INTERNATIONAL SPACE STATION

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LESSONS LEARNED

AS APPLIED TO EXPLORATION

Kennedy Space Center
July 22, 2009

International Space Station
Multilateral Coordination Board
Consolidated Lessons Learned
For Exploration

As of July 22, 2009, my agency's lessons learned are documented in the attached. We will continue to clarify and refine this document over time. As the program evolves further additional lessons will be added.

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EXECUTIVE SUMMARY

In 2009, as construction of the International Space Station (ISS) approached completion, and the program's Multilateral Coordination Board (MCB) reflected on the process, they thought it would be valuable to future exploration programs to capture the lessons learned over the ISS design, development, assembly, and operations phases.

A summary of this effort, as conducted by all of the ISS International Partners (the National Aeronautics and Space Administration, the Canadian Space Agency, the European Space Agency, the Japanese Aerospace Exploration Agency/Ministry of Education, Culture, Sports, Science and Technology, and the Russian Federal Space Agency), is provided below.

The results are organized in seven categories:

- Category 1 - Mission Objectives
- Category 2 - Architecture
- Category 3 - International Partner Structure and Coordination
- Category 4 – External Communications
- Category 5 - Operations
- Category 6 - Utilization
- Category 7 - Commercial Involvement

Each lesson learned is accompanied by a corresponding application to future exploration programs. A more detailed discussion for each of these lessons and applications and the Partner origin are provided in the attached appendices.

CATEGORY 1 – MISSION OBJECTIVES

1-Lesson: Accommodate Partner's Own Objectives

The most significant outcome of the station mission has been the sustainment and growth of each Partner/nation's aspirations for human spaceflight. This occurred because from the onset all Partners shared a common objective to build, operate and utilize a crewed multi-discipline laboratory in low earth orbit as an international partnership. The partnership was also flexible enough to foster collaboration with other non-Partner nations.

Application to Exploration: Develop a long-term shared vision for space exploration that transcends domestic policies and fosters a shared destiny among the Partners. The mission objective should be a succinct, inspiring statement that enables Partner to participate based on their objectives and priorities to the greatest extent possible while ensuring the provision of all critical path items. Each phase of space exploration should also be defined by clear goals. Plans should also allow for unforeseen events, or withdrawal of participants, without jeopardizing the overall mission objective.

2-Lesson: Establish Realistic Expectations

The purpose of the mission should be defined as thoroughly and clearly as possible with planned achievements that are commensurate with planned spending. It is particularly important not to overestimate the mission objectives and scientific outputs.

Application to Exploration: The goal for each space exploration program must be realistic and well articulated to include the global problems that the mission will help to resolve. For example, if the goal of the mission is scientific research, integration of the Partner research programs can help in meeting this requirement.

3-Lesson: Employ Reference Missions to Define Requirements

Reference missions developed in cooperation with all Partners were useful in identifying unique and common requirements. These requirements needed to be defined, in order to develop an architecture that met the needs of all Partners.

Application to Exploration: Reference missions and requirements need to be defined in cooperation with all Partners, in order to accelerate and materialize the on-going joint study of the architecture for international human exploration. Reference missions that reflect the stated goals and maximize accomplishments of common Partner objectives should be defined in cooperation with all Partners. They should demonstrate how international cooperation advances accomplishment of goals and objectives.

4-Lesson: Use Clear Mission Objectives to Drive Support

Properly formulated mission objectives (i.e. they are ambitious, attractive and achievable) will ensure stable political and social support. Stages of mission accomplishment must be timely with achievements reported promptly and comprehensively. Continuous progress toward achievement of mission objectives must be observed.

Application to Exploration: Exploration programs should establish clear intermediate objectives in time-phased stages that show consistent progress toward overall mission objectives.

5-Lesson: Allow Mission Objectives to Evolve Gracefully

As mission objectives evolve over time, the impact of changes to the mission objectives of the other Partners need to be considered since individual Partners have differing objectives.
Mission objectives should be flexible enough to make maximum use of spacecraft elements as the program evolves with better understanding of capabilities and resources.

Application to Exploration: Periodic review of the mission objectives is needed and Partners should re-affirm or re-align as needed.

6-Lesson: Ensure All Mission Objectives are Well-Integrated

A clear definition of different roles, responsibilities and scope of activities should be established at a top level. The mission objectives should be supported by an integrated architecture including end-to-end system requirements and plans for the safety of the crew. Standardization of technical interfaces and interoperability aspects are critical to success. Clear functional objectives for each specific element to be developed should be defined in the context of the overall mission.

Application to Exploration: Roles and responsibilities of each Partner, and clear functional objectives for the elements developed must be carefully integrated in the overall exploration architecture with close attention to technical interfaces and aspects of interoperability and crew safety.

CATEGORY 2 – ARCHITECTURE

7-Lesson: Establish Appropriate Interdependencies
Interdependencies are beneficial when they leverage a Partner's investment to accomplish a more robust mission than the Partner could have achieved had they remained independent. For example interdependency in Mission Control Centers and flight crew brought new achievements for the program. However, it is very important that interdependencies should be appropriately established with respect to the Partner contributions. Over-dependence on a single Partner for a critical element does not promote program stability and changes in key areas such as engineering interfaces, element readiness dates, and flight schedules can add unplanned cost and delays.

Application to Exploration: Partners should seek interdependencies where they are essential or beneficial to the exploration mission; however, critical elements must be ensured in each Partners contribution and single sourcing of critical elements should be avoided whenever financially practical. The trade between Partner autonomy and mission effectiveness is especially critical in human exploration due to the large investment.

8-Lesson: Avoid Elements on the Critical Path that Cause Interdependency

Interdependency may entail Partners depending on each other's contributions to achieve mission success but having a single Partner contribution on the critical path should be avoided. Interdependencies are best if balanced (equal Partners), long-term oriented (based on clear predicted needs) and flexible (allow for contingencies) with changes quickly communicated (allows time for reaction to minimize impacts). An international framework of joint strategy and contributions is key to program stability.

Application to Exploration: A better mix in the contribution between system and utilization infrastructure would be more suitable. Duplication of capabilities between at least two Partners in key strategic areas, corresponding to their financial and technological capabilities, would be preferred.

9-Lesson: Redundant Transportation Commitments

The ISS program clearly demonstrated how transportation resources affect all Partners. Constricted transportation has long-term implications that may limit the capability to operate, maintain and utilize the ISS. Transportation should have been treated as a core system that was a fundamental commitment to the partnership rather than a unique program. Dissimilar redundancy in transportation has been critical to the preservation of the ISS.

Application to Exploration: Future exploration programs must be structured with alternative transport vehicles, so there is no particular system that becomes a single-point-of-failure.

10-Lesson: Micromanage Consumables

Resupply, logistics and onboard stowage have proven to be critical issues for the ISS. Out of necessity, the program carefully re-evaluated the usage rates for critical consumables and found innovative ways to reduce resupply requirements. Micromanagement of consumables was found to be essential to ensure adequate supply inventories. Reliability and maintenance strategies are critical.

Application to Exploration: Consumables will be even more critical for extended lunar or Mars expeditions because of the more limited resupply opportunities. Micromanagement of consumables and inventory will be critical and should be thoroughly addressed during the systems design phase.

11-Lesson: Plan for an Evolving Public Policy

Along with the mission objectives, the station architecture accommodated each Partner's sensitivities and priorities in human space flight. The station architecture allowed each Partner to develop the technical capabilities and functions that met their goals and did not over extend their political and budgetary constraints. The ISS partnership also allowed for different public affairs policies and strategies.

Application to Exploration: Align international Partner technical responsibilities with their programmatic and political needs. Be sensitive to each Partner's domestic policy process, including media relations and public advocacy. Structure the exploration architecture to reduce issues involving any future changes in Partner policies.

12-Lesson: Employ a Robust Design

The modularity of station elements provided the needed configuration flexibility when the program faced budgetary and political challenges. This architecture provided long-term operability and reliability robustness for critical systems. However, the station architecture also relied on critical path elements for which there were no alternatives. The delay in delivery of those also delayed achievement of mission objectives.

Application to Exploration: In order to meet the mission objectives, the architecture should be robust and flexible enough to take into account the potential loss of a key function (e.g., transportation) for many months, or the loss of any single deployable element. The architecture should include redundant and dissimilar critical functions.

13-Lesson: Apply Common Standards and Tools for Developing Interfaces

The ISS Partners instituted a robust interface management and change control process that was able to keep track with the design of elements and distributed system across the ground and on-orbit segments of all Partners. The actual design of the station interfaces evolved around industry standards where available, but also unique interfaces were created where needed.

Application to Exploration: Apply commonly used standards and tools to implement and manage rigorous interface control. Only when absolutely necessary should Partners develop unique capabilities to meet unique challenges.

14-Lesson: Apply Existing Interface Designs Where Available

Full commonality is not necessary as historical and cultural specificity of each Partner will remain individual. However, standardization and unification of appropriate interfaces in basic spheres of interaction (system integration, power, transportation, management, etc.) are critical.

Application to Exploration: Interfaces already agreed to and used in practice under the ISS program should be investigated for application to future exploration programs wherever practical.

15-Lesson: Implement Processes to Establish Common Interfaces with Modular Design

A multi-Partner advisory team is best qualified to assess, recommend, coordinate and implement areas eligible for interface commonality before phase A, and to apply dissimilar redundancy for critical applications. This process is best addressed in international agreement documents. Also, modular design should be applied to the production process.

Application to Exploration: A process to thoroughly address commonality issues and opportunities should be formally established, at the highest level, early in exploration programs and a modular design approach should be encouraged.

16-Lesson: Establish Core System Interface Documents Early

Common core system interface documents should be generated at the onset of the program, and should accommodate design options that initially use state-of-the-art technology, but also provides hooks and scars for enhancements as technology advances throughout the life of the program.

Application to Exploration: Common core system interfaces should be specified as early as possible in exploration programs, and should include provisions for later systems upgrades as technology advances.

17-Lesson: Minimize External Interfaces to End-to-End Systems

Whenever possible, a single agency should design, develop, test and integrate hardware to a standard core interface as a complete end-to-end system. This minimizes duplication of effort and contractual disputes between system designers and contracting organizations.

Application to Exploration: Exploration programs should partition end-to-end systems in order to ensure that a single Partner manages all internal interfaces.

18-Lesson: Verify Interface Requirements Compliance Early

Sharing of verification closure material for interface requirements needs to be done early in the development process, in order to minimize rework. Partners should have mutual access to verification closure materials for interface requirements, and Partners should be invited to all design and test reviews.

Application to Exploration: Exploration program agreements should be developed to include mutual access to design and verification closure information to ensure interface compliance and suitability.

19-Lesson: Plan for Flexibility in Design Life

The design life of the ISS began as a design constraint. However, this has been overtaken by the desire of the partnership to extend ISS life. It would have been beneficial to further modularize systems to accommodate an indefinite presence in space. A system design requirement of 15 years does not necessarily dictate the system be retired in that period if it continues to hold value.

