Section 5 - Joint Shuttle-*Mir* Operations

Authors:

Victor Dmitriyevich Blagov, Deputy Co-Chair, Flight Operations and Systems Integration Working Group (WG) (Operations)
Oleg Nikolayevich Lebedev, Co-Chair, *Mir* Operations and Integration WG

Philip Engelauf, Co-Chair, Flight Operations and Systems Integration WG (Operations)
Jeffery Cardenas, Co-Chair, *Mir* Operations and Integration WG

Working Group Members and Contributors:

Vladimir Alekseyevich Solovyev, Co-Chair, Flight Operations and Systems Integration WG

Robert Castle, Co-Chair, Flight Operations and Systems Integration WG (Operations)
Rick Nygren, Former Co-Chair, *Mir* Operations and Integration WG (MOIWG)
Charles Stegemoeller, *Mir* Operations and Integration Working Group
Gary Kitmacher, *Mir* Operations and Integration Working Group
Richard Meyer, *Mir* Operations and Integration Working Group
Donald Schmalholz, *Mir* Operations and Integration Working Group
Michael Hendrix, *Mir* Operations and Integration Working Group
Karen Morrison, *Mir* Operations and Integration Working Group
Gloria Salinas/Lockheed, *Mir* Operations and Integration Working Group
Darren Lajaunie/Lockheed, *Mir* Operations and Integration Working Group
Sharad Bhaskaran/Lockheed, *Mir* Operations and Integration Working Group
Ronald Crawford/Lockheed, *Mir* Operations and Integration Working Group
Debbie Babic/Lockheed, *Mir* Operations and Integration Working Group
Kevin Upham/Lockheed, *Mir* Operations and Integration Working Group
Brian Rhone/Lockheed, *Mir* Operations and Integration Working Group
Lynn Pickett/Lockheed, *Mir* Operations and Integration Working Group

Ludmilla Nikolaevna, *Mir* Operations and Integration Working Group
Raf Murtazin, *Mir* Operations and Integration Working Group
Andrei Manzhelei, *Mir* Operations and Integration Working Group
Ekrem Koneev, *Mir* Operations and Integration Working Group
Skella Bugrova, *Mir* Operations and Integration Working Group

5.1 Mission Control and Real-Time Operations During Shuttle Docking Flights

5.1.1 Introduction

The Phase 1 Program included a total of 10 joint Shuttle-*Mir* missions. The first of these, STS-63, was designed only as a rendezvous demonstration mission, since the Shuttle carried no docking mechanism. This flight provided a validation of the rendezvous technique and MCC to MCC interactions that would be required on all subsequent missions. All nine remaining missions included successful dockings, transfers of cargo and consumables, exchanges of both U.S. and Russian *Mir* crews, and the performance of joint docked experiments.

The Shuttle and the *Mir* were originally developed independently, for fundamentally different purposes, and were not inherently compatible vehicles. Numerous dissimilarities required both engineering and operational solutions to facilitate joint operation of the docked vehicles. The processes developed to achieve these solutions, the procedures and techniques used to execute them, and the knowledge gained from nominal flight and unexpected events are all the primary basis for the development of joint operational principles for future programs such as the International Space Station (ISS).

5.1.2 Implementation of Joint Operations

The development of a joint operations process was divided into numerous functional areas or subgroups. Prior to each joint flight, each discipline's top-level agreements for the conduct of planned operations were documented in Joint Agreements, which were the source of the detailed operational plans and procedures for flight. A document control process for making changes to these documents was developed, so that both parties could review and agree to the proposed changes. Although this process was somewhat cumbersome and could be refined for future programs, the concept of using configuration-controlled documents is valid and contributed to the success of the joint program.

Real-time operations for the Shuttle-*Mir* missions were conducted with the agreement that neither vehicle and neither MCC was in charge of the joint operation. The MCC-M controlled and had authority for the *Mir*, and MCC-H was responsible for the Shuttle. Similarly, the Shuttle commander was responsible for the Shuttle and crew, and the *Mir* commander was likewise responsible for his vehicle and crew. This arrangement formed the basis of a need for mutual agreement on every aspect of joint operations. One of the primary tools for these agreements was the use of Joint Flight Rules. Developed before each mission, these written rules documented both planned operations as well as responses to off-nominal situations. The rules minimized the need for real-time decisions, and ensured that all impacts of each course of action had been reviewed and agreed by both sides for operational adequacy.

Execution of the joint missions required coordination between two control centers thousands of miles away from each other, in different time zones, and with different native languages. Communications links, processes and procedures were developed to exchange information between the control teams, coordinate decisions, and accommodate changes of plan. In addition to development of these joint control center capabilities, groups of consultants were exchanged during the mission to facilitate technical discussions between the control centers, and to observe and learn how the other team performed their tasks.

The detailed planning and control of the joint missions was performed through joint consensus at the individual discipline level; for example, the orientation requirements were agreed to by the respective attitude experts, procedural issues were worked out by the individual procedure specialists, and so on. Addressing the issues at this level resulted in mutually acceptable recommendations to the Flight Directors and mission managers, and was a very efficient method of resolving technical issues.

