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**Paper Session II-B - Integration of Systems on MIR Processes and Comparisons**

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INTEGRATION OF SYSTEMS ON MIR
PROCESSES AND COMPARISONS

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Johnson Space Center
National Aeronautics and Space Administration
February, 1996

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Integration of Systems on Mir
Processes and Comparisons

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National Aeronautics and Space Administration

INTRODUCTION

The Priroda module is the last of six principal modules that will compose the Mir space station. To be launched in April, 1996, it will be added to the Mir base block, Quant, Quant II, Kristall, and Spektr, each launched between 1986 and 1995. Together with Soyuz and Progress transport vehicles, the system has been in operation in orbit for more than ten years.

In 1990, the U.S. and Russia began a joint program of scientific and manned space flight studies in response to agreements reached by the Bush Administration. Initial activities included the conduct of medical experiments studying the effects of long-duration space flight on board Mir. Provisions were made for the flight of a Russian cosmonaut on Space Shuttle, and of an American astronaut on board Mir. After an initial period of activity of approximately one year, the program was expanded through a contractual agreement to include the docking of up to ten Space Shuttle missions to Mir, the addition of several American astronauts on Mir and of Russian cosmonauts being brought to and from Mir on the Shuttle, and of the flight of approximately 2000 kilograms of scientific hardware and support systems on board Mir.

Both the Spektr and Priroda modules were designed in the mid to late 1980s and the flight systems constructed and assembled in 1989 to 1991. Priroda was to have been launched by 1992. As the U.S./Russian contract was put in place the modules were reconfigured and retrofitted to house U.S. science hardware. This resulted in the elimination of some Russian scientific systems, and in the addition of module secondary structure and other modifications.

In May, 1994, the Spektr module was launched to the Mir station. It carried approximately 700 kilograms of U.S. scientific payload, principally in the medical fields. The launch, docking, and subsequent activation of Spektr occurred during the same period that the American astronaut, Dr. Norman Thagard, was completing a four month endurance mission on Mir.

The U.S. Priroda effort, coming after a period of intense work to meet the Spektr integration activity schedule, was structured and organized in an effort to establish long-term working relationships and to develop an infrastructure for the integration and operation of future spacecraft systems. In addition to the spacecraft systems and experiments integrated on Priroda, several significant integration mechanisms were established. These included prototypes for the definition of systems requirements, integration documentation, and resources, including manifest, control documentation. Also, new concepts and hardware was introduced for the housing of hardware on Shuttle and Mir, and to expedite hardware transfer between the two vehicles.

Perhaps one of the greatest benefits of the NASA/Mir program has been the ability and necessity of the Russian and American program's engineering and management staffs to work together, gaining mutual experience, trust and respect.

THE PRIRODA MODULE

Priroda, at the time of the signing of the U.S./Russian contract, was due to be launched in 1991, though a more realistic launch date was probably in early 1992. As a result of additional effort required to implement the NASA/Mir contract, delays in work on the Spektr and other difficulties, including internal Russian funding, manpower, and contractual problems, the
Priroda launch was repeatedly delayed, until at the time of this writing the launch is scheduled for mid-April, 1995.

Priroda’s total mass is 19.5 metric tons, of which 3400 kg is scientific hardware, most of which is Russian and Russian affiliated earth resources observation equipment. Of the total, the U.S. is providing 850 kg of materials processing, life sciences, earth observation and support systems at launch and will also bring considerable additional equipment for placement on Priroda during the course of the NASP/Mir science program. The module is capable of autonomous flight prior to its docking with Mir, and includes significant new service systems which will enhance Mir’s earth observation and telemetry capabilities.

A representation of the major Priroda features is included as figure 1.

The Priroda module is approximately 2.9 m in diameter over most of its length, with five bulkhead rings, a spherical base to which an unpressurized instrumentation structure is mated, and a conical base (at launch) in which is placed the docking system and hatch for crew intravehicular transfers.

