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FROM LEO, TO THE MOON AND THEN MARS: DEVELOPING A GLOBAL STRATEGY FOR EXPLORATION RISK REDUCTION

Kathleen C. Laurini
Associate Program Manager for Lunar Formulation, Constellation Program
NASA Johnson Space Center, Houston, Texas, USA
kathy.laurini-1@nasa.gov

Bernhard Hufenbach
Head of Architecture Office, Human Spaceflight Directorate
European Space Agency, Noordwijk, The Netherlands
Bernhard.Hufenbach@esa.int

Britta Schade
Program Manager
DLR, German Space Agency, Bonn, Germany
britta.schade@dlr.de

Peter Weber
Senior Scientist
DLR, German Space Agency, Bonn, Germany
PKH.Weber@dlr.de

Andrea Lorenzoni
ASI, Italian Space Agency, Rome, Italy
andrea.lorenzoni@asi.it

Most nations currently involved in human spaceflight, or with such ambitions, believe that space exploration will capture the imagination of our youth resulting in future engineers and scientists, advance technologies which will improve life on earth, increase the knowledge of our solar system, and strengthen bonds and relationships across the globe. The Global Exploration Strategy, published in 2007 by 14 space agencies, eloquently makes this case and presents a vision for space exploration. It argues that in order for space exploration to be sustainable, nations must work together to address the challenges and share the burden of costs. This paper will examine Mars mission scenarios developed by NASA and ESA, and show resulting conclusions regarding key challenges, needed technologies and associated mission risks. It will discuss the importance of using the International Space Station as a platform for exploration risk reduction and how the global exploration community will develop lunar exploration elements and architectures that enable the long term goal of human missions to Mars.

The International Space Station (ISS) is a critical first step both from a technology and capability demonstration point of view, but also from a partnership point of view. There is much work that can be done in low earth orbit for exploration risk reduction. As the current "outpost at the edge of the frontier", the ISS is a place where we can demonstrate certain technologies and capabilities that will substantially reduce the risk of deploying an outpost on the lunar surface and Mars mission scenarios. The ISS partnership is strong and has fulfilled mission needs. Likewise, the partnerships we will build in exploring the Moon will provide a strong foundation for establishing partnerships for human Mars missions. The Moon is interesting from a scientific point of view, but it is extremely important for development and demonstration the technologies and capabilities needed for human missions to Mars. This paper will show the logic and strategy for addressing technological, operational and programmatic challenges by using low earth orbit and lunar missions to enable the long term goal of exploration of Mars and other destinations within our solar system.

1. INTRODUCTION

Outlining the reasons for exploration beyond low earth orbit, the *Global Exploration Strategy: The Framework for Coordination*, addresses themes to define both human and robotic missions and stresses the importance of international cooperation to meet the challenges. It identifies Mars as the most intriguing destination for human missions that is within our grasp. There is much work to be done before a human mission to Mars can be undertaken with acceptable risks. Technical advances in propulsion, power generation, life support systems and other areas are required. Increased understanding of operations concepts in a microgravity and fractional gravity environment are required. Enhanced international partnerships will be needed. Robotic missions to Mars can provide information that will reduce the risks of a human mission and increase its scientific return. In order to address these challenges and succeed in mounting a successful human mission to Mars, the agencies participating in the International Space Exploration Coordination Group (ISECG) believe that a coordinated and evolutionary strategy must be employed. In order for space exploration to be sustainable across many generations, the strategy must deliberately contain components that capture the imagination of our youth resulting in future engineers and scientists, advance technologies which will improve life on earth, increase the knowledge of our solar system, and strengthen bonds and relationships across the globe.

