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Paper Session II-B - Shuttle- MIR a KSC Perspective

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INTRODUCTION

Last summer the world witnessed an event that was over two years in the making, but twenty years overdue—the docking of the American space shuttle Atlantis to the Russian space station Mir. A poll conducted by Space News ranked it as the number one news story of the year. Other newspapers printed excavated time capsules of the Apollo-Soyuz mission. What caused these two nations to awake from their “Rip Van Winkle” state of sleep and more importantly, how will the current Shuttle-Mir program build foundations for future joint programs into the 21st century? The wake-up calls were a product of disarmament and economics. The Cold War was over and space exploration had become too expensive for any one nation to go it alone. Russia had an operational space station, but limited funds to go further. The United States had tentative funding, but no space station. A joint program based on solid technical advances became good scientific and foreign policy. Kennedy Space Center (KSC) has become the center of implementation for a major portion of the Shuttle-Mir program. All the hardware, modification, manifest changes and flight acceptance testing come together at KSC and are implemented prior to the launch of each successful mission.

INITIALIZATION OF PHASE ONE

Born during the halcyon days of Détente, the Apollo-Soyuz Test Project (ASTP) laid the groundwork for the Shuttle-Mir docking missions. These missions are collectively known within NASA, and the human space flight community, as Phase One. The genesis of using the Russian Androgynous Peripheral Docking System (APDS), has its roots in ASTP. A very similar docking mechanism was used during that historic 1975 mission. The most obvious physical difference between the two mechanisms was the alignment petals, which extended outward on the ASTP version and which now extend inward on the newest design. During the Space Station Freedom design days, there was much debate over what docking system to use. In 1992, NASA had a team of engineers, led by Arnie Aldrich, look at using the Russian APDS on Space Station Freedom, and they found that it would be acceptable for use.

Proof-of-Concept In the spring of 1993, as a proof of concept and to further international relations with Russia as it emerged from the old Soviet Union, it was
agreed that the United States Space Shuttle would make a visit to the Russian Mir Space Station to pick up a U.S. astronaut who was to be launched to the Mir three months before aboard a Soyuz spacecraft. This was an agreement between NASA and the Russian Space Agency (RSA), and it was to be a one-time effort. Also in the spring of 1993, the Space Station Redesign Team (SRT) was convened. The SRT was to look at all concepts for the space station, and come up with three low priced recommendations to take forward to the Congress and the President as a substitute for Space Station Freedom, which was suffering political, and fiscal turmoil.

EXPANSION TO NINE FLIGHTS

As a part of the final report, the SRT called for the use of some Russian capabilities and hardware. The SRT recommended evaluation of Russian launch vehicles and life support systems because of their proven track record and the potential for cost savings. The SRT recommended outright the use of Soyuz capsules as the assured crew return vehicle (ACRV) and the APDS. As a result of these overtures to the Russians, and their willingness to participate, they were ultimately welcomed aboard the International Space Station (ISS) as full partners. As a part of the spirit of cooperation, the U.S. agreed to have the Space Shuttle visit the Mir space station ten times during the interim years, while both countries awaited the beginning of construction. (Later, in 1994, the number of flights was reduced to seven and now, as of 1996, it is back up to nine.) A primary concern for the Russians during these early negotiations was that they get good use out of the Mir and not abandon it before its planned useful life had expired. Toward that end, the U.S. saw an opportunity to begin collecting extended duration scientific data prior to permanent human presence on the ISS.

Early Implementation

The challenge for NASA to safely meet the schedule of Mir flights was daunting. It was well known that KSC would have to take the orbiter fleet and modify them with external airlocks for ISS docking and construction missions by 1998. However, the first Mir flight would require an external airlock by early 1995. As JSC and Rockwell set to work on the analysis and design tasks, KSC kept having to react to design changes. The schedule quickly showed that the orbiter Atlantis would be the best choice for the first seven Mir missions. Design review dates were arranged which would meet the schedule. Of much concern to the JSC and RI designers was the use of the Russian APDS. Loads and factors of safety in the APDS were critical to the design of the external airlock, and ultimately to the orbiter itself. KSC was of course concerned with ease of handling, checkout, and maintainability. As a result, KSC engineers were included in the design reviews held at JSC, RI-Downey, and at what was known as NPO-Energia in Kaliningrad, Russia. (NPO-Energia is now Rocket Space Corporation (RSC)-Energia.)