Application to Exploration: Agreements for long duration international missions should be reached to design for disposal and expansion and to provide the capability to replace aging, or end-of-life systems, with new and improved products for as long as the Partners need to conduct the mission.

20-Lesson: Use Dissimilar Redundancy in Systems for Program Flexibility and Stability

Any critical element of the program should have a dissimilar backup. During the on-orbit integration stage, redundancy is especially critical and dissimilar redundancy of functions must be ensured. This improves program flexibility and stability in case of contingencies, accidents, delays, etc.

Application to Exploration: Future long-life exploration systems should be designed as “open systems” based on modular infrastructure with capability for the modules replacement through uniform interfaces.

21-Lesson: Establish Dissimilar Redundancies Early in the Program

Operation of the ISS stabilized when dissimilar redundancy in systems (e.g., transportation, environmental control and life support, etc.) was achieved. Unfortunately, this occurred relatively late in the program for some systems.

Application to Exploration: The necessity for dissimilar redundancies in all critical systems could be much higher as exploration expands outward. To sustain the program in a stable state, these redundancies may be necessary for some critical functions at an early program phase.

22-Lesson: Apply Dissimilar Redundancy to Critical Systems Comprehensively

Critical functions for dissimilar redundant systems in the ISS program included crew transportation, life support, power generation, cargo logistics, communication, launch facilities, control centers, data management, countermeasures and in-situ resource generation.

Application to Exploration: In human exploration both dissimilar redundancy and robustness for the critical functions are necessary because they affect crew safety and mission success. In order to identify the underlying strategic implications, an analysis at the total system level with identification of critical risks, definition of acceptable risk levels, implementation of mitigation concepts, and ultimately trades between robustness and dissimilar redundancy is essential.

23-Lesson: Use Commercial Off-the-Shelf Products Where Possible

An effective strategy in the ISS program was to simplify designs by utilizing commercial off-the-shelf (COTS) hardware and software products for non-safety, non-critical applications.

Application to Exploration: Use of COTS products should be encouraged whenever practical in exploration programs.

24-Lesson: Employ Common Processes, Interfaces and Standards

The standardization of technical interfaces and interoperability aspects are critical to success. In the ISS program, commonality of various interfaces made it possible to simplify the interface definition significantly.

The ISS is the longest duration international space effort to date that is available as a test bed for verification of systems interoperability, as well as international science and space exploration studies. Common partnership interfaces and standards create a common operational environment that leads to on-orbit flexibility and adaptability as situations evolve.

Application to Exploration: Agreements to utilize common processes, interfaces and standards are necessary to build-in flexibility and adaptability for future missions. Commonality of interfaces should be achieved as much as possible in the exploration program.

25-Lesson: Establish Export Control Practices Early

Frequently, program-related information needs to be exchanged that is likely to involve trade secrets or intellectual property. The imposition of ITAR (International Traffic in Arms Control) created difficulty for all ISS Partners in getting ITAR-classified data from NASA contractors. The added costs and delays needs to be averted to the maximum extent possible by avoiding inclusion of broad-brush classifications or by being more specific on those elements that really need to be export control protected.

Application to Exploration: Ensure workable provisions for export control are established early in exploration programs.

26-Lesson: Improve Technology Transfer Procedures for Common Interfaces

There were numerous obstacles in transferring technical information regarding the common interfaces.

Application to Exploration: Improve the procedure for technical information transfer related to common interfaces.

27-Lesson: Improve Data Sharing Practices

In the ISS program, a number of hardware components were procured from foreign countries. Export controls of some countries often constrained technical information transfer and led to delays in schedule and increases in development cost.

Application to Exploration: Common hardware will continue to be procured overseas in the exploration program. A comprehensive framework for technical information transfers is needed, in order to simplify procedures, reduce cost, and accelerate program implementation.

28-Lesson: Employ Automation Wherever Practical

The ability to use automation to operate mission systems without crew intervention has provided significant benefits. International Partners should have the capability and responsibility for direct command from multiple control centers, with their local facility serving as the primary control and monitoring of the end-to-end system.

Application to Exploration: Use automation to relieve the crew of routine or hazardous functions wherever practical. Furthermore, optimize the use of automation to provide operational flexibility. Partners should have the capability and responsibility for direct command from multiple control centers in order to improve operational robustness.

CATEGORY 3 - INTERNATIONAL PARTNER STRUCTURE AND COORDINATION

29-Lesson: Carefully Balance Specificity and Flexibility in Program Agreements

Multilateral and bilateral partnership agreements need to be explicit while still allowing some flexibility for each agency to contribute to the resolution of unforeseen circumstances. The ISS IGA and MOU documents spell out roles, duties, commitments and responsibilities for the partnership, and provide an overarching framework tested over time with a track record of experiences for the partnership.

Application to Exploration: Future international programs agreements need to be specific from the onset to deal with ownership, commitments, roles, Partner responsibilities and technical interchanges or transfers.

30-Lesson: Manage Working Groups Judiciously

The ISS management framework demonstrated the utility of working groups. However, some revision remains necessary: (1) the activity of working groups must be deeper integrated in the system to include all participants; (2) scope and authority of actions set by groups must be strictly determined; (3) number of groups should be limited; and, (4) the process of establishing and dismissing groups should be closely regulated.

Application to Exploration: Exploration programs should use working groups when necessary, but not indiscriminately. The groups should consist of all participants in the subject domain, and operate under specific terms of engagement.

31-Lesson: Establish Inter-Partner Technical Liaison Offices

In the ISS program, Partners agreed to establish technical liaison offices with other key Partners with whom there was major interaction. There are significant benefits in terms of easy access to program personnel and data, as well as the ability to expedite a variety of development and operational issues.

Application to Exploration: Establish technical liaison offices with key Partners in order to facilitate communications.

32-Lesson: Obtain Early Agreement on Common Technical Communications

The ISS international agreements provided, to the maximum extent possible, common technical communications for language, units of measurement, distributed system and element nomenclature, and interface standards (human and robotic).

Application to Exploration: All exploration Partners should agree on common technical communications at the beginning of the program.

33-Lesson: Use Consensus Approach to Decision Making

The practice of governance by consensus within the ISS partnership provides assurance that Partners have a voice in decisions, management and other issues. The partnership benefitted from consensus building by identifying major Partners' interests, including constructive changes. A provision in which one Partner has the ability to make a decision in those rare cases in which consensus could not be reached is essential to ensuring that the program continues.

Application to Exploration: Governance by consensus is beneficial in major international projects. Agreements should encourage consensus decisions while allowing for a means of resolution in extreme cases.

34-Lesson: Use a Formal Framework for International Cooperation

The ISS Program had a Governmental-level commitment from all the Partners called the IGA (Intergovernmental Agreement). This greatly contributed toward maintaining support for the ISS program from each participating government and to the program's stability despite its complexity and long duration.

Application to Exploration: A Governmental-level international commitment would be effective for exploration programs, since a withdrawal or delay of the program due to a cooperating agency's circumstances could prove critical. Even if the architecture is a "program of programs" (integrated series of disparate programs), it would be effective to construct such an international framework for cooperation, so that each participating country could view their contribution toward achieving common global goals.

35-Lesson: Use a Dedicated Group to Develop the International Framework

The ISS approach of tasking a dedicated group to develop initial proposals which can be subsequently reviewed, amended and further developed in a full multilateral environment, representing all envisaged Partners, is an effective and workable approach to developing a formal framework for international cooperation.

Application to Exploration: In the human exploration management process, many key parameters must be identified and assessed. Due to the increased complexity and arrival of new Partners, the decision making process needs to reach the right balance of each Partner's investments. An experienced dedicated group should be assembled for these purposes.

36-Lesson: Accommodate Partner Budget Cycles

Each Partner agency in the ISS program must be aware of the evolution of policies of the other Partners, and the ways in which each Partner budgets operations. These differences are crucial in planning program milestones, in order to best build global political support.

Application to Exploration: Each Partner must be aware of the budget cycles of other Partners and be willing to accommodate to the greatest degree possible. Maintaining a high level of situational awareness is beneficial in improving cooperation on both a political and a technical level, tactically and strategically.

37-Lesson: Anticipate Budget Fluctuation

During the course of ISS development, each Partner's space station budget changed to varying degrees from the ideal profile due to national policies. The budget strategies for each Partner's program did not always take these funding disruptions into account and was a significant factor in the delay of ISS assembly completion.

Application to Exploration: Programs should take into account the probability of periodic budget discontinuities and disruptions among the Partners. Interim milestones which show technical achievements throughout the schedule are critical. A singular focus on a common major milestone that requires extensive interdependencies should be de-emphasized.

CATEGORY 4 - EXTERNAL COMMUNICATIONS

38-Lesson: Recognize the Criticality of Strategic Communications

Active management of strategic communications concerning the ISS is critical. Current conditions require a formal commitment by management to manage all facets of the programs' communications. To avoid crisis, or to respond expertly, in a timely manner to unplanned events requires a dedicated, proactive team with expertise in all areas.

Application to Exploration: In addition to a highly structured array of boards and reviews for technical aspects of system development and operations, thought needs to be paid to developing an effective mechanism for coordinated strategic communications on exploration programs

39-Lesson: Support Public Relations

Public relations (PR) activity is particularly important in large and expensive programs like the ISS. Smart and well thought-out PR activity is a useful way to minimize the non-profitable character of human space flight by offering intangible benefits.

Application to Exploration: Many people are ready to accept and support the idea of exploration if it is attractively offered. Joint efforts of all Partners should be thoroughly communicated.

40-Lesson: Include Flight Crew in Public Relations

In the ISS Program, public relations are playing an important role to gain the understanding and support of the general pubic. In particular, having the flight crew talk to citizens around the world from the ISS has a great impact through inspiration.

Application to exploration: In the space exploration program, enabling flight crew interaction with the public at early stage of the program would be highly effective. There is also a need to inform the outcomes of the space exploration program to the general public in each participating country efficiently and widely.

41-Lesson: Include Educational Projects in Public Relations

Activities involving education have been very important to the ISS program and play a significant role in contributing to a scientifically literate society. ISS outreach and education programs have directly involved teachers and students in a variety of contexts (e.g., contests, classroom lessons, publications, educational kits, etc.).

Application to exploration: Educational activities performed on the ISS can be linked to the exploration beyond earth orbit. This requires a joint effort by all Partners and necessitates starting promotion and outreaching activities from the very early stages.

42-Lesson: Include Tangible Benefits with Early Visibility to the Public

Public support and understanding of the ISS program declined, because it took 20 years from the start of investments in 1987 to the deployment on orbit of international Partner elements.

Application to exploration: For the future exploration program, it is desirable to establish a program whereby the outcomes from contributions and investments by international Partners can be obtained and become visible to the public as early as possible.

43-Lesson: Plan Early Achievements to Sustain Political Support

The ISS program was ambitious and developed over a significant time period. Much of the emphasis was on the final goal to complete assembly. As a result, political support tended to weaken at times.