This paper will introduce an evolutionary strategy, and provide recommendations on how to advance this concept in an international context. We lay out several major elements that must be included, beginning with maximizing use of the International Space Station to buy down risks associated with living, working and travelling in a microgravity environment. Simultaneously, robotic missions to the Moon and Mars can provide a wealth of scientific information, and inform future decisions on how to best conduct human missions, maximizing overall return on investment. Human missions to the Moon will enable the advancement of certain key technologies and operational concepts. Then, leaving the earth/moon system is a next logical step, perhaps mounting a mission to a near earth asteroid before committing to a human mission to Mars. Such a coordinated and evolutionary strategy will serve to increase our confidence in the reliability of our systems and operational concepts and the strength of our partnerships, enabling the exciting, inspiring and challenging human mission to Mars.

2. A ROADMAP TO ENABLE SUSTAINABLE EXPLORATION BEYOND LOW EARTH ORBIT

The authors propose a roadmap for human space exploration that contains three key destinations, the International Space Station (ISS), the moon and Mars. These destinations may not be all inclusive, but they provide a very good opportunity to tackle the challenges precluding a sustainable space exploration program. The roadmap begins with the ISS, performing research, validating technologies and gaining valuable operational experience. It follows with human and robotic missions to the surface of the Moon to demonstrate other key technologies and capabilities. Robotic missions to Mars will also serve to enhance the return of an eventual human mission. The roadmap should be a coordinated international strategy to prepare for human missions to Mars, recognizing the importance of each evolutionary phase for the development and demonstration of needed technologies and capabilities. The three key destinations are described in this chapter with essential elements of the roadmap introduced in Chapter 3.

2.1 THE INTERNATIONAL SPACE STATION

The International Space Station (ISS) is a highly capable platform in low earth orbit which can serve as a test bed for vital technologies and needed research. The ISS partnership can provide insights and opportunities for building the international coalition for exploration of space beyond low earth orbit. The existing ISS partnership, the European Space Agency, the Canadian Space Agency, the Japan Aerospace Exploration Agency, the Russian Federal Space Agency and NASA have joined together to build, equip, maintain, and operate the multidisciplinary laboratory. The ISS has shown that a robust and reliable life support system is essential to minimizing the consumables needed on a long duration mission. Advances in this area are critical. There are other systems whose reliability and performance can be demonstrated on the ISS, such as standard docking systems and communication systems to name a few. In addition, the ISS provides the best opportunity to conduct the human health research necessary to mitigate human system risks.

2.2 The Moon

The members of ISECG have intensified their advancement of lunar exploration planning based on the conclusion that the Moon is of high interest for scientific and technological reasons. The successful robotic missions of the Japanese Kaguya, Chinese Chang'e, Indian Chandryaan, and the US Lunar Reconnaissance Orbiter continue to produce interesting and compelling results. Future robotic missions to the moon are sure to provide the same. It should be noted that not all ISECG space agencies agree that the Moon is the next logical step for the exploration of our Solar System, however there is increased emphasis in that direction.

International exploration needs a sustainable capability to perform missions on a regular basis to the moon. To initiate the next major steps towards robotic and human exploration missions to the Moon, it is vital to take the technical and programmatic experiences made by operation and utilization of the ISS into consideration. The lessons to be learned from future technology demonstrations and the operation of new transportation vehicles are mandatory.

In the ISECG framework, a working group called the International Architecture Working Group (IAWG) is currently examining three different types of lunar surface exploration scenarios and associated surface elements for transportation, habitation, and scientific investigations: a sortie mission, an extended sortie missions, and the establishment of a polar outpost. Each scenario provides the opportunity to advance certain technologies and capabilities necessary for human exploration of Mars and other destinations in the Solar System. The scenarios and their contribution to technical advances are described below:

Sortie Mission Scenario

A lunar sortie mission scenario allows the crew to stay approximately one week and conduct a variety of activities, using the lander as home base. It would enable short duration flights to any location on the moon depending from the area of scientific interest. This scenario will demonstrate technological key capabilities like the development of a man-rated launch and return vehicle, the validation of soft precision landing and surface technologies and infrastructures. These missions should satisfy a range of science objectives as well as public engagement aspects.

