The Proton Launcher

Series Editor
Jean-Luc Lefebvre

The Proton Launcher

History and Developments

Christian Lardier
Stefan Barensky

iSTE

WILEY

First published 2018 in Great Britain and the United States by ISTE Ltd and John Wiley & Sons, Inc.

ISTE Ltd
27-37 St George's Road
London SW19 4EU
UK

www.iste.co.uk

John Wiley & Sons, Inc.
111 River Street
Hoboken, NJ 07030
USA

www.wiley.com

Library of Congress Control Number: 2017962688

British Library Cataloguing-in-Publication Data
A CIP record for this book is available from the British Library
ISBN 978-1-78630-176-5

Contents

Foreword

The Proton rocket has played a formidable role in several key historic milestones in space history, marking some of the most complex scientific and technological achievements of mankind. Some notable examples include launching exploratory missions that produced the first samples of the lunar surface to be returned by an unmanned spacecraft and the first soft landing on the surface of Venus. The orbiting of the Salyut International Space Station (ISS) series and the MIR ISS modules were also enabled by Proton.

Over time, Proton has evolved to become one of the core heavy-lift vehicles for the Russian Federal space program as well as the global commercial satellite industry. The commercial missions are conducted under the auspices of International Launch Services, a US-based company.

On a bitterly cold day, on April 9, 1996, the first commercial launch of Proton was conducted with the Astra 1F satellite for Luxembourg-based SES. This launch is a memory that will be etched in the minds of those who witnessed it forever. For those viewing the launch at the Baikonur Cosmodrome, in the dessert steppes of Kazakhstan, in –30° F weather, the memory of the spectacular lift-off and successful mission for the first commercial satellite aboard a Russian launch vehicle far surpassed the icy chill in the air that night.

One of the most successful post-Cold War US–Russian cooperative efforts, the commercial Proton has launched some of the world's most powerful communications satellites, providing critical connectivity around the globe via land sea or air with mobility services, video, data and broadband services, broadcasting, direct-to-home TV and satellite radio.

The lift capability of the workhorse Proton has increased – as of this writing – to 6.27 metric tons to reference Geostationary Transfer Orbit (GTO) and 6.47 metric tons to Super Synchronous Transfer Orbit (SSTO) at 1,500 m/s. The Proton Breeze M vehicle's restartable Breeze M upper stage allows each mission to be optimized and projected in orbit lifetime to be maximized for single or multiple satellites supporting missions to Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Highly Elliptical Orbit (HEO), GTO, GSO and SSTO.

In the fall of 2016, the two-stage variants of Proton were unveiled, further supporting the proven heritage of the vehicle to adapt, change and compete in a highly competitive commercial marketplace. Driven by the influx of electric and hybrid propulsion satellites, the sleek two-stage Proton offers satellite operators a much-needed cost-effective and high-performing solution to orbit. This sort of "back to the future" design is reminiscent of the early Proton vehicle design, when it was a two-stage vehicle called the "UR-500", launched in the early 1960s.

The concept for this book was born many years ago by one of the premiere space historians of our time, and author of this book, Mr. Christian Lardier. A true labor of love, Mr. Lardier was determined to write this powerful book about one of the world's most intriguing Russian launch vehicles, despite some challenging circumstances and several stops and starts along the way. We owe much gratitude to Mr. Lardier for his tenacity and unwavering dedication to this very in-depth project which tells, in great detail, after countless interviews with Russian scientists and others, Proton's unique story about its incredible journey to orbit. We also give our thanks to co-author, Stefan Barensky, for the second part of this work and the remarkable history of International Launch Services.

INTERNATIONAL LAUNCH SERVICES

Preface

July 16, 2015 marked the 50th anniversary of the heavy launch vehicle Proton's first flight. Proton was designed and developed under the direction of Vladimir Chelomey, the main rival of Sergei Korolev, Soviet Wernher von Braun, designer of the R-7 "Semyorka". In June 2013, Stefan Barensky and I published the The Soyuz Launch Vehicle (3 years after the original French title, *Les deux vies de Soyouz*, was published). It tells the story of the rocket with the world's most launches out of Baikonur, Plesetsk and the Guiana Space Centre (GSC) since 2011, and from Vostochny as of December 2015.

June 30, 2014 also marked Chelomey's 100th birthday. He was initially working for the Ministry of Aviation Industry (MAP), designing cruise missiles for the Navy, whereas Korolev was from the Ministry of Defense Industry (MOP) working on ballistic rockets for the artillery. In March 1965, they were brought together under the Ministry of General Machine Building (MOM). From 1960 to 1965, Chelomey completed the UR-200, UR-500 and UR-100 for the Ministry of Defense. At this time, strongly supported by Khrushchev, he built a true industrial empire. In 1965, the UR-500 then became Proton, whose name was taken from Chelomey's first payload, the Proton-1 satellite designed for studying cosmic rays. It was the beginning of a long career for the heavy launch vehicle, the equivalent of the US Saturn-1B, which became the main competitor of the European rocket, Ariane, on the commercial market. In January 2016, it was launched 410 times, whereas Ariane had only taken 228 flights. The medium rocket, Soyuz, had already been launched 1,854 times. Since 1995 Proton has been marketed across the world by the American company International Launch Services (ILS). The launch system is predicted to remain in use until 2025, before being replaced by a new rocket, Angara.

Our second book is dedicated to the history of the Proton rocket, to its creator Vladimir Chelomey and his Reutov Design Office OKB-52, which celebrated its 60th birthday on August 8, 2015. Proton was designed and manufactured in the Khrunichev factory and the Salyut Design Office in Fili (former production plant and OKB no. 23). The two were officially merged together to become the Khrunichev Center on June 7, 1993 by order of decree no. 421-RP. Finally, March 2011 marked the OKB Design Office's 60th birthday, while the factory celebrated its centenary on April 30, 2016.

The final book of the trilogy, which is scheduled for publication in 2017, focuses on the third Soviet/Russian space empire, that of designer Mikhail Yangel who created the OKB-586/NPO Youjnoe Design Office in Dniepropetrovsk (now Dnipro) in 1954. It was at this OKB that the R-12, R-14, R-16, R-36, R-36M and R-36M2/Dnepr missiles, the Cosmos-2, 3M, Cyclone-2, 3, 4 and Zenith launchers (Zenith-2, Energia Booster, Sea Launch, Land Launch), and a very large number of satellites were designed.

We offer our thanks to ILS (Mark Albrecht, Frank McKenna, Phil Slack, Jim Bonner, Karen Monaghan, James Youdale), the Khrunichev State Research & Production Space Center (Anatoly Kiselev, Vladimir Nesterov, Evgueny Koulaga, Grigori Khazanovitch, Sergei Chaevitch, Ines Glazkova), Vladimir Poliatchenko (NPO Mach), Alexandre Chliadinsky (Proton drawings), Igor Afanaseiev (Novosti Kosmonavtiki), Mikhail Pervov (Stolitchnaya Entsiklopedia) and others.

In order to obtain authorization rights for the publication of certain figures, we have agreed to cite the following publications from which they have been taken: *The Illustrated Encyclopedia of the Aircraft of V.M. Myasischev, Volume 2* by A. A. Bruk, K. G. Oudalov, S. G. Smirnov, N. G. Brezginova, Avico Press 2001 (figures with symbol *); the article "*35 ans du lanceur Proton*" (35 Years of the Proton Launch Vehicle) no. 1/98 by Novosti Kosmonavtiki (figures with symbol **); and *L'histoire du développement des satellites russes* (History of the development of Russian Satellites), Stolitchnaya Entsiklopedia, Moscow, 2015 (figures with symbol ***).

Christian LARDIER
December 2017

PART 1

The Proton in the East

1

Vladimir Chelomey: From the V1 to Proton

Vladimir Nikolayevich Chelomey was born on June 17, 1914 (Julian calendar), or June 30, 1914 (Gregorian calendar) into a family of teachers in Sedletz (Poland). He spent his childhood in Poltava and then moved to Kiev in 1926. At 18 years of age, he finished his studies at the Technicum Automobile of Kiev (Ukraine) and entered the Institut PromEnergetik, studying the internal combustion engine. But the young Vladimir was interested in the then emerging field of aviation. He was accepted into the aerospace faculty at the Kiev Polytechnic Institute (since renamed the National Aerospace University). During his first year, while studying, he also worked as a technician in the subsidiary of the Institute of Civil Aviation.

Figure 1.1. *Vladimir Chelomey (source: rights reserved)*

In 1936, while still a student, he published a paper on vector analysis and taught vibration theory to engineers working at the Zaporozhye aircraft engine factory. This production facility, no. 29 (now Motor Sich), had the manufacturing license for French engines Gnome and Rhône at the time. In 1937, a year ahead of his fellow

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

students, he successfully received his qualifications from the Institute. He was then accepted to the Institute of Mathematics at The National Academy of Sciences (NAS) of Ukraine where, in July 1939, he presented a PhD proposal in Technical Sciences ("Dynamic Stability of Elements in Aerospace Construction").

In 1940, he was selected by the NAS to be part of a special group of 50 PhD students, bringing together some of the best doctorate candidates in the country. He then prepared a thesis on the dynamic stability of elastic systems in airplane engines. He submitted the thesis at the beginning of 1941 but was turned down by the administration, and would have to resubmit it at the MVTU in 1951 ("Study of torsional vibrations in aircraft engines").

Figure 1.2. *The German V-1 (source: rights reserved)*

When war broke out in June 1941 he was evacuated from Kiev to Moscow. He became a member of the Communist Party (CPSU) and joined the Moscow Central Institute of Aviation Motors (TsIAM) where he became head of reaction engines. It was here that he designed a pulsejet engine. In Kazan, in the OKB-16 *charaga* (prison Design Office), B. S. Stechkin designed another pulsejet engine: the US accelerator designed for the Pe-2 aircraft. The US-K model was tested in December 1942 but work was interrupted when Stechkin returned to Moscow in early 1943.

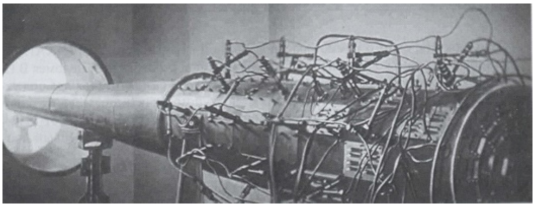


Figure 1.3. *The TsIAM pulsejet engine (source: rights reserved)*

1.1. The Soviet V-1 designer

This type of engine had been used by the Germans on the V-1 cruise missile (Fieseler 103 with Argus 109-014 engine) since December 24, 1942. The first V-1 was fired at London on June 13, 1944. During World War Two, approximately 30,000 missiles were produced, 10,000 of which were directed at London. Moscow decided to produce a similar device. On September 19, Chelomey was appointed Director and Main Designer at production facility no. 51, previously led by aircraft designer N. N. Polikarpov (deceased July 30 1944). Chelomey's appointed deputy was D. L. Tomachevich. Much like Chelomey, he was a graduate from the Kiev Polytechnic Institute and had worked with Polikarpov since 1931. But following an accident that cost the life of pilot V. P. Chkalov, he was sent to the *charaga* from 1938 to 1943. Upon his return, he became Polikarpov's deputy but only until July 1944. He then continued to work with Chelomey but following a deep disagreement about technical solutions, he left in 1947 to go on to develop a national version of the German Hs-293 missile: the RAMT-1400 Schuka (aka KSCh).

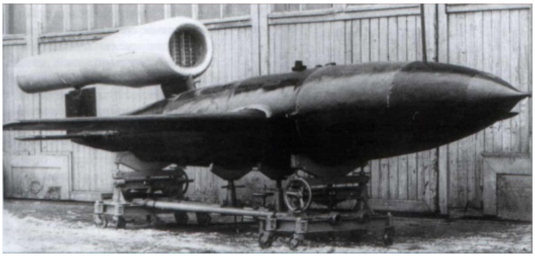


Figure 1.4. *The 10X missile from 1944 (source: all rights reserved)*

On September 23, Chelomey received a V-1 missile recovered in Dembitza, Poland. It was, in fact, the 10X with a D-3 engine. Unlike the V-1, the 10X was launched from an airplane. Consequently, three Pe-8 and two Er-2 aircrafts underwent modifications for flight tests. The 10X weighed 2,130 kg and could fly at a speed of 620 km/h across a distance of 240 km. On November 17, the first version was transferred to TsAGI for aerodynamic testing in the T-104 wind tunnel. The engine, with a 270 kg thrust, was tested on a test-bench, then on the test-aircraft Pe-2. On January 18, 1945, by order of decree no. 7350, work began on the construction of 100 missiles, as well as preparations for producing 300 additional units in March. Mass production would be completed by factories no. 456 in Khimki near Moscow, no. 125 in Irkutsk, no. 118 in Moscow (autopilot system) and no. 458 in Savelovo near Dubna (catapult). Following this, on March 20, 1945, the 10X was launched for the very first time in Sjizak, Uzbekistan. The tests continued until August (63 launches) but the success rate was only 30%. The Commission of Inquiry, led by V. F. Bolkhovitinov, S. A. Lavochkin and N. A. Jemchujin, finally concluded that the failure was the result of a problem with the fuel supply regulator. Nevertheless, Chelomey received his first Order of Lenin on September 16, 1945.

Around this time, Sergei Korolev was sent to Germany to recover the V-2 and became its main designer on August 9, 1946.

Figure 1.5. *The OKB-51 team in 1944 (source: rights reserved)*

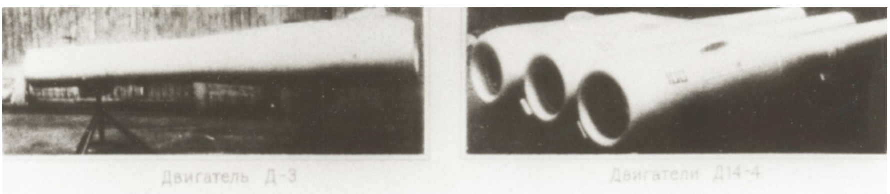


Figure 1.6. *Pulsejet engines D-3 and D14-4 (source: rights reserved)*

In November 1945, Chelomey requested that the Minister of Aviation Industry, A.I. Chakhurin, send specialists from his Design Office (OKB-51) to Germany in order to recover the fuel supply regulator and the Askania autopilot system. One month later, V. I. Tarasov, Chief of the Engine Division, returned with a regulator. By order of decree no. 606-249c, on March 16, 1946 a commission led by A.S. Yakovlev regarding the use of German specialists was initiated. The NKVD General, I. A. Serov, the Aviation General, V. I. Stalin (son of the Head of State) and V. N. Chelomey were also members of the commission. They headed to Germany, where the Sector Chief V. V. Sachkov, at that time visiting Nordhausen, Berlin and other cities, was also present. They returned with autopilot systems and control surfaces from Nordhausen, as well as 129 intact V-1 missiles and three piloted ones from Pulverhof. The autopilot system was copied by production facility no. 118 and renamed AP-4. This gave way to the creation of the PSU-20 pneumatic autopilot system, followed by the AP-52 in 1951. In addition, the electric ESU-1 was also used, followed by the AP-56 in 1952. The ESU-1 was developed by the

Kuibyshev OKB-3 Design Office. There, a group of 61 Germans working for Askania were deported in October 1946. Led by Peter Lertes, the group included specialists such as Waldemar Möller, Helmut Breuninger, Georg Orlamünder, Kurt Kracheel, as well as others. In 1948, the group was placed under the direction of Russian designer P. D. Mitiachin, who manufactured autopilot systems in facility no. 118. But in 1950, the group was transferred to KB-1 in Moscow to contribute to developing the ground-to-air guided missile S-25 Berkut. Here, the group was joined by 13 high-frequency experts from Monino, Johannes Hoch's group from Gorodomlia, and 35 people from Krasnogorsk. Two of them (Bruno Fischer and Wilhelm Fischer) received the Stalin Prize in 1952. They were then transferred to Sukhumi in 1955 before being sent back to Germany.

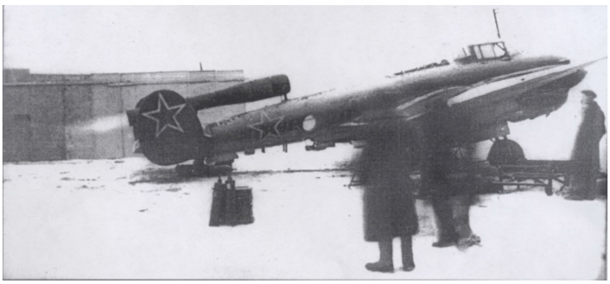


Figure 1.7. *The D-3 engine on the TU-2 (source: rights reserved)*

In 1946, 180 improved missiles were built and two additional Pe-8 aircrafts underwent improvements. The missile was tested at the Kapustin Yar polygon (73 launches) between December 15, 1947 and July 20, 1948. It was then recommended that the 10X be included in the Army's weaponry, but was refused due to its weak thrust and low speed, lower than other aircraft from that period. But Chelomey continued his tests: 18 launches between late 1948 and October 1949 (11 with the PSU-20 guidance system, five with the PSU-30 and two with the ESU-1).

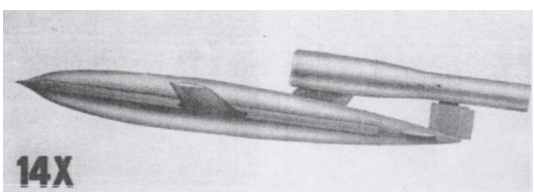
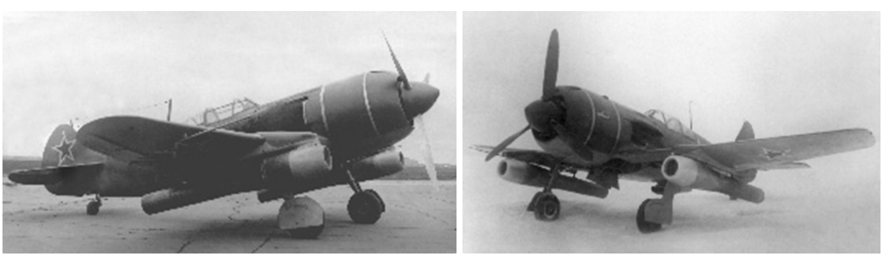


Figure 1.8. *The 14X missile (source: rights reserved)*

At the same time, Chelomey developed the D-5 engine with 400 kg thrust, and the 14X missile with the ability to cruise at 800 km/h. Facility no. 456 went on to produce 20 missiles. The engine was tested in March 1947 and the 14X flight tests (10 launches) took place in July 1948 using a Pe-8. Four flights allowed for testing of the PSU-20. By the end of 1946, the D-6 engine, with a thrust of 600 kg, successfully passed all flight tests. It was mounted onto the 14XK1 missile the following year, in the first stage of the Kometa program. But once again, the Army refused to integrate it into its weaponry.

Kometa was intended to be a guided anti-ship missile. On September 8, 1947, by order of decree 3140-1026, the special Design Office SB-1 was created and ordered the guidance system to be developed with the assistance of the captured Germans. The Chief of SB-1 was P. N. Kuksenko, and his Deputy was none other than the son of L. P. Beria, Minister of the Interior and Stalin's right-hand man, S. L. Beria (from his real surname Gegechoria). Having just completed the Budyonny Military Academy of Communications, he was now responsible for radio devices on the missile (Kometa-I), on the carrier plane (Kometa-II) as well as on the autopilot system for the missile (Kometa-III). The carrier plane was a Tu-4 (a copy of the B-29). For the missile, several options were possible. Chelomey then proposed a missile equipped with a 900 kg thrust D-7 engine. But in 1947, aircraft designer A. I. Mikoyan opened Department B in his Design Office. Led by M. I. Gourevich, he was in charge of guided missiles. Artem Mikoyan was none other than Anastas' brother, member of the Politbureau and Deputy President of the Ministers Council. In the beginning, Mikoyan proposed a smaller version of the Mig-9, but, in the end, the Mig-15 was finally selected. The KS-1 Kometa, propelled by a RD-500 turbojet, could cruise at more than 1,000 km/h while Chelomey's missile in comparison could only reach 950 km/h. Production for the KS-1 was entrusted to facility no. 256 in Dubna (subsidiary no. 2 of OKB-155). The SB-1 and OKB-155 were awarded with the Stalin Prize in 1953. Among the recipients of the award were S.L. Beria, of course, but also D.L. Tomachevich, who had left the KB-2 in 1949 to become Chief of Sector 32 at SB-1. Tomachevich held a grudge against Chelomey.



a) b)

Figure 1.9. *a) La-7 with two D-10 and b) La-9 with two D-13 (source: rights reserved)*

During this time, the pulsejet engines were used as fighter plane accelerators. The D-10 engine was then mounted onto the Lavochkin-designed La-7 in 1946, and the D-13 engine was mounted onto the La-9 in 1947. Each plane had two engines with a 200 kg unit thrust and were featured in the Tushino Air Show in August 1947.

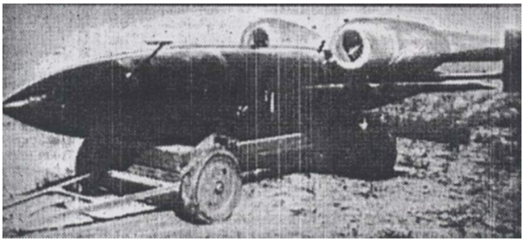


Figure 1.10. *The 16X Priboy missile (source: rights reserved)*

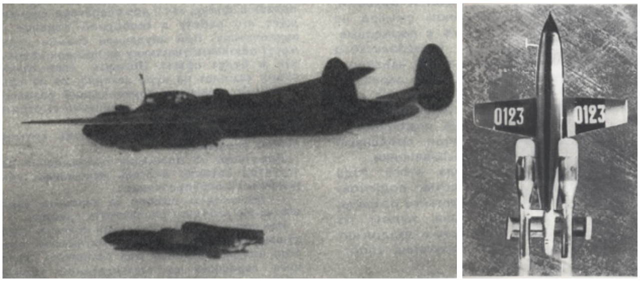


Figure 1.11. *The 16X missile in flight (source: rights reserved)*

On May 7, 1947, by order of decree 1401-370 the airborne missile 16X Priboy was developed (2,557 kg). Likewise, the 15XM was also requested for the Navy. On April 14, 1948, by order of decree no. 1175-440, production of the 15XM (generic program Chtorm) was entrusted to M. R. Bisnovat at facility no. 293 in Khimki. Bisnovat had worked at the NII-1 (Kostikov rocket-aircraft 302 between 1942 and 1944), at factory no. 153 between 1944 and 1946, before working for himself on June 7, 1946 (5 aircraft between 1946 and 1949). The 15XM was propelled by M. M. Bondariuk's ramjet and the Priboy was propelled by two pulsejet engines, namely the D-312 followed by the D-14-4 (251 kg unitary thrust). Following decree no. 1175-440, two variants of the guidance system were planned for production (PSU-20 and ESU-1). From July 22 to December 25, 1948 in Akhtuba (Vladimirovka station in the Kapustin Yar polygon), six missiles underwent flight testing. In 1949, the tests continued over three stages. The first stage involved four launches. The second, with 11 launches, showed that the engine cut off when it reached 720–775 km/h. To increase speed while maintaining stability, they decided that the nozzle had to be shortened. The D-312 was replaced by the D-14-4, allowing it to reach 1,000 km/h. The new engine could be tested in the third stage with 13 launches: the results showed that the 16X could reach 872 km/h in normal regime and 912 km/h in forced regime. Out of 34 launches, eight were performed from a Tu-2 and 26 from a Pe-8. Twenty-nine of them were equipped with a PSU-20A and five with an ESU-1. A new round of tests (20 missiles, all featuring a PSU-20A) was conducted with a Tu-4 (2 missiles), and a Tu-2 (1 missile) between September 6 and November 4, 1950. The first stage included four launches, the second also had four, and the third had 12. It reached a speed of 900 km/h and a range of 170 km. All launches reached the 10.8 × 16 km target. The second round of flight tests comprised six launches between June 12 and 17 (with the AP-56 autopilot system), and 22 launches between August 2 and 22, 1952. Regardless of the tests, the Army was persistent in its decision not to integrate it into the weaponry due to a lack of precision and reliability. However, the Army did eventually request additional testing on the 16X in late 1952 (15 missiles), before forming a Tu-4 squadron in 1953 (60 missiles, 20 of which used warheads).

