The ISS Russian Segment: Recent Developments and Future Prospects

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Introduction

This article will look at developments on the Russian side of the International Space Station between early 2002 and the middle of 2005. It will also discuss the currently proposed final configuration of the Russian segment and the future role of Russian transportation systems such as Soyuz, Progress and Kliper in ISS operations.

Modules

Current Status

Currently the Russian segment of the ISS still consists of three permanent elements: the Zarya "Functional Cargo Block" (launched 20 November 1998), the Zvezda "Service Module" (launched 12 July 2000) and the Pirs "Docking Compartment" (launched 14 September 2001). Zarya is primarily a fuel and cargo storage depot, Zvezda provides living quarters and work facilities and Pirs acts as an airlock for spacewalks with the Russian Orlan-M spacesuits. There are three docking ports to receive arriving Soyuz and Progress vehicles, namely the aft port of Zvezda (mainly used for Progress) and the nadir-facing ports of Pirs and Zarya (mainly used for Soyuz).

All these elements have continued to operate smoothly throughout the period covered here. Zarya, the oldest element of the ISS, was originally certified for a 15-year mission, meaning that its warranty theoretically expires in 2013. However, with all the delays in assembly, the station will have far from outserved its usefulness by then and the manufacturers at the Khrunichev plant have begun looking at ways of extending its lifetime to 2018 [1]. One of the many design features built into Zarya to ensure its durability is an external thermal regulation system that can easily be serviced during EVAs. Unlike similar systems on earlier modules, its pumps and coolant flow regulators have been designed such that they can be replaced in orbit without much effort. The first swap-out of a coolant flow regulator panel was conducted by Expedition 9 crew members Gennadiy Padalka and Michael Fincke during an EVA on 3 September 2004. The external thermal control system has two fully independent loops, one of which is switched off as long as the other is functional [2].

The main headache on the Russian segment unquestionably has been the Elektron oxygen generator aboard Zvezda, which one internal NASA report in August 2004 described as "the leading trouble spot aboard the ISS". About the size of a water heater, the device uses the process of electrolysis to separate waste water into its component parts of oxygen and hydrogen, the latter of which is dumped overboard. Elektron is built by the Research and Design Institute of Chemical Engineering (OAO NIIkhimmash) in Moscow. About a half dozen models have been flown ever since the Mir days, but most of them have experienced problems at one point or another and have eventually broken down beyond repair. The problems usually stem from bubbles of oxygen and hydrogen gas jamming the unit's small pumps.

Expedition 4 crewmember Daniel Bursch working on the Elektron unit in the Zvezda module. (NASA)

The regularly recurring Elektron glitches have never been life-threatening, because the station always has several weeks' worth of bottled oxygen in attached Progress cargo ships and the US Quest airlock module. It also has a supply of solid-fuel oxygen generators (SFOG), the same type of "candles" that caused the fire aboard Mir in February 1997. Still, the repeated breakdowns are a nuisance to the crew members and divert them from their regular activities. For instance, Expedition 9 commander Gennadiy Padalka spent nearly a month struggling with the balky Elektron after it had shut down in the summer of 2004. In May 2005 the device once again went on the blink and it was not immediately clear if it was still fixable. The Elektron is reportedly no longer being manufactured and is supposed to be replaced in 2005 by a new device which will rely on a solid polymer electrolyte rather than the liquid-gel electrolyte system that has been causing all the trouble. In 2009 NASA is expected to launch its own solid-polymer electrolyte system aboard Node 3, allowing the station to be permanently staffed by a crew of six [3].

In the absence of a geostationary relay satellite, communications between the Russian segment and Russian ground stations continue to take place either when they are in direct line of sight or via American communication facilities when the station is not over Russian territory. The last Russian Luch tracking and data relay satellite broke down in 1998. Although another one was built by NPO PM in Krasnoyarsk, the Russian Space Agency could not afford to buy the Proton rocket needed to launch it, as a result of which the satellite ended up in a museum in St.-Petersburg. Currently, NPO PM is working on a new generation of lighter Luch satellites called Luch-M that can be orbited by the Soyuz-Fregat booster. Two of these satellites may be launched in 2008 and 2009 if enough funding is available [4]. Also used as part of the Russian communications network are Molniya satellites in highly elliptical orbits, but these are only employed to ensure communications between distant tracking stations and the TsUP mission control centre in Korolyov.

Expansion Plans

Status in Early 2002

As things stood in early 2002, the following elements were planned to be added to the Russian segment:

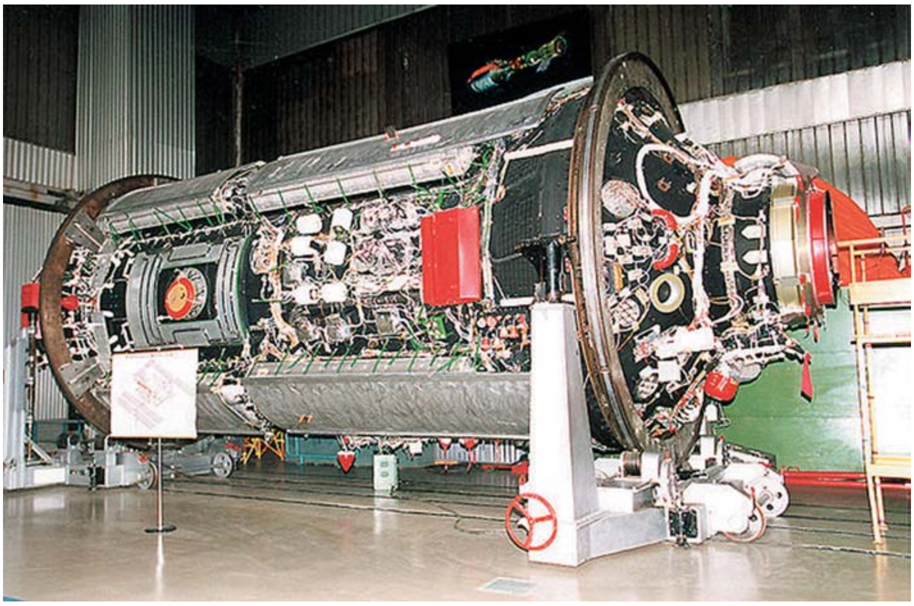
- the Commercial Space Module (CSM), a commercial version of the earlier planned Universal Docking Module (Russian acronym USM). Built on the basis of "FGB-2", the Zarya back-up, it was to be developed and financed jointly by Boeing and Khrunichev.
- the Enterprise Multipurpose Module (Russian acronym MTsM), to be developed and financed jointly by RKK Energiya and Spacehab.
- the Science Power Platform (Russian acronym NEP). Much simplified from its earlier versions, it would consist of a truss, four solar arrays (instead of the eight planned earlier) and the European Robotic Arm (ERA)
- two Research Modules (Russian acronym IM)

The planned sequence was for the USM/CSM to go up first in early 2004 and dock to the nadir port of Zvezda. Shortly before that Pirs would be transferred to the Zvezda zenith port to make room for the new module. In the summer of 2004 Space Shuttle assembly mission 9A.1 was to deliver the Enterprise module and all the elements of the NEP (truss, four solar panels and the ERA). The plan was for Enterprise to occupy the nadir port of Zarya, with the NEP to be mounted on top of the Pirs module. Assembly of the Russian segment was to be completed in 2005/2006 with the docking of two Research Modules to the lateral docking ports of the USM/CSM.

Commercial Hopes Dashed

Unable to finance any new add-on modules with the means available from their own budget, the Russians were banking heavily on commercial deals between Boeing-Khrunichev and RKK Energiya-Spacehab to see their space station segment expanded. Boeing and Khrunichev had announced their intention to build a Commercial Space Module on the basis of FGB-2 in July 2000. On 27 December 2001 the two companies reached a preliminary agreement under which Boeing would pay the $50 million needed to adapt the FGB-2 for its new role as a Commercial Space Module. Khrunichev had earlier spent $53 million of its own resources to build FGB-2 as the back-up for Zarya. The CSM was to house 36 work stations which could be used on a commercial basis by space agencies of various countries to conduct scientific experiments.

Unfortunately, the CSM died a quiet death in the following months, without any official reasons being given. Reportedly, the main stumbling block was the Iran Nonproliferation Act (INA), enacted by Congress in 2000 to help



The FGB-2 module at the Khrunichev plant. (Khrunichev)

stop Russian arms and missile transfers to Iran. Point 6 of the Act bans US payments to Russia in connection with the ISS unless the President determines that Russia is taking steps to prevent such proliferation [5]. In principle, the ban is restricted to government agencies such as NASA and does not apply to money transfers between private companies. Still, the INA seems to have caused Boeing to shy away from signing a final CSM deal because of legal uncertainties over the use of the ISS by private US companies and Boeing's plans to offer some of the resources on the CSM to NASA. Following Boeing's withdrawal, Khrunichev tried to evoke the interest of European partners, but to no avail. Having suffered financial losses from a decline in the rate of commercial Proton launches, Khrunichev was unable to complete financing of the module all by itself and was forced to revert back to the earlier plans to turn FGB-2 into a government-funded Universal Docking Module [6].

The Enterprise project, started by RKK Energiya and Spacehab in December 1999, did not fare much better. The original idea was to equip the module with a tiny broadcast studio to produce educational and entertainment programming to be distributed on a commercial basis via television and the Internet. Enterprise was also to be used for microgravity experiments like the ones Spacehab had been flying for paying customers on the Space Shuttle for many years. After NASA's decision in 2001 to indefinitely delay the Habitation Module, Spacehab and Energiya came up with an alternative plan to outfit Enterprise with living quarters and accommodations for three crew members, making it possible to expand the ISS permanent crew from three to six. The idea was to rent Enterprise to the space station partners in a package with the Soyuz spacecraft, which would serve as a lifeboat for the additional crew members aboard Enterprise. The Enterprise option was one of three considered in the US by an independent task force in late 2001 to eventually give the station the needed life support capacity for a six-man crew.

In 2000 RKK Energiya and Spacehab had formed the Space Station Enterprise LLC (SSE LLC), a Delaware limited liability corporation responsible for completing required financing for Enterprise and marketing and operating the facility as part of the ISS Russian segment. Spacehab and Energiya had an equal ownership interest in SSE LLC. In June 2002 SSE LLC signed a contract with the Florida Space Research Institute to deliver an instrument called the Scanning Microscope for Microgravity (SPMM) to Enterprise in 2006 [7]. However, it seems that Enterprise LLC had a hard time finding additional marketing and business opportunities for Enterprise. In its report on operations in Fiscal Year 2002 (ending 30 June 2002) Spacehab noted that it was awaiting decisions to be made at a meeting of space agency heads in Tokyo in late 2002 and that the future utilization of Enterprise was expected to be determined "within the next 9-12 months" [8].

