The U.S.-Russian Space Relationship: Symbolism At Any Cost?
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Two space stations, one old, one new, circle the Earth in orbits deliberately kept far apart. But the ties that bind the two, Russia's Mir and the multinational International Space Station (ISS), are closely intertwined due to technology, diplomacy, and money.

Aboard the veteran Soviet Mir, finally, things seem to have settled down after its annus horribilis, 1997, when every new day seemed to bring a new crisis. So too, more or less, aboard the embryonic International Space Station, now consisting only of the two modules Zarya and Unity, where it's all been almost routine. Unexpected problems did crop up in the International Space Station (ISS), mainly in the station's power and communications systems, and back on Earth engineers went about solving them.

The heart of the International Space Station is supposed to be a Russian-built and control module, holding the air and water supply equipment to keep the station's permanent crew alive. It also is to contain the station's primary maneuvering rockets and control computers. The U.S.-built section, Unity, is a giant hollow node with attachment ports for six additional modules that will make up the ISS.

Once called the FGB (a Russian acronym for "functional cargo block"), then re-named Zarya ("Star" in Russian), the second module flying in the ISS is not for full-time life support, but sort of a construction crew trailer on a building site. Built to fly for only a few months-the time necessary supposedly for the Russians to get their Service module project in gear-it was designed so that the ISS would not look like American attachments to an existing Russian space station. The US Node-1 module Unity had to get into space first, for appearances. So, essentially for political reasons-something which is seen again and again in ISS development-the United States paid for the temporary module, Zarya, which was built in Russia but technically "owned" by the United States. Zarya was launched in November 1998 and the Unity module was attached the following month.

Premature Trajectories

The stop-gap Zarya reached orbit at about the time launch schedules agreed upon by Nasa and the Russian Space Agency collapsed. The Russian government had cut funding to its own space agency every year through the mid-1990s. By the time of a major economic crisis in the fall of 1998, not only was the Russian central government no longer funding its own space program, it was actually taxing all foreign cash contributions, including Nasa's, requiring its space agency to kick back to the federal government a portion of the U.S. money sent to bail out the Russian space program from the consequences of federal non-support.

Temporarily reprieved by the U.S. funding for the Zarya module, Russia still has been unable to fly the long-term module, for the same reason as before: not enough money. With the most optimistic forecasts now hoping for launch of Russia's Service Module in November 1999, it looks like it will be more than a year of mostly unmanned flight before this crucial next step. As a result, flight controllers at Russia's Mission Control Center north of Moscow and at Nasa's facility in Houston will have to nurse the unoccupied space station by remote control for more than three times the period originally intended [Fig. 1].

And even after the Zarya service module is attached to the station, it could be months before a permanent three-man crew goes aboard-unless some bold new plans to eliminate preparatory manned flights are implemented. The problem is that the amount of rocket propellants aboard the Zarya and the lifetime of its avionics-guidance computers, batteries, navigation instruments, and communications electronics-are all based on schedules that have become obsolete. Although Zarya can be refueled and its avionics boxes be replaced during shuttle visits, this recently stretched mission-from four months to more than twelve-is opening the entire ISS program up to new risks.

Mir's nine lives

Meanwhile, in mid-February, as Russia's existing space station Mir plugged away past its thirteenth year in space, a new crew was launched for a six-month mission. That Soyuz crew comprised a veteran Russian commander, a French astronaut whose government paid cash for his ticket, and a Slovakian "guest cosmonaut" on a week-long visit, whose trip was paid on credit.

Mir appears to be in adequate health, all things considered. The rash of spectacular breakdowns throughout 1997 had eased when nine shuttle trips between 1996 and 1998 brought new equipment and supplies. Breakdowns may still be occurring but without a U.S. presence on board, they probably are just not announced. Occasionally news of problems does leak out. In April, for example, Russia's last geostationary radio relay satellite broke down, cutting off communications with Mir except through a handful of ground stations within Russia.