The Priroda module includes a payload shroud, the instrument/payload compartment, and an instrument module. The shroud is deployed during the launch sequence and protects the module and external equipment from aerodynamic effects. The instrument compartment is the main portion of the module and houses spacecraft systems, experiments, and the pressurized area for crew operations. The instrument module is unpressurized sections housing spacecraft systems.

The instrument / payload compartment is divided lengthwise into three sections. The first compartment principally houses modules systems hardware while the later two house primarily payload systems. All of the U.S. designed hardware is installed in the instrument / payload compartment. The instrument / payload compartment is divided into an inner habitation and work compartment and an outer instrumentation compartment. The two are divided by aluminum-magnesium coated plastic panels. The panels provide a fire break and form a significant portion of the modules environmental control system, allowing conditioned air to flow through the crew compartment before returning through the instrumentation compartment.

The instrument module, in part aft of the instrument / payload compartment and in part surrounding the compartment, carries propulsion system components, EVA restraints, and scientific equipment.

In order to accommodate U.S. systems and scientific hardware the Russians modified the Priroda module to include additional structural load bearing elements and the addition of additional openings and internal compartments for containment of U.S. systems. Several Russian experiment systems, some in the biotechnological area, had to be eliminated in favor in order to meet contractual obligations with the U.S.

THE U.S. PRIRODA EFFORT

Phase 1A of the program was in progress during a major period of development and integration of medical science hardware in support of Spacelab missions. The effort was placed under the auspices of the Johnson Space Center. Consequently, Spacelab hardware, such as the Standard Interface Assembly (SIA) Rack and MIPS data management system hardware were adopted for use in outfitting Mir. These resources were invaluable in saving the development effort the resources of time and dollars, especially as the Phase 1A started principally as a medical research effort using many of Spacelab’s existing experiment systems.

In planning for Phase 1 B, efforts were being made to expand the Mir research program into the areas of materials processing, biotechnology, and earth resources research. Many of the
systems in use or in development in these areas had been developed for use in the Space Shuttle middeck.

In the period from 1993 through early 1994, a significant effort was being directed by NASA Headquarters to reduce the resource requirements associated with flying Shuttle missions. Included in the cost reduction efforts would be an effort to reduce the costs associated with payloads and science implementation. Spacehab, Incorporated had recently flown the first successful Spacehab mission on STS-57, and put forward an unsolicited proposal to support the Mir missions. Spacehab was built to support the NASA commercialization effort under the Commercial Middeck Augmentation Module Project, specifically to expand the capability to fly payloads developed for use in the Shuttle middeck.

By the late spring of 1994, it appeared likely that NASA would shift its Mir efforts away from Spacelab and towards Spacehab. The availability of experiment systems developed for use in the Shuttle middeck, combined with the potential for use of the Spacehab module for the Mir missions, led to the adoption of middeck compatible resources on board Priroda. Although a new design specifically for use in Priroda, single lockers were designed specifically for commonality in dimensions and utility routing with similar systems on board the Shuttle middeck and Spacehab. In order to expedite the logistics of hardware transfers between Space Shuttle and Mir, a family of soft stowage bags designed for fit into the lockers was designed and developed. Payload utility panels adapted from the Middeck Utility Panel on Shuttle, and designed specifically as an interface between the Priroda power system and middeck-class experiments provided power resources. The centralized PUPS also limited the number of interfaces directly between the U.S. experiments and the Mir power system, thereby simplifying the developing of electrical interface drawings and affording some protection to both Mir systems and U.S. payloads. In order to meet Russian schedules for a launch by early summer of 1995, a crash development process was put in place by July, 1994, with a preliminary design review in August, 1994, a preliminary ICD issued concurrently, and flight ready systems hardware was in hand beginning in September, 1994. Fabrication of all mounting panels, adapter plates, and single and double lockers was completed by December, 1994, and racks, and the U.S. power distribution system were completed by February, 1995.

