for future missions to the Moon and the lunar vicinity, asteroids and Mars and its moons, SKGAT members have assembled multiple sets of SKGs developed by a number of key independent Analysis/Assessment Groups from NASA (e.g. LEAG (Lunar Exploration Analysis Group), MEPAG (Mars Exploration Program Analysis Group), P-SAG (Precursor Strategy Analysis Group), SBAG (Small Bodies Analysis Group),…), ESA Topical Teams and mission scientists, and JAXA experts for each destination. For each destination, these SKGs have been integrated and grouped by areas of knowledge. In some cases, they have been further subdivided into high level SKGs and associated detailed SKGs to fully describe the gap in strategic knowledge.

Subsequently, the high level SKGs have been mapped to past, currently in operations or planned robotic missions and ground based activities that can contribute to filling the gaps. While the mapping to robotic missions has been quite exhaustive, the mapping of the ground based activities is still incomplete. This is due to the fact that contrary to robotic missions, space agencies are not necessarily responsible for all relevant ground based activities and thus the related mapping is very demanding.

The last portion of the effort involves prioritising the complete set of SKGs following a set of criteria identified to aid in discriminating their relevance with respect to the ISECG GER DRMs. Such criteria are essentially related to crew safety and risks, mission success and applicability to more than one destination.

The outcome of this analysis will help to identify those high priority SKGs not currently addressed or only incompletely being addressed and will inform ISECG participating agencies joint efforts at planning robotic and human precursor missions to advance exploration of the Moon and the lunar vicinity, asteroids, and Mars and its moons.

The table below provides an illustrative example of a relevant set of high level SKGs for the main potential destinations, Moon, asteroid, and Mars. It provides insight into how the gaps are categorized and the information which is available on each gap.

Destination	Knowledge Domain	Strategic Knowledge Gap Description	Target Measurement	Mission or Ground Based Activity Addressing the SKG	Additional Measurements: R = Robotic Mission SR = Sample Return G = Ground Based Activities
Moon	**Resource Potential**	**Lunar Cold Trap Volatiles:** Composition/ quantity/ distribution/ form of water/ H species and other volatiles associated with lunar cold traps.	In-situ measurement of volatile characteristics and distribution within permanently shadowed lunar craters or other sites identified using remote sensing data (e.g. from LRO).	Roscosmos Luna-25/ Luna-27 NASA-CSA RESOLVE Roscosmos Luna-28/ Luna-29	**R, SR**
Near-Earth Objects (NEOs)	**Human Mission Target**	**NEO Composition/ Physical Characteristics:** Rotation State.	Light curve and radar observations from different ground (Earth based telescopes) and space based assets. Depending upon the visibility of NEOs from different assets capable of making light curve observations, all such assets should be engaged.	e.g. Goldstone Observatory (US); Bisei Spaceguard Center (Japan), Observatoire du Pic du Midi (France)	**R, G**
Mars	**Atmosphere**	**Atmospheric Modelling:** The atmospheric models for Mars have not been well validated due to a lack of sufficient observational data, and thus confidence in them (for use in mission planning, including entry, descent and landing) is limited.	Density, pressure, temperature, and wind data, trajectory performance information.	NASA Viking, Pathfinder, MGS, MERs, Phoenix, MRO, MSL ESA Mars Express ESA-Roscosmos ExoMars 2016 (TGO, EDM), 2018 (rover)	**R, G**

Table 1: Excerpt of the High Level SKGs Summary Table.

The Summary Table includes columns that identify:
1) in the first column the destination;
2) in the second column, the knowledge area to which it is associated;
3) in the third column, a brief description of the SKG;
4) in the fourth column, specific measurements which would contribute to filling the gap;
5) in the fifth column, insights into how past, on-going or future robotic missions and ground-based activities contribute information related to the gap;
6) and an indication in the very last right column where additional measurements will be useful to fill the gap.
The colour code keys are shown below in Table 2.

Mission or ground based activity addressing the SKG			
Mission	**Ground based activity**		**Additional Measurements:** **R = Robotic mission** **SR = Sample Return** **G = Ground based activities**
Concluded /In ops	Under develop-ment	Under study	R/ SR/ G

Table 2: Summary Table colour code.

The full list of SKGs has been summarised and the high-level SKGs Summary Table, i.e. the table showing the complete set of high level SKGs is available on the ISECG website. It reflects integration of the far more detailed and refined comprehensive set of SKGs. It contains information on the gaps and identifies specific measurements which would contribute to filling the gaps. The list also gives insights into how recent and planned robotic missions and ground-based activities will contribute information related to the gaps, and where additional measurements will be useful to fill the gaps. A close inspection of the two last columns reveals a number of potential opportunities for future robotic precursor missions and ground based activities that could address SKGs not already addressed or only partially being addressed by currently operational, or planned missions and activities.

Lastly, it will also show the gaps priority once this last part of the assessment will have been completed.

III CONCLUSION

Whether robotic mission formulation is primarily for scientific investigation or to prepare for human exploration, there are opportunities to significantly increase the benefit to each community. As can be seen from the missions listed in the fifth column of the table, identified precursor and/or science missions are already significantly contributing to both science and preparation for human exploration. The SKGs analysis will support the identification of the appropriate steps toward further coordination in order to increase the value of space exploration investments to the global stakeholder community. The SKGAT work is intended to inform the definition of objectives for future robotic missions and ground-based activities.

The value of this analysis is readily identifiable:

- For Agencies:

  - Inform the definition of future robotic missions and ground based activities objectives;

  - Identify missions of opportunity, i.e. SKGs filled by science driven missions and precursor missions providing opportunities for science.

- For the Scientific Community:

  - Identify additional opportunities for conducting compelling and high priority science by exploiting synergies with human exploration precursors.

In conclusion it can be said that robotic science missions provide an important technique for obtaining the data needed to prepare for human exploration beyond low-Earth orbit. It is generally accepted by both the science and exploration communities that measurements and data sets obtained from robotic missions support both the advancement of science and the preparation for human exploration.

[1] ISECG Global Exploration Roadmap published in August 2013 – available at www.globalspaceexploration.org