Section 8 - Extravehicular Activity (EVA)

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8.1 Executive Summary

For decades, the U.S. and Russia evolved independent space programs. Many of us were always curious about what our counterparts were accomplishing and if we could learn anything from each other. Tentative informal contacts have blossomed through the Phase 1 program to the point where strong mutual understanding now exists. We have found more common ground on a wide range of topics than differences. We built a strong foundation for future International Space Station (ISS) efforts in the course of accomplishing useful work. The individual missions, hardware and operations were tools in this work. Above all, we know the people and processes which will carry us forward.

For external tasks, the means of accomplishing these mutual efforts was the joint EVA WG. This group was chartered in September 1994 with responsibilities for the safe and successful development of all *Mir*-NASA EVA requirements and much of their implementation. It included representatives from all the key U.S. and Russian organizations. From hardware development to crew training and real-time Mission Control Center (MCC) support, this group led the charge on all joint EVA ventures. Interaction and support involving all of the other joint WGs was essential to overall success, since EVA is not and cannot ever be accomplished by a single discipline.

This report highlights the primary accomplishments, lessons learned and processes which are felt to have been of most importance. For most cases, the lessons are merely reinforcements of ideas we hopefully already knew independently. Now that we have a better common understanding of each other, together we realize that we have the potential to be stronger and more capable with our combined resources than if we go it alone. The trick is finding the path which uses each other's strengths.

8.2 Structures/Processes/Relationships

From the start, the joint EVA WG has relied upon the positive characteristics of the people involved. On both sides, each participant brought a high level of experience to bear on all issues. Each side shares a common desire for crew and task safety/success as well as a sense of the importance of each spacewalk to the perceived overall readiness to the long-term future. All exhibited a strong dose of common sense and trust in approaching each problem. Patience was the essential virtue to finding common understanding and solutions. In resolving each objective, motivations and physics tended to be universal rather than unique.

As with most projects, early and continuous participation of experienced team members is essential. Initial solution concepts evolve over time for many reasons. With numerous parallel projects occurring at the same time and limited manpower, plowing up old ground is not efficient (though sometimes valid as a sanity check). Even so, for the sustained long-term health of all, new personnel and ideas must be injected periodically. For joint efforts, it is best if personnel start out knowing the fundamentals and grow over time. Hands-on or suited trial and error learning opportunities with real hardware and facilities benefit everyone because paper level engineering is only as good as the experience of the participants. Attention to training skilled personnel is just as important to ground activities as it is to on-orbit operations.

To avoid reinventing the wheel and repeating past mistakes, knowing a certain amount of history is invaluable. Too many times, we have a tendency to focus so hard on current and future issues and not take advantage of past successes. New solutions balanced with consideration of existing hardware designs and experience can be faster, better, and cheaper. The EVA group spent considerable time exchanging records of past on-orbit statistics and task accomplishments. This historical information often expedited and helped validate solutions which would otherwise have been more difficult and had higher perceived risk.

As with most ventures, the start-up can be the most painful and time critical period. Team building and familiarity with each other's organizational hierarchy really enhance this transition. A clear understanding of personal and institutional responsibilities is also essential. Work and social time must go hand in hand so each learns interpersonal and organizational handling skills. People and cultural skills are critical to joint efforts. Being able to walk in the shoes of others is an old but true cliché. Overseas survival skills were learned that can be built upon. Things normally taken for granted like business services, facility access, transportation, food, health services, and entertainment may still need improvement, but the essentials do exist and are practically obtainable. These details make all the rest of the joint activities livable and more sustainable.

Advance planning and well-thought-out conceptual solutions are fundamentals, the importance of which cannot be understated. A weak up-front understanding of the problems and the pros/cons of each alternative can lead to a late realization of major painful changes. Margin in schedules, redundancy, and physical parameters cannot be overemphasized. Like a game of chess, more steps worked through in advance and more contingency plans in your pocket lead to victory. Proactive anticipation of issues allows maximum response time. Afterwards, attention to detail and constantly searching for weaknesses is important, but overall, a good end product starts with a good idea.

Coordinated implementation of each problem solution has to be facilitated by a variety of communication methods. Considering the long distance and time differential between Moscow and Houston, each communication opportunity is precious. Each agreement has to be clear, fully understood and well distributed. Face-to-face meetings and teleconferences have been the primary means of exchanging information. Agreements are recorded in protocols, faxes, drawings, electronic mail and formal documents. Without these and other information exchange alternatives, no productive work can be accomplished. Even so, periodic progress reviews and each side's coordination and enforcement of joint agreements are most critical to the quality and timeliness of implementation efforts.