Application to exploration: Future exploration programs should include major milestones in segments with clear objectives to be achieved in the short, medium and long term. All Partners in a joint communication plan should coordinate this.

CATEGORY 5 – OPERATIONS

44-Lesson: Decentralize Certain Operations

Decentralizing certain ISS operations allowed each Partner to develop the necessary skills and capabilities to conduct human space flight domestically, as well as to develop a global human spaceflight culture. Mission preparation and real-time operations have continued to evolve to be more efficient and less travel-intensive with more capable collaboration and training tools.

Application to Exploration: Each Partner should be encouraged to develop the human spaceflight skills and capabilities necessary to complement their contribution. A technology roadmap for such collaboration should be developed to augment, and possibly reduce, the amount of human transit time between Partner sites.

45-Lesson: Include Long Term Planning for Extended Operations

It was important for each Partner to have a vested interest in the continuing operations, not just the development of the ISS. Termination, or exit criteria, by one Partner are not simple due to obligations to remaining Partners. Decisions about assets upon dissolution and the terms that apply may be problematic.

Application to Exploration: Partners providing systems and components need to commit to the total life cycle of the program including any likely extended operations and disposal.

46-Lesson: Reduce Payload Processing and Launch Schedules

Because it takes a long time in the ISS Program to manifest a payload, there is a risk of loss of science community involvement (e.g., particularly when lead times are longer than a post-graduate program).

Application to Exploration: Manifest lead times need to be shortened and payload processes need to be simplified to ensure greater science community involvement in exploration programs. An optimized operations architecture should be forseen.

CATEGORY 6 - UTILIZATION

47-Lesson: Integrate the Utilization and Operations Strategy

The ISS suffered from an unevenly managed operations and utilization effort. User communities had difficulty defining a responsible organization and advocating benefits of the program. A single organization combining development, operations and utilization would have been much more committed to overall program success.

Application to Exploration: Utilization should be developed as part of the long-term mission strategy for the program, with clear technical, policy, and communications goals, and appropriate stakeholder buy-in. Future exploration programs should have scientific elements thoroughly defined and fully integrated with system development and operations.

48-Lesson: Fully Develop Flight Crew Experience

The experience flight crew gain working on the ISS has expanded their professional skills, increased their self-reliance in space operations, and lowered the risk of dangerous situations. The ISS can now be considered as a part of our versatile human existence and as a natural transfer of the earthly life to the space platform.

Application to Exploration: Exploration flight crew should be afforded as many opportunities as practical to expanding their experience base living and working in space.

49-Lesson: Use Available Space Assets as Technology Test Beds

The ISS Program used the Space Shuttle and Mir Station as technology test beds and now the ISS is serving as a unique testing platform for development and qualification of space technologies. It will be further strengthened as experience grows and capability of autonomous existence in space increases.

Application to Exploration: Exploration programs should use the ISS to develop, demonstrate and qualify next generation space technologies and operations relevant to the future of space exploration. The ISS partnership can accommodate Non-Partner use of the ISS for development and qualification of space technologies.

50-Lesson: Use Available Space Assets to Conduct Training and Maintain Operations Skills

The ISS Program used the Space Shuttle and Mir Station to conduct training and maintain operations skills**.** Now, the ISS is being effectively utilized to sustain operation skills and conduct flight and ground crew training.

Application to Exploration: Exploration programs should use the ISS to conduct training and maintain operations skills relevant to the future of space exploration. For example, the ISS can be used to demonstrate maintenance and repair operations mandatory as the distance from Earth increases.

51-Lesson: Use Available Space Assets to Pursue Science and Applications

The ISS Program used the Mir Station, Space Shuttle, Spacelab and Spacehab to conduct precursor science and applications research in preparation for the ISS era. Now, the ISS has proven to be the most capable platform ever produced to conduct science and applications development in a microgravity environment.

Application to Exploration: Exploration programs should use the ISS to pursue science and applications relevant to the future of space exploration. The ISS should be used to develop in-situ research capabilities.

52-Lesson: Consult with End-Users Early in the Program

The ISS benefited from consulting with scientists early, in order to ensure the ISS would be useful and productive. The mission performance requirements were established at the 1993 CDR (critical design review) milestone, and the "as-built" configuration meets all requirements (except logistics due to unanticipated termination of the Space Shuttle program).

Application to Exploration: Engage end-users early to ensure program design will meet the needs of all parties.

53-Lesson: End-Users Should Coordinate Internationally

International science working groups were formed early in the ISS partnership to coordinate utilization activities at the agency science level. These groups reduced unnecessary redundancy, introduced efficiencies in the planning and selection of payloads, and enabled international technical and scientific collaborations.

Application to Exploration: Coordination of end-users from all Partners can bring benefits with respect to the ultimate productivity of the utilization program.

54-Lesson: Recognize Value of Prior Exploration Programs

The ISS leveraged considerably from the value of previous human and robotic space exploration efforts, and has now has proven to be an extremely valuable platform for exploring long-duration human stays in space. In addition, the ISS allows us to perform many complex hypothesis-driven studies requiring human intervention or monitoring.

Application to Exploration: Exploration science and technology should take advantage of the human presence, the life-friendly environment and the possibility of long-duration free-fall study with the possibility of direct intervention that is only available on ISS.

55-Lesson: Considering Commercial Engagements Early in the Process and Determine the Best Stage to Pursue

Partners should determine how to deal with commercial engagements early in the Partnership and then each Partner can determine when the best time is to pursue commercial engagements depending on their program.

In the ISS Program, each Partner has taken a unique approach to commercial engagement. A variety of engagements have contributed toward decreasing program costs and stimulating the space industry. These activities were conducted amid international harmony and within the responsibility and rights of each participating agency. Attention was necessary to clarifying the responsibility of each participating agency for safety.

One Partner believes that commercial engagement brings almost nothing during the early stage -- just minor additional financial support. In the later stage, when technology spin-offs became more and more visible, business also gets interested. Even later, business starts investing in large commercial projects (e.g., communication, navigation, Earth remote sensing), appreciably supporting and helping in development of space infrastructure.

Another Partner thinks we should consider the ISS an extension of life on earth and, thus, there is no need to invent a particular arrangement for ISS commercial development as business will develop as soon as necessary conditions appear. Nonetheless, it is important to offer and ensure the opportunity for business involvement at the earliest stage of the program. Business will find the right time and way by itself.

Application to exploration: It is important to consider the possibility of commercial engagement from an early phase of the space exploration study. However, attention should be given to effects on safety, Partner responsibilities and rights. Opportunities for business to participate in exploration programs should be carefully and appropriately timed.

56-Lesson: Establish Framework and Await Clear Markets for Commercial Engagement

Commercial engagement can provide beneficial effects, however it can also lead to conflicts of interest and endangerment of operations with risks that are difficult to quantify. In the ISS program, the overall strategy and legal framework was not always clear, and it was difficult for a commercial Partner to find a profitable role.

Application to exploration: The definition of a clear market that would allow industries to invest and obtain a return, plus a legal framework that allows industry to own what they would achieve, is the best means to assess and prepare for commercial engagement. A common approach among the partners should be sought.

Appendix

The following are the unedited inputs from the ISS International Partners: the National Aeronautics and Space Administration, the Canadian Space Agency, the European Space Agency, the Japanese Aerospace Exploration Agency/Ministry of Education, Culture, Sports, Science and Technology, and the Russian Federal Space Agency.

NASA ISS Lessons Learned February 2009

Mission Objectives

ISS Lesson:

The Partnership's primary objective has been to build, operate and utilize a crewed multi-discipline laboratory in low earth orbit as an international partnership. This has proven to be a significant and inspirational objective. The mission objective took advantage of, and further built upon, long-established relationships between government and industry around the globe. The mission objective also allowed the space station Partnership to evolve throughout the years based on fluctuations in support, technological challenges and budgetary pressures. Probably the most significant impact of the station mission is the sustainment and growth of each nation's aspirations for human spaceflight in collaboration with other nations.

Application to Exploration:

Develop a long-term shared vision for space exploration that transcends domestic policies and fosters a shared destiny among the partners. The mission objective should be a succinct, inspiring statement that enables partner nations to participate based on their national objectives and priorities. It should also allow for unplanned events, or withdrawal of participants, without jeopardizing the mission objective.

Architecture

ISS Lesson: Budget

A first order impact on development of the ISS has been the national budget allocations. In the early stages of the space station program, development was based on conventional funding profiles that grew to a peak at the critical design and testing phases and then tapered off. These budgets reflected the allocations that each partner needed to accomplish their respective responsibilities efficiently. The reality was that each partner's space station budget changed to varying degrees from the ideal profile (e.g., in the US, NASA's budget was capped on a yearly basis and for a time was capped for development content). The budget strategies for the each partner's program did not always take these funding disruptions into account and was a significant factor in the delay of ISS assembly completion.

Application to Exploration: Budget

Program formulation should take into account the probability of periodic budget discontinuities and disruptions among the partners. Interim milestones should be well-defined, in such a manner as to show meaningful political and technical achievements along the pathway to the ultimate mission objective. A singular focus on a common major milestone that requires extensive schedule and budget to achieve should be de-emphasized.

ISS Lesson: Planning

Along with the mission objectives, the station architecture accommodated each partner's sensitivities and priorities in human space flight. The station architecture allowed each partner to develop the technical capabilities and functions that met their national goals and did not over extend their political and budgetary constraints.

Application to Exploration:

Align international partner responsibilities with both their technical and programmatic/political capabilities and needs. Be aware and sensitive to partner domestic political and budget processes, including media relations and public advocacy. Engineer the architecture to avoid or mitigate potential issues involving partner interdependencies affected by political, or internal budgetary considerations.

ISS Lesson: Robust Design

The station architecture from the beginning was modular in nature. This modularity provided the needed configuration flexibility when the program faced budgetary and political challenges. Also, with the addition of the Russian space agency to the partnership, some of the station systems became redundant, but dissimilar. This architecture provides robustness in long-term operability and reliability for critical systems. However, certain other aspects of the architecture handicapped its completion and operations. Two of these aspects proved to be critical: transportation and critical path elements. For transportation, relying solely on the Space Shuttle for the US portion of the station extended the assembly schedule and critically limited station operations after the *Columbia* accident. However, the redundant and dissimilar Soyuz transportation system was able to sustain operations. The station architecture also relied on critical path elements for which there were no alternatives, or backups. The delay in delivery of the Russian Service Module and U.S. Laboratory also significantly delayed assembly of the ISS. In retrospect, if one of these elements were lost, the station mission objective may not have been realized.

Application to Exploration: Design

Human space flight is inherently prone to contingencies, delays and unplanned failures. In order to meet the mission objectives, the architecture should be robust and flexible enough to take into account the potential loss of a transportation system for many months and the loss of any single deployable element. The architecture should include redundant and dissimilar critical functions, as well as alternatives to particular critical elements.