Extended Sortie Mission Scenario

A significant enhancement of the previous scenario can be achieved if additional elements are placed on the lunar surface. This scenario is characterized by extended lunar surface installations for fixed and mobile habitation and research. These missions could demonstrate key technologies such as mobility with astronaut rovers, EVA in a dusty planetary environment, in-situ resource utilisation (ISRU) and validation of key scientific experiments needed for Mars exploration. Important elements are crew habitats as well as the demonstration of capabilities and technologies necessary for manned long duration missions to Mars (e.g. radiation protection). The duration of crew stay will be determined by the pre-deployment of capabilities but can be envisioned in the 45-90 day range.

Outpost Scenario

A human lunar outpost at one of the poles is a more challenging scenario compared to the sortie missions. This scenario build up the capabilities and elements to allow a long term presence of astronauts on the Moon, with individual stays of up to 180 days. A continuous presence of astronauts with the ability for fully automated phases for certain periods (men-tended outpost) should also been taken into consideration. A lunar outpost would enable data to be collected associated with the long term performance of humans and systems in a fractional gravity environment. It is important that the outpost scenario recognize that when Mars preparation objectives are reached, its continued operation depends on the remaining value it delivers to stakeholders.

2.3 Human Missions to Mars

Several space agencies have independently studied human Mars mission architectures, and while approaches may differ, common assessments of the challenges emerge. NASA and ESA have recently compared the results of independent Mars mission architecture studies. Highlights of mission architecture commonalities and differences are shown in Table 1. Many commonalities could be identified related to the mission strategy, propulsion requirements, sizing of the architecture building blocks and number of ARES V type heavy-lift launches required. In particular it is worthwhile to note that NASA and ESA both agree on the need to develop nuclear propulsion capabilities for human Mars missions. The only significant difference concerns the approach for vehicle assembly: while NASA assumes fully automated assembly in LEO, ESA considered the use of a man-tended servicing station. General enabling capabilities include:

- Heavy lift launch capability;
- Capabilities to land large/heavy payloads;
- Medical care capabilities;

- Radiation shielding and mitigation techniques;
- Highly reliable systems/components;
- Highly autonomous/ automated operations capabilities;

Table 1: Comparison of NASA and ESA Human Mars Reference Mission Architecture

Strategy Element	NASA	ESA
Commonalities		
Mission Class	Utilization of conjunction class mission type for human mission (180 day transit/ 500 days surface stay)	
Mission Strategy	Use of split mission separating cargo from crew mission on energy efficient trajectories	
	One cargo mission prior to crew flight	2 cargo missions prior to crew mission
Propulsion	Use of nuclear thermal propulsion for TMI, MOI and TEI maneuvers of human and for TMI and TEI maneuvers of cargo mission	
Mars Aero-capture	Utilization of aero-capture technique for MOI[1] in case of cargo missions	
Differences		
Crew Size	6	4
Propulsion for Human Mars Ascender	Utilization of in-situ produced propellants for ascender for first mission	Delivered from Earth
Vehicle Assembly Approach	Automated rendezvous and docking	Use of LEO servicing station
LEO Departure Orbit	400 km (TBR)	800 km departure orbit
Mars Parking Orbit	250 x 33,793 km	500 km circular
Minimum Number of Launchers	7 ARES V type launchers with payload performance into LEO > 135t and 1 man-rated launcher	6 ARES V type launchers with payload performance into LEO > 125 t and 1 man-rated launcher
Total Mass into LEO	850 tons	~ 800 tons

There are a number of key technologies, which would significantly reduce the requirement for total mass and volume to be launched. These technologies are listed below and their contribution to mass reduction is shown in figure 1.