During the same time period, major experiment systems were being adopted for use in Priroda. These included the Microgravity Glovebox, a system designed originally for use in Spacelab, adopted for use in the middeck, and modified to meet Priroda requirements. Accommodations for Shuttle Thermal Enclosure System (STES) units, which had been in extensive use for a variety of commercial and scientific efforts such as the Protein Crystal Growth series of missions, were included in the Priroda planning. The Bioreactor, a system for the development of living cells and which had a near term requirement for long duration missions, was adopted for use on Priroda in the form of the Biotechnology System. An agreement between NASA and the Canadian Space Agency brought a third nation’s experiment’s into the U.S. Priroda effort in the form of the Microgravity Isolation Mount (MIM) and experiments designed for use with it. Other systems included the Enhanced Dynamic Load Sensor (EDLS), for making anthropometric measurements, the Commercial Generic Bioprocessing Apparatus, video and photographic equipment, and several experiments in combustion, fluid dynamics, and biology. A data management system, the Mir Interface to Payload Systems (MIPS), developed initially for use on Shuttle and adapted for use on Spektr, was also included.

INTEGRATION PROCESS

With the beginning of Phase 1 B of the NASA/Mir program, a contract for the integration of U.S. hardware was established between the Russian Space Agency and NASA. In response the Russians began to centralize their integration organization.
The Rocket and Space Company (RSC) Energia, as the prime contractor for defining integration requirements and vehicle configuration for the Russian Space Agency, has been responsible for the development of all of the Russian, and previously Soviet, manned space vehicles. The company is organized into several major groups responsible for:

- vehicle definition, development and integration,
- systems design and integration
- science and applications
- testing

An organization chart based upon the author’s observations is included as figure 2.

As the NASA/Mir program developed, responsibility for integration of U.S. hardware was delegated to the science and applications group. This group had been responsible for the definition and development of technological, biotechnological, and medical experiment systems for Energia. Though the group had been responsible for preparing integration documentation for their own systems and also had a science program management and integration department.

At the beginning of the U.S. effort to develop systems for use on Priroda, NASA already had over a year and a half of experience with the Spektr activities. Though the Spektr effort was largely successful, it was not without difficulty. Spektr comprised most of Phase 1A of the program. The Phase 1A portion of the NASA/Mir program was done without the benefit of a formal contract and therefore firm guidelines, processes, and programmatic or technical requirements were not established and a formal, centralized configuration control system was not in place.

Although a programmatic requirements document, the US/R-001, was initiated by the Russian side’s medical research/integration group, the document was never completed and never formally signed. Consequently no schedules, programmatic requirements, or documentation requirements were ever firmly established.

Integration documentation, in the form of ‘100 Series’ documents, equivalent to the Space Shuttle program’s Payload Integration Plan, Annexes, and ICDs, were not consistently required or applied. Individual Russian engineers from the science and applications group were responsible for guiding the development of the integration documents, but content of the documents was largely up to each individual engineer’s personal definitions. Similarly, hardware testing requirements were not uniformly applied. In some cases, the Energia integration group was bypassed by NASA investigators working directly with other Russian science organizations such as the Institute for Biomedical Problems (IBMP).

Similarly, though a systems and environmental requirements document was developed and signed during Phase 1A, it was incomplete and inadequate, and without a defined configuration control mechanism, new requirements were being established continuously. By mid-1994, no fewer than six, sometimes conflicting, versions of the US/R-002 Systems Requirements document were in use.

The process for integrating hardware and preparing documentation was largely ad hoc, with the integration groups, hardware test engineers, principal investigators and experiment engineers, and hardware coming together for meetings at which the U.S. side presented the experiment hardware and set about preparing and reviewing integration documentation. Frequently hardware had been tested and certified prior to the test and certification requirements having been defined.

Early in the Priroda effort, meetings were held between the principal NASA and contractor engineers and their Russian counterparts in Russia. A plan was developed for the definition of design and test requirements and for the development of draft integration documentation. This would occur in two phases; the initial would occur in Russia approximately six months prior to hardware turnover. A second review of documentation in the U.S. would occur two
months prior to hardware certification testing. Although the design of many of the support and experiment systems was already well along by the time either of the reviews would occur, the reviews would allow the definition of an acceptable hardware testing program far enough in advance to permit the program to be planned and scheduled accordingly.