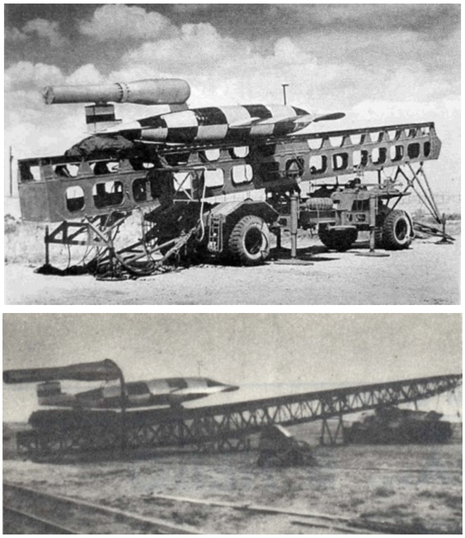


Figure 1.12. *The 10XN missile (source: rights reserved)*

At the same time as the 16X, Chelomey developed the mobile, land-based version of the 10X for the Army, the 10XN (N for *Nazemlie,* meaning *land*). It had been approved by decree no. 4814-2095 of December 4, 1950. It was equipped with a D-16 engine, reaching a 320 kg thrust from a rail launcher (mobile version on the T-34 tank), using a powder-based accelerator to propel for lift-off. In 1945, the first project used the German accelerator that had been recovered by designer I.V. Chetverikov from facility no. 458, but the project was abandoned due a to lack of materials. In March 1946, a second project was initiated, using an accelerator from the KB of factory no. 81 (now MKB Iskra), with 16 cartridges of M-31 shells. From May 19 to October 19, 1948 at the Sofrino polygon (now NII Geodesia), 12 missiles were launched on rails of 40 m and 30 m length. In 1949 and 1950, five missiles were launched with RBT-700 accelerators. In 1951, the latter was replaced by the SD-10XN, developed by the Krasnoarmeysk KB-3 (now KNIIM). From 23 to 31 July, the 10XN was launched 12 times out of Kapustin Yar (10 with the PSU-30 guidance system and two with the AP-52 autopilot). From May 12 to June 20, 1952, the factory tests were inconclusive: seven out of the 20 launches failed. An additional four launches took place between September 19 and 24. But on February 19, 1953, upon Beria's initiative, Chelomey's OKB-51 was closed down by order of decree 553-271, and his activity was transferred to Mikoyan's OKB-155. OKB-293 was also closed and transferred to KB-1 (former SB-1) to help with the development of ground-to-air missiles from the Third Main Directorate (TGU) of the Ministers Council. It should be noted that the V-1 had been rebuilt by Republic Aircraft (Ford engine) in the United States under the name JB-2 Loon. The first flight had taken place in Eglin in October 1944, and 1,385 models were delivered to USAF. The KGW-1/LTV-N-2 version was developed specifically for the Navy. Tests were carried out on the USS-348 Cusk submarine from February 1947 but, finally, the program was stopped in 1950 much to the advantage of the Regulus missile.

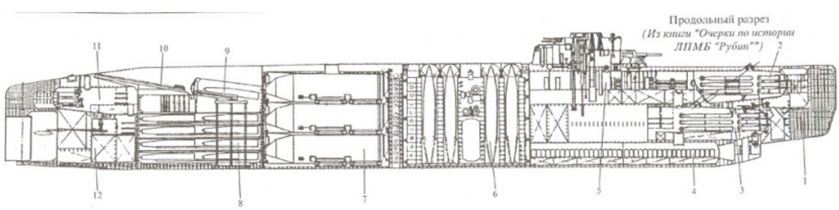


Figure 1.13. *The P-2 submarine project from 1949 fully equipped with the 10XN missile (source: rights reserved)*

However, the 10XN would still be used as a target device. Decree no. 5472 of May 19, 1954 ordered the production of 100 units from facility no. 475 in Smolensk. However, this would be reduced to just 50 units by November 3, 1955. This version was fully equipped with the AP-66 autopilot system and a PRD-15 powder-based accelerator. Six missiles were tested in 1956 and five additional launches for quality control took place in July 1957.

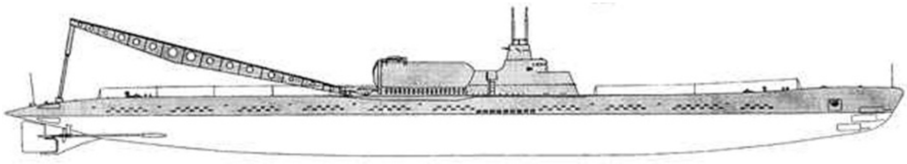


Figure 1.14. *The Pr628 submarine project from 1952 and 1953 with the 10X missile (source: rights reserved)*

In addition, decree no. 4814-2095 of December 4, 1952 required Chelomey to develop a supersonic missile that would be mounted onto a submarine. In 1949, F.A. Kaverin's TsKB-18 started two *Lastochka* projects: the P-2 submarine with 51 10X missiles and the P-4 submarine (Project 624) with Lavochkin's P-40 missiles.

But these projects were quickly abandoned. Chelomey then went on to review the Volna project, which planned to load the 10XN onto a Project 628 submarine. But, once again, in early 1953, the OKB was closed down which put an end to the project.

Figure 1.15. *Missile wing deployment mechanism (source: Christian Lardier)*

When the OKB was shut down, some of Chelomey's colleagues were transferred to Mikoyan's production facility, whereas others preferred to change company altogether. Chelomey's Deputy, V. S. Avduyevsky, went to the NII-1 in G. I. Petrov's laboratory to focus on aerodynamic heating and atmospheric entry. He had studied the centrifuge injector for pulsejet engines at the TsIAM in 1944, then combustion by diffusion at the NII-1 before joining OKB-51. He went on to become Deputy Director of the NII-1 (Keldysh Center) in 1965 until 1973, Vice Deputy of the TsNII Mach between 1973 and 1987, then Vice Deputy of the Institute of Machines at the Academy of Sciences from 1987 to 2003.

1.2. The designer of Soviet naval missiles

However, Stalin died on March 5, 1953 and Sergei, Beria's son, was arrested in July, which greatly changed things. Sergei was eventually liberated and sent to work at the NII-592 in Sverdlovsk from 1954 to 1964. He then went on to work for the NII Kvant in Kiev from 1964 to 1988 and led a department on new physics principles at the Institute for Mechanical Engineering Problems of the Ukrainian Academy from 1988 and 1990. At the end of his career, he was Director of the TsNII Kometa subsidiary in Kiev, from 1990 until 1999.

Figure 1.16. *The 1955 P-5 missile (source: NPO Mach)*

OKB-51, which had become a subsidiary of OKB-155, was taken over by designer P. O. Sukhoi in October. Chelomey, who wanted to pursue the development of the Volna program, requested for a new Design Office to be opened. He obtained a special group (SKG-10, with 20 people) located in production facility no. 500 in Tushino (airplane engines) on August 9, 1954. M.I. Livshitz joined Chelomey as deputy, having been responsible for guidance systems in OKB-51.

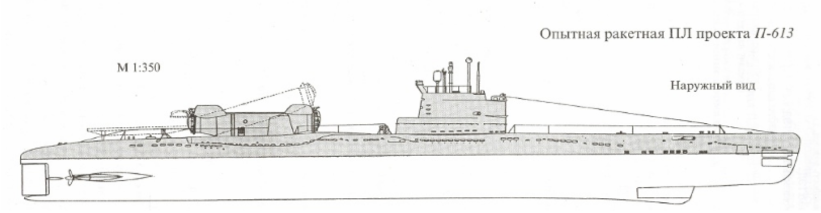


Figure 1.17. *The 1955 Pr613 missile with the P-5 missile (source: rights reserved)*

From then on, he was no longer working for the Air Force but instead for the Navy. On March 5, 1955, he put forward his anti-ship missile MD-1, weighing 3.5 tons. It could reach a speed of 1,500 km/h, with a 400–600 km range depending on the altitude. The originality of the device was in the deployment of the wings after launch from a tube measuring 1.65 m diameter by 11 m length. He obtained approval from Admiral S. G. Gorshkov who led the Navy from 1956 to 1985, and Vice-Admiral P. G. Kotov from the naval artillery department.

On July 19, 1955, Chelomey moved to the OKB-52 in Reutov (former mechanics factory). His progress here came on rapidly. Decree no. 1457-809 on August 8, 1955 ordered P. P. Pustintsev (TsKB-18) to lead submarine project 613. Chelomey, in OKB-52, was required to design the P-5 missile (4K34), measuring 10.8 m and weighing 5.1 tons. It was ejected from an SM-49 tube (TsKB-34) using a powder-based PRD-34 accelerator developed by I. I. Kartukov (KB of factory no. 81). The wings were deployed by the ARK-5 hydraulics system. It was then propelled at 1,300 km/h by V. N. Sorokin's turbojet KRD-26 (OKB-26 in Ufa). The AP-70A guidance systems made it possible to cruise at a minimum altitude of 400 m. The warhead could be either classic or nuclear (RDS-4, identical to missile R-11FM). The launch management system was developed by S. F. Farmakovsky from NII-303 (TsNII Elektropribor).

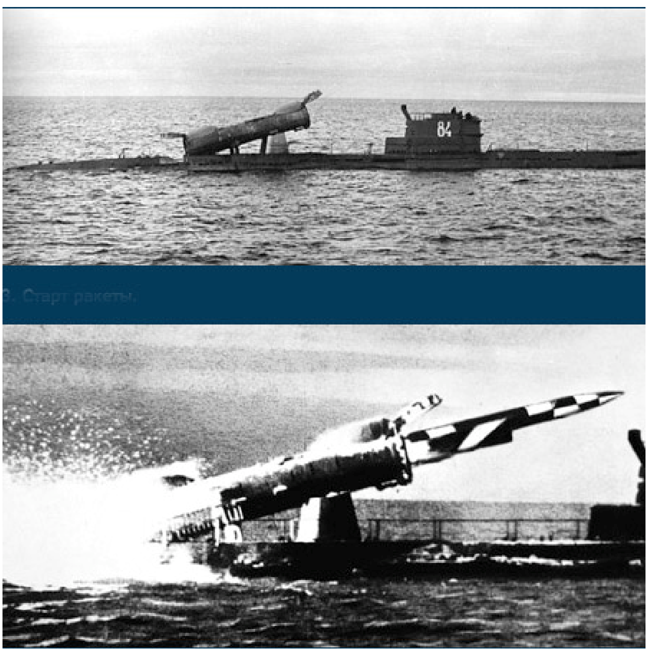


Figure 1.18. *P-5 flight test in 1957 (source: rights reserved)*

The first launch of a prototype took place on March 12, 1957 from the NII-2 base in Belozersky-Faustovo, near Moscow. The NII-2 of aviation industry was established in February 1946 (now named GosNIIAS). From 1951 to 1970, it was led under the direction of V. A. Djaparidze, previous Head of the TsAGI laboratory, who later proposed an air-cushion landing system for one of Chelomey's space shuttles. The P-5 flight tests went ahead in Balaklava from August 1957 to March 1958. The first submarine, Project 613 no. S-146, was built by production facility no. 112 in Krasnoye Sormovo (Gorky). The first launch from the submarine took place on November 22, 1957 in Severodvinsk. In total, 21 launches took place and on June 19, 1959, by order of degree 685-313, the missile was declared operational.

Figure 1.19. *P-5 launch from submarine Pr659 (source: rights reserved)*

The P-5 was deployed on several types of submarine. Project 613 no. S-80 was turned into Project 644, a two-missile carrier, and a salvo of two missiles was carried out in December 1959. Following this, six units of Project 644 were produced (S-44, S-46, S-69, S-80, S-158, S-162). Project 665, a four-missile carrier, was also produced in six units (S-61, S-64, S-142, S-152, S-155, S-164). Finally, Project 659, a nuclear propeller, was equipped with six missiles and produced in six units by production facility no. 199 in Komsomolsk-sur-Amour (K-43, K-59, K-66, K-122, K-151, K-30).

The P-5D version (4K95) was fitted with a Doppler for measuring the speed and drift angle of Zhukovsky's NII-17 to improve accuracy and lower the flight altitude. As such, it reached an accuracy of 4 km/500 km and the altitude decreased from 400 to 200 m. The barometric altimeter was replaced by a RV-5 radio altimeter from OKB-379 in Kamensk-Ural (now UPKB Detal). Between 1959 and 1960, 22 missiles were tested in Kapustin Yar. It was then tested on submarine Project 644D no. S-162 between 1960 and 1961. It was declared operational on March 2, 1962. The P-5SN version was fitted with a RV-5M radio altimeter. Finally, the P-5U was equipped with an inertial guidance system provided by V. I. Kuznetsov from NII-944 (a gyroscopic platform) and E. F. Antipov from OKB-923 (barometric altimeter).

Figure 1.20. *The 1960 S-5 missile (source: rights reserved)*

Chelomey also studied a P-5P for the Army and a P-5N for the Air Force. The S-5 ground version (2K17) was transported by one of V. A. Grachev's ZIL-135K trucks. Seven launches were carried out in 1960, and an additional five launches allowed them to take part in State testing in 1961. It was declared operational on December 30, 1961 and then became the FKR-2 system (frontal cruise-missile). The FKR-1 (or KS-7) had been developed by Mikoyan based on the Kometa missile. The airborne version had not been developed since Mikoyan's X-20 was selected. The S-5L (2K17M) was designed by order of decrees from June 19, 1959 and January 9, 1963. The 9M78 missile was given a 4L44 accelerator, a 4D95 turbojet and a RV-15 radio altimeter. Six launches were fired between August 1 and October 20, 1964. Finally, the S-5V, transportable by Mi-10 helicopter, was reviewed between February 1962 and November 1965.

The P-5 was mass produced in aviation factory no. 292 in Saratov and no. 99 in Ulan-Ude. It cost 1.5 times less than a Mig-21, or half as much as a Su-7B. On the other hand, it cost twice as much as A. Ya. Berezniak's P-15, and six times more than P. D. Gruchin's S-75.

Its two competitors were G. M. Beriev's P-10 and S.V. Ilyushin's P-20. As decided on June 19, 1955, the first had been flight tested in 1956 and abandoned in 1957. Decree no. 1601-892 of August 25, 1955 planned to have it assigned to the Project 642 submarine (replaced by Project 646 in 1956). The second rival, decided in April 1956, had also been abandoned in 1960. Decree no. 1601-892 of August 25, 1955 planned to allocate it to the submarine Project 627A (Project 653 in 1958).

The 1959 Lenin Prize was given to V. N. Chelomey, S. N. Khrushchev, M. I. Livchitz, V. A. Modestov, I. M. Chumilov, V. E. Samoylov, S. B. Purzin, A. I.

Korovkin and V. V. Krylov. In addition, Chelomey also received his first Hero of Socialist Labor medal and became General Designer of the aviation industry. At this time, Korolev was only Main Designer as he was working for the Ministry of Defense Industry which did not yet have general designers. On March 1958, Chelomey hired Khrushchev's son who had just completed his schooling at the Moscow Energy Institute (MEI). As a specialist of anti-ship guidance missiles, he quickly became Deputy of the OKB where he worked up until July 1968. This enabled Chelomey to win the full support of the Head of State until his dismissal in October 1964. He then created his empire, employing 25,000 people, which dominated the aerospace sector for 5 years. During this time, he took over the NII-642 and its production facility on November 6, 1957 (subsidiary no. 2), plant no. 23 and its OKB on October 3, 1960 (subsidiary no. 1), as well as facility no. 301 and its OKB in 1962 (subsidiary no. 3).

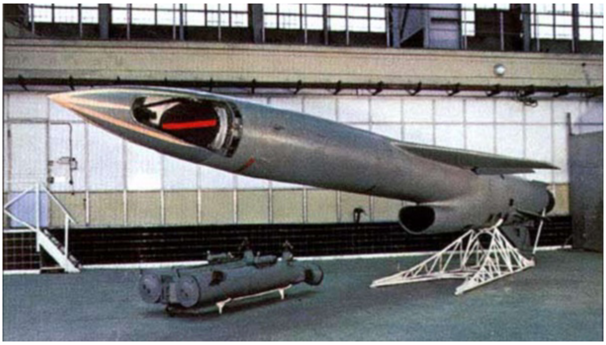


Figure 1.21. *The P-6 (4K48) missile (source: NPO Mach)*

Figure 1.22. *The P-35 (4K44) Redut missile (source: NPO Mach)*

Following the success of P-5, Chelomey went on to design a series of naval cruise missiles: the P-6 (4K48), P-35 Redut (4K44), P-7 (4K77), P-25 (4K70), P-70 Ametist (4K66), P-120 Malakhit (4K85), P-500 Bazalt (4K80), P-700 Granit

(4M45), P-750 Meteorit (3M25), P-800 Yakhont/Onyx (3M55) and P-1000 Vulcan (3M70).

The corresponding NATO codes are SSN-3 Shaddock (P-5, P-6, P-35, P-7), SSN-7 Starbright (P-70), SSN-9 Siren (P-120), SSN-12 Sandbox (P-500), SSN-19 Shipwreck (P-700), SSN-24 Scorpion (P-750), SSN-26 Strobile (P-800) and SSN-27 (P-1000).

Figure 1.23. *Mobile version of coastal defense Redut (source: rights reserved)*

Decree no. 1149-592 of August 17, 1956 required the development of the P-6 (4K48) submarine-launched missile and P-35 (4K44), which was launched from the surface. Produced in Reutov, the first missile was equipped with a guidance system taken from NII-49 (now NPO Granit), and the second developed by the NII-10 subsidiary (now NPO Altair). They were 10 m in length and weighed 6 tons. The P-6 was propelled by a KRDF-26 (4D48) turbojet designed in the Ufa OKB-26-300 (where V. N. Sorokin was replaced by S. A. Gavrilov in 1962). The SM-77 launcher was provided by TsKB-34 and the Leningrad Bolshevik facility.

The first stage in the P-6 tests began in December 1959 and ran until July 1960 in Kapustin Yar (five launches). The second stage, in Nenoksa, ran from July until October 1960 (six launches). But the guidance system was causing problems. A series of launches took place from August to December 1961 (seven launches). The launches from swing bench started in May until December 1962 (seven successful launches out of 13). This was followed by tests from a Pr-675U submarine between July and October 1963 (five launches). The last stage, from October to December 1963, consisted of three launches from a 651 submarine and nine launches from a Pr-675. On July 23, 1964, the State commission, led by Vice-Admiral V.A. Sitchev, declared the P-6 operational after 46 launches. This was then mass produced by facility no. 292 in Saratov and no. 126 in Komsomolsk from 1962 to 1967. It was deployed on the 16 diesel Pr-651 submarines (four missiles) and the 26 nuclear Pr-675 submarines (eight missiles). The submarines were designed by the TsKb-18 in Leningrad (now the TsKB MT Rubin).

The P-35 flew for the first time on October 21, 1959. It was propelled by S.K. Tumansky's KR-7-300 turbojet (OKB-300). The launch accelerator was a SPRD-38 by I. I. Kartukov. The TsKB-34 along with the TsNII-173 developed the launchers: SM-70 (four tubes) for the Pr-58 Grozny cruiser, SM-82 (four tubes) for the ground tests and SME-142 (one tube) for the tests on ship OS-15. From October to March 1960, five launches took place with no radio-technical systems. Between July and August 1960, seven launches were fired with the APLI-1 autopilot system but the results were not encouraging. After some improvements, another 10 launches took place in 1961, six of which were successful. Following this, five launches took place from Grozny between June and July 1962. The missile was incorporated into the weaponry on August 7, 1962. The production facility no. 292 in Saratov was entrusted with mass producing the missile. It was deployed on four Pr-58 ships (eight tubes) between 1962 and 1964, and on four Pr-1134 ships (four tubes) between 1967 and 1969. Decree 903-378 of August 16, 1960 ordered for a coastal defense version of the P-35B Redut to be designed, transported by a ZIL-135K truck. Flight tests began in 1963 and the system was declared operational on August 11, 1966. After this, 52 units were deployed.

The P-6 and the P-35 were awarded the Lenin Prize in 1967 (A. I. Eidis, A. S. Mironov).

On July 16, 1961, a decree ordered the coastal defense missiles S-2 Sopka (Mikoyan's Kometa missile) to be replaced by P-35B missiles. The guidance system was produced by the NII-303 (now TsNII Elektropribor). The first launch took place on May 30, 1971. The fixed Utes installation was declared operational on April 28, 1973. Twelve further installations were launched in three divisions in Balaklava in Crimea (object 100) and on Kildin Island near Murmansk (object 101).

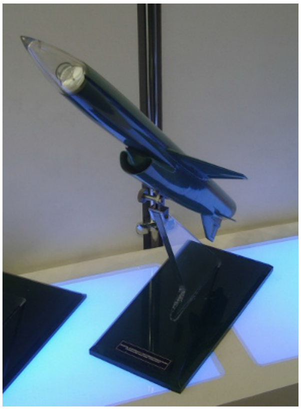


Figure 1.24. *The 3M44 Progress (source: Christian Lardier)*

It was improved and developed into the 3M44 Progress in 1973. The flight tests took place between October 1976 and October 1977 in Severodvinsk. It was announced operational in 1982 and then mass produced. It was deployed on the Pr58 and Pr1134 ships, as well as on the Redut and Utes systems.

The P-6 and P-35 were the first to use the new Uspekh-U Naval Reconnaissance and Target Designation System (MRSTs) by Main Designer I. V. Kudriavtsev from the Kiev NPO Kvant. The system was mounted onto the Tu-16 and Tu-95 planes, as well as onto the Air Force's Ka-25 helicopters. With this system, it was possible to attack targets outside the visibility zone. This led to the development of Chelomey's space MKRTs.