- Nuclear (thermal and / or electric) propulsion;
- LO_2/CH_4 based propulsion systems for landers with high thrust and throttle-ability capability (enables utilization of locally produced CH_4);
- Cryogenic fluid management;
- Regenerative life support systems;
- Aero-capture of large payload;
- Lightweight/ inflatable structures launchers;
- In-situ resources utilization, repair and maintenance;

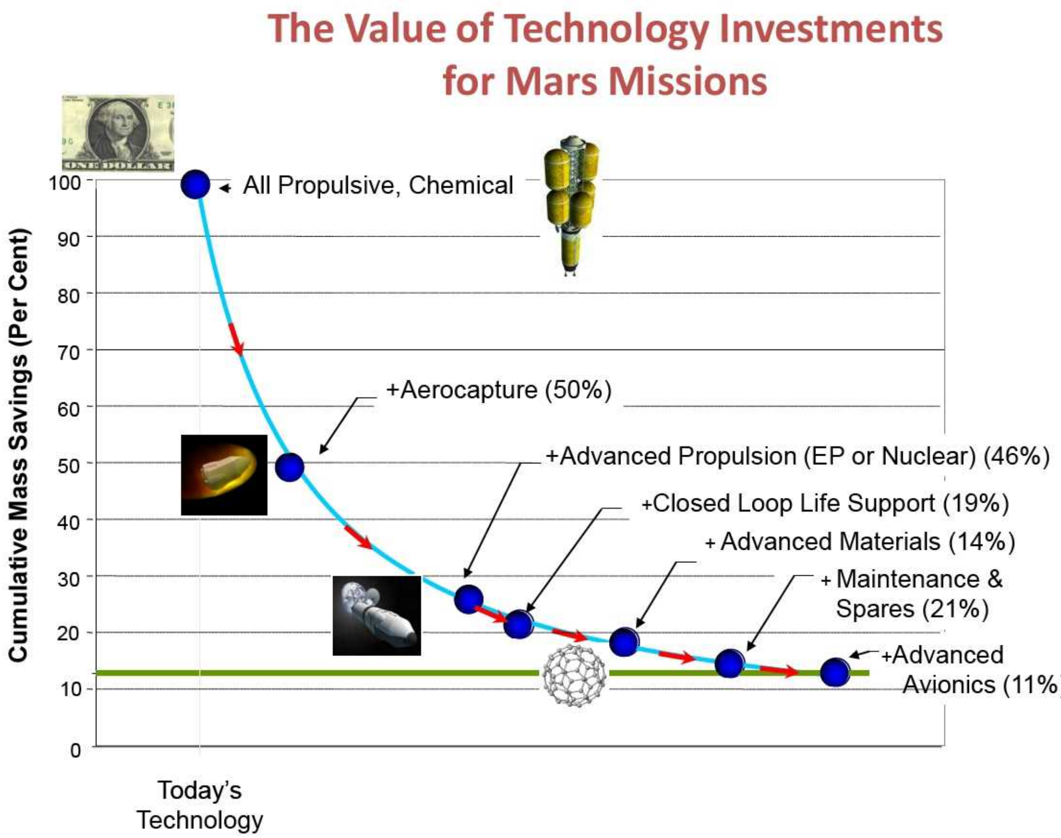

Figure 1: Impact of key enabling technologies

Those related to improving surface operations include

- Advanced surface mobility systems with more autonomy, larger exploration range and in-situ analysis capability;
- Advanced power generation and storage systems (including nuclear);
- Dust removal, mitigation techniques;
- Advanced EVA capabilities including some radiation protection, enabling more human mobility and increasing the ratio of actual EVA operations to EVA preparation time;
- Advanced navigation systems providing better absolute and relative navigation accuracy;
- Advanced communication systems enabling higher data-rates (optical);

Furthermore, knowledge gaps need to be closed prior to the first human mission to Mars. In particular a better understanding of biological effects of radiation (Galactic Cosmic Rays and Solar Particle Events) and partial gravity on the human body and long-term impacts of human isolation is required together with better models of the space weather, the Mars atmosphere, weather and surface (resource, radiation,…).

