ISECG SPACE EXPLORATION GOALS, OBJECTIVES, AND BENEFITS

Nantel Suzuki
NASA Headquarters, USA, nantel.h.suzuki@nasa.gov

Kohtaro Matsumoto
JAXA Japan Space Exploration Center, Japan, matsumoto.kohtaro@jaxa.jp

Bernhard Hufenbach
ESA ESTEC, The Netherlands, bernhard.hufenbach@esa.int

Jean-Claude Piedboeuf
CSA Headquarters, Canada, jean-claude.piedboeuf@asc-csa.gc.ca

William Cirillo
NASA Langley Research Center, USA, william.m.cirillo@nasa.gov

William Carey
ESA ESTEC, The Netherlands, william.carey@esa.int

This paper summarizes work performed by space agencies to build consensus regarding the overarching aims and desired outcomes of space exploration. Participating agencies of the International Space Exploration Coordination Group (ISECG) collectively defined an initial set of common goals and supporting objectives for space exploration and used this as a basis for the ISECG's development of *The Global Exploration Roadmap (GER)*. The ISECG's International Objectives Working Group (IOWG) consolidated general and destination-specific inputs from participating agencies to establish the common goals and to identify, for each goal, key supporting objectives that reflect the interests of individual agencies. These goals and objectives guided development of the GER, including potential pathways to various Solar System destinations and associated 25-year mission scenarios, to inform future interagency discussions and help build a global consensus on exploration plans and architectures. After review by senior managers of ISECG agencies, the initial version of the GER was publicly released in September 2011. The development of goals and objectives is an inherently iterative process that reflects continuously evolving space agency priorities. Space agencies of the ISECG will monitor this evolution, update and refine the common goals and objectives as necessary, and ensure that the GER continues to reflect this commonality. While the common goals and objectives describe what agencies want to accomplish in the long term as they conduct space exploration, the overarching value of this activity will be measured in terms of the resulting outcomes and benefits imparted to society. This paper summarizes some of the anticipated benefits of space exploration, organized in accordance with exploration-related themes introduced in *The Global Exploration Strategy: The Framework for Coordination.*

INTRODUCTION

In 2007, 14 space agencies developed a vision for globally coordinated human and robotic exploration of destinations where humans may one day live and work and published the results in *The Global Exploration Strategy, The Framework for Coordination*. The International Space Exploration Coordination Group was created to share information on exploration activities and plans, and work collectively in order to advance the Global Exploration Strategy.

In 2009, the ISECG formed an International Objectives Working Group (IOWG) to collect existing national space exploration objectives, assess the degree to which commonality exists among these objectives, and use the results to guide the development of high-level exploration plans and architectures. The ISECG agencies' focus at that time was on the Moon, and the IOWG produced a set of 15 common goals for human lunar exploration which formed part of the foundation for an *ISECG Reference Architecture for Human Lunar Exploration.*

In June 2010 at Washington, DC, senior managers from the ISECG member agencies endorsed the common goals and reference architecture for lunar exploration, and also directed the ISECG to develop a Global Exploration Roadmap. The GER was envisioned as the ISECG's overall exploration roadmap that reflects the GES and the exploration policies of participating agencies and that helps to align programs and plans over time.

To clearly represent the consolidated high-level interests of the agencies and support development of the GER, the ISECG determined that common goals should be established, and the IOWG was tasked with extending the work it had completed for the Moon and identifying common goals that apply to various Solar System destinations where humans may one day live and work.

The initial set of common goals and supporting objectives was incorporated into the GER, which was publicly released in September, 2011. The GER provides a framework for agency-level planning discussions, and in addition to goals and objectives, it outlines potential long-range exploration mission scenarios to destinations such as the Moon, near-Earth asteroids, and Mars, and identifies near -term opportunities for international coordination and cooperation. A more detailed description of the GER can be found in the paper *"The ISECG Global Exploration Roadmap"*, IAC-11-B3.1.8, 2011.