Figure 1.25. *The P-7 missile from 1959 to 1965 (source: rights reserved)*

The decree on June 19, 1959 ordered the development of the P-7 missile with a 900–1,000 km range, with the mass increased from 1.2 to 6.6 tons. The engine was a KR-21-26 designed by S.A. Gavrilov and the launch accelerator was a PRD-94 by Kartukov. The guidance system was completed by the NII-923 (V. V. Drabkin). It had an NII-17 Doppler system by V. A. Granovsky. The subsidiary of OKB-52 in production facility no. 256, Dubna, was in charge of mass production. The first launch from a SM-49 tube took place on April 21 1961 at Kapustin Yar (10 launches). The submarine tests (S-158) took place from October 1962 to 1963 in Severodvinsk (11 launches). Two additional launches took place in November 1964, reaching a total 23 launches. On August 2, 1965, the program was closed down.

Figure 1.26. *The P-70 (4K46) missile Ametist (source: rights reserved)*

The P-25 (4K70) missile was designed following decree no. 926-386 of August 26, 1960. With a solid propellant engine, it was meant to replace the Berezniak P-15 on the Pr205 torpedo. Production began in facility no. 642 between 1961 and 1962, but the program was transferred to the Lavotchkin facility on December 18, 1962.

On April 1, 1959, decree no. 363-170 ordered the development of the P-70 Ametist, the world's first anti-ship missile with a submerged launch. With a mass of 3.7 tons, it had a 70 km range and flew at 60 m altitude. It had a 293-P solid propellant engine from KB-2 (I. I. Kartukov). The guidance system was provided by the NII-49 (B. A. Mitrofanov). It included an autopilot system, a radio altimeter, a calculator and a radar seeker. The TsKB-34 produced four types of launch tubes: SM-101 for ground tests, SM-107 for the Pr613A submarine, SM-97 for the Pr661 atomic submarine and SM-7A for the Pr670A atomic submarine. The first stage in the tests included 10 launches from SM-101 in Balaklava (first underwater launch on June 24, 1961). On December 12, 1962, the first launch of the Pr613A submarine failed. The flight tests started once again in Feodosi in 1963 with 10 launches, but on December 17, a decision was taken to stop the tests in order to make modifications to the submarine. The third stage took place from July to December 1964 with six launches in the White Sea. The combined tests took place from March 1965 to September 1966 with 13 launches, and the control tests during October–November 1967 (10 launches with salvos). The missile was declared operational on June 3, 1968 after 50 launches. It was then mass produced in facility no. 126 in Komsomolsky-sur-Amour (KnAPO) and in facility no. 301 in Khimki (Lavotchkin). It was deployed on 10 Pr670 submarines (eight missiles) between 1967 and 1972 and on a Pr661 (10 missiles) between 1969 and 1970.

The Ametist was awarded the Lenin Prize in 1970 (V. I. Patruchev, N. M. Tkachev).

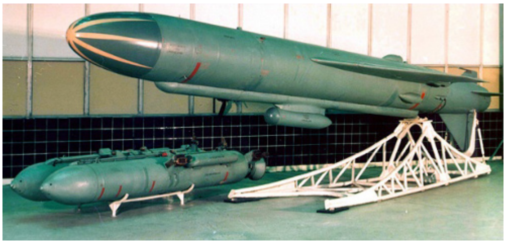


Figure 1.27. *The P-120 (4K85) missile, Malakhit (source: rights reserved)*

The P-120 Malakhit missile was developed by order of decree 250-89 from February 28, 1963. It was the first missile to use two radar and thermal (infrared) guidance systems. This system, Delfin, designed with the NII-10 (V.E. Krasnov), included the Dvina radar, the infrared seeker Drofa and the APLI-5 Dniepr autopilot system. The solid propellant engine 4D85 (I. I. Kartukov) was more efficient. With a mass of 3.8 tons, it had a 150 km range and flew at 900 km/h. It was launched from the SM-156 tube from atomic submarine Pr670M and from Pr1234 torpedoes. The first round of flight tests began on September 25, 1968 until February 1969 in the Black Sea. From July to October 1969, three launches were carried out from a depth of 50 m, and four launches took place from a coastal installation. From March to August 1970, six launches took place from the Pr1234 Buria. Altogether, the combined tests took place between September 1970 to 1972 (14 launches). On March 17 1972, the missile was declared operational on the Pr1234. From April to December 1974, the tests were combined with the Pr670M submarine (eight launches). On November 21 1977, the Malakhit was also declared operational on the Pr670M. There were 44 launches between 1968 and 1975. Mass production commenced at production facility no. 301 in Khimki and at facility no. 47 in Orenburg. It was deployed on 33 Pr1234 (six missiles) and on six Pr670M (eight missiles). It was also scheduled to be deployed on the Pr705 submarine (12 missiles).

Figure 1.28. *The P-500 (4K80) Bazalt missile (source: rights reserved)*

The P-500 Bazalt missile was initiated under the same decree as the Malakhit. It was propelled by a KR-17-300 Ufa engine, allowing it to fly a Mach 2 and have a 550 km range. It had a mass of 4.8 kg and was 11.7 m long. The NII-49 Argon (TsNII Granit) guidance system was, for the first time, equipped with an onboard computer. The first round of flight tests started on October 1969 until October 1970 in Nenoska. Afterwards, the tests continued up until 1974. On August 11, 1975, the missile was declared operational. It was produced in the no. 292 Saratov facilities, as well as no. 1 in Kuybichev and no. 47 in Orenburg. It was then deployed on 10 Pr675MK submarines (eight missiles), on the four Pr1143 aircraft carriers Kiev, Minsk and Novosibirsk with eight missiles, and on Admiral Gorchkov/Baku with 12 missiles between 1975 and 1987. It was further deployed on the three Slava Pr1164 class cruisers Moskva, Marshal Ustinov and Variag (16 missiles) between 1983 and 1989. The MRSTs Uspekh (Ka-25RTs, Tu-95RTs) and Legend (satellites US-A and US-P) controlled the target identification.

Figure 1.29. *The P-1000 Vulcan (source: Christian Lardier)*

The decree of May 15, 1979 required the Bazalt to be modified into the P-1000 Vulcan. Because of the use of modern materials, it allegedly weighed 1–2 tons, which enabled an increased range reaching 700 km. The flight tests started in July 1982. The first launch from a Pr675MKV submarine took place on December 22, 1983. On December 18, 1987, the State Commission, led by Rear Admiral O. D. Bobyrev from the Nenoska polygon (GTsMP-21) declared it operational. Five submarines were equipped with eight missiles. The decree of October 13, 1987 requested that the three Pr1164 cruisers be equipped with 16 missiles, which took place between 1983 and 1989.

Figure 1.30. *The P-700 (4M45) Granit missile (source: rights reserved)*

The development of the P-700 Granit missile, a 7-ton device able to fly at 2.5 Mach across a distance of 550 km, was authorized by decree on July 10, 1969. It was launched underwater from a tube of TsKB-34 (V.V. Chernetsky) with an accelerator. Two versions were developed, one using liquid propellant with the RD-0231 engine from KB Khimavtomatiki in Voronej, and another using solid propellant and an engine from the KB Mach in Perm (L. N. Lavrov). The second was finally chosen. The cruise missile engine was a KR-21-300 from Ufa (S.A. Gavrilov). For the very first time, it used a solid propellant ignition and an electronic regulator in operating regime (ERRD-21). The guidance system was produced by the TsNII Granit (V. V. Pavlov, I. Yu. Krivtsov, V. V. Golovanov). The flight tests took place from November 1975 to August 1983, with the first underwater launch on February 26, 1976 and the first launch from a Pr949 submarine in December 1980. The State Commission led by Rear Admiral K. K. Frantz from NII-28 declared it operational on March 12, 1983. Production was entrusted to facility no. 47 in Orenburg. It was deployed on four nuclear cruisers: Pr1144 Admiral Uchakov, Admiral Lazarev, Admiral Nakhimov and Piotyr Velikiy (20 missiles), as well as the aircraft carrier Pr1143.5 Admiral Kuznetsov in 1990 (12 missiles), and finally, three Pr949 atomic submarines between 1980 and 1996, and nine Pr949A from the TsKBMT Rubin (24 missiles) between 1980 and 1996. The Granit was awarded the Lenin Prize in 1984.

Figure 1.31. *The P-750 (3M25) Meteorit cruise missile (source: Christian Lardier)*

The intercontinental strategic missile P-750 Meteorit was authorized on December 9, 1976. Three versions were meant to be developed: land-based variants (Meteorit-N, aka SSC-5), sea-based variants (Meteorit-M, aka SSN-24 Scorpio) and air-based variants (Meteorit-A, aka ASX-19 Koala). It weighed 6.3 tons, measured 12.8 m in length and 5 m in width. It was a tube-launched cruise missile, propelled by a KR-93 ramjet from OKB-26 in Ufa (mass produced at the Tyumen engine facility). It flew at 2.3–3.0 Mach across a distance of 5,000 km at an altitude of 22–24 km. The high-precision guidance system operated and adapted according to ground conditions. The map of the zone surrounding the target was introduced into the onboard computer. The trajectory could be corrected during flight and the missile could make a return flight across several thousand kilometers (Kapustin Yar to Balkhash and back again). It was equipped with an anti-jamming protector and a stealth system (it was covered by a film, making it practically invisible). As a strategic missile, the warhead was therefore a nuclear one. The land and sea variants were launched using a 6,270 kg liquid propellant accelerator. It was propelled by two RD-0242 engines with 12.6-ton thrust power (KB Khimavtomatiki), which could operate for 32 s.

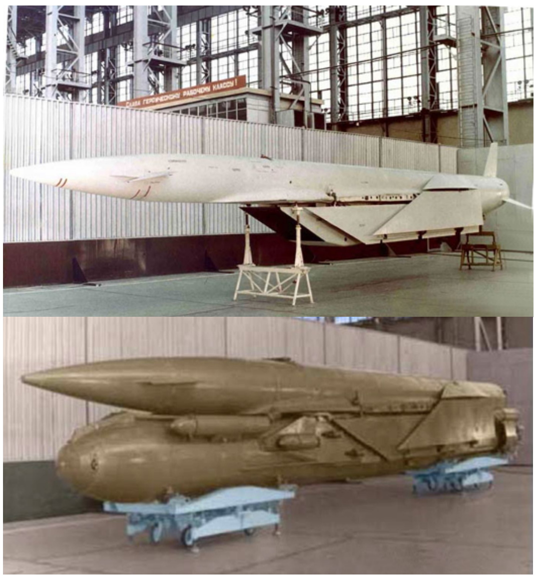


Figure 1.32. *The space (top) and naval (bottom) Meteorit (source: rights reserved)*

The sea-based variant was ready in December 1978 and the air-based variant in January 1979. Facility no. 23 Khrunichev was responsible for production. The first ground stand flight took place on May 20, 1980 but the rocket did not leave the tube. The three following launches also failed. On December 12, 1981, it flew 50 km. Initially, the sea version was meant to be deployed on the Pr949M submarines. Eventually, the Pr667 no. K420 was changed into Pr667M (12 missiles) in Severodvinsk. It was launched from a depth of 40 m. The first launch from a submerged tube took place on January 29, 1982. The first launch from the Pr667A in the White Sea was performed on December 26, 1983. As for the air-based variant, which was dropped in flight (no tube, no accelerators), a Tu-95MS plane was transformed into a Tu-95MA by the Taganrog facility. The first flight was carried out in January 1984. The flight tests continued up until the end of the 1980s. The State Commission was led by Captain E. M. Kutovoy from the Kuznetsov Academy for the sea variant and by Major General L. V. Kozlov from the NII-8 for the air-based version. By the program's definitive end in 1992, there had been 70 flights, 50 of which were land launches (ground stand and submarine), and 20 from the plane. One of these innovations received a government award in 2001.

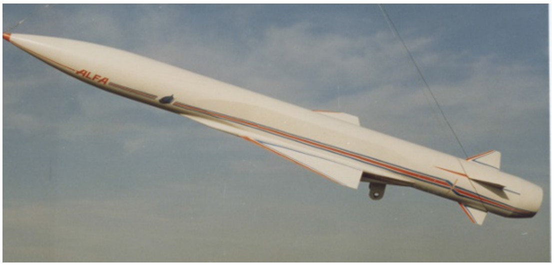


Figure 1.33. *The Alpha project missile (early 1990) (source: NPO Mach)*

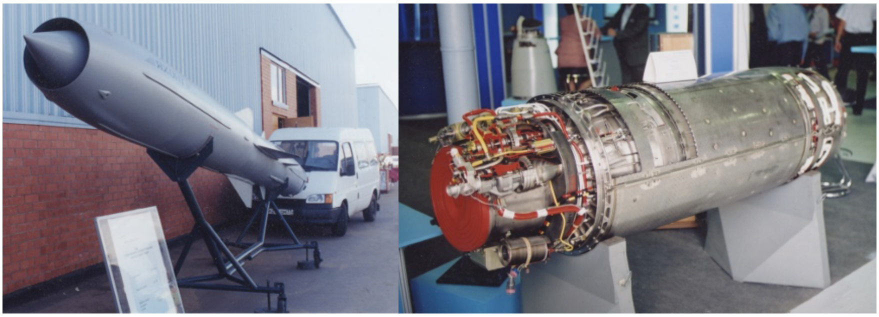


Figure 1.34. *The P-800 Onyx/Yakhont missile and the Plamyia ramjet (source: Christian Lardier)*

The P-800 Onyx/Yakhont was being developed from March 1982 onwards, to replace the Malakhit. Weighing 3.0 tons, it was put into a tube measuring 8.9 m in length and 0.71 m in diameter, designed by the TsKB-34 (V. F. Potapov). It was propelled by a 3D55 supersonic ramjet by the company Plamya (I. B. Levanov), spun off from the KB Soyuz in Turaevo, located in the Keldysh Center from 1978 to 1991. After a few years of operating independently, it was integrated into the Zvezda-Strela holding between 1998 and 2004 before later closing. A solid propellant engine located in the ramjet nozzle enabled lift-off. The missile flew at

2.8 Mach with a 300 km range. The guidance system was produced by the TsNII Granit (inertial navigation and radar seeker). The first mock-up flew on April 26 and July 19, 1985. The first flight from a ground launcher in the Black Sea took place on December 29, 1986. The missile was launched from the Pr1234.7 Nakat ship (12 missiles) in September 1987. Following this, the Pr670M no. 452 (24 missiles) was transformed to launch the Onyx, the first launch taking place on December 14, 1990. From 1985 to 2000, there were 61 flight tests and the missile was declared operational on September 23, 2002. The missile and the engine were manufactured by facility no. 47 in Orenburg. The missile was fully multifunctional, with sea (surface ship and submarine), air-based (Alpha system), and coastal defense (Bastion system using the Maz-543 vehicle) variants. Thirty units of nuclear submarine Pr885 Yassen were to be produced. The first model, the Severodvinsk, has been in the sea since 2010. It carried eight vertical SM-346 tubes for the Onyx missile. 20 of the frigate Pr22350 were also to be produced. The first, Admiral Gorshkov, has been at sea since October 2010. It carried 16 tubes for the Onyx. Finally, 30 models of the Pr12300 Scorpio were produced and carried four tubes for the Onyx.

Figure 1.35. *Air-based variant of the Yakhont (source: Christian Lardier)*

Figure 1.36. *Indian version, Brahmos (source: Christian Lardier)*

In exported markets, it is known as Yakhont, and Brahmos is the version sold under licence to India.

Figure 1.37. *From left to right: G. A. Efremov, S. N. Khrushchev, A. I. Eidis, I. M. Chumilov, M. I. Lifchitz, V. A. Modestov and V. V. Satchkov (source: rights reserved)*

Several people were awarded the Socialist Labor Hero medal for their work on the navy missiles: V. N. Chelomey, G. A. Efremov, M. I. Lifchitz, V. F. Malikov, V. A. Modestov, V. V. Satchkov, S. N. Khrushchev, I. M. Chumilov from OKB-52, as well as A. A. Kobzarev (Deputy Minister of the Aviation Industry), V. A. Kazakov (Head of NII-923 who was Minister of the Aviation Industry between 1977 and 1981) and others.

Figure 1.38. *Socialist Labor Hero medalists in 1963: (from left to right) I. M. Chumilov, V. A. Kazakov, M. I. Lifchitz, A. A. Kobarev, V. N. Chelomey, V. F. Malikov, S. N. Khrushchev, V. V. Satchkov, G. A. Efremov and V. A. Modestov (source: rights reserved)*

2

Chelomey's Subsidiaries

2.1. Institute no. 642

The institute was established as KB-2, under the responsibility of the Ministry of Agricultural Machinery in 1946. It was located on the territory of the no. 67 "Mastiajart" weaponry factory in Moscow. It developed missiles derived from German trophies: the Hs-293A was transformed into the RAMT-1400 Shuka by D. L. Tomashevich (then M. V. Orlov), the Taifun was transformed into Strizh and the Fritz-X into the UB-2000F Chaika by A. D. Nadiradze. Moreover, in 1948 D. M. Svecharnik began developing the SNAB-3000 Krab guided bomb while E. N. Kacherininov was working on an air-to-air missile.

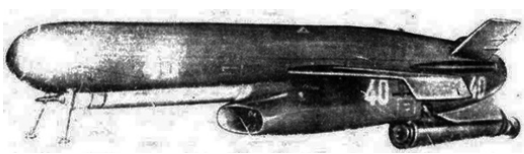


Figure 2.1. *The KSCh Shuka missile derived from the German Hs-293A (source: rights reserved)*

Decree no. 5119-2226 of December 15, 1951 merged KB-2 and the factory into a new company: GSNII-642. In 1955, Svecharnik was transferred to NII-48 in Novosibirsk, whereas Kacherininov moved to NII-1 in Moscow (later the MIT). Orlov, however, worked on the Shuka until 1958 before moving to NII-1.

Chelomey took over the company on December 6, 1957 (Ministerial decree no. 368). The Shuka was then abandoned. By order of decree 293-140 of March 8, 1958, the NII-642 was transformed into a subsidiary of OKB-52 for designing Navy missile guidance systems. Nadiradze became Chelomey's Deputy. However, he was

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

making solid-propellant ballistic rockets at the time and did not want to make Navy missiles. He subsequently moved to the NII-1 where he was Head of Section from 1958 to 1961, before becoming Director and Main Designer. He would then produce the Temp, Pioneer and Topol missiles, among others.

The company was then restructured and several laboratories were created: complex tests, gyroscopic devices (assisted by Professor L. I. Tkachev) and autopilot systems (responsible for the autopilot systems provided by OKB-923, NII-49 and NII-10). In June 1958, the autopilot laboratory was transformed into complex no. 1 under the direction of V. E. Samoylov. His Deputy was S.N. Khrushchev, son of the Head of State. Then, from 1958 to 1960, the personnel from the NII-642 were transferred to Reutov.

Figure 2.2. *V. M. Baryshev (source: rights reserved)*

In 1961, following the merger with V. M. Myasishchev's OKB-23, designer G. I. Arkhangelsky's group (complex no. 3) moved into the NII-642 premises to develop rocket launch installations. Arkhangeslsky gained recognition when he developed the in-flight refueling system (rod and cone) with designer S. M. Alexeyev from factory no. 918. Then, on January 15, 1963, Chelomey established subsidiary no. 2 on this territory. V. M. Baryshev was entrusted with directing it. As former Deputy to Myasishchev, Baryshev had worked on the 3M, M4, M50 and M52 bombers, for which he received the Lenin Prize in 1957. In 1965, after the Ministry of General Machine-Building (MOM) was established, the factory and the OKB were separated. The former became MMZ Vympel and the latter became the TsKBM subsidiary no. 2. The two entities were merged once again in 1978 until 1991. In December 1991, they became independent from each other once more.

Figure 2.3. *Award ceremony at the Vympel factory (1970s). First row, center: V. M. Baryshev, V. N. Chelomey and S. A. Afanaseyev (source: rights reserved)*

OKB Vympel was led successively by V. M. Baryshev from 1963 to 1985, followed by O. S. Baskakov from 1985 to 1995 and D. K. Dragun from 1995. It developed launch pad parts for Chelomey's rockets (8K81, 8K82, etc.), transportation and launch tubes and silos for ICBM (8K84, 15A20, etc.), as well as technical installations for preparing satellites (IS, US, etc.) in co-operation with other companies (OKB Gorizont, the Projektor factory, etc.). In particular, it also took part in orbital station programs (Almaz, Salyut, Mir). It has been looking after part of the Baikonur installations since 1995. In 1998, it employed 690 people. Since January 2009, it has been part of the TsENKI holdings, which owns all ground infrastructure companies.

As for the Vympel factory, this was led successively by N. I. Krupnov from 1955 to 1956, D. G. Diatlov from 1957 to 1958, A. I. Shapovalov from 1958 to 1980, M. I. Gomenyuk from 1981 to 1982, V. I. Senin between 1982 and 1993 and S. P. Nikulin from 1993 to 2010. Besides the products from OKB Vympel, it also produced the NPO Lavochkin Prognoz research satellites.

2.2. Myasishchev's OKB-23

This was opened on March 24, 1951 to develop a strategic reaction bomber (aircraft 25, M4). This was in partnership with the Fili factory no. 23 in Moscow. The team included G. N. Nazarov (first Deputy), and Deputies V. M. Baryshev, L. L. Selyakov, L. M. Rodnyansky, N. M. Glovatsky and Ya. B. Nodelman, among others. The first flight took place on January 20, 1953. The in-flight refueling system (aircraft 36, M6, 3M) took flight on March 27, 1956.

Figure 2.4. *V. M. Myasishchev (source: rights reserved)*

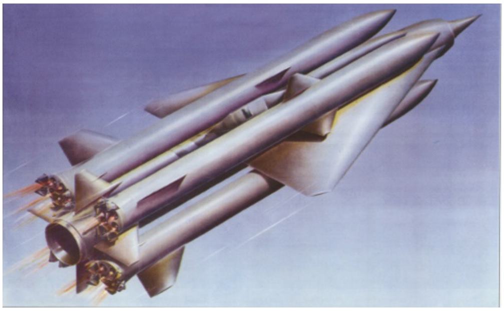


Figure 2.5. *The M-40 Buran missile (source: Bruk, 2001*). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

Decree no. 957-409 of May 20, 1954 decided on the development of the Buran intercontinental cruise missile (M-40, including the first stage M-41 with the RD-213 engine and the M-42 winged vehicle with RD-018A ramjet). The team's Head Designers were D. F. Oroshko (M-40), A. I. Zlokazov (M-41), G. D. Dermichev (M-42) and K. S. Chanko (engines). One unit was produced but the program was abandoned in November 1957 following the success of S. P. Korolev's R-7.

