Capturing and Transferring Lessons Learned for Risk Reduction: NASA's Phase 1 Program

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Abstract: The National Aeronautics and Space Administration (NASA) and the Russian Space Agency (RSA) conducted the Phase 1 (Shuttle-Mir) Program from 1993 through 1998. The joint manifest of this cooperative effort consisted of Russian Soyuz (crew) flights, Progress (cargo) flights, Russian science module flights (Spektr and Priroda), U.S. space shuttle docking missions, and nine long duration missions aboard Russia's Mir space station by U.S. astronauts. The purpose of the program was to establish and create a cooperative technical, operational and managerial experience base between Russia and the United States to reduce risks associated with the assembly, operations, science and logistical support of the International Space Station (ISS). In this paper we take a retrospective look at the extensive capture of lessons learned—gained from Phase 1 and transferred to the ISS program (ISSP)—and how this effort served to mitigate risk.

Key Words: Lessons Learned, Risk Reduction, Knowledge Capture and Transfer

1. The Past is Prologue

The Phase 1Program was rooted in the history of U.S. and Soviet human spaceflight collaboration. While the 1960s were a largely a period of a superpower competition, détente arguably began with the Nuclear Non-Proliferation Treaty (1968) and continued throughout the 1970s. In 1972, discussions began between the two parties on in-space rescue modalities and the docking interfaces required to accomplish such a mission. Uri (2022) notes that the 1972 Agreement Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes between President Nixon and Premier Kosygin laid the groundwork for what would become the Apollo-Soyuz Test Project (ASTP) in 1975. In the aftermath of ASTP, joint discussions were held regarding "the objectives, feasibility, and means of carrying out a joint experimental program using the Soyuz/Salyut [space station] and Shuttle [still in development] spacecraft" to take place in the 1981 timeframe (OTA, 1985). However, several geopolitical and military events, including the Soviet invasion of Afghanistan in 1979, terminated these plans. It would be almost two decades before the subject would be revisited. Fortunately, the institutional memory as well as the means of organizing joint spaceflight operations between the U.S. and Russia was still available in both countries in the early 1990s.

2. Phase 1 Background

In early 1993, Vice President Al Gore and Russian Prime Minister Viktor Chernomyrdin signed the *Gore-Chernomyrdin Commission* agreement. One of the elements of this agreement envisioned a single long-duration mission aboard Mir by a NASA astronaut, along with a single docking mission by the space shuttle to Mir. Beyond that, NASA, the Russian Space Agency (RSA) and Rocket and Space Corporation Energia (RSC-E) were in early discussions to use the Soyuz-T spacecraft as an assured crew return vehicle (ACRV) for the ISS. The reliable Soyuz had been used as a crew transportation system since 1977 to Russia's six Salyut space stations, as well as the Mir (Portree 1993).

These cooperative activities proceeded with the Clinton administration's Office of Science and Technology Policy (OSTP) in full support. NASA and RSA signed a contract for $400M: $335M for additional NASA astronaut long duration flights to Mir and $65M for early ISS hardware (Phase 2). As Cline (2002) notes, "Russia's motivations to join the program are perhaps the most complex of all the [international] partners...the station could bring Russia into the "free world" and at the same time help the partners with its years of experience in space." This rapprochement was reminiscent of the diplomatic efforts leading to the Apollo-Soyuz Test Project (ASTP) some 23 years earlier at the height of the Cold War. Through Viet Nam, Bosnia-Kosovo, Gulf Wars I and II, and the Ukraine-Russia conflict, cooperation in space seemingly transcends diplomatic relations on Earth.

In June of 1995, space shuttle Atlantis, on mission STS-71 (the 69th shuttle flight), docked with the Mir space station for the first time. Two cosmonauts were ferried to Mir while NASA astronaut Norm Thagard was returned to Earth on the shuttle. At the time, NASA had 14 years of operational space shuttle experience and only 24 weeks of operational space station (Skylab) experience. In 1994-1995, NASA ISS personnel were reflecting on lessons from space station analogs (e.g., nuclear ballistic missile submarines, Antarctic scientific expeditions, etc.) in an effort to glean engineering design, human factors, and operational lessons for application to the ISS.

From 1995 to 1998, NASA had use of the Mir, an actual working laboratory in space, as well as a cadre of Russian managers, engineers, scientists, flight and ground operations personnel, cosmonauts, and physicians to learn from.