5.1.3 Joint Operations Accomplishments

The planning and execution of these joint missions encompassed many significant accomplishments. There were numerous challenges resulting from the technical complexity of the task as well as the practical considerations of technical and language differences. Among the most significant are:

Docking of very dissimilar vehicles — The operational techniques for final approach and docking of the Shuttle to the *Mir* orbital complex were developed and gradually improved over the duration of the program. The *Mir* complex continued to change throughout the program with the relocation and addition of modules and relocation of solar arrays. Issues of plume loads, contact loads, and vehicle dynamics required continual reassessment to account for these changes. During the early portion of the program the Shuttle technique was changed from approaching from the velocity vector ("V-bar approach") to approaching from below ("R-bar approach") in order to help reduce plume-loading concerns. Throughout the joint program the dockings were consistently within the required contact conditions.

Technical Operation of the Docked Complex — Mutually compatible operation of the Shuttle-*Mir* complex required extensive work in the areas of attitude control, thermal and power management, and atmosphere maintenance. The primary strategy for attitude and atmosphere control was to allow a single vehicle to control, thus avoiding interactions between the two vehicles' systems. Refinement of the Shuttle digital autopilot control parameters and hardware additions to the Shuttle environmental control system were required to accomplish these changes. The technique of replenishing the *Mir* atmosphere from excess Shuttle consumables was a byproduct of this work. Management of the attitude was complicated due to the conflicting requirements of the two vehicles. Management of the attitude was complicated due to the conflicting requirements of the two vehicles. Extensive efforts were necessary to balance power generation for *Mir*, *Mir* and Shuttle thermal considerations, communications antenna blockage, and attitude control propellant usage.

Mission Control Operations — One of the greatest challenges of the joint operations was the coordination of control between the two mission control centers. The development of strong working relationships between the two control teams required practice through simulations and the development of clear, unambiguous communications channels and methods. Special console positions (RIO and PRP) were created to assist with this interface function. Procedures were developed for information exchange between the control centers, specifying reporting points, and making decisions. In addition, the use of the Consultant Groups provided a capability for detailed face-to-face technical discussions, when required. All of this work was performed in different languages, requiring the use of interpreters. The successful accomplishment of the entire sequence of missions serves as testimony to the technical abilities of both sides, given the practical difficulties. The mutual trust and respect for technical ability developed through the joint meetings and pre-mission work were crucial to this working relationship.

5.1.4 Joint Operations Lessons Learned

Dual Language Procedures — Although each Shuttle crew had at least some familiarity with the Russian language, and the Russian crews knew some English, it was not possible within the scope of the Phase 1 Program to converge to a single-language operation. Yet in the interest of safety and effective operation, it was crucial that both sides have a clear understanding of all procedures and plans. As a result, a method was developed to present all detailed joint procedures in both languages. Identical steps in each language were printed on facing pages of checklists. Printing techniques were used to distinguish which steps were to be performed by each side. Because it was crucial that both MCCs fully understand the flight rules, they too were printed in both languages on facing pages. Crew timelines were presented in both English and Russian as well.

In the future, when more than two languages are involved, as with the ISS, convergence to a single language of operation would be preferable where the time is available to gain language proficiency for all parties. However, it is still crucial that some time-critical and safety-critical procedures be absolutely clear and easily understood in an emergency, so some minimal amount of multilanguage procedures may be required.

Crew Operations — The efficient utilization of the combined Shuttle and *Mir* crews required clear planning and coordination. Conduct of the transfer operations for cargo, performance of experiments during docked operations, handover time for the long-duration crew change, and routine operation of both vehicles' systems created complex demands on crew time and available volume. Over the length of the Program the planning technique evolved significantly, resulting in a mixture of tightly constrained crew events and loosely scheduled crew time to complete unconstrained activities. The daily exchange of information between the MCC teams allowed planners to monitor the completion of tasks. Time was scheduled for both crews to meet and review the daily plans in order to improve coordination between the two crews.

Sleep Cycle Management — The *Mir* crews were accustomed to a standard-length 24-hour day on a repeating schedule, synchronized with Decreed Moscow Time (DMT). Shuttle crews, however, have a variable crew workday length in order to adjust the crew wakeup times to support launch and entry schedules. Due to orbital mechanics effects, the sleep/awake periods for the two crews rarely coincide. However, efficient crew worktime requires that some minimum joint workday must be achieved and compromises were required from both crews in order to align the workdays. Through the Phase 1 experience it was determined that the minimum joint workday for the crews should be at least 8 hours of joint worktime in order to accomplish the transfer of the full cargo and perform the other assigned tasks. This required shifting the sleep period of the station and Shuttle crews each by as much as 4 hours.

5.1.5 Applications to ISS

While many of the operational techniques and specific procedures developed in the course of the Shuttle-*Mir* program were specific to the *Mir*-Shuttle configuration, many general principles can be applied to future joint operations such as ISS.