ISS Lesson: Design

One of the true successes of the ISS program has been the management, design and testing of interfaces. The ISS partners instituted a robust interface management and change control process that was able to keep track with the design of elements and distributed system across the ground and on-orbit segments of all partners. The actual design of the station interfaces evolved around industry standards where available, but also unique interfaces were created where needed. Industry standards such as Mil-Std-1553 protocols, CCSDS communications, and electrical connectors are just some examples that were employed. Unique interfaces such as the Common Berthing Mechanism were created where no industry or existing capability existed.

From a software perspective, the use of a common data standards and databases greatly facilitated the exchange of software and data at complexity levels that were unprecedented in space flight. Transactions now take place between multiple contractors and multiple government agencies with a relatively low occurrence of error.

Application to Exploration: Design

Apply commonly used standards and tools to implement and manage rigorous interface control. Only when necessary, partners should develop unique capabilities to meet unique challenges. When unique capabilities are needed, apply standardization across the architecture (e.g., EVA tools).

Operations

ISS Lesson: Operations Decentralization

The ISS program was initially conceived as a U.S. centric partnership, in which operations were planned, trained, and conducted primarily at NASA centers. This required the partners to expend resources, mainly manpower, in the U.S. instead of their home countries. As the program evolved to include Russia, the original partners wanted to expand the U.S. centric operations to include control centers and more training in their respective countries. This had both positive and negative impacts. Decentralizing operations allowed each partner to develop the necessary skills and capabilities to conduct human space flight domestically, as well as to develop a global human spaceflight culture. However, it does require extensive travel on the part of operations personnel and flight crews from each partner to integrate and train for operational readiness. Operations are inherently human-intensive efforts. Unlike development, which peaks and then subsides, long duration human spaceflight is 24x7x365 days per year for as long as the program is operational. Mission preparation and real-time operations have continued to evolve to be more efficient and less travel-intensive with more capable collaboration and training tools, as well as real-time management tools.

Application to Exploration:

Distributed operations need not be an impediment to long duration human spaceflight. Each partner should be encouraged to develop the human spaceflight skills and capabilities necessary to complement their contribution. Investment in advancements for collaboration tools and techniques, training and real-time execution should continue and expand based on the experience of the ISS partners. A technology roadmap for such collaboration should be developed to augment, and possibly reduce, the amount of human transit time between partner sites. Tools and software however should not be viewed as substitutes for face-to-face communication.

Logistics, Resupply, and Stowage

ISS Lesson: Micromanagement of Consumables

Resupply, logistics and onboard stowage have proven to be critical issues for the ISS, especially in the years after the *Columbia* accident when the ISS resupply capability was severely curtailed. A system failure or consumables shortage could have necessitated abandonment of the ISS had

Progress vehicles not been available to replenish the ISS with spares and consumables. Out of necessity, the ISS Program carefully re-evaluated the usage rates for critical consumables and found innovative ways to reduce resupply requirements (e.g., reoriented solar arrays to minimize drag/propellant, used towels/clothes as packing materials, replaced film/paper with digital media, reduced clothing 85%, recycled water from clothes/towels prior to disposal). The key lesson learned was that micromanagement of consumables is essential to ensuring adequate supply inventories. The items available onboard, their stowed locations, and their rate of use or lifespan must be tracked, forecast, and carefully planned in great detail. Onboard stowage must also be carefully planned to maintain accessibility to critical areas.

Application to Exploration

These issues will be even more critical for extended lunar or Mars expeditions than they were for ISS because of the more limited resupply opportunities. Based on the ISS experience, careful management of consumables and inventory will be critical and should be thoroughly addressed during the systems design phase. The Exploration Programs should utilize technologies that were not readily available at the beginning of the ISS Program to help minimize resupply requirements and track inventory. For example, Radio-Frequency Identification Devices (RFID) might help to simplify inventory tracking. Also, limit the number of environmental samples that must be stowed and returned by giving the crew better means to monitor the vehicle/habitat environment (e.g., Lab-On-A-Chip-Development).

Utilization

ISS Lesson: Integrated Utilization and Operations Strategy

The ISS suffered from an unevenly managed, and at times competitive, operations and utilization effort. Dispersed user communities had difficulty defining a responsible organization and effectively advocating the benefits of the program. Because of the divisions between space station development, operations and utilization, no organization was responsible for advocating the merits of the mission. A single organization combining development, operations and utilization would have been much more committed to overall program success.

Application to Exploration:

Utilization should be developed as part of the long-term mission strategy for the program, with clear technical, policy, and communications goals, and appropriate stakeholder buy-in. Future missions for human space flight, especially exploration of the Moon and Mars, should have the scientific or utilization elements thoroughly defined and fully integrated into and managed with system development and operations, so that appropriate resources are available for program development, and efforts across the utilization, development and operations communities are better coordinated.

External Communications

ISS Lesson: Criticality of Strategic Communications

In 1993, during the first years of the Clinton Administration, an amendment in the US House of Representatives to terminate the space station was narrowly defeated - by a single vote. While much has changed since 1993, there is still a strong need to actively manage communications concerning the ISS, or any large multi-year program. Current conditions require a formal commitment by management to manage all facets of the programs' communications. ISS communications is a very broad subject and has many levels, in many arenas. Executive branch, congressional, international, public affairs and education are all areas that a robust communications plan should encompass. To avoid a crisis or to respond expertly in a timely manner to unavoidable events requires a dedicated, proactive team with expertise in all critical communications areas.

Application to Exploration:

In addition to a highly structured array of boards and reviews for technical aspects of system development and operations, a focused organization should be created for strategic communications.

International Coordination

ISS Lesson: Accommodating Partner Budget Cycles

Each partner agency in an international partnership must be aware of and attuned to the evolution of policies in each other's countries, and the ways in which the different countries budget operations. For instance, ESA is authorized funding every five years, while NASA is funded year-to-year. These differences are crucial in planning program milestones, in order to best build global political support. Overlooking these cycles could result in differing objectives among partners and become a source of conflict. On a tactical level, keeping closely attuned to differing funding cycles is key to avoiding short-term crises; this is especially important with partners who fund year-to-year, like the U.S and Japan. On a strategic level, attention must be paid to longer-reaching appropriations, as is the case with ESA; while the U.S. must justify its programs on a yearly basis and maintain political support year round, every fifth year is likely to be more important to an agency like ESA.

Application to Exploration:

Each partner must be aware of the budget cycles of other partners, and be willing to accommodate to the greatest degree possible. The history of the ISS has shown repeatedly that maintaining a high level of situational awareness is greatly beneficial in improving cooperation on both a political and a technical level, tactically and strategically.

CSA Lessons Learned: from participation in the International Space Station
December 5, 2008

International Program Agreement Lessons

Master agreements

To preclude programmatic complications from arising in international programs, it is recognized that agreements need to be explicit while yet allowing some flexibility for each nation to contribute to the resolution of unforeseen circumstances. The ISS MOU and IGA documents spell out roles, duties, commitments and responsibilities for the partnership. The ISSP MOU and IGA provide a strong overarching framework that is being tested over time and is establishing a track record of experiences for the partnership to consult.

Future international programs agreements need to be specific from the onset to deal with ownership, commitments, roles, partner responsibilities and technical interchanges or transfers.

Export control

It follows from the challenges experienced by the ISS partnership that there should be provisions for export control licensing and Technology Transfer Agreements (TTA). Frequently, program related information needs to be exchanged that is likely to involve trade secret and intellectual property. The imposition of ITAR restrictions on key parts of the ISSP created a very significant difficulty for all of the partners in getting ITAR-classified data from NASA contractors. The added costs and delays of such policies need to be averted to the maximum extent possible by avoiding inclusion of broad-brush classifications or by being more specific on those elements that really need to be export control protected.

Liaison offices

Based upon CSA experience with the ISS, it is recommended that partners agree to establish a liaison office with their key partners, especially those with whom there will be major interaction. There are significant benefits in terms of easy access to program personnel and data as well as the ability to expedite a variety of development and operational issues.

Standards and interfaces

From ISS experience, the international agreements also need to provide to the maximum extent possible a common technical framework of language, units of measurement, architectures (power, data, video, ground systems) and interface standards (user/human factors (MSIS), GUI, and Robotics (RSIS).

Consensus decision making

The practice of governance by consensus within the ISS partnership provided assurance that partners have a voice in decisions, management and other issues. The partnership benefits from such building of consensus by identifying major partners' interests and jointly planning activities including constructive changes. Partners often modify options or seek alternatives until everyone comes to the conclusion that the best approach is reached given the situational constraints of the partnership.

Transportation Systems Lessons Learned

Transportation commitments and redundancy

Based upon ISSP experience, transportation resources affect all partners. With the long-term transportation challenges experienced by the ISS partnership, there exists a shortfall on up and down mass availability. All of the ISS international partners have been affected by the decision to retire the space shuttle. This has impacted the ability of the partnership to deploy not only science but also to have adequate up mass and down mass for logistics and spares. Constricted transportation has longer term implications that may limit the capabilities to extend the life of the ISS. Assurance of transport is fundamental to future activities on ISS as well as other international long-term initiatives. A principle for future partnerships should be that transportation commitments between partners cannot be revoked unilaterally. Transportation should be treated as a core system that is a fundamental commitment to the partnership rather than a unique national program. Moreover, future international space programs must be structured with alternative transport vehicles so that there is not a single transport system point of failure.

Payload processing and launch

Currently, it takes too long to manifest a payload and partners risk the loss of science community involvement - (especially when lead times are longer than a post-grad program for example). Effective mechanisms to shorten manifest lead times need to be addressed along with transportation shortfalls especially for long-term sustainable human spaceflight.

Technical Lessons

Interface documentation

Experience from ISS indicates that common core system interface documentation should be generated at the onset of the program to avoid rework and/or incompatible interfaces resulting in significant increase in scope. The core systems network should accommodate design options that initially utilized state of the art technology and provide hooks and scars for enhancements as technology advances throughout the life of the program.

Minimizing interfaces

Hardware should be designed, developed, tested and integrated to the standard core interface networks as a complete end-to-end system by a single organization. This will avoid duplication of effort and contractual disputes between system designers and contracting organizations. CSA as an integrator of the entire MSS has learned this lesson as a result of experience encountered with the integration of the RWS from NASA. It is good practice to partition end-to-end systems minimizing internal interfaces or architectural elements to international partners.

Interface documentation verification processes

Experience with MSS and Dextre continues to indicate that the sharing of verification closure material for interface requirements needs to be invoked earlier. Specific instances where CSA has noticed problems with ORUs and robotic tools resulted from interfaces that were not respected. International partners should have mutual access to verification closure materials for interface requirements and partners should be invited to TRRs and TRRBs. The earlier in the development cycle the better it is to find non-compliances as it becomes more costly to rework flight hardware.

