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DEVELOPING A COMMON SET OF HUMAN LUNAR EXPLORATION GOALS AND OBJECTIVES

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ABSTRACT

In 2007, international space agencies expressed their “increasing intent and determination to explore earth’s nearest companions, with the Moon as our nearest and first goal”. It was in this spirit that in July 2008 the members of the International Space Exploration Coordination Group (ISECG) agreed to collectively explore ideas and plans for human exploration of the Moon and to jointly develop the international lunar reference architecture that could be used to inform subsequent decision milestones of individual agencies.

In March 2009, the ISECG recognized that many space agencies had been or would be conducting national reviews to develop exploration themes and objectives useful for driving architecture development. The International Objectives Working Group (IOWG) was formed from this discussion, and was tasked with collecting existing national space exploration objectives and assessing the degree to which commonality exists among these objectives. The IOWG was also tasked with assisting, advising, and assessing the lunar architecture development work to determine the best architectural approaches for achieving these collective goals and objectives.

Starting in mid-2009, Objectives Workshops, open to all ISECG members, have been held among interested agencies. The primary task of collecting and integrating an initial set of over 600 agency national objectives has been accomplished, recognizing many

agencies are in the midst of objective development and will be for some time to come. The initial set is expected to grow and evolve as national objectives do, and as discussions on commonality proceed. This initial set provides insight into potential common themes, goals, and objectives. This set of objectives has been compared and mapped against themes developed in the Global Exploration Strategy. *On the basis of these objectives, a set of 15 common lunar exploration goals has been adopted by ISECG expressing the shared interests of the participants and providing the rationale and guidance for developing and evaluating an international architecture for human lunar exploration.*

INTRODUCTION

The Global Exploration Strategy (GES)ⁱ identified the Moon as one of the key destinations for future exploration missions. Just three days from Earth, it has low gravity, a dusty environment and natural resources that make it an ideal location to prepare people and machines for venturing farther into space. As a repository of four billion years of solar system history, and as a vantage point from which to observe the Earth and the universe, it also has great potential as a base for scientific research.

Near the end of 2008, it became clear that many space agencies¹ associated with the International Space Exploration Coordination Group (ISECG) were engaged in plans and preparations for missions beyond Earth orbit that could benefit from early coordination in the spirit of the GES. In early 2009, the ISECG endorsed the development of a

¹“Space Agencies” refers to government organizations responsible for space activities. Those involved in the ISECG include, in alphabetical order: ASI (Italy), UKSA (United Kingdom), CNES (France), CNSA (China), CSA (Canada), CSIRO (Australia), DLR (Germany), ESA (European Space Agency), ISRO (India), JAXA (Japan), KARI (Republic of Korea), NASA (United States of America), NSAU (Ukraine), Roscosmos (Russia).

Reference Architecture for Human Lunar Exploration (the “Reference Architecture”) and invited interested agencies to participate. To further the goal of cooperation, it established the International Architecture Working Group (IAWG) and a companion group, the International Objectives Working Group (IOWG).

This first study focuses on the Moon, not only because it is expected to play an important role in future exploration endeavors, but also because many space agencies have expressed an interest in the Moon in their exploration plans. Moreover, NASA has invested a significant effort in understanding human lunar architectures in furtherance of the US Space Exploration Policy. Therefore, the participating agencies recognized that collaborating on a Reference Architecture would help introduce multilateral consensus to preparations for future space exploration.

A set of *Common Goals for Human Lunar Exploration (the “Common Goals”)*, along with strategic and programmatic guidance aligned with these goals, became the foundational information for the construction of the Reference Architecture and the later evaluation of its suitability.

This paper is a part of a series describing the Reference Architecture for Human

Lunar Exploration and its development process. Interested readers are directed to the list of references herein for complete information.

COMMON GOALS AND THEIR MAPPING TO GES THEMES

Collecting and Analyzing Objectives

The IOWG first collected and integrated an initial set of existing and emerging national lunar exploration objectives from CNES, CSA, DLR, ESA, JAXA, KARI, NASA, NSAU, and UKSA. Many agencies are still developing their objectives and will be for some time to come, so the initial set is expected to grow and evolve as national objectives do, and as discussions on commonality proceed.

More than 600 national objectives were collected, representing the spectrum of what is currently thought to be important for humans and robots to achieve in lunar exploration. Described in both broad, sweeping terms and very specific, contextual terms, they provided insight into similarities in the themes and goals identified by individual nations.