At the Tokyo meeting Russian officials again proposed to increase the ISS crew to six in 2006-2007 by including a second Soyuz lifeboat and the Enterprise module, but NASA rejected the offer [9]. With Enterprise already on thin ice, the project's fate was definitively sealed when the Space Shuttle Columbia broke up during re-entry on 1 February 2003. Not only did the accident throw the ISS assembly schedule into complete disarray, the loss of Columbia was also a major financial blow to Spacehab, which lost the Research Double Module flown on STS-107 and future Space Shuttle related business as well. This, along with the restrictions imposed by the Iran Nonproliferation Act, undoubtedly was a contributing factor in Spacehab's decision to withdraw from the project. In its report on Fiscal Year 2003 the company stated:

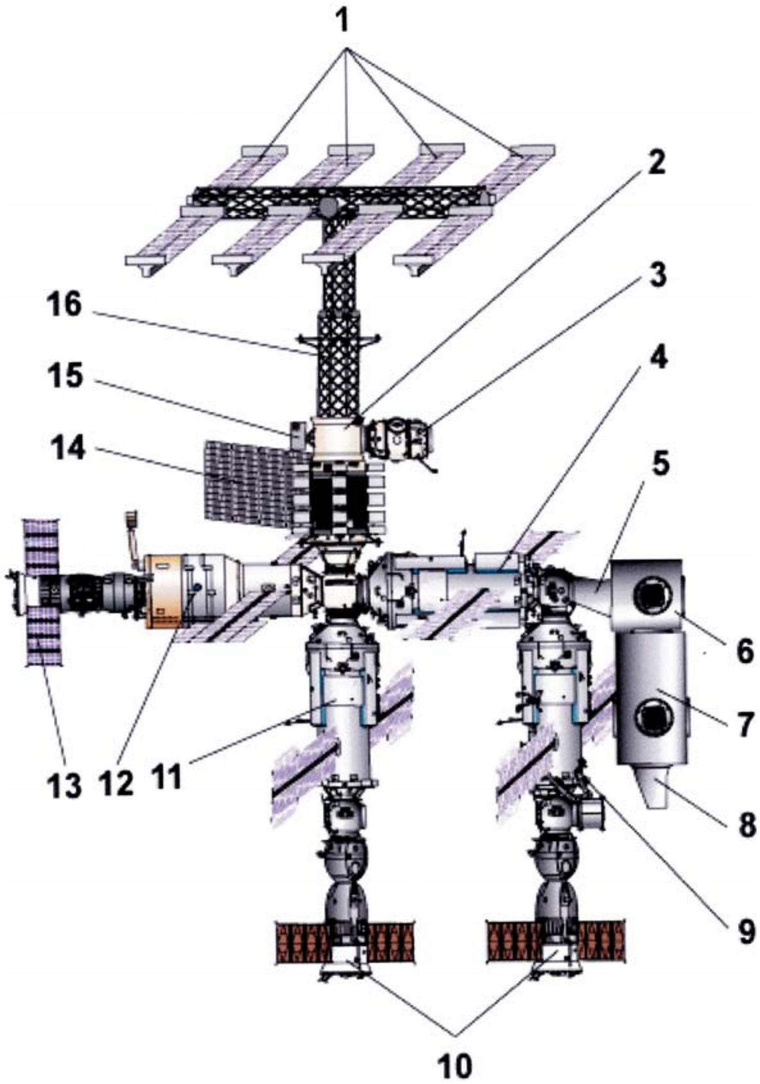
"In evaluating the Company's investment in Enterprise in June 2003, the Company identified significant uncertainties in new human spaceflight programs. While the company believes the service offered is a valuable service and is actively marketing this service to NASA, the Company ceased funding development and was unable to determine if or when the investment would be recovered. Therefore, the Company wrote down its full investment of $8.2 million in Enterprise as of June 30, 2003"[10] .

Currently Planned Elements

Sometime in 2003 a decision was made to further downsize the Russian segment with the addition of just three more elements: a Multipurpose Laboratory Module, the Science Power Module and one Research Module. RKK Energiya proposed to build the MLM using the Enterprise design, while Khrunichev once again pushed the FGB-2. In August 2004 the Russian Space Agency announced that the choice had fallen on the FGB-2 because of its relatively high state of readiness. A description of the three elements will be given here.

Multipurpose Laboratory Module (MLM): **the role of the MLM is to expand the resources and the scientific potential of the Russian segment. The preliminary design ("draft plan" in Russian terminology) of the module was expected to be completed at Khrunichev's Salyut Design Bureau in the first quarter of 2005. Mass at launch will be 20.3 tons, but once fully outfitted in orbit it will weigh as much as 24 tons. With a length of 13.0 metres and a maximum diameter of 4.1 metres, the MLM will consist of an aft conical section and a long cylindrical section together known as the Instrument and Cargo Compartment (PGO) and a spherical Pressurized Adapter (GA). A pair of solar panels will extend from the PGO.**

The MLM will have three docking ports: a front axial port to link up with Zarya, an aft axial port to receive Soyuz and Progress vehicles and a lateral port on the GA to attach a small airlock through which experiments can be exposed to



The ISS Russian segment after completion.
(Novosti Kosmonavtiki)

Key:
1. solar panels
2. pressurized section of the NEM
3. Pirs docking compartment
4. Zarya
5. PMA-1 (Pressurized Mating Adapter)
6. Unity (Node-1)
7. Node-3
8. PMA-3
9. Multipurpose Laboratory Module with small airlock module
10. Soyuz-TMA spacecraft
11. Research Module (in FGB configuration)
12. Zvezda
13. Progress-M spacecraft
14. radiator panel
15. thruster package
16. NEM truss

the vacuum of space. The module will have three types of thrusters: the Correction and Approach Engines (DKS), the Approach and Stabilization Engines (DPS) and the Precision Stabilization Engines (DTS). After having been used for orientation and orbit corrections during autonomous flight, some of these engines will be employed for roll control of the ISS once the MLM is docked. The engines will draw their propellant from 8 tanks mounted on the outer hull of the MLM. Propellant delivered by Progress vehicles can be routed to Zarya and Zvezda via the MLM. Although the standard docking port for Progress ships is the Zvezda aft port, this will be regularly occupied for long periods by European Automated Transfer Vehicles (ATV) beginning in 2006.

A novelty compared to earlier plans is that the European Robotic Arm (ERA) will be launched on the outside of the MLM rather than on the Shuttle. Stowed on the outer hull of the MLM during launch, it will be deployed after arrival at the ISS and be able to "walk" over the Russian segment with the help of special fixture points that provide both electrical and mechanical interfaces. There will also be room on the MLM's hull to install a Shuttle-delivered cargo platform carrying scientific instruments, ERA grapple fixtures and other equipment. Also mounted on the outside will be so-called "Universal Work Platforms" (URM) to which cosmonauts can anchor themselves during spacewalks.

The overall habitable volume will be 71 m³ (64 m³ for the PGO and 7 m³ for the GA). On board will be several systems to make living conditions for the crew more comfortable. There will be one personal sleeping cabin (volume 1.2 m³) (in addition to the two already aboard Zvezda) and one personal hygiene facility with toilet (volume 1.2 m³). In addition to that, the MLM will house a system to regenerate water from urine, a small sauna and a system to disinfect air. The MLM will also have 8 m³ of storage room, while scientific equipment will occupy a volume of 4 m³. Up to 3 tons of scientific equipment can be installed inside the module. Also aboard the module will be a work station to operate the ERA.

Science Power Module (NEM): **this is the new name of the earlier Science Power Platform (NEP). The NEP was considerably simplified in the 2001 design of the Russian segment, basically consisting of just a truss and four solar arrays. Now with the NEM the Russians have returned to their more complex pre-2001 NEP design. The NEM features a truss with a small cross beam on top carrying eight solar arrays, which will be able to provide a total of about 5 kWt of power. The boom is placed on a pressurized section which externally is somewhat reminiscent of the Enterprise module. Inside this section are gyrodins and systems to distribute the power produced by the NEP solar arrays. Outside the module are storage batteries, radiator panels, a lateral docking port for the Pirs module and a thruster package for roll control of the ISS (similar to the VDU thruster packages mounted outside Mir). In the 2001 design of the Russian segment the gyrodins, radiator panels and power distribution systems had been moved to both the USM/CSM and Enterprise.**

Research Module (IM): **current plans call for just one Research Module, which will offer 13 m³ of space to install scientific instruments. The module may be built using either the Enterprise or FGB design, with the Russian Space Agency currently favouring the latter option. Aside from a front axial port to dock with Zvezda and an aft axial port to receive Soyuz and Progress vehicles, the Research Module is supposed to have a lateral docking port for additional payloads. The idea is to use this port to attach two small add-on scientific modules, based either on the Enterprise or Pirs design.**

Assembly Schedule

The Russian Space Agency is currently targeting the launch of the MLM on a Proton-M rocket for November 2007. The module has to be in place at the nadir port of the FGB before the launch of Node-3, which will occupy the neighbouring nadir port of Unity ("Node-1") and would not leave enough clearance for a safe docking of the MLM. Node-3, on the other hand, can be docked even with the MLM in place since it is delivered by the Shuttle and installed by the Space Station Remote Manipulator System (SSRMS). The launch of Node-3 is now tentatively scheduled for October 2008 on Shuttle assembly mission 20A (STS-131). It was mainly because of this time constraint that the Russian Space Agency decided to construct MLM on the basis of the partially completed FGB-2 rather than build it from scratch using the Enterprise design. Even so, there will not be enough time to fully outfit the MLM with scientific gear and other instruments in time for a 2007 launch. Therefore, the MLM will be orbited with only the most critical equipment on board and then be further outfitted in 2007-2009. Much of the additional equipment that needs to be installed outboard as well as the small airlock to be attached to MLM's lateral port are supposed to be launched by the Space Shuttle, although these payloads are currently not clearly manifested in the Shuttle flight schedule.

Scheduled for launch in January 2008 (UF-3/STS-127) are debris shields for the Zvezda module. Next it will be the

turn of the Science Power Module. The earlier plan was to launch the simplified NEP along with Enterprise and the ERA on Shuttle mission 9A.1 and fly solar panels for the NEP to ISS on one or two subsequent Shuttle flights. With the ERA going up on the MLM and Enterprise scrapped, it is possible that the complete NEM can now be launched on a single Space Shuttle mission, although the reintroduced pressurized section will occupy just about as much room in the cargo bay as Enterprise. Mission 9A.1 (STS-136) is now slated for launch in October 2009. Any additional equipment for the NEM or for the Russian segment in general could be launched in July 2010 on mission 9A.2 (STS-139), which was especially inserted into the schedule for that purpose several years ago. Space Shuttle operations are scheduled to be terminated with STS-141 in December 2010.

Once the NEM is assembled on the Zvezda zenith port, the Pirs module will be relocated from the Zvezda nadir port to the lateral port on the pressurized section of the NEM. This operation will be conducted using either the ERA or the SSRMS. Pirs will continue to act as the airlock for the Russian segment. Its aft port will remain available for Soyuz dockings, although other station elements may hamper Soyuz approaches from this new angle. Finally, the Research Module should link up with the Zvezda nadir port in 2011 and may receive two smaller scientific modules later on.

With the resumption of Shuttle missions and the introduction of the European ATV, the ISS will be much less dependent on Russian resupply missions than it has been since the Columbia accident. Although this should leave more room in the Russian ISS budget to finish construction of the add-on elements, there is no guarantee that they will be ready in time. An additional problem is that the launch of the MLM and NEM hinge very much on US planning. The launch of Node-3 is essentially the cut-off point for the MLM, while the NEM has to be ready before the Space Shuttle programme is closed down in 2010 [11].

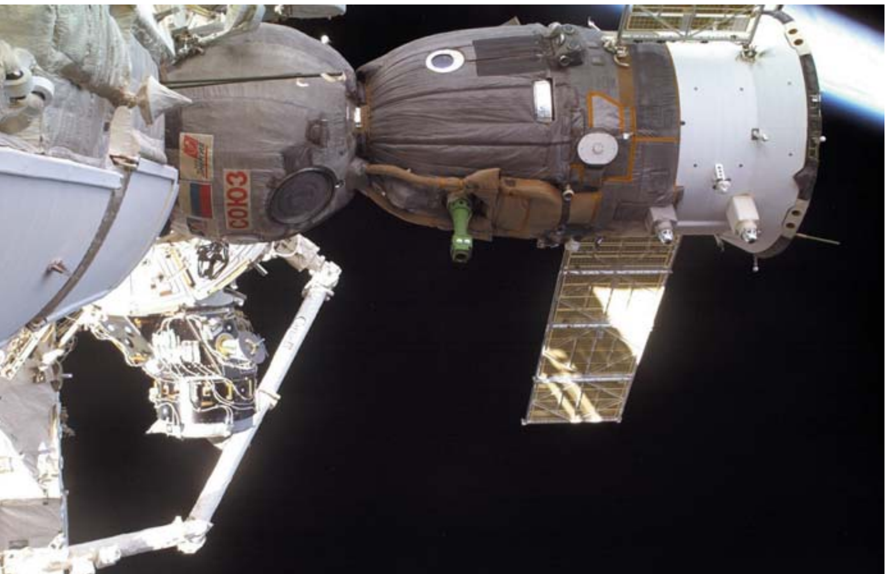
Transportation Systems

Soyuz and Progress: The ISS Lifeline

After Columbia broke up in the skies over Texas on 1 February 2003, the burden of delivering crews and supplies to the ISS fell entirely on Russia's shoulders. The ISS would now have to be operated very much as Mir had been in its first decade, with only Soyuz and Progress vehicles carrying up the astronauts and supplies needed to keep the station running. Although this situation more or less put Russia into a victim role, it should not be forgotten that until the Columbia accident America had contributed more than its fair share to crew transport and logistics supply.