Still, nobody knows what will happen when this newest expedition on Mir ends. The lifetime of Russia's manned Soyuz transport spacecraft reaches its limit sometime in August, when it must return to Earth -- with the Mir crew aboard, who do not stay in the station without a Soyuz as lifeboat. NASA had hoped that the Russians would follow through with their plans to deorbit the Mir over the South Pacific in August. But that option has become physically impossible: far from letting Mir's orbit decay lower and lower, Russian controllers have been reboosting it.

Orbital Design

Last November, as the first two ISS launches (Zarya and the Unity node) approached, even the relatively simple task of designing orbits for the two spacecraft became an object of controversy. Since their ground sites could not rapidly switch back and forth between the frequencies and codes of the two different stations, they wanted the orbits designed so that all of each day's passes from one station be completed before the next station began passing within range. As a result, during the three years of detailed pre-flight mission design and planning, Russian orbital experts had insisted that the orbital plane of the ISS be shifted far away from the orbital plane of Mir.

As eventually designed, this requirement was satisfied by having the points on the equator where each station is heading northbound (called the "longitude of the ascending node") be 165 degrees apart, with Zarya west of Mir. In spherical trigonometry, the two orbital planes intersect at an angle of about ninety degrees -- that is, as far apart as they can be.

Then, only a month before launch, the Russians changed their minds. They wanted to make it possible for equipment from Mir, and perhaps even several of the newer twenty-ton research modules, to be transferred over to the ISS, something that couldn't be done with a ninety-degree orbital plane change. To allow this, they proposed delaying their Zarya launch about eleven hours, letting Earth's rotation to carry the launch site closer to the orbital plane of Mir, so the orbits of the two stations-the old and the new-would be more closely aligned in space.

Aside from the obvious disruption to planning for space shuttle missions, Nasa experts who talked off-the-record with Spectrum suspected the last-minute demand had more to do with finding ways to get Nasa to help prolong the Mir, than it did with useful proposals to help build the ISS. The United States rejected the suggestion, and the Russians withdrew it. Zarya was launched November 20 at the long-ago-planned time, and the assembly of the ISS had begun.

Since then, the smooth sailing of the International Space Station has only had enough bumps to keep things interesting for the ground controllers in both countries. Communications and command sequences have been practiced, as the complicated software interfaces between the two nations' modules were tested by forwarding signals to each module through the other.

Coordination between operators in both control centers, in Moscow and Houston, has been polished. There have been the predictable slew of minor anomalies-called "funnies" on Nasa documentation-that require attention and resolution, but there have been no emergencies.

Electrical "funnies"

On January 11, 1999 the man/machine engineering system of the ISS suffered its most serious breakdown: following signals of imminent failures in the power system, a series of human commands and automated actions in the station resulted in the shutdown of all but the most critical systems such as the radio link and attitude control. Technically the problem was manageable, and was eventually isolated and solved. But both the genesis of the problem and the process of solving it are themselves problematic, and reveal disturbing symptoms of the program as a whole.

Due to the normal periodic drift in the station's orbit relative to the Sun, the solar arrays were not operating at peak efficiency. Main bus voltage dropped from the nominal 28 volts toward an emergency level of 26.5, where an automated load shed routine kicks in ("load shed" is an automatic procedure that shuts down a list of non-essential power users). Controllers in Moscow noticed the voltage drop, realized that it might soon trigger the 'load shed' routine, and tried to intervene before the automated program was tripped. They sent shut-off commands to heaters and smoke detectors and other non-critical items. But they couldn't keep bus voltage high enough, and the load shed was activated, turning off all but the most essential equipment.

Over the next few days, as the station's orbit went through its normal shifting in space, solar illumination and consequent power generation improved. Controllers commanded these systems back on one by one, restoring the station's normal configuration. They also tried to understand why they were caught flat-footed by the speed of the voltage drop in the main bus.

Hidden Shortcomings Show Up

Early in the flight, Russian controllers had noticed degraded performance in Zarya's six nickel-cadmium batteries. The batteries did not seem to be absorbing full charge from the solar arrays, and the problem appeared to be worsening with time. To maintain peak efficiency for the batteries, deep discharge cycles had originally been planned to occur once a month. But they soon had to be performed more and more frequently, and by mid-January the batteries were being cycled every five days.