Besides these more technical and research issues, programmatic challenges need to be addressed early in the program definition. Programmatic challenges include the need to mobilize investment for preparation of human missions to Mars (e.g. investments in enabling technologies like nuclear propulsion) while maintaining possibly human operation in LEO and human missions to Moon, if these are still strategically relevant. In general, the support and engagement of decision-makers and the public needs to be maintained over a long period of time so deliberate planning is required to enable this. Human exploration, and certainly a human mission to Mars is a high-risk undertaking. The key mission risks sorted in terms of level of influence on the overall probability of mission success are

- Vehicle assembly operation in LEO;
- Total mission duration without re-supply/ return opportunity in deep space environment, i.e. equipment reliability;

- Mars entry, descent and landing;
- Complex aero-assisted maneuvers around Mars.

3. ESSENTIAL ELEMENTS OF THE ROADMAP

As stated above, the roadmap should be a coordinated international strategy to prepare for human missions to Mars, recognizing the importance of each evolutionary phase for the development and demonstration of needed technologies and capabilities. It calls for an increased coordination between human and robotic exploration missions, recognizing the symbiotic relationship that exists on many levels.

The authors see five essential elements of the roadmap. First, robotic missions should be used to the greatest extent to learn about the Moon and Mars, and demonstrate key capabilities. Second, a dedicated and coordinated effort to use the ISS and the Moon to advance technologies and capabilities should be undertaken. Third, a coordinated effort to buy down human system risks should be mounted. Fourth, it recognizes the importance of expanding the operational expertise that the ISS and lunar missions provide. Lastly, it calls for the expansion of international partnerships to get the job done.

3.1 Using Robotic Missions to Improve our Knowledge of the Moon and Mars

The knowledge that we gain from robotic exploration allows us to make expensive and hazardous human operations much more scientifically productive than they would have been otherwise. Robotic missions can also serve as a platform for critical enabling technologies. Because the capabilities of humans surpass those of robots in complex environments, the scientific value of human exploration of the Moon and Mars will be immeasurable. For these reasons, it is recommended that future robotic missions to the moon and Mars include components designed to reduce the risks of future human missions, while pursuing the best possible scientific return of each individual mission.

Moon

Lunar robotic missions of the past are joined most recently by India's Chandrayaan-1, China's Chang e`, Japan's Kaguya, and the NASA Lunar Reconnaissance Orbiter (LRO). These can be considered precursor missions as each will provide various generic data of the lunar surface and landing areas of interest. They will provide high resolution maps which will be used for defining lunar landing spots and insights into the wealth of the resources which are buried in the Moon´s regolith. Radar measurements of the magnetic field and subsurface screening will increase our geophysical and geochemical knowledge about the Moon and will deliver new insights about the interdependence of the Earth-Moon system.

The Moon is an archive, which will help to trace back events in the solar system that are not conserved on Earth. Study of various craters on the moon will give us an idea of the bombardment of solar system objects in the last 4.5 billion years. The far-side of the Moon may prove to be a good site for deep space observations. Another interesting question to be solved is, whether some form of water is present in the permanently shadowed craters of the Moon. Its discovery would allow a more sustainable lunar exploration campaign, because it is the essential resource for survival in such a hostile space environment. This is one reason why the NASA Constellation Program plans to return humans anew to the Moon. Other countries are laying the groundwork for future human lunar programs. Finally, China announced to consider a manned lunar landing in the next decades.

Mars

The search for extant and extinct forms of life on our neighbour planet Mars, opens a new era in planetology. Observations by a radar instrument of ESA´s Mars Express Orbiter indicated that a huge amount of water-ice exists in the polar regions of Mars. The NASA-Phoenix mission discovered unambiguous proof of the existence of water. Water-ice, which exists at the poles of Mars in huge abundance, is regarded as a key feature for the detection of traces of life. Missions by NASA, Russia, ESA, Japan, China and India throughout the next years will give us valuable information about the planet and inform our understanding of different human landing sites. They will generate numerous data and results, thereby enhancing our knowledge of the red planet. From where we stand now, the greatest stimuli for a science and sample return mission to Mars lie in the fields of exobiology, geophysics, and geo-chemistry. Influencing the plans for these next unmanned missions to Mars will allow the opportunity to test technologies and mitigation strategies to reduce human mission risks.