As far as Soyuz was concerned, nothing really changed. Under a bilateral station agreement signed between the US and Russia in 1996, Russia was obliged to provide eleven Soyuz rescue vehicles during the assembly phase, with a new ship going up approximately every six months. At the time of the Columbia accident, only five had been launched, with six more to go before that obligation expired. The only thing that *did* change was that Soyuz would now have to fly Expedition Crews rather than short-term visiting "taxi" crews. Until then all but one of the Expedition Crews had been launched by the Shuttle (and *all* without exception had *returned* aboard the Shuttle), even though this had not been stipulated as such in the original station agreements. This had allowed the Russians to reserve at least one Soyuz seat (and theoretically *two*) for paying passengers such as visiting ESA astronauts and space tourists Dennis Tito and Mark Shuttleworth. Even that opportunity remained available, because the station would now host two-man "caretaker" crews as long as the Shuttle fleet remained grounded. That still left the third seat available for paying passengers on Soyuz exchange missions. In the spring of 2004 the Russians proposed a plan to extend Expedition 10 to one year, making it possible to fly two paying passengers on Soyuz TMA-6 in April 2005, but NASA rejected the idea.

Soyuz TMA-4 docked to Zarya. (NASA)



The picture was more complex for the Progress resupply ships. According to the original station agreements Russia was to launch as many as six Progress ships per year, but that launch rate had never been achieved (two vehicles in 2000, four in 2001 and three in 2002).


Progress M-47 leaves the ISS. (NASA)

Actually, the Shuttle had substantially reduced the Russians' resupply burden by delivering massive amounts of dry cargo and water to the ISS as well as by regularly boosting the station's orbit. Space agency heads meeting in Tokyo in December 2002 had agreed to reduce the required annual Progress launch rate to just three missions, but the Shuttle disaster turned all that upside down again. In the weeks and months following the STS-107 accident the Russians regularly demanded financial contributions from NASA to keep up the required Progress launch rate, with the Russian Space Agency at one point asking for $100 million over a two-year period to build three to four additional vehicles. NASA, however, declined, citing the fact that the money would not provide any relief in the short run. Since it takes about two years to manufacture a Soyuz or Progress spacecraft, the results of any US financial contributions would not be felt until 2005, by which time the Shuttle was expected to have returned to flight. Perhaps most important of all, there was a major political hurdle to making such payments in the form of the Iran Nonproliferation Act.

At the next meeting of space agency heads in Monterey, California in July 2003 Russia vowed to meet its station obligations until the resumption of Shuttle missions, then expected in September 2004. Meanwhile, the Russian government provided some relief by deciding in April 2003 to pay the ISS funds originally earmarked for the second half of the year (1.2 billion rubles) in the second quarter of the year and allocated an extra 1.5 billion rubles in December [12].

Russia has since kept its promises by duly launching Soyuz spacecraft every six months and sending up three Progress ships in 2003 and four in 2004. Russian demands for the US to foot some of the Soyuz bill even before Russia's obligations expired were put aside in late September 2004, when Russian Space Agency head Anatoliy Perminov and NASA Administrator Sean O'Keefe signed an agreement (seen as an addendum to the bilateral agreement of 1996) that Russia would provide free rides for US astronauts until the end of 2005 [13]. However, beginning with Soyuz TMA-8 in March 2006, NASA will have to pay the Russians for flying its astronauts on Soyuz, even though such money transfers are legally forbidden by the Iran Nonproliferation Act.

In the summer of 2005 the INA impasse finally seemed to be nearing an end, when the White House sent Congress a proposed revision to the INA that would make it possible for NASA to pay Russia for hardware and services related to the ISS programme, including cash payments for the use of Soyuz and Progress spacecraft. The only space station-related payments that would still be banned would be payments for services Russia agreed to provide for free as part of its contribution under the space station partnership agreement.

Soyuz Operations 2002-2005

In April 2002 Russia launched its 34th and final Soyuz-TM spacecraft. Thirty of the ships had flown to Mir between 1986 and 2000 and four to ISS between 2000 and 2002. When the ISS was due for its next Soyuz exchange in October 2002, it was time for the modified Soyuz-TMA spacecraft to make its debut. Under development since 1996, the vehicle among other things sports redesigned seat frameworks to carry larger astronauts, new computer displays on the control panel and two improved soft-landing engines [14]. Soyuz TMA-1 went up with a three-man "taxi" crew (Zalyotin-Lonchakov-De Winne) that subsequently returned aboard Soyuz TM-34. This was the first time that a crew had been launched aboard one type of Soyuz and returned in another, placing extra demands on the training programme. The launch of Soyuz TMA-1 also marked the inaugural manned flight of the Soyuz-FG rocket, which uses improved fuel injectors in the core stage and strap-on boosters [15]. Before committing the FG to a manned mission, the rocket was tested during the launches of Progress M1-6, M1-7 and M1-9 in 2001 and 2002. While Progress has since reverted back to the older Soyuz-U model, the FG is the standard launch vehicle for Soyuz-TMA.

In April 2003 Soyuz TMA-2 delivered the first two-man "caretaker" crew (Lu-Malenchenko) to ISS and the Expedition 6 crew (Budarin-Bowersox-Petit) returned to Earth aboard Soyuz TMA-1 rather than being picked up by STS-114

Recovery teams greet members of the Expedition 6 crew following the off-target landing of Soyuz TMA-1. (Novosti Kosmonavtiki/RKK Energiya)

as planned originally. The first re-entry of a Soyuz TMA vehicle did not go entirely by the book. The ship performed a ballistic re-entry, exposing the crew to twice the nominal amount of deceleration forces (about 8 g) and coming down about 440 km short of the expected landing point. To make matters worse, radio contact with the crew was lost just prior to touchdown and it took about two hours to locate them, causing some anxious moments among flight controllers. An investigation showed that the ballistic re-entry had been triggered by a violent yaw motion of the descent capsule some three minutes after the separation of the orbital and instrument modules. Although uncomfortable for the crew, ballistic re-entries are a standard back-up procedure on Soyuz missions and had been carried out earlier [16].

This time the problem was traced to a random electrical fault in a re-entry control device called BUSP-M, which had wrongly interpreted signals from the ship's KI00-18 gyroscope and the angular velocity measurement system. The BUSP-M device was not new to Soyuz-TMA, having been introduced on a Soyuz-T test flight (Kosmos-1074) in 1979 and used ever since on both Soyuz-T and Soyuz-TM. It is one of the 20 to 25 instruments on the Soyuz descent capsule that is regularly re-used to save costs, this particular one having flown earlier on Soyuz TM-29 in 1999. The electrical problem turned out to be so uncommon that it could be re-created in just one of forty tests performed after the mission. Nevertheless, a few minor modifications were made to the device beginning with the Soyuz TMA-3 mission. A recommendation made as a result of the (totally unrelated) communication problems was to provide future crews with mobile satellite phones to make contact with recovery forces after landing [17].

Other Soyuz TMA missions flown since have been relatively uneventful. There was a small incident just prior to the undocking of Soyuz TMA-2 in October 2003, when the ship's Approach and Orientation Engines were accidentally fired. This sent the station into an unexpected roll, which had to be stopped using Zvezda's thrusters. An analysis showed that one of the crew members had probably inadvertently touched a hand controller on the control panel during ingress into the Soyuz return capsule. To avoid such an eventuality, the control panel had been protected by a special cover, but this apparently was too soft [18]. The Soyuz TMA-3 vehicle experienced a leak in the helium pressurization system of its Combined Engine Installation, but this did not in any way affect the approach to the station or the return procedure.

Soyuz TMA-5 saw its launch delayed by a total of five days because of problems that cropped up during final processing at Baikonur. First, one of eight fuse bolts in the docking system was accidentally activated, forcing the entire system to be replaced. Subsequently, tests in a vacuum chamber revealed a leaky pressure membrane in a hydrogen peroxide tank of the descent capsule attitude control system. Problems kept dogging the spacecraft after it reached orbit. The automatic approach to the ISS was interrupted with just about 45 metres left to go because a forward-facing thruster (DPO 18) did not provide the required amount of braking, leaving commander Salizhan Sharipov no choice but to back off and conduct a manual docking.

The problem occurred despite the presence of two extra braking thrusters (DPO 27 and 28) in addition to the two mounted on the interface between the descent module and the propulsion compartment (DPO 17 and 18). The two new thrusters had already been tested before that on a Progress mission and were now flown for the first time on Soyuz to improve docking safety. Also introduced on TMA-5 was a thermoelectric cooling system (STEO) for the hydrogen peroxide tanks of the descent module's attitude control thrusters. Temperature extremes can cause hydrogen peroxide to decompose into oxygen and water and this has been one of the main factors limiting the on-orbit lifetime of Soyuz vehicles to about 180 days. If successful, the tests of the new cooling system could extend the warranty of the descent module attitude control system to one year [19].

These are the first two modifications implemented as part of a Soyuz upgrade effort begun by RKK Energiya in the second half of the 1990s under the names Soyuz TMM and Soyuz TMS [20]. Another is an improved computer system, which is expected to begin testing on Progress missions in 2006 for later installation on Soyuz TMA. Still others are an improved telemetry system, a satellite data relay system called Regul, an autonomous satellite navigation system , an improved Kurs-MM rendezvous system and various other improvements to increase landing accuracy and extend on-orbit lifetime to one year. The status of the latter plans is unclear.

Soyuz for Crew Expansion

Original station plans called for the ISS to be operated by three-man crews during the assembly phase and to host a permanent crew of up to seven once assembly was complete. From then on, Russia had the right to have three representatives on the station, while the remaining four-man "Western" crew would consist of a mix of American, European, Japanese and Canadian astronauts. Soyuz was to provide rescue capability for all three crew members (irrespective of nationality) during the assembly phase and then for the three Russian crew members during the operational phase. America's Crew Rescue Vehicle (CRV) would need to be available after completion of assembly to evacuate the four "Western" crew members.

These plans fell through in 2001 when budget realities forced NASA to suspend work on the Habitation Module and CRV. The agency was now aiming for a "US Core Complete" in 2004 without these elements, implying crew size would remain limited to just three. At the end of the year an independent task force headed by former Martin Marietta President Thomas Young recommended three ways of giving the station the needed life support capacity to house six crew members on a permanent basis. One was to build a habitation module on the basis of the Multipurpose Pressurized Logistics Modules (MPLM), a second to equip Node-3 with US life support systems and a third to outfit Enterprise with Russian life support systems. The first option foresaw the use of the CRV with a considerable financial contribution from ESA, while the second and third options involved the purchase of Russian Soyuz rescue craft.

