



The Global Exploration Roadmap and its significance for NASA



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ABSTRACT

The Global Exploration Roadmap reflects the collaborative effort of twelve space agencies to define a long-term human space exploration strategy which provides substantial benefits for improving the quality of life on Earth and is implementable and sustainable. Such a strategy is a necessary precondition to the government investments required to enable the challenging and rewarding missions that extend human presence into the solar system. The article introduces the international strategy and elaborates on NASA's leadership role in shaping that strategy. The publication of the roadmap, a reflection of the space landscape and multilateral agency-level dialog over the last four years, allows NASA to demonstrate its commitment to leading a long-term space exploration endeavor that delivers benefits, maintains strategic human spaceflight capabilities and expands human presence in space, with human missions to the surface of Mars as a driving goal. The road mapping process has clearly demonstrated the complementary interests of the participants and the potential benefits that can be gained through cooperation among nations to achieve a common goal. The present US human spaceflight policy is examined and it is shown that the establishment of a sustainable global space exploration strategy is fully consistent with that policy.

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1. Introduction

The first fifty years of human activity in space has significantly contributed to improving life on Earth in many ways. Currently, the primary focus of human activity in space is the International Space Station (ISS) where NASA and its partners from Russia, Japan, Europe and Canada are utilizing the space station for a range of activities that are enabled by successfully operating, on a permanent basis, a world-class research facility in low-Earth orbit (LEO). Findings and results from space station research increasingly lead to new insights and knowledge having significant benefit to humanity [1]. The ISS user base is expanding, including public and private sector entities which see the opportunity provided by the ISS and LEO. Space agency transportation and habitation capabilities and risk management techniques allow astronauts to spend six to twelve months onboard the ISS conducting a wide range of activities including gaining a better understanding of how issues associated with long duration human spaceflight can be addressed. These government investments have fostered an emerging commercial effort to visit and utilize LEO. The ISS and its international

partnership are leading the way for a robust future for human activities in LEO and beyond, conducted by both space agencies and the private sector.

Human space exploration, including missions to explore the surface of Mars, will be enabled through international partnerships [2]. Public-private partnerships will play an important role, but it remains clear that very significant government investment will be required to achieve this ambitious goal. Exploration missions will need multiple agencies providing critical contributions, building on capabilities operational around the world today and establishing a true dependence on each other for execution of the endeavor. Dependency can be a difficult choice for government leaders to accept but history has shown that it frees funds for additional developments that would not have been possible without it and establishes an endeavor stronger than the sum of its parts. Yet, international partnerships offer advantages beyond spaceflight itself. As Susan Eisenhower stated during the April 9, 2014 U.S. Senate hearing, "Space has unique capacities to serve the global community. It can be a force for preventive diplomacy, transparency and for sustaining and building bonds among those who are willing to put aside solely national pursuits" [3].

The reality of interdependence necessitates a collaborative international strategic planning effort where common goals and objectives are established and national capabilities and long-term

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interests are considered. Stakeholder equities from all participants must be understood and considered if any strategy is to be sustainable in the long term. Effective leadership will also be essential to its success and as such NASA has been fully engaged with ISS partners and other space agencies in discussions to lay the groundwork for future partnerships in space exploration. The collaborative work of twelve space agencies over the past four years, with NASA playing a leading role, has resulted in the release of an updated Global Exploration Roadmap [4]. It reflects an international strategy for human space exploration, beginning with the ISS and the step-wise extension of human presence into the solar system, with human missions to the surface of Mars as the driving goal. As part of this process, all space agencies shared their objectives, priorities and constraints and contributed their ideas. The non-binding Global Exploration Roadmap helps NASA to articulate its vision for future exploration and demonstrate its robustness in the changing environment in which multi-decade programs must exist. It does likewise for other participating space agencies and provides a foundation for future mission collaborations.