3.2 Using the ISS and the Moon to Advance Technologies and Capabilities for a Human Mission to Mars

We have described the large number of technologies and capabilities which need to be developed and demonstrated prior to a human mission to Mars. As Table 2 shows, with the exception of aero-capture of large payloads, all of these capabilities can be demonstrated through a combined capability demonstration roadmap including demonstration onboard ISS and in the context of human lunar surface operations. This however requires that the planning for utilization activities during a possible extended lifetime of ISS and the definition of the architecture for human lunar operations takes these demonstration needs into account from the start. Specific technology maturation goals must be set and progress measured each step of the way. As is suggested for robotic missions to the Moon and Mars, human missions to ISS and the Moon must always maximize scientific return while paving the way for future Mars exploration missions. Without this determination and programmatic focus, the opportunity to use the ISS and lunar missions for the benefit of buying down risks to future human exploration missions will be lost.

ISS	**Moon**
Advance development of advanced capabilities enabling sustained and long-term human operations in space with reduced logistics and demonstrate operations in actual space environment including • Maintenance workshop; • Crew health and medical support facility including telemedicine capabilities; • Advanced habitation systems including regenerative life support, greenhouse module and inflatable structure; • Environmental monitoring. Enhance understanding of biological effects of microgravity gravity and radiation exposure over long period of time (1 – 2 years). Perform partial rehearsal of human mission scenario to Mars (transit period). Improve cost-efficiency and effectiveness of human operations in space through automation of operations and use of advanced robotics. Test elements of propulsion systems required for human Mars mission (cryo-management)	Advance development of surface systems and demonstrate their operations in the actual space environment including • Advanced power systems including also nuclear. • Advanced habitation and life support systems; • Science instruments, EVA and mobility systems; • Dust mitigation techniques; • Radiation protection; • Advanced operations and automation; • In-situ resource utilization; • In-situ repair and maintenance; • Terminal descent and hazard avoidance. Demonstrate surface operations concepts for automatic, man-tended and permanently manned installations and optimize planning capabilities. Assess impacts of long-term exposure of systems to deep-space environment. Improve reliability of components and systems. Perform complete rehearsal of human mission scenario to Mars. Demonstrate operations of advanced communication and navigation technologies. Enhance understanding of biological effects of reduced gravity and deep space radiation environment. Demonstrate elements of propulsion systems required for human Mars mission (electric propulsion, nuclear power generation, cryo-management)

Table 2: Role of ISS and Moon for Development & Demonstration of Enabling Capabilities

3.3 Mitigating Risks to the Human System

Arguably the greatest risk to successful completion of a human mission to Mars is tackling the issue of long duration exposure to the space radiation environment. This and other human health risks associated with a Mars mission make understanding and mitigating human health and performance risks an important enabler of exploration missions. The International Space Station (ISS) is an excellent platform to study microgravity effects, while the Moon offers many insights into human adaptation to a partial gravity environment, plus the opportunity to demonstrate reliable and effective telemedicine capabilities. The ISS partners, CSA, ESA, JAXA, NASA and Russia, are all performing numerous studies of human adaptation to microgravity, and understanding the importance of these effects on crew health and mission risks. The partners are increasingly combining their efforts and resources to maximize data gathering opportunities and sharing of results as all recognize the unique opportunity provided by the ISS and its 6 person crew.

NASA's Human Research Program (HRP) is focused on mitigating the highest risks to human health and performance on exploration missions. These risks are many, including the risks associated with exposure to the natural and induced radiation environment. Research into understanding and mitigating these risks is an important enabler to exploration missions beyond low earth orbit. The NASA HRP has developed an Integrated Research Plan to set measureable goals for achieving human risk reduction. Such an approach can be adopted by international agencies in order to leverage available resources in the most effective manner.