External Airlock

It was determined that the positioning of the external airlock in the payload bay of the orbiter would have to be different from its planned position for ISS missions. There were many factors in making this decision including loads, line of sight, and plume impingement. Because of these criteria, it was decided to place the external airlock and APDS over four feet further aft in the payload bay than it would be for the ISS missions. This meant that Shuttle-Mir mission kits for the orbiter would have to be modified, or extended, by that additional amount. Electrical and fluid lines would all have to be extended and supported. This also meant that a longer tunnel would have to be found, which would extend from the crew module out to the
external airlock. A tunnel adapter normally used for Spacelab missions was deemed acceptable for use, but it would have to be slightly modified. While JSC and RI were responsible for the design and fabrication of parts, KSC would be responsible for the actual installation and checkout of the new and/or modified components.

**FIRST ODS EXPERIENCE**

In the late Spring of 1993, additional modifications were defined and engineered for the Space Shuttle Atlantis. The modifications were to add scar hardware to the orbiter flight deck and midbody to support the external airlock and Orbiter Docking System (ODS). These scar mods added over 1400 wire segments, and interface feed thru connector plates. Rockwell/Palmdale completed the scar modifications and returned the spaceship to KSC in the Spring of the following year. In parallel with the orbiter scar modifications, a joint team of engineers from Energia, Rockwell, NASA/JSC and NASA/KSC received the first ODS hardware from Russia. The hardware was delivered to Rockwell/Downey.

**Checkout Prior To KSC** Prior to the flight hardware arriving at the Rockwell plant, Energia sent a “brass board” arrangement. This hardware accurately identified the shape and size of the black boxes and other components of the ODS. The hardware was configured like the flight hardware that would be flown. Wire routing, interface design characteristics, and design concept acceptance were all part of the brassboard experience. Once the flight hardware arrived at Rockwell/Downey, the team of engineers tested the hardware. The ODS hardware was integrated with the External Airlock. Each block box was installed, cable harnesses were routed, APDS was attached and system confidence checks were completed. Minor changes to engineering and peripheral hardware were made during this period. In late 1994, the first flight hardware was shipped to KSC for checkout and integration into the orbiter.

**Team Building** With the arrival of the first ODS hardware at KSC, the engineering team set off to perform a large number of hardware inspections, checks and tests. Routine issues such as platform configuration, access requirements and hardware familiarity had to be overcome. Ground support equipment, and drawings for that equipment were in Russian. Steps were in place to convert much of the information over to English. In the interim, system engineers managed using interpreters and common sense. Many of the Russian solvents, greases and lubricants did not have all of the hazardous material data requirements. Together, the Rockwell, Energia, Lockheed and NASA engineers prepared the appropriate information in time to use the materials on the flight hardware. A set of Special Test Equipment was designed and fabricated by Rockwell for use in the standalone checkout of the ODS hardware. For three weeks, Russian engineers were on site at KSC to participate in the battery of tests that were required to be completed prior to integrating the hardware into the orbiter. This hand-to-hand exchange, on a daily basis, was critical to resolving the numerous technical questions which surfaced. The ODS hardware was in great shape, with only one minor technical problem which needed hardware replacement. However, the integration of a new set of flight hardware into the well known and standardized system on the space shuttle proved to be the biggest challenge. In the end, the ODS and External Airlock were ready to support the Orbiter Atlantis’ installation schedule. The next phase of joint operations was to install the Russian hardware into the orbiter and perform the End-To-End tests.
Requirement Iteration

The tests required to be completed in the orbiter were defined in the Operations and Maintenance Requirement Specifications Document (OMRSD). The first set of these requirements were agreed to after the brassboard experience. A few weeks prior to the Orbiter-to-ODS checkout, another series of reviews were held on the test requirements. This was the first face-to-face meeting on the requirements with all of the appropriate engineering parties. New information from the Russian engineers, data from the follow-on brassboard tests and standalone flight hardware experience were used to revise a number of requirements prior to the End-to-End test. This iteration of the requirements, based on each past phase of hardware processing, provided a complete set of requirements to be implemented prior to OPF rollout of Atlantis. The End-to-End testing proved that the joint team approach to the ODS design and implementation paid off.