NASA's exploration strategy formed a good basis for the multi-lateral discussion which led to the Global Exploration Roadmap. NASA's strategy, as currently documented in the white paper *Pioneering Space, NASA's Next Steps on the Path to Mars* [5], includes initial missions beyond LEO in cis-lunar space on the way to Mars. The strategy is enabled by capabilities which are multi-use and evolvable to enable increasingly challenging missions to multiple destinations in deep space. Cis-lunar space provides an excellent proving ground for capabilities and operational risk management techniques needed to explore beyond. Current and past Mars mission studies and lessons learned, as far back as those shaping the Space Exploration Initiative in 1989, show that certain capabilities and technologies are fundamental and enable exploration of multiple destinations. These are the focus of NASA's investments and mission planning. With Exploration Mission (EM)-1 and EM-2—the first un-crewed and crewed flights of Space Launch System (SLS) and Orion, NASA is demonstrating foundational exploration investments for exploration. The Asteroid Redirect Mission [6] provides the opportunity to use SLS and Orion, as well as demonstrate advanced solar electric propulsion and deep space operations techniques, using cis-lunar space as a proving ground for missions beyond the Moon. A key feature of NASA's long-term planning is maintaining the flexibility to adjust the mission content and sequencing to adapt to new objectives. As we learn more about our solar system and develop new technologies, new ways to use human presence in space for the purpose of exploration and discovery will emerge. A more detailed NASA roadmap to Mars will be released at the end of the year in revision of the *Voyages* document [7].

A successful global strategy must reflect the realities of today and be resilient to the uncertainties of tomorrow if a multi-decade endeavor such as human space exploration is to be sustainable. Global technical and political realities dictate that the near-term planning horizon is clear and compelling while follow-on steps remain open to the benefits of new technologies, knowledge and partners. The international road mapping process has demonstrated the complementary interests of the participants and the expanded set of benefits that can be gained through cooperation among nations. The success of the ISS Program gives confidence that an international exploration strategy can be realized by partnerships where nations depend on each other to accomplish shared goals. Because of the strategic importance of space and range of resultant benefits, human spaceflight programs are unique in their capacity to create opportunities for addressing global challenges, whether space-based (such as near-Earth asteroid threats or solar storms) or man-made [8].

2. Factors influencing a successful space exploration strategy

Before describing the international strategy in detail, it is worth expanding on three considerations with particular significance in today's environment which influenced NASA's strategic planning. First, the success of NASA's commercial cargo program and the emerging number of actors developing space transportation and utilization capabilities, capitalized in part with private funding, give support to the notion of human spaceflight-based commerce in LEO. Utilization of space around Earth by satellites providing communication, navigation, and weather monitoring services demonstrates the role of space in the economic sphere of Earth. With the ISS, humans have been able to spend more time in space and to spend that time more productively. The ISS continues to raise awareness of the opportunities of human presence in LEO and of the human experience of being in space. Real returns from research investments on ISS are being felt in global efforts to improve the human condition such as clinical health care practice, space imagery and clean water [9]. Continuing to foster all of these developments appropriately is in the best interest of NASA and other space agencies for a number of reasons. The ISS serves as a proving ground for commercial human activity in space. Expanding space based commerce with humans in LEO will enable governments to focus new investments on beyond-LEO technologies and capabilities while purchasing commercial services in LEO as needed for scientific research and technology development. Human activities in LEO must become private sector activities and not the sole domain of governments, allowing space agencies to focus more of their resources on beyond LEO exploration. It should also be noted that as commercial service providers demonstrate capabilities in LEO, this increases the opportunity for public-private partnerships as space agencies look further into space.

Second, the global economic crisis that began in 2008 has put continuing pressure on space agency budgets around the world. Without providing a detailed summary of NASA's budget history over the last seven years, it can be said that total agency funding levels and buying power since 2009 are significantly lower than prior projections. While it is clear that human missions to the surface of Mars in the 2030s will not be conducted on the NASA human spaceflight budget of today [10], affordable approaches requiring a modest increase in NASA human spaceflight accounts can be identified, based on the step-wise application of multi-use, evolvable exploration capabilities provided by several space agencies. These approaches rely on extending capabilities in-use today supporting the ISS (such as habitation and life support systems, propulsion systems, etc.) for beyond LEO application. In addition, further advancements of the solar electric propulsion to be demonstrated on the Asteroid Redirect Mission can be used for Mars-class missions. The challenges of Mars missions are great and require capabilities and techniques beyond our experience base. Using the proving ground of cis-lunar space to demonstrate evolved capabilities and learn to operate independent of support from Earth is a significant first step in an endeavor which is sustainable over the long term.

Thirdly, and in this vein, the ISS by its very existence demonstrates that a partnership of nations working together can accomplish much more than any nation operating on its own. For almost twenty-five years, the ISS has reinforced the geopolitical importance of human spaceflight, demonstrating the ability of nations to transcend politics for the benefit of humanity. This is especially evident today. Under NASA leadership, capabilities and expertise provided by the US, Russia, Japan, Europe and Canada have realized a robust and capable laboratory. All ISS partners have demonstrated the expertise necessary to extend the capabilities developed for the space station to make critical contributions to the challenges which

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