Design life

The design life of the ISS hardware has spanned several generations of technology developments. The inherent limit to the ISS life began as a design constraint. This now appears to be somewhat overtaken by the desire of the partnership to extend ISS life. This leads to the conclusion that it would have been beneficial to modularize systems to accommodate continuous presence. A system design requirement for a 15 year life does not mean that the station life will only be 15 years. For long duration international missions, agreements should be reached to design for continuous disposal and expansion and to provide the capability to replace aging and/or end-of-life systems with new and improved products for as long as the partners need to operate the mission..

COTS

ISS experience has shown that it can be an effective strategy to simplify designs while utilizing commercial off-the-shelf (COTS) products (hardware and software) for non-safety, non critical applications.

Operational Lessons

Common processes, interfaces and standards

The ISS is the longest duration international space effort to date that is available as a test bed for verification of systems interoperability as well as international science and space exploration studies. Common partnership interfaces and standards create a common operational environment that leads to on-orbit flexibility and adaptability as situations evolve. Common processes, interfaces and standards are appropriate to build-in flexibility and adaptability for future missions. Through the operation of the MSS since 2001, Canada has been able to respond to many on-orbit planned activities and unplanned situations that demonstrate the value of designing to common processes, interfaces and standards over long duration space missions.

Automation

Automation should be the primary means of operations for mission systems with crew intervention required on an "as needed" basis only. CSA is following this principle in the development of operations of the MSS and Dextre. CSA is convinced of the effectiveness of this approach. This means international partners should have the capability and responsibility for direct command from multiple control centers, with their local facility serving as the primary control and monitoring of the end-to-end mission system.

Long term Planning for Extended Operations

In order to carry out a long-term program, participants must commit not only to a significant development phase for their hardware contributions and the costs of launching and integration of this hardware, but also to an extended period of operation. CSA original forecasts were based on the presence of a crew of seven astronauts on the ISS. Since the ISS has run into difficulties during the construction period, the scientific and technological benefits that were initially anticipated have been postponed as the ISS will not be completed within the original timeframe. In any future large-scale cooperative program, the apportionment of operations costs will be a matter of major importance, particularly as such programs can be expected to have a very long operational phase. It is important for a partner to have a vested interest in the continuing operations, not just the development. Termination or exit criteria for the ISS or a partner are not simple due to obligations to remaining partners. Decisions about assets upon dissolution and the terms that apply may be problematic. All partners need to take into consideration the total life cycle including any likely extended operations and / or disposal.

CSA: Updated ISS Lessons Learned
April 24, 2009

Category 1-Mission Objectives

CSA Lesson: Mission Objectives
Mission objectives evolve over time. The impact of changes to these objectives may impact other partners and these impacts need to be considered since individual partners have differing national objectives.

Application to Exploration:
Mission objectives need to be flexible to make maximum use of facilities as program evolves with better understanding of capabilities and resources. Periodic review of the mission objectives is needed and partners should re-affirm or re-align as needed.

Category 2-Architecture

CSA Lesson: Interface Documentation

Experience from ISS has demonstrated that common core system interface documentation should be generated at the onset of the program to avoid rework and/or incompatible interfaces resulting in significant increase in scope. The core systems network should accommodate design options that initially utilized state of the art technology and provide hooks and scars for enhancements as technology advances throughout the life of the program.

Application to Exploration:

Develop common core system interfaces and document them early in the program. Use state of the art technology, and provide flexibility for enhancements as technology advances throughout the life of the program.

CSA Lesson: Minimizing interfaces

Hardware should be designed, developed, tested and integrated to the standard core interface networks as a complete end-to-end system by a single agency. This will avoid duplication of effort and contractual disputes between system designers and contracting organizations. CSA as an integrator of the entire MSS has learned this lesson as a result of experience encountered with the integration of the RWS from NASA.

Application to Exploration:

It would be good practice to partition end-to-end systems to ensure all internal interfaces or architectural elements are controlled by a single partner.

CSA Lesson: Interface Documentation Verification Processes

Experience with MSS and Dextre continues to indicate that the sharing of verification closure material for interface requirements needs to be invoked earlier. Specific instances where CSA has noticed problems with ORUs and robotic tools resulted from interfaces that were not respected. International partners should have mutual access to verification closure materials for interface requirements and partners should be invited to design and test reviews (PDR, CDR, TRR and TRRB). The earlier in the development cycle the better it is to find non-compliances as it becomes more costly to rework flight hardware.

Application to Exploration:

Program agreements should be developed to include mutual access to design and verification closure information to ensure interface compliance and suitability.

CSA Lesson: Design life

The design life of the ISS hardware has spanned several generations of technology developments. The inherent limit to the ISS life began as a design constraint. This now appears to be somewhat overtaken by the desire of the partnership to extend ISS life. This leads to the conclusion that it would have been beneficial to modularize systems to accommodate continuous presence. A system design requirement for a 15 year life does not mean that the station life will only be 15 years.

Application to Exploration:

Agreements for long duration international missions should be reached to design for disposal and expansion and to provide the capability to replace aging and/or end-of-life systems with new and improved products for as long as the partners need to operate the mission.

CSA Lesson: Commercial Off-the-shelf Products

ISS experience has shown that it can be an effective strategy to simplify designs while utilizing commercial off-the-shelf (COTS) products (hardware and software) for non-safety, non critical applications.

CSA Lesson: Common Processes, Interfaces and Standards

The ISS is the longest duration international space effort to date that is available as a test bed for verification of systems interoperability as well as international science and space exploration studies. Common partnership interfaces and standards create a common operational environment that leads to on-orbit flexibility and adaptability as situations evolve. Through the operation of the MSS since 2001, Canada has been able to respond to many on-orbit planned activities and unplanned situations that demonstrate the value of designing to common processes, interfaces and standards over long duration space missions.

Application to Exploration:

Agreements to utilize common processes, interfaces and standards are necessary to build-in flexibility and adaptability for future missions.

CSA Lesson: Automation

The ability to use automation to operate mission systems without crew intervention has provided significant benefits.. CSA is following this principle in the development of operations of the MSS and Dextre. CSA is convinced of the effectiveness of this approach. This means international partners should have the capability and responsibility for direct command from multiple control centers, with their local facility serving as the primary control and monitoring of the end-to-end mission system.

Application to Exploration:

Use automation to relieve the crew of routine or hazardous functions wherever possible. Furthermore, optimize the use of automation to provide operational flexibility. Partners should have the capability and responsibility for direct command from multiple control centers. The capability for multiple control centers would also improve operational robustness.

Category 3-Partnership Structure and Interactions

CSA Lesson: Agreements

To preclude programmatic complications from arising in international programs, agreements need to be explicit while yet allowing some flexibility for each agency to contribute to the resolution of unforeseen circumstances. The ISS MOU and IGA documents spell out roles, duties, commitments and responsibilities for the partnership. The ISSP MOU and IGA provide a strong overarching framework that is being tested over time and is establishing a track record of experiences for the partnership to consult.

Application to Exploration:

Future international programs agreements need to be specific from the onset to deal with ownership, commitments, roles, partner responsibilities and technical interchanges or transfers.

CSA Lesson: Export Control

It follows from the challenges experienced by the ISS partnership that there should be provisions for export control. Frequently, program related information needs to be exchanged that is likely to involve trade secret and intellectual property. The imposition of ITAR restrictions on key parts of the ISSP created a very significant difficulty for all of the partners in getting ITAR-classified data from NASA contractors. The added costs and delays of such policies need to be averted to the maximum extent possible by avoiding inclusion of broad-brush classifications or by being more specific on those elements that really need to be export control protected.

Application to Exploration:

Ensure workable provisions for export control are established early on in the program.

CSA Lesson: Liaison offices

Based upon CSA experience with the ISS, it is recommended that partners agree to establish a liaison office with their key partners, especially those with whom there will be major interaction. There are significant benefits in terms of easy access to program personnel and data as well as the ability to expedite a variety of development and operational issues.

Application to Exploration:

Establish liaison offices with key partners to facilitate communications.

CSA Lesson: Standards and interfaces

The international agreements also need to provide to the maximum extent possible a common technical framework of language, units of measurement, architectures (power, data, video, ground systems) and interface standards (user/human factors (MSIS), GUI, and Robotics (RSIS).

Application to Exploration:

Recommend that all partners agree on a common technical framework at the beginning of the program.

CSA Lesson: Consensus decision making

The practice of governance by consensus within the ISS partnership provided assurance that partners have a voice in decisions, management and other issues. The partnership benefits from such building of consensus by identifying major partners' interests and jointly planning activities including constructive changes. Partners often modify options or seek alternatives until everyone comes to the conclusion that the best approach is reached given the situational constraints of the partnership.

Partner agreements should provide for a capability to still make decisions and allow the program to continue in the rare cases where consensus cannot be reached. This capability can be allocated to one organization or defined in some other manner that is agreed to at the start of the program.

Application to Exploration:

Governance by consensus is beneficial in major international projects. Agreements should encourage consensus decisions, but still allow for a means of resolution in extreme cases.

Category 6: Operations

CSA Lesson: Long Term Planning for Extended Operations

In order to carry out a long-term program, participants must commit not only to a significant development phase for their hardware contributions and the costs of launching and integration of this hardware, but also to an extended period of operation. CSA original forecasts were based on the presence of a crew of seven astronauts on the ISS. Since the ISS has run into difficulties during the construction period, the scientific and technological benefits that were initially anticipated have been postponed as the ISS will not be completed within the original timeframe. In any future large-scale cooperative program, the apportionment of operations costs will be a matter of major importance, particularly as such programs can be expected to have a very long operational phase. It is important for a partner to have a vested interest in the continuing operations, not just the development. Termination or exit criteria for the ISS or a partner are not simple due to obligations to remaining partners. Decisions about assets upon dissolution and the terms that apply may be problematic.

Application to Exploration:

All partners need to commit to the total life cycle of the program including any likely extended operations and / or disposal.

CSA Lesson: Payload Processing and Launch

Currently, it takes too long to manifest a payload and the process is onerous and long. As a result, partners risk the loss of science community involvement - (especially when lead times are longer than a post-grad program for example). Effective mechanisms to shorten manifest lead times need to be addressed along with transportation shortfalls especially for long-term sustainable human spaceflight.

Application to Exploration:

Manifest lead times need to be shortened and payload processes need to be simplified to ensure greater science community involvement.

Category 7: TRANSPORTATION, Logistics, Resupply, and Stowage

CSA Lesson: Transportation Commitments and Redundancy

Based upon ISSP experience, transportation resources affect all partners. With the long-term transportation challenges experienced by the ISS partnership, there exists a shortfall on up and down mass availability. All of the ISS international partners have been affected by the decision to retire the space shuttle. This has impacted the ability of the partnership to deploy not only science but also to have adequate up mass and down mass for logistics and spares. Constricted transportation has longer term implications that may limit the capabilities to extend the life of the ISS. Assurance of transport is fundamental to future activities on ISS as well as other international long-term initiatives. Transportation should be treated as a core system that is a fundamental commitment to the partnership rather than a unique national program.