Flexibility

Throughout the first hardware processing at KSC, flexibility in the schedule to account for the learning process, was instrumental in making the technical preparation of the flight hardware compatible with the schedule to launch on time. There was not one Interim Problem Report generated from the End-to-End test. During the successful flight of STS-71, there were no Inflight Anomalies associated with the ODS hardware or operations. The NASA, Russian, Lockheed, and Rockwell engineering teams worked together to communicate and resolve any issue. Each member of the team clearly understood the importance of each other in reaching to the goal of mission success.

SECOND FLIGHT OF ODS

The second docking with MIR was completed in November of 1995. In preparation for this mission the team took the advances of the first flight and needed to almost double its performance. Since the STS-71 mission came back with no ODS problems, and only one minor problem with a blanket for the Vacuum Vent valve on the External Airlock, KSC's team focused on repeating past performance.

Rewire For Docking Module

The additional set of tasks to complete during this second flight were related to the mission of bringing the MIR Docking Module (DM) to the Russian space station and permanently attaching it to a station node. This required a complete rewire of the External Airlock, and the orbiter Aft Flight Deck. The engineering to support the rewire was established, and negotiated with the team members, two months prior to the modification processing. Many of the harnesses were fabricated in Russia, shipped to Rockwell/Downey for testing, and further integrated into mission kit harnesses and shipped to KSC. This time intrusive task required constant coordination and partial shipments of hardware and engineering. Secondary structure was also added to the External Airlock to support the harnesses and new black boxes used for switching control from the Orbiter ODS to the DM ODS. KSC implemented these mods and the corresponding checkout of the standalone hardware in less then two months.
Docking Module To ODS Interface Testing

While the ODS was being processed, the Russian Docking Module (DM) was shipped from Russia and processed in the payload processing buildings. A team of 100 Russian engineers worked for two months configuring, preparing and testing the DM systems. Midway through the DM process, NASA, McDonnell Douglas and Lockheed engineers started additional checkout of the DM. Once installed in the orbiter Atlantis, a complete set of interface tests were completed. The control and operation of each APDS was tested from the Aft Flight Deck. These tests ensured that with modifications the flight hardware would operate as expected. Like STS-71, these tests were conducted with no Interim Problem Reports generated against the flight hardware. A repeat performance was accomplished.

Routine Checkout And Solid Agreements

Since this was the second flight of the ODS, a strong sense of teamwork was apparent. The agreements derived for the first experience now developed into solid long term arrangements for system checkout and operation. The team was well entrenched on the learning curve, and technical decisions were reached much quicker and with a deeper knowledge base. The experiences of the second flight led to an established process for future flights. Unique checkout procedures were developed into routine procedures. Test requirements were standardized to the long term. Finally, the system performance on orbit was repeated. During STS-74, there were no Inflight Anomalies associated with the ODS or the DM.

TECHNICAL LESSONS LEARNED FOR ISS

The integration and processing activities at KSC will play a vital role in the readiness of the Space Shuttle to support the first U.S. launch, STS-88 ISS-01/SSAF-01-2A, the first Element Launch (FEL) assembly flight. The lessons of the Phase 1 Shuttle/MIR experience have become the foundation in the planning for the launch, and assembly, of the on-orbit Cargo Elements and crew compartment items.

Orbiter Modifications

The following is a brief overview of some of the major modifications to the Orbiter which are required to support ISS missions.