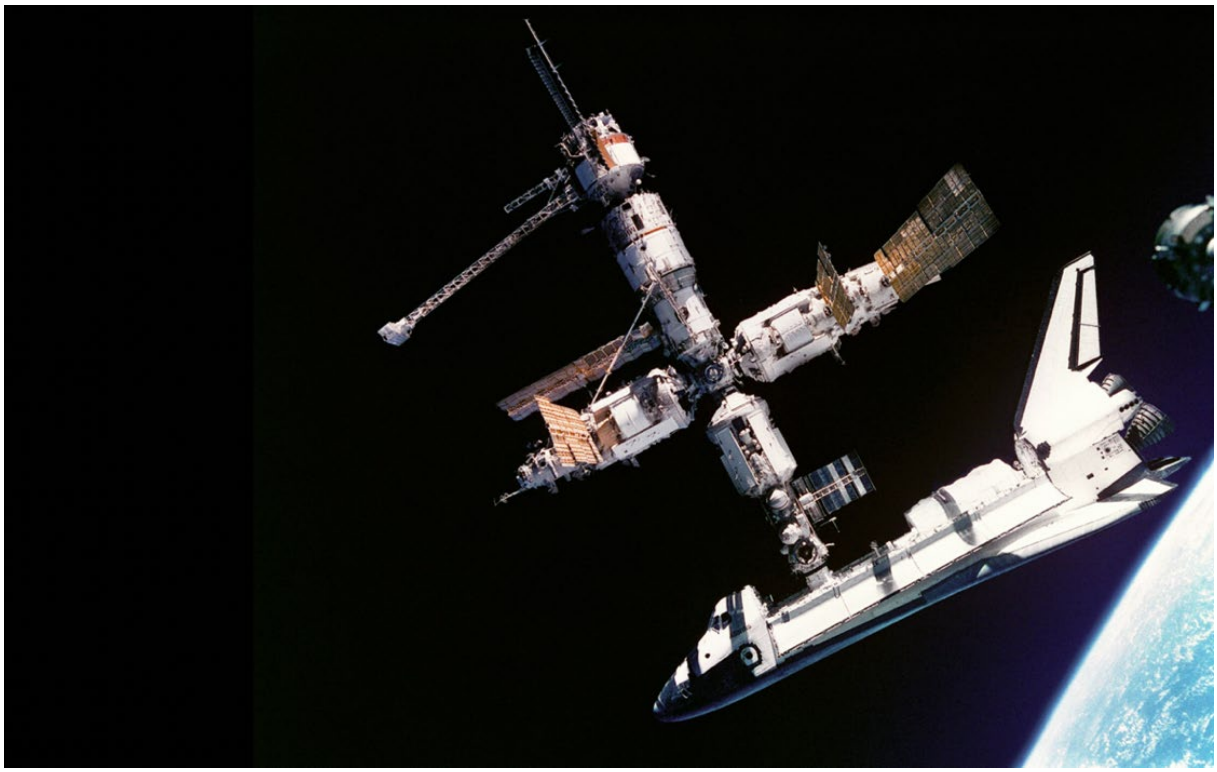

Figure 1: Space Shuttle Atlantis Shuttle Docked to Mir (Credit: NASA)

3. Risk Reduction

As the first phase of the ISS, the Shuttle-Mir Program was a risk reduction effort between NASA and RSA designed to increase the likelihood for safe and reliable operations of the future ISS. Risk reduction generally involves identifying known risks, then developing and executing mitigation plans to reduce the likelihood or consequence of the risks. Learning is generated from the difference between carefully planned activities, expected versus real outcomes, as well as from risk mitigation efforts. Major categories of risks, which may also be referred to as critical knowledge areas, included but were not limited to:

- Developing U.S. and Russian collaborative relationships;
- Refining Space shuttle proximity, rendezvous, and docking operations;
- Developing mission control center integration and joint operations;
- Performing long-duration mission increment planning and execution;
- Integrating crew training (Houston and Star City) and;
- Discovering other knowledge gaps in long-duration spaceflight.

However, not all risks can be effectively identified before flight. In some cases, unforeseen circumstances occur. During Phase 1 an onboard fire caused by a faulty oxygen generator cannister and a collision and depressurization mishap between Mir and a Progress cargo vehicle both occurred. These incidents generated many lessons which were then applied to future ISS emergency procedures (Thieme, 2003). Reflecting on these events, Jim van Laak, Phase 1 Deputy Program Manager stated that, “the relationship we developed with the Russians as a result of these near catastrophes is what enabled ISS to be successful (Van Laak, 2024).”