Along with objectives, many agencies had developed measures whereby objectives could be met, deemed ‘satisfaction criteria’. Since this information would be important in the ultimate measurement of the Reference Architecture’s promise, the IOWG established traceability from objectives to these satisfaction criteria for later use (see Comparative Assessment of Alternatives).

Defining a Hierarchy—Themes, Goals and Objectives

The next step was to compare these objectives to the five themes of the Global Exploration Strategy and to come up with a set of Common Goals for human lunar exploration that could be used to define a Reference Architecture.

The five primary themes of the GES are:

- New knowledge in science and technology
- Sustained human presence in space
- Economic expansion
- Global partnerships
- Inspiration and education

An articulation of a set of Common Goals provided the bridge between the five high-level GES Themes, and the large set of very detailed and specific lunar objectives.

Defining Common Goals

A series of workshops was held to develop a set of common lunar exploration goals. These goals, which are listed in Fig. 1, were accepted by the ISECG in December 2009. *They represent the shared interests of the participants and provide the rationale and guidance for developing and evaluating an international architecture for human lunar exploration.*

The participants’ individual objectives require further consolidation and will evolve over time, based on discoveries made along the way. Participants recognize that as they plan future cooperative undertakings, further dialogue on common objectives will be needed.²

² In recognition of the importance of public outreach goals, the IOWG reviewed this set of goals with the ISECG Public Outreach Working Group to solicit feedback prior to presentation to ISECG