The Orbiter Interface Unit (OIU) is a new avionics box designed to be the primary command and data interface between the Orbiter and the ISS command/data handling (C&DH) system. There will be two OIU’S per orbiter, located in the aft flight deck. The OIU’S will be manifested on each ISS assembly and utilization mission. The OIU essentially converts the ISS, Mini-Pressurized Logistics Module (MPLM), Space-to-Space Orbiter Radio (SSOR) MIL-STD-1553B commands and data to Orbiter format, and vice versa. The OIU telemetry downlink, via the Orbiter Payload Data Interleaver/Pulse Code Modulation Master Unit (PCMMU), has a capability for up to 64 kilobits per second. The Orbiter’s PCMMU telemetry output is 128kbps. Thus, the Orbiter’s health and monitor data will be limited during Shuttle ground processing operations in parallel with OIU checkout operations.
The Space-to-Space Orbiter Radio (SSOR) will provide a two way digital voice channel from the Orbiter to ISS, and a telemetry/command response from the ISS to the Orbiter. It will also support the Extravehicular Mobility Units during Extravehicular Activity. The SSOR will interface to the OIU via the MIL-STD-1553B data bus network and transmit and receive via a UHF antenna located in the Orbiter payload bay.

The Assembly Power Converter Unit (APCU), provided by the ISS Program, will convert the Orbiter’s 28 Vdc to 124/140 Vdc to support the ISS and MPLM power requirements. The APCU will be located on the Port Side in Bay 5 of the payload bay under the blankets. The avionics currently located there on this shelf will be relocated so the APCU can be placed on the top with a new coldplate. The supporting wire harness mission kits and APCU installations will be accomplished at KSC on a mission to mission basis.

The Orbiter Docking System (ODS) consists of the Russian Androgynous Peripheral Docking System (APDS), the Docking Base, and the external airlock. It will be positioned in the ISS position, located in Bays 1 and 2 of the Orbiter payload bay. The internal airlock will be removed, and all internal airlock functions will transfer to the external airlock. Also, the currently designed Russian Mir APDS docking mechanism will be redesigned to support ISS with different springs and dampers to allow for “softer” docking.

STS-88 Integration Activities In April 1997, the Space Shuttle Endeavor will begin its post OMDP and “Up Mission Processing” activities at KSC for STS-88 ISS-01/SSAF-01-2A (FEL). KSC will be challenged by the new orbiter design changes and the new processing and checkout procedures that go with them. KSC has put together a steering team, and forum, comprised of NASA and contractor personnel, to assist in the integration of ISS into Shuttle Ground Processing and Launch/Landing Operations. Also, this team will continue to support the ODS/APDS off-line and on-line operations to identify, and communicate, those issues that affect ISS operations and engineering to the appropriate ISS Integrated Processing Team at KSC. One of the first products of this team for STS-88 was to integrate a combined problem of relocating the ODS from across Bays 1 and 2 position (ISS) to the Bay 3 position (Mir), and accepting delivery of the ISS APDS late in the Orbiter Processing Facility (OPF) flow.

Tunnel Adapter Assembly The Mission Operations Directorate at Johnson Space Center concluded that for STS-88, the Node 1/PMA geometry, with its offset, provides no direct view of the Russian FGB during on-orbit rendezvous and proximity operations with the ODS installed in the Bays 1 and 2 position. Thus, a decision was made to relocate the ODS to the Mir position. (Bay 3) This created a dependency on a scarce resource, the tunnel adapter assembly (TAA). There are only two TAA’s to support our fleet of four Orbiters. Analysis of the Shuttle manifest revealed a TAA will be available post STS-83 (OV-102), but with limited time to perform the new bracket modifications required and their alignment to support the fluid transfer lines to the ODS. With the STS-88, flight 2A, launch date, Dec. 4, 1997, being a hard fried point in the Shuttle manifest, it was decided to perform the TAA mods at an earlier opportunity. The TAA mods will be performed in an off-line facility when it is not being used between STS-78 (OV-102) and STS-83 (OV-102), during a four month window. But once the modification and fluid line alignment has been completed, this will be
the only TAA which can be used without repeating the process. The TAA and the flexible extension will have to fit between the Orbiter’s Xo576 bulkhead and the external airlock. The associated fluid lines cannot be installed on the TAA during the actual installation of the TAA into the Orbiter because of the hard fluid line interface at the 576 bulkhead. With the alignment already done, the fluid lines can be installed and serviced before TAA installation.

