Lessons Learned from Mir – A Payload Perspective

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Abstract

Among the principal objectives of the Phase 1 NASA/Mir program were for the United States to gain experience working with an international partner, to gain working experience in long-duration space flight, and to gain working experience in planning for and executing research on a long-duration space platform. The Phase 1 program was to provide to the US early experience prior to the construction and operation of the International Space Station (Phase 2 and 3). While it can be argued that Mir and ISS are different platforms and that programmatically Phase 1 and ISS are organized differently, it is also clear that many aspects of operating a long-duration research program are platform independent. This can be demonstrated by a review of lessons learned from Skylab, a US space station program of the mid-1970's, many of which were again "learned" on Mir and are being "learned" on ISS. Among these are optimum crew training strategies, on-orbit crew operations, ground support, medical operations and crew psychological support, and safety certification processes.

Introduction

The Soviet Union launched the first space station, called Salyut, in 1971. Through the 1970's and 1980's, the Soviets launched a series of stations of increasing complexity and sophistication, culminating with the Mir complex, which had an outstanding career as a long-duration human outpost from 1986 to 2001. The Russian philosophy in this time period was to make incremental improvements to the newer stations based on experience from earlier platforms. During this time, the United States flew its highly successful Skylab space station in 1973-4, and began planning for its next space station in 1984. That project, after several significant modifications during its planning and development, eventually emerged as International Space Station in 1993, and brought Russia into an already existing multilateral partnership including Canada, Japan and the European Space Agency. The ISS program today is the inheritor of the accumulated experience, principally Russian and American, of the past three decades. As a research platform, that experience will provide the necessary skills to maximize the quality and quantity of science conducted there.

Background

Evolving out of the original 1992 US-Russian agreement to fly each other's crewmembers on Shuttle and Mir, the NASA/Mir Program became a more comprehensive international endeavor. The program was formalized in October 1994, and became known as the Phase 1 Program to note that it was part of the overall International Space Station Program, which became Phase 2 and 3. The Phase 1 Program Plan identified the mission and goals of the program:

"Phase 1 represents the building block to create the experience and technical expertise for an International Space Station. The program will bring together the United States and Russia in a major cooperative and contractual program that takes advantage of both countries' capabilities."

The four main objectives of NASA for the Phase 1 Program were:

To learn how to work with International Partners;

To reduce the risks associated with development and assembling a space station;

To gain operational experience for NASA in the planning and execution of long-duration missions;

To conduct life science, microgravity, and environmental space research.

To accomplish these objectives, a Joint US/Russian Working Group structure was established between NASA and the Russian human space flight organizations. The nine working groups were responsible for the planning and execution activities involved in their respective areas, and reported to a Program level Team 0. Each Working Group was jointly chaired and was empowered to make and sign agreements within their area of responsibility. At the science level, two Working Groups were established: the Mission Science Working Group (MSWG) was responsible for defining the research requirements for all disciplines and provided science guidance and prioritization during preflight planning and on-orbit operations as required; the Mir Operations and Integration Working Group (MOIWG) was the implementing organization, and included subgroups for training and operations, hardware integration and Shuttle manifesting of science payloads. As outgrowths of earlier Spacelab organizations, the MSWG and MOIWG essentially provided the traditional Mission Science and Mission Management functions.

Research Program Planning

Initial research planning for the NASA/Mir program was on a very tight schedule. At the time of signing of the first intergovernmental agreement in June 1992, the first long-duration astronaut flight on Mir was scheduled for September 1994. This 15-month template was far shorter than what NASA was accustomed to for planning a typical Spacelab research mission, which from Announcement of Opportunity (AO) to flight was typically 2-3 years. In the event, the mission launched in March 1995, but the shortened template did not allow for the normal processes to operate, and the vast majority of science for that flight was solicited from NASA in-house investigators, many of whom were principally involved in Shuttle-based research.

At the inception of the more comprehensive program to be called Phase 1, the initial missions were also constrained in terms of schedule, with the NASA 2 mission launching only 18 months after the release of the first dedicated AO, which was limited to life sciences. As a result, experiment selection did not occur until other significant milestones, such as crew training, hardware development and timeline development, would have been passed. In addition, experiment selection was done with an incomplete understanding of the available resources, such as on-orbit crew time.

One of the results of these factors was a significant amount of replanning and "negative" work. For example, the first science requirements document, called Integrated Payloads Requirements Document (IPRD), for NASA 2 was compiled prior to full definition of the selected experiments, but was required by the Russian side so they could begin their timeline development. Clearly, this document contained a significant amount of educated guess work, and within a few months a nearly completely revised document was created.

As the program matured, these schedule conflicts were resolved, and every attempt was made to baseline the initial research requirements in the IPRD by about 17 months prior to the start of the increment (I-17 months). Even so, as new experiments were added to the program, there was still a certain amount of revision, but the amount of accuracy was greatly increased. Programmatic events, such as the Progress collision, added a new variation as research programs were replanned due to loss of research hardware in the Spektr, as well as to a realignment of programmatic priorities such as increased US astronaut participation in Mir station operations.