In addition to identifying goals and objectives that describe what is to be accomplished as a space exploration campaign is executed, the ISECG agencies recognize the need to articulate the ultimate value of space exploration to its stakeholders. A clear understanding of both the intended goal of exploration missions and the anticipated societal benefits that these missions will produce can together contribute to ongoing efforts to clearly articulate the rationale for space exploration. This paper provides some of the current thinking within ISECG agencies regarding exploration benefits and value.

COMMON GOALS AND SUPPORTING OBJECTIVES

Why shall we explore space? Development of a Global Exploration Roadmap should be based on a clear understanding of the outcomes expected by participating agencies. It is important that mission scenarios reflect what space agencies want to accomplish as they explore the Solar System. A set of common space exploration goals and supporting objectives defined collectively by participating space agencies provides a sound basis for developing scenarios and reference missions at destinations of interest. Together with strategic principles such as the need for affordability, robustness, and a phased/step-wise approach, the goals and objectives drive development of the GER.

Eight common goals for space exploration were identified and are listed in Table 1. The IOWG formulated these by first collecting both general and destination-specific goals and objectives from participating agencies. Based on a consolidation of these inputs, a consensus was built to establish the common goals.

For each goal, supporting information is provided below, including a basic description, rationale, associated societal benefits, and examples of key supporting objectives. The objectives provide detail and clarify what the goals mean, and individual agencies support these particular example objectives to varying degrees. Some goals and objectives apply uniformly to all destinations in the GER while others do not. For example, the "Search for Life" goal is more central to the exploration of Mars than to that of the Moon.

The formulation of goals and objectives is an iterative process that must reflect ongoing refinement as agency priorities evolve. As space agencies continue to refine and share their goals and objectives, the ISECG will look for commonality and ensure that updated versions of the GER reflect that commonality.

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

Table 1: Common goals for space exploration.

Search for Life. Determine if life is or was present outside of Earth and understand the environments that support or supported it. The search for life is a central goal of space exploration. Pursuing this goal continues the cultural quest of humankind to determine whether we are alone in the universe and answers deeply-rooted questions about our origin and evolution. The question of whether life exists beyond Earth has great philosophical and scientific significance.

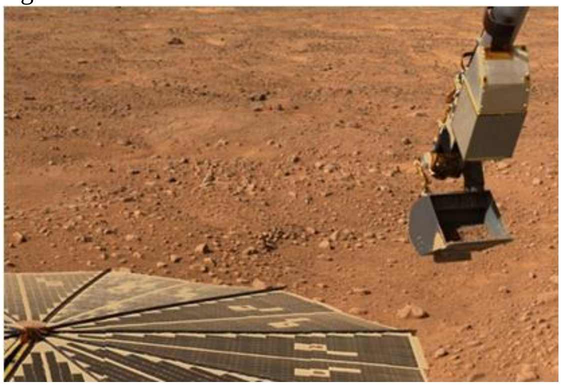

Fig. 1: Searching for evidence of life outside of Earth.

Example supporting objectives:

• Find evidence of past or present life
(e.g. Investigate astro-biological evidence indicating the origins of life on Earth, or biosignatures that would indicate the presence or past presence of life on Mars)
• Explore the past or present potential of Solar System destinations to sustain life
(e.g. Assess the principle determinants of habitability for life on Mars such as the presence, persistence, and chemical activity of liquid water and the protection from hazards detrimental to sustaining life)

Extend Human Presence. Explore a variety of destinations beyond low Earth orbit with a focus on continually increasing the number of individuals that can be supported at these destinations, the duration of time that individuals can remain at these destinations, and the level of self-sufficiency. Extending and sustaining human presence beyond low Earth orbit is another central goal of space exploration. This enables humankind to live and work in space, to harness Solar System resources for use in space and on Earth, and eventually to settle on other planets. Pursuing this goal expands the frontiers of humanity, opens doors to future utilization of space, and re-shapes how we think of ourselves and our place in the universe.

Fig. 2: Extending human presence across the Solar System.