Mir APDS Another related issue to the ODS, is that the delivery of the new ISS APDS may not meet the KSC need date, and may jeopardize the STS-88 launch date. JSC and the KSC /SSIT team recommended to use the STS-71 Mir APDS to support STS-88. The revised plan calls for NASA/Rockwell International to modify the Mir APDS, and install four umbilicals and add a switchbox to support the ISS APDS. The “softdock” concern is not an issue with the first assembly flight for mating the Node I/PMA to the Russian FGB.

CULTURAL LESSONS LEARNED

In the business world, too much emphasis is often placed on the bottom line and expediency, and not enough effort is placed on establishing and nurturing relationships. When addressing the Mir Symposium held in Washington, D.C. in July 1993, Dr. Brian Dailey of Lockheed Missiles and Space advised “if anything fruitful is to be harvested from this joint venture, we must enter for the long haul and an enduring friendship and be cautioned against the quick buck approach.” Following Astronaut Norm Thaggard’s return from the Russian Mir space station, NASA Administrator Dan Goldin identified language as the top priority in working with the Russians. Language can be further defined as aspects of communication, cultural sharing, respect and mutual growth. Putting this advice into practice, the Kennedy Space Center has provided cultural and linguistic training for the engineering and technical personnel interacting with the Russian teams. The engineers have learned to become aware of and capitalize on shared values: national pride and patriotism, self-sufficiency and strength, intellectual and scientific achievement. Despite a number of obstacles such as limited instructors, and the inability to use the Russian language daily, a handful of engineers continue to study the language.

Overcoming Barriers At the same time, there is an increase in the frequency of contact with the Russian teams. Last year, KSC hosted 100 Russians, over a five month period, in preparation for the STS-71 and STS-74 Atlantis missions to Mir. Telecons with Moscow are now a weekly routine involving interpreters on both sides of the ocean. Critical design reviews for the International Space Station are scheduled every three to four months. Consequently, the difficulties in overcoming language and cultural barriers have increased. Securing visas, getting materials and hardware through US and Russian customs, dealing with time differences of up to twelve hours, receiving documents requiring translation, and the transliteration of part numbers have all proven to be a challenge. Adding to the difficulties is
the “generation gap” between the older Russian engineers and their much younger American counterparts. Younger American engineers, on the Shuttle program, are much more mobile in their career moves, thus reducing the time to overcome many of these difficulties. Social interactions have proven to be equally challenging, often leading to missed opportunities. While interpreters are busy translating lengthy protocols, the Russian and American teams often sit across from each other in silence. Even a rudimentary knowledge of Russian with a few simple questions to ask or a few simple phrases, could be used to break the ice and go a long way in establishing relationships, even friendships. Interpreters are not always the answer. Both Americans and Russians may feel uncomfortable using interpreters to discuss what appears to be less significant matters, and the interpreters very presence may make the conversation less personal. What brings true stability to Russian business dealings is the fact that steady partners, as a rule, quickly become friends. The team being used in the Phase One Program are developing working friendships with their Russian partners. These working friendships will help bring success to the ISS program.

**SUMMARY**

In summary, the goals of the scientific and foreign policy makers have been converted into a solid foundation of joint space operations between the United States and Russia. The initial challenge of making a one time docking with the Mir Space Station has become a concentrated effort to prove joint operations are possible, and in fact, highly desirable for both nations. KSC brought together the necessary engineering, hardware and tests to make the first two Shuttle-Mir missions a complete success.

The lessons learned from the Shuttle-Mir experience will provide the foundation for ISS success. The frost ISS assembly flight, STS-88 ISS-OI/SSAF-OI-2A, will have many “firsts”, just like STS-71, with new designs, new requirements and new processes. The vehicle modifications, their associated Ground Support Equipment/Field Support Equipment and reliance on international partners continues to provide a high level of complexity to the overall integration activities for the first ISS assembly flight. As our nations prepare for the follow-on construction of the International Space Station, each engineer will have to grow and expand upon their knowledge of their foreign partners. In haste to build, each member of the international team cannot overlook the necessities of establishing long term relationships, and therefore recognizing the common goal of a truly international space station. As each makes the effort to learn about their foreign partners, the focus will not just be monetary or foreign policy, but rather the focus will be the greater good of cooperation with all humanity in space exploration well into the 21st century.