4. Knowledge Capture / Transfer (KC/T) Modalities

In risk management parlance, the purpose of a mitigation plan is to change the relationship between the existing condition and the potential consequence. Risk statements are therefore carefully written as: Given [condition

X]; there is a possibility that [consequence Y] may occur. Exploration of the relationship between the condition and consequence allows the risk owning organization to develop an effective mitigation plan.

Many ISS risks were unknown and/or undocumented when the Phase 1 Program began due to the ISS nascent risk management processes. As a result, the identification of risks of related to the planning and execution of long duration missions aboard Mir were more a matter of discovery than an intellectual effort of foresight. This was a missed opportunity for the two programs to collaborate and use ISS risk issues to cue KC/T activities in Phase 1, i.e., to capture lessons most useful to buy down risk for the ISS. Despite this, there were several traditional means of KC/T employed during the Shuttle-Mir Program which included:

- Long-Duration Mir Crew Mission Debriefs;
- Space Shuttle Crew Mission Debriefs;
- Mission Operations Directorate Flight Control Team Debriefs and;
- NASA Lessons Learned Capture Activities and Reports (See Para. 4 below).

After the close of the program, knowledge capture involved the following KC/T modalities:

- Technical/Engineering Papers (NASA Technical Reports Server);
- Human Spaceflight Conference Papers;
- Academic Journal Articles;
- Oral History Project Interviews (e.g., Johnson Space Center) and;
- NASA History Office Narrative Reports.

Other sources of lessons learned documented outside of NASA efforts included:

- U.S. Government Accountability Office (U.S. GAO) reports;
- Aerospace Industry Press Articles (e.g., Aviation Week and Space Technology, etc.);
- Non-Fiction Historical Books (e.g., *Dragonfly, Star-Crossed Orbits*) and;
- Congressional Hearing Testimony (Written Submissions and Transcripts).

Had the Shuttle-Mir Program been conducted today, several other means of KC/T activity may have included information technology (IT) aids:

- Collaborative online meetings tools such as MS Teams, Zoom, or MeetingSphere to capture knowledge in real-time and;
- Collaborative team-oriented tools such as wikis, particularly blogs and discussion boards to capture knowledge asynchronously.

One should note that tacit knowledge, the knowledge, skills, and abilities an individual gains through experience, also played an important role in both knowledge capture and transfer. The personnel who worked in NASA functional organizations, such as engineering, space and life sciences, mission operations, flight crew, payload integration and operations, ground systems and operations, all built a knowledge base which was directly applied to the ISS Program. This also includes NASA contractors such as Boeing, United Space Alliance, and Lockheed-Martin. Some senior managers were transferred into leadership positions in the ISS Program, where their management experience and relationships with their Russian colleagues was highly beneficial.

5. The Lessons Learned Architecture

Abiding by the dictum that a little structure goes a long way, particularly when it comes to KC/T activities, two significant and complementary efforts occurred at the end of Phase 1 which merit a more detailed discussion. The first involved the documenting of over 500 individual lessons from each of the Phase 1 working groups, followed by peer-to-peer exchanges with ISS personnel to ensure that each lesson found a home in the Station Program Integration Plans (SPIPs). SPIPS were the backbone of the document/information architecture to guide NASA management of ISS activities. The goal of this approach was to ensure that the ISSP accommodated both positive and negative lessons; the latter included risk issues including the previously mentioned experiences of the onboard fire and depressurization. In addition to SPIPS, there was also transfer of Shuttle-Mir lessons to the ISS vehicle engineering documents, the medical operations requirements document, and standard operating procedures for public affairs activities. Oberg (1998) observed that the lesson insights “dealt less with hardware design than with operational philosophies and that ninety percent of these lessons were process oriented." Many lessons dealt with cross-cultural issues in addition to operational processes.