Joint Control Team Structure — For Phase 2, there will be both U.S. and Russian control teams for the ISS vehicle. Unlike the Shuttle-*Mir* program structure, the ISS will be operated as a single combined vehicle, with the Russians responsible for executing Russian segment operations and the U.S. responsible for the U.S. segment. However, the U.S. will maintain responsibility for the overall conduct of the ISS operation. Although one control center will have primary overall control responsibility at any given time, the principle of joint coordination at the discipline level and agreement between Flight Directors will still be the primary operational technique, an approach which was developed during Phase 1. The use of consultant groups will be continued in the ISS team structure.

Structure of Joint Documentation:

The use of documented Flight Rules and MCC procedures will continue as standard operational practice. The system of agreeing to and introducing changes to joint documents, developed during Phase 1 missions, may be fully applied to the ISS.

Acceptance of Joint Decisions:

The interaction of the MCC's and their Flight Directors during nominal flight and during emergency situations was adjusted and assured the success of the 9 missions. The exchange of flight documentation and real-time procedures for making decisions including: oral discussions of the problems, questions via fax, and Flight Director briefings to provide the partner with exhaustive data concerning the problems that arise will apply, in general, to the ISS.

Joint Planning:

Joint planning and agreeing on the joint plans during Phase 1 was also refined and in general may be used for the ISS. It would be useful to expand the use of digital communication links and equipment for real-time exchange of plan variations to accelerate their concurrence.

The use of the partner's flight and ground segments:

The partner's flight segment during Phase 1 was used fairly widely (exchange of atmosphere, vector states, step-by-step attitude control, and the use of the partner's ground stations and communications links). It follows that this practice will be continued on the ISS and further advanced in the direction of increasing these types of services.

And, finally, in the area of engineering accomplishments, the most important accomplishment of Phase 1 would be the friendly, creative atmosphere that developed among the specialists of our countries during the Phase 1 joint operations.

5.2 Operations During the Long-Duration Missions

5.2.1 Executive Summary of the Joint *Mir* Operations and Integration Working Group (MOIWG/WG-6)

The Joint *Mir* Operations and Integration Working Group (MOIWG/WG-6), was established in the Spring of 1995 as a part of the Phase 1 Program, and was responsible for the implementation of the joint NASA/*Mir* Research Program on board the Shuttle and *Mir*-Orbiting Station (OS). Given this, the Joint MOIWG was tasked with the responsibility of developing, defining, and executing the processes of integration, mission preparation, and operation of joint research on the Shuttle and *Mir*-OS. Through the use of the jointly agreed upon Integrated Payload Requirements Documents (IPRDs), research program requirements were baselined and implemented through various joint working group documents and protocols. This implementation included, but was not limited to, flight crew and ground controller training, integration of payload and medical hardware, operation preparation and execution, as well as real-time mission support for the flight crew on-orbit. On the U.S. side, the MOIWG functions were divided into five functional groups: Analytical Integration, Mission Management, Operations, Training, and Integration Integrated Product Teams (IPTs). Each of these areas interfaced directly with the payload disciplines and other Phase 1 Program Working Groups to further define requirements and develop an implementation plan to execute the program requirements. The MOIWG also interfaced with multiple Russian organizations such as the Institute of Biomedical Problems (IBMP), RSC-Energia (RSC-E), TsNIMASH, and the Gagarin Cosmonaut Training Center (GCTC) to complete these joint activities.

The accomplishments from the Phase 1 Program included not only the scientific return, but also the knowledge gained on how to plan for and conduct long-term operations aboard a space station. The past histories of both the U.S. and Russia in their respective programs — Mercury, Gemini, Apollo, Skylab, and Space Shuttle; Vostok, Voskhod, Soyuz, Salyut, and Mir — brought different cultures with respect to planning and operations for spaceflight activities to the Phase 1 Program. By working together, the two sides learned to employ the best practices of each program to come to terms with the constant flow of technical, operational, and political issues that are part of the dynamic nature of a permanently manned space station environment.

The following sections briefly describe the structure, processes, joint accomplishments, and recommendations from each of the components of the MOIWG.

5.2.2 Analytical Integration Team (AIT)

5.2.2.1 Overview

The MOIWG was responsible for ensuring payload test and integration, preparation of required test and integration documentation, flight crew training and supporting documentation, actual integration of payload systems on board, execution of experiments and investigation in real time, and processing and distributing pre- and postflight data as required.

The MOIWG AIT served as the primary coordinating interface for payload requirements, development, delivery, schedule tracking, and issue resolution for the MOIWG. It served as the primary responsible MOIWG entity for management and coordination of payload implementation across the IPTs, the NASA/*Mir* Working Groups, and other NASA and Russian organizations. The relationship between the joint working groups for the purposes of the implementation of the research program was governed by US/R-001.

5.2.2.2 Structure and Processes

NASA was responsible for management of the MOIWG using a programmatic structure across all the Increments within the five major areas: AIT, Mission Management, Operations, Training, and Integration. The use of consistent processes and systems and the implementation of critical lessons learned from previous missions were key to the success of the MOIWG. The prime support team for the MOIWG was also organized along these functional lines, and dedicated increment teams followed each mission from requirements definition and development through postflight analysis and reporting.