On July 30, 1954, decree no. 1607-728 ordered the M-50 long-range supersonic bomber to be designed. The first flight took place on October 27, 1959. However, it was stopped in 1960 and the aircraft took its last flight during the Tushino Air Parade on July 9, 1961. On December 17, 1956, Myasishchev was appointed General Designer. He was awarded the Hero of Socialist Labor medal and the Lenin Prize in 1957 (along with Nazarov, Baryshev, Selyakov and Rodnyansky). On October 1, 1959, he absorbed P. V. Tsybin's OKB-256. Located in Dubna, the aforementioned OKB had been established on May 23, 1955 to develop a strategic supersonic aircraft: the RSR, a type of American SR-71. The demonstrator NM-1 was built: it performed 32 flights from April to October 1959.

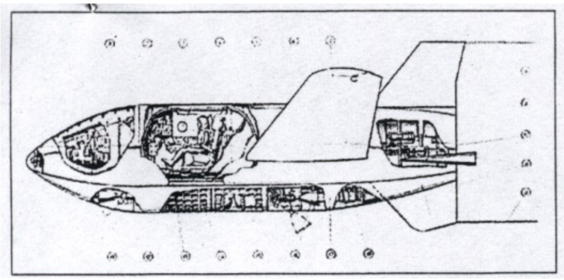


Figure 2.6. *Tsybin's spaceplane project (source: rights reserved)*

During this time, on May 17, 1959, Tsybin had presented a spaceplane project named *Lapotok* (*slipper*). It was a 3.5-ton winged vehicle launched by Korolev's Vostok rocket. Following the OKB's closure, work was transferred to Mikoyan. After the merger with OKB-23, the RSR was moved from Dubna to Fili. But when Chelomey took over OKB- 23, he put an end to the M-50 and RSR programs. Tsybin only stayed with Chelomey for 6 months before going to work with Korolev.

Myasishchev had studied several projects that would never come to fruition. On the aircraft front, the decree of July 31, 1958 ordered the development of the M6-K14 (3M equipped with K-14 missiles), the M-52K (M-50 equipped with X-22 missiles) and the M-56K (a new aircraft, equivalent of the American XB-70, equipped with M-44 missiles). A model of the M-52K was in construction from April 1959 to late 1960.

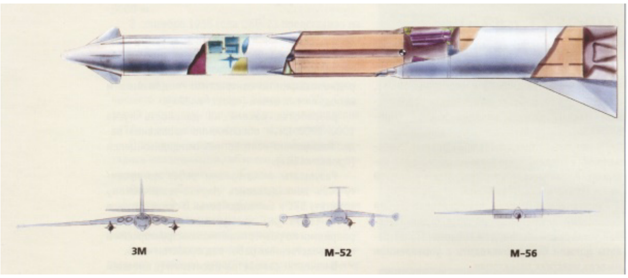


Figure 2.7. *The M-43 missile project (source: Bruk, 2001*). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

Figure 2.8. *The M-44 missile project (source: Bruk, 2001*)*

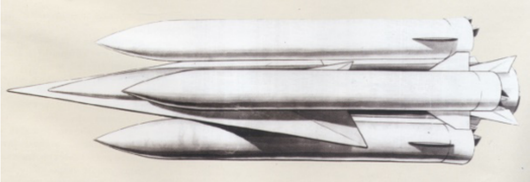


Figure 2.9. *The M-45 missile project (source: Bruk, 2001*)*

Moreover, he studied the M-51 (an unmanned vehicle used for carrying an atomic bomb up to 10,000 km), the M-53 and the M-55 (passenger planes), the M-54 and M-57 (bombers), the M-58 and M-59 (strategic systems), and the M-30 and M-60 (nuclear-powered aircraft). The M-57 was derived from R. L. Bartini's A-57 (SibNIIA in Novosibirsk), which would be a carrier of Tsybin's PSS (an RSR-derived missile). The M-58 was a three-stage vehicle: the first stage consisted of four M-41 (Buran) type boosters, the second was a bomber (two pilots) propelled by two ramjets on the end of the wings and the third stage, on the nose of the bomber, was an M-45 type missile. Lastly, the M-59 was derived from the M-56, propelled by either six RD-7-300 engines or four NK-11.

With regard to missiles, he studied several vehicles. The air-to-ground, solid-propellant M-43 missile was designed for the 3M, M-52 and M-56 aircraft. The M-43A had a 500 km range, and the M-43B could reach up to 1,000–1,200 km. The M-44 supersonic missile was a winged vehicle weighing 11 tons propelled by two turbojets. It could fly at Mach 3 over a distance of up to 2,000 km. The M-45 cruise missile was derived from the Buran M-40. It existed in two different variants: one with a liquid-propellant first-stage (four boosters with 5.5 tons unit thrust) or as an air-to-ground missile dropped from the M-50. The 20.5-ton vehicle, propelled by four rocket engines with 160 kg thrust, flew at Mach 12 across a distance of up to 3,600 km.

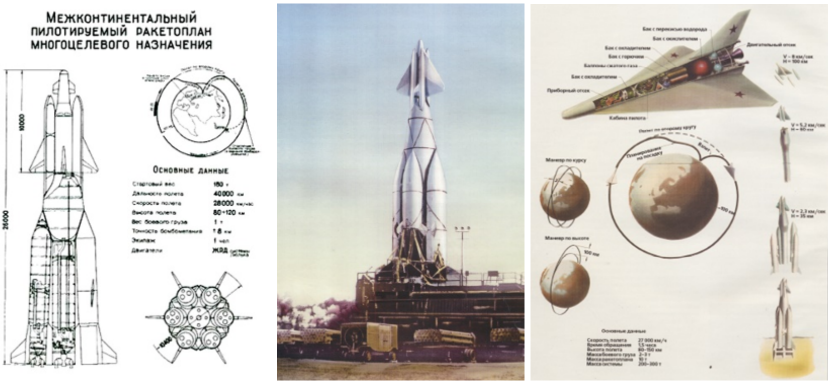


Figure 2.10. *The M-46 Raketoplan project (1956) (source: Bruk, 2001*). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

The hypersonic M-46 Raketoplan was an equivalent of the American X-15. However, it was not a rocket plane but an orbital plane weighing 10 tons, launched by a rocket weighing 200–300 tons at lift-off. It flew at an altitude of 80–150 km. The first stage was a four-booster rocket which mimicked Korolev's R-7. The second stage was the central body that followed the ascent at an altitude of up to 80 km. Lastly, the third stage consisted of four droppable reservoirs placed around the plane's fuselage supplying the engine until satellization at 100 km altitude. The aircraft was called a "satelloid." The program planned to test an experimental vehicle in 1961, the second stage in 1962, the whole vehicle in 1963, the manned reconnaissance version from 1964 to 1965, then the reconnaissance and bomber version from 1965 to 1966. The M-46A version, weighing 240 tons at lift-off, was equipped with A. M. Liulka's rocket engines.

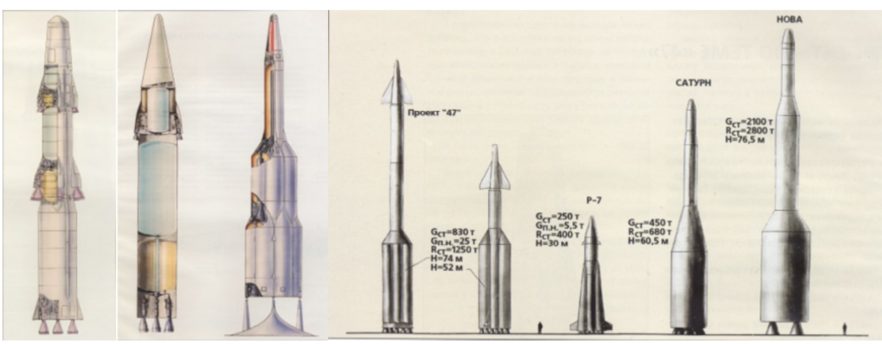


Figure 2.11. *The ICBM and M-47 space launch vehicle project (1959) (source: Bruk, 2001*). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

The M-47 was an ICBM studied in 1959. Three versions were developed: the two-stage M-47A (51 tons at lift-off) with Liulka rocket engines, the three-stage M-47B (64 tons at lift-off) with the same engines and the three-stage M-47V (80 tons at lift-off) with solid propellant engines. By order of decree 715-296 of June 23, 1960, lunar super rockets were studied based on the American Nova model. Two models with two and three stages (52 and 74 m high) were designed with a spaceplane as the payload. The first stage was a barrel made up of four identical blocks. In total, the thrust at lift-off was 1,250 tons.

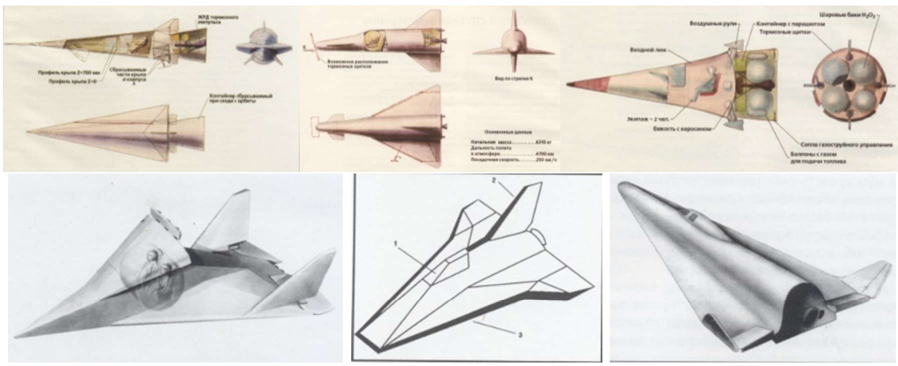


Figure 2.12. *The M-48 Raketoplan project: top (from left to right) variants 48-I, 48-II, 48-IV; bottom (from left to right) variants VKA-23 from 1958, 1959 and 1960 (source: Bruk, 2001*). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

The M-48 was a space shuttle that responded to decree no. 1388-618 of December 10, 1959. G. D. Dermichev studied four blueprints: a winged vehicle weighing 4,530 kg with a hypersonic shield, a winged vehicle weighing 4,310 kg with gliding flight, an unwinged vehicle weighing 4,440 kg with a rotor for vertical landing and a vehicle with lifting surfaces and braking shield. In 1960, Myasishchev contacted Korolev (OKB-1) and Keldysh (NII-1) to launch his shuttle with an R-7 rocket. At this time, Korolev was finishing construction on the Vostok spacecraft which took its first flight in May. The VKA-23 vehicle, which weighed 3.5 tons, could carry a 700 kg payload across a 500 km orbit. The pilot, wearing a spacesuit, was strapped to an ejection seat (160 kg). Some devices were identical to those of the Vostok. Three versions of the vehicle were planned: first, one derived from the satelloid, then a single-fin vehicle and lastly a double-fin vehicle. Upon return, at an altitude of 40 km, it was able to manoeuver into a lateral offset of 100 km.

Finally, the M-61 was a winged rocket with an RD-013 ramjet, designed to be carried on the M-52 bomber.

By order of the decree on June 23, 1960, the government requested that three companies cooperate together for the ICBM: the first and second stages were entrusted to Myasishchev, the third to P. O. Sukhoi and the upper stage to Chelomey. However, discrepancies between the designers led to a reorganization: on October 3, 1960, by order of decree no. 1057-437, OKB-23 was handed over to Chelomey. Myasishchev, however, was sent to become head of the TsAGi in Zhukovsky. OKB-23 then became subsidiary no. 1 of OKB-52 (or F1 TsKBM).

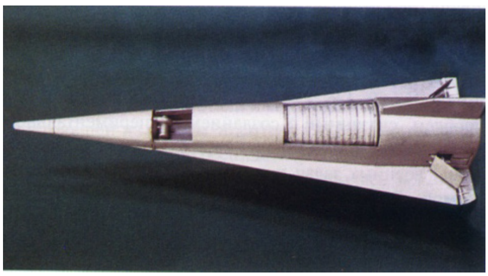


Figure 2.13. *The Tu-130 project (source: rights reserved)*

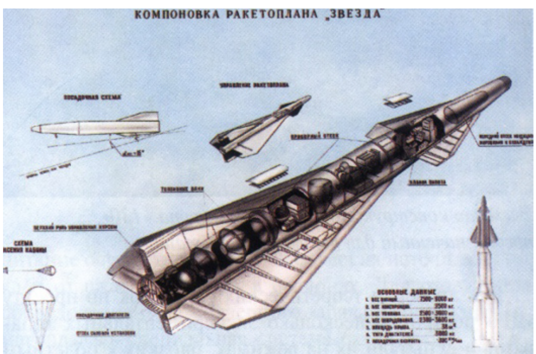
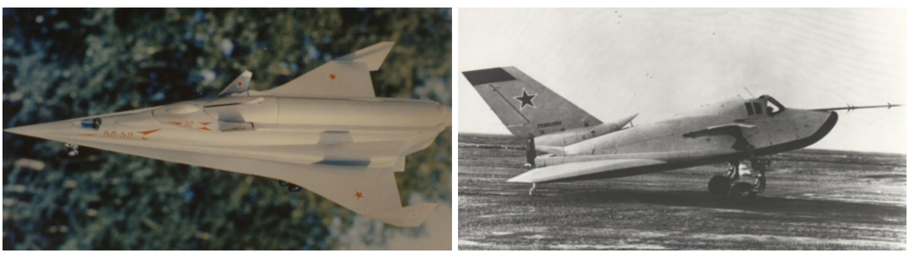


Figure 2.14. *The Tu-136 project (source: rights reserved). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

Indeed, when Korolev's R-7 became the first ICBM and the first Soviet space launcher, Khrushchev decided that aviation was then being surpassed by rockets, which had to be prioritized. He had made a request to the Minister of Aviation Industry, P. V. Dementiev, that part of his OKB and factories be dedicated to the field of rocketry and space. Thus, the aircraft designers began designing rockets. At A. N. Tupolev's facility (OKB-156), sector K studied the Raketoplan Tu-130 first of all. This was a missile (Korolev's R-5 or Yangel's R-12) which would put a flying winged vehicle into an orbit at 80–100 km. Equipped with a thermonuclear bomb, it would re-enter the atmosphere and glide until reaching its target. One model, propelled by a solid propellant engine, was dropped from a Tu-16LL by the Flight Research Institute (LII). A glider had been prepared to fly in 1960 but on February 5, the program was cancelled by order of decree. The glider was destroyed, but the work was used for the Raketoplan Tu-136 Zvezda and its variant, Sputnik. It was an equivalent of the American Dyna-Soar. It could be used for reconnaissance, bombing and intercepting enemy rocket and satellites. The vehicle, weighing 7.5–9.0 tons, was launched by a rocket carrier able to send 10–20 tons into low orbit. The flight tests were planned in five phases: a model dropped from a Tu-16, a model dropped from a Tu-95 to fly up to 1,000 km/h (Tu-136/1), a model flying in subsonic, transonic and hypersonic (Tu-136/2), a model with an additional propulsion module for flying at Mach 12 at an altitude of 100 km (136/3), and then an orbital model flying at Mach 25. The Tu-137 Sputnik version was designed to stay in orbit for several days before returning to Earth. Work was stopped in 1963.



a) b)

Figure 2.15. *a) The Spiral project of OKB-155 and b) aircraft 105 (source: rights reserved)*

At Mikoyan's facility (OKB-155), M. I. Gurevich's Sector B was in charge of guided missiles (KS-1, FKR-1, K-10, X-20). In 1958, the KOMIK project (Korolev–Mikoyan–Kisunko) on anti-satellite satellites (ASAT) was studied until November 1960, but Khrushchev had already handed the space interceptor program over to V. N. Chelomey in June. On June 29, 1966, Mikoyan appointed G. E. Lozino-Lozinsky to become the head of his Dubna subsidiary to develop the Spiral 50-50 system. This was a space shuttle launched from a hypersonic aircraft. A subsonic model (aircraft 105) was dropped from a Tu-95 and hypersonic re-entries were achieved using BOR = Bespilotnyi Orbitalnyi Raketoplan. A prototype launched by a Soyuz rocket was meant to be tested in orbit, but the program was abandoned in 1976.

The second stage of the 1958 launch vehicle was to be designed at the Sukhoi facility (OKB-51). In addition, in 1960, the OKB was competing with Lavochkin and Gruchin for the V-1100 antimissile missile project for the Moscow A-35 protection system.

The engine designers followed the same path. N. D. Kuznetsov (OKB-276 in Kuybichev) completed his first rocket engine (8D517) between 1959 and 1960. He then went on to produce the engines for the lunar rocket N-1. A. M. Liulka (OKB-165 in Moscow) had started working with Myasishchev in 1958. Two years later, he became involved in the development of cryogenic engines (oxygen-hydrogen) for the lunar launch vehicle N-1 (11D54 and 11D57). He continued with this work until the N-1 was abandoned in 1976. S. P. Izotov (OKB-117 in Leningrad), who succeeded V. Ya. Klimov in 1960, was developing his first engine (5D12) between 1958 and 1961 for Gruchin's S-200 missile. Next, he produced the engine for the second stage of the antimissile missile A-350. From 1962, he worked with Chelomey and designed engines for the UR-100 (second stage), UR-200 (third stage), UR-500 (warhead) and UR-700 (Block-L) rockets. S. K. Tumansky (OKB-300 in Moscow), who replaced A. A. Mikulin in 1956, specialized in small engines: R201-300 for Raduga's X-22 missile, R203-300 and R204-300 engines for Chelomey's IS (anti-satellite) and US (ocean monitoring) satellites, etc. In 1964, he transferred this activity to the new Turayevo subsidiary (TMKB Soyuz). Finally, P. F. Zubetz (OKB-16 in Kazan), who produced derivatives of Mikulin's RD-3M turbojet, began designing solid-propellant rocket engines (first stage 5S47 for the A-350 missile on the A-35 system, first stage for the 9M82 and 9M83 missiles of the S-300V, 9M38 Buk rocket, etc.).

Figure 2.16. *V. N. Bugaisky (source: rights reserved)*

Following Myasishchev's departure, the OKB was managed by V. N. Bugaisky. He had started working for S. V. Illuchin (OKB-240) in 1934. In 1940, he was Deputy Main Designer for the Il-2, the famous Shturmovik, which he mass produced in factory no. 18 in Kuybichev during the Second World War. In 1946, he became the company's First Deputy. In 1958, Chelomey invited him to take over OKB

Salyut. He then began developing the UR-100, UR-200, UR-500 and UR-700 rockets as well as orbital stations (Almaz, Salyut, etc.). In 1973, he left Chelomey for OKB-455 Strela in Kaliningrad (now Zvezda). Here, he worked on air-to-air and ground-to-air missiles until 1983. He then ended his career at the NPO Molnya until 1989. A Doctor of Technical Sciences and a three-time winner of the State Prize, he passed away in 1994.

Figure 2.17. *D. A. Polukhin (source: rights reserved)*

His successor from 1973 to 1993 was D. A. Polukhin. After qualifying from the Moscow Aviation Institute (MAI), he went straight to OKB-23 where he progressed from engineer to Main Designer. From June 1981 to June 1988, the OKB was put under the responsibility of the NPO for experimental machine building (later NPO Energiya) led by V. P. Glushko. When the NPO was taking back its independence, between 1988 and 1993, Polukhin was the Director and General Designer. A Technical Sciences candidate, a Hero of Socialist Labor in 1980, recipient of the Lenin Prize in 1976 and the State Prize in 1967, he died in 1993.

Figure 2.18. *A. K. Nedaivoda (source: rights reserved)*

He was succeeded by A. K. Nedaivoda from 1993 until 2003. Qualified from the University of Dnipropetrovsk in 1961, he joined OKB-23 in 1965. He was Technical Director of preparing launches for 18 years. As such, he was part of several State commissions. He was a Doctor of Technical Sciences in 1992, a Professor in 1994 and Head of Department at the Moscow State Aviation Technological University (MATI) as of 1999. Lastly, in 2003, the General Designer was Yu. O. Bakhvalov. Born in 1954, he joined the OKB in 1977 where he went on to become Deputy General Designer in 1999.

Figure 2.19. *From top to bottom and left to right: V. K. Karrask, Yu. V. Diachenko, Ya. B. Nodelman, G. D. Dermichev, E. T. Radchenko, V. A. Vyrodov, D. F. Orochko, G. A. Khazanovitch, Yu. N. Trufanov and V. N. Ivanov (source: rights reserved)*

The following people were in charge of the OKB: V. K. Karrask (First Deputy from 1964 to 2004, Lenin Prize in 1964, State Prize in 1985), V. N. Ivanov (First Deputy from 1994 to 2004, State Prize), Yu. G. Dobrovsky (Deputy for theory and calculations), Yu. V. Diachenko (Deputy for flight tests, Lenin Prize in 1967), Ya. B. Nodelman (Deputy, Main Designer of the Meteorit, State Prize), E. T. Radchenko (Deputy), G. D. Dermichev (Head of Sector, State Prize), V. A. Vyrodov (Design Sector), D. F. Orochko (Designer in Chief of the UR-200 and UR-100, State Prize in 1967), G. A. Khazanovitch (Designer in Chief of the UR-100 and Meteorit, Main Designer of the Proton-M), Yu. N. Trufanov (Designer in Chief of the UR-500, Lenin Prize in 1970), V. F. Gussev (Designer in Chief of the UR-500), Yu. A. Koloskov (Designer in Chief of the UR-500, State Prize), E. S. Kulaga (composite materials), N. N. Mirkin (engines), A. S. Chekhoyan (flight tests) and others.

2.3. Factory no. 23 in Fili

Factory no. 23 had been created in 1916 to build cars. At the time, it was called the Russo-Balt factory. In 1923, the German company Junkers was producing the Ju-20 aircraft there under a licensing agreement. In 1927, it became factory no. 22 and began producing Soviet aircraft: ANT-3 (79 units), ANT-4/TB-1 (216 units), ANT-5 (371 units), ANT-6/TB-3 (740 units), ANT-7 (45 units), ANT-9 (61 units), ANT-35 (13 units) by A. N. Tupolev, ANT-40/SB (5,695 units) by A. A. Arkhangelsky and the DB-A (2 units) by V. F. Bolkhovitinov. During World War Two, it was evacuated to Kazan where it went on to produce the AR-2 (190 units) by A. A. Arkhangelsky and the Pe-2 (1,120 units) by V. M. Petliakov. Factory no. 23 was built on its site on December 17, 1941. It produced the Il-4/DB-3F (367 units) by S. V. Iluchin between 1942 and 1943 and Tupolev's Tu-2 from 1943 to 1946. Next, it produced the Tu-4 (160 units), the Tu-12 (3 units) and the Tu-14 (3 units) up until 1951.

Next, the factory produced the aircrafts designed at Myasishchev's OKB: the M4/3M bombers (89 units), followed by two prototypes of the M-50. But on February 6, 1960, the Council of Ministers stopped the production of Myasishchev's aircraft and production of M. L. Mil's Mi-6 helicopter (110 units) began.