A major stumbling block for a Soyuz deal was the The Iran Nonproliferation Act of 2000. In hopes of eventually working around that problem, NASA officials did begin negotiations on a Soyuz deal with the Russians in the spring of 2002, but these did not progress very far, not in the least because the Russians reportedly asked $65 million for one Soyuz, which would amount to $1.3 billion over a 10-year period. Nevertheless, there was considerable pressure from both the European and Japanese sides to work out a Soyuz deal, because if the ISS increment crews remained limited to three, European, Canadian and Japanese astronauts would barely have a chance to fly to the station. Still, NASA did not bow to that pressure at a meeting of space agency heads in Tokyo in December 2002.

Meanwhile, NASA had begun looking at alternative options such as flying a seven-man crew with just one Soyuz lifeboat attached to the station and providing a "safe haven" aboard ISS for four crew members to keep them alive until a Shuttle was ready to pick them up. In November 2002 NASA presented a new Integrated Space Transportation Plan which would see the development of an Orbital Space Plane (OSP) to act as a crew transport and rescue vehicle, but this was not expected to become available until 2008 at the very earliest.

After the Columbia disaster in February 2003 the discussion on crew expansion and the purchase of Soyuz vehicles by NASA took a backseat to the more immediate concern of launching enough Progress cargo ships to sustain even a two-man caretaker crew aboard the ISS. However, as NASA slowly recovered from the accident, attention once again turned to the future of ISS and the role of Soyuz. The next major development came in January 2004 when President Bush announced the New Vision for Space Exploration, calling for an end to Space Shuttle operations in 2010. Rather than build the OSP, NASA was now instructed to develop a Crew Exploration Vehicle (CEV) that could be adapted for both Earth-orbital and lunar missions and would have to be ready for its first manned mission by 2014.

The Bush initiative also revived US interest in flying large-size crews on ISS. Ever since taking the helm at NASA in late 2001, Administrator Sean O'Keefe had publicly challenged the need for expanding the station crew. He was only strengthened in that belief when the two-man caretaker crews that began flying to ISS in April 2003 demonstrated they could not only perform maintenance work, but do a considerable amount of science as well. Now, having been given the go-ahead to prepare for future piloted deep space missions, NASA showed renewed interest in flying the type of large crews that will probably eventually set out to the Moon and Mars.

With no independent crew rescue capability until the CEV becomes available, NASA now has little choice but to continue to rely on Soyuz as a lifeboat for at least another decade. Not only that, after the termination of the Shuttle

Soyuz TMA-6 on its final approach to the ISS. (NASA)

programme in 2010 Soyuz will even become the sole means of *delivering* crews to the station until the CEV is ready to fly. In the weeks following the Bush announcement, statements from various NASA officials (including O'Keefe) indicated the agency was finally beginning to warm to the idea of large crews and a second Soyuz lifeboat. By late February 2004 internal NASA documents obtained by the weekly *Space News* showed that NASA "expected to acquire Soyuz or other vehicles for crew transport to and from the station" after the Space Shuttle was retired in 2010 and that two percent of NASA's aggregate budget through 2020 would be spent on Soyuz and cargo services for the ISS [21].

At a meeting of the Multilateral Control Board in Toronto in June 2004 the partners reached preliminary agreement on expanding the crew to six around 2009, with Russia receiving financial compensation for providing Soyuz vehicles. Additional US life support systems will be installed aboard Node-3, which has now again been included in the ISS assembly plan after having been scrapped earlier. Space agency heads meeting in Noordwijk (the Netherlands) in July 2004 unanimously agreed on the need to make a Soyuz deal, although NASA officials declined to say outright that the US government would purchase the vehicles. Associate Administrator Fred Gregory said the informal agreement reached on 23 July "does not imply that there would be a purchase that would involve an INA [Iran Nonproliferation Act] waiver. It does imply that there would be an acquisition of Soyuzes by some means. It has not been determined how that would occur" [22].

As things stand now, two issues remain to be resolved. First, when Russia's Soyuz obligation expires at the end of 2005, NASA will in principle have to pay for any Soyuz rides by its astronauts to the ISS as long as the assembly phase continues. Then, once Node-3 is in place in late 2008 and the permanent crew can be increased to six, NASA will have to purchase *entire* Soyuz spacecraft to provide rescue capability for its crew members (plus those of Europe, Canada or Japan) and eventually to fly them to the station as well after the Shuttle fleet is retired in 2010. The cost could be significantly reduced if Soyuz on-orbit lifetime is increased from six months to a year, but there are no signs that this will happen any time soon.

The decision to build a launch pad for commercial flights of the Soyuz launch vehicle at Kourou in French Guyana opens the prospect of flying Soyuz missions from there, but this idea has received only a lukewarm reception from the Russian side. First, the near-equatorial location of Kourou does not provide any advantages over Baikonur in launching payloads into the space station's 51.6° orbit. Another drawback would be the need to develop a costly ocean search and rescue infrastructure for launch emergencies.

Progress operations 2002-2005

The Progress resupply ships have continued their unblemished record of service. Since 1978 over 100 Progress ships have been launched and despite some occasional docking problems none them has ever failed to deliver its precious cargo to a space station. The vital importance of these spacecraft once again came to a head after the Columbia accident in 2003, when Progress became the sole means of providing ISS crews with critical supplies.

The Russians have continued to fly both the Progress M and M1 models. The main difference between the two vehicles is the amount of propellant tanks in the mid compartment (eight on Progress M1 as compared to four on Progress-M). Theoretically, the Progress M1 tanks are able to hold a maximum of 1950 kg of propellant (compared to 870 kg for Progress-M), but they have only been used to full capacity on Progress M1-5 to deorbit Mir in 2001. Both types of Progress vehicles are regularly used to boost the station's orbit. Some 250 kg of the spacecraft's own fuel reserves in the propulsion section are available for such manoeuvres.

Because of the room taken up by the extra propellant tanks, Progress M1 does not carry the two "Rodnik" water tanks that Progress M has in its mid section. Until the Columbia accident the bulk of the station's water supply had come from the Shuttle, whose electricity generating fuel cells produce water as a byproduct. When Progress became the station's sole source of water, the absence of the Rodnik tanks on Progress M1 proved to be a problem. This is why extra containers with water had to be flown in the front "dry cargo" section beginning with Progress M1-10 in June 2003 [23].

TABLE 1: *Mass Distribution of Cargo Carried by Progress Vehicles Between Early 2002 and mid 2005.*

Vehicle and launch date	Dry cargo	Propellant for refuelling	Oxygen	Water in Rodnik tanks	Propellant for reboost	Total cargo mass	Total vehicle mass
Progress M1-8 21.03.2002	1337	780	40	-	250	2407	7286
Progress M-46 26.06.2002	1455	825	50	-	250	2580	7290
Progress M1-9 25.09.2002	1444	854	40	-	n/a	n/a	7440
Progress M-47 02.02.2003	1328	870	50	70	250	2568	7267
Progress M1-10 08.06.2003	1612	403	40	-	250	2305	7270
Progress M-48 29.08.2003	1498	353	45	420	250	2566	7283
Progress M1-11 29.01.2004	1459	659	40	-	250	2408	7230
Progress M-49 25.05.2004	1177	640	48	420	250	2535	7261
Progress M-50 11.08.2004	1405	442	49	420	250	2566	7264
Progress M-51 24.12.2004	1352	480	49	420	250	2551	7268
Progress M-52 28.02.2005	1347	262	109	420	250	2388	7259

Notes:
All figures in kg.

- ”dry cargo” is all cargo placed in the front compartment (including water)
- Propellant for refuelling, oxygen and air supplies and Rodnik water tanks (only for Progress-M) are all in the mid-compartment
- Propellant for reboost is propellant reserved in the Progress instrument/propulsion compartment for boosting the station’s orbit during docked operations
- NASA uses its own numbering system for Progress missions to ISS (Progress 1, 2, 3 etc.), but this is very confusing, since exactly the same numbers were used by the Russians for their first-generation Progress vehicles between 1978 and 1990. In NASA’s system Progress M1-8 is Progress-7, Progress M-46 is Progress-8 etc.

Although Progress usually takes 48 hours to reach the ISS, some missions in the past three years have followed longer approach routes. Progress M1-8 spent one additional day in autonomous flight to test new accelerometers for Soyuz TMA. Progress M-46 and Progress M1-9 were underway for respectively three and four days to analyze a problem with one of the Service Module’s Kurs antennas that had surfaced during the docking of Progress M1-8. Another three-day approach was followed by Progress M-50 to take accurate thrust measurements of the space-craft’s eight approach and docking thrusters. When those same thrusters were used to boost the station’s orbit several days later, the data from the manoeuvres was compared to calculate the mass of the ISS with great accuracy.

Some Progress vehicles have also been used for additional experiments after undocking from the station. Progress M1-7 released the Kolibri-2000 microsatellite, a 20.5 kg educational/scientific satellite developed jointly by Russia and Australia. Two supply ships (Progress M-46 and M1-10) spent extra time in orbit to film areas on the ground with the black and white cameras used during docking. Progress M1-11 and Progress M-51 remained in space to test passive orientation modes that could later be used to conduct materials processing experiments in a vibration-free environment. Once the experiments are finished, the Progress could then return to ISS to deliver the samples back.

The launch of Progress M1-10 in June 2003 saw a change in the pre-launch flow for Progress and Soyuz vehicles at the Baikonur cosmodrome. The assembly of the rocket was moved from the old MIK-2A assembly building in Area 2 of the cosmodrome to one of the low bays of the former Energiya assembly building in Area 112. This had been unaffected by the roof collapse in the adjacent high bay in May 2002, which destroyed the only flown Buran vehicle. Although the new assembly hall is much roomier than MIK-2A, it is much farther away

from the “Gagarin” launch pad in Area 1, making the roll-out procedure more cumbersome. First, a locomotive pulls the rocket out of the the Energiya assembly building with the first and core stages facing forward (unlike the roll-out from the old Soyuz assembly building where the locomotive pushes rather than pulls the rocket). The assembly then moves in the direction of the defunct Energiya/Buran pads (Area 110). At a juncture in the railway not far from the pads a locomotive is attached to the front side of the assembly which pulls the assembly in the direction of Area 2 with the payload shroud facing forward. Having reached a turn in the railway in Area 2, the rocket’s engine nozzles now face the Gagarin pad, one locomotive is detached and the other pushes the rocket to the pad as in the old days. The roll-out now takes about 2 hours (compared to 30 minutes in the old days) [24].

