Starcrossed Orbits, pp. 231-243
McGraw-Will, New York, 2002

Chapter 14 --- Staking Out The ISS Orbit

Nikolay Ganzen and I had a lot in common. We both liked French wine. We were both big men, and we had a big sense of humor. But most of all, we had unearthly minds. One way that it showed up was in the things that we, almost alone amongst our fellow countrymen, thought were humorous.

He spoke Russian and I was raised with English, but we shared a common language that few in either of our countries understood: in Russian, it was called “ballistics“, in English, “orbital mechanics”. Based on mathematics, this specialty defines the curving paths that objects follow as they swooped through space under gravitational forces and steered by periodic rocket firings.

It was in this unusual language that the final designs for the foundation of the International Space Station would be expressed.

By early 1996, the Russian-American space marriage had been consummated with the first shuttle dockings to Mir. Hardware for a dozen different modules was taking shape. The design and assembly sequence of the International Space Station had been defined. Now the questions concentrated on how to carry out these plans.

Ganzen and I first met at a quarterly “Technical Interchange Meeting”, or “TIM”, in Houston. Two dozen different teams of specialists from both countries met in row after row of cubicles to thrash out specific topics. There were questions about communications, life support, logistics, “who was in charge of what”, flight crew activity scheduling, and so many more that often a particular panel would “splinter” into sub-groups assigned to more highly specialized questions.

Our panel was “flight design”, and we were supposed to specify the exact orbit into which the very first ISS module would be launched. The flight, planned for the following year, didn’t actually occur until November 1998. By then, as it turned out, I had already left the program to pursue a full-time career in writing and consulting. But NASA ultimately followed the plan that we came up with at the meeting.

My job in 1996-1997 was to coordinate the “orbital design” of the shuttle mission that was to carry up the first US segment, a few weeks after the Russians launched the first part. To do this, we had to determine what kind of orbit we needed to end up in.

“Orbits” have been the professional focus of most of my life. In college, I studied the mathematics of orbital rendezvous. That was during the same period of time in which the Gemini spacecraft actually performed the maneuver in orbit. In graduate school, funded by NASA, I studied computational techniques for planetary swing-by trajectories. In the post-Apollo cutbacks, NASA wasn't hiring, so I joined the Air Force, where I kept tabs on Soviet spy satellites. I issued alerts to my base about when the satellites would be overhead, warnings that we shouldn't be doing sensitive activities outside. When Soviet space stations maneuvered in orbit to line up for new launchings from the ground, I compared the maneuvers to their standard patterns in order to forecast the launchings themselves. Accurate forecasts of Soviet launches could be thus made in the absence of any official announcements.

Orbits remained the focus of my professional life, and some of my hobbies. At Mission Control in 1982-3, I led a contractor team that supported the first shuttle experiments with free-flying payloads and with rendezvous. I then literally "wrote the book" which explained astronaut procedures for space shuttle rendezvous. When the Long Duration Exposure Facility (LDEF) satellite was retrieved in 1990, I was the lead "Guidance and Procedures Officer" at Mission Control. Several DoD shuttle missions also needed my specialty, but that's all that I can say about that. I also wrote the console reference handbook and the training plan. In the early 1990's, I tracked down, collected, and annotated several dozen key reports for a comprehensive "History of Orbital Rendezvous" for the library at NASA. It's safe to say I often dreamed about space orbits.

Describing space orbits verbally, without using gestures, has always been a challenge. It's sort of like trying to get someone to describe a spiral staircase while sitting on their hands. But with the right analogies, it can be very illuminating. Since I've done it for my mother, my Boy Scouts, visiting NASA managers, miscellaneous politicians, and even an astronaut or two, I know it can be done.

Think of a space orbit as a wire circling a globe. One end is tilted up from the globe's equator (and so the other end is tilted down) . But the center of the wire circle has to match the center of the globe. The circle defines a flat plane in which the satellite moves, like a bead along the wire.