The primary document describing the scope of work for each flight increment was the IPRD, as developed by the Mission Science Working Group (MSWG/WG-4).

The MOIWG worked most closely with the MSWG, and the two groups conducted quarterly meetings and reviews jointly with their Russian counterparts, who served as Russian interfaces to WG-4 and WG-6. Due to the dynamic nature of a space station environment, these joint meetings were invaluable since they provided the opportunity for direct contact between the U.S. and Russian science communities as well as the personnel tasked with implementing requirements. In addition, critical issues were brought forward to the program through weekly NASA Phase 1 Program meetings and telecons and through periodic Phase 1 Team 0 meetings.

5.2.2.3 Joint Accomplishments

Given the scope of the U.S. Research Program, Russian experts were not involved in establishing experiment objectives, the analyses of experiment results, or the evaluation of experiments, except with regards to the assessment of *Mir*-OS parameters, or in those cases where Russian investigators were directly involved as Co-Investigators.

During the program development and implementation stages, both sides worked together in the spirit of mutual understanding without resorting to undue formality, thereby promoting overall activity success.

A continually improved understanding of the launch and return capabilities and processing schedules of each side's vehicles allowed the program to supply or return critical items based on events that occurred on the *Mir*-OS.

This understanding enabled each side to reevaluate and to replan the scientific program based on the dynamic nature of a space station environment.

5.2.2.4 Joint Lessons Learned/Future Applications

Establishment of working forums to address all issues associated with integration and operation of payload systems on partner elements, especially in the situations of differing module and element designs and accommodations.

Establishment of working forums with decision-making authority and responsibility to implement and execute positions and solutions.

5.2.3 Mission Management IPT

5.2.3.1 Overview

The MOIWG Mission Management IPT was assigned the task of managing the NASA/*Mir* mid-deck science and transfer activities. Some of the primary activities included training the crew members on the STS (Space Transportation System) mid-deck science in-flight operations and/or transfers, assessing ground and flight safety hazards, replenishing consumables, supplying new hardware, returning samples and experiment hardware, providing pre- and postflight ground operations, and leading the destow process at the landing site.

5.2.3.2 Structure

Each of the Payload Element Developers (PEDs) reported to the MOIWG Mission Managers regarding mid-deck payloads under their responsibility, and concentrated on the transportation of the science experiments to/from the *Mir*-OS utilizing the STS.

The Mission Management function entailed many roles and responsibilities ranging from maintaining a manifest of science payloads, real-time operations during the missions and coordinating the postflight activities after landing (destow and ground operations). In addition, the MOIWG Mission Manager served as the MOIWG representative to the Phase 1 IPT in an effort to maintain strong communications.

In addition, the Mission Management Team worked closely with the Spacehab Team to integrate flight hardware manifested in the Spacehab module.

5.2.3.3 Processes

New inputs or changes from the PEDs (in-flight operations and/or hardware changes) were reviewed by the MOIWG Configuration Control Board (CCB) and approved manifest changes were submitted to the Phase 1 Program Requirements Control Board (PRCB). The Mission Management team worked within the MOIWG and with the MSWG to identify the hardware that would be required to support the selected experiments. The final manifest and subsequent changes were then used by the MOIWG Mission Manager to generate the appropriate documentation.

The Mid-deck Payload Requirements Document (MPRD), JSC-27898, defined the PEDs' requirements for mid-deck science and technology payload elements. All STS phases of the ground integration and de-integration, crew training, and flight and ground operations were included in this document.

In addition, the safety team developed the integrated flight and ground safety packages for the mid-deck payloads and compiled the Material Safety Data Sheets (MSDS), Process Waste Questionnaire (PWQ), and Hazardous Material Summary Table (HMST) inputs.

The Mission Management IPT controlled the science hardware ascent/descent manifest using the Phase 1 Requirements Document (P1RD) and provided inputs to Shuttle documentation. Mission Management repeatedly updated and cross-checked the real-time manifest against the official list of hardware items in the IPRD, the *Mir* manifest document (US/R-004), and the Phase 1 Requirements Document in order to maintain hardware configuration control. Updates generated from MOIWG CCB Directives were reflected in the P1RD and in Shuttle documentation. Timeline issues were primary considerations in development of the Shuttle manifest as well. Ensuring that the timeline matched the late changes in science requirements was an important Mission Management Office (MMO) responsibility.

5.2.3.4 Joint Accomplishments

During the course of the Phase 1 Program, MOIWG Mission Management developed plans and procedures, including the following:

1. Mid-deck Science Familiarization - A mid-deck science familiarization was presented to the assigned flight crew and Mission Operations Directorate (MOD) flight controllers. This provided the crew a general overview of the mid-deck payloads, any payload constraints, cold stowage (requirements, units flying, contents, general activities involved), training schedule and training activities.

2. Cold Stowage Plan - Due to a well-established plan, carefully executed operations and thorough crew-training, frozen and refrigerated samples were transferred between the Shuttle and the *Mir* on each of the Shuttle/*Mir* flights without any loss of samples.