Example supporting objectives:

• Explore new destinations
(e.g. Expand the presence of humans in the Solar System through exploration of new, diverse destinations, including Earth orbits, Lagrange points, Earth's Moon, near-Earth asteroids, and Mars)
• Increase opportunities for astronauts from all partner countries to engage in exploration
(e.g. Provide significant opportunities for astronauts to visit destinations that allows for participation by a number of partners)
• Increase the self-sufficiency of humans in space
(e.g. Enable humans to operate more independently from Earth by, for example, reducing resource requirements, taking advantage of in-situ resources, and improving operational autonomy)

Develop Exploration Technologies and Capabilities. Develop the knowledge, capabilities, and infrastructure required to live and work at destinations beyond low Earth orbit through development and testing of advanced technologies, reliable systems, and efficient operations concepts in an off-Earth environment. This goal establishes the fundamental capabilities to extend and sustain space exploration beyond low Earth orbit and support more distant, more capable, and longer duration human missions. Specific objectives are likely to change over time in response to evolution of both mission requirements and technological state-of-the-art. Pursuing this goal also yields spinoff products, new materials and manufacturing processes, and various technologies that can address major global challenges.

Fig. 3: Demonstrating advanced robotics technologies and systems (Canadarm2 and Dextre) to berth HTV-2 to the International Space Station.

Example supporting objectives:

• Test countermeasures to maintain crew health and performance, including radiation mitigation technologies and strategies
    (e.g. Advanced diagnosis and treatment protocols, and radiation mitigation approaches to improve human health and performance)
• Demonstrate and test power generation and storage systems
    (e.g. Advanced solar or nuclear power generation and battery or fuel cell storage capabilities)
• Develop and test high performance mobility, extravehicular activity (EVA), life support, and habitation capabilities
    (e.g. Advanced EVA suits, suitports, airlocks, surface rovers and hoppers, habitats)
• Demonstrate the use of robots to explore autonomously and to supplement astronauts' exploration activities
    (e.g. Advanced capabilities for autonomy, artificial intelligence, and tele-operations to lower risk and increase productivity of human missions)
• Develop and validate tools, technologies and systems that extract, process, and utilize resources to enable exploration missions
    (e.g. Efficient and reliable resource prospecting and processing capabilities)
• Demonstrate launch and advanced in-space propulsion capabilities
    (e.g. A robust capability to launch large, massive cargoes to Low Earth Orbit in support of future exploration missions, as well as fuel-efficient in-space transportation systems)
• Develop thermal management systems, including cryogenic fluid management capabilities
    (e.g. Systems that can operate at length in extreme temperature environments, and cryogenic fluid management, storage, and distribution capabilities)
• Learn how to best perform basic working tasks and develop operational protocols
    (e.g. Test operational concepts to reduce uncertainty and risk for ambitious, long-term missions)
• Test and demonstrate advanced entry-descent-landing (EDL) technologies
    (e.g. Test advanced EDL capabilities that can accommodate descent into the Martian atmosphere and Earth re-entry speed from deep space)
• Test Automated Rendezvous and Docking, On-orbit Assembly and Satellite Servicing capabilities
    (e.g. Advanced in-space maneuver and servicing capabilities)
• Development and demonstrate technologies to support scientific investigation
    (e.g. Technologies to implement scientific missions)
• Develop space communications and navigation capabilities
    (e.g. Reliable, high bandwidth deep-space communications and navigation systems)

<u>Perform Science to Support Human Exploration.</u> Reduce the risks and increase the productivity of future missions in our Solar System by characterizing the effect of the space environment on human health and exploration systems and by assessing the availability of space resources. This is essential for human exploration and will enable a human presence across the Solar System. Pursuing this goal also yields innovation for Earth-based health care.

Fig. 4: Understanding the effects of space on humans.