The object of our attentions, the vehicle that we were designing an orbit for, was called the F-G-B. In Russian, Funktsioniy Gruzovoy Blok means "Functional Cargo Block", and it was the Russian designation for the twenty-ton vehicle that NASA at first just called the "Salyut Tug".

It may have been new to NASA, but these "FGB" vehicles had been a part of the Soviet space program since the mid-1970's, as described in an earlier chapter. Their ancestor was called the "TKS", and it was designed to ferry both supplies and, with a capsule mounted on the front, cosmonauts to military space stations.

My friend Ganzen had been a part of this, as a team member in what is today called the "Khrunichev Center" in the Fili neighborhood of Moscow.

Back when the Russians first joined the ISS partnership and the idea of using am 'FGB' came up, NASA soon realized that the Russian government wasn't going to fund it , so the U.S. would have to. Besides, since an 'American' module had to be the cornerstone of the ISS, NASA would have to hold the deed of ownership for the FGB. For the sake of that piece of paper, NASA agreed to send the Khrunichev firm more than $200,000,000 via NASA's space station contractor, Boeing.

So officially it was an American module, even though it was built in Russia according to Russian designs. The design included an earth-space command and control system, through which Mission Control operated the vehicle in orbit. but the Russians never even told NASA what the command codes were, even after they were asked directly to do so. Such behavior might indicate who THEY considered the FGB's real owner to be. And NASA's own internal documents seemed to agree, lumping the FGB into the "Russian segment" of the station.

I annoyed a whole series of NASA management and publicity officials by innocently asking whether there really shouldn't be an American flag on the FGB, since it was after all an American spacecraft. The question was considered tasteless, ridiculous, and meaningless, probably because nobody knew the answer. I finally was told that along the FGB's bottom rim, about four inches high, there was in fact an American flag, and I later found a handful of photographs that showed it. The Khrunichev factory had charged the US an astronomical amount of money (one official told me it was about a million dollars) to paint it on.

In the original "Russian Alpha" design for the space station, from 1993, when a combined US-Russian space station was first discussed, the FGB was serving as the stabilization and control module for the early space station structure in what was called the "man-tended mode" (the early flight phase when crews were present only part of the time). That was before the arrival of life-support equipment that could support a permanent human presence, although some power modules and a laboratory module were already on board. A competing spacecraft, the Pentagon's so-called "Bus-1", promised similar capabilities but at the cost of almost a billion dollars, so choosing the Russian option made economic sense.

Over the next three years, the design of the station evolved, and the purpose of the FGB underwent a major but unheralded transformation. The arrival of Russia's "Service Module", with its control and life support functions, was moved to occur much earlier in the assembly sequence, only four months after the launch of the FGB. By that time, only a single module -- the U.S. "Node-1" connection block – would be hooked to the FGB.

The reason for pushing up the date was based on the need to mate the two Russian modules -- the FGB and the Service Module -- in space. Both were launched separately aboard powerful Proton rockets. But only FGB had the steering rockets and the guidance sensors to chase down and dock with another vehicle. The Service Module could "cooperate" by holding its position and sending out answering radar pulses, but it couldn't maneuver at all.

So for the FGB to be able to fly its docking profile, it couldn't be encumbered with too much extra baggage. The "Node-1" module could be mounted on its back end, and the FGB would still be able to haul it as it chased and captured the Service Module. But adding anything more would make it too heavy and its weight too off-center for it to steer properly.

This reasonable alteration of the assembly sequence led to one very embarrassing question, however. If the Service Module, with its control computers and thrusters, would be sent into space only a few months after the FGB, what purpose did the FGB serve that was worth its $200 million price tag? Why not just launch the Service Module alone, send up a shuttle with the "Node-1", and proceed with the assembly from there?

NASA headquarters vetoed that suggestion. The FGB would remain part of the sequence. No other options would be considered.

It turned out that the decision to keep the FGB was pure public relations, or more specifically, congressional relations. It went to the core of the concept of the International Space Station project, which was designed to be led by the Americans. If Russia's "Service Module" was the first element placed in orbit, the Russians could proclaim that the new station was a Russian station, with subsequent American add-ons. Congressional and public support could evaporate.