New route to the pad for Soyuz and Progress. Roll-out of Progress M-50 from the former Energiya assembly building. The defunct Energiya/Buran pads are in the background. (RKK Energiya)

Alternative Cargo Carriers

Logistics Transfer Vehicles

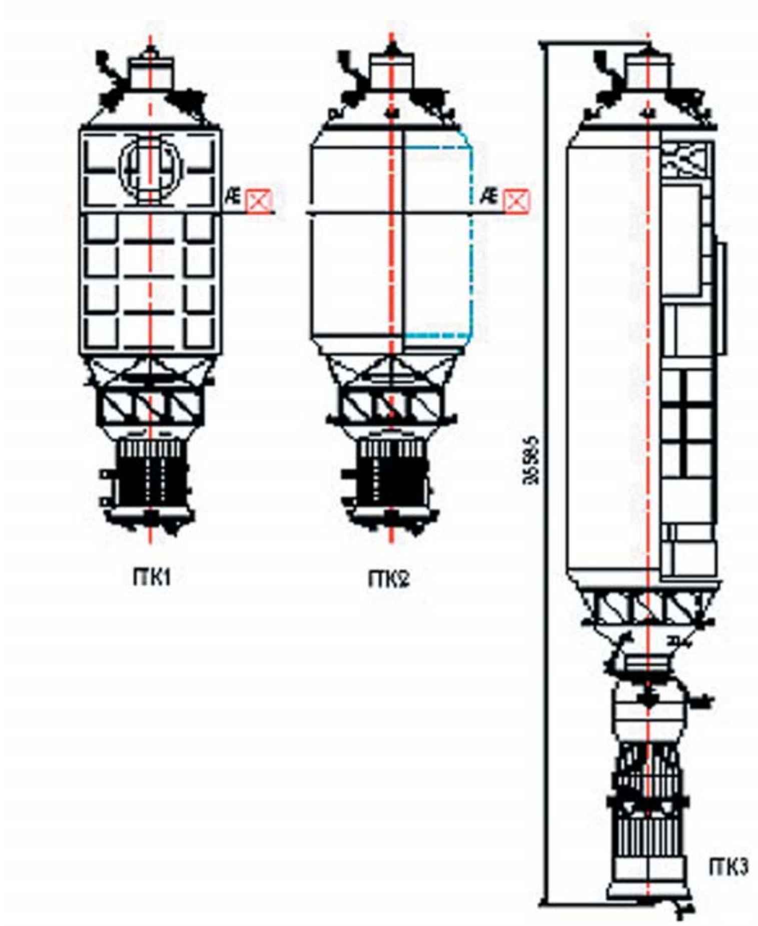
In the original station plans dating back to the mid-1990s, RKK Energiya had planned to use Zenit rockets to launch enlarged Progress vehicles (Progress-M2) with a maximum cargo capacity of 5.7 t. However, in early 1996 the Zenit rocket was dropped from the ISS assembly schedule, following which Khrunichev came up with a proposal to use FGB-based cargo ships to deliver as much as 10 tons of cargo to ISS. Referred to by NASA as Logistics Transfer Vehicles (LTV), they were to be jointly financed by Russia and the US, but in 1997 NASA decided not to fund the LTVs and instead carry up additional supplies on the Shuttle. Khrunichev then tried in vain to have the LTVs financed by the Russian Space Agency alone, proposing on several occasions to turn the Zarya back-up (FGB-2) into an LTV demonstrator. Khrunichev director A. Medvedev once again put forward this idea when Russian Foreign Minister Igor Ivanov visited the company just three days after the Columbia accident, adding that yet another FGB could also be built if necessary [25]. With FGB-2 now scheduled to be converted into the Multipurpose Laboratory Module, it looks unlikely it will ever perform that role.

Cargo Transport Ships

Also in the wake of the Columbia accident Khrunichev and RKK Energiya jointly proposed an alternative way of delivering Shuttle-sized payloads to the ISS. Actually, those plans seem to have harked back to earlier studies conducted by both companies to launch large Russian payloads to the station (based either on Progress-M2 or the FGB). Even during very early ISS negotations in the spring of 1993 the Russians had tabled a proposal to launch large payloads such as the European and Japanese modules with the Proton rocket. The idea proposed now was to use the Proton-M rocket to launch large ISS payloads in pressurized modules or on unpressurized platforms. These vehicles, called “Cargo Transport Ships” (GTK), were to consist of a Payload Compartment (OPG) using elements of Zarya and Zvezda, and a Mission Support Module (MSS) using elements of the Progress cargo ships. Three configurations were proposed:

- GTK-1: a pressurized OPG with a Progress-M propulsion compartment acting as the MSS
- GTK-2: an unpressurized OPG (payloads up to 10 tons) with a Progress-M propulsion compartment as MSS
- GTK-3: an unpressurized OPG (payloads up to 13-15 tons, length up to 14 m) with a complete Progress-M1 vehicle performing the role of MSS.

In the GTK-1 configuration the OPG could carry consumables and standard science racks like the ones flown on the Multipurpose Logistics Modules (MPLM). After initially docking to the Zarya nadir port, GTK-1 would be relocated to Node-2 using the SSRMS and then be unloaded like an MPLM. The OPG would have a laterally mounted Common Berthing Mechanism (CBM), enabling it to be docked with Node-2.



GTK-1 (left), GTK-2 (middle) and GTK-3 (right).
(Novosti Kosmonavtiki/Khrunichev)

The GTK-2 configuration could conceivably be used to transport modules such as Columbus and Kibo to ISS. The GTK would remain docked to the Zarya nadir port, with the SSRMS transferring the payload to the required location.

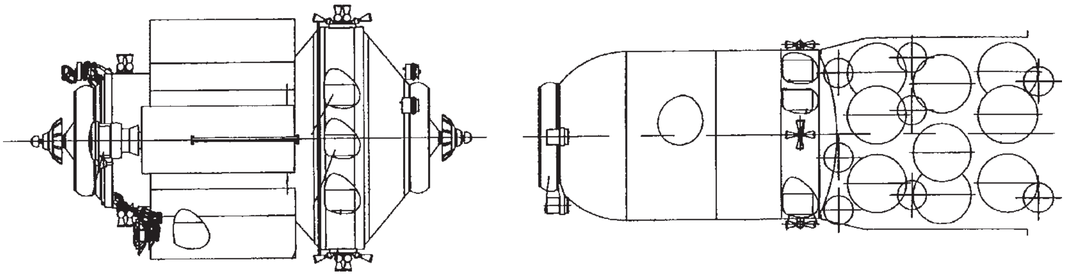
GTK-3 was intended to launch elements of the truss such as P3/P4 and S3/S4. In this scenario the OPG would be launched separately on a Proton-M rocket and then link up with a Progress M1 spacecraft that would tow it to the station. After arrival at the Zarya nadir port, the truss section would once again be transferred to the required location by the SSRMS.

In all scenarios the OPG had the same type of interfaces as the Shuttle cargo bay, enabling the payloads to be launched with minimal modifications. RKK Energiya and Khrunichev said at the time that if they were given the go-ahead to develop these vehicles by mid-2003, the first GTK-1 could be ready in the last quarter of 2005 and the first unpressurized GTK by the first quarter of 2006. The vehicles were to be constructed on a commercial basis, for instance with money originally intended for the Shuttle missions that were supposed to launch the payloads in question. Considerable financial savings would be achieved because the Proton is a relative bargain compared to the Shuttle. However, NASA rejected the offer, saying the Shuttle's human-friendly launch profile had allowed the modules to be designed for a gentler ride into space than that provided by the Proton [26].

Now that Space Shuttle operations have been resumed, it looks unlikely that any of these back-up plans will be required. However, if for some reason the Space Shuttle cannot fly all the missions still manifested until 2010 (as looks very likely now), this may be one way of launching any remaining Shuttle-sized payloads to ISS, at least as long as the Zarya nadir port is not occupied by the MLM. It could also be an alternative option to carry up Russia's Science Power Module in case that is not ready for launch before the end of the Space Shuttle programme.

Parom

More recently, plans have emerged for an RKK Energiya vehicle called Parom ("Ferry"), which is supposed to act as a reusable space tug. Although the company took out a patent on this vehicle in October 2001, its existence was not



Parom space tug (left) and cargo container. (Rospatent)

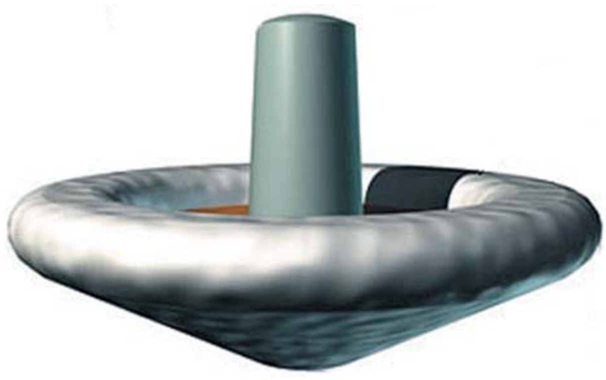
unveiled until April 2004 by RKK Energiya deputy general director Nikolai Bryukhanov. The idea is that the fully-fuelled, highly manoeuvrable space tug is launched for a mission lasting five to ten years. It will pick up individually launched cargo containers and then tow them to the required location (such as the ISS), obviating the need to outfit the containers with expensive and heavy propulsion systems. The combination can dock with a space station either on the side of Parom or that of the container. Once a container has been unloaded and stuffed full with waste, the tug returns it to a lower orbit, releases it and awaits the launch of the next one. According to Bryukhanov the containers could be launched by "virtually any Russian or foreign rocket" and carry dry cargo or propellant. Parom could also be used to transport large unpressurized platforms carrying solar panels, modules or elements of future interplanetary spaceships. So far RKK Energiya has funded all work on Parom with its own means. The spacecraft has been presented to the Russian Space Agency, which "has promised its support" [27].

In the late 1970s and early 1980s Energiya worked on several concepts for interorbital tugs with nuclear electric engines, but indications are that Parom will use conventional chemical rocket engines and that there is no link with these earlier studies [28]. Although Parom is externally somewhat reminiscent of Khrunichev's FGB type vehicles, any such resemblance is probably superficial. Clearly, the Russians will have to carefully assess if the use of such a space tug in combination with cargo containers is economically more advantageous than regular launches of Progress spacecraft. One factor to be taken into account here is that Parom will have to be occasionally refuelled in orbit, not only to perform its space tug role, but also to keep its orbit co-planar with that of the station. This would have to be done with propellant delivered aboard the containers themselves. Possibly, the main role for Parom is seen not so much in ISS operations, but in future assembly work in Earth orbit.

Recoverable capsules

While vehicles such as Progress, Europe's ATV and Japan's HTV should largely be able to replace the Shuttle for the *delivery* of cargo, a more nagging problem after the end of the Shuttle era will be the *return* of cargo back to Earth. Until a more advanced manned spacecraft comes along, the only vehicle capable of doing that will be Soyuz, which besides a three-man crew can bring back a payload of just about 50 kg. One way of addressing this problem may be the use of small cargo containers protected during re-entry by inflatable heatshields and not requiring parachute systems. This so-called Inflatable Re-entry Descent Technology (IRDT) was pioneered by the NPO Lavochkin design bureau for the penetrators of the ill-fated Mars-96 mission and then later perfected in co-operation with the German Astrium company. Three IRDT demonstration missions flown in 2000-2002 were almost complete failures, but further test flights are planned.

If these prove to be successful, future Progress spacecraft could be outfitted with small capsules that separate from the cargo ships after the de-orbit burn and re-enter using the inflatable heatshields. They would be quite similar to the Raduga capsules flown in the Mir programme in the early 1990s, but the absence of heavy heatshields and parachutes would enable them to return 200-250 kg of payload to Earth (compared to 150 kg for Raduga). Similar capsules could also be deployed from ATV cargo ships once their missions are complete. IRDT also holds the promise of landing much heavier payloads on the Earth or other planetary surfaces and is actively being studied by the Russians for future manned programmes [29].



Recoverable cargo capsule with inflatable heatshield. (NPO Lavochkin)

Kliper

Until early 2004 it looked as if Soyuz TMA and its further modifications were going to serve the Russian space programme indefinitely. That picture changed when Russian Space Agency chief Yuriy Koptev held a news conference in Moscow on 17 February 2004. Answering a totally unrelated question about possible manned Soyuz missions from Kourou, Koptev remarked almost in passing that RKK Energiya was working on a new manned vehicle "with a reusable return capsule and with a mass of 12-14 tons". He added that the ship would be able to carry up to six cosmonauts and was to be orbited by a rocket called Onega, "a further development of the Avrora" [30]. Two days after Koptev's disclosure, RKK Energiya deputy general director Nikolai Bryukhanov revealed to journalists of the Russian space magazine *Novosti Kosmonavtiki* that the vehicle was called "Kliper" ("Clipper") [31] and that Energiya had begun work on it "on its own initiative" as early as 2000 [32].