So to summarize this narrative, an important lesson learned was that selection of science experiments, and the development of a mission complement, must match other development milestones (i.e., precede them), and must take into account the available resources predicted for the increment in question. Failure to do so results in costly and time-consuming replan efforts, and overall reduced training efficiency. On the other hand, definition of a mission complement should not occur too early, since dynamics inherent in a long-duration space platform would limit the ability to reliably predict the resources that would be available. Although the number of increments flown during Phase 1 was probably too limited to provide a robust statistical analysis, the I-17-month time frame seemed to appropriately balance all competing factors to begin development of a mission research complement.

Tracking of Requirements

Early in the planning of the Phase 1 research program, it was realized that a robust yet flexible system was required to track the large quantity of requirements data. Based on Spacelab Life Sciences experience, a document called the Integrated Payload Requirements Document (IPRD) was developed. The heart of the document was science session based descriptions of all preflight, in-flight and postflight requirements, providing information on the science objectives, session flow, crew time, power and hardware requirements. Further, a relational database system called Payload Integration Planning System (PIPS) was developed using COTS software application to store, track and manipulate the information. The database was designed to be bilingual, since the IPRD would become the governing document, agreed by both sides, for the research activities to be conducted on Mir. Reports from PIPS provided not only the IPRD itself, but could also generate rudimentary timelines and Shuttle manifests. The IPRD was placed under configuration control, and all changes were reviewed by representatives from the Mission Science, Training and Operations, Integration and Shuttle manifesting organizations prior to approval at the Phase 1 Research Configuration Control Board.

This process allowed for rapid responses to changes from the scientific community with regards to science requirements, as well as to programmatic changes. Among the latter were such events as increased duration of mission length, late crew changes, and impacts from the Progress collision.

Mission Planning

The NASA experience during years of Space Shuttle missions was to develop very detailed mission timelines, which is appropriate to take maximum advantage of the relatively limited on-orbit time. For long-duration missions, however, such detailed crew timelines are neither appropriate nor desirable, partly because it is simply impossible to predict with any certainty all possible contingencies during a multi-month-long mission. In fact, one of the top ten lessons learned from Skylab was in response to the fact that most detailed timelines became obsolete within days of the start of the mission, and recommended a more general timeline to scope requirements against available resources, followed by shorter cycle real time planning during the mission to respond to on-orbit needs. This process has been in use by the Russians since their early space station days, and was learned by NASA during Phase 1.

To maximize effective use of on-board resources, research tasks should be categorized according to time criticality. Those tasks that have a unique or relational time criticality should be timelined first; activities without such constraints can be then scheduled, or even in some cases added to a crew task list, providing crewmembers with flexibility and a sense of control over their schedule.

It should be noted that priority was almost always given to station operations and maintenance, particularly in critical moments, and this has also been true for ISS to date, with regard to assembly and maintenance tasks. Research activities then are somewhat at the mercy of these higher priority activities, and must, to the extent possible, retain as much flexibility with regard to timing as inherently possible.

Research Resupply and Logistics

A detailed resupply and logistics support plan was established for all NASA payloads, which proved to be very effective. However, there were instances when the plan had to be modified, primarily to respond to significant programmatic changes and to on-orbit situations. As for the former category, one example was the occasional change in launch order between Shuttle and Soyuz. The Shuttle was used almost exclusively for transport of NASA science hardware, and American astronauts used the Shuttle for transport, while Russian cosmonauts used Soyuz vehicles, but in most instances, all crewmembers participated to some degree in the NASA experiments, especially the human investigations. These occasionally required crewmember unique hardware, which would typically be launched on the Shuttle, in advance of the cosmonauts arriving on the next Soyuz. But if the launch schedule changed, and the Soyuz now preceded the Shuttle, specific hardware items would have to remanifested to an earlier Shuttle to ensure its timely arrival on Mir. Late changes in crew composition also added to this challenge. A flexible response was required to ensure the changes could be made to minimize loss of science.

A major change in the on-orbit situation occurred after the Progress collision with the Spektr module, essentially sealing off that module and all its NASA research hardware. The first order of business was to identify just exactly what hardware was now inaccessible. This was made difficult by a lack of an adequate inventory management system, and much time was spent both on the ground and in space to determine which items had to be replaced. Then, replacements had to be identified and Shuttle manifests updated to reflect not only hardware lost that could not be replaced, but also to include any replacements that were available. In the end, this impacted two subsequent Shuttle missions, as well as one Progress manifest.

Another aspect of this issue is that most Phase 1 increments were extended beyond their expected durations (as has every ISS increment to date), from a few days to as much as six weeks. It became clear that planning had to account for this, and the resupply and logistics plan needs to include additional items, such as extra samples or consumables, that can be processed in a mission extension scenario, first to accomplish additional science and second to keep the crewmember gainfully occupied.