3. Destow Plan/Ground Operations Plan - A destow process was established that allowed for receipt, inventory and distribution of all Phase 1 hardware in a timely and systematic manner. This provided Phase 1 with a record of what was returned and accountability for that hardware.

4. MMO Manifest - The MMO manifest provided the required detail for MMO to integrate the ascent and descent hardware as well as to provide inputs to the P1RD.

5.2.3.5 Joint Lessons Learned

The following lessons were learned by the Mission Management IPT during their involvement in the Shuttle/*Mir* missions, and would be applicable for ISS.

1. Establish a streamlined configuration control system for processing late changes. Set up a process that brings together key personnel from all required elements to evaluate and disposition all proposed changes subsequent to a freeze point at L-2 months.

2. Formalize preflight coordination between the Shuttle Mission Management, Program Office, MOD, PEDs and *Mir* Long-Duration Integration and Operations IPT members to specifically discuss transfer and operational issues.

3. Hardware drawing names, label names, and part numbers should be included on hardware lists. Common names should be avoided in any official documentation. Developing a separate drawing for hardware labels may reduce drawing changes if the crew has label name modifications. Revision of the JSC Drawing Control

Manual to specify the proper procedures for handling the various nomenclature issues would help. Inclusion of part numbers along with names in procedures and other documentation can eliminate potential confusion.

4. Use the documentation plan as a model for future ground destow operations. Hardware would be delivered to a central location for dispositioning and inventory control. The requirements would be documented in one universally recognized destow document. Alternatively, require the crew to pack all early destow and nominal destow items in separate bags (requires more space and crew coordination on-orbit). The destow plan established is a good template for future programs to build on.

5. Some dedicated facility with adequate processing and laboratory space needs to be identified or constructed at Dryden Flight Research Center for ISS use. The potential loss of long-duration science would far exceed the cost of an adequate facility.

6. Set aside an area onboard station for stowage of common-use supplies such as ziploc bags, Velcro, pens, and batteries. At a specified time prior to the next Shuttle launch, have a crew member inventory the supplies on hand. On the ground, have a catalog of core pre-approved supplies that the Flight Equipment Processing Contract maintains to replenish those supplies. Remove these items from the standard manifesting process. Under the present system, it takes almost as much manpower to manifest a ziploc bag as it does to manifest a payload.

7. Provide an electronic still camera (ESC) to photograph all powered hardware after installation or for any other activities that require detailed configuration knowledge by ground specialists involved with the crew in inspections, troubleshooting, or visual science observations.

5.2.4 Research Program Training IPT

5.2.4.1 Executive Summary

Crew training for the NASA *Mir* Program was an essential component of the success of the research program. Close coordination with the Crew Exchange and Training Working Group (WG-5) was required of the effective planning and implementation of the payload training program. The quality of the crew training was dependent on the constraints of crew schedules and manifests, launch dates, trainer and hardware availability, supporting operational documentation, level of procedure maturity, and programmatic changes. The planning and implementation of crew training for NASA/*Mir* required careful analysis of training requirements, taking into consideration crew background and previous training, as well as science and operational requirements. This was complicated by the use of different launch vehicles for astronauts and cosmonauts. Due to limited crew time, particularly in the U.S., efficient and optimal training was essential. Eliminating redundant requirements and streamlining training session content and methods provided the most efficient training possible. In addition, the IPT coordinated training programs to provide certified ground controllers to operate the Spaceflight Control Center – Kaliningrad (TsUP) and Payload Operations Support Area (POSA).

5.2.4.2 Structure and Processes

The structure of the Training IPT was determined by the requirement for a core group of U.S. and Russian specialists to support payload training across the breadth of the program. This group worked closely in coordinating the necessary support from experiment investigators and developers in the execution of flight crew and ground controller training. With this in mind, U.S. Training IPT personnel were stationed both at the NASA Johnson Space Center (JSC) and in Russia at GCTC. Moreover, this group was responsible for the completion of ground controller training, both in the U.S. and Russia.

Analysis and definition of payload training requirements was based on a thorough review and assessment of science and operations requirements as defined in the IPRD. While the 100 series documentation and the IPRDs contained preliminary training requirements, it was the responsibility of the Training IPT to develop and define training concepts, guides, and jointly agreed-upon plans to ensure the successful completion of the NASA *Mir* Research Program. Through joint working group and U.S.-based training sessions and discussions, the Training IPT established jointly agreed-upon training concepts, principles and increment-specific training plans. Changes and modifications to the increment level training requirements were under the jurisdiction of the MOIWG CCB, and implementation was coordinated through joint MOIWG meetings and protocols.

