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Far from Home – Human Presence on the ISS as a Preparation for a Lunar Base and Beyond

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Human space exploration missions by their very nature impose a certain set of requirements to achieve mission success. Regardless of location or duration, the physical and psychological well-being of the crews must be maintained to ensure continued optimal and uninterrupted work performance, and the physical environment must be maintained in good working order. Typically, these missions involve a small number of crew members in an isolated environment, with resupply quantities and frequencies governed by distances and available vehicles, so crews must learn a certain degree of self-reliance, posess independence and ingenuity, and occasionally develop new skills *in situ*.

Since late 2000, International Space Station has been this planet's human space exploration mission, with successive crews building and maintaining the outpost in low Earth orbit, conducting research, and successfully responding to new situations as they develop. It is the very human presence that ensures the ongoing success of the program. For example, when supply lines were reduced, such as occurred after the temporary grounding of the Shuttle fleet, crews responded accordingly with the resilience to handle on-orbit situations not previously foreseen. The ISS Program's continuing response and commitment to maintaining a human presence, even in the face of difficult circumstances, is excellent preparation for future exploration missions. This paper describes how the experiences gained on maintaining and continuing a human presence on ISS will serve as a model for preparing for a lunar base and beyond.

I. Introduction

The International Space Station (ISS) was developed with the operations scenario of using a Space Shuttle to provide logistics and maintenance support. Lessons learned in the wake of the *Columbia* accident about doing research and maintaining a vehicle are being considered in the formation of requirements for Exploration Systems. As NASA continues to refocus its research programs, the value of the ISS is broadening from a world class research laboratory to a pivotal resource necessary for realizing the Exploration Vision.

II. Lessons Learned through Maintaining the ISS without the Space Shuttle

The logistic and maintenance requirements for the ISS were developed with the assumption of a steady supply pipeline. This pipeline was to be supported by transport vehicles such as the Russian Progress and the European Automated Transfer Vehicle (ATV). But, the real workhorse was always envisioned to be

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NASA's Space Shuttle. With the grounding of the Space Shuttle, expectations for resupply had to be readjusted. This readjustment would be felt by those responsible for maintaining the critical ISS systems and those responsible for planning the ISS science utilization program.

The operations scenario in place before the *Columbia* accident for maintaining ISS systems was that of a depot. Spares of large ISS systems would be ready on the ground awaiting a planned switch-out, or contingency replacement. It was not envisioned that astronauts would be responsible for much on-orbit repair work. Without the Space Shuttle flying, this operations plan was no longer viable. For those critical systems that have failed and for which there are no on-orbit spares, the ISS Program and astronauts have started relying on *in-situ* repair.

One example of unplanned on-orbit repair of research hardware involved a middeck-locker size refrigerator-freezer called ARCTIC. Two units were launched in mid-2002, and operated continuously for a total of 6500 hours, supporting six investigations, before experiencing similar failures. One unit was returned to Earth for detailed failure analysis, while the other remained on orbit. While these units were not designed for on-orbit repair, it was decided that due to the delay in the launch of a much larger freezer following the *Columbia* accident, an unprecedented effort would be made to salvage the one remaining unit. Using only tools and materials available on-orbit, and the crewmember's considerable electronics skills (he had not received any training prior to flight on how to repair the ARCTIC), an elaborate yet flexible procedure was developed that allowed the crewmember to use his own judgment, resulting in a successful repair. The six-stage process involved removal of 150 small parts; disassembly of system components; removal of corrosion that had precipitated the failure in the first place; repair of the heat pump that involved soldering; testing and rewiring of freezer components; reassembly of the heat pump; and finally testing of the repaired freezer. While the corrosion had damaged the unit to the point that it ultimately failed again, the repair demonstrated the ability of the crewmember, with guidance from the ground, to repair hardware that was not designed for in-flight repair.[1]

Another example of an unplanned repair has also demonstrated the uniqueness of the ISS as a testbed. During Increment 9, one of NASA's Extravehicular Activity (EVA) suit's cooling system failed. Russian Progress vehicles are not capable of launching full, refurbished EVA suits, so spare parts had to be launched instead. The Increment 9 crewmember uninstalled the water pump from the spacesuit's backpack, replaced the pump filter, cleaned the seal cup, replaced the pump rotor, and reinstalled the pump. Afterwards, a wet/dry test of the pump was performed.[2] As this level of repair was never foreseen before, a method for certifying the suit for safe use had to be devised. We know that on exploration missions we will experience hardware failures. This experience will push us to put foresight into planning for these failures and developing procedures for re-certification of critical hardware without the expansive testing laboratories that are available to us on Earth.