A multidiscipline and multilevel participation approach also aided our joint efforts. We worked from the bottom up and the top down (especially when time was short). Driving assumptions toward zero was accomplished by coordinating with hardware designers, manufacturers, technicians, training organizations, crew members and management to confirm that all were headed in the same direction. Since late surprises are hard to recover from, more widespread involvement and regular peer review aids implementation and acceptance of the end solution (though it can also slow things down if not carefully managed).

Mutual time management was enhanced by Phase 1 involvement. Real schedules and templates of generic processes were exercised and understood that apply to ISS. From hardware development to crew training flows and on-orbit timelines, we have a good grasp of realistic milestones and durations for implementing various future activities.

One of the real strengths of the joint EVA WG, relative to some of the other joint groups, was that participants on both sides supported both Phase 1 and ISS work simultaneously. For us, there was no real distinction and the lessons learned in one program fed directly into the other. This accelerated our understanding of issues and solutions. In summary, the EVA WG, which participated in both programs, became much stronger as a result.

8.3 Certificate of Flight Readiness (COFR) Process

The COFR process related to EVA evolved over time during the *Mir*-NASA program. As with past well-rehearsed Shuttle missions, it addresses readiness of the people, operations and hardware prior to launch. During *Mir*, it also adapted to address unanticipated tasks/training. Feasibility and safety reviews were held for new operations before allowing on-orbit training or external activities. Future joint reviews will continue to emphasize early data exchange to avoid last minute "just-in-time" assessments. This extension of past Shuttle-style real-time planning and implementation reviews can be used for ISS events.

8.4 Training

Additional details on EVA training are further discussed in Section 7.

8.5 Accomplishments

1. STS-71 96 Bolts and Capture Latches - If the Shuttle and ISS fail to undock normally, the ultimate failure response calls for EVA release. Safely separating two massive objects without a major redesign of either vehicle was successfully developed before the first *Mir* docking. The same tools/techniques will be available for all ISS missions.

2. STS-71/*Mir*-18 Spektr Solar Array Cutter - After Spektr docked with *Mir*, one of its fishtail arrays failed to deploy normally. EVA was requested to develop a solution to improve available power for *Mir* systems and science. NASA and RSC-Energia (RSC-E) each manufactured, certified, and delivered candidate cutting tools in a matter of days. Using a small experienced team and adapting off-the-shelf parts, NASA's tool was ultimately used by the *Mir* crew to free the array. Similar tools/techniques will be available on ISS and can be utilized if needed again. This joint demonstration of rapid information exchange and accelerated tool development is a positive example of successful response to ISS assembly and maintenance failures.

3. STS-74 Docking Module (DM) and Solar Arrays - Design development and verification of the flight DM, its external solar arrays and water tank mockups of both served as an early example of the future for ISS. Joint requirements and inspection methods utilized for this *Mir* module have been migrated into use with ISS modules. Many design features have 1:1 correlation with ISS. The mockup implementation taught concrete lessons for the future. The benefit of start-to-finish experience with real hardware is invaluable.

4. *Mir*-21 Particle Impact Experiment (PIE) and *Mir* Sample Return Equipment (MSRE) - The first "joint" EVA called for *Mir* cosmonauts to deploy external U.S. science experiments. The up-front design of packaging, handling, locating, and attaching these items taught many of the fundamentals of *Mir*/ISS EVA integration and operations. NASA had not worked with similar science equipment since Skylab, so the extensive Russian experience in this realm was essential.

5. STS-76 Docked EVA (*Mir* Environmental Effects Payload [MEEP], Camera, Tethers/Foot Restraint) - The second "joint" EVA was not much different than most past Shuttle EVAs. It was, however, the first example of how the U.S. will perform EVA while docked and how to safely maneuver and restrain crew and equipment along ISS-type vehicles. Tasks included the deployment of 4 passive MEEP material science experiments, retrieval of a video camera for future reuse and evaluation of jointly designed tethers and foot restraints.

6. *Mir*-23 Joint EVA (Optical Properties Monitor [OPM], PIE, MSRE, Benton) - The next "joint" EVA was the first one to mix astronauts and cosmonauts outside in Orlan suits. Between preflight development, crew training and on-orbit work, most of the fundamental processes and techniques of Russian EVA were jointly exercised. While the experience with external science was important, the real benefit came from detailed understanding of generic EVA implementation.