So the supreme requirement for the ISS design was a good political appearance. Whatever the reality behind the way the station was being assembled, it had to LOOK like it was mainly an American system, with Russian add-ons. Even if it weren't true (and in the beginning it wasn't), it had to be made to look that way so that Congress and the American public would perceive the desired image, not the reality.

So an American module just HAD to go up first, or at least, ahead of any purely-Russian module. The FGB launch was an acceptable mongrel, "half Russian and half American". And the Russians did pay for the launch, which was only fair considering how much the U.S. overpaid for the module itself. But then the follow-on all-American "Node-1" established U.S. priority as the station cornerstone, even though once in orbit it really didn't do anything useful until the Service Module arrived, and nothing significant until the US Laboratory module showed up a year after that.

The plans were that once the SM arrived in a few months, the FGB would be demoted to a storage shed and spare fuel tank. Its electronic systems would be deactivated, their functions assumed by the SM. One consequence of this -- which would come back to haunt NASA -- was that unlike the SM and other mainstream ISS modules, which were designed for a full fifteen year lifetime, the FGB was considered only "temporary", and its equipment didn't require anywhere near that longevity.

For Nikolay, myself, and our fellow ballisticians, we just had to worry about the orbital consequences of these designs. These policy questions were way above our heads, or, as we used to say, "way above OUR pay grade." We were faced with a more immediate technical question when selecting the initial orbit for the FGB/Node complex. Where would it lie in relation to the orbit of Mir?

Mir was occupied by teams of cosmonauts during our design process that year, and during the next year as well. And although the Russians kept assuring NASA that they would close down and de-orbit the aging station once the assembly of ISS began, we knew there would be at least a few months of overlap.

Nikolay and I had essentially two options. We could place the FGB/Node in an orbit "near" to Mir, which could make station-to-station transfers possible, or we could place it in an orbit as far AWAY from Mir as possible. In evaluating these possibilities, we were assisted by a senior ballistics expert from RSC-Energia named Ludmilla Chaikina. A diminutive, slightly graying woman with a shy smile, Chaikina had a classic 'steel trap mind' and an iron backbone when it came to her own views. We all got along great.

As I discussed these strategies with my management, I made sure that everyone understood the implications of each choice. The Russians had already tried to delay the delivery of their Service Module once and to substitute the existing Mir as the "foundation" on which the new ISS modules would be assembled. NASA managers rejected this proposal immediately, since the impression of being an "add-on" to the veteran Russian station would have been political suicide. But if we placed the FGB/Node in an orbit "close" to Mir, we would be giving the Russians the options to pull a fait accompli by announcing that their Service Module had suddenly been "unexpectedly delayed". They would then be able to fly the FGB/Node over to Mir and dock it there, since the orbit we had chosen quite fortuitously allowed for such a maneuver.

The joint meeting began with the aim of listing the operational requirements that would determine the selection of the best orbit. We were expecting the Russian side to propose that the chosen orbit should allow station-to-station transfers, thus enabling them to move two of the science modules from Mir over to ISS for extended operations. They had been talking about the need to retrieve and transfer up to five tons of other miscellaneous equipment -- research equipment, cameras, supplies, even musical instruments and memorabilia -- from Mir to ISS.

Ganzen wasn't interested in these options. To our total surprise (and delight), he carefully described a number of technical reasons that he, too, wanted the FGB/Node to be as far AWAY from Mir as possible. Chaikina agreed with him.

To understand how orbits can be "close" or "distant" to each other, you have to abandon earthside notions that distance is a measurement of physical separation. In space orbits, everything is moving very fast and distances are changing constantly. What "distance" really means to a "ballistics" nut like Nikolay, Ludmilla, or myself is the amount of effort needed to get from one orbit to another. That effort is usually measured in "change in speed", or "delta velocity", or just "Delta-V". In practice, that means burning a portion of your on-board rocket propellant supply, which is always very limited.