Table 1 below outlines both the Phase 1 management structure versus the ISS SPIPs:

Table 1: Phase 1 Working Groups and ISSP Integration Plans

Phase 1 **Management Structure:**	**Station Program Integration Plans (SPIPs)**
Team 0 Senior Management	Program Management (SPIP Vol. 1)
WG-1 Public Relations	Manifesting and Schedules (SPIP Vol. 2)
WG-2 Safety and Mission Assurance	Cargo Integration (SPIP Vol. 3)
WG-3 Flight Operations and Systems Integration	Payload Integration (SPIP Vol. 4)
WG-4 Mission Science	Logistics and Maintenance (SPIP Vol. 5)
WG-5 Crew Training and Exchange	Launch Site Processing (SPIP Vol. 6)
WG-6 Mir Operations and Integration	Training (SPIP Vol. 7)
WG-7 Extravehicular Activity	Increment Execution Preparation (SPIP Vol. 8)
WG-8 Medical Operations	Real-Time Operations (SPIP Vol. 9)
WG-9 Institutional Communications	Sustaining Engineering (SPIP Vol. 10)

Another lessons learned effort involved the joint NASA-Russian technical teams producing the Phase 1 Program Joint Report. For this heavily researched narrative report, "the Working Groups were tasked to describe the organizational structure and work processes that they used during the program, joint accomplishments, lessons learned, and applications to the International Space Station Program (Nield and Vorobiev, Eds. 1999)." As a joint report, it helped define a path forward for working with the Russians and was a critical part of the KC/T effort.

6. How to Operate a Space Station

Although transferring Phase 1 knowledge to the ISS Program was a collegial exercise, there were a number of issues raised by Phase 1 personnel early on which were ignored or shrugged off as being artifacts of NASA's "customer" role onboard a Russian space station. For example, ISSP operations managers pushed back on the Phase 1 conclusion that ISS operations would most likely be dual-language (Russian and English) and not English-only. Over time that risk was realized by the ISSP and a great deal of resources had to be spent on interpreter and translator services, flight crew language training, dual-language procedures development, as well as a requirement for NASA and Russian support group flight controllers and planners to be stationed in Houston and Korolev.

The language issue was likely due to a cognitive bias exhibited by many ISS Program personnel. Hence, the belief early on that Phase 1 lessons were not necessarily applicable to the multi-international partnership that defined the ISSP. In Russia however, many of the personnel involved in Phase 1 believed that the ISS was simply an extension of the Mir operational philosophy. Unlike NASA personnel, the assumption on the Russian side was that most management, engineering, systems integration, crew training, medical support, etc., would remain the same or very similar. To some extent that was true during early ISS operations but there is no argument that the risks associated with rendezvous and docking, planning and execution, and, perhaps most importantly, crew training and bridging the cultural gaps, had been mitigated to very low risks levels by the Phase 1 Program.

Aside from three missions to NASA's Skylab in 1973 and 1974 for a total of eight months, NASA philosophy was focused on turning space shuttles around for six-to-sixteen-day flights. Reflecting on the Phase 1 program, NASA Flight Director Paul Dye noted that; "I think everybody knew all along that flying a Space Station is different than flying a Shuttle, and we probably would have come to the answers that they [Russians] have, sooner or later, too, but by sitting and watching how they do business, and looking at it, I think we probably shortcut some of the mistakes that we might have made (Dye, 1998)."

7. Conclusions

Measuring the value of the knowledge gained from Phase 1 in terms of the risks mitigated in the early operational years of the ISSP in an economic sense is a difficult endeavor. However, it could be inferred that the success of ISS assembly missions, on-orbit flight crew operations, ground operations, and increment and real-

time planning operations can be attributed in part to what both space agencies and their contractors learned in Phase 1. As astronaut and Phase 1 Program Manager Frank Culbertson explained; "the expense of flying the Shuttle is there, whatever the mission happens to be. I think that flying to Mir is one of the most productive ways to fly the Shuttle in terms of what we learned and what we accomplished...the cost of the contract with the Russians is about the same, rough order of magnitude, as one shuttle flight. And for the cost of one shuttle flight, we've flown to the Mir ten times and brought back innumerable lessons learned and probably saved unsuccessful shuttle flights in the future because of knowing something that we now know from Phase1. I believe it has been a very cost-effective insurance policy for the future (Oberg, 1998)."