7. STS-86 Joint Docked EVA (MEEP, Tethers/Foot Restraint, Simplified Aid for EVA Rescue [SAFER]) - To round out our joint experience, this EVA again mixed astronauts and cosmonauts, but in NASA extravehicular mobility units (EMUs). Besides retrieving the MEEP experiments, it yielded final experience with new EVA support equipment and utilization techniques prior to ISS implementation.

8. STS-86/*Mir*-24 Spektr Repair Hardware - Another example of rapid response to on-orbit problems is exemplified by the Spektr leak repair equipment delivered to

Mir by STS-86. Joint efforts included late training of the Shuttle EVA crew to transfer a large sealing cap from the cabin interior to the DM exterior for later use by *Mir* cosmonauts. Information exchanged on the devices and materials involved in finding and fixing module pressure shell leaks was mutually beneficial for ISS.

9. *Mir*-24 Spektr interior EVA - To restore power from the depressurized Spektr module, precedent setting internal work was planned, hardware was delivered to *Mir* and the tasks were safely implemented. Techniques of working internally in small volumes with poor lighting while anticipating and avoiding hazards were rapidly refined from past experiences. As another example for the future, the adaptability of basic EVA capability was proven in reaction to unanticipated hardware and situations.

10. *Mir*-24 Joint EVA (Spektr inspection, on-orbit training, Benton) - In the midst of a difficult period for all involved with *Mir*, the opportunity was made for more intense and first-hand joint experience in inspecting and diagnosing significant and widespread vehicle damage. Again, a mixed EVA crew of one astronaut and one cosmonaut was utilized for maximum mutual experience. This again showed the feasibility of building upon basic skills/experience via on-orbit training to safely react to unforeseen events and unquantified external conditions.

11. *Mir*-25 Joint EVA (preflight training, on-orbit training, space portable spectral reflectometer [SPSR]) - This was the third and last time a U.S. astronaut conducted EVA on *Mir*. Despite the extra challenge induced by a malfunctioning external hatch which altered the nominal egress/ingress procedures, the work was safely completed. The combination of all preflight and on-orbit experiences built a strong foundation for these on-orbit efforts.

12. STS-91/*Mir*-25 hardware transfer/return - The return of previously delivered, used and stored EVA hardware was a successful example of early coordination between past crew members and ground personnel. Clearly communicating where to look and what to look for was implemented by making sure everyone involved in MCC-M, on-orbit and in postflight processing had the same equipment information. The pre-pack effort was facilitated by starting early, consulting the memories of past cosmonauts, and getting photos and part numbers to all in MCC and on orbit.

13. Interoperable hardware - One of the big goals implemented and validated during Phase 1 was the development of hardware for shared use by both Orlan and EMU suited crew. Simple suit components like radiation dosimeters, moleskin abrasion protection, helmet visor antifog and personal hygiene underwear were jointly certified and used. Universal foot restraints, tether hooks, safety tethers and tool/body restraint tethers were proven and are being carried over for ISS.

14. Energy Module - The energy module was to be a Shuttle-delivered solar dynamics demonstration project that was ultimately canceled, but before that time,

it reached the critical design stage. EVA participation in its development had a direct benefit as a joint learning experience. This large complex hardware not only needed EVA crew for assembly, contingencies, and maintenance, but it would have required direct interaction between EVA crew and a robotic manipulator. It also helped us address "what-if" questions related to simultaneous operations with 2 EMU and 2 Orlan suited crew members. Except for the 4-person scenario, many of the operational EVA and robotic concepts and some of the interface hardware will be reused for the ISS 9A.1 SPP.

8.6 Lessons Learned

To do any productive joint work, you have to have at least a basic understanding of each other's capabilities, strengths, and weaknesses. Knowledge of each other's suits, airlocks, tools, facilities, vehicle interfaces and operational techniques is crucial to finding common solutions. Independent of differences like quantity of available documentation, we found no fundamental technical difficulties precluding joint cooperation. For example, the EMU and Orlan are both adequate to do productive work when properly used within design parameters. This flexibility will be utilized to optimize and balance the work wherever it may be needed on ISS.

On-Orbit Training

Since an infinite level of pre-mission planning cannot anticipate all on-orbit contingencies and keep the crew proficient forever, the means of adapting to off-nominal situations is extremely important. Together we confirmed that the ground and on-orbit crew must have rapid, identical and detailed data on the hardware and operations for vehicle, airlock, suit and tool interfaces (CD-ROMS, scale models, procedures, videos, photos, etc.). Quality time spent coordinating subtle implementation details between the ground teams and each member of the flight crew must not be excluded. The crew members must further work out roles and responsibilities among themselves by pre-EVA choreography of each step of nominal and off-nominal procedures. In-cabin practice with the suits, tools and worksite mockups helps all confirm EVA readiness for almost any situation.