Both Mir and the ISS were going to be circling Earth about two hundred miles above the atmosphere. These circles were "flat", in a single plane. But that plane was tilted relative to Earth's equator, about half way (by 51.6 degrees, to be precise, but you can forget that exact number).

If both Mir and the ISS were in the same plane, the transfer of goods between them would be relatively easy. Raising and lowering an orbit is simply a matter of speeding up or slowing down. You might need to vary your speed about ten or twenty feet per second, relative to your normal orbital speed of 25 thousand feet per second.

The Russians had performed exactly such a trick in 1986, when they had just launched Mir and were at the very zenith of their spaceflight power. The first pair of cosmonauts who boarded Mir later undocked their Soyuz and flew over to the Salyut-7 space station, where they stayed for about a month. After performing a few more space walks and loading their Soyuz with a half a ton of specialized equipment and memorabilia, they flew back to Mir.

It wasn't as simple as it sounds. The two stations had to be kept in a relatively tight formation, so that their orbital planes didn't shift apart. When the time came to initiate the transfer, the station holding the crew was put through a very fuel-expensive firing of its rockets to push it towards the other station. The crew then detached in their Soyuz, and a day later, they used the fuel in the Soyuz to make the final rendezvous with their destination. As they were docking, the station they had just left went flying past, a few miles beneath them.

But for ISS and Mir in the 1997-1998 time frame, station-to-station transfer wouldn't be so simple. That's because of another variable of the orbit, the "hinge line" along which the orbital "tilt" is made. That line can be in any orientation as long as it passes through the center of the Earth and the equator. Both orbits can have exactly the same tilt -- the identical "inclination" angle to the equator – but if the 'hinge line' at which each orbit is tilted is too far apart, they still would be hopelessly far apart when it comes to trying to go from one to the other.

Prove it to yourself with a simple demonstration. Hold a CD-ROM (or a plastic plate) in both hands, fingers at the 9 o'clock and 3 o'clock positions. Tilt the end close to you down about halfway (the end far from you tilts up) and remember the pathway along the disk's rim. Now, again from a level position, put your fingers on the 12 and 6 o'clock positions, and tilt the left edge upwards about halfway (the right edge goes down). Look at the pathway along the rim and compare it to the previous case. They both are tilted up about the same, but the two pathways -- the orbits, in my analogy -- cross each other at steep angles. This is because their hinge lines are different. And a spaceship doesn't have enough rocket power to jump from one orbit to another.

Before my colleagues in the ballistics brotherhood make too much fun of me, I should point out that the angle of "tilt" of the CD-ROM is equivalent to the "orbital inclination" of a space vehicle, and that the orientation of the "hinge line" is technically called the "longitude of the ascending node", or "right ascension". The first time Nikolay, Ludmilla, and I had to get the NASA interpreter to figure out those words, we watched her nearly choke. So we just made a few sketches and invented our own "Runglish" ballistics terms.

Although Mir and ISS were following a simple near-circular orbit in space, the paths that they each traced out on Earth's surface were complicated by another type of motion, that of Earth's own rotation. And locations on Earth's surface, particularly Russian space tracking sites, would also have a crucial influence on the selection of the orbits.

If Earth didn't turn on its axis, the "ground track" of a satellite would just be a big circle around the globe. It would be tilted to the north and south of the equator at the same angle as the orbit was "inclined" at its "hinge line". When plotted on a flat map -- say, a Mercator-type projection -- this track would look like a "sine wave".

Now add in Earth's motion as the circling satellite continues to trace a line on Earth's surface. It takes about 90 minutes for the satellite to complete one full circuit. When it gets back to its starting point, Earth's surface has moved eastwards. It moves 360 degrees in 24 hours, or 15 degrees per hour. So after each repeated satellite circuit in 1.5 hours, it has moved about 1.5 times 15 degrees, or 22.5 degrees, farther to the east.