NASA, ESA, DLR and Russia are engaged in an international coordinated effort to define and test effective countermeasures that mitigate human health risks. This activity, known as the International Countermeasure Working Group (ICM) provides a forum for member agencies to coordinate activities and exchange research information directly related to the cooperative planning and execution of countermeasure research on Earth and in space. The initial focus of this group is on mitigating human health risks of microgravity, this approach can also serve as a model for expanded international cooperation as research into the risks of partial gravity environments is enabled by human missions to the Moon.

3.4. Reducing Mission Risks

Continuous operations in space allow partners to build and maintain the technology base and workforce necessary to conduct increasingly challenging missions. The ISS program, and other low earth orbit activities, will provide such a platform associated with the risks of conducting missions in a microgravity environment. Another set of risks are associated with missions to planetary surfaces. These can be better understood and mitigated through human missions to the Moon. The space exploration strategy must be mindful of the importance of continually providing the opportunities to identify and mitigate the mission risks, so as to ensure that the totality of mission risks associated with a human mission to Mars are understood and accepted.

Agencies engaged in human spaceflight gain a better understanding of mission risks as their experience increases. A dedicated international effort to understand and characterize these important challenges would benefit nations planning to contribute to a sustainable space exploration future.

3.5 Building and Maintaining a Global Partnership

The Global Space Exploration Strategy* clearly states that "Sustainable space exploration is a challenge that no one nation can do on its own." "Space is an unforgiving environment and no nation has the resources to take on all of its challenges at once." "International cooperation expands the breadth of what any one nation can do on its own, reduces risks and increases the potential for success of robotic or human space exploration initiatives." For human space exploration to be sustainable, overlapping capabilities for essential and critical functions need to be developed and operated to ensure overall architecture robustness against system failures. A reasonable assumption to make is therefore that the sustainability of human exploration of the Earth-Moon-Mars space depends strongly on the success in building a strong and global partnership for sharing resources, dealing with risks to human life and

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* The Global Space Exploration Strategy – a Framework for International Coordination" has been jointly developed by 14 space Agencies (ASI ,Italy, BNSC, 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) in the 2006 – 2007 timeframe and been published in spring 2007.

benefiting from complementary competences and benefit.

Reviewing also the lessons learned from the ISS program, the biggest peaceful international partnership program even undertaken so far, some key challenges and elements associated with the build-up and management of a global partnership can easily be identified and are listed below.

Common Vision/ Goal:

The development of a common vision and goal is required to enable the alignment of resources, capabilities and competences towards this vision/ goal. At the same time individual partners should be able to pursue their individual objectives.

Interdependency:

A global partnership will furthermore become more effective, if the partners invest in complementary capabilities. The implementation of sustained human exploration and the achievement of the associated common vision/ goal will therefore require each partner to accept inter-dependencies with others. Partners will more easily accept interdependence if approval for the vision/ goal and program elements is sought at the highest political level and associated cooperation agreements are implemented at governmental level. Furthermore, to assure overall robustness of the program, the achievement of the common vision/ goal should not depend fully on the contribution a single Partner makes.

Program Integration:

New methodologies for program integration need to be developed to assure the management of cost, schedule and risk of such a complex and global program and reduce the impact of one Partner's schedule delay on the costs and schedule of the other Partner.

International Standards:

Interfaces between Partners' contributions need in general to be simplified to facilitate program integration and operations. Interfaces may occur at different levels of the architecture. An important issue will be to plan for such interfaces from the start and develop international standards in the areas concerned to facilitate interoperability. Standards may also be developed for common products which find applications in different systems of the architecture.

Partnership Build-up and Management:

The largest partnership existing today working on a common science and technology program is the ISS Partnership. For addressing the ambitious goals of human exploration, these bonds and relationships need to be maintained over a long-period of time, and enlarged as emerging nations demonstrate the capabilities and willingness to contribute to a global space exploration endeavor. Integrating other Partners with yet again different political systems and cultural backgrounds is a challenge in itself. A clear cooperation framework will be required building on lessons learned by the ISS program[†] which clearly defines ownership, commitments, roles, Partner responsibilities, and technical interchanges or transfers, export control and decision-making rules. Furthermore, the Partnership needs to be build such as to be sustainable over a long period of time during which it will certainly be faced with critical events such as mission failures, possible loss of crew, changes in national priorities, budget crisis and international tensions. It is therefore important to plan not only for the nominal scenario, but to develop a risk management plan for the Partnership and associated contingency scenarios. For building a strong global Partnership, such a Partnership needs probably not only to be seen as a necessary means for implementing a common vision, but rather it needs to be an integral element of a shared political vision.