Intravehicular Activity (IVA) Crew Support of EVA

Each of the *Mir* astronauts supported a number of EVAs performed by Russian cosmonauts. This included operating the *Mir* as well as, for example, controlling the deployment of the solar arrays. This support was essential to successful EVA completion. It also served as a reminder that IVA crew readiness to aid external work can only be accomplished with preparation/training and an adequate understanding of essential vehicle systems.

MCC-M, MCC-H and Station Operations

All other activities are sometimes secondary to what happens during real-time interactions between the crew and ground control teams. Quickly responding to problems and questions relies on all past knowledge and experience with a measure of creative responsiveness. Each side gained first-hand practice in the methods and limitations of each other's air-to-ground voice, telemetry and email communication capabilities. Failure analysis and root cause information sharing was demonstrated. It was reinforced that EVA is just a part of the total operations of a station and that external task workload must suit the overall mission objectives of IVA science, maintenance, cargo transfer, crew handovers, and basic living.

Organizational Responsibilities

In the dynamic organizational environment leading into ISS, all are relearning their roles and responsibilities. JSC institutional groups, which did not fully embrace Phase 1 efforts early on, have now realized that their support for ISS cannot be restricted to U.S. boundaries. A reasonable and necessary level of joint insight and cooperative implementation is required that involves all. While information for early, easy, and comfortable decision-making may be challenging to acquire, if we all rely on consistent fundamental principles (and not format/quantity), then most issues are not that difficult. ISS is truly a global multinational vehicle and needs to be treated as such by all.

8.7 Summary of Joint Cosmonaut-Astronaut EVA

The EVA WG (WG-7) coordinated spacewalk operations for astronaut and cosmonaut EVAs on *Mir* and the Shuttle for the NASA science program.

An agreement confirmed in the protocol of the meeting of September 28, 1994, established a program for conducting astronaut and cosmonaut EVAs during implementation of the *Mir*-Shuttle and *Mir*-NASA program. The *Mir* EVA program foresaw joint participation of astronauts and Russian cosmonauts in EVAs with the goal of carrying out the science program, inspecting the modules, and recovering operability of the systems as well as of the station assemblies. Shuttle EVAs for *Mir* were based on the situation on *Mir*.

Working with cosmonaut V. Tsibliev, J. Linenger was the first astronaut to conduct an EVA in an Orlan-DMA suit. The program, which included installation of an OPM, an external dosimeter array (EDA), an orbital debris collector (MSRE), and a panel with blanket samples (PIE), was completely fulfilled. Thermal luminescence dosimeters (TLDs) were installed on the space suits. The American-design joint safety tethers mounted on the Orlan-DMA suits were tested.

M. Foale and A. Solovyev conducted the second joint EVA on *Mir* in order to inspect the Spektr module. They also removed the Benton dosimeter. During the spacewalk, astronaut M. Foale demonstrated his expertise and capability of carrying out not just the planned program, but also operations which might be necessary during EVA. M. Foale's good knowledge of Russian also contributed to the success of his work.

The third astronaut, D. Wolf, and A. Solovyev successfully completed a joint spacewalk. Their goal was to work with the experimental spectroreflectometer SPSR. The EVA was successful, and unique data regarding the condition of the outer coating of several *Mir* surface areas were obtained.

During the STS-86 and *Mir*-24 mission, S. Parazynski and V. Titov, who were suited in EMUs, moved and fastened a large device designed to seal the Spektr solar array (СБ) drive from the Shuttle to the *Mir* docking compartment. The Russian restraint method utilizing two safety tethers was verified while working in the EMUs; mutually acceptable Yakor foot restraints for the ISS were tested.

Data on *Mir* EVA missions carried out jointly by the cosmonauts and astronauts are shown in Table 8.1.