Example supporting objectives:

• Evaluate human health in the space environment
    (e.g. Understand physiological and biological effects of space on humans, such as bone and muscle loss, diminished immune efficiency, slower wound healing, and poorer cognitive

performance, as well as the effects on the fundamental biological processes and subsystems upon which health depends)

• Monitor and predict radiation in the space environment
  (e.g. Observe the sun, its corona, and space weather in real-time to detect solar and galactic events that will affect operations and support future predictions of such events)

• Characterize the geology, topography, and conditions at destinations
  (e.g. Perform surveys of geologic, topographic, atmospheric, thermal, lighting, and micrometeorite conditions at sufficiently diverse sites to support identification of future exploration sites)

• Characterize available resources at destinations
  (e.g. Map out and generate greater understanding of resources, employing remote sensing, in-situ methods, resource extraction process evaluations, and economic studies)

• Evaluate the impacts of the surface, near-surface, and atmospheric environment on exploration systems
  (e.g. Research the impact of the destination's environment on the performance of exploration systems to inform future design activities)

Stimulate Economic Expansion. Support or encourage provision of technology, systems, hardware, and services from commercial entities and create new markets based on space activities that will return economic, technological, and quality-of-life benefits to all humankind. Pursuing this goal generates new industries, spurs innovation in fields such as robotics and energy systems, and creates high-technology employment opportunities. As space activities evolve from government research to exploration to utilization, new economic possibilities may extend beyond low Earth orbit to the Moon and elsewhere in the Solar System.

Fig. 5: Encouraging economic expansion into space.

Example supporting objectives:

• Provide opportunities for the integration of commercial transportation elements into the exploration architecture
  (e.g. Ensure that the transportation architecture provides opportunities for commercially developed transportation systems and elements)

• Provide opportunities for the integration of commercial surface and orbital elements into the exploration architecture
  (e.g. Ensure that the in-space and surface architectures, including orbital assets, provide opportunities for commercially developed infrastructure systems and elements)

• Evaluate potential for commercial goods and services at exploration destinations, including markets for discovered resources
  (e.g. Determine opportunities for feasible commercial activities by establishing which goods and supplies could be created at exploration destinations or which developed technologies may have commercial spin-off opportunities)

Perform Space, Earth, and Applied Science. Engage in science investigations of and from Solar System destinations, and conduct applied research in unique space environments. Pursuing this goal delivers valuable knowledge to society, and deepens understanding of our home planet.

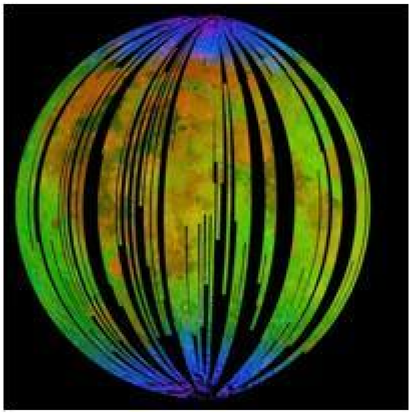

Fig. 6: Lunar spectroscopic data collected by the Moon Mineralogy Mapper during the Chandrayaan-1 mission.

Example supporting objectives:

• Perform Earth observation, heliophysics, and astrophysics from space
  (e.g. Perform remote observation studies from the vantage point of space)

• Gather scientific knowledge of destinations

(e.g. Develop an improved understanding of Solar System destinations to deepen understanding of their physical nature and processes)

• Gather scientific knowledge of Solar System evolution

(e.g. Develop an improved understanding of destinations and their history in order to deepen understanding of Solar System evolution)

• Perform applied research

(e.g. Understand and exploit phenomena affected by the microgravity environment in space, such as combustion and multiphase flow)

Engage the Public in Exploration. Provide opportunities for the public to engage interactively in space exploration. Space agencies have a responsibility to return value directly to the public that supports them by disseminating knowledge and sharing in the excitement of discovery. A participatory approach to exploration helps provide this value and maximizes opportunities to leverage public contributions to exploration missions. Pursuing this goal also creates opportunities to educate and inspire citizens, particularly young people, and to contribute to the cultural development of communities.

Fig. 7: Virtual, participatory exploration of the International Space Station.