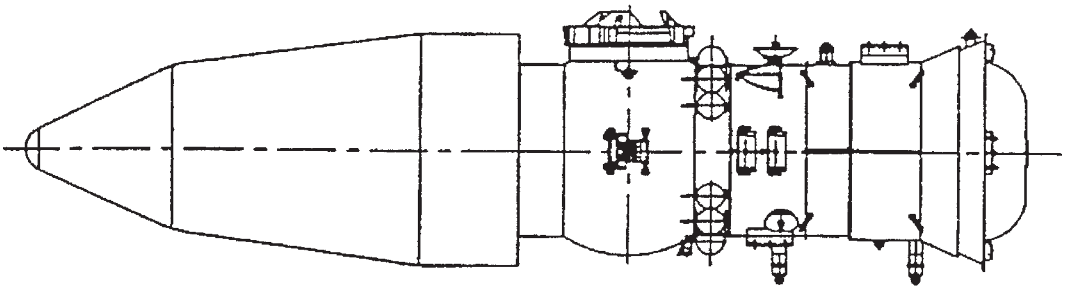
In the following weeks more details about the project gradually surfaced, although it took quite a while before a clear picture of the vehicle's design emerged. Clearly, the project is still in the conceptual stage, because even in the year and a half or so that has elapsed since it was unveiled it has undergone a number of changes. The most important of these were a decision to launch Kliper by Zenit rather than Onega and a proposal to turn the re-entry vehicle from a lifting body into a winged spacecraft.

Origins

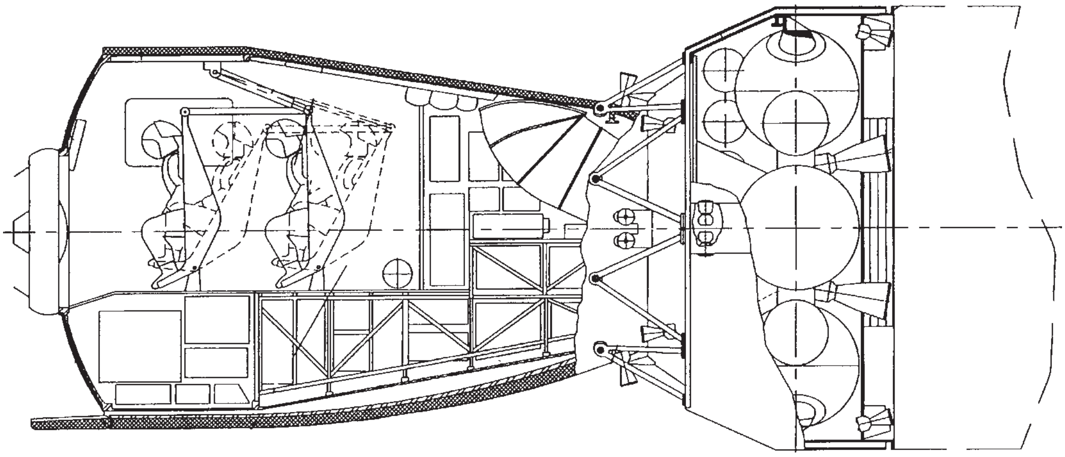
Kliper's design cannot be traced back to one single vehicle. It reflects the experience accumulated over the years by RKK Energiya in designing capsule type spacecraft, winged vehicles and lifting bodies.

The idea to develop a lifting body class vehicle as a successor to Soyuz probably evolved from research conducted in the late 1980s and early 1990s on a variety of re-entry vehicles intended to return cargo from space stations and perform microgravity experiments in orbit. This work began in 1988 with the development of the earlier mentioned Raduga ballistic capsules to return cargo from the Mir space station. Launched aboard Progress spacecraft, they could be loaded with about 150 kg of cargo and separated from Progress just before the latter burned up on re-entry. Nine of these capsules were flown between 1990 and 1994. The next planned step was to turn these capsules into autonomously functioning spacecraft by equipping them with their own instrument/propulsion sections. Called Small Orbital Spacecraft (OMA), they would fly solo unmanned missions to carry out various experiments in microgravity and return the results to Earth. Three such OMA vehicles appeared on the drawing boards, two using the Raduga capsules and the Kosmos-3M booster (return capacity 150 kg) and one employing an enlarged version of Raduga and the Tsiklon-2 booster (return capacity 450 kg). NPO Energiya proposed an OMA for the German Express spacecraft, but this was turned down in favour of a competing proposal from the Salyut Design Bureau.

Eventually, the goal was to replace the ballistic capsules by lifting body re-entry vehicles known as Recoverable Manoeuvrable Capsules (VMK). These would have a cross-range capability of 1000 km and be capable of making controlled re-entries, resulting in reduced g-forces and precision landings with an accuracy of about 2.5 km. The VMK was to land vertically using parachutes and soft-landing engines. The idea was to have four VMKs of different sizes attached to individually tailored instrument/propulsion compartments. The launch vehicles for the four versions were Tsiklon-2, Soyuz, Zenit and Proton. The Tsiklon-launched version (known as the Transport Research Vehicle or TIK with a VMK called "Zarnitsa") was apparently designed for unmanned microgravity missions similar to those to be carried out by the OMAs. However, the VMKs were also said to be designed to return large and heavy payloads from space stations, with the three heavier versions also capable of acting as space station lifeboats. The manned



Zenit-launched manned spacecraft with lifting body re-entry vehicle proposed in the early 1990s.
(RKK Energiya)



Manned spacecraft with lifting body re-entry vehicle proposed in 2001. (Rospatent)

versions were reportedly called Piloted Transport Spaceships (TPKA). A drawing of the Zenit-launched version shows a re-entry vehicle shaped almost exactly like that of Kliper and a docking compartment with a north-facing androgynous docking port inbetween the re-entry vehicle and the instrument/propulsion compartment [33]. A patent application for this type of re-entry vehicle was submitted in July 1994 [34].

Indications are that the VMK studies were discontinued in the mid-1990s, but then were picked up again when RKK Energiya began working on a Soyuz successor in 2000. Aside from a lifting body type vehicle, RKK Energiya initially also studied capsule type and winged re-entry vehicles, but in early 2002 decided that a lifting body was the best choice. The VMK type configuration was not the only one studied. At least three patents for lifting body re-entry vehicles were granted to RKK Energiya after 2000. One concept consisted of a lifting-body type re-entry vehicle and an instrument/propulsion compartment. The vehicle would be mounted nose-down on the launch vehicle, with the crew seated with their backs to the nose of the spacecraft. The docking collar was on the re-entry vehicle itself and therefore probably reusable. There are no indications in the patent how many crew members this vehicle could carry [35].

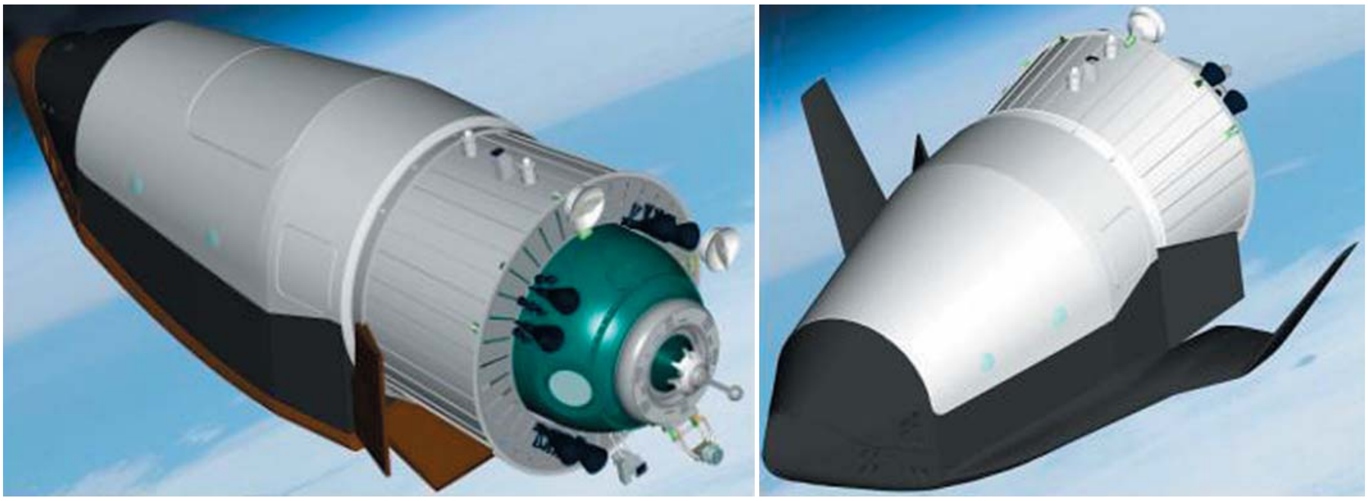
Design

The present Kliper has a reusable "Return Vehicle" (VA), made up of a crew cabin partially ensconced in an unpressurized fuselage. Attached to the aft of that is the expendable "Aggregate Compartment" (AO), consisting of a habitation compartment surrounded by the AO body. About half of the habitation compartment protrudes from Kliper's aft section and has a docking port to link up with the ISS or other spacecraft.

The Return Vehicle's blunt-shaped crew cabin offers 20 m³ of working space (five times as much as Soyuz) and can house a maximum crew of six (minimum crew two). The earliest cut-away drawings showed three seats in the front and three in the back, but in the latest drawings there are just two seats in the front and four in the back. The crew cabin contains the most valuable equipment (control systems, life support, thermal control). The cabin has a side hatch for crew entry and exit and also sports four windows. Mounted on top is a parachute compartment with a jettisonable cover.

Protecting the lower portion of the crew cabin during re-entry is an unpressurized lifting-body type fuselage. Equipped with two vertical and one horizontal rudder, it provides a cross-range capability of up to 500 km (10 times more than Soyuz). Installed on the fuselage are thrusters for attitude control in orbit and during re-entry and soft-landing engines to be ignited just prior to touchdown. Also softening the landing will be an inflatable cushioning device that will be deployed at the same time as the parachutes. The fuselage and the upper part of the crew cabin will have a heatshield consisting of 60 x 60 cm thermal covers made from the same material as Buran's tiles. The fuselage's nosecap will be covered with a non-reusable ablative heatshield similar to the one used on Soyuz.

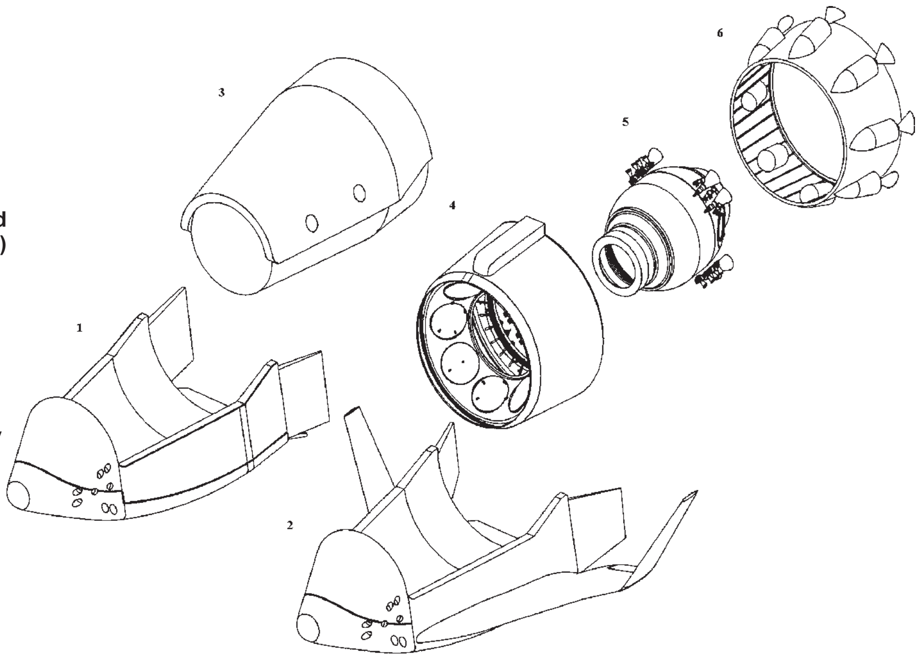
During a press tour of RKK Energiya facilities on 30 November 2004 company officials revealed an alternative winged design for the fuselage, which would increase cross-range capability to 2000 km. In this configuration the vehicle would not have a parachute compartment and make a classical horizontal runway landing. In case of a launch abort, it would also have to be able to reach the nearest available runway. A final choice between the lifting body and



Two currently proposed versions of Kliper: a lifting body and a winged vehicle. (RKK Energiya)

Exploded view of Kliper (Zenit-launched version). (RKK Energiya)

Key:
1. fuselage shaped as lifting body
2. winged fuselage
3. crew cabin
4. instrument/propulsion compartment
5. habitation compartment
6. launch vehicle adapter with emergency escape rockets



winged designs remains to be made. The shape of the fuselage does not affect the design of the crew cabin itself, meaning that the two can be developed independently.