Application to Exploration:

Future international space programs must be structured with alternative transport vehicles so that there is not a single transportation system point of failure.

Category 8: Utilization

CSA Lesson: Early Consultation with Scientists

Utilization of the ISS benefited from consulting with scientists early (three space station user workshops (1983-84), Task Force on Scientific Utilization of the Space Station, Mission Requirements Database) to ensure that what was to be built would be useful to scientists. To keep the dialogue going between the builders and the users, the partners established several venues including the NASA's Space Station Utilization Advisory Subcommittee and its international counterpart, the International Forum on the Scientific Uses of Space Station.

Application to Exploration:

Engage end users early on to ensure program design will meet the needs of all parties.

CSA Lesson: International Coordination Among Users

The International Space Life Sciences Working Group and the International Microgravity in Space Planning Group were formed early in the partnership to coordinate international utilization activities at the agency science level. These groups reduced unnecessary redundancy, introduced efficiencies in the planning and selection of payloads, and enabled international technical and scientific collaborations. Through these forums, the partners have significantly increased the scientific return from the ISS.

Application to Exploration:

Coordination among all partners can reduce unnecessary redundancy, introduce efficiencies in the planning and selection of payloads, and enable international technical and scientific collaborations.

CSA Lesson: Value of ISS as a Space Research Platform

The ISS has proven to be an extremely valuable platform for exploring long-duration human stays in space. This is clearly necessary to prepare for human exploration of space beyond LEO. The uniqueness of ISS as a permanently occupied outpost in free fall provides an ideal testbed for determining the effects of long-duration spaceflight on humans, testing countermeasures against the health impacts and studying how accidental passengers such as micro-organisms interact with humans. In addition, the ISS allows us to perform many complex hypothesis-driven studies requiring human intervention or monitoring. This unique aspect should not be lost as we explore further out in space.

Application to Exploration:

Exploration science and technology should continue to take advantage of the human presence, the life-friendly environment and the possibility of long-duration free-fall study with the possibility of direct intervention that is only available on ISS.

The Director of Human Spaceflight

Mr. W. Gerstenmaier
Chair, International Space Station
Multilateral Coordination Board
NASA HQ
Washington DC 20546-0001
USA

Noordwijk, 24 April 2009

Subject: ISS Lessons Learned – ESA Inputs

Dear Mr. Gerstenmaier Bill,

Let me first of all thank you for the great leadership and vision with which you and your people have conducted this very important exercise.

Please find attached the ESA inputs, elaborated by experts in the Directorate of Human Spaceflight, to the ISS Lessons Learned exercise focused on its relevance to future global exploration undertakings.

I am convinced that together we will able to reinforce the synergies between the International Space Station and future exploration endeavours.

Looking forward to working with you and your staff in these very interesting times.

Yours sincerely,

Simonetta Di Pippo

Encl.

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International Space Station
Lessons Learned
EUROPEAN SPACE AGENCY
April 10, 2009

1. Need for quick achievements for sustainable political and public support

- Taking your ISS experience, how can this best be done for exploration?

Since ambitious programmes such ISS and Exploration are developed over a significant time period, it should be foreseen the introduction of major milestones, with a segmented programme with clear objectives to be achieved in the short, medium and long term, to be presented to the public as tangible measurement of progress and achievements. If only the final goal is emphasised, because of the long duration of such programmes, the risk of having the public support drifting away is significant.

To bridge the gap between the scientific community and the civil society the publication of scientific / technology achievements must be presented as soon as they become available, Additionally an attempt should be made to match exploration strategies and roadmaps with scientific/technological interests of the general public and of decision-makers as well as to the interest of major stakeholders (including user communities and industries). This is very challenging especially over a long period of time that is why such an effort should be pursued by all partners, in a coordinated manner through a joint communication plan that would emphasise the international nature of the programme while leveraging on themes closer to national sensitivities.

2. Appropriate interdependency creates program stability

- What suggestions do we have in this area?

Interdependency may entail partners depending on each other contributions to achieve mission success but it should be avoided that a single partner contribution is on the critical path.

- Define appropriate from your ISS experience?

An appropriate definition should be a balanced (equal partners), long-term oriented (define the predicted needs, contributions and interactions of partners over a long time frame), flexible (allowing flexibility and contingency backup options in connection to dissimilar redundancy), reactive (each partner to communicate modifications early through existing forums, and to react quickly to such changes).

That is why a better mix in the contribution between system and utilisation infrastructure would be more suitable. On top of that, duplication of capabilities between at least two partners in key strategic areas in correspondence to their financial and technological capabilities would be a possibility.

Also, reactivity in communication and reaction to changes might be areas which could be improved, i.e. to involve earlier partners in the information loop, in order to avoid technical hitches due to unannounced ISS operations, for example.

At the end, an international framework of joint strategy and contributions is key to programme stability. Based on firm international agreements the risk for sudden programmatic changes is lower and the overall scenario augmented by the various international contributions and technology assets.

3. Need for mission requirements to be clearly defined early: what are the most critical mission requirements that need definition?

In a first place, a clear definition of different roles/responsibilities and scope of activities should be established at top level. The related mission scenario should be based on an integrated architecture including end-to-end system requirements and instructions for the safety of the crew. On the technical and engineering levels, the standardization of technical interfaces and interoperability aspects are also important. Finally, clear objectives and aim of each specific development should be defined with respect to the overall exploration goal.

4. Critical redundancy

- What functions, such as transportation, are critical and desirable to have dissimilar redundancy?

Following ISS experience the critical areas that shall have redundancy are crew transportation, life support (oxygen and power generation inside the space vehicle), cargo logistics, communication, launch facilities, control centres, data management, countermeasure and in-situ resource generation.

- What are your thoughts on robustness vs. dissimilar redundancy? At NASA, we are starting to discuss strategic implications of alternate crew transportation in the lunar case and thought ISS could provide some helpful insights?

In human exploration there is a need for both dissimilar redundancy and robustness for the majority of the critical functions because it affects crew safety. In order to identify the underlying strategic implications of such question it requires an analysis at systems level with identification of critical risks, definition of acceptable risk levels, mitigation concepts and means where the choice between robustness and dissimilar redundancy will be the outcome of the analysis.

In general terms, if redundancy is based on different areas, it could protect from common mode failure thus offering increased reliability and robustness to the overall project but the question is affordability. For example, for a complex programme as Moon exploration, dissimilar redundancy could be focused on transportation vehicles to the Moon with and without using the ISS; however who can provide dissimilar redundancy on the transportation system end-to-end!? Also, cost considerations to maintain the ISS operating during the Moon explorations must be taken into account.

5. Using the ISS as a test bed for exploration

- How do we use it multilaterally as a risk reduction platform?

Risks can come from accidents, systems failure, delays, etc. In our case, the acceptable risk is close to zero. ISS provide the best platform to conduct research activities and technological development in orbit in zero-g environment, to test systems and flight procedures. The ISS is critical for future space exploration initiatives, in combination with ground-based activities. There is a suite of dedicated experiments both in life and physical sciences which cover a broad portfolio of human risks and related exploration technology development needs. The ISS should be used to assess these various systems and operations for both new technologies designed for exploration (e.g. in area of closed ECLSS, inflatable structures) and crew operations.

A risk management plan should be carried out, proposing scenario-based risks identification and new alternatives such as extended crew stay time in space to use the ISS as a test-bed efficiently. In this perspective, there will be substantial programmatic benefits to extend the development and use of the ISS beyond the horizon currently scheduled for the exploration programme needs.

- Can we use ISS as a test bed to train the next generation of space engineers?

The utilisation of ISS to train space engineers can appear on a first examination very expensive for an activity that can be done on the ground. However if we take into consideration that the whole ISS infrastructure development and operations (incl. maintenance/evolution) is based on a stepwise approach with enormous interface challenges (technical and cultural) and that engineers are on a day-by-day basis aware of the multitude of human spaceflight requirements, this viewpoint can lead to the conclusion that ISS utilisation for training purposes is indispensable. Also the next generation of astronauts need to be trained on the ISS to develop the concept of long term autonomy of the crew.

In any case, experiences like Mars500 will teach us more on this issue and provide basic information to apply an appropriate method to train astronauts on the ISS.

Finally, the presence of 'astronauts trainees' in this configuration can bring more visibility to our exploration plans and can bring valuable benefits for the promotion of exploration activities.

- **How can ISS operations be expanded to better test and develop operational experience for use in Exploration?**

A significant amount of technology and operation means need to be developed using the ISS as a test bed with the ultimate goal to achieve higher autonomy. For example maintaining a complex system such as the ISS is achieved via the Orbital Replacement Unit (ORU) exchange and repair on ground. An exploration mission cannot be supported by such an approach and new design and operational means will require to be developed in support of an alternative maintenance concept more oriented into the repair during mission. In addition, smart in-situ measurement and on-orbit analysis equipments are mandatory elements to cope with the constraints of remote planetary sites. Equipments (e.g. for research) must be designed in a modular way to be long-term maintainable and even offering technical evolution options. Automation and human intervention must be balanced to cope with crew limitations. The ISS will give the opportunity to develop such capabilities that will allow to operate a large exploitation infrastructure with a much greater degree of autonomy compared to the ISS.

Another point is that the crew operations on ISS should be more independent, particularly crew communication with control centres, in order to simulate the conditions of exploration. A solution could be to organise regularly a week of exploration where the communication conditions would be the one of an expedition on Mars: delay in the voice loop, email instead of voice, IVA fully in charge of EVAs, etc...

Finally, ISS operations environment, upon achievement of 6 crew capability and resolution of cargo up and download traffic volume, should represent an excellent test and development environment for Exploration.

6. Commercial engagement to support exploration

- **What does commercial engagement add to the partnership?**

Commercial engagement can provide various beneficial effects: on the financial level, it can lead to low cost access to functions and technology required for the exploration; on the technological level, in principle, it would increase competition among industries, leading to innovative, more efficient and non-conventional approaches for certain well defined functions/systems in a global exploration scenario as well as introduce some sort of cost control. In a larger extent, commercial engagement could help in broadening the experience and knowledge base, allowing in the meanwhile further support to promotion of space activities by the general public.

- **What barriers exist to increased commercial involvement?**

In practice, such activity would imply to have profit driven partners in a very risky enterprise. In a context where in a first hand, the aim is to perform research for exploration, and on the other hand, business involved in the project would intend to make profit, may perhaps probably lead to a certain conflict of interest, endangering our activities.

Another issue would be the specific nature of the project in relation to the market projected. For the moment, no market neither business cases exist – the latest being generally generated when a minimum production threshold is reached. There is also no any available information regarding commercial applications. On the top of that, due to the novel nature of the project, risks are difficult to quantify.

On the financial level, while usually commercial partners are dependent from short- and medium-term revenues, the timeframe required for any return of investment is, in the early stage of Human Exploration and adding to the fact that there are only a very limited number of companies having the required expertise, unknown and if it is, it probably won't fit with the traditional time periods for high tech business (equally long time periods). Then the profits will possibly be limited within a very restricted, single customer and market.