In capturing and transferring knowledge, it is beneficial to consider a combination of techniques to ensure a comprehensive and accessible knowledge base, both tacit and written. Some of the positive aspects of the Phase 1 KC/T were that it was well documented, well communicated, and contextual. Having said that, the process was sub-optimal and could have been improved with a more disciplined planning process upfront. I offer the following KC/T planning checklist for those looking to reduce future risks through KC/T activities:

> Start with a **Systems Analysis** to ensure that problem definition, requirements, goals, and objectives are clearly defined. The analysis should ensure that all "systems" associated with the program (organizations, hardware, software, infrastructure, etc.) are properly incorporated, as well as interfaces between systems, to include international partners.
>
> Identify **Critical Knowledge** needed using a risk-based approach. The risk register, problem reporting systems, system safety analyses, mishap and close call systems, etc. can provide a valuable cueing system pointing to value-added information.
>
> A **Knowledge Architecture or Taxonomy,** whether it be an organizational breakdown, work breakdown, or engineering and science disciplines, is useful in organizing the information for later discovery and reuse. Within the architecture, key word **Tagging** of all products will aid in online search discovery.
>
> Clearly defined **KC/T Management Roles and Responsibilities** are required to ensure accountability, **Appropriate Resource Allocation,** and decision-making authority. In many cases, a KC/T effort is task organized and will therefore require coordination across multiple operational and institutional organizations (e.g., IT department, history office, public affairs and media), making an **Integrated Product Team Charter** a useful coordinating tool.
>
> Development of a **KC/T Schedule** allows more efficient resource allocation, progress tracking, alignment, and coordination among the stakeholders in the KC/T effort. Obviously, sufficient time should be allocated to the KC/T effort so as not to shortchange the quality of the knowledge products or formal transfer processes.
>
> Development of a **KC/T Communications Plan** will ensure the objectives of the capture and transfer effort are clearly defined, both internally and externally. When combined with the KC/T schedule, the communications plan should inform stakeholders of the key activities, milestones, and flow of information between all parties. The plan should identify opportunities to engage the public in the output of KC/T products via social media channels.
>
> Lessons learned are often best learned when they are codified in **Programmatic, Design, Operational and Training Documentation.** They become the standard for future efforts by identifying the documentation as targets for key **Validated Practices.**
>
> Execution of **Knowledge Capture / Transfer Activities** can include interviews, videography, writing assignments, creation of a **Narrative Report**, media preparation, training products development**,** population of a **Knowledge Portal** (if required), conduct of **Lessons Learned Forums,** establishment of **Mentoring Programs,** development of an **Expertise Locator,** and so on.
>
> **Encourage and Reward Personnel** participating in the KC/T process. This includes encouraging the writing of academic journal and conference papers. Obvious benefits include improving the morale, motivation, and retention of employees. As new programs ultimately replace programs that are completed or cancelled, the problem of **Knowledge Retention** may become acute if personnel are not transferred to the new program(s). To the extent possible, consideration should be given to retaining experienced personnel in their functional areas on new programs.

8. Epilogue

Established in 1996, the goal of the NASA Johnson Space Center Oral History Project (JSC OHP) is to capture history from the individuals who first provided the country and the world with an avenue to space and the moon. Participants include managers, engineers, technicians, doctors, astronauts, and other employees of NASA and aerospace contractors who served in key roles during the Mercury, Gemini, Apollo, Skylab, and Shuttle programs.

These oral histories ensure that the words of these space pioneers live on to tell future generations about the excitement and lessons of space exploration (JSC OHP, 2024). The following two interview segments provide a good synopsis of the knowledge gained from the Phase 1 Program which ultimately benefitted the ISS Program.

Andy Thomas, NASA Astronaut: "Throughout the course of the Phase 1 Program we've learned the mechanics of how you service and operate a space station; how you arrange and load a vehicle, launch it, rendezvous and dock to the space station, transfer goods, transfer crews, which we wouldn't have otherwise. It shouldn't be underestimated how to work collaboratively with the Russians because we have different cultures, different languages and that itself is a big accomplishment…it's inconceivable to do the International Space Station without first taking these steps in the Phase 1 Program (Thomas, 1998)."

General Yuri Nikolayevich Glazkov, Deputy Director of the Gagarin Cosmonaut Training Center: "I think the main result of Phase 1, which is coming to an end, is our successful transition to the International Space Station. Of course, everything that is ending now is not really an end; it is flowing into the building, assembling of the future Space Station and its future operation. I heard President Bill Clinton a few times calling the future International Space Station "the bridge into the future," and I do believe that it is the transfer of our achievements of the twentieth century into the twenty-first century, especially for our kids. That's why I'm preparing my daughter to become a cosmonaut (Glazkov,1998)."

Figure 2: Phase 1 Astronauts (1st Row L-R: Norm Thagard, John Blaha, Jerry Linenger, David Wolf, 2nd Row, L-R: Andrew Thomas, Shannon Lucid, Michael Foale. Credit: NASA)

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