



Developing the global exploration roadmap: An example using the humans to the lunar surface theme



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ABSTRACT

The development of the Global Exploration Roadmap (GER) by 12 space agencies participating in the International Space Exploration Coordination Group broadly outlines a pathway to send humans beyond low Earth orbit for the first time since Apollo. Three themes have emerged: Exploration of a Near-Earth Asteroid, Extended Duration Crew Missions, and Humans to the Lunar Surface. The lack of detail within each of these themes could mean that realizing the goals of the GER would be significantly delayed. The purpose of this paper is to demonstrate that many of the details needed to fully define and evaluate these themes in terms of scientific rationale, economic viability, and technical feasibility already exist and need to be mapped to the GER. Here, we use the Humans to the Lunar Surface theme as an example to illustrate how this process could work. By mapping documents from a variety of international stakeholders, this process can be used to cement buy-in from the current partners and attract new ones to this effort.

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1. Introduction

The Global Exploration Roadmap [1,2] has been developed by the International Space Exploration Coordination Group (ISECG – comprised of 14 space agencies, 12 of which developed the GER; <http://www.globalspaceexploration.org/wordpress/>) to define a path to get humans beyond low Earth orbit and eventually to Mars. The path is visiting the lunar vicinity (including an asteroid brought there by a robotic mission), lunar surface, Mars vicinity, and finally the surface of Mars. While a conceptual outline for coordinated space exploration is articulated in this document, many details remain to be defined. In order that this document can be used to direct investment, architecture, and cooperative agreements, an expansion of the GER is required.

While the Apollo program served to demonstrate that one nation could send and return safely humans to the surface of another planet, the program was not sustainable and it was canceled in 1972. As humanity begins to reach for the stars once

again, the lessons learned from Apollo need to be implemented. The importance of President George W. Bush's "Vision for Space Exploration" [3] has been underestimated because of the political rhetoric that surrounded its inception and execution [4]. It provided a focus for NASA and other space agencies to start the long-term objective moving humanity off planet to the Moon and beyond (*cf.* [5]), and a "Global Exploration Strategy" [6] was developed by 14 space agencies. However, with the change of administration in 2008, the US changed its approach on human exploration of the solar system.

In 2009, the Global Exploration Strategy set a top-level vision for human space exploration and was followed by the Global Exploration Roadmap (GER), which started the process of realizing the initial vision. The initial GER [1] espoused a flexible path to getting to Mars involving a Moon next or an asteroid next approach for human spaceflight. A study by Szajnfarber et al. [7] concluded that when international partners considered endogenously, the argument for a "flexible path" approach is weakened. This is because international contributions can make "Moon first" economically feasible, and characteristics of proposed flexible path approaches may preclude international involvement because of the disproportionate risk that those contributions inherently bear.

In 2013, a revised GER was published that dropped the flexible path approach in favour of a common pathway to Mars involving

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visiting the lunar vicinity, lunar surface, Mars vicinity and eventually Mars itself. Three near-term themes have emerged: Exploration of a Near-Earth Asteroid (in the lunar vicinity), Extended Duration Crew Missions, and Humans to the Lunar Surface [2]. As the feasibility of sending humans to a Near-Earth Asteroid in the relative near term has faded, a robotic Asteroid Redirect Mission (ARM) is now under consideration, with a small asteroid (or part thereof) being redirected to a stable lunar orbit for humans to explore. This would form part of the extended duration crew mission theme. Other options have been studied that could also form part of this theme, including placing the Crew Exploration Vehicle at Lagrange point 2 on the farside of the Moon and undertaking tele-robotic exploration of the lunar farside, including sample return and deployment of a radio telescope on the surface of the radio-quiet lunar farside [8–10].