III. Lessons Learned through Maintaining a Viable Science Program without the Space Shuttle

As with the adaptation made by those planning logistics and maintenance, unique strategies are being implemented to continue a meaningful science program while upmass and downmass are severely limited. This interim research strategy has focused on five primary methods for continued ISS utilization.[4]

The first of these strategies is to complete investigations that have already been pre-positioned on the ISS. Some Research Integration Offices were fortunate to have manifested enough equipment to continue with their investigations before the *Columbia* accident. An example of this is the Pore Formation and Mobility Investigation (PFMI). This investigation had its hardware and samples onboard the ISS to be one of the first investigations to utilize the Microgravity Sciences Glovebox (MSG). Because of this prepositioning, this investigation's on-orbit operations have been completed by the Increment 5, 7 and 8 crewmembers. The Principal Investigator has been able to publish some preliminary results using video downlink, but more analysis will be completed when the samples and video tapes are able to be returned by the Space Shuttle.[3]

A second strategy has been to re-use or re-test samples beyond what the original science protocols had required. The InSPACE investigation, which examined the properties of fluids with and without a magnetic field, utilized samples that could be re-run to add to the science that had already been completed.[3] This underlined the importance of understanding an investigation's minimum requirements while guarding for the opportunity to provide additional science to the investigator if the opportunity presents itself.

The third of these strategies is to develop safe, small (< 2.5 kg), low volume (< 2 L) investigations that could utilize the limited upmass provided by the Russian Progress vehicles. A call for this type of investigations went out when it became apparent the shuttle would be grounded for a number of years. In most cases, these investigations were defined, developed and implemented on ISS all within about a 1.5 year timeframe—an extremely short turnaround by NASA standards. A successful example of this type of investigation is the Capillary Flow Experiment (CFE). This investigation consists of three related investigations that are designed to answer questions about capillary flows in microgravity. The first of these investigations has already been performed and the results the Principal Investigator has received could not have been predicted using current, analytical fluid models. These results will provide future spacecraft designers more reliable computer models that will ultimately decrease fluid systems' mass and reduce overall system complexity.[5] These short turnaround investigations will help NASA realize a new paradigm in proposing and executing results driven, directed research on the schedule necessary to support design of exploration vehicles.

At the same time the call went out for low upmass, simple investigations, NASA further challenged the research community by requesting experiments that could be performed with no upmass. This fourth strategy called for investigators to devise experiments utilizing materials already on the ISS. An example of this ingenuity was demonstrated by the Miscible Fluids in Microgravity (MFMG) investigation. Using extra urine collection syringes (from another investigation), some Russian honey (discovered by watching videos of a past crewmember's Saturday Science sessions), Duxseal (used for plugging small holes) and dye that was sent up to be used on a birthday cake, this investigation was performed on-orbit exactly one year after receiving approval to proceed from NASA Headquarters. Preliminary results were recently presented at the 43rd AIAA Aerospace Sciences Meeting.[6] By providing the research community a better understanding of what materials will be readily available on exploration missions, creative, relevant, *in-situ* research will be able to be accomplished using minimal additional resources.

A fifth strategy that has been relied upon in the past has shown itself to be critical while the shuttle is grounded. This strategy is that of international cooperation. From the use of the Soyuz and Progress for transferring supplies and crew, to the utilization of the European Space Agency's Microgravity Sciences Glovebox for the PFMI investigation, NASA's continued science program has had to rely on help from its International Partners. Alternatively, NASA has been able to return this favor in a number of instances. One such instance involved the European "Performance of heatpipes in microgravity (HEAT)" investigation that ran into problems during its planned run on the Dutch Taxi Mission. NASA was able to help ESA realize all of HEAT's experimental objectives later in Increment 9 through NASA's Saturday Science program. The robustness provided by utilizing and relying on International Partners has demonstrated itself as a critical component to continuing a science program on the ISS.[2]

A more informal, yet truly multilateral, collaboration involved the Granada Crystallisation Facility (GCF) payload. The GCF hardware is built in Spain for ESA and has been used on several ESA missions to ISS to conduct crystallization experiments for multiple international investigators. As part of a long-term arrangement between the Japanese Aerospace Exploration Agency (JAXA) and Russia, several long-duration flights of the GCF were planned beginning in 2003. As originally envisioned, each flight campaign would consist of launch of the GCF on a Progress vehicle, transfer to a quiescent location in the Russian segment for a period of several weeks, and then return to Earth with the next Soyuz vehicle. For the second and third GCF flights, NASA offered up the use of the Commercial Generic Bioprocessing Apparatus (CGBA), a middeck-locker size EXPRESS (Expedite the Processing of Experiments to the Space Station) Rack based facility, to provide thermal conditioning for the growing crystals. Perhaps a small step, but the GCF experiment combined the resources of four International Partners with a minimum of planning to optimize the science for multiple international investigators.[7]

IV. Translating ISS Lessons Learned into Exploration Mission Requirements

The agency is developing 13 Strategic Roadmaps and 16 Capability Roadmaps during 2005 that will shape the plans for how the ESMD will meet its exploration goals.[8] One of the Strategic Roadmaps is entitled, "Complete assembly of the International Space Station and focus utilization." This Roadmap will see NASA through assembly complete of the ISS with the delivery of all International Partner modules and a permanent crew of up to 6 persons. It goes on further to lay a plan that will focus ISS research on those knowledge gaps critical for NASA to establish a lunar base or go on to Mars.