As a NASA engineer told me at the time, "the problem incrementally crept up on us. It's a little disturbing because it's not the performance we expected."

The 27-kg Russian batteries, each a bit larger than an automobile battery, are rated at 60 amp-hours. Although designed for a five-year lifetime, they were already three years old when launched, and there was concern that the performance degradation was age-related. NASA's weekly report on January 13 bravely asserted that "the slight decrease in voltage

that had been seen is not believed to have been an indication of any mechanical problems." But things were far worse.

Within a week of the automatically-tripped load shed on January 11, Nasa engineers in Houston began to suspect that the problem was not with the batteries themselves but with the control circuits that calculated charge levels. The actual charge is below the calculated charge, one engineer suggested at a weekly status review meeting, "due to premature termination of the charge cycle."

By February, Russian specialists had confirmed Nasa's fears: a measurement device on all six batteries called the MIRT, Russian for "integrating amp meter," had a generic flaw. One circuit was miswired during manufacture, and the results were readings that were getting more and more in error with time. The error fooled the batteries into thinking they were fully charged when they weren't, leading them to terminate any further charging from the solar panels even though their actual amp-hours were much lower than normal.

Back in Houston, flight controllers responsible for monitoring the station's electrical power developed a procedure to "spoof" the MIRT circuits and force full charges on the batteries. They tricked the charge controller circuit into ignoring its erroneous estimate of actual accumulated charge, so that it would stay hooked up to the solar cells longer. But with this temporary "work around", the greatest concern was for how the problem with how far and how frequently the batteries charged and discharged would effect the lifetime of the battery

Consequences of Flaws

American experts also pointed out an even more worrisome aspect of the MIRT flaw. "This problem could have been detected by ground testing prior to flight," one specialist told me. The reason? "The Russians skipped end-to-end testing, they never put the whole power system through a series of charge-discharge cycles," he explained, attributing the oversight to lack of time and money.

In fact, early in Zarya's flight, similar circumstances had led to a different type of failure of the batteries, this time traced to another battery controller. The design of the battery called for redundant pass-throughs on a circuit board, but the manufacturer had built only one. One of the leads broke a few days after the November launch, crippling the circuit that linked the battery to the main bus. The circuit was repaired last December by the STS-88 crew, when they hooked Utility and Zarya together.

Another embarrassing oversight had been noticed right after the load shed event on January 11. Once the station had been returned to its nominal configuration, the ground controllers attempted to reset the load shed routine which had been triggered by the main

bus drop below 26.5 volts. The routine was still necessary to restore protection during the 10 to 12 hours a day when the station was out of range of Russian tracking sites.

To their astonished dismay they discovered that there was no ground command to reset the routine. Only with an astronaut typing on a keyboard aboard the station could it be set in action. One manually instigated load shed had in fact occurred before, during the STS-88 flight in December, a result of still immature coordination between flight controllers in Moscow and Houston. But now, the station was unmanned (which of course had been planned from the very beginning), but the Russian designers had apparently overlooked the need for an off-site reset command.

The Russians insisted on replacing all six MIRT units. The first Shuttle launch coming up, STS-96 scheduled for late May, was hastily rearranged for the new purpose. As with every Shuttle flight, the load and task schedule had been prepared months-sometimes years-in advance. A new one was drawn up to accommodate the repair.

Test? Launch!

Engineers then realized that the same battery hardware was installed on the "real" life-support and control Service Module, still on the ground, and had to be replaced and retested. This fairly simple error seems to implicate seriously inadequate Russian ground testing and system analyses, it raises the question about what other flaws were not discovered.

Consider the failure of the latest Mir experiment. A thin-film aluminum "space mirror" was to be unfurled, as part of a program intended to illuminate regions on Earth with reflected sunlight. In February of this year, as the rotating dispenser unfurled what was supposed to become 25-m diameter aluminum disk, a command was issued to deploy a boom-mounted antenna. The boom extended directly into the region where the disk was deploying; the aluminum wrapped itself around the boom and tore itself into shreds.