The Humans to the Lunar Surface theme is probably the most advanced because of the work conducted following the announcement of the Vision for Space Exploration [3]. The latest version of the GER [2] further states that: “Many agencies consider human missions to the lunar surface as an essential step in preparation for human Mars missions”, and “Lunar missions are favored by agencies who view the Moon as the next step for human planetary exploration and NASA may contribute to such missions.” The recently published NRC report entitled “*Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration*” [11] provided a clear recommendation to extend a human presence beyond low Earth orbit (LEO). In the report a number of advantages to the United States being a more active player in lunar surface operations was emphasized. A return to extended surface operations on the Moon was recommended (i) to support the long-term strategy to land humans on Mars and (ii) to provide ample opportunities for international and commercial cooperation.

In this paper, we focus on developing the ‘Humans to the Lunar Surface’ theme of the GER [2] to illustrate that by mapping a number of recent reports/documents to it each theme can be developed. The other themes can be similarly developed and, as the title indicates, this study is an example. These documents are in no way meant to be encompassing everything that is relevant to this process (indeed, many others can and should be added). This exercise is intended to demonstrate that existing detailed documents can be mapped into the GER, despite the differences in focus and level of detail, and provides an avenue to promote broader international buy-in, especially from those ISECG agencies that are not part of the GER.

2. The global exploration roadmap (2013)

A brief overview of the GER is given in order that the mapping process outlined in this paper is put into context. The common goals are:

- Develop Exploration Technologies & Capabilities.
- Engage the Public in Exploration.
- Enhance Earth Safety.
- Extend Human Presence.
- Perform Science to Enable Human Exploration.
- Perform Space, Earth, and Applied Science.
- Search for Life.
- Stimulate Economic Expansion.

These rather broad goals lead to the six principles driving the mission scenarios and themes of the current GER: affordability, exploration value, international partnerships, capability evolution, human/robotic partnerships, and robustness. While the principle of

robustness is articulated as “provide resilience to programmatic and technical challenges” it also implies sustainability. As Mars is currently termed the “horizon destination”, the GER has the opportunity to provide not only a pathway to Mars, but also to include and highlight opportunities to make the pathway sustainable. This principle, we believe, has its origins in the goal to stimulate economic expansion.

When detailing the humans to the lunar surface scenario, the GER gives a number of activities that will be woven into such missions:

- Technology test bed (surface power systems, long distance mobility concepts, human-robotic partnerships, precision landing).
- Characterizing human health and performance outside Earth’s magnetosphere and in a reduced gravity environment.
- Conducting high priority science benefiting from human presence, including human-assisted lunar sample return.
- Advance knowledge base related to use of lunar resources.
- Explore landing sites of interest for extended durations.

For the purposes of this paper, these activities will form the basis of our mapping activity as an example to demonstrate that much of the work to develop the GER has already been conducted. There have been many studies since Apollo on returning to the Moon, and these are still valid. By recognizing the existence and utility of these documents, the ISECG can focus on developing mission concepts.

3. The mapping process

The documents used here represent a selection of internationally authored papers as well as documents from the Lunar Exploration Analysis Group (LEAG) that includes the extensive Lunar Exploration Roadmap. The documents are as follows:

- The Committee on Space Research (**COSPAR**) Panel on Exploration report on developing a global space exploration program [12],
- The Strategic Knowledge Gaps report from the LEAG (**LEAG-SKGs**) published in 2012 [13],
- The Lunar Exploration Roadmap developed by LEAG (**LEAG-LER**), which is updated periodically [14],
- The National Research Council report Scientific Context for the Exploration of the Moon (**SCEM**) published in 2007 [15],
- The Scientific Rationale for resuming lunar surface exploration (**SR**) [16], and
- The astrobiological benefits of human space exploration (**ASTROBIO**) [16,17].

The abbreviations used to designate each publication are in parentheses and bold type. For this activity, we tried to map each of the publications to the activities envisaged for the Humans to the Lunar Surface theme. Much more detail is given in the individual publications and we only summarize the main points here.

3.1. Technology test bed

The Moon represents a key asset for testing planetary exploration technologies because of its proximity to Earth. The GER is quite expansive about such issues listing one high-level common goal of “Develop Exploration Technologies & Capabilities” and one specifically under the humans to the lunar surface category [“Technology test bed (surface power systems, long distance mobility concepts, human-robotic partnerships, precision landing)”].

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