In executing payload training, two U.S.-based training sessions were identified during the mission preparation phase of each increment. This served to complement continuous crew training ongoing at GCTC, based on the availability of crew training hardware of required fidelity. Indeed, training hardware destined for Russia underwent acceptance testing, requiring the presence of GCTC specialists to familiarize themselves with training units, verify training and flight hardware fidelity, and experiment procedures. Training lesson plans for each session were developed, and session evaluation logs were compiled to assess the effectiveness of each session, and as a method of continuous process improvement. Sessions involved U.S. science experts, RSC-E experiment curators, GCTC crew instructors, and crew procedure developers. Flight crew training was held on both an individual and group basis, supporting prime and backup flight crew requirements, as well as requirements for operators and subjects. While in Russia, weekly payload training sessions were held in compliance with the jointly agreed-upon increment training plan. At GCTC, available integrated *Mir* and module simulators, including specialized hardware stands, were used for theoretical and practical crew training. Moreover, all EVA training for external payloads was performed at GCTC. Medical discipline science crew training not only utilized the joint resources established at GCTC, but also required close coordination with IBMP specialists. Through the early identification of refresher and proficiency training, and the tools required to support this, such as Computer Based Training and Field Deployable Trainers, both on the ground and on orbit, a high degree of proficiency was achieved prior to execution on orbit.

To take advantage of PED and hardware efficiencies, the Ground Controller Training Program was conducted in parallel with the U.S.-based crew training sessions. Supplemental training was provided at JSC.

Crew readiness for the science program implementation was determined based on the results of test training sessions.

5.2.4.3 Joint Accomplishments

The Spektr incident and late crew changes proved that the developed training processes were flexible, yet structured enough to hold up under changing programmatic conditions.

Meeting the goal of efficient, effective training required close coordination with Russian counterparts and U.S. training personnel in Russia to maintain continuity and consistency of training plans for U.S. and Russian sessions across increments. Negotiations often resulted in specialization of cosmonaut crew members, procedures reviews, consolidated requirements, and revision of planned training hours.

Coordination of training schedules with hardware and procedure development schedules proved to be critical to the success of training. In later increments, improved working relationships, streamlined processes, and reflown experiments made such coordination possible.

Streamlined processes also allowed for the effective accomplishment of Ground Controller training in conjunction with crew training, and for the development of various innovative training methods and materials, such as computer-based training for on-orbit use.

The development of NASA/*Mir* payload training processes allowed for the successful training coordination of an entire program across several increments, and even on an international basis.

Indeed, continuous process improvement led to a streamlining and improvement of the negotiation process, and the ultimate synchronization of the procedure development process with the training schedule. Development of upgraded training and laboratory facilities at GCTC in support of program research disciplines.

5.2.4.4 Joint Lessons Learned/Future Applications

The experience of long-term spaceflight has demonstrated the need for active participation by the crew in the research and experimentation aspects of scientific investigations. This is achieved through the accumulation by the crew of the scientific aspects of the phenomenon under study and the basic principles behind the science hardware, its design and functionality.

The criticality of outfitting of trainers and mockups cannot be understated. It essential to support integrated payload training, on both a system and element basis. The certification of training units in ground utilization needs to be clearly defined, being sure to address safety and hardware fidelity to flight units.

In order to continuously improve crew training for the science experiment and research program execution, the training process must be updated on a continuous basis based on experiment results from previous and ongoing missions. This will require trainers to be updated with the latest experiment results and reports.

Development of operations documentation in support of crew training is critical, and integrated schedules must be developed which allow for this close coordination.

5.2.5 Operations IPT

5.2.5.1 Executive Summary

The MOIWG Operations IPT was tasked with providing operational evaluations and assessments of payload requirements, defining and developing mission preparation activities and products, providing real-time mission execution in the U.S. and Russia, and developing postflight assessments and reports.

5.2.5.2 Structure and Processes

In satisfying these requirements, the Operations IPT was structured to support increment-based teams as well as provide the operational products required for each and every mission. Thus, there existed a core group of operations specialists who provided data and communications support, systems engineering, procedure development, flight planning and operational assessments and requirements. Also, the Operations IPT was tasked with providing *Mir* systems insight in support of the overall NASA *Mir* Program, and in preparation for ISS. In its implementation, the Operations IPT provided support teams of rotating personnel for the two Mission Control Centers that jointly managed the real-time missions. Close coordination with the MSWG operations support was required to ensure implementation of NASA/*Mir* Research Program requirements. The POSA, located in the Mission Control Center (MCC-H) at JSC, served as the U.S. operations integration facility for NASA/*Mir* mission operations, and the Spaceflight Control Center (TsUP), located in Moscow, served as the interface to the *Mir* Flight Control Team and the U.S. long-duration crew member.

The mission operations processes were based on the Russian long-duration system for the development of nominal flight plans, research and experiment plans, daily flight plans, procedures development and implementation, including real-time updates, data and communications sessions, and telemetry data processing and distribution.

In implementing these tasks, the Operations IPT worked through periodic Phase 1 Program meetings, joint MOIWG meetings and standalone flight planning and mission product discussions and teleconferences. Moreover, due to the operational nature of the roles and responsibilities, frequent and routine interface with STS mission operations personnel and the MOIWG Mission Management IPT was required.

5.2.5.3 Joint Accomplishments

In the implementation of these tasks, the Operations IPT interfaced directly and continuously with Russian counterparts during the course of the program in these areas, developing a working relationship that directly led to the operational success of each increment.

Development of a process for tracking the orderly packaging and return of the scientific data products from long-duration missions.