Table 3 suggests how to approach the challenges identified above and in particular outline the role of Analogue missions, ISS operations and utilization and international human missions to the Moon for building the Global partnership.

[†] The ISS cooperation framework is based on an Intergovernmental Agreement (IGA) and bilateral Memoranda of Understandings between the Space Agencies.

Approach	Role of Analogue Missions	 ISS Operations and Utilization	 International Human Missions to the Moon
I Common Vision			
Build on the ISS lessons learned and Global Exploration Strategy to develop common goals for exploration	Demonstrate in the near-term achievements related to elements of the goals (e.g. International ISRU Architecture).	Integrate ISS into common vision for Human Exploration and develop specific related goals for ISS utilization	Develop common goals for international human missions to the Moon which clearly relate to the broader vision and goals
II Interdependency			
Analyze the level of interdependency required for succeeding in implementing the common goals	Demonstrate and communicate the value of complementary competences and investments by Partners		Analyze related ISS lessons learned for its relevance to the human lunar exploration architecture
III Programme Integration			
Define and analyze optional approaches for integrating the international programme addressing the common vision/ goals.	Test optional programme integration mechanism in place	Analyze relevance of lessons learned from ISS for exploration	Put selected programme integration mechanism in place
IV International Standards			
Identify early areas in which International Standards are required to facilitate cooperation	Use activities to inform standard development	Review applicability of applied standards for exploration	Identify needs for standards for the international human lunar reference architecture
V Partnership Management			
Start from ISS partnership to build an enlarged partnership for human exploration.	Engage new partners and demonstrate early the value of an enlarged Partnership.	Develop options for other Partners to join ISS related activities. Create stronger linkage between the ISS cooperation framework (MCB) and the build-up of human exploration framework (ISECG).	Develop a cooperation framework which integrates the lessons learned from ISS and is open to integrating new partners.

Table 3: Roadmap towards a Global Partnership for Exploration

4. WAY FORWARD

Studies done by NASA, ESA, Russia and other agencies to understand Mars mission requirements and challenges provides a good starting point for developing a coordinated approach to advancing technologies and capabilities. The ISECG has proven to be an effective forum for communicating shared goals and objectives and jointly exploring how exploration scenarios and architectures can enable goals and objectives to be met. An ISECG roadmap such as the one discussed in this paper and discussion on investments in a synergistic and coordinated manner will ensure the maximum return on investment across the board.

The following activities may be addressed by ISECG members to advance a coordinated exploration strategy:

(1) Advancement of reference mission scenarios and architectures;
(2) Development of a coordinated technology development roadmap;
(3) Development of a coordinated risk mitigation roadmap;
(4) Discussion of the importance of coordination of research plan;
(5) Analysis of cooperation scenarios and frameworks.

5. CONCLUSION

A highly coordinated and evolutionary program for activities associated with a human mission to Mars is required to address the programmatic challenges, build up a global partnership, and optimize the utilization of resources necessary to achieve this important and inspiring goal. The strategy presented here starts the discussion of what such an evolutionary program would need to look like in order to address the sustainability over multiple generations. To make real and measurable progress towards a future human mission to Mars, the requirements derived from reference mission architectures need to be translated into concrete objectives and requirements to be address on Earth, LEO and the Moon. The task is large, but the rewards are many and will result in inspiring missions that will indeed capture the imagination of our youth resulting in future engineers and scientists, advance technologies which will improve life on earth, increase the knowledge of our solar system, and strengthen bonds and relationships across the globe.