On the political and legal level, the overall strategy and implementation roadmap as well as formal agreements and legal framework in the overall international endeavour are unclear and incomplete. It may be difficult for a commercial partner to find its role.

The definition of a clear market that would allow industries to invest and obtain a return on investment plus a legal framework that allows industry to own what they would achieve is the best means to assess and prepare the terrain.

- **What ground can ISS continue to plow to make it easier for commercial engagement?**

ISS can be used as a promotion platform for experiments with commercial applications. The scheme could entail: small steps in well defined functions with prospects for return on investment in traditional time periods for high tech business; to make the ISS more readily available to commercial users indicating that industry could access to ISS with an affordable bill; generalise the use of COTS items when applicable for commercial transportation, the latter being a key to future commercial engagement in Human Exploration. In future also Industrial R&D activities on ISS could play a certain role if the benefits of research activities in space can be visibly demonstrated.

- **What outpost support functions best lend themselves to commercial service providers, aside from logistics and communication?**

Primarily it is necessary to focus on functions that do not involve any critical application, such as safety. The outpost support functions that could be eligible and safe for application are the lunar outposts, HW-HW, services, operations, marketing (depending on outpost activities), mission integration and COTS infrastructure equipments (and tbd crew supplies) which are state-of-the-art and eventually allow for a cost-efficient and overall effective implementation approach. This could also include preferably repetitive tasks such as limited production as well as innovative technologies.

7. Management framework

- **Using the GES, how would you organize a human lunar exploration management framework?**

In the human lunar exploration management process, many key parameters must be identified and assessed:

- on the technical level, the most unpredictable, and taking into account the specificity of the project (long duration missions, with limited supply possibilities), a technology road map as well as high level requirements must be determined from the beginning. Subsequently, this will allow to identify the areas where cooperation is possible and when inter-dependency is desirable and apply for each stage, standardisation, dissimilar redundancy, interoperability, architecture and interfaces when required, enabling robustness and sustainability of the programme. On the top of that, efforts must be done in designing new collaboration methods and tools, and create a new official framework for knowledge transfer allowing easier and safer exchange and share of information.

- on the communication level, the scope of the programme must be defined at the onset. Improvements have to be done in particular on the reactivity, to provide timely information. Encourage public interest in space exploration through original educational activities (science experiments, astronauts' involvement in PR activities). Human lunar exploration is different from ISS project and a relatively new concept for the population under 40 years old (the first moon landing dates back forty years) and we must take into account that for Europeans, it is the first time that they will be involved in it; we must educate people about this new ambition.

Due to the increased complexity of the project and the arrival of new partners, the decision making process should be reviewed in order to reach a right balance of each partner's investments. It is necessary to take into account each partner's contributions in conjunction with its capabilities/skills/resources.

- **What guidelines can you suggest regarding planning of necessary multilateral process development and initiation?**

ISS approach of tasking a dedicated "Expert Group" to develop initial proposals which can be subsequently reviewed, amended and further developed in a full multilateral environment, representing all envisaged partners, appears the most effective and workable approach for this extremely challenging assignment.

8. Systems commonality and standard interfaces

- **How would you implement this in a multilateral framework?**

Set up an advisory team of engineers and experts whose members are coming from all partners to assess, recommend, coordinate and implement the areas that are eligible for cooperation (example: propose standardised and common interfaces in basic domains before phase A of the project and after the definition of the building blocks, such as system integration, power, transportation, management) and apply dissimilar redundancy for critical applications (eg: crew transportation vehicle).

Reinforce and implement in the GES (or any other international agreement document) the necessity to provide common technical framework of language (commonality in nomenclature, units of measurements, architecture studies, roadmaps) and interface standardisation.

Apply modular design to production process. This implies the division of product design into modules, that is standard pre-developed sub-assembly of parts regarded as individual units, implying that the final product assembly is created by standard units as well as specific custom components (either pre-developed or new ones).

9. Data sharing issues

The ITAR has slowed down crucial collaboration between U.S. and European contractors, resulting in many difficulties from ESA side on key moments of its participation to the ISS, especially for the preparation and the launch of the European ATV. The approach of ITAR does not allow any mutual exchange of information and safe cooperation on the technical level among partners.

With a common objective of sustainable exploration programme, it would be preferable to find clear and workable solutions for export control related issues which represent a serious impediment for an efficient cooperation.

10. Using Public Relations to relate exploration activities to the general public

- How do we use the ISS as a platform to educate about exploration?

Using the ISS, ESA has been able to gain public enthusiasm on human spaceflight activities. This has been done by various means. Astronauts activities on board the ISS and in PR activities appears to be the most efficient one. Other activities are however very important such as education, which is a fundamental part of the mandate of ESA and plays actually a significant role in contributing to a scientifically literate society. ESA's Human Spaceflight outreach and education programmes strive to involve directly teachers, pupils and students in HSF activities, such as contests that call students to fly their experiments on the ISS and use it as a means to capture their interest and attract them to study, in particular, scientific and technical disciplines; this effort also include the development of education material around ISS, including the work and lives of astronauts on board ("ISS Education Kit"), basis for classroom lessons. Medias and general PR activities play also a primary role in ESA's outreach and awareness efforts.

The introduction of campaigns on activities performed on the ISS linked to the exploration of the moon is an exercise that requires a joint effort by all partners and necessitates starting promotion and outreaching activities from the very early stages.

From the ISS, astronauts can play even greatly the role of ambassadors of humankind, showing how the work made on ISS prepares the future crew to exploration. The start of mature 6-crew operations increasing the level of exploitation of the ISS is also a "selling" point.

Education activities remain critical for rallying a broad basis of stakeholders to support human exploration and may include an increased and all the more original activities (e.g. evolved model of contests) involving European schools, universities.

Connect the ISS activities to ground-based experiments operated in parallel, such as the Concordia Station in Antarctic used as a test bed for the recycling of waste water or Mars500, for the preparation of long duration interplanetary missions.

Participation of the general public to ISS activities related to exploration may be envisioned, with large media coverage, e.g. participation to experiments for physical studies shown on the TV with live connection (through in-flight calls with the ISS) with astronauts that are on the ISS.

Develop communication messages that clearly state the variety of benefits stemming from activities performed on ISS for mankind on Earth.

11. Other Thoughts

a) Inject the ISS lesson learned in the Global Exploration Strategy (GES) group and reflections and continue the successful cooperation of the current ISS International Partners within GES/ ISECG with the aim to fulfil the GES objectives, building on the ISS accomplishments, together also with current and future GES members.

b) Foster the recognition of the ISS as the first exploration outpost and work together to develop exploration missions based on the ISS capabilities

International Space Station Lessons Learned by MEXT/JAXA
January 9, 2009

Preface

Based on the establishment of the Basic Space Law in 2008 in Japan, our plan for space development and utilization including the human space exploration is currently being studied by the leadership of the Strategic Headquarters for Space Policy.

Because the shape of our country's human space exploration will become clear as this study progresses in the future, here we would like to discuss this in general terms.

Lessons Learned

1) Need for quick achievements for sustainable political and public support

- Taking your ISS experience, how can this best be done for exploration?

Lessons Learned for Japan:

Because the ISS program was faced with substantial delays in the launch of the Japanese Experiment Module (KIBO), the start of the experiments in Kibo and the long-term stay of the Japanese ISS astronauts, it took more than 20 years from the start of investments in 1987 to present the outcomes of the ISS Program to the Japanese public.

Consequently, it is undeniable that the Japanese public's support and understanding of the ISS program have declined.

Application for the space exploration program:

For the future space exploration program, it is desirable to establish a program whereby the outcomes from contributions and investments by international partners can be obtained and become visible to the public as early as possible.

2) Appropriate interdependency creates program stability

- What suggestions do we have in this area?
- Define appropriate from your ISS experience?

Lessons Learned for Japan:

In the ISS Program, Japan managed to initiate its own human space program within affordable resources by relying on human space-faring countries for the critical systems such as crew transportation, module launches and on-orbit resource supplies while concentrating on developing the nation's experiment module.

However, we must also note that the negative effects of the high interdependencies such as the delays in the Kibo launches and the significant changes in the interfaces due to the ISS Redesign.

Also, although ISS is an efficiently integrated complex built from partner's multiple systems, there were problems with the inflexibility in the system construction due to its high interdependency. (i.e. Inflexibilities in the assembly sequence and in major configuration changes.)

Application for the space exploration program:

While interdependency should be minimized in consideration of the autonomy of each nation's program, it is important to have an appropriate level of interdependency with the balance between autonomy and effectiveness especially in the human space explorations requiring a huge amount of investment.

3) Need for mission requirements to be clearly defined early

- What are the most critical mission requirements that need definition?

Application for the space exploration program:

Reference mission requirements need to be defined in order to accelerate and materialize the on-going joint study of the architecture for the international human lunar exploration.

4) Critical redundancy

- What functions, such as transportation, are critical and desirable to have dissimilar redundancy?
- When in the program life cycle is critical redundancy most desirable?
- What are your thoughts on robustness vs. dissimilar redundancy?
  At NASA, we are starting to discuss strategic implications of alternate Crew transportation in the lunar case and thought ISS could provide some helpful insights.

Lessons Learned for Japan:

In the ISS Program, the stability of the program has significantly increased by attaining dissimilar redundancy of the crew and cargo transportation with the participation of Russia and the development of HTV/ATV.

In addition, the operation of the ISS has stabilized due to the appropriate redundancy in critical on-orbit functions, such as a power production, thermal control, environment control and life support.

These successful experiences are a great legacy that should be carried over to future programs.

Application for the space exploration program:

Because we must overcome a larger gravity potential in the space explorations than in the International Space Station, the necessity for dissimilar redundancies in transportation systems is thought to be much higher.

In addition, having rescue vehicles is also worth considering as one method for securing the redundancies.

Furthermore, in view of the space exploration taking place in unfamiliar environments, we need to consider dissimilar redundancies not only for the transportation capabilities, but also for critical functions such as power, thermal control, environment control, and life support systems.

To sustain the program in a stable state, those redundancies may be necessary to the critical functions at an early phase of the program.

5) Using the ISS as a test bed for exploration

- How do we use it multilaterally as a risk reduction platform?
- Can we use ISS as a test bed to train the next generation of space engineers?
- How can ISS operations be expanded to better test and develop operational experience for use in Exploration?

Application for the space exploration program:

The ISS would play an important role for technology development of the necessary functions for space exploration (i.e. environment control and life support system, crew health management, thermal control, docking/berthing mechanisms). Therefore, the ISS could be effectively utilized as a test bed.

In addition, with regard to the operation aspect of human space exploration, the ISS could be effectively utilized to sustain operation skills and conduct various training.

6) Commercial engagement to support exploration

- What does commercial engagement add to the partnership?
- What barriers exist to increased commercial involvement?
- What ground can ISS continue to plow to make it easier for commercial engagement?
- What outpost support functions best lend themselves to commercial service providers, aside from logistics and communication?