Aiding the Strategic Roadmaps are a number of Capability Roadmaps. Two of these will specifically address refocusing utilization. The first of these, "Human health and support systems" will look at the human as a critical system and identify what knowledge is necessary to ameliorate the risk of sending humans past low earth orbit. Another tool that will help guide the agency with future human research is the Bioastronautics Roadmap. This Roadmap identifies the critical gaps in our knowledge about how the human body adapts to other-than earth gravity environments. It further prioritizes and categorizes the research into discipline (radiation, bone/muscle, cardiovascular, etc.) and attempts to determine the best platform for performing the research (ground analog, ISS, animal model, etc.)

Another of these Capability Roadmaps is "Human exploration systems and mobility". This roadmap will help focus the agency on developing technologies that will reduce cost or risk at the same time improve mission robustness and efficiencies. Possible areas of focus include: advanced in-flight training, lower residual food mass, better countermeasure equipment, autonomous medical care, advanced life support systems and in-situ analysis of samples.

In addition to the roadmaps, the ESMD Requirements Division is doing an assessment of all ISS research programs. Using Quality Function Deployment (QFD) techniques, ESMD is mapping proposed ISS research projects to the requirements developed for the Crew Exploration Vehicle and the Exploration Spirals. These Spirals define capability to be developed for the Exploration of the Moon and eventually Mars. The results of this assessment will assist in the prioritization of ISS research, aiding in the development of manifests for the Shuttle and other logistics vehicles.

Upon completion of these roadmaps and the ISS research assessment, the ESMD will have tools that define future ISS research. Besides utilizing the ISS for research, invaluable lessons are being learned about hardware development and operations—what type of pumps work, what kinds of inflight maintenance is possible, etc…. This research, hardware development, and operations experience will directly map to the requirements the ESMD will be developing for the interim milestones necessary for the Moon and Mars missions.

V. Using ISS as an Exploration Analog

An exciting prospect is the potential of the International Space Station as an analog for a long duration flight to Mars. With a high-thrust transfer vehicle, potentially powered by a Nuclear Thermal propulsion system, an opposition class mission to Mars could be designed with a 7 month outbound leg, a one month stay on the Martian surface, and then a seven month return flight to Earth. Such a mission could be simulated on ISS. Technologies and mission conditions for such a trip could be provided to: evaluate advanced in-flight training; lower residual mass foods (such as bulk foods and fresh food growth); investigate more intense exercise on better countermeasure equipment; incorporate communication delays to simulate the long distance nature of Earth/Mars communications; utilize virtual reality activities to simulate Mars landing; evaluate autonomous medical care and advanced life support systems; and minimize mission consumables.

We can define a six month ISS mission in Mars exploration terms, allowing substitutions for capabilities not ready or not applicable to an orbiting spacecraft in low-Earth orbit. Potentially, a six-month ISS mission could be divided into 3 phases. The first three-month phase could simulate a return trip to Mars, and could concentrate on Exploration-focused research addressing technology gaps. The last three-month period on ISS could simulate the final part of an outbound trip to Mars. The third phase could occur after return from the station, with the post landing period becoming a simulation of Mars landing and exploration.

A Mars landing simulation would require the development and validation of an analog Mars landing environment. Prior to use by returning ISS crews, the analog could be developed to validate and test exploration concept of operations, develop and test candidate habitat technologies, develop and test candidate space suit designs in an applicable environment, test logistics and supportability models, and evaluate forward and backward contamination issues. Upon completion of a rigorous development effort, the Mars analog could be used to ascertain capabilities of returning ISS crews after landing in an Exploration relevant environment.

A post-ISS landing Mars simulation could incorporate a variety of tasks. These tasks could include simulated Mars lander control to a landing, lander safing, extravehicular activity (EVA) suit checkout and donning, and simulation of a typical EVA (Mars walk). After the Mars walk, which would include collection of geologic samples, the crew could perform suit refurbishment, initial assay of collected samples, logistics and habitation tasks, and robotic probe direction. The capstone of the analog would be a simulated launch/docking with a Mars-to-Earth transfer vehicle. It is expected that the duration of such a post-landing analog would incrementally increase as ISS physiological countermeasures and planning improve. Medical monitoring would be a high priority during the activities at the analog, and would help develop operational concepts for actual mission medical monitoring. Also, it is expected that crewmember physical rehabilitation would be embedded into the post landing schedule, potentially as an evaluation of proposed Mars habitat exercise hardware.

VI. Conclusion

We've learned much in the past two years operating the ISS in unforeseen circumstances that have informed our planning for NASA's Exploration missions. The ISS can provide an excellent facility to permit the evaluation of technologies and techniques necessary for human space exploration far from home!

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