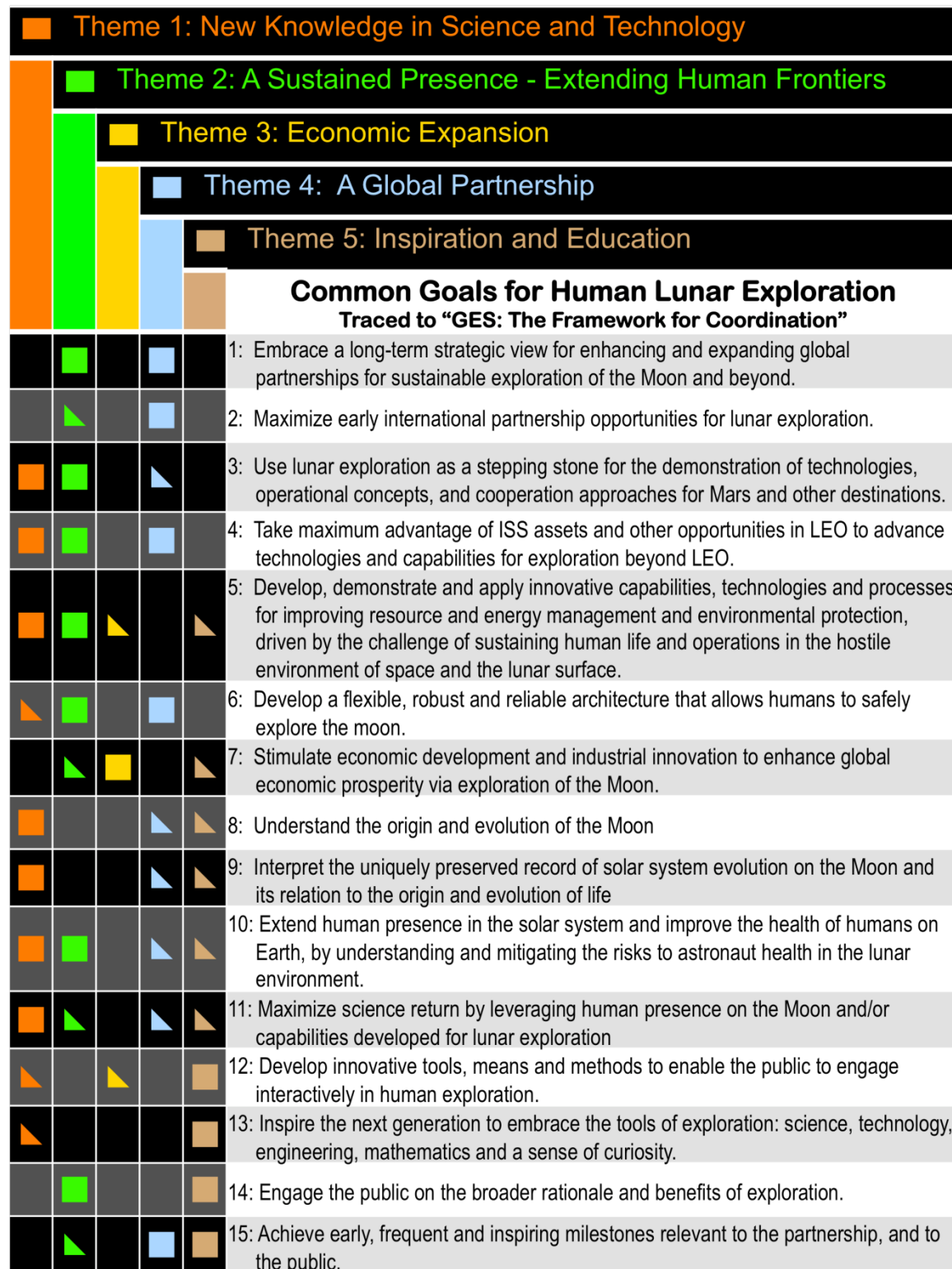


Figure 1: 15 Common Goals for Human Lunar Exploration mapped to the GES Themes. Squares indicate primary themes; triangles indicate secondary themes.

DRIVING THE REFERENCE ARCHITECTURE

While the common goals were developed to guide the Reference Architecture, they are independent of any particular architectural approach or solution. Indeed they may inspire many potential architectural solutions that could meet the goals in a variety of ways.

To drive a *specific* architectural approach, it was necessary to develop guidelines that express the strategic principles shared by the participating agencies. These guidelines emphasize some specific goals, provide balance among others and emphasize particular aspects of some. They also capture concerns such as ensuring timely development of program phases to improve affordability.

Strategic Guidelines

The strategic guidelines followed in developing the Reference Architecture are:

- Advance the principles of programmatic and technical sustainability and ensure their early incorporation in the architecture. While these concepts are reflected in the goals, they are especially important in developing the architecture. There was particular emphasis on methods of incorporating these principles:
 - Apply a phased approach to exploration, with interim milestones to accommodate evolving mission objectives and changes in program priorities

- Include a phase involving robotic missions to the Moon in preparation for human lunar surface operations
- Maximize the synergies between human and robotic activities.
- Consider affordability in laying out approaches.
- Balance compelling science and Mars-forward objectives, understanding that specific Mars-forward and science priorities will evolve. Both the common goals and the guidelines emphasize the long-term strategic importance of lunar exploration in the context of other destinations (Mars) and the need to accomplish important scientific objectives in parallel. A robust architecture must also allow for evolution in scientific and Mars-forward objectives resulting from new discoveries and technologies.
- Take due consideration of ISS Lessons Learned.ⁱⁱ For example, the principle of dissimilar redundancy in critical systems is of paramount importance to ensure the sustainability of exploration programs and technical capability. The ISS was sustained by using the Russian Soyuz and Progress spacecraft during the hiatus in Space Shuttle flights after the loss of the Shuttle Columbia in early 2003.

The Reference Architecture was driven, and later evaluated, through the combination of the Common Goals and the above strategic and programmatic considerations.

OVERVIEW OF THE REFERENCE ARCHITECTURE^{iii iv}

The ISECG Reference Architecture for Human Lunar Exploration envisions how the space-faring nations of Earth

can collaborate in exploring the Moon using the coordinated assets of many space agencies. It marks the first time that a group of space agencies has worked together to define a complex human exploration mission scenario. It represents a concrete step towards realizing the vision of the Global Exploration Strategy, which identified the Moon as one of the key destinations for future human space exploration.

The Reference Architecture involves a flexible, phased approach for lunar exploration that demonstrates the importance of agencies working together early in program formulation. It is designed to achieve significant scientific and exploration goals while recognizing global realities and challenges. This approach accommodates technological innovation, international priorities and goals, and programmatic constraints and it offers opportunities for multiple partnerships among space agencies.

The Reference Architecture is neither a lunar base, nor a series of Apollo-style missions. It is composed of largely independent phases that will deploy a range of international human-rated and robotic international technologies over time on the lunar surface. It provides continuous robotic and/or human scientific and exploration activity in multiple locations on the Moon starting at least one year before the first flight crew arrives. These phases include:

Robotic precursor phase: This phase provides early technology demonstrations and engagement among international partners, the scientific community and the public. It highlights important activities intended to reduce the risks associated with human missions and to ensure sustainability of the

architecture. These activities will also help target human missions toward the most promising objectives for scientific discovery and exploring Mars.