Example supporting objectives:

• Use interactive hands-on communications tools to provide virtual experiences using real and live exploration data

(e.g. Provide members of the public with opportunities to tele-operate lunar rovers from Earth)

• Enlist amateur/citizen scientists to contribute to exploration-related knowledge collection

(e.g. Design research investigations that employ network technologies to allow greater participation in scientific discovery by motivated members of the public)

Enhance Earth Safety. Enhance the safety of planet Earth by following collaborative pursuit of planetary defense and orbital debris management mechanisms. Pursuing this goal lowers the risk of unforeseen future catastrophic asteroid collisions, as well as damage to current space assets in Earth orbit.

Fig. 8: Enhancing the safety of planet Earth.

Example supporting objectives:

• Characterize potential near Earth asteroid collision threats

(e.g. Understand the population distribution and physical characteristics of near Earth asteroids more fully)

• Test techniques to mitigate the risk of asteroid collisions with Earth

(e.g. Evaluate techniques and capabilities to alter the path of near Earth asteroids and prevent a potentially catastrophic impact event)

• Manage orbital debris around the Earth

(e.g. Test methods to manage orbital debris)

BENEFITS OF SPACE EXPLORATION

While common goals and objectives describe what agencies collectively want to accomplish, and are needed for providing long-term guidance to high-level planners and architects, they do not fully address the needs of agency stakeholders, whose interest is in ultimate outcomes that directly or indirectly benefit them. This paper has briefly mentioned some of the benefits that are imparted to stakeholders and linked these societal benefits to particular goals. Additionally, the *Global Exploration*

Strategy noted that space exploration delivers substantial benefits to society and can help solve economic, environmental, educational, and political global challenges. These benefits were organized according to five themes: acquiring new knowledge, human frontiers, economic expansion, global partnership, and inspiration and education

Acquiring New Knowledge. Societies are recognizing the need to be increasingly knowledge-based to assure economic prosperity and responsible environmental stewardship. Space exploration provides an opportunity to obtain unique scientific knowledge of the cosmos with critical value to life on Earth.

This includes conducting comparative planetary science to deepen our understanding of climate change on Earth and perhaps point the way toward better strategies for managing the environment of our home planet. Actively exploring near-Earth asteroids will lead to a better understanding of their population distribution and characteristics, and make it possible to test methods for deflecting them to prevent potential collisions with Earth.

Human health research conducted to understand how the body responds to the extreme gravity and radiation environment of space has driven health care innovation on Earth, ranging from new medical implants, diagnostics, surgical capabilities, and more, and space exploration will continue to stimulate medical advances.

The extreme performance, reliability, and safety requirements for exploring the Solar System requires innovation and breakthrough in a variety of exploration technologies. Some of these technologies, such as improved energy systems, robotics, and nanotechnology help drive modern economies and are key to assuring a better quality of life for citizens.

Sustaining and Extending Human Frontiers. In addition to the near-term benefits that can result from science and technology, space exploration offers the potential for tremendous long-term value to society.

A sustained and extended presence in the Solar System will eventually allow for the practical utilization of space. Long-term benefits include the capability to harness mineral and energy resources in space to support the needs of a growing population on Earth that is faced with clearly limited resources.

Additionally, an extended human presence in space provides a universal intellectual benefit that, while intangible, is nevertheless significant, and this is the deepened understanding of the fragility of our home planet and of humankind's relationship to it and the rest of the universe.

Enabling Economic Expansion. One of the most significant ways in which space exploration can benefit society is by laying the groundwork for future economic development in space. Humankind's first decades in space have already created industries such as satellite-based communications and navigation, but the resources and vantage point of space provide the potential for greatly expanded economic return. New commercial space-based industries, including transportation, tourism, manufacturing, and delivery to Earth of solar energy, precious minerals, or other space resources could create significant employment opportunities and enhance the quality of life for citizens.