The Aggregate Compartment's habitation compartment, situated behind the crew cabin, looks almost identical to the Soyuz orbital module and performs the same functions. Providing 8 m^3 of living space, it will among other things have a personal hygiene facility, sleeping bags and carry various consumables. At the aft end will be an active Soyuz-TM type docking port, a new Kurs-N rendezvous system amd several orbital manoeuvring engines and attitude control thrusters.

Surrounding the habitation compartment is the torus-shaped AO body which among other things will carry a thermal control radiator and propellant tanks for the aft engines and thrusters. The propellants are liquid oxygen and ethanol. Originally, Kliper had a pair of solar panels, but these have now been replaced by fuel cells. Derived from the ones developed for Buran, the fuel cells are configured such that Kliper can fly autonomously for five days during docking missions and up to 15 days during solo missions. The Aggregate Compartment is jettisoned from the rest of Kliper after the de-orbit burn and burns up on re-entry. The designers opted to include it as an expendable section to avoid problems associated with returning engines and tanks with propellant remnants and also to simplify the design of the parachute and landing systems.

Kliper will be mounted on top of its launch vehicle, unprotected by a nose fairing. In the Onega configuration, Kliper had an emergency escape tower installed on top of the payload shroud. Outwardly very similar to the Soyuz emergency escape system, it was capable of pulling the vehicle from the rocket on the launch pad and in the early

stages of the launch. In the Zenit configuration the emergency escape system consists of eight solid rocket motors installed on an adapter between the launch vehicle and the spacecraft. If no abort is required, four of the motors will still be used for the final orbit insertion manoeuvre, thereby providing extra weight savings. In the latest design the total mass of Kliper is said to be 13 tons, with the Return Vehicle accounting for 8.8 tons of that.

In April 2004 RKK Energiya president Yuriy Semyonov said the plan was to build four Kliper Return Vehicles for both autonomous missions and flights to the ISS. He estimated it would take no more than 5 to 6 months to prepare them for a new mission and install non-reusable components. Each Return Vehicle's crew cabin should be capable of making 20 to 25 missions over a 10-year period [36].

The Onega Launch Vehicle

The launch vehicle originally considered for Kliper was Onega. Named after a lake not far from St. Petersburg, it maintains the basic lay-out of the Soyuz rocket, but would be capable of lifting a much heavier payload thanks to the use of a larger propellant load and improved engines. Onega has its roots in two independent upgrade programmes for the Soyuz rocket. One of these is a government-funded project called “Rus”, the goal of which is to gradually uprate the capacity of the rocket to just over 8 tons by flying more capable engines and a modernized control system (Soyuz-FG, Soyuz-2-1A and 1B). “Rus” is managed by the Central Specialized Design Bureau (TsSKB) in Samara (formerly Kuibyshev). This bureau originated as Branch Nr. 3 of Sergei Korolyov’s OKB-1 in 1959 to oversee the further development of R-7 based rockets and later also to design the nation’s photoreconnaissance satellites. Aligned with the design bureau was a factory known as “Progress”, where the bureau’s rockets and spy satellites were integrated, although it also performed work for other design bureaus (such as building various elements of the N-1 rocket for the Kuznetsov design bureau). Not eager to take part in the development of the Energiya rocket, Branch Nr. 3 became independent as TsSKB in 1974, with NPO Energiya setting up a new branch in Kuibyshev (the so-called “Volga” branch) to design Energiya’s giant core stage.

It was the Volga branch that embarked in the late 1980s/early 1990s on a separate effort to turn Soyuz into a medium-lift rocket capable of lifting over 10 tons. An early idea (called “Volga”) was to equip a widened R-7 core stage with a single RD-0120 liquid oxygen/liquid hydrogen engine (from the Energiya rocket), flanked by four standard R-7 strap-on boosters. Subsequent studies focused on the NK-33 engines originally developed for the N-1 moon rocket by the Kuznetsov design bureau, another Samara-based organization.

More specifically, the Volga designers proposed a rocket with standard-sized strap-on boosters, but with a widened core stage powered by a single NK-33 engine. The lower part of the core stage was widened from 2.06 m to 2.66 m and the upper part from 2.66 to 3.44 m. When topped up to maximum capacity, the core stage would now carry 40-50 tons more fuel than the standard Soyuz core stage. The third stage was also widened to 3.44 m to remain compatible with the core stage and because of that carried about 5 tons more propellant than the standard third stage.The rocket also borrowed two elements from the Rus programme, namely RD-107A (14D22) engines with improved fuel injectors in the first stage strap-on boosters (first flown on Soyuz-FG) and the new RD-0124E engine for the third stage (a modified version of the RD-0124 for the third stage of the Soyuz-2-1B). All these modifications would enable the rocket to lift a payload of up to 11-12 tons into low Earth orbit. The rocket could also be adapted for missions to higher orbits by adding a fourth stage (“Taimyr” or “Korvet”) inheriting technology from the Blok-L and Blok-D. Having virtually the same length as the standard Soyuz rocket, the new rocket required only minor modifications to existing Soyuz launch pads.

In 1996 the Volga branch proposed to use the four-stage version to launch RKK Energiya’s Yamal communications satellites into geostationary orbit one at a time from Baikonur (rather than launching them in pairs on Proton rockets). RKK Energiya’s central bureau in Moscow liked the idea and –in keeping with Russian tradition- named the rocket after its (expected) first payload. The three-stage version of the Yamal rocket was also eyed to launch Russian modules to the ISS, replacing the Ukrainian-built Zenit. However, there were no immediate prospects of

(Left) Kliper mounted atop the Onega launch vehicle. (Novosti Kosmonavtiki/RKK Energiya)

receiving government funding for the project, which would have to be financed through private investments and loans. TsSKB did join the Yamal development programme, but – officially at least – displayed little enthusiasm, claiming it was preoccupied with the Rus programme. At any rate, its involvement was needed, if only because the Progress factory (with which TsSKB had merged in 1996) was the only facility equipped to manufacture the rocket. Until late 1999, Yamal was mainly run by RKK Energiya and its Volga branch.

Meanwhile, sometime in 1998 the Russian Space Agency had begun negotiations with the Asia Pacific Space Centre (APSC) to launch Soyuz-2 rockets from Christmas Island in the Indian Ocean. By early 2000 these negotiations, involving TsSKB and KBOM (the bureau building the Soyuz pads), had produced little result. Koptev invited RKK Energiya to join the negotiations and propose the Yamal rocket instead. The commercial version of Yamal was named "Avrora" (Aurora), but financial problems eventually grounded the project [37].

In 2001 RKK Energiya began working on a rocket called Onega with the same dimensions as Yamal/Avrora, but specifically intended to launch a wide variety of Russian payloads from the Plesetsk cosmodrome, thereby minimizing Russia's reliance on Baikonur in Kazakhstan. Although initial plans called for Onega's core stage to retain the NK-33, the ultimate plan was to equip it with the LOX/kerosene RD-191, developed by NPO Energomash for the core stage of the Angara rocket family. The strap-ons were to employ the LOX/kerosene RD-120.10F, a slightly modified version of the RD-120 LOX/kerosene engines used on the second stage of the Zenit rocket. The engine considered for the third stage was the RD-140E, a liquid oxygen/liquid hydrogen engine developed by the Design Bureau of Chemical Automatics (KBKhA) in Voronezh (also planned to be used on upper stages for Proton and Angara). For geostationary missions Onega would have a "Yastreb" upper stage using the RD-0126E, another liquid oxygen/liquid hydrogen engine developed by KBKhA [38].

The Zenit Launch Vehicle

Although Onega has the same basic configuration as the Soyuz rocket, it would essentially be a completely new launch vehicle. Except for the RD-120.10F engines to be used in the strap-ons, all the engines are new and have not yet been tested in flight. Moreover, there are no clear signs that the rocket will receive any significant government funding in the foreseeable future.

It is probably these considerations that eventually persuaded the Russians to switch to a rocket perfectly capable of doing the same job, namely the Zenit, in use since 1985. The reasons for not making this choice earlier must primarily have been of a political nature. First, despite the fact that Zenit uses engines developed by Russia's NPO Energomash, it is a Ukrainian launch vehicle, built by the GKB Yuzhnoe design bureau in Dnepropetrovsk. Second, it can only be launched from the Baikonur spaceport in Kazakhstan. Construction of a Zenit pad at Plesetsk *did* get underway in 1986, but it is now being rebuilt to support Angara launches. To make matters worse, there is only one single Zenit pad at Baikonur, the other one having been destroyed in a pad explosion in October 1990. Any bad accident on the remaining pad would therefore ground Kliper indefinitely. Finally, Zenit's safety record is not all *that* impressive, making it questionable if it can be man-rated any time soon. On the other hand, Zenit *was* originally intended to become a man-rated rocket. It was supposed to launch a Soyuz successor called "Zarya" studied by Energiya at the end of the 1980s, and was also considered for launching small spaceplanes. One relic of those early plans is a crew access tower at the surviving Zenit pad, which could be refurbished for future Kliper launches.

Whatever the drawbacks of using Zenit, they must still be dwarfed by the problems associated with developing, building and especially funding a new launch vehicle as Onega. It would appear that the idea to use Zenit was backed by Anatoliy Perminov, who took over from Yuriy Koptev as the head of the reorganized Russian Space Agency (the "Federal Space Agency" or "Roskosmos") in March 2004 after having served as head of the Russian Space Forces. During his first visit to Baikonur in his new capacity in early June 2004, Perminov instructed officials of Roskosmos, RKK Energiya and KBTM (the bureau that designed the Zenit pads) to study the possibility of launching Kliper on Zenit and estimate the cost of rebuilding the destroyed Zenit pad [39]. In an interview later that month he said the second Zenit pad would only be rebuilt if there are enough customers for a commercial version of Zenit to be flown from Baikonur under the "Land Launch" project [40].

Perminov presumably had more discussions on the Kliper/Zenit issue during a little-publicized visit to GKB Yuzhnoe on 27 August [41]. One source claims that Y. Semyonov himself had approached the Ukrainians with the proposal to use Zenit, having realized that the simultaneous development of Kliper and a new launch vehicle would be too costly [42]. The next

Montage of Kliper mounted atop the Zenit launch vehicle. At left is the crew access tower built in the 1980s. (RKK Energiya)

major development came on 15 September, when the Presidents of Russia, Ukraine, Kazakhstan and Belarus met in the Kazakh capital Astana to move their countries closer to the ultimate goal of creating a free trade zone between them in a so-called Single Economic Space (SES). Cooperation in space was also on the summit's agenda. While Kazakh President Nursultan Nazarbayev put forward the idea of setting up "a joint rocket and space corporation" uniting the space industries of the four nations, Ukrainian President Leonid Kuchma launched a proposal to jointly develop the Kliper/Zenit system. With GKB Yuzhnoe and its production plant (the Yuzhnoe Machine Building Plant) being responsible for the launch vehicle, RKK Energiya would build Kliper, Belarus would deliver "optical components" for the spacecraft and Kazakhstan would provide the launch complex [43].