Inadequate ground preparation by Russia's Mission Control Center in Korolev, just north of Moscow, had been the cause of the error, according to French space official Guy Pignolet, who observed the experiment from the control center as a guest of the Russian space program. Vladimir Syromyatnikov, the developer of the mirror, remarked bitterly to a TASS reporter that "Our style of life is responsible -- such a complex experiment demands more time, more specialists." When asked why the antenna deployment command had not been cancelled, he answered, "Because we didn't think of it."

Meanwhile the ISS's long-awaited Service Module had been completely assembled on the ground, and in early April it was shipped to the Russian launch site at Baykonur (near the Aral Sea in Central Asia) for final assembly, re-flight checks and eventual launch. The Russians still claimed that it could be loaded on a scheduled Soyuz September 20, 1999

flight. Nasa, prudently, had adjusted its schedules expecting a November 20 launch, and more realistic officials warned that it was unlikely to fly before early in 2000.

As the clock ticked away and their money was being eaten up, the Russians dispensed with buying flight spares -- that is, hardware qualified to replace units that failed in testing. So now the Service Module that is responsible for the life support of the entire ISS crew has only one flight-qualified unit for oxygen generation.

Errors in testing are one thing, but the temptation may be growing for the Russians simply to pull their punches to speed up the long-delayed launch. Even though this is the kind of short cut that led to the early-1999 failures of the Zarya's electrical power system (and their time consuming and costly repair), and the kind of superficial planning that destroyed the Znamya experiment, it can easily seduce program managers who are obsessed with only the most immediate schedule goals.

By March, Nasa sources were telling Spectrum that there was a growing desperation to "get it in the air" almost no matter what its condition, and hope that the inevitable equipment breakdowns could be repaired on later shuttle flights at US expense. Space experts with long memories have told Spectrum that this obsession on sticking to a schedule by overlooking adequate pre-flight testing is frighteningly reminiscent of the push to launch the doomed Challenger Shuttle in January 1986. And even if systems do not fail catastrophically, in the long run it is hundreds of times cheaper and easier to find and fix problems on the ground than in space.

Rushing the Russians

Just as strident as those calling to quickly launch hardware -- any hardware, seemingly -- are those who want a manned presence as soon as possible. After the STS-96 Shuttle mission to the ISS in May (the one with the MIRT battery replacements), Nasa had expected three more Shuttle flights and one Russian supply flight before sending up a crew aboard a Soyuz. The four flights were to add equipment for electrical power generation to the outside of the station and to emplace spare parts and backup hardware inside the station for critical life support systems.

However, responding to the longer-and-longer delays, Russian and American space officials developed a new plan: sending up the three-man crew as soon as the Service Module reaches orbit, without waiting for the four preparatory missions. Thus, ISS's first long-term crew -- American astronaut Bill Shepherd and Russian cosmonauts Yuri Gidzenko and Sergey Krikalyov -- would board the "final" Service Module before it had begun automated approaching and docking with the Zarya/Unity complex. The one major advantage of this option is that the crew on the Service Module could provide manual backup to the automated linkup, a critical procedure that officials in both countries have begun to worry more and more about.

But by going to the Service Module that early, the crew would be exposed to the risk of not having the degree of backup systems that would seem mandatory. What's more, they would have to rely on the systems in the Service Module, whose pre-flight verification is likely to have been even less thorough than those that so clearly failed for Zarya and the space mirror. If worse comes to worse, and enough time were available, the crew could abandon ship, flying home aboard the docked Soyuz.

Stealing a Soyuz

The prospect of prolonging the lifetime of the worn Mir space station provides another hiccup to plans for the ISS. The next Mir crew is to be launched in August, with two fresh cosmonauts and possibly with a paying British industrialist as a passenger. The problem with launching this new crew to Mir is that since it was not anticipated a year ago, no manned Soyuz ferry craft was ordered from the factory to carry out the mission (it takes about 18 to 24 months of fully funded work to produce a Soyuz in the plant north of Moscow).