Joint Shuttle/*Mir* EVAs

Table 8.1

№	Spacecraft (КК), Orbital Station (ОС)	Crew	Date	Duration	EVA Operations	Space Suit (СК) СК-1, СК-2	Compartment
1	*Mir*-21	Onufrienko Usachev	06/06/96	3 hr, 34 min	Installation of PIE sample hardware; Installation of MSRE sample hardware	Orlan-DMA 25 Orlan-DMA 26	Special airlock (ШСО)
2	*Mir*-23	Tsibliev Linenger	04/29/97	4 hr, 58 min	Instillation and removal of U.S. science equipment. Installation of: optical properties monitor, external dosimeter array, Removal of: Kvant-II (ЦМ-Д) special airlock module (ШСО) debris collector (MSRE), Kvant II (ЦМ-Д) special airlock module (ШСО) panel with samples (PIE); Testing of joint safety tethers; Exposure of the TLD experiment dosimeters (2)	Orlan-M N4,5 Orlan-M N4,5	ШСО ШСО

Joint Shuttle/*Mir* EVAs

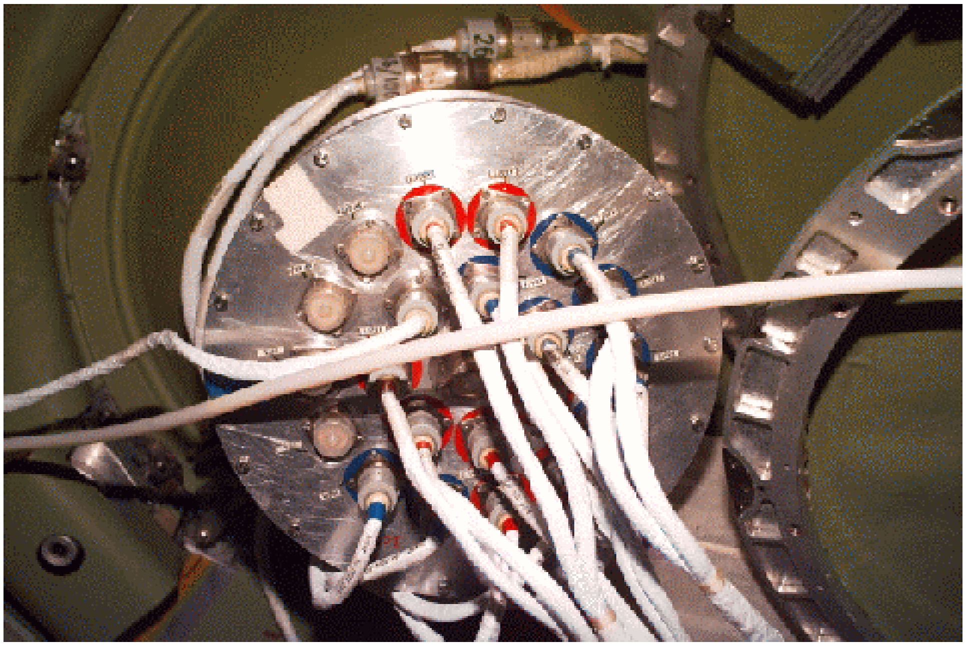
Table 8.1 Cont.

№	Spacecraft (КК), Orbital Station (ОС)	Crew	Date	Duration	EVA Operations	Space Suit (СК) СК-1, СК-2	Compartment
3	*Mir*-24	A. Solovyev M. Foale	09/06/97	6 hr, 00 min	Inspection of the outer surface of the depressurized Spektr module (link rods 110, 111, 112, 113, 115 were inspected); Measurement of the gap around Б16 drive of the solar array (СБ-1V); Deployment of solar array (СБ-1V) and auxiliary solar array (ДСБ-1V); Removal of the American dosimeter Benton	Orlan-M N4,5	ШСО
4	*Mir*-24	A. Solovyev Vinogradov	01/09/98	3 hr, 06 min	Disassembly of the OPM and inspection of the special airlock (ШСО) hatch	Orlan-M N4,5	Instrument science compartment (ПНО)-ШСО
5	*Mir*-24	A. Solovyev David Wolf	01/14/98-01/15/98	3 hr, 52 min	Measurements using the SPSR device and inspection of the special airlock (ШСО)	Orlan-M N4,5	ПНО-ШСО

Joint Shuttle/*Mir* EVAs

Table 8.1 Cont..

№	Spacecraft (KK), Orbital Station (OC)	Crew	Date	Duration	EVA Operations	Space Suit (CK) CK-1, CK-2	Compartment
6	*Mir* STS-76	R. Clifford L. Godwin	3/27/96	6 hr, 03 min	Installment of MEEP on the docking compartment (CO)	EMU	Shuttle airlock
7	*Mir* STS-86	V. Titov S. Parazynski	9/3/97	5 hr, 01 min	Transfer and securing of the solar array (СБ) drive sealing unit cover on the docking compartment (CO); disassembly of MEEP equipment on the docking compartment (CO)	EMU	Shuttle airlock



Replacement Hatch for the Spektr Module

NASA 5 Astronaut Michael Foale on the treadmill aboard the *Mir*