Factory no. 23 and OKB-23 were never linked structurally. Indeed, the factory was under the direct supervision of the Ministry. On June 2, 1961, it took the name of M. V. Khrunichev who had just died. But who was he? Khrunichev was an *apparatchik* who started his career in the Ukraine militia. After a period studying, he was made Deputy Director of Luganks's cartridge factory, then Director of Zelenodolsk's munitions factory. In 1937, he became Head of Directorate in the Ministry of Defense Industry. The following year he became Deputy Minister. During World War Two, he was Deputy of the Ministry of Munitions. From 1946 to 1953, he was Minister of the Aviation Industry. In 1953, he was Deputy of the Ministry of Medium Machines for the atom and rockets. In February 1955, he became Vice President of the Council of Ministers. Then, from December 1956 to June 1961, he was Gosplan's Deputy. Simultaneously, from April to June 1961, he was President of the State Committee for coordinating scientific and technical work.

Figure 2.20. *From left to right: S. M. Lechenko, D. N. Osipov, M. I. Ryjik and A. I. Kiselev (source: rights reserved)*

The factory was led successively by S. M. Lechenko between 1946 and 1952, D. N. Osipov from 1952 to 1961, M. I. Ryjik from 1961 to 1975 and A. I. Kiselev from 1975 to 1993. M. I. Ryjik qualified from the Kharkov Aviation Institute in 1936. First, he went to work at factory no. 135 in Kharkov which was evacuated to Perm in 1941. He then went on to factory no. 23 in Moscow where he stayed for the rest of his life, until 1982. He was awarded the Hero of Socialist Labor medal in 1966.

Figure 2.21. *S. A. Afanaseyev, A. I. Kiselev and V. N. Chelomey (source: rights reserved)*

Figure 2.22. *First row to center: N. D. Kokhlov, Chelomey, S. A. Afanaseyev and A. I. Kiselev (source: rights reserved)*

He was succeeded by A. I. Kiselev in 1975 who was living in Fili after having completed the local technical school at 18 years old and joined factory no. 23 as an electrician in a workshop. He then started work on the VD-7 engines for the M-4 bomber, then on the M-50. In 1962, he began working on the UR-200 rocket (Kosberg engines). At the same time, he took evening classes at the MATI which he completed in 1964. He became an experimenter engineer at the Control and Testing Station (KIS) for the UR-200, UR-100 and UR-500 rockets. In July 1965, he witnessed Proton's first launch. He was then in charge of rendering the UR-100 operational. On February 19, 1968, he was appointed as the factory's Deputy Director. Next, between 1972 and 1975, he was called in to the Ministry (MOM) where he held the position of Deputy Head of the First Directorate (glavka). Here, he looked after the production of rockets and submarine launched missiles (designers Chelomey, Yangel, Reshetnev, Makeyev). Finally, at 37 years old, he returned to the factory that he would run for 26 years. To be able to market the Proton rocket in the West, the factory and the OKB were brought together in the Khrunichev State Research and Production Space Center (GKNPTs). It was managed, successively, by A. I. Kiselev from 1993 to 2001, A. A. Medvedev between 2001 and 2005, V. E. Nesterov from 2005 to 2012, A. I. Selivestrov between 2012 and 2014, then by A. V. Kalinovsky. At the same time, in 1993, the marketing company formed of Lockheed, Khrunichev and Energiya was created: known as LKEI, it would later go on to become ILS. Kiselev was a member of the Council of Directors from 1993 to 2002. He was a Doctor of Technical Sciences, Professor, Hero of Socialist Labor in 1990, Lenin Prize recipient in 1978 and received the State Prize in 1996.

Figure 2.23. *A. A. Medvedev (source: rights reserved)*

A. A. Medvedev qualified from the MAI in 1975, and joined OKB Salyut where he went from being an engineer to Main Designer. In April 1995, he became the Deputy General Designer, then Managing Director on February 6, 2001. He was a Doctor of Technical Sciences, Professor and State Prize recipient in 1999.

Figure 2.24. *V. E. Nesterov (source: rights reserved)*

In 2005, he was replaced by V. E. Nesterov who qualified from the MAI in 1972 and served in the Army until 1996. He completed the Dzerjinsky Military Academy in 1978. From 1992 to 1999, he was Deputy Head of Directorate for launch vehicles and ground infrastructure at the Russian Space Agency. He was Director from 2000 to 2005. On November 25, 2005, he was appointed Head of the Khrunichev Center. He received two State Prizes in 1997 and 2007.

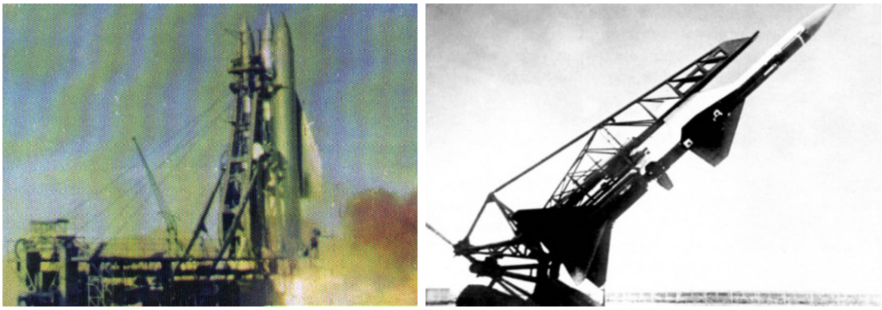
Figure 2.25. *A. I. Selivestrov (source: rights reserved)*

On September 5, 2012, following a failed launched of the Proton on August 6, Nesterov was replaced temporarily by the First Deputy V. N. Sychev. At the end of the selection process, the role of Managing Director was entrusted to A. I. Seliverstov on October 19. After graduating from the MATI in 1987, he joined Khrunichev's factory where he started as a technical engineer and went on to become the factory's Director, and then Deputy Managing Director in 2008. From then on, the factory was headed by V. N. Sychev (First Deputy), Yu. O. Bakvalov (General Designer), V. A. Petrik (Factory Director), V. Ya. Ivanov (ZERKT Director), I. S. Dodin (Deputy), V. L. Ivanov (Deputy), V. N. Ivanov (Deputy), S. V. Anisimov (Deputy for External Affairs), A. I. Kuzin (Deputy for Matters of Strategy and Innovation), A. I. Kobzar (Deputy for quality control), G. M. Mitinsky (Deputy for Social Matters), E. M. Karachenkov (Deputy for Executives), A. I. Ostroverk (Deputy for the Economy), S. I. Antakov (Deputy for Safety), I. A. Glazkova (Director of Information Systems), G. M. Murakovsky (Director of the Poliot Factory), I. G. Panin (Director of KB KhimMach), I. T. Koptev (Director of the Voronej Engines Factory), P. V. Abramov (Director of the Ust-Katav Wagon Factory), Yu. L. Arzumanov (Director of KB Armatur), M. I. Makarov (Director of NII KS) and A. P. Petukov (Director of Khrunichev Telekom).

Figure 2.26. *A. V. Kalinovsky (source: rights reserved)*

On August 8, 2014, following the failed launch of the Proton on May 16, Selivestrov was replaced by A. V. Kalinovsky who qualified from the MVTU in 1986. He worked in the Ijevsk mechanics factory, then at RostSelMach between 2002 and 2007, became Director of the Novosibirsk aviation factory from 2007 to 2013, and led the production of the Superjet 100 from Sukhoi to Komsmolsk-sur-Amour from May 2011. On March 13, 2015, Bakvalov left Khrunichev's facility. He was replaced by A. A. Medvedev who then left his position as Vice President of the aviation company Irkut.

2.4. Lavochkin's OKB-301



a) b)

Figure 2.27. *a) The La-350 Burya missile and b) the La-400 DAL missile (source: rights reserved)*

Established following the decree of September 1, 1939, this design bureau developed a series of fighter planes made famous during the Second World War: LaGG-3 (6,645 units), La-5 (10,002 units) and La-7 (5,905 units). After the war, S. A. Lavochkin, Main Designer of OKB-301, developed jet planes. But in 1950, he started looking after the first Soviet ground-to-air missiles. This is how he came to make the V-300 missile for the S-25 Berkut system, which was deployed around Moscow. He then received the Hero of Socialist Labor medal in 1956. The same year, he became General Designer. He led several developments at the same time: the target-vehicle La-17, the La-250 Anaconda with the air-to-air K-15 system, the La-350 Burya cruise missile and the ground-to-air missiles. In 1958, he was elected as Corresponding Member of the Academy of Sciences. His final design was the DAL system La-400 missile. But he died of a heart attack during flight tests in Sary-Shagan on June 9, 1960.

Figure 2.28. *M. M. Pashinin (source: rights reserved)*

By 1959, the La-250 had already been abandoned. In February 1960, the La-350 followed suit. Lavochkin's successor, his First Deputy M. M. Pashinin, pursued developments on the La-400 missile. But this was unsuccessful and the program was abandoned after 77 launches. The other Deputy, N. S. Cherniakov, who led the La-350 program and some of its team, went to work with Chelomey. But Cherniakov only stayed with Chelomey for a year before going to work at Sukhoi where he made the T-4 plane (or aircraft 100).

Finally, on December 18, 1962, the OKB and the factory became subsidiary no. 3 of OKB-52. Head of the subsidiary was A. I. Eidis, Chelomey's Deputy. The company was dedicated to producing the P-5, P-35 and P-35B Navy missiles, the Ametist and the P-25, as well as developing the DAL-M (object 420) and DAL-2 (object 500) projects. Three years later, on March 2, 1965, the company took back its independence. It was handed over to G. N. Babakin who became the Main Designer of the interplanetary probes Luna, Venera and Mars, as well as the Block-L upper stage (work of Korolev's OKB that was transferred to Podlipki in Khimki). Korolev died on January 14, 1966 and the Luna-9 probe softly landed on the Moon on February 3: it was Babakin's first success to receive, on this occasion, the Lenin Prize in 1966. He became a Doctor of Technical Sciences in 1968, a Corresponding Member of the Academy of Sciences in 1970 and a Hero of Socialist Labor in 1970 for Luna-17. He died on August 3, 1971. His successors were S. S. Kriukov from 1971 to 1977, V. M. Kovtunenko from 1977 to 1995, V. A. Serebrenikov (temporary) between 1995 and 1996, S. D. Kulikov from 1997 to 2003, K. M. Pitchkhadze from 2003 to 2005, G. M. Poleschuk from 2005 to 2010, then lastly V. V. Khartov. The factory of OKB-301 was led successively by I. N. Lukin between 1954 and 1970, A. P. Milovanov from 1970 to 1987, A. M. Baklunov from 1987 to 1996, then V. N. Poletsky.

2.5. Factory no. 292 in Saratov

Established in 1939, factory no. 292 produced Yakovlev's aircraft from 1940 (13,000 Yak-1 and Yak-3 during World War Two). After the war, the factory produced jet planes. In particular, it produced the Yak-24, Yak-25 (1954–1955), Yak-25M (1955–1957), Yak-25R (1957), Yak-27 (1957), Yak-27V (1958), Yak-27R (1958–1962), Yak-36, Yak-38 (1974–1988), Yak-40 (1,011 units between 1968 and 1981), Yak-42, Yak-141, etc. From 1957, it produced sea-to-sea missiles from Chelomey's OKB-52: P-5, P-5D, P-6, P-35 Redut, P-35B Progress and P-500 Bazalt. From 1958, it produced the ground-to-air missile 11D (S-75 system) from Gruchin's OKB-2. Lastly, it produced the air-to-ground 112E/X-58 missile by MKB Raduga.

Figure 2.29. *N. S. Denisov (source: rights reserved)*

The Directors were I. S. Levin from 1940 to 1950, A. I. Chibaiv from 1950 to 1955, B. A. Dubovikov from 1955 to 1957, N. S. Denisov from 1957 to 1979 (Hero of Socialist Labor in 1971), A. I. Krivokhijin between 1979 and 1985, V. G. Konyashko from 1985 to 1987, A.V. Ermichin between 1988 and 2006, then O. V. Fomin in 2007. The factory filed for bankruptcy in 2010.

2.6. Factory no. 47 in Orenburg

Figure 2.30. *L. A. Guskov and D. A. Tarakov (source: rights reserved)*

Established in 1928, factory no. 47 was originally an aircraft repair factory in Leningrad that was evacuated to Orenburg (Chkalov) in August 1941 where it remained. It produced the AIR, UT-1, UT-2, Yak-6, Che-2, Po-2, Il-10 and Mi-1 planes, then the La-17 target vehicles in 1952. It then went into the rocket industry: Korolev's R-11 in 1957, Mikoyan's KSS Sopka from 1957 to 1958, Yangel's R-12 in 1959, Chelomey's UR-100 in 1964 and Chelomey's Navy missiles from 1969 (P-120, P-500, P-700, P-1000, Yakhont/Brahmos). In addition, it produced blocks for the interplanetary probes by NPO Lavochkin (E-8, M69, NM) from 1968 to 1969. A subsidiary of OKB-52 was opened in 1972. The factory became PO Strela in 1986, then became part of the NPO Machinostroenie holding in 2004. The Managing Directors were M. G. Anisimov from 1947 to 1955, L. A. Guskov between 1955 and 1972 (Hero of Socialist Labor in 1961), V. S. Sizov from 1972 to 1975, D. A. Tarakov between 1976 and 2001 (Hero of Socialist Labor in 1983), S. I. Grachev from 2001 to 2003, then A. M. Markman in 2003.

2.7. The engine designers

Figure 2.31. *V. G. Stepanov (source: rights reserved)*

Chelomey started working with S. K. Tumanksky (OKB-300) on Navy missiles, then with S. A. Kosberg (OKB-154) for the UR-200 because V. P. Glushko was occupied with Korolev. Next, he called upon Glushko (OKB-456) for the UR-500 and S. P. Izotov (OKB-117) for the UR-100.

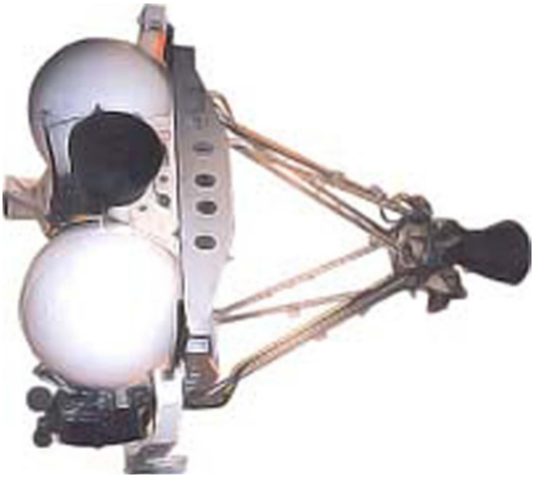


Figure 2.32. *5D18 engine from the IS satellite (source: rights reserved)*

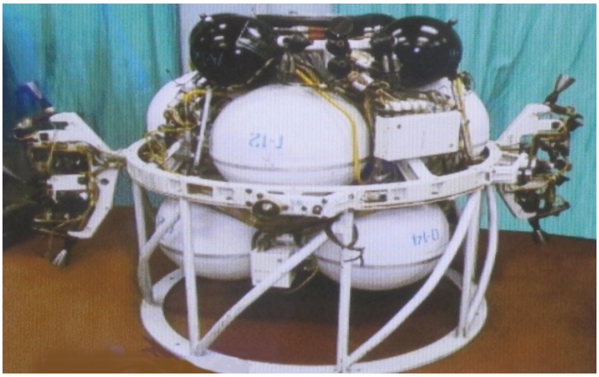


Figure 2.33. *The 4E18 engine from the US satellite (source: rights reserved). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

S. K. Tumansky had been building aviation engines since 1931. He was Deputy to A. A. Mikulin at OKB-300 (AMNTK Soyuz in Tushino) in 1943. He then replaced Mikulin and became General Designer in 1956. He then made the KR-15-300 ramjet for Tupolev's Tu-121 winged vehicle (first flight in 1959), then Yastreb's Tu-123 (first flight in 1960). At the same time, he designed the KR-7-300 for Chelomey. He then started to make rocket engines: first, the R201-300 for the X-22 missile and the R209-300 for Berezniak's KRM target vehicle. Next, he developed the R203-300 engines for the US (4E18) satellites and R204-300 for Chelomey's IS (5D18/5D26) satellites. On August 1, 1964, he created a subsidiary in Turayevo, near Lytkarino (a region of Moscow), to make low-thrust engines for satellite orientation and stabilization systems. OKB-4-300, which later became the TMKB Soyuz, was led successively by V. G. Stepanov (1964–1983), D. D. Guilevitch (1983–1991), V. G. Komisarov (1991–2004), Yu. T. Rudnev (2004–2009) and N. N. Yakovlev (2009–2010). In particular, it designed the 210A (KD-1-300) with 0.6 kg thrust, the 210B (KD-2-300) with 10 kg, 210V (lunar module) and 210D with 1.3 kg, and the 210E with 16.5 kg thrust.

In early 1960, Tumansky and his Deputy for science, G. L. Livchitz, started working on a nuclear generator (TEU-5 Topol, alias Topaz-1) for the electric propulsion of space vehicles in cooperation with O. N. Favorsky of TsIAM (who would later succeed Tumansky between 1973 and 1987). In 1968, the work was handed over to the TMKB. On November 28, 1972, this part of the TMKB was transferred to the new NPO Krasnaya Zvezda, which was formed by joining the MKB Krasnaya Zvezda (former OKB-670 in Bondariuk) and D. D. Sevruk's OKB Zarya. The NPO would be led successively by G. M. Griaznov (1973–1997), then V. S. Vasilkovsky (as of 1997).

Since its creation, OKB-300 has worked with a series of companies: OKB-500 "Soyuz" in Tushino, OKB-16 "Soyuz" in Kazan, OKB-26 "Motor" in Ufa, OKB "Soyuz" in Turayevo and NPO Krasnaya Zvezda.

V. Ya. Klimov had also built aircraft engines since 1931. He created the OKB of factory no. 117 in Leningrad in 1946. He became General Designer in 1956. He worked with factory no. 466 Krasny Oktyabr in Leningrad. From 1958, the aforementioned was in charge of mass producing A. M. Isayev's liquid propellant engines (S2.711 and S2.720 of the ground-to-air missile V-750, and S2.726 of the ABM V-1000 missile). He was equipped with an independent OKB, managed by A. S. Mevius, which designed liquid-propellant rocket engines (5D12 and 5D67 for the ground-to-air missile V-860/V-880, and 5D16 for the ABM A-350 missile).

Figure 2.34. *A. S. Mevius and S. P. Izotov (source: rights reserved)*

In December 1962, OKB-117 and 466 were merged and, two months later, Mevius's team was transferred to the OKB run by Klimov, who retired in 1960. He was replaced by S. P. Izotov, while P. D. Gavra succeeded Mevius in January 1968. He started by designing the 5D18 and 5D22 (R5-117) engines for the ABM A-350 missile of the Moscow A-35 system. Between 1960 and 1963, he made the R1-117 engines for the third stage of the UR-200A, and the R2-117 for Chelomey's UR-500 warhead.

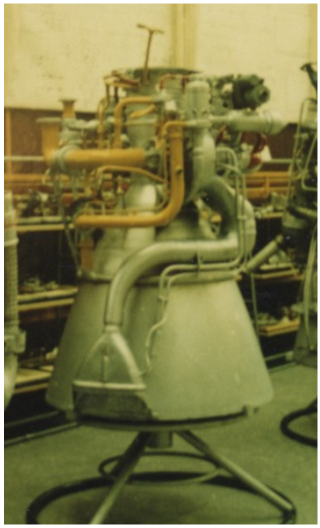
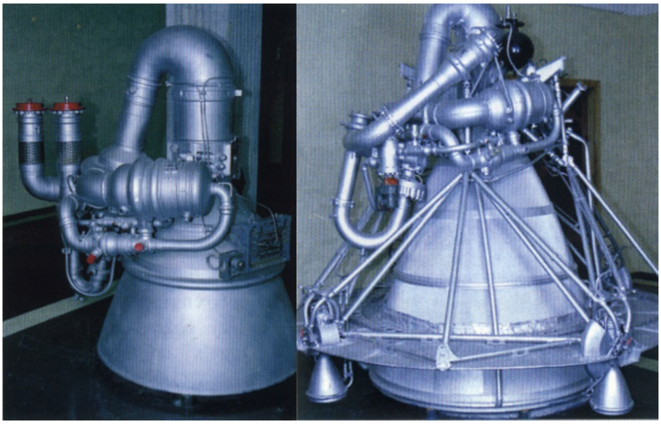


Figure 2.35. *The 15D13 engine (source: rights reserved)*

Then in 1963, he made the 15D13/15D14 (13.4-ton thrust) engine for the second stage of Chelomey's UR-100 missiles. Factories no. 466 (Leningrad), no. 29 (Omsk) and no. 47 (Orenburg) were in charge of mass production. This engine was also meant to equip the LK-1 lunar vehicle designed by Chelomey between 1964 and 1965. Izotov received the Hero of Socialist Labor medal for this work in 1969. Lastly, the company made the engines for Gruchin's ABM 5Ya27/V-825 and 51T6/A-925 missiles, as well as the 5D21M engine for the spaceplane from Mikoyan's Spiral program. The company was led by V. G. Stepanov from 1983 to 1988, A. A. Sarkisov between 1988 and 2003, V. Chirmanov and then A. V. Grigoriev.

Figure 2.36. *S. A. Kosberg, A. D. Konopatov and V. S. Ratchuk (source: rights reserved)*

S. A. Kosberg had led KB Khimavtomatiki since October 13, 1941. At the time, it was the OKB of factory no. 296 Imeni Dzejinsky in Berdsk, in the region of Novosibirsk. In April 1946, it was transferred to Voronej where it became the OKB of factory no. 154. It produced injectors, pumps, regulation aggregates and start systems. He started to design rocket engines in 1954 (D-154, D-7 SK-1/RD-0101, SK-1K/RD-0102, SK-2/RD-0103, R1-154/RD-0200, RD-0201). On February 20, 1958, Korolev asked him to make the engine for the third stage (Block-E) of the R-7. It was completed within 9 months with the help of OKB-1 (M. V. Melnikov). It was an engine with 5-ton thrust, 316 s of specific impulse and 45.9 atm pressure in the chamber. Kosberg became Doctor of Technical Sciences in 1959, received the Lenin Prize in 1960 and the Hero of Socialist Labor medal in 1961.



a) b)

Figure 2.37. *a) The RD-0203 engine and b) the RD-0205 engine (source: rights reserved)*

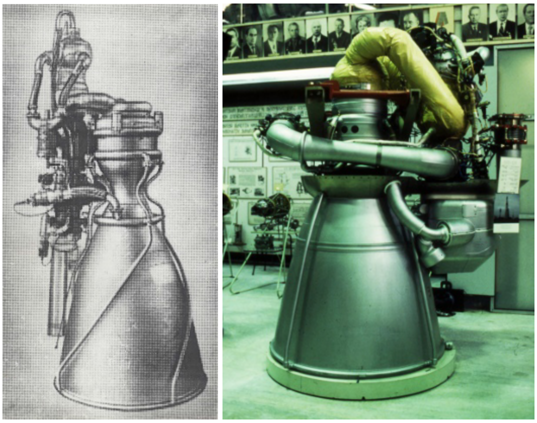
Between 1961 and 1963, he completed the RD-0202 to 0207 engines for Chelomey's UR-200. They were some of world's first integrated flow engines. The RD-0202 included four chambers with 57-ton thrust (3 × RD-0203 + 1 × RD-0204). The chamber pressure was 144 atm. The RD-0205 of the second stage was a single chamber (RD-0206 + verniers RD-0207). He then made the engines for the UR-500 (Proton) second stage from 1962 to 1965. Derived from the UR-200, it had four chambers with a thrust of 60 tons (3 × RD-0208 + 1 × RD-0209). For the 1967 four-stage UR-500K version, the second stage engines became RD-0210 and RD-0211, while the third stage was equipped with a RD-0212 (RD-0213 + verniers RD-0214), which also had a thrust of 60 tons. Mass production was entrusted to factory no. 154 in Voronej (VMZ).