The resulting ground track, over a period of a day or so, looks like a squashed slinky, or maybe like a "ripple tank" physics demonstration from High School. Repeated copies of the "sine wave" pattern appear, each displaced slightly from the previous one. Now take a deep breath. However complex the final pattern, it came from only two simple motions: the satellite moving straight forward in its "inclined" circular orbit, and Earth going about its business of making sunrise and sunset shows for the observers on its surface.

There was one more motion that needed to be considered over long periods of time, say weeks or months. For various subtle reasons of geophysics ("Earth's equatorial bulge" is the theme here), the orbit of a satellite near Earth is slowly twisted in space. For objects such as Mir or the FGB, the "hinge line", or the orientation of the orbital plane in which they travel, was moving westwards about 6 degrees per day. For any two satellites in similar orbits, the motions nearly matched each other, so the orbits of the two satellites stayed at about the same relative position. But for observers on Earth's surface -- at a radio tracking site, or a launch base, for example -- that motion meant that on average the satellite repeated its passes about twenty four minutes earlier every day (earth rotates 15 degrees in one hour, or four degrees per minute). So launching into the proper relationship with Mir's orbit was shooting at a target that was moving in several different directions at different rates. Nobody ever said it was easy.

What Ganzen wanted for the FGB module was a ground track that was always west of Mir's track. If for example the Mir's track carried it northeast across Africa, then across Siberia and thence southeast across the Pacific, then the FGB's track during the same period would run from the eastern Pacific northeast across the Atlantic, across Europe, then southeast across the Middle East and on to the Indian Ocean. And every hour and a half, these paths would be repeated, only Earth would have rotated farther east so that the tracks on the ground would have been displaced to the west.

Viewed on a map, his logic was very clear, and he explained it to us in detail. Mir would cross near a tracking site in Russia, and be in radio communications with them for five or ten minutes. An hour and a half later, it might cross Russia so that it again passed within range of the tracking site. Sometimes a tracking site might catch sight of Mir four or five times in a row before Earth's rotation carried the site too far to the east to be close enough to Mir's next ground track.

But then the same tracking site would get its first visit of the day from the FGB, passing nearby. There would be a few more passes before the FGB, too, had shifted too far to the east to be within range.

"At any ground site," Ganzen explained through an interpretor and through sketches on paper, "all the Mir passes for each day must be completed before the first pass of the FGB occurs." He explained the practical reason for this: "We use the same radio equipment for both vehicles but it takes about an hour to manually reconfigure the receivers."

According to his calculations, Ganzen told us that this convenient situation would occur if the two orbits were shifted to be about 140 degrees apart. The FGB's orbit would be "west", as measured along Earth's equator, of Mir.

Since the shuttle would blast off two weeks after the FGB, into this same orbital path through space, we were under some constraints of our own. There was the desire to have the landing take place during daylight (it would also be "nice" to have the launch in daylight but that wasn't nearly so necessary). Our rendezvous sequence was based on making certain course corrections based on visual sightings of the target, and since these occurred at specific day/night points in each orbit, our ultimate arrival next to the FGB was locked to "orbital daylight". The Russians required that the actual contact to occur over Russian radio sites, so that they could send backup commands as needed.

Requirements had to be balanced, then carefully prioritized, and adjustments had to be made in the normal sequences of both sides' schedules. But over the period of six months, Nikolay, Ludmilla, myself, and our team developed a workable compromise that satisfied all of the important features. We then began briefing our management concerning the results. They liked it, and I received a "Sustained Superior Performance" award for the process. Best of all, all of us on the US side liked the fact that it was based on the Russian requirements that the new station would be so far "out of plane" with Mir that any transfers to ISS would be impossible to perform.

One thing that bothered me was that even though all of us 'worker bees' thought that the orbital plan was hot stuff, it remained easy for top management to undo it on a whim. As I kept circulating reports throughout the US side of the space station project, warning that we needed formal program approval to 'lock down' the plan, I kept getting the same old looks. I was being obsessively paranoid again.