The establishment of a Photo/Video Coordination Group to provide a complete set of photo/video hardware and consumables for all payloads was beneficial to the program. By consolidating the photo/video stowage effort, all film was returned, used or not, to ensure no photo/video data was stored on film that had been degraded by excessive amounts of radiation. In addition, the expert advice on photo/video planning, crew training, procedures, and products ensured success when conducting joint activities.

Development of a process for providing operational assessment of payload requirements and implementation of these requirements on the *Mir*-OS through flight plans, procedures, and supporting operational documentation.

Evolution of a crew onboard procedure development and implementation process that served to support hardware integration schedules, crew training plans, and mission operations requirements.

Development of a mission nominal flight plan, based on launch schedules for manned and cargo vehicles, plans for science and engineering experiments, and with regards to resource and environmental constraints during the course of the mission. Further development of a two-week plan addressing daily work distribution and accommodating real-time changes in status of flight systems and vehicle resources. Final development of a Detailed Flight Plan, detailing daily operational program covering station systems, crew, and ground control facilities.

Development of a Daily Assignment Plan in English and Russian, to communicate to the flight crew current daily schedules and plans.

Development and establishment of a 6.5-hour crew workday for planned payload flight operations, excluding medical operations requirements.

Development of daily research program reports, and weekly *Mir* system status reports.

Development of a plan of action for addressing anomalous conditions in payload hardware, given limited communication with on-orbit vehicle and differing work schedules and hours between the U.S. and Russia.

Development and implementation of a plan for utilization of U.S. ground communication sites in support of *Mir* on-orbit operations. These sites were used for air-to-ground (A/G) voice and telemetry operations.

Utilization of Russian A/G communications and telemetry in support of NASA *Mir* operations for medical, payload, and public affairs operations.

5.2.5.4 Joint Lessons Learned/Future Applications

Development of integrated, coordinated procedure development process, taking into account integration and training requirements and schedules.

Development of close working relationships between flight controllers from distant sites and cultures.

Establishment of routine process for review and unlink of messages to flight crew from differing control facilities.

Development of a flight planning process based on NASA-*Mir* lessons learned, utilizing design (pre-mission) and real-time (in-flight) planning. Need to make allowances for experiment setup, deactivation requirements, photo/video setup sessions, hardware anomalies, etc.

Enhanced A/G communications in support of on-orbit operations, including greater use of satellite communications, and expanded ground support networks.

5.2.6 Integration IPT

5.2.6.1 Executive Summary

The primary challenge for NASA/*Mir* Integration was to provide quality payload management, processing, and delivery while adapting to changing technical and programmatic requirements and adjusting to cultural obstacles. The organization also designed, certified, and delivered shared hardware equipment for use by multiple users on the *Mir*-OS. The planning and implementation of payload integration for NASA/*Mir* required careful analysis of payload technical requirements, successful management of the acceptance testing (AT) process, effective coordination between payload providers and vehicle managers, and timely delivery and integration of payloads to the appropriate carrier elements.

The success of the payload integration task can be traced to the solid working relationships developed between integration personnel, payload developers and the Russian technical specialists. These groups were able to integrate different philosophical and historical approaches to design and testing so that the ultimate goal of launching and operating science payloads was always kept in focus. The processes developed to attain these goals were tested and refined as the program progressed, resulting in a well-defined set of processes that can be applied to future crewed spaceflight programs.

5.2.6.2 Structure and Processes

The programmatic and technical requirements imposed upon the NASA/*Mir* program were documented in the US/R-001, Plan for Managing the Implementation of the NASA/*Mir* Science Program, and the US/R-002, Hardware General Design Standards and Test Requirements. These documents contained the required processes, document blank books and the technical design requirements for hardware operating aboard the *Mir* Space Station. Each of these documents went through extensive joint review to develop a mutually agreed-upon set of requirements.

The MOIWG Integration IPT was responsible for ensuring that all payload hardware was certified for flight aboard the U.S. and/or Russian launch vehicles, and that all required documentation was complete, with the overall objective and goal of ensuring that no hazardous conditions existed for the crew or station. Integration documentation prepared for the NASA/*Mir* program consisted of the following jointly signed documents:

100 - Hardware Development Requirements
101 - Equipment Technical Description
103 - AT Procedures
104 - Incoming Inspection and Performance Checks
105 - Certification Test Procedures
106 - Certification Test Protocols and Reports
107 - Safety Report and Findings
109 - Technical Description of Test Hardware

In addition, Dimensional Installation Drawings (DIDs), Electrical Interface Drawings (EIDs), ACTs (Russian certification statements) and 100 passports were also required. Documents were updated based on certification results, and in the course of AT-1 and AT-2. The span of this responsibility covered various Progress flights beginning with Progress 224 in August 1994, all NASA/*Mir* Space Shuttle flights beginning with STS-71, Soyuz launches during the NASA/*Mir* program and the two Russian modules, Spektr and Priroda. This work proved to be very challenging since it required integrating requirements and processes from the U.S. and Russian programs. Each side utilized a similar structure with an Integration lead and technical specialists associated with each payload, including Russian curators and U.S. payload engineers.