Lastly, he designed the four engines (3 × RD-0216 + 1 × RD-0217) with 22.3-ton thrust in a vacuum for the first stage of the UR-100 between 1963 and 1965. The chamber pressure was 150 atm. The steering of the chamber was ensured by a hydraulic transmission designed by OKB-279 "Rubin" (designer I. I. Zverev). The no. 19 factory in Perm (later Perm Motor) was in charge of mass production.

But on December 28, 1964, he had a car accident and died from injuries on January 3, 1965. He was replaced by A. D. Konopatov from 1965 to 1993. From 1969 to 1974, he designed the four engines (3 × RD-0233 + 1 × RD-0234) with 52-ton thrust in a vacuum for the first stage of the UR-100N (SS-19, Rockot, Strela), but also the engine of the second stage (RD-0235 + verniers RD-0236) with 24-ton thrust, as well as the RD-0237 engine for the warhead's bus. Its mass production was entrusted to factory no. 19 in Perm (RD-0233/0234), factory no. 466 in Leningrad (RD-0235/RD-0236), the factory in Ust-Katav (RD-0237), factory no. 154 in Voronej (RD-0235 chamber) and factory no. 26 in Ufa (RD-0236 chamber). Konopatov received the Hero of Socialist Labor medal in 1966, the State Prize in 1970 and the Lenin Prize in 1976. He was succeeded by V. S. Ratschuk in 1993. Today, KB KhimAvtomatiki designs the RD-0124 and RD-0124A engines for the Soyuz-2.1b, Soyuz-2.1v and Angara launch vehicles, the RD-0110R for the Soyuz-2.1v, RD-0146 and RD-0146D for Angara and Rus-M. The VMZ, which has been producing rocket engines since 1958, was led by I. I. Abramov from 1957 to 1965 and 1969 to 1976, B. A. Chevela from 1965 to 1969, V. F. Solovyev between 1976 and 1981, G. V. Kostin from 1981 to 1993, A. I. Chasovskikh, A. V. Bondar, and then I. T. Koptev since 2010. On February 3, 2007, it was integrated into the Khrunichev Centre holding group.

Figure 2.38. *V. P. Glushko (source: rights reserved)*

Lastly, V. P. Glushko had been designing rocket engines since 1930. He worked at the GDL from 1929 to 1933 and at the RNII from 1933 to 1938 before being imprisoned from March 23, 1938 to July 27, 1944 (first at factory no. 82 in Tushino, then at factory no. 16 in Kazan). From July to December 1945 and from May to December 1946, he studied the V-2 in Germany. On July 3, 1946, he was appointed Main Designer of factory no. 456 (Khimki). Here, he produced the RD-100, RD-101, RD-103, RD-107 and RD-108 engines of Sergei Korolev's ballistic rockets. He received his first Hero of Socialist Labor medal for the R-5M in 1956, the Lenin Prize for Sputnik-1 in 1957 and his second Hero of Socialist Labor medal for Vostok-1 in 1961. Then, he stopped designing oxygen-kerosene rockets to focus on storable propellant engines (N_2O_4-UDMH). It was for this reason that he would work more with M. K. Yangel and V. N. Chelomey than with Korolev.



a) b)

Figure 2.39. *The RD-253 engine: a) initial version (source: rights reserved) and b) OKB-456 museum (source: Christian Lardier)*

On April 3, 1961, he proposed the RD-253 (11D43) and RD-254 (11D44) engines to Yangel, which had initially been designed for Korolev's N-1 (who would keep N. D. Kuznetsov's engines), to propel the two stages of the R-46 weighing 360–400 tons. These were engines of 150-ton thrust with integrated flow (the first to use this design was the S1-5400 in 1960, then the RD-0202, RD-253 and the NK-9 in 1961). With four RD-253 on the first stage, the thrust at lift-off was 600 tons. The R-46 could carry an atomic bomb with 100 megatons[1], or send 12 tons into low orbit (manned space station with spying and antisatellite capabilities). As a comparison, the Tsar-Bomb (202N) tested on October 30, 1961 had a 100 megaton capacity but had been restricted to 50 megatons.

1 "Alternativnaya Luna" in *Novosti Kosmonavtiki*, no. 7, pp. 72–73, 1999).

However, Yangel soon abandoned the R-46 for the R-56 (8K68). The decree for the R-56 was published on April 16, 1962. The first and second stages were bundles of four R-46, while the third stage was derived from the second stage of the R-46. The fourth stage was used to put the payload on a lunar trajectory. There were 16 RD-253 on the first stage, four RD-254 on the second and one RD-254 on the third stage. Finally, a monoblock version was authorized on May 22, 1963. It performed at 40 tons in low orbit or 12 tons toward the Moon. But the project was abandoned by the decree of June 19, 1964.

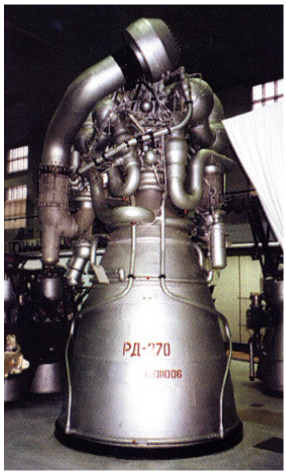


Figure 2.40. *The RD-270 (OKB-456 museum) (source: rights reserved)*

On June 26, 1962, decree no. 631-257 decided the RD-270 (8D420) engine with 600-ton thrust (255 atm in the chamber). Glushko immediately offered it to Yangel for the R-56: four engines could replace the 16 RD-253. But what he was unable to achieve with Yangel, Glushko would go on to do with Chelomey. Chelomey selected the RD-253 for the 540-ton UR-500, which could send 14 tons into low orbit. He then kept the RD-270 for the 4,800-ton UR-700, which was able to send 150 tons into low orbit or 50 tons toward the moon.

On March 30, 1964, Glushko wrote to Chelomey to offer him a UR-1000 launch vehicle, which had the same design as the UR-500 with eight RD-270 engines on the first stage (4,800-ton thrust at lift-off), an RD-270 on the second stage (660-ton thrust) and the third stage being a derivative of the UR-500's second stage. He also proposed that the first two stages be built in Dnipropetrovsk, while the third stage and the payload would be produced by OKB-52 and Khrunichev's factory. It would perform at 120 tons in low orbit compared to 75 tons by Korolev's N-1. On December 7, 1964, he wrote to the Central Committee to explain that the launch vehicle was more compact than the N-1 and used fewer engines. He also pointed out that a UR-700 equipped with a fluorine-ammonia third-stage (RD-305 with 50-ton thrust) could launch 150 tons into low orbit or 56 tons toward the Moon. In a letter to Chelomey on August 28, 1965, he denounced Korolev and Pilyugin's criticisms of the UR-500 during a VPK meeting (Military-Industrial Commission of the Council of Ministers). On October 16, 1965, Chelomey, Glushko, V. I. Kuznetsov and V. P. Barmin drew up a common proposal for the UR-700 instead of Korolev-s N-1 to send a man to the Moon. The UR-700, with a fourth-stage with four fluorine-ammonia engines (RD-301 with 10-ton thrust), could launch 46 tons into a direct flight to the Moon. An RD-305 version increased the performance to 50 tons. On December 12, 1966, a new letter was sent to the Central Committee. This time, it was signed by Chelomey (OKB-52), Glushko (OKB-456), A. D. Konopatov (OKB-154), S. P. Izotov (OKB-117), A. M. Isayev (OKB-2), V. Ya. Likhuchin (NII-1), V. A. Pukhov (NII KhimMach), V. I. Kuznetsov (NII-944), V. G. Sergeyev (OKB-692) and V. P. Barmin (KBOM). They self-appointed themselves as the lawyers of the UR-700 and the LK-700 spacecraft in order to send two cosmonauts to the Moon. The RD-253 and RD-270 ensured propulsion. The project received approval from the expert committee in late 1968 for a moon landing at the end of 1969. The planned cost was 24 million rubles for the launching complex and 600 million for the launch vehicle.

These letters, published in 2008, allow us to better understand why Korolev and Glushko, after having worked together since the beginning of the 1930s, became rivals in the late 1960s. They also reveal that the other members of Korolev's Council of Chief Designers backed Chelomey over Korolev for the lunar program (with the exception of Pilyugin and Ryazansky).

On December 4, 1968, Glushko proposed a liquid oxygen RD-270 for Michin's NI-F launch vehicle: the launcher would have, then, 9–12 engines instead of 36.

Work on the RD-253, which started in 1961, was finally chosen for the UR-500 in April 1962. The first firings took place in November. In 1963, mass production was transferred to factory no. 19 in Perm (later Perm Motors). The first flight took place in July 1965. In 1967, the engine led to Glushko, M. R. Gnessin and R. A. Gemranov receiving the State Prize. With regard to the RD-270, a gas–gas engine (two prechambers that fueled the main combustion chamber), it was ground tested 27 times between October 1967 and July 1968.

Then on May 22, 1974, he became Director and General Designer of NPO Energiya, which grouped together OKB-1, OKB-456, their experimental factories and their subsidiaries. He first designed a series of RLA launch vehicles that responded to the decree of May 17, 1974: RLA-120 for sending 30 tons into low orbit, RLA-130 for launching a space shuttle and RLA-150 for 250 tons into low orbit. The latter was a bundle of six RLA-120. These projects developed into different variants. Then, decree no. 132-51 of February 17, 1976 decided on the creation of the Energiya–Buran system. This was a 2,400-ton vehicle (four boosters), which would send 100 tons into low orbit. But it also existed in two-booster versions (Energiya-M), as well as eight boosters (Vulcan). The latter weighed 4,747 tons and could send 200 tons into low orbit, 36 tons into geostationary orbit (Vesuvius upper stage), 43 tons into orbit around the Moon or 52 tons toward Mars.

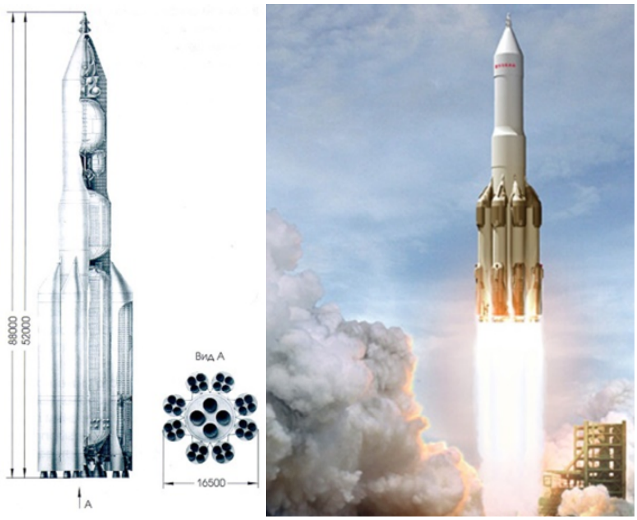


Figure 2.41. *Vulcan project (source: rights reserved)*

However, only Energiya and Buran would fly. Energiya, on May 15, 1987, launched the prototype of the space laser Skif-DM (17K19DM), designed by KB Salyut and Khrunichev’s factory. But the 77-ton vehicle dove straight into the Pacific. As for the Buran shuttle, it flew on November 15, 1988, without Glushko who had a heart attack on April 8. He celebrated his 80th birthday on August 20 and died on January 10, 1989.

3

Intercontinental Missiles, Booster Rockets and Satellites

In May 1959, Chelomey began to take an interest in long-range ground-to-air missiles like the American Bomarc. This program had been decided on by a decree from June 4, 1958 and the designer Mikoyan then got involved in the development of the R-500 missile with an RD-085 ramjet from Bondaryuk. Chelomey subsequently got in touch with the designers A. A. Raspletin and G. V. Kissunko, who created the guidance systems for Mikoyan, Lavochkin and Grushin's missiles, as well as M. M. Bondaryuk (ramjet), L. S. Dushkin (ramjet-rocket) and N. D. Kuznetsov (liquid-fuel rocket engine) for propulsion. He then studied the 6.8-ton DD-400, with a range of 400 km. He quickly moved on to the 9.0-ton DD-600 with a range of 600 km, then to the DD-B with vertical liftoff capable of gliding at an altitude of 40 km. The program was abandoned, however, in early 1961.

In July, Chelomey studied a long-range ballistic cruise missile: the KBR-12000. This was a vehicle like the antipodal bomber from Sänger. The three-stage suborbital version flew at Mach 22 and the four-stage orbital version, or Raketoplan, at Mach 28. The 120-ton Raketoplan was propelled by liquid-fuel rocket engines.

In September, two design bureaus studied the S-500 ground-to-air system: Mikoyan (7- to 8-ton liquid-fuel RM-500 rocket) and Chelomey (solid-fuel RTch-500 rocket). In December, the program planned combined tests during the second quarter of 1964, but the solid-fuel motor posed a problem and the project reached an impasse: it was finally abandoned.

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

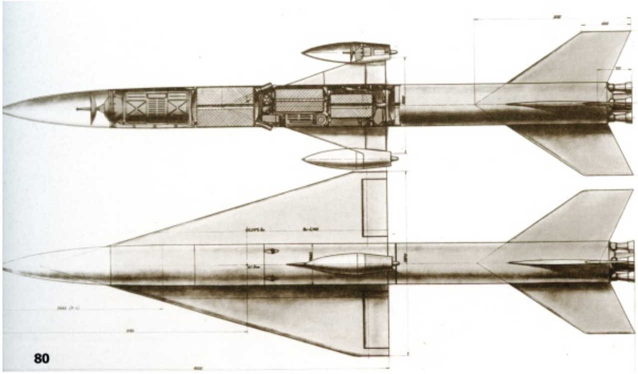


Figure 3.1. *The RTch-500 ground-to-air missile (source: NPO Mash)*

Although Korolev was pragmatic, Chelomey was a creator of sometimes fantastic ideas. In August 1958, he submitted the "ballistic cruise missile" (KBR) project as an invention. In December 1959, he evoked the idea of a spy satellite capable of being propelled by an electronuclear ramjet (EYaRD). In June 1960, he sent patent requests for the "guided ballistic rocket for launch from a submarine", "guided ballistic rocket" and "cosmic vessel" projects.

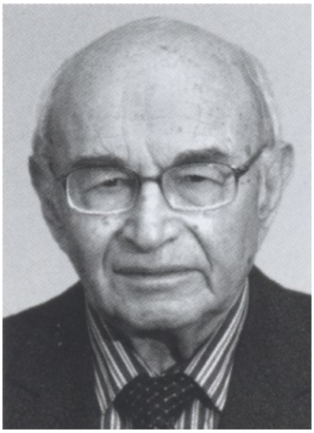


Figure 3.2. *V. A. Polyachenko (source: NPO Mash)*

On February 21, 1960, sector no. 10 (design) was divided into two sections: section A of V. A. Polyachenko for space matters and section B of G. A. Efremov for naval missiles.

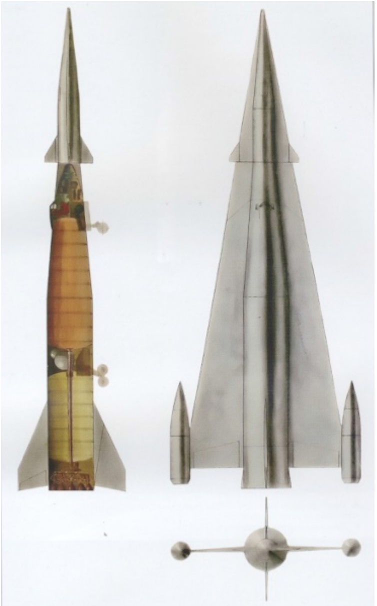
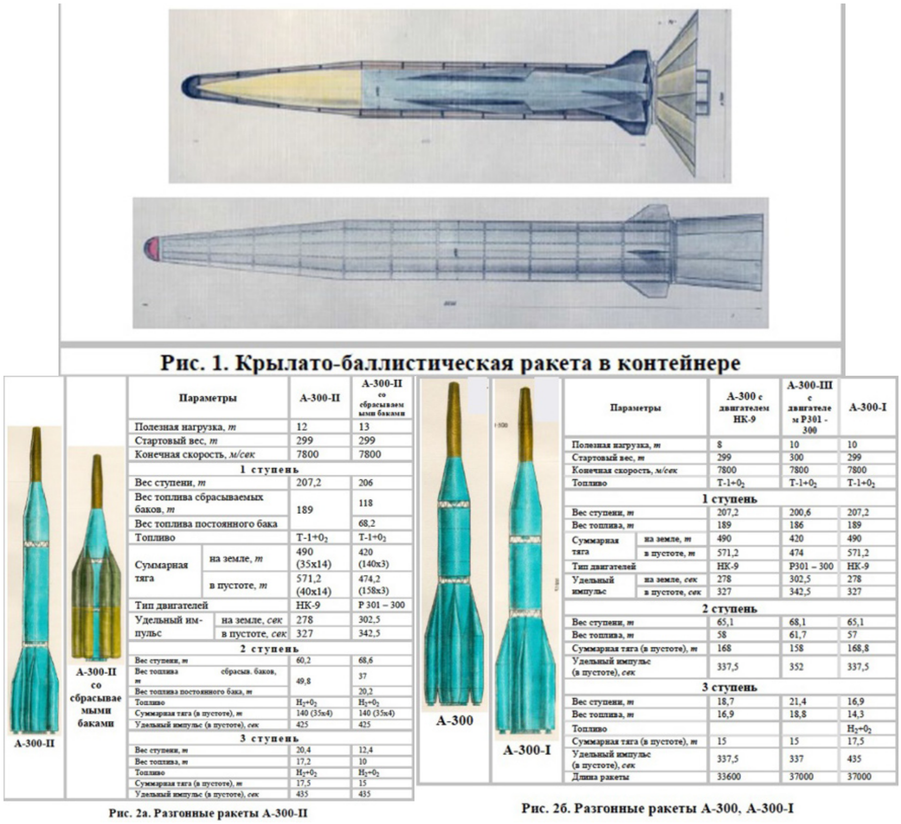


Figure 3.3. *The ballistic cruise missile (source: NPO Mash)*

For the ballistic cruise missile, Chelomey replaced the solid-fuel engines with liquid-fuel engines and the wings went over the payload (Raketoplan). The rocket had several versions ranging from 150 to 1,500-ton at liftoff. In April, section A elaborated the A-300 (8.0 tons of payload), A-300-1 (10.0 tons of payload), A-300-2 (12.0 tons of payload), A-600 (17.0 tons of payload), A-600-2 (25.0 tons of payload), and A-1700 and A-2000 (85.0 tons of payload) rocket projects. Each number indicates the mass at liftoff. They had three or four stages. The first stage was propelled by engines from N. D. Kuznetsov and S. K. Tumansky. For the second stage, he proposed a cryogenic engine from A. M. Lyulka. On May 14, he presented the ministry with his plans for the Kosmoplan, the Raketoplan, the US-guided satellite and the UB-200 guided warhead (destruction of naval targets). On May 21, the propositions were submitted to the scientific-technological committee in the presence of general and main designers. The Kosmoplan was an interplanetary vehicle. It was equipped with a plasma engine to go to Mars or Venus, and then performed a winged return to Earth. As for the Raketoplan, it was a circumterrestrial vehicle. It existed in piloted, unpiloted and interceptor versions. The ballistic missile was meant to destroy terrestrial or maritime targets. The US satellite was meant to guide the naval missiles to their target. Chelomey also mentioned man’s flight into space.



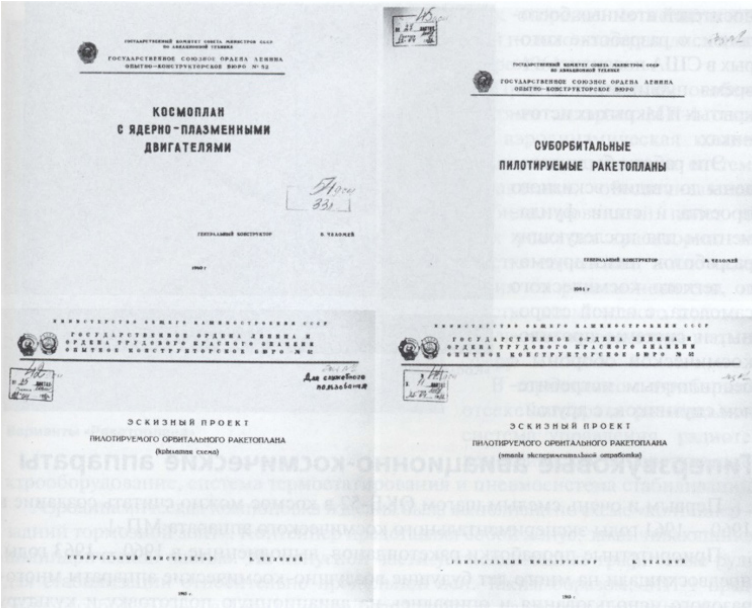
Параметры		А-300-II	А-300-II со сбрасываемыми баками
Полезная нагрузка, *т*		12	13
Стартовый вес, *т*		299	299
Конечная скорость, *м/сек*		7800	7800
1 ступень			
Вес ступени, *т*		207,2	206
Вес топлива сбрасываемых баков, *т*		189	118
Вес топлива постоянного бака			68,2
Топливо		Т-1+0_2	Т-1+0_2
Суммарная тяга	на земле, *т*	490 (35x14)	420 (140x3)
	в пустоте, *т*	571,2 (40x14)	474,2 (158x3)
Тип двигателей		НК-9	Р 301 – 300
Удельный импульс	на земле, *сек*	278	302,5
	в пустоте, *сек*	327	342,5
2 ступень			
Вес ступени, *т*		60,2	68,6
Вес топлива сбрасыв. баков, *т*		49,8	37
Вес топлива постоянного бака, *т*			20,2
Топливо		H_2+0_2	H_2+0_2
Суммарная тяга (в пустоте), *т*		140 (35x4)	140 (35x4)
Удельный импульс (в пустоте), *сек*		425	425
3 ступень			
Вес ступени, *т*		20,4	12,4
Вес топлива, *т*		17,2	10
Топливо		H_2+0_2	H_2+0_2
Суммарная тяга (в пустоте), *т*		17,5	15
Удельный импульс (в пустоте), *сек*		435	435

Параметры		А-300 с двигателем НК-9	А-300-III с двигателем Р301 - 300	А-300-I
Полезная нагрузка, *т*		8	10	10
Стартовый вес, *т*		299	300	299
Конечная скорость, *м/сек*		7800	7800	7800
Топливо		Т-1+0_2	Т-1+0_2	Т-1+0_2
1 ступень				
Вес ступени, *т*		207,2	200,6	207,2
Вес топлива, *т*		189	186	189
Суммарная тяга	на земле, *т*	490	420	490
	в пустоте, *т*	571,2	474	571,2
Тип двигателей		НК-9	Р301 – 300	НК-9
Удельный импульс	на земле, *сек*	278	302,5	278
	в пустоте, *сек*	327	342,5	327
2 ступень				
Вес ступени, *т*		65,1	68,1	65,1
Вес топлива, *т*		58	61,7	57
Суммарная тяга (в пустоте), *т*		168	158	168,8
Удельный импульс (в пустоте), *сек*		337,5	352	337,5
3 ступень				
Вес ступени, *т*		18,7	21,4	16,9
Вес топлива, *т*		16,9	18,8	14,3
Топливо				H_2+0_2
Суммарная тяга (в пустоте), *т*		15	15	17,5
Удельный импульс (в пустоте), *сек*		337,5	337	435
Длина ракеты		33600	37000	37000

Figure 3.4. *The 1960 A-300 launcher project (source: NPO Mash). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

Kuznetsov presented the propulsion bay with 10 NK-9 for the A-300, while Lyulka presented its cryogenic engine and Bondaryuk its nuclear engine. The first and second stages were to be made by the aircraft designer V. M. Myassishchev, the third and fourth stages by P. O. Sukhoy[1].