Payload Hardware Testing and Acceptance

The US and Russian programs have developed their own hardware integration, test, acceptance and certification requirements and processes that have worked well for their own programs. For the Phase 1 program, NASA hardware providers had to comply with both sets of requirements. This proved both costly and time-consuming, and there were recurring questions of what if any additional testing was required to meet the Russian requirements. As the program matured, and the sides became more comfortable working with each other mainly as a result of continued personal relationships, common approaches were developed and the overall process became more efficient but still had room for improvement. A concerted effort needs to be made to consolidate the different program processes into a single ISS process to be used by all International Partners, regardless of the vehicle of launch or operation. An alternative approach would be mutual acceptance by each side of the other's processes and products.

Training and Operations

The effectiveness of payload training during Phase 1 was affected by several factors. Of primary concern was the scheduling of the training sessions. Starting about 18 months prior to their missions, the Phase 1 astronauts spent the majority of their time training in Russia, as would be expected since they were preparing to fly on a Russian vehicle. By mutual agreement, it was arranged that each Mir long-duration crew, astronaut and cosmonauts and their backups, would spend 2 three-week sessions in the US at the Johnson Space Center, roughly 9 months and 6 months prior to flight. The majority of this time was dedicated to training on the US research program. These sessions were found to be beneficial to the crews, since they were essentially immersed in the payload training for a dedicated time, taking maximum advantage of any synergies among the various payloads and support systems. For the training personnel, it was also advantageous, since they could dedicate their energies to these dedicated sessions and also derive maximum benefit from having the payload developers, procedure writers and other support personnel essentially available throughout the three-week training session. Some additional payload training was also conducted in Russia, but at obvious greater expense.

Another important aspect that impacted payload training was the required bilingual nature of the training, including bilingual flight procedures and instructions. This aspect also included providing US payload training to Russian instructors, and in some cases to support training in Russia, including shipping of hardware and personnel to Russia. Although great improvements were made in the course of the Phase 1 program, some of these issues, especially the translation and sometimes unexpected modification of US payload procedures by Russian procedure writers, sometimes with changes in technical content.

As noted above in the mission planning discussion, in-flight operations on Mir were also conducted in a manner unlike that used in US Spacelab missions. This was true not only because of the long-duration environment but also due to the relative lack of space-to-ground communications with the crew. This required weekly and daily flight timelines to present a broader scope of activities, rather than a minute-by-minute scheduling. The crews were typically more involved in the scheduling and performance of the onboard activities, as they sometimes had to rely on themselves to respond to unexpected situations, without immediate ground support. Crewmembers felt this more flexible and crew autonomous approach not only worked best in the environment but also provided them with more control over their daily lives.

Baseline data collection

An aspect of the Phase 1 research program that was unique to the human life sciences investigations was the conduct of ground-based data collection, both before and after flight. Owing to the divided nature of crew transport, in terms of time, location and vehicle, facilities for data collection had to be established and supported both in the US and in Russia. Existing facilities from previous programs at JSC and KSC, as well as at Dryden (alternate landing site), were used for US-based data collection. Primary data collection facilities in Russia were established in Star City, but additional facilities were used in various institutions in Moscow for specific studies. Logistically, this required understanding of Russian customs regulations, and renting of space in Star City facilities. Due to limited numbers of data collection hardware, some items and the support personnel had to be shipped back and forth between the US and Russia to support launches and landings that sometimes were only days apart. Over the course of the Phase 1 program, processes were established that enabled these logistics challenges to be successfully overcome, again often through the establishment of personal relationships with Russian individuals.

Multilateral coordination

The Phase 1 program also offered NASA a preview of coordination of research and other operational aspects with multiple national partners. As part of their Mir commercial program, Russia offered up the Soyuz third seat to a paying customer, typically from a foreign entity, who would spend one to three weeks aboard Mir conducting research. During the course of the Phase 1 program, there were three such flights, two French and one German. In addition, although no US astronaut was onboard at the time, there were some low level cooperative activities during the 6-month Euromir 95 mission of an ESA astronaut. The French had a long history of working with the Russian program, flying a series of their astronauts on Russian space stations since 1982, and ESA had completed a 30-day flight on Mir shortly before the first US astronaut arrived. To take advantage of this experience, NASA representatives from the Phase 1 Research Program spent considerable time learning the lessons learned by these other agencies about conducting research in the Russian system. During flight operations, these representatives also worked closely with these other agencies to minimize any potential conflicts when astronauts were on board at the same time. Some research products were also returned on the Shuttle for these agencies. These contacts proved to be highly beneficial to all parties.

Summary

The Phase 1 program offered a unique opportunity for NASA to gain long-duration human space flight experience, in preparation for operation of ISS. In addition, it offered NASA the opportunity to begin building the relationships, primarily with Russia and to a lesser degree with other international partners, required to accomplish the most ambitious multinational space endeavor in history.

References

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