Initially, requirement reviews and documentation reviews were scheduled according to hardware development plans. This proved to be unworkable as there were frequently overlapping activities occurring in both the U.S. and Russia. Therefore a phased approach was introduced in which reviews would be planned so that the center of activity would shift approximately every one to two months. The schedule of meetings carried out was:

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>City</th>
<th>Activity Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>August</td>
<td>Moscow</td>
<td>Final documentation preparation and test activities for support systems</td>
</tr>
<tr>
<td></td>
<td>November</td>
<td>Houston</td>
<td>Requirements definition for support systems</td>
</tr>
<tr>
<td>1995</td>
<td>February-March</td>
<td>Moscow</td>
<td>Requirements definition for experiment systems and support system hardware turnover</td>
</tr>
<tr>
<td></td>
<td>May-June</td>
<td>Houston</td>
<td>Final documentation preparation and test activities for experiment systems</td>
</tr>
<tr>
<td></td>
<td>July</td>
<td>Huntsville/Moscow</td>
<td>Requirements definition for experiment systems and experiment system hardware turnover</td>
</tr>
<tr>
<td></td>
<td>August</td>
<td>Houston</td>
<td>Final documentation preparation for stowed hardware and test activities for experiment systems</td>
</tr>
<tr>
<td></td>
<td>November</td>
<td>Moscow</td>
<td>Integrated testing of active hardware in the Priroda module and turnover of stowed hardware</td>
</tr>
<tr>
<td>1996</td>
<td>February-March</td>
<td>Baikonur</td>
<td>Integration of experiment systems and stowed hardware for flight</td>
</tr>
</tbody>
</table>

Periodically, the schedule became compressed and U.S. and Russian engineers would find themselves flying back and forth between the U.S. and Russia, together, as the center of activity shifted. But generally the approach always permitted the full understanding of hardware test requirements early enough that changes could be introduced, sometimes to the hardware design, and frequently to the hardware test program. The approach permitted time for developing document translations and also permitted hardware developers to plan for a second opportunity for hardware acceptance testing in the case that the first opportunity had to be aborted for technical problems.

Typically, an overview of the hardware, its operational procedures, and the test plans and requirements were defined first (100, 101, 102, 105 and 108 documents). Test results and safety documentation (106, 107) were submitted approximately at the time of hardware testing. Russian engineers responsible for hardware integration frequently had the opportunity to participate in and observe the hardware testing, and they concentrated their documentation reviews on all but crew training and safety documentation.

After the initial phase of documentation generation for support systems was completed (August, 1994), both sides agreed that it would be of mutual benefit to develop a set of guidelines or ‘blank books’ for experiment developers to use in preparing their integration documentation. The documentation being developed until this time was frequently inconsistent owing to different Russian engineer’s opinions on the appropriate document contents. It was also anticipated that standardizing the content and structure would simplify the job of translation, also reducing the cost for this considerable effort. The U.S. side lead this effort, reorganizing some of the document outlines so that redundancies could be eliminated. Blank books were formally approved by both sides in March, 1995. Unfortunately the late distribution did not permit their full use by the major experiment developers as their
documentation was already well along in development. Stowed systems and later Space Shuttle launched payloads going to Mir would find the documents of value, however.

Also during this period a new 001 document was prepared, identifying major milestones to be met by experiment developers; the 002 document was expanded and the multiple versions consolidated into a single set of requirements; and the format and contents of an 004 document were defined in order to maintain a manifest of all systems, interfaces, and resource requirements. A schedule of activities covering all documentation and hardware testing was published approximately every six weeks, and when managers and engineers were not attending meetings or reviews in one another’s country, telecons were being held frequently. Communications, either through telecons or faxes had to be maintained, as did the schedule of activities.

PROBLEM AREAS

Difficulties arose most frequently when organizations external to those responsible for U.S. experiment integration or for science were required to support activities. These incidents were most notable in the areas of training, operations and safety.