1 P. O. Sukhoy's OKB had been opened in 1953. It is said to have studied a cruise missile called the Burel and to be a competitor to Mikoyan for the Spiral project (or 50/50). Then, it was involved in Chelomey's first launcher projects, the V-1100 missile of the A-35 anti-missile system, the air-to-air K-9-51 missile for the T-37 fighter jet and the X-30 air-to-ground missile for the T-4 aircraft (or 100 aircraft).


ГОСУДАРСТВЕННОЕ СОЮЗНОЕ ОРДЕНА ЛЕНИНА
ОПЫТНО-КОНСТРУКТОРСКОЕ БЮРО № 52

КОСМОПЛАН
С ЯДЕРНО-ПЛАЗМЕННЫМИ
ДВИГАТЕЛЯМИ

ГОСУДАРСТВЕННОЕ СОЮЗНОЕ ОРДЕНА ЛЕНИНА
ОПЫТНО-КОНСТРУКТОРСКОЕ БЮРО

СУБОРБИТАЛЬНЫЕ
ПИЛОТИРУЕМЫЕ РАКЕТОПЛАНЫ

Для служебного пользования

ЭСКИЗНЫЙ ПРОЕКТ
ПИЛОТИРУЕМОГО ОРБИТАЛЬНОГО РАКЕТОПЛАНА

ЭСКИЗНЫЙ ПРОЕКТ
ПИЛОТИРУЕМОГО ОРБИТАЛЬНОГО РАКЕТОПЛАНА

Figure 3.5. *The Raketoplan and Kosmoplan projects (source: NPO Mash)*

On May 24, the OKB had a meeting with the ministry of the radio industry for the satellite guidance system. There were representatives of the following institutions: NII-10 (Altaïr), NII-108 (TsNIRTI), NII-380 (NII Televidenie), NII-131 (Leninetz), NII-17 (NIIP Tikhomirov), NII-648 (NIITP), NII-33 (VNIIRA), NII-5 (MNIIPA) and SKB-567. Four groups were formed for the US satellite, the winged ICBM, the Kosmoplan and the Raketoplan. The next day, Chelomey received information on the United States' Dyna-Soar, which comforted his position. In June, he also met the NII-49 (NIIKP) and OKB-692 (Khartron).

3.1. Kosmoplan and Raketoplan

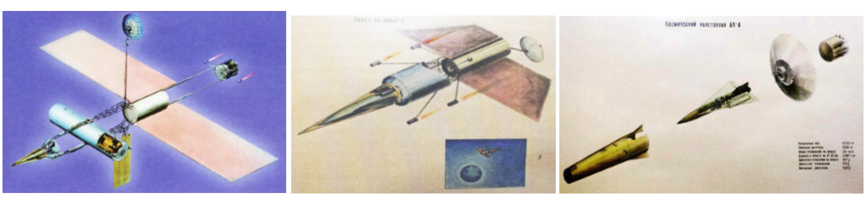
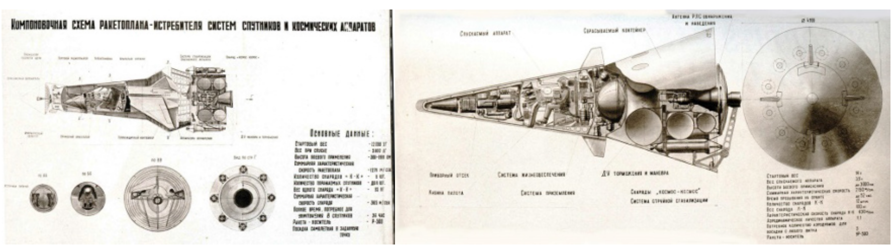


Figure 3.6. *The Kosmoplan project (source: NPO Mash). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

Figure 3.7. *The Raketoplan project (source: NPO Mash). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

In a letter sent on May 30, 1960 to the VPK and the ministry of the defense industry, Korolev mentioned the rockets weighing 300 tons and 600 tons at liftoff. Attached, it included a decree project on the space program. It proposed the development, by Chelomey, of a 600-ton launcher and an automatic Kosmoplan (object K) for missions to the Moon, Mars and Venus returning to an airfield in the period from 1965 to 1966, an ocean surveillance satellite (object US) to aid the P-6 naval missile in the period from 1962 to 1964, a Raketoplan spaceplane (object R) for orbital missions returning to an airfield in the period from 1960 to 1961 for the automatic version, 1963 to 1965 for the piloted version and 1962 to 1964 for the satellite-interceptor version (ASAT).



a) b)

Figure 3.8. *a) The hooded Raketoplan and b) the conic capsule (source: NPO Mash)*

On June 23, 1960, two decrees were made: no. 714-296 ("on the production of rockets, satellites and spaceships for the armed forces in 1960–1967"), which asked Chelomey for drafts of the UR-200, the IS (space interceptor) satellites and US (ocean surveillance) satellites, while no. 715-296 ("on the creation of powerful booster rockets, satellites and spaceships for the conquest of space in 1960–1967") asked Korolev for drafts of the N-1 and N-2 rocket for the TMK Martian spaceship.

In order to achieve success, Chelomey had to face the opposition of D. F. Ustinov, president of the VPK in 1957–1963. In fact, he had not liked Chelomey since their first encounter. Chelomey went through the defense sector of the Central Committee, headed by I. D. Serbin or directly by Khrushchev himself. When the latter was fired in October 1964, a special commission would take inventory of the portfolio of contracts that Chelomey had amassed since 1958 and a large part would be taken from him. From 1965 to 1976, Ustinov would be secretary of the CP for military-industrial affairs and Chelomey's projects would not end up being ordered (like the UR-700 lunar program). However, he would have the support of Minister of Defense A. A. Grechko for the development of his ICBM. The situation would once again turn when Ustinov succeeded Grechko from 1976 to 1984. He would ask his generals not to work with Chelomey. Some said, "Korolev works for the TASS agency, Yangel works for us, and Chelomey works for the toilet bowl".[2]

Let us return to August 3, 1960. During a meeting with representatives of the ministries, the council of designers decided: it would meet on October 11. The OKB-51 from Sukhoy and the OKB-23 from Myassishchev would make the first and second stages of a 600-ton rocket capable of being separated into 300-ton and 150-ton rockets. For the IS and US guidance systems, it would turn to the KB-1 from A. A. Raspletin (A. I. Savin's group) and the NII-17 (I. A. Brukhansky's group). On September 21, Chelomey proposed making tests on a Raketoplan model with R-12 and R-14 rockets from Yangel.

3.2. The UR-200

On October 3, the OKB-23 became a subsidiary of the OKB-52. The new main designer was V. N. Bugaisky, Chelomey's deputy. In January 1961, he was given the task to design the IS satellite launcher: it would be the UR-200. It was to provide a speed of 7.3–7.4 km/s, while the satellite was to be sent into orbit by producing another 400–500 m/s.

2 In KHRUSHCHEV S. N., *NIKITA KHROUCHTCHEV: Crisis and Rockets*, vol. I, 1994, p. 495.

Figure 3.9. *The UR-200 (source: Christian Lardier). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

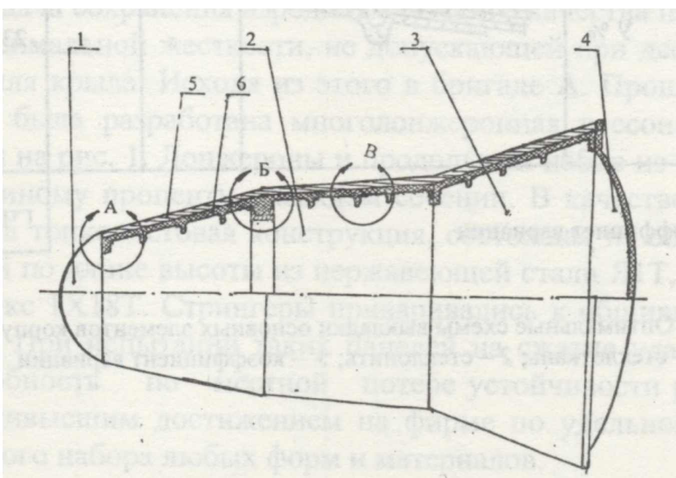


Figure 3.10. *The 8F144 warhead (source: "Scientific Technical developments of OKB-23-KB Saliut", vol. 1, 2006)*

Decrees no. 258-110 from March 16, 1961 and no. 689-288 from August 1, 1961 requested the development of the UR-200 (8K81) rocket in ICBM and space launcher versions. Chelomey entrusted this job to the OKB-23, the Khrunichev factory and the Vympel subsidiary. With a mass of 138 tons, it could launch a 3.9-ton payload. It measured 32 m high and had a diameter of 3 m. The first stage was propelled by an RD-0202 (8D45) engine. It included three RD-0203 and one RD-0204, the total thrust reaching 200 tons at liftoff. The second stage was equipped with an RD-0205 (8D46) including a primary RD-0206 engine and four RD-0207 steering engines. The thrust was 57.0 tons in vacuum. All these engines, developed by Kosberg, had an integrated flow cycle (chamber pressure of 144 atm). This schema had been developed at NII-1 in 1958 and the first to fly was Melnikov's S1-5400 (fourth stage of the R-7) in 1960. However, it used oxygen-kerosene, whereas the UR-200 engines used N_2O_4 (Russian name, amil) and UDMH (Russian name, heptil). The radio-corrected intertial guidance system was made by Pilyugin (NII-885). OKB Vympel was responsible for the launch installation, along with the Jdanov heavy machines factory (later AzovMash): an automatic chariot carried the rocket to the erector. It was verticalized and the pneumatic, electric and fueling connections were automated. The 327UV silo from TsKB-34 was unified for the UR-200 and Yangel's R-16 rocket.

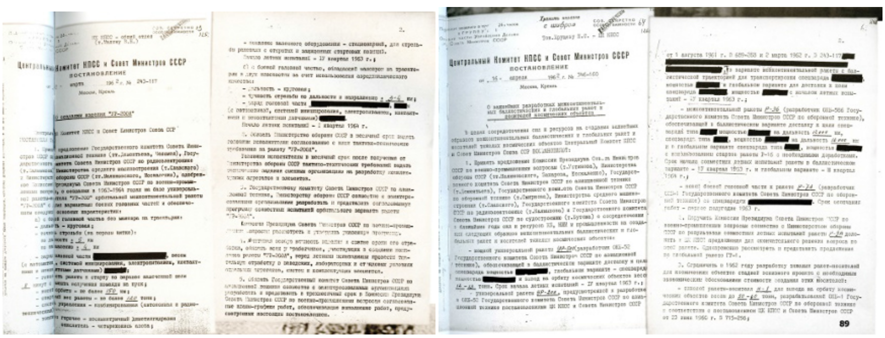


Figure 3.11. *The decrees from March 2 and April 16, 1962 (source: all rights reserved)*

Decree no. 243-117 from March 2, 1962 and decree no. 346-160 from April 16, 1962 asked for UR-200 (8K81), UR-200A (8K83), UR-200B (8K85), UR-200V (silo) and UR-200UV (silo) variants to be created. They were to launch the IS satellites (1.6 tons), US satellites (2.5 tons), 2.5-ton BB warheads over 12,000 km or 2.0-ton ones over 14,000 km and the maneuverable AB-200 warheads into a 150-km orbit (UR-200A global rocket). For the first time, the 8F114 warhead was in fiberglass (silicon material), whereas the others were made up of asbestos material. For this job, performed with the NII-88 (Kompozit), the VIAM and the NIAT, a State prize was awarded.

Figure 3.12. *The UR-200 launch (source: NPO Mash)*

In March 1962, however, the UR-200 not being ready on time, it was decided that the first IS and US launches would be made with Korolev's R-7. The 8K74 (R-7A) became the 11A59 to launch the IS, while the 8A92 (Vostok-2) became the 11A510 to launch the US.

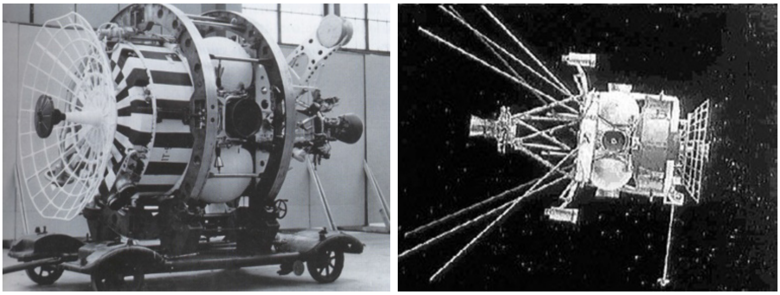


Figure 3.13. *The IS a.k.a. Polyot satellite (source: NPO Mash)*

On August 11, 1962, a decree entrusted the production of the UR-200 to factory no. 23, which inaugurated its activity in the rocket-space domain. In Baikonur, unit 44108 was formed in August 1963 (area no. 90). The first UR-200 and IS satellite models (the IS being renamed Polyot, which means flight) arrived in September. The state commission for the UR-200 was headed by General A. I. Sokolov. The first launch took place on November 4, but one of the four engines on the first stage failed to ignite and the rocket later crashed. The second launch on April 11, 1964 was also a failure. The first success would come on May 15. Six more launches took place on May 30, June 17, August 1, September 24, October 2 and October 20. The launch on September 24, 1964 took place during the Kedr operation in the presence of Khrushchev.

On August 3, 1964, decree no. 655-268 ordered 10 UR-200 for atmospheric reentry tests in 1965–1966 and four more rockets to launch the scientific Plasma satellites (to study phenomena linked to solar activity and radiation in circumterrestrial space) and GFS (geophysical satellite N-2) in 1966, but the program was stopped by decree no. 532-205 from July 7, 1965.

The IS satellite, created for the fourth directorate of the Ministry of Defense (4 GUMO), could intercept targets from altitudes of 120–1,000 km. It was made up of a container (thermic regulation of the OKB-124) with a radar in the front (KB-1) and an engine installation behind (OKB-300 and OKB-2). The destruction of the target was ensured by a fragmentation weapon. The orientation and stabilization system, as well as the on-board guidance system, were developed by P. M. Kirillov's OKB-36 (KB-1). The OKB-300's engine installation included five engines (one primary and four lateral) with 600 kg of thrust, six 16-kg bipropellant engines and six more with 1 kg of thrust. Likewise, the OKB-2 developed an engine installation with 400 kg of thrust. The propellants were separated in the reserves by a metallic diaphragm. Feed into the engines was ensured by pressurization.

Figure 3.14. *Tyulpan (source: Christian Lardier)*

In late 1962, two models were built: the I-1B with OKB-300 engines (no. 111 for tests, no. 112 and 113 for flight) and the I-2B with OKB-2 engines (no. 101 for tests, no. 102 and 103 for flight). However, the OKB-300 engines were not ready on time. The I-2B no. 102 arrived in Baikonur in the fall of 1963. The president of the State

Commission was General A. G. Zakharov (director of the cosmodrome). On November 1, it was launched by the R-7 (11A59) rocket and became Polyot-1 (1.95 tons). It made the first orbital maneuvers of a Soviet spacecraft (altitude of 339/592 km brought to 343/1,437 km, 60º inclination reduced to 59º). Next, the I-1B no. 112 was launched on April 12, 1964 (altitude of 242/485 km brought to 310/500 km, 60° inclination reduced to 58°).

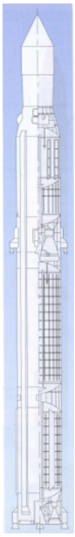


Figure 3.15. *The 11K67 (source: NPO Yuzhnoye)*

The decree from August 24 1964 modified the organization: project management was assigned to the KB-1 (main designer A. I. Savin). It turned out that the UR-200 could not ensure launches for the overly heavy IS and US. In December, it was decided to continue the program with Yangel's R-36 launcher (180 tons instead of 138 tons for the UR-200). The I-2M targets were derived from the interceptor. They had no guidance system nor military load, but an inflatable envelope with a reflective surface, like the American Echo, developed by V. P. Grigoryev from the OKB-424, which made balloons in Dolgoprudny. Zone 90s launch platform was transformed for the R-36 (11K67 version, aka Cyclone-2A). The first launch took place on October 27, 1967 (Cosmos-185). The president of the State Commission was General M. G. Mymrin. The I-2BM no. 104 satellite (target variant) was placed in orbit to test the OKB-300's engine installation. On April 24, 1968, the I-2M target was launched (Cosmos-217), but the satellite did not separate from the launcher. The launch of the I-2P (5V91) interceptor was cancelled. This operation was repeated in October: Cosmos-248 (target) was intercepted by Cosmos-249 in the second orbit, but it was not destroyed. Cosmos-249 then self-destructed. However, Cosmos-252 would manage to destroy it on November 1. Then, the 11K69 Cyclone-2 started its flight tests: the first two launches on August 6 (Cosmos-291) and December 23, 1969 (Cosmos-316), with I-2M targets, were failures, but in October 1970, the October 1968 operation was repeated with success (Cosmos-373, Cosmos-374 and Cosmos-375).

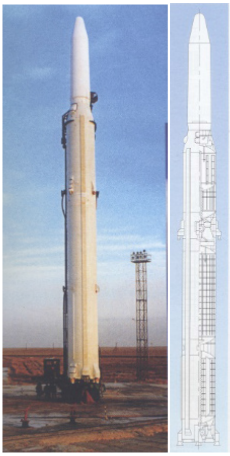


Figure 3.16. *The 11K69 Cyclone-2 (source: NPO Yuzhnoye)*

Yangel was then asked to make targets derived from its small calibration satellite: this was the 645-kg DS-P1-M (11F631, Tyulpan, Lira complex), launched by the Cosmos 11K65M rocket. The first, on December 23, 1970, did not reach orbit. The first successful launch came in February 1971 (Cosmos-394). The target was destroyed by Cosmos-397. Other interceptions were performed in March 1971 (Cosmos-400 and 404), November 1971 (Cosmos-459 and 462) and September 1972 (failure of the Cosmos-521). On February 13, 1973, the system was put into experimental use. The intercepter was then improved: the IS-M (4Ya11) was equipped with a new guidance system. New tests were performed in February–April 1976 (Cosmos-803, 804 and 814), July 1976 (Cosmos-839 and 843), December 1976 (Cosmos-880 and 886 equipped with an infrared autopilot), May–June 1977 (Cosmos-909, 910 and 918), October 1977 (Cosmos-959 and 961) and December 1977–May 1978 (Cosmos-967, 970 and 1009). On June 1, 1979, the system was declared to be operational. Following this, there would be three more tests in April 1980 (Cosmos-1171 and 1174), January–March 1981 (Cosmos-1241, 1243 and 1258) and June 1982 (Cosmos-1375 and 1379). The last of these was part of the Chit-82 maneuvers. On August 18, 1984, however, Yuri Andropov stopped these anti-satellite trials. The IS-MU (14F10) was, nevertheless, declared operational in 1991.

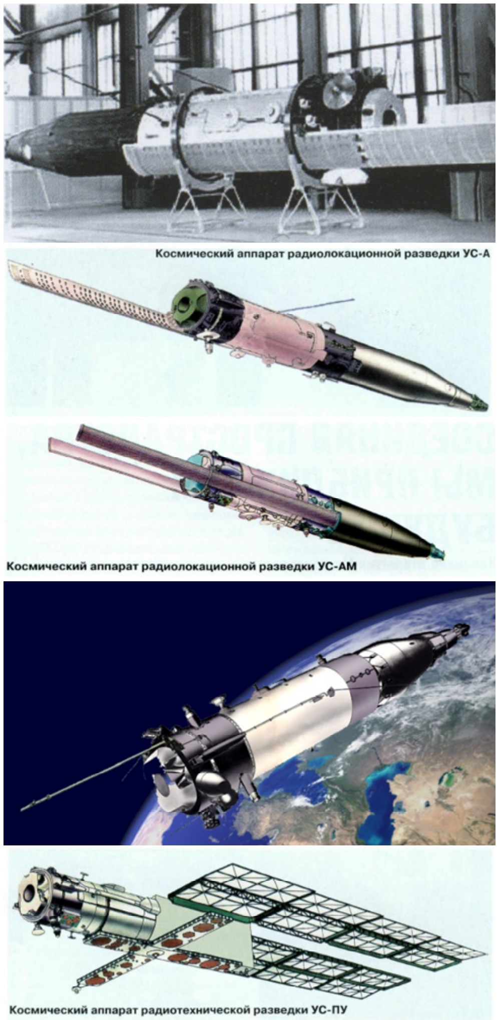


Figure 3.17. *The US, US-A, US-AM, Plasma-A and US-PU (source: NPO Mash, KB Arsenal). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

The US ocean surveillance program was developed in two versions: the US-A (active) with a lateral vision radar fed by a nuclear generator (3.5kW) and the US-P (passive) with a radiogoniometer fed by solar panels. The US-A (4Ya11) weighed 3.8–4.1 tons, whereas the US-P (4Ya14) weighed only 2.5 tons.