Polar exploration and system validation phase: This phase initiates human exploration of the Moon. It leverages the robotic precursor work to build confidence in operations and systems design in preparation for more aggressive human and robotic lunar exploration. This phase involves locating an international fleet of robots and rovers at one of the lunar poles to prepare the way for the landing of the first human crew.

Polar Relocation phase: In this phase, the fleet of robots and rovers, controlled from Earth, will be relocated from the pole to new sites of interest. Along the way, they will perform scientific studies and enable interactive participation from the public. Once in place, they will meet and assist human crews deployed to these new sites.

Non-polar and long-duration phase: This phase may involve multiple short missions to various lunar sites of interest or long-duration missions of about 70 days at one site. Longer missions, that will require the addition of living modules or habitats, would be particularly useful for collecting data and testing technology for future Mars missions.

This plan allows for significant time to be devoted to science and other utilization activities. Some examples of such activities include:

fieldwork: mapping; collecting and analyzing rock and soil samples; measuring the Moon's gravitational, atmospheric and radiation environment; surveying for geological resources and

landing sites; education and public outreach events.

human health risk reduction: measuring radiation doses and cardiovascular function; analyzing blood and urine samples; studying astronaut behaviour and performance.

flight test and demonstration: testing navigation and other systems to improve the ability of spacecraft to orbit the Moon, make precise landings on the surface and avoid landing hazards.

MEETING THE GOALS: Comparative Assessment of Alternatives

The proposed Reference Architecture was evaluated against each of the common goals through the use of both qualitative considerations and quantitative metrics. Since satisfaction of the common goals is, in most instances, not directly measurable, both qualitative and quantitative factors were considered.

A relatively simple but effective methodology was used to assess the degree to which the Reference Architecture was able to meet the common goals. This methodology is more fully described in Carey et al.^v A pair-wise comparison technique – a process for determining preference among options by comparing those options against quantitative properties^{vi} – was then undertaken for three options under consideration.

In addition to the proposed Reference Architecture, two scenarios previously developed by participating agencies were used as the basis for comparison^{vii}:

a sortie-based campaign involving stand-alone flights to the Moon with

little or no dependence on pre-deployed assets, and

an outpost-based campaign focussed on developing a permanent human presence in a single location (a lunar pole) as rapidly as possible.

The primary objective of this process was to identify which was best suited to meet the 15 common goals.

Ratings were determined by consensus as to how well particular pairs under comparison best met each goal. The completed evaluations, along with qualitative and quantitative measures, and the associated rationale, are included in Carey et al.

The results showed that the proposed Reference Architecture best met the set of common goals and provides for a robust and flexible exploration strategy for the Moon.

NEXT STEPS: Goals and Objectives

The ISECG Reference Architecture for Human Lunar Exploration is a concept for human and robotic exploration of the Moon designed to deliver important scientific discoveries and prepare for more challenging and distant planetary exploration aspirations. It was developed to encourage the international partnerships needed to prepare and execute human lunar exploration.

Coordination at this stage is considered important for exploring concepts that reflect common goals and maximize the opportunities to achieve the objectives of the individual agencies. It enables leveraging the preparatory activities of individual agencies but it is not mature

enough to begin traditional Phase A program formulation activity.

The following areas—specific to the area of goals and objectives—are suggested for follow-up if agencies decide to pursue lunar exploration collectively:

Evolve Common Goals and Objectives:

As summarized previously, a relatively simple but effective approach was chosen for comparative assessment. Further work is needed to support more detailed architectural evolution. Beyond the conceptual level, participating agencies will require a deeper understanding, and ultimately agreement upon, common objectives in all of the areas addressed by the common goals. An understanding of the degree to which objectives can be met, based on measurable criteria of objective satisfaction, will be needed to support this dialogue.

Expand Exploration Destinations:

Having established an efficient and effective collaborative method of identifying common goals and developing a Reference Architecture for Human Lunar Exploration, the ISECG can undertake similar work for additional exploration destinations identified in the GES, such as Near Earth Objects, Lagrange Points, and Mars and her satellites.

In this regard, it could be tempting to simply modify the Common Goals listed in Figure 1 for another exploration destination. However, the authors and members of the IOWG do not recommend this approach. The

‘bottoms-up’ approach of identifying and collecting individual agency objectives utilized herein was essential in establishing the common understanding and appreciation of agency needs required to drive an architecture. Additionally, the inclusion of key members from the design teams in this goals dialogue led to the resulting robust and flexible Reference Architecture, and by all accounts, its ability to meet the Common Goals.

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