Training is conducted not by the Energia organization but by the Russian military at Star City. Energia science ‘curators’ are responsible, however, for on-orbit experiment operations. Although Star City trainers came to the U.S. to support some documentation and hardware reviews, training documents (108) were almost never reviewed or ultimately used. Energia curators almost never attended training sessions in the U.S. or in Russia. And other Energia operations personnel from the TSUP control center appeared totally unaware of U.S. experiment systems, their operations or requirements, until after the systems arrive in orbit.

Safety reviews of experiment or other systems have not been regularly conducted by the Russian safety organization. Safety approvals have been a major difficulty. The most emphasis is given in the materials area, though even here the organization and individuals responsible for the review, and who do not represent the safety organization, do not appear to go through a rigorous review process. Few detailed safety requirements have been defined and no “standard practices” guidelines, such as are available for the U.S. Shuttle program, have been provided. Russian materials engineers failed to attend many hardware reviews and test sessions and safety engineers were never in attendance.

Frequently inconsistencies arose in the handling of potential issues between different experiments, or even on the same system or experiment, from one review to another. One of the best examples occurred in the area of stowage provisions. After encountering serious materials concerns and issues with stowage foam provided by the U.S. for Spebr, the use of new acceptable materials was given a high priority early in the Priroda activity. Materials, processes and requirements were defined early with the full support of the Russian materials organization. But after hardware had been completed and submitted for final review prior to flight, new requirements were imposed, ultimately resulting in a total rebuilding of the stowage system.

Although safety associated documentation was required to be provided early, the information was not reviewed as it was being provided. Feedback on the results of the Russian reviews was so late that little remedial action could be taken-hardware had already been delivered and installed for flight.

The Russian organizational structure has been a hindrance in efficiently carrying out the overall Priroda effort. For instance, considerable flight-like training hardware was provided for outfitting a trainer at the Star City training facility. But since the trainers come under the responsibility of the military rather than the Energia hardware integration group, much of the U.S. training hardware has never been used.
Maintaining the schedule was a principal difficulty in the integration effort. Part of this problem was a result of inaccurate schedules provided by the Russians early in the program. For instance, the design, development, production, and testing of the U.S. support systems was expedited at some expense in man-hours and dollars, in order to meet the initial spacecraft integration schedule requirements. Hardware such as the lockers and electrical system was ready for the initial Russian review in late September of 1994, but the Russian’s first trip to the U.S. to review the Priroda hardware was delayed until November as a result of bureaucratic problems. Hardware which the U.S. was required to deliver in early 1995 was never used until late in the year.

Early in the program, delays to the Russian’s travel in turn delayed several of the hardware test activities until complete joint approval was gained and until Russians were physically present to observe some testing. The decision was reached, mutually, at the time of this November meeting, that in the future test activities would be conducted according to the schedule jointly agreed to at the previous meeting, regardless of whether all appropriate engineers would be in place by the required time. Such agreements, including schedule details, were included in joint meeting ‘protocols’.

Another schedule challenge faced in late 1994 and early 1995, was shipping and customs. Lockers, some four dozen of which completed testing activities by early December, 1994, were shipped immediately from the U.S. Shipping delays initially occurred as a result of common carrier problems. Then, when the hardware reached Russia, it was immediately taken into Russian Customs storage facilities. There it stayed through late February, 1995. After a thorough series of investigations, including researching the shipping policies for overseas airlines and several visits to the Russian Customs house, it was determined that delays resulted from two principal difficulties. The first was related to the size of the hardware shipping container. The larger the container, the more likely hardware would miss overseas flights. The second problem was due principally to delays by the Energia organization. These investigations led to discussions with the NASA shipping organization on how to package items in the future, with U.S. customs and the NASA Headquarters international office on required shipping documentation and external markings, and ultimately to the decision to attempt to hand-carry most hardware with engineers attending reviews in Russia. The concerted effort resulted in the reduction of typical transportation time to two days for hand-carried items and to approximately two weeks for typical shipped items.