The prime contractor was the KB-1, which had become TsNII Kometa (Raspletin, Savin, etc.) in 1965. The Chayka radar was provided by the NII-17 from Moscow, which became MNIIP, then NPO Vega-M (I. A. Brukhansky). The Kortik radiogoniometer came from TsNII-108 (P. S. Pleshakov).[3] The guidance and stabilization system was created by the OKB-36 (P. M. Kirillov). It was equipped with the Neptune astronavigation system. The engine installation was produced by the OKB-300 (Tumansky). For the US-A, the BES-5 Buk nuclear generator with thermoelectric conversion was developed by the OKB-670, which became Krasnaya Zvezda (Bondaryuk). The ground segment was created by the NII-648. The Uspekh-U terminals mounted on the ships came from the NII-132 in Kiev, which had become NPO Kvant (I. V. Kudryatsev). All of this came together to form the MKRTs Legend system (17K114).

a) b)

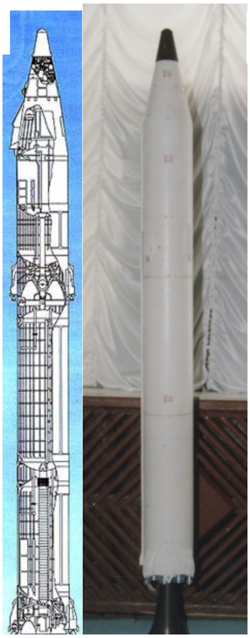


Figure 3.18. *a) The 8K69 (source: NPO Yuzhnoye) and b) R-36Orb (source: Christian Lardier)*

The first flight trial stage concerned a US-A whose radar and nuclear generator were replaced by models. The launcher was the R-7 (11A510). The president of the State Commission was General A. M. Voytenko (deputy director at Baikonur). Two

3 In 1967, this work had been transferred to the KNIRTI subsidiary of Kaluga (S. I. Baburin).

satellites were launched on December 28, 1965 (Cosmos-102) and July 20, 1966 (Cosmos-125). The second stage involved satellites equipped with a battery-powered radar. It allowed the transfer system of a reactor model to be tested in a more elevated orbit at the end of its life. The launcher was henceforth Yangel's R-36 (11K67). Three launches took place on December 27, 1967 (Cosmos-198), March 22, 1968 (Cosmos-209) and January 25, 1969 (failure). The reactor models were placed into 889/948km orbits for Cosmos-198 and 874/932km for Cosmos-209. Then, the third stage started with the 11K69 launcher and the whole satellite. The State Commission was headed by Admiral N. N. Amelko. The first active reactor (no. 31) was launched on Cosmos-367 on October 3, 1970. It worked for 110 min. Then, three other satellites followed in April 1971, December 1971 and August 1972, but April 25, 1973, was a failure: the satellite engine did not work and placement into orbit was unsuccessful. The satellite and its reactor fell back into the Pacific Ocean.

In May 1969, the transfer of production to the Arsenal factory in Leningrad was decided on. Their first US-A (or EP) was launched on December 27, 1973 (Cosmos-626). It worked for 45 days. Four other satellites were launched successfully and the system was declared operational on May 20, 1975. All in all, 31 satellites were placed into orbit by 1988. They worked for between 45 and 120 days. Two satellites accidentally fell back to Earth: Cosmos-954 in January 1978 and Cosmos-1402 in January 1983. The penultimate satellite, Cosmos-1900, was an improved version of the US-AM (or EPM or 17F16) equipped with a Chayka-M radar (two antennas) and the BES-5M/Buk-3 reactor. It worked for 9 months rather than the planned 6 months. Moreover, two experimental Plasma-A (or E3A) models were launched in February and July 1987 (Cosmos-1818 and 1867). They were equipped with a 5-kW TEU-5 Topol or Topaz-1 thermoemission reactor and electric propulsion from the OKB Fakel (six SPD-70). They worked for 142 and 342 days, respectively.

As for the US-P (or E2), it was directly produced by Arsenal starting in 1972. The first was launched on December 24, 1974. Then, four other satellites were launched and the system was declared operational in 1978. The constellation then included four US-A and three US-P in service. In 1982, the US-M (Pirs-1) system was proposed, with US-AM (17F16) and US-PM (17F17) satellites. They had a lifetime of 6 months. The US-PM was equipped with a larger number of batteries to increase the electrical resource. The first model flew in January 1985 (Cosmos-1625). Then, in 1988, a new variant, US-PU (17F120) allowed the lifetime to be extended to 1.5–2.0 years. In all, there were 19 US-P, 21 US-PM and 10 US-PU launched from 1974 to 2006. They are gradually being replaced by Liana satellites.

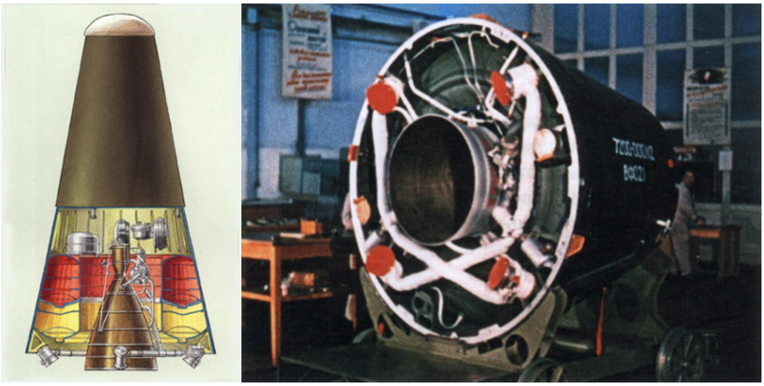


Figure 3.19. *The 8F673 FOBS warhead (source: NPO Yuzhnoye). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

Global bombs, or the Fractional Orbit Bombardment System (FOBS), were decided upon in 1962: GR-1 (8K713) from Korolev, UR-500 (8K82) and UR-200A (8K83) from Chelomey and R-36Orb (8K69) from Yangel. These were the object of decrees no. 243-117 from March 2 (UR-200A), no. 346-160 from April 16 (UR-500, UR-200A, R-36, GR-1) and no. 1021-438 from September 24 (GR-1). On September 28, 1963, the R-36 made its first flight and the missile won the competition. It became R-36Orb with the 8F673 warhead, whose first flight took place on December 16, 1965. Korolev and Chelomey's projects were abandoned.

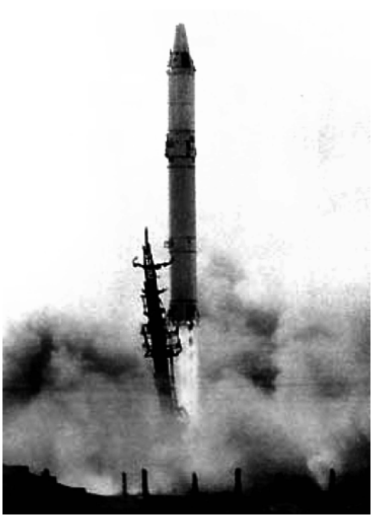
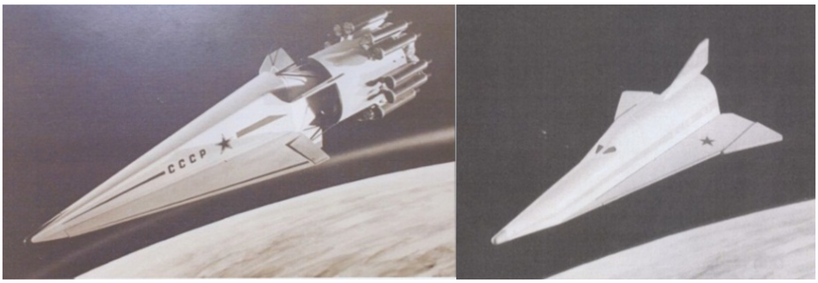


Figure 3.20. *An R-36Orb launch (source: NPO Yuzhnoye)*

Launched by a 600-ton booster rocket, the Kosmoplan and the Raketoplan were 10- to 12-ton engines capable of returning to Earth by landing on an airfield runway. The project's originality lay in placing the return vehicle, a winged craft, in a container serving as a heatshield loop during atmospheric reentry. It was a cone whose tail was equipped with ring-cone breaks opening up like an umbrella.

This original idea came from V. A. Djaparidze, who was head of Institute No. 2 of the aeronautics industry (later GosNIIAS) in 1951–1970.



a) b)

Figure 3.21. *The spaceplane project: a) R-1 and b) R-2 (source: NPO Mash)*

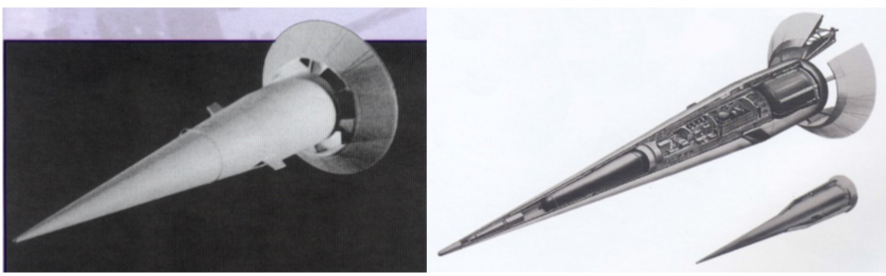


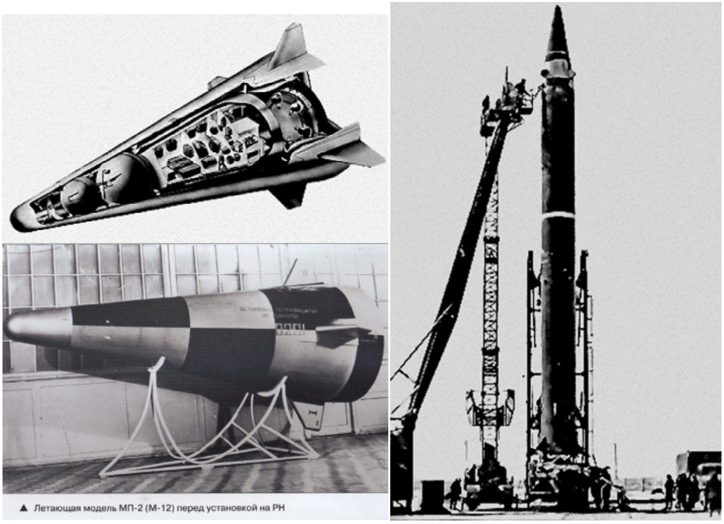
Figure 3.22. *The MP-1 demonstrator with ring-cone breaks (source: NPO Mash)*

Several versions of the Kosmoplan were studied: AK-3, AK-4, etc. It was equipped with new sources of energy and electrical propulsion (plasma, ionic and nuclear). Several versions of Raketoplan were also studied: the "hooded" version (airplane in a container) with eight Cosmos-Cosmos missiles (launched by the UR-500), the "cone" (conic capsule), weighing in at 14.0 tons and equipped with 12 Cosmos-Cosmos missiles (launched by the UR-500), and the winged craft whose suborbital version could carry up to seven passengers over a distance of 8,000–40,000 km. On May 13, 1961, however, the Kosmoplan and Raketoplan were abandoned and a new Raketoplan was developed. A 6.3-ton model, launched by the UR-200 into an orbit at 160 × 290 km, was studied in two versions, the automatic R-1 and the manned R-2.

a) b)

Figure 3.23. *a) The AB-200 and b) the M-12 on an R-12 (source: Christian Lardier)*

The ring-cone breaks demonstrator was the MP-1 (1,750 kg) launched by an R-12 rocket on December 27, 1961 from Kapustin Yar. The tip and the rudders were made of graphite. Following a suborbital flight at an altitude of 405 km, it reentered at Mach 13 (3,800 m/s), then was recovered with three parachutes to study thermic protection after the flight. The demonstrator for the AB-200 warhead was the MP-2 (1,700 kg), a.k.a. M-12, which flew on March 21, 1963. This time, the break panels were replaced by titanium aerodynamic rudders. The guidance system allowed for maneuvering during atmospheric reentry. However, on May 22, 1964, this work was stopped. On October 19, 1964, the Raketoplan study was transferred to Mikoyan, which started the Spiral program on June 29, 1966. In 1964, Chelomey studied a new Raketoplan: the P-2I interceptor. On November 10, document no. 38 provided codes for the OPS orbital station and the manned PP interceptor (S-1 and D-1). This project, like the others, was abandoned.



a) b)

Figure 3.24. *a) The M-12 demonstrator of the UB maneuverable warhead and b) launch on an R-12 (source: NPO Mash)*

3.3. The UR-500

In April 1961, the deputy minister of the Aviation Industry, A. A. Kobzarev, developed the plan for work on the UR-500: elaboration of the technical characteristics from then to December, the creation of the draft and manufacturing of the model by June 1962 and the creation of plans and experimental work by December 1962.

The UR-500 was to be developed in three forms: intercontinental ballistic missile, global rocket and space launcher capable of putting 12–13 tons into orbit. The start of these test flights was fixed for the fourth quarter of 1963. It could carry an 8F117 nuclear warhead (with a strength of 150 megatons)[4] or the maneuverable AB-500 head. The launch was to take place from a terrestrial platform and from silos.

4 According to the book *Tchelomei* by N. G. Bodrikhiin (2014). 100 Mt according to V. M. Petrakov and I. B. Afanaseyev in *A&K*, no. 4, 1993, and V. A. Polyachenko in his book *Na morie i v Kosmos*, 2008. S. N. Khrushchev speaks of 30 Mt in his book *Nikita Khrouchtchev: crise et fusées*, vol. II, 1994. The most powerful bomb was the one from October 27, 1961: it weighed 50 Mt and, according to A. D. Sakharov, a 100 Mt bomb was planned at that time.

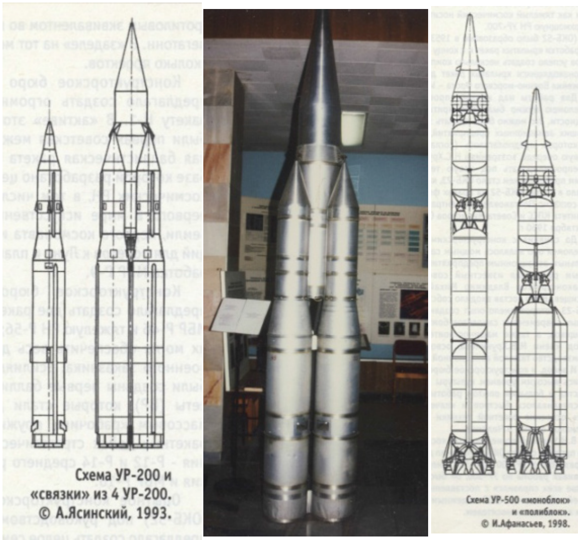
a)  b)

Figure 3.25. *a) First UR-500 design (4 × UR-200) and b) second UR-500 design (source NK no. 1/98**) (photo: Jacob Terweij (TsNII Mach Museum)**)*

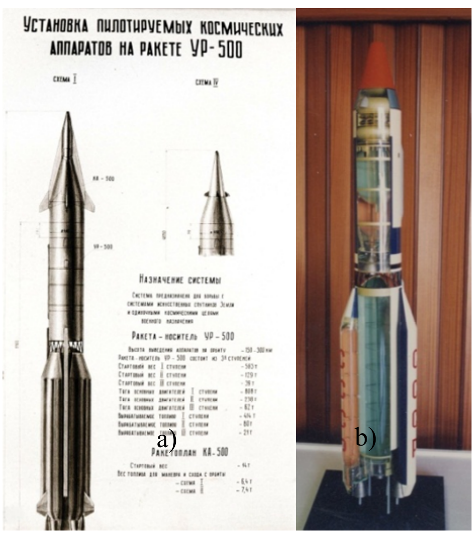


Figure 3.26. *a) The UR-500 with the KA-500 spacecraft and b) the ICBM UR-500 (source: NPO Mash and Christian Lardier)*

The first project was a bundle of four UR-200s with a third stage on top (modified second stage of the UR-200). This was not enough, however. The second was a three-stage pencil-type rocket (the upper part was also derived from the UR-200). For the first stage, two concepts were studied: monobloc or multibloc. The first was made up of an oxidizer tank and another of fuel equipped with the propulsion bay. They were transported separately and assembled at the cosmodrome. The second was made up of a central, large-diameter tank of fuel and several lateral small-diameter oxidizer tanks. This concept, accepted in January 1962, was the subject of patent no. 36616 from July 26, 1966 (Chelomey, V. N. Bugaysky, V. K. Karrask, G. D. Dermichev, E. T. Radchenko, Ya. B. Nodelman, V. A. Vyrodov, N. I. Egorov, Yu. P. Kolesnikov). It bore some semblance to the schema of the United States' Saturn-1. It was a cluster of eight small lateral tanks (four of oxygen and four of kerosene) surrounding a central tank (oxygen). These fed eight H-1 engines with a total thrust of 85.0 tons. Studied since 1958, it flew for the first time on October 27, 1961. With a mass of 528 tons, it placed 10.0 tons into a low orbit.

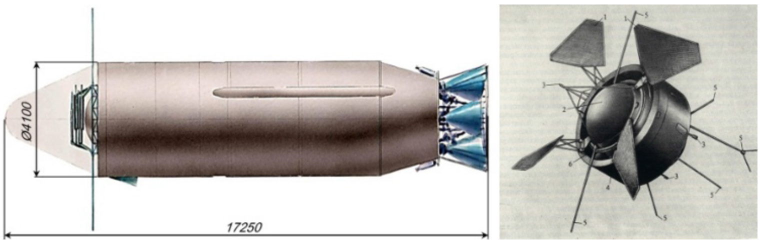


Figure 3.27. *The Proton-1 satellite (N-4 no. 1) (source: NPO Mash***)*

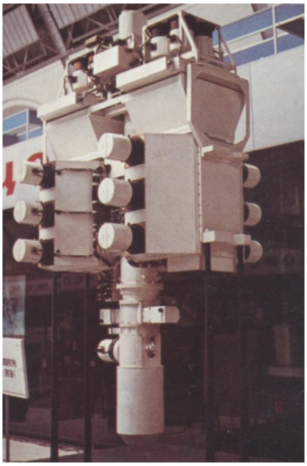


Figure 3.28. *The payload (source: all rights reserved)*

For propulsion, the use of Kosberg's 50.0-ton thrust engine required the placement of 15–16 units on the first stage. Glushko's 150-ton thrust RD-253 engine was thus kept. It was not on a gimbal, however. Additionally, it was first planned to place four RD-253s in the center and four Kosberg engines to ensure steering. In the end, Glushko modified it to make it steerable and only six motors sufficed. The number of engines was reduced and the thrust was also increased by 12.5%. The organization of the stage evolved as a result: the central body no longer had engines, but the six boosters each had one. This was the schema that was chosen by decree no. 409-183 on April 29, 1962. The first chief designer was P. A. Ivensen. He was a glider constructor who had worked at Bartini's OKB in 1932, then Grokhovsky's in 1934 before being imprisoned in July 1935. He was in Tupolev's sharashka in 1939, then he was transferred to Kuybishev. In 1956, however, he was rehabilitated and returned to Moscow. There, he worked at Tsybin's OKB-256, which was absorbed by Chelomey's OKB in 1960. He was on Proton in 1961–1962, then finished his career on the Almaz orbital station until 1975. The following deputy chief designer was Yu. N. Trufanov. He had worked at the KB Salyut since 1955. His work was on Proton from 1962 to 1968, then he became deputy head of the third directorate of the MOM. In May 1974, he was Glushko's first deputy at TsKBEM (Energiya). In March 1976, for health reasons, he became the first deputy of the NPO Lavochkin. Finally, in 1980, he moved to the NPO Molnya, where he was named adjunct general director and main designer in 1995.

Figure 3.29. *The UR-500 in Baikonur (source: all rights reserved)*

The main problem with the UR-500 was its transport to the cosmodrome, 2,000 km from the factory. At the time, O. K. Antonov had created the An-22 cargoplane and M. L. Mil the V-12 heavy helicopter. However, air transport was not chosen: the choice was instead for railway transport, which imposed a restriction on the diameter: 4.1 m. Each element was in a separate wagon: three wagons for a pair of boosters, one wagon for the central body and one wagon for the upper stage. This device was the object of a patent. The second problem was the use of storable propellants (nitric acid-UDMH, then amil-heptil) on a heavy launcher, particularly as an R-16 rocket from Yangel had exploded at Baikonur, killing 92 people, on October 24, 1960. Security needed to be ensured during filling and during the time that the launcher had filled tanks. The pneumohydraulic propellant-feeding system used hermitic junctions with two barriers (labyrinth) instead of welding. This kind of junction was also patented. According to E. S. Kulaga, there had not been the slightest loss of airtightness in 40 years of using the launcher. In the end, following in the footsteps of the UR-200, the launch platform was equipped with fully automatic mechanical, electrical and pneumatic connections.

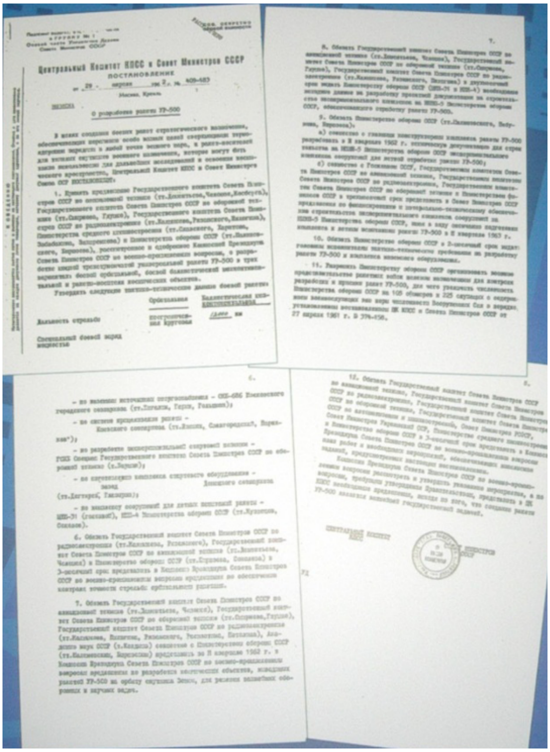

Центральный Комитет КПСС и Совет Министров СССР
ПОСТАНОВЛЕНИЕ
Москва, Кремль
О разработке ракеты УР-500

Figure 3.30. *The decree from April 29, 1962 (source: Christian Lardier)*

The two decrees that decided on the UR-500 were no. 346-160 from April 16 and no. 409-183 from April 29, 1962. The project was ended in 1963. It was the work of D. A. Polukhin, V. K. Karrask, G. D. Dermichev, V. A. Vyrodov, E. T. Radchenko, E. S. Kulaga, N. N. Mirkin, Yu. N. Trufanov, Yu. P. Kolesnikov, V. F. Gussev and A. T. Tarassov. The rocket, 42-m tall, weighed 575 tons at liftoff. The central body had a diameter of 4.1 m, but with the lateral blocks, the diameter reached 7.4 m (which would have required a silo with a diameter of 8 m).

On August 5, 1963, however, the United States, the USSR and the United Kingdom signed an agreement banning nuclear tests in the atmosphere. Then, on October 17, 1963, the UN General Assembly adopted resolution 1884, which forbid launching weapons of mass destruction into space. Khrushchev decided to abandon the UR-500 missile project, but the UR-500K space launcher remained. The initial payload was to be the Raketoplan, but that was also abandoned in May 1964.