There is only one newly-completed Soyuz spaceship available in that time period. This one -- it's factory identifier is 'Soyuz-204' -- has always been allocated to the International Space Station's first expedition. If the "early crew" option were chosen and if the Service Module actually were launched on schedule, that Soyuz would be launched with Bill Shepherd and his crew sometime in October 1999.

This Soyuz is being completed in part with American money which Nasa provided to the Russian Space Agency last fall. The factory's next-in-line Soyuz wouldn't be ready until the end of the year and only then if Nasa comes up with more money.

A Nasa source has privately told Spectrum that "Nasa would not look kindly" on any Russian attempt to divert Soyuz-204 from ISS to Mir instead. However, Congressional space staffer Eric Sterner explained that Nasa carefully wrote the latest contracts with the Russian Space Agency (RSA) to avoid specifying how the U.S. money would be spent. "Nasa conceded that that's one of the things it expected RSA to use the money for," Sterner told me, adding that although Congressman Sensenbrenner's staff had urged more explicitly binding Nasa-RSA contracts, "the appropriators have not backed us up." So legally the Russians can get away with misusing the Nasa money for a purely Russian space project.

In 2000, Nasa's flight plans calls for a total of ten Russian launchings of manned Soyuz and unmanned 'Progress' type vehicles in support of the ISS. However, over the past few years, as part of the Mir program, Russia has been able to annually build and launch about half that number. So even without the need to support Mir as well, Russia already must

double its production rate in less than a year. If there is an additional need to continue supporting a prolonged Mir station, Russia's annual spacecraft production rate must triple.

Shortly before he resigned in April, Randy Brinkley, Nasa's Space Station program manager, was asked by me whether he believed Russia was capable of that flight rate next year. He answered softly and simply, "No."

Official production records from the "Progress" plant in Samara, which builds the booster rockets for the Soyuz and Progress, confirm Brinkley's skepticism. The Russian plans show that of 18 rockets scheduled for delivery in 2000, and only four are allocated to missions for the ISS (and none are allocated to Mir). The others are for commercial customers or Russian Ministry of Defense missions. Clearly the over-ambitious Russian promises of 10 flights -- or even 14, if Mir is prolonged -- are either delusional or prevaricating. Unless Nasa also is delusional or prevaricating, if ISS assembly plans aren't severely modified, more delays will catch Nasa "by surprise" next year.

Preserving Mir

The official need to terminate the Mir program this year is entirely financial. But many Russians still hope to find that necessary funding for Mir from "off budget" sources, even if it conflicts with the ISS commitment to support manpower, material, and services that would be stretched to support a single space station project, not to mention two of them.

In late January Ex-Prime Minister Primakov authorized the Energia Rocket and Space Corporation, which owns and operates Mir, to begin soliciting money from private sources. Energia, which has built all Russian manned space vehicles for 40 years, was privatized in the early 1990s and has been forced to seek private funding.

Non-government funding was nothing new for Mir. Russia began selling seats on manned space missions to the Salyut-7 space station in the early 1980s, and by the mid-1990s was earning between $50-100 million per year from European space organizations alone to fly astronauts aboard Mir.

And still Mir's fate is linked to the ISS's. In January this year, just when pulling the plug on Mir seemed to be a fait accompli, Russian space officials began talking up a mysterious "secret foreign investor" who would provide the Mir's entire $250 million annual operating budget. The deal? In return, the "foreign investor" would get in-flight cosmonaut man-hours for research and other activities on Mir.

Speculations abounded about who the Russians were hoping would save Mir: a secret, retiring Australian millionaire, the decidedly unretiring U.S. billionare and ex-Presidential candidate Ross Perot, or even the Chinese space program, which wanted a docking site for its planned two-man space capsules. Some pocket money money was

supposed to come from a film company shooting scenes aboard Mir -- a money-making spin-off from deals with advertisers for various commercial beverages.