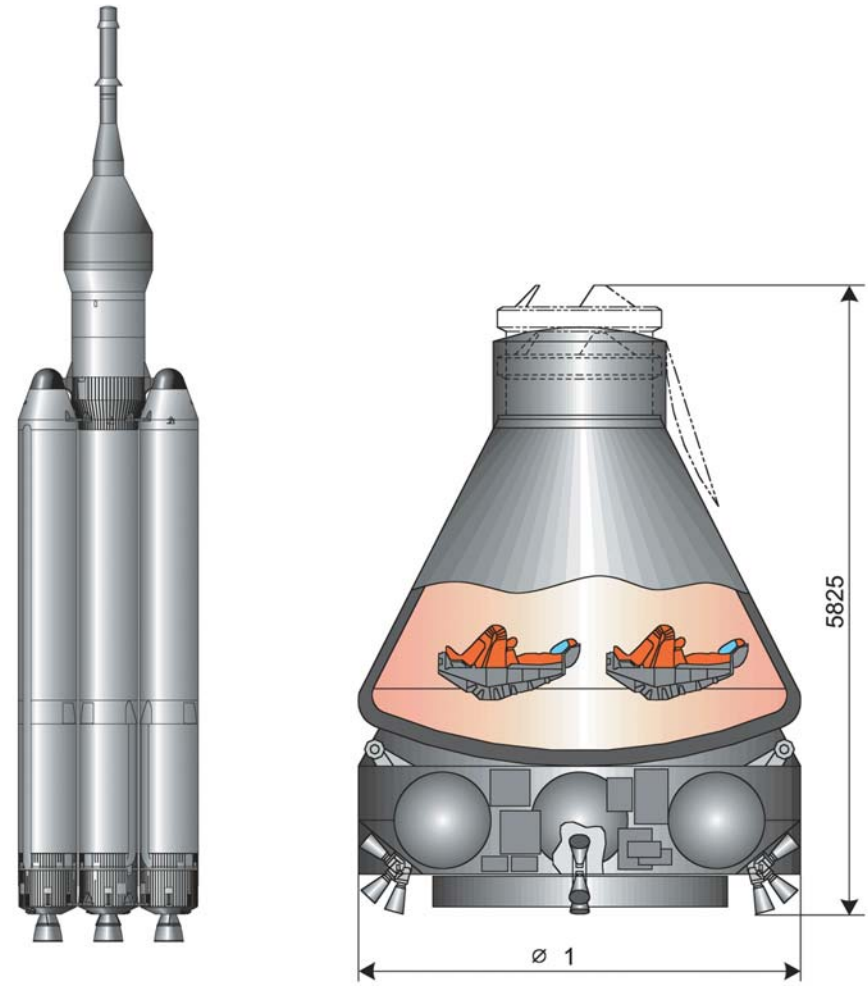
The idea had already been tabled the day before at a preparatory meeting of the so-called High Level Group on the Formation of the SES. Speaking to reporters after the meeting, Ukraine's Deputy Foreign Minister Vladimir Makuhka said the project could be carried out in three stages. In the first stage (2004-2008) Kliper would make its first unmanned test flights (estimated cost $15 million), the second stage (2009-2013) would see the vehicle perform its first manned missions ($70 million) and in the final stage the vehicle's safety features would be further improved ($35 million) [44]. Vladimir Putin made no specific statements on the Kliper/Zenit proposal at the summit, but reportedly expressed his support for the idea [45].

During a press briefing at RKK Energiya on 30 November journalists were told that Zenit was now considered the prime contender for launching Kliper, with Onega only considered as a back-up option. The Kliper/Zenit proposal was discussed at a meeting of representatives of the four countries' space agencies in Moscow on 18 November. It was also on the agenda of the monthly meetings of the High Level Group on the Formation of the SES in Kiev (22 October), Moscow (19 November) and Minsk (15 December). The goal of these meetings was to prepare a set of agreements to be approved at another summit of the four countries' presidents in St-Petersburg at the end of the year. However, the summit was delayed indefinitely due to the political turmoil surrounding the Ukrainian presidental elections in late December. It remains to be seen what effect the election of Viktor Yushchenko will have on the Kliper/Zenit proposal and future Russian-Ukrainian space cooperation in general, certainly in light of the fact that former President Leonid Kuchma once headed the plant where the Zenits are manufactured. A leading RKK Energiya official was among a Russian industry delegation that held wide-ranging talks with Yushchenko on 13 March 2005, but it is unclear whether this led to any progress on a Kliper/Zenit deal [46].

Goals and Future Prospects

Right now Kliper is still in the earliest stage of the design process ("Technical Proposals"), with work on the so-called "Draft Plan" (preliminary design) expected to begin in 2005. The earliest possible launch date for the first mission would be 2011. Much, of course, will depend on funding. So far RKK Energiya has financed Kliper development with its own means and no funds for it were earmarked in the Russian Space Agency's budget for 2005 [47]. For it to receive government funding, it needs to be taken up in the so-called "Federal Space Programme for 2006-2015" now being drawn up by the Russian Space Agency. Officials have indicated Kliper will be included [48]. However, this is no guarantee the programme will get the estimated $360 million required to launch the first mission within a reasonable amount of time.

Therefore, the Russians have been trying hard to attract foreign partners, in particular the European and Japanese space agencies. Meeting with Russian Space Agency officials in Moscow on 10 June 2005, ESA representatives said a proposal for European participation in Kilper would be discussed at a meeting of European government ministers responsible for space in December 2005. The initial step would be a two-year $61 million ESA study into the viability of participating in Kliper, with a final decision to be made afterwards. At the same time, ESA is in talks aimed at bringing the Japanese on board, with the Japanese space agency now considering to include involvement in Kliper in its long-term vision plan expected to be submitted for approval at the end of 2005 [49].



Khrunichev's proposed manned spacecraft for the Angara-A3M rocket. (Khrunichev)

European participation in Kliper would also open the prospect of launching the vehicle with an uprated Soyuz launch vehicle from Kourou. During the Russian-European talks on 10 June and the Paris Air Show later that month plans were presented for a rocket called Soyuz-2-3 or Soyuz-3, which seems to be a crossing between Onega and the earlier Yamal/Avrora. The rocket would have a single NK-33-1 engine in the core stage, RD-120.10F engines in the strap-on boosters and as many as four RD-0146E cryogenic engines in the third stage. This would enable it to launch a 14 ton version of Kliper plus a 3.8 ton emergency escape system. The rocket could also fly from Baikonur. However, it is unclear at this stage whether this represents a definitive move *back* from Zenit to a Soyuz-based rocket. Possibly, initial flights will be flown on Zenit, with the switch to the new launch vehicle being made whenever that becomes available.

Meanwhile, the Khrunichev Centre has come up with a proposal for a reusable spacecraft resembling an enlarged version of the return capsules (VA) of the Transport Supply Ships (TKS). The TKS spacecraft were originally conceived as transport vehicles for the Almaz military space stations, but eventually only flew to Salyut-6 and Salyut-7 in the 1980s. Six-man versions of the VA had already been considered during the development of the TKS and were also offered up in the early 1990s as lifeboats for Freedom and ISS. Weighing about 14 tons, the new vehicle is supposed to be launched by a man-rated version of Khrunichev's unflown Angara-3 rocket designated Angara-A3M. Capable of flying up to ten missions, it would carry a crew of two to six cosmonauts. It could also fulfil the role of an unmanned cargo carrier, carrying up a payload of 6350 kg and returning 1870 kg back to Earth. In early 2005 Khrunichev offered the vehicle for use in NASA's New Vision for Space Exploration, but as of yet there are no indications NASA is showing any interest in it. Neither are there any signs that it stands a serious chance of becoming a competitor to RKK Energiya's Kliper in Russia's national human space programme [50]. At the same time, it remains to be seen if the newly appointed RKK Energiya head Nikolai Sevastyanov will throw his full weight behind Kliper.

Clearly, Kliper could play an important role in ISS operations. Officials have indicated it could be used to carry crew and cargo and also act as a lifeboat, with a single vehicle making it possible to evacuate a complete six-man resident ISS crew. Kliper could stay docked to the station for an entire year, twice as long as Soyuz, and haul 500 kg

Kliper mock-up at RKK Energiya. (Novosti Kosmonavtiki)

of cargo to the station and back to Earth. The Russians have also said it could perform autonomous missions for "research purposes" or with tourists on board. In 2005 the Russian Space Agency plans to carry out a study of the role that Kliper could play in ISS and Russia's "future orbital infrastructure" [51].

Indeed, the Russians are slowly beginning to look at the post-ISS era. Speaking at the IAF congress in Vancouver on 4 October 2004, A. Perminov pointed out that Russia is using the experience gained aboard ISS and its long-standing experience with long-duration manned missions to prepare for future piloted flights to the Moon and Mars. Since the assembly and launch of interplanetary spaceships will have to take place in Earth orbit, Perminov said "this will require the creation of an assembly platform and an effective technical and transportation system to support assembly operations". He noted that Russia is hoping to include in its Federal Space Programme for 2006-2015 a periodically visited "orbital base platform combining the advantages of a piloted complex and an automatic spacecraft. Such a platform will make it possible to continue and expand the scientific and applications research now being conducted aboard the ISS. It is primarily intended to test elements of future interplanetary complexes and a new generation of transportation and technical systems. This will include a reusable system to deliver cargo to orbit and new braking devices to deliver cargo to Earth and to the surface of planets". Perminov seemed to indicate that although Kliper will be used in connection with the ISS, its primary role will be in that future orbital infrastructure [52]. He has also stated several times that Kliper *itself* can ultimately be used for flights to the Moon [53]. Kliper look-alike ships have even appeared as Earth return vehicles in preliminary RKK Energiya concepts for future piloted Mars missions [54].

The "orbital base platform" referred to by Perminov may be a "high-latitude space station" mentioned by several other Russian sources recently. This would have an inclination higher than the 51.6° orbits used by the Salyuts, Mir and the ISS, enabling cosmonauts to observe larger portions of the Earth's territory. As a matter of fact, 65° inclination orbits had already been envisaged both for Mir and Mir-2. However, Mir saw its inclination lowered when the Mir core module turned out to be heavier than expected and for Mir-2 the 51.6° inclination became a compromise when it was merged with Freedom to form the ISS. The high-latitude space station would make it possible to conduct "research and other activities which are an expansion and supplement of activities on the ISS", indicating the intention may be to launch it when the ISS is still operational. Three basic tasks have been identified for the station:

- Earth remote sensing in different spectral ranges
- basic and applied research (materials processing, biotechnology, medicine and biology, geophysics and astrophysics, demonstration of space technologies)
- support of future human space missions [55]

Perminov has indicated on several occasions that Russia is planning a gradual approach to the human exploration of the Solar System. Speaking to reporters after a meeting of space agency heads in Montreal in January 2005, he said manned expeditions to Mars will be impossible without more space stations in low orbit, without manned expeditions to the Moon and without human settlements on the Moon [56]. In a later interview he said: "In the first stage we had the Mir station, now we have the ISS. Using its example, we are learning to build enormous space systems in Earth orbit. After that we can get down to studying the Moon and Mars, but this will have to happen on a step-by-step basis and increasingly obtain an international character" [57].

Despite such lofty statements, there are few signs at this time that the big spacefaring nations will soon be embarking on a jointly co-ordinated effort for piloted deep space exploration. Although the ultimate objectives are similar, NASA's Project Constellation, ESA's Aurora programme and the Russian human space programme each seem to have their own agendas to reach those goals. Obviously, the further these individual programmes evolve, the more difficult it will become to integrate them. One is left wondering if the lessons learned to date from the International Space Station are discouraging rather than stimulating further international co-operation in the human exploration of space.

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