Exploration can play a vital role in realizing the economic potential of space and can help create commercial opportunities in two critical ways: lowering technical risks, and contributing to the demand for space-based goods and services. Public investments in technology development and in the collection of strategic knowledge about the space environment and resources reduce the unknowns and help attract the private investments needed to spur the creation of commercial industries. By creating a stable demand for commercial space goods and services, as the ISS does for Earth-to-LEO space transportation, space agencies can reduce market risks, encourage the creation of new space ventures and stimulate economic expansion. In the long-term, sustained exploration and profitable commercial activity enable each other.

Cultivating a Global Partnership. Space exploration provides a unique opportunity to unify the international community in a meaningful, challenging, and peaceful endeavor. By participating in space exploration activities, traditional and new space-faring nations may all share in its benefits and jointly cultivate multi-cultural understanding.

Inspiring and Educating Society. An intangible but fundamentally significant benefit of space exploration is its inherent ability to inspire citizens from all nations . Exploration stimulates the imagination and generates a sense of pride, especially through involvement in the unique achievements of humans in space. Space exploration can motivate students to extend their education and help build more economically-competitive and knowledge-based societies.

A general sampling of benefits has been described here, but the ISECG agencies recognize that additional work is needed to better understand and articulate the value of space exploration.

CONCLUSION

Common space exploration goals and objectives were established by the ISECG and are a key element of the Global Exploration Roadmap. They were used for performing initial evaluation of GER mission scenarios, and will inform development of subsequent versions of the GER.

Space agencies will continue to refine their goals and objectives, in accordance with evolving policies and stakeholder requirements. The ISECG will perform periodic consolidation to ensure that common goals reflect this evolution and remain up-to-date.

Space exploration has provided substantial tangible and intangible benefits to society and it is imperative that it continue to deliver value. The ISECG plans additional work to understand and articulate the societal benefits of space exploration.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of many agency representatives who supported the IOWG for this activity, with special thanks to Kandyce Goodliff and Chel Stromgren of NASA for their critical leadership in consolidating agency inputs and helping to establish the common goals.

Francois Spiero/CNES
Julie Cavanagh/CSA
Graham Gibbs/CSA
Andrea Boese/DLR
Britta Schade/DLR
Juergen Schlutz/DLR
Sylvie Espinasse/ESA
Micheline Tabache/ESA
D.P. Karnik/ISRO
Hae-Dong Kim/KARI
Kathy Laurini/NASA
Neal Newman/NASA
Kevin Watts/NASA
Helen Sinyuk/NSAU
Alexey Korostolev/Roscosmos
Konstantin Elkin/Roscosmos
Georgy Karabadzhak/Roscosmos

REFERENCES

1. *"The Global Exploration Roadmap"*; published by 12 participating agencies of the International Space Exploration Coordination Group (in alphabetical order: ASI (Italy), CNES (France), CSA (Canada), DLR (Germany), ESA (European Space Agency), ISRO (India), JAXA (Japan), KARI (Republic of Korea), NASA (United States of America), NSAU (Ukraine), Roscosmos (Russia), UKSA (United Kingdom)); 2011; available at www.globalspaceexploration.org.

2. "*The Global Exploration Strategy: The Framework for Cooperation"*; published by 14 space agencies (in alphabetical order: ASI, BNSC–now UKSA, CNES, CNSA (China), CSA, CSIRO (Australia), DLR, ESA, ISRO, JAXA, KARI, NASA, NSAU, Roscosmos); 2007; available at www.globalspaceexploration.org.

3. *"ISECG Reference Architecture for Human Lunar Exploration"*; published by 9 participating agencies of the International Space Exploration Coordination Group (in alphabetical order: ASI, CNES, CSA, DLR, ESA, JAXA, KARI, NASA, UKSA); 2010; available at www.globalspaceexploration.org.

4. *"The ISECG Global Exploration Roadmap"*; Hufenbach, B., Laurini, K., Piedboeuf, J.C., Matsumoto, K., and Schade, B.; International Astronautics Congress (2011), IAC-11-B3.1.8; 2011.