But by early February, hopes for financial salvation outside U.S. government sources had collapsed: As Yuri Koptev, head of the Russian Space Agency, told newsmen, "Unfortunately our lives are such that we sometimes consider the desirable already a reality. It was just wishful thinking."

I've learned that "secret financiers" did in fact exist, at least potentially. A group of American businessmen in Florida had intended to line up commercial users willing to buy time aboard the born-again Mir. But the capabilities of Mir fell short of many of their customer's requirements -- for example, less than 10 kW is available for experiments, and even then the power isn't assured. After looking deeper into it, most of the potential investors passed on the deal.

Yet once again, some Russian officials are placing bets on the British industrialist who paid for a ride on Mir next August, and who they think could be interested in some kind of arrangement. Whether or not this latest financial gimmick works out, Russian space officials promised to keep Mir going with bank loans, if necessary.

The death of Mir

Why this need to prolong the agony of Mir, and by doing so wrenching apart even more the entire Russian space effort? Until now, space stations have had limited lifetimes. In the early 1970s, Nasa's Skylab and the early Soviet Salyut stations carried supplies for less than a year of operations. Later Salyuts could be resupplied and thus could operate for up to three or four years.

Although the Russians had been supposed to make a "final decision" about deorbiting Mir in April, they were still boosting its orbit, a clear signal that they intended to prolong its life well beyond the official termination date. Perhaps they realize that the longer Nasa hopes that Mir will be terminated as promised, the longer the flow of American money can be continued.

Despite these new difficulties, officials in both countries remain committed to seeing the International Space Station through, no matter the distraction about Mir's uncertain fate. Yuri Koptev, the Russian Space Agency director, has repeatedly warned his countrymen that Russian withdrawal from its ISS commitments would mean cancellation of Western commercial space contracts, now approaching a billion dollars a year. For its part, the White House still sees the partnership as central to its policy towards Russia, and repeated efforts in Congress to expel the Russians from the ISS grand plan have been soundly voted down.

As the International Space Station completes is first months in orbit, and Mir completes what may be its last months, both programs have repeatedly underscored an old lesson in space: whatever the experts have planned and attempted, reality still provides surprises and challenges. The only reliable prediction is that these projects, a year from now, won't look anything like today's expectations.
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Where do space stations go when they die? Most Soviet stations at the end of their missions were steered into the South Pacific. However, some stations went out of control as their orbits decayed, and they fell to Earth randomly. Two twenty-ton Salyut vehicles fell back to Earth randomly in 1973 and luckily missed dry land. The uncertain impact point of the hundred-ton Skylab provided weeks of tension as it skimmed the upper atmosphere in mid-1979, finally scattering debris across western Australia (nobody had paid any attention when its second stage rocket, almost as large, fell out of orbit a few years earlier. In 1991 pieces of Russia's forty-ton Salyut-7 space station actually hit a populated area, the western suburbs of Buenos Aires. No one was hurt and no damage was ever recorded in any of these incidents.

The Russians have stressed that they intend a controlled de-orbit of Mir at the end of its mission. Clearly they do not need yet another headache, as bad publicity mounts over a "death watch," with every nation in the world fearing it will be the one eventually hit.

Although falling satellites usually are torn apart by atmospheric deceleration forces about 80 km up, metallic fragments often reach Earth's surface. Even though the odds are very good that a randomly falling Mir wouldn't hurt anything, a "Mir Decommissioning and Disposal Plan" has been drawn up by the Russians and reviewed by Nasa.

Mir's current altitude of about 355 km is being maintained against losses due to air drag by periodic small rocket burns from docked supply ships. But once the decision has been made to terminate the program, it will be allowed to naturally decay to about 250-300 km, which would take about six months. At that point, a specially-outfitted supply drone carrying only rocket propellant would dock to the station, and, after the crew had left in a Soyuz, fire its engines to lower the Mir's orbit into the atmosphere over an area of the South Pacific.

Nasa plans to be there, and not just to make sure that Mir is really dead. Specially outfitted US aircraft will observe the entry fireball and spacecraft breakup to better understand the process and to refine predictions of what will happen when the ISS too reaches the end of its life.