A year after I'd left the program, with the launching only two weeks away, somebody high in the Russian space hierarchy suddenly realized that the agreed-upon orbit made cross-transfers impossible. On November 4, 1998, I received a short email from a friend: "[Energia] has complained that they were not involved in the FGB time of launch development and suggest [it] be moved 11h40m." Other messages said the proposal had already been rejected by NASA.

Of course, Energia had been involved in the original discussions, in the person of Ludmilla Chaikina. No, if Energia wanted to change the orbit, it was because they realized that they couldn't afford to build any new add-on modules. They wanted to use old ones already hooked to Mir to fulfill their promises to ISS.

An even more alarming possibility was that the move was an opening gambit in a game that would see the SM delayed still further, then cancelled. The old Mir would then be the "obvious" replacement facility, and we'd be back at the December 1995 proposal that was so vigorously rejected by NASA at that time. This interpretation was supported by the timing, only two weeks before launch and right in the middle of NASA's exuberance over the spectacular public relations triumph of the John Glenn space shuttle mission, then in orbit.

Although everybody assumed that Russia's new proposal would be rejected, by the beginning of the following week, a worrisome rumor began to spread that the demand would be settled "at the White House level." That meant that politics, not practicality, would rule again.

NASA officials said the proposal was a modest one. "The Russians said they wanted to transfer some equipment off of Mir to the International Space Station," Dwayne Brown told the N.Y. Times. "The request only concerned moving internal equipment from Mir, not transferring modules from Mir to the new station." But the same article quoted me as saying that once the "modest" intention was satisfied, far more profound and worrisome station-to-station transfers were possible. For example, environmental experts at NASA were convinced that the chemical contamination inside the Mir modules far exceeded the permissible levels for ISS.

One NASA worker showed that he'd been learning over the years. "This Russian tendency toward changing things at the last minute reminds me of the book, 'You Can Negotiate Anything'," he emailed me. "One of the key bits of advice in that book was to slip in seemingly small changes at the last minute."

The White House rumor turned out to be false, and NASA officials rejected the Russian proposal. After a "frank and candid" discussion, program manager Randy Brinkley told newsmen on November 13 that "the conclusion was mutual" and that "both sides concluded that it did not make sense."

But the Russians pulled one last trick on unsuspecting NASA officials. Since the 'FGB' still didn't have a 'name', Russian officials suggested that it be called 'Zarya', which means 'Dawn'. They volunteered no information on the name's origin deep within the history of their space station program -- it had also been the original name of the USSR's first manned space station, in 1971. NASA had no idea of the historical significance of the name, so they agreed. By agreeing, they tacitly confirmed that the FGB was and always had been a Russian module, and the tiny US flag painted on the side was the diplomatic equivalent of a fig leaf.

During the long design process, one vivid image had stuck in the back of my mind. Given a launch date, we were compelled to pick a precise launch time because of the desired relationship with Mir's orbital plane. All subsequent launchings throughout the history of the program would have to align themselves with the orbital plane that we had specified.

Hundreds of teams of engineers in both countries had spent years developing items of hardware, step-by-step procedures, complex control software, and other palpable contributions to the huge space complex. But our contribution was the essence of invisibility, an absolutely weightless sine-qua-non. Its importance was paramount, I told myself, because every other item being built by every other worker would be steered by our numbers. It didn't sound very objective, but maybe because we had spent so much time with cold-blooded calculations, we felt like basking in some hot-blooded self-congratulation to restore some balance.

"Think of us as advance scouts for a huge army," I had told Ganzen and Chaikina one afternoon when the day's negotiations had been completed. "Behind us are miles-long columns of personnel and equipment. Ahead of us is a vast empty meadow, where we will soon make camp."

There we were, in our imaginations walking out onto the trackless field where a great assembly of tents and trenches would soon fall into place. But at what place? Aligned to what base marker?

"We pounded in the first stake," I bragged, going through the motions of wielding a hammer while holding a wooden pole. "This point right here will be the 'origin', the 'Square-1', the cornerstone for all future construction which will depend on this baseline." We all smiled. It had been an interesting problem in ballistics and we were very proud of the solution we came up with.