Acceptance testing of hardware to verify compliance with the hardware development requirements, and to authorize manifesting aboard the *Mir*-OS was accomplished via Acceptance Testing procedures (ATs). This process included jointly reviewing all of the technical documentation and test data and physical inspections of the hardware, and documenting the results through jointly signed protocols. AT activities occurred at JSC (AT-1) and Moscow (AT-2) as well as at the launch facilities at Kennedy Space Center and Baikanour (incoming inspections). Incoming inspections were performed with respect to hardware that was modified following AT, in cases where the final hardware processing for flight had a negative effect on its safety, or on hardware that had originally failed previous ATs. In the cases of defects or failures, a defect analysis protocol was compiled together with a plan of action including a partial rerun of the acceptance tests. AT activities for Progress, Soyuz and Shuttle flights primarily consisted of joint testing and documentation review with the physical integration of the hardware aboard the launch vehicle being the responsibility of the vehicle owner. The AT process continually improved over the NASA/*Mir* program and culminated in agreement on AT by Accompanying Documentation (AD) which allowed reflown hardware to be accepted without joint inspection or documentation review.

Previously flown hardware, that had not undergone modifications, was accepted for flight based on cover documents; the U.S. side performed acceptance testing internally, in conjunction with U.S. Quality Assurance requirements, and accompanying documentation was submitted for review and approval by the Russian side.

Safety approval for payloads flying aboard the *Mir* Space Station proved to be an evolving process. The Russian side had an extensive knowledge of long duration effects and hazards that had to be incorporated into the U.S. hardware design primarily in the materials area. Safety was originally worked independently by both the Joint Safety Assurance Working Group, WG-2, for vehicle safety and by WG-6 specialists for payload safety, each through a different set of documentation: Safety Analysis Reports (SARs) and Safety Certificates for WG-2 and the 107 document for WG-6. This dual path continued for the first 5 Increments, but these two documents and processes were combined for the last 2 flights in order to provide efficiency and to ensure consistent requirements review.

Stowage and hardware manifesting were managed through the US/R-004 document, Configuration and Status of U.S. Hardware on the *Mir* Station. This document contained information on the launch and return manifests for each Space Shuttle flight as well as on-orbit information for hardware aboard the *Mir* Space Station. This manifest was ultimately used to define the list of hardware requiring AT activities.

5.2.6.3 Joint Accomplishments

The evolution of the safety process from the independent SARs and 107 document into one document which was reviewed and approved by both WG-2 and WG-6 was representative of the teamwork and cooperation demonstrated during the Phase 1 Program. This change increased the efficiency of the safety process and the approval time for payloads aboard the *Mir* Space Station.

The design, delivery and integration of interface hardware as well as the integration of science payloads into the Spektr and Priroda modules was a monumental step in the Phase 1 program. These modules allowed the expansion of the science program and demonstrated the technical accomplishments that were performed during the program. The requirements definition, design to fabrication, and final testing processes that were developed for Phase 1 were examples of these accomplishments. All these achievements were a result of the intense technical and programmatic negotiations among multiple interagency and international partners that were driven by tight development and launch schedules.

The development of the AT by AD process represented an example of the relationships built between the U.S. and Russian sides. Initial AT activities were long and arduous processes requiring very detailed reviews of the hardware and documentation. The AT by AD process was based on the improvements made during each AT. This process led to cost savings by reducing the duration of AT activities and the number of personnel required to support them.

The development of shipping/logistics processes to and from Russia required a significant amount of coordination with Russian specialists, customs officials, JSC transportation and U.S. Embassy officials. It also required shipping/logistics personnel to maintain cognizance of all domestic and international export/import regulations. The successful implementation of these processes resulted in timely deliveries of flight and training hardware for tests, training and launch aboard Russian vehicles.

The establishment of a liaison office in Moscow to work as a direct interface between the U.S. and Russian sides improved the ability to transfer information and products. This office was extremely helpful in coordinating document approvals and hardware deliveries for Russian vehicle launches.

The integration of the Spektr and Priroda modules was a fully joint effort with both sides contributing to the design activities and physical integration of the modules. Electrical power, mechanical and data telemetry interfaces to the Russian systems were designed and developed.

5.2.6.4 Joint Lessons Learned/Future Applications

It is critical that integration documentation be prepared and delivered prior to delivery of the flight hardware for acceptance testing. Delays involved in the review of integration documentation unnecessarily prolong the AT process, and can be easily avoided by strict adherence to delivery schedules. This also applies to adherence to certification testing schedules and documentation.

It is essential that integration and operations personnel be involved in the early stages of hardware development and verification, in order to facilitate hardware acceptance and improve equipment operations and safety. The use of flight units to support certification testing can lead to hardware reliability issues, and thus should be minimized.

Cosmonaut Yuriy Gidzenko, astronaut Ken Cameron, cosmonaut Sergei Avdeyev, and astronaut William McArthur, shown working on board the *Mir* during STS-74

NASA 1 astronaut Norm Thagard