The lack of a single authority to control all components of a space mission to the same degree that NASA does for the U.S. frequently creates inefficiencies and confusion’s that thwarts the best efforts of the individuals and individual organizations. Separate entities are responsible for integration and integration requirements (Energia), physical development and integration (Krunechev), training and training facilities (military-), and for launch processing (military Space Command). Within Energia, different organizations appear responsible for pre-flight integration and for in-flight operations.

**HARDWARE INTEGRATION**

After several delays to the Priroda module schedule, the module was ready for the integration of U.S. hardware in December, 1995. Testing at the KIS test facility in Kaliningrad proceeded according to plan with a single serious technical problem, fully the responsibility of the U.S. side. The problem points out the significance of standardizing engineering practices and maintaining communications.

A data cable connecting the MIPS data system to the MIM experiment, was miswired, causing a blown fuse in the MIM. The failure resulted form a combination of problems. The MIPS system utilized non mil spec connector which had not been wired in accordance with mil spec requirements. The data cable was improperly designed, and miscommunication, first between the MIPS, MIM, and Star City training group resulted in no test having been conducted between training hardware units, even though it was believed that a successful
test had been performed. Next, Russian engineers failed to follow jointly approved test requirements for an interface and functional test external to the Priroda module, prior to integration.

In January, 1996, a new MIM unit, already in preparation, was shipped to Moscow and then to Baikonur Cosmodrome in Kazakhstan. It was the last major piece of U.S. hardware accepted for integration.

U.S. engineers worked together with their Russian counterparts to integrate and test U.S. hardware at Baikonur. This activity occurred over a week long period without significant difficulties. Those which did arise came about mainly because the physical integration of hardware it the responsibility of the Krunechev Manufacturing company, rather than the Energia company which had responsibility for defining systems and integration requirements.

SUMMARY

Priroda provided an excellent challenge and an opportunity for the U.S. to demonstrate that it still has the capacity to develop space hardware for flight according to compressed schedules-something we have not had to do routinely in recent years.

Perhaps more significantly, Priroda permitted Russian and U.S. personnel to gain insight into the mechanisms and operations, frequently very different, in use by one another in order to prepare and fly their spacecraft, and perhaps most importantly, it created new friendships and developed confidence in one another’s technical abilities. Both could have great importance for future cooperative efforts in space.

ABOUT THE AUTHOR

Gary H. Kitmacher has been at the NASA Johnson Space Center since 1981. He worked for the Rockwell Space Shuttle Orbiter Division for four years in the areas of payload integration and configuration management. He joined NASA in the JSC Man-Systems (now Flight Crew Support) Division, where he was responsible for managing Shuttle crew equipment and stowage provisions and for developing and integrating systems for the international Space Station and lunar and Mars spacecraft. In these efforts Kitmacher worked closely with ESA and NASDA, and served on the contract source boards for the Space Station at MSFC and JSC. In 1991 he joined the Commercial Middeck Augmentation Module Project Office, served as the NASA manager for the second Spacehab flight, and prepared studies on NASAS potential uses for the Spacehab module, including a study which resulted in Spacehab's selection to support the NASA/Mir missions.

Mr. Kitmacher has a Bachelor’s degree in Geology from the University of Massachusetts, a Master’s equivalency in Astronomy and Physics from Michigan State, and a Master’s of Business Administration from the University of Houston. Prior to coming to JSC, Kitmacher was a planetarium director and taught at the secondary school and college levels.
Модуль дистанционного зондирования Земли "Природа" для орбитальной станции "Мир".

FIGURE 1A: MAJOR EXTERNAL FEATURES OF PRIRODA
FIGURE IB: U.S. SYSTEMS INTERNAL TO PRIRODA

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This chart is based on organizational relationships as observed by the author during development and integration of U.S. systems for the Priroda module of the Mir Orbital Station. It is nonofficial and was not produced or provided by Rocket and Space Company Energia.

FIGURE 2: Energia Organizational Structure. Department heads are indicated inside each box. Assistant department heads are below each box.