Lessons Learned for Japan:

In the ISS Program, as NASA plans to utilize Commercial Orbital Transportation Services (COTS) for its transportation, the commercial engagement is starting to contribute toward decreasing the program costs and stimulating the space industry. Also, Japan is starting the commercial utilization scheme by using Kibo.

Application for the space exploration program:

It seems important to consider the possibility of commercial engagement from an early phase of the space exploration study. As in the ISS Program, cargo transportation and commercial use of lunar outposts could be considered.

However, we should note that these activities need to be conducted amid international harmony and within the responsibility and rights of each participating agency, and for those activities. Moreover, attention must be paid about clarifying the responsibility of each participating agency for safety.

7) Management framework

- Using the GES, how would you organize a human lunar exploration management framework?
- What guidelines can you suggest regarding planning of necessary multilateral process development and initiation?

Lessons Learned for Japan:

In the ISS Program, program integration was effectively conducted through the United States' leadership.

Also, from the standpoint of the framework, there is an international commitment at the treaty level called IGA, which has greatly contributed towards maintaining support for the ISS program from each participating government and to the program's stability, despite its long duration.

Application for the space exploration program:

While an open and equal framework such as ISECG (International. Space Exploration Coordination Group) is necessary too, agencies with a leadership role may also be needed to promote investigation of the program efficiently.

In addition, the framework for the space exploration ought to be determined in accordance with the architecture structure of the program.

If the architecture is to be one complex system such as the ISS, the interdependency of the program will increase. In this case, as we learned from the experience of the ISS, a treaty-level international commitment would be effective since a withdrawal or delay of the program due to a cooperating agency's circumstances could prove critical.

Even if the architecture is to be a program of programs, it would be effective to construct a framework of international cooperation enabling each participating country to achieve common goals.

8) Systems commonality and standard interfaces

- How would you implement this in a multilateral framework?
- What interfaces should be standardized?

Lessons Learned for Japan:

In the ISS program, commonality of various interfaces such as the berthing mechanism, robotics, power, communication and human interfaces made it possible to simplify the interface definition significantly.

Nonetheless, it also should be noted that there were a few obstacles in the technical information transfer regarding the common interfaces.

Application for the space exploration program:

From the same point of view, commonality of interfaces should be achieved as much as possible in the space exploration program. Especially for the transportation systems in which a dissimilar redundancy is essential, various interface commonalities may be necessary including the interface to launch vehicles (i.e. docking systems). Also, as addressed in the next section, we need to improve the procedure for the technical information transfer of common interfaces.

9) Data sharing issues

Lessons Learned for Japan:

In the ISS program, a number of hardware was procured from foreign countries, but time and cost were often spent because of the lack of enough technical information due to the export controls of those countries, which led to the delays in the schedule and increases in the development cost.

Application for the space exploration program:

It is anticipated that common hardware will be procured from overseas in the space exploration program also. By establishing an agreement in a comprehensive framework on these technical information transfers, we should be able to simplify procedures for this activity which would result in a reduction of the total program cost and an acceleration of the program's implementation.

10) Using Public Relations to relate exploration activities to the general public
- How do we use the ISS as a platform to educate about exploration?

Lessons Learned for Japan:

In the ISS Program, public relations are playing an important role to gain the understanding and support of the general pubic. Especially, it is thought having the astronauts talk to Japanese citizens from the ISS via the media will have great impact and inspiration on the people.

Application for the space exploration program:

In the space exploration program, public relations will also play an important role in gaining the understanding and support of the general public who are also taxpayers.

Especially, for participating countries that have not produced as many as astronauts as the US and Russia, having astronauts interact with the general public is a most effective means of public relations, and a scheme to enable this activity at early stage of the program would be highly desirable.

Additionally, there seems to be a need to examine how to inform the outcomes of the space exploration program to the general public in each participating country efficiently and widely. (i.e. development of integrated database on program outcomes, establishment of an integrated information center, etc.)

ISS Lessons Learned
Federal Space Agency
January 2009

1) Need for quick achievements for sustainable political and public support
  ** Taking your ISS experience, how can this best be done for exploration?*
  ** Define appropriate from your ISS experience?*

Social and political support will be always stable, provided that mission goals are formulated properly (i.e. they are ambitious, attractive and really achievable), mission stages are being timely accomplished and results/accomplishments are reported promptly and comprehensively. Along with this going on, continuous progress must be observed in the mission realization. Not all the time such progress was evident in the ISS mission that, indeed, affected negatively its political and social support.

2) Appropriate interdependency creates program stability
  ** What suggestions do we have in this area?*
  ** Define appropriate from your ISS experience?*

Generally – yes it does. Interdependency with respect to the united Mission Control Center, crew etc showed itself worthy. It has brought along new merits to the program. However, very important is that interdependency should be appropriately established and balanced with respect to the partner contributions. Overaccentuating of the dependence on a partner would doubtfully promote better stability of the program.

3) Need for mission requirements to be clearly defined early
  ** What are the most critical mission requirements that need definition?*

Purpose of the mission should be defined. Important is to do this as thoroughly and clearly as possible. In particular role of the mission in the space exploration process is to be determined as well as those global problems, which the mission will help to resolve. Basic requirement is that whole achievements, both material benefits and immaterial wealth, must be adequate to the total spending. Here very important is not to substantially overestimate the mission objectives and scientific program outputs. Maximal integration of the partner research programs can help in meeting of this requirement.

4) Critical redundancy
  ** What functions, such as transportation, are critical and desirable to have dissimilar redundancy?*
  ** When in the program life cycle is critical redundancy most desirable?*
  ** What are your thoughts on robustness vs. dissimilar redundancy? At NASA, we are starting to discuss strategic implications of alternate crew*

transportation in the lunar case and thought ISS could provide some helpful insights.

Apparently, the ISS lessons show that any critical element of the project should have a dissimilar backup. As a rule such elements are boosters, crew and transportation vehicles, MCC. On the integration stage of the project infrastructure (ISS integration for instance) redundancy of these elements is especially critical. On the implementation stage dissimilar redundancy of particular functions must be ensured (by means of different modules and elements), such as habitation, power provision, partly – payload complex. Reliability requirements are undisputable with respect to all project elements. As soon as the redundancy improves the program flexibility and stability in a whole (in case of contingency, accident, delay in creation of particular elements), it thought to be expedient being strategic reserve of the program management. Future long living space systems should be designed as "open systems" based on modular infrastructure with capability of the modules replacement, uniform interfaces etc.

5) Using the ISS as a test bed for exploration

** How do we use it multilaterally as a risk reduction platform?*

Just in the same way as on the land. We're simply working there! Any experience astronaut gains in space inculcates in his professional skills, makes higher his self-reliance and lower risks of uncontrolled dangerous situation development. Generally speaking, if the ISS is considered as a part of our versatile human existence, as a natural transfer of the earthly life to the space platform, many questions will become easier.

** Can we use ISS as a test bed to train the next generation of space engineers?*

Yes, we can. The ISS could serve as a unique testing platform for elaboration of advanced technologies. As the matter of fact this process has already started. It will be certainly strengthened as our experience grows and capability of autonomous existence in space increases. As the resources quote for the ISS maintains gets lower and living quality for crewmembers improves both professional astronauts and armatures will have more and more opportunities to utilize their engineer and scientific skills in the condition of the space flight. NASA, Roscosmos, ESA and other partners plan to utilize the ISS for elaboration of Lunar and Martian exploration technologies as well as for testing of particular elements of perspective systems and new generation of infrastructure. This suggests one more argument in favor of extending the ISS mission to 2020 and farther.

** How can ISS operations be expanded to better test and develop operational experience for use in Exploration?*

Enlarge the list of particular tasks, which are to be carried out on the ISS, extend limits of the allocated resources, onboard system capabilities and upmass volumes for payloads. Diversify crew life, making it looking like the earthly one. Increase comfort of the crew transportation and habitation on the ISS. Aspiration for and capabilities of "exploration of unexplored" will be realized better, yielding their fruits.

6) Commercial engagement to support exploration
* *What does commercial engagement add to the partnership?*

It brings almost nothing on the early stage. Just a small addition to financial support. Natural conflict of interests between exploration and commercialization (to learn, to comprehend, to research for exploration and to make a profit for business) is the real barrier preventing involvement of business into the process of space exploration. Furthermore, investment in space exploration assumes very big and very long-term revenue money. Judicious businessman would apparently consider such investment as very risky and completely unjustified one. Businessmen, which were ready to support first missions of our cosmonauts or Apollo missions to the Moon, would be unlikely found back in the time of sixties-seventies of the last century. On the later stage when technology spin-off became more and more visible, business got interested too. Else later it started investing in large commercial projects (communication, navigation, Earth remote sensing), appreciably supporting and helping to development of space infrastructure and space exploration activity (indirectly indeed).

* *What barriers exist to increased commercial involvement?*
* *What ground can ISS continue to plow to make it easier for commercial engagement?*

If ideally we consider the ISS as continuation of our earthly life, there is no need of inventing particular arrangement for the ISS commercialization. Business will break through to such kind of projects as soon as necessary conditions appear. We just need to offer and ensure the opportunity for business involvement at the early stage of the mission already. There must be no artificial barriers. In this prospective space tourism, ad projects, other commercial initiatives (even marginally extravagant!) should be supported to some extent. This attitude will demonstrate that "doors toward the space exploration" are always open for business and it's going to find the right time and way by itself.

7) Management framework
* *Using the GES, how would you organize a human lunar exploration management framework?*
* *What guidelines can you suggest regarding planning of necessary multilateral process development and initiation?*

The ISS management framework has already demonstrated its success. So, utilization in other international projects of the existing system based on working groups looks reasonable. Indeed, some revision/tuning is necessary. In particular, the activity of the working groups must be deeper integrated in the system of partner mutual relations and into the system of other cooperative participants, which stay behind the ISS official partners. Status and obligatory character of actions set by the working groups must be strictly determined. Number of the groups should be limited (within the ISS project there are more than 60 groups, that is apparently too many). Process of establishment and dismissing of the working groups should be better regulated.

8) Systems commonality and standard interfaces

** How would you implement this in a multilateral framework?*

** What interfaces should be standardized?*

There is no need to strive for full commonality. In any case, historical and cultural specificity of each partner nation will stay individual. Of course, in this situation appropriate interfaces in basic spheres of interaction (system integration, power, transportation, management etc) should be standardized and unified. Purposefully would be implementing of the interfaces developed within the ISS project.

9) Using Public Relations to relate exploration activities to the general public

** How do we use the ISS as a platform to educate about exploration?*

The ISS lessons show that PR activity is very important in the large and money consuming projects, such as the ISS one. Wise and well thought-out PR activity is the only way to justify non profitable character of the project, suggesting immaterial objective's substitutes. Many people are ready to accept and support the idea of Exploration if it is nicely and attractively offered. Joint efforts of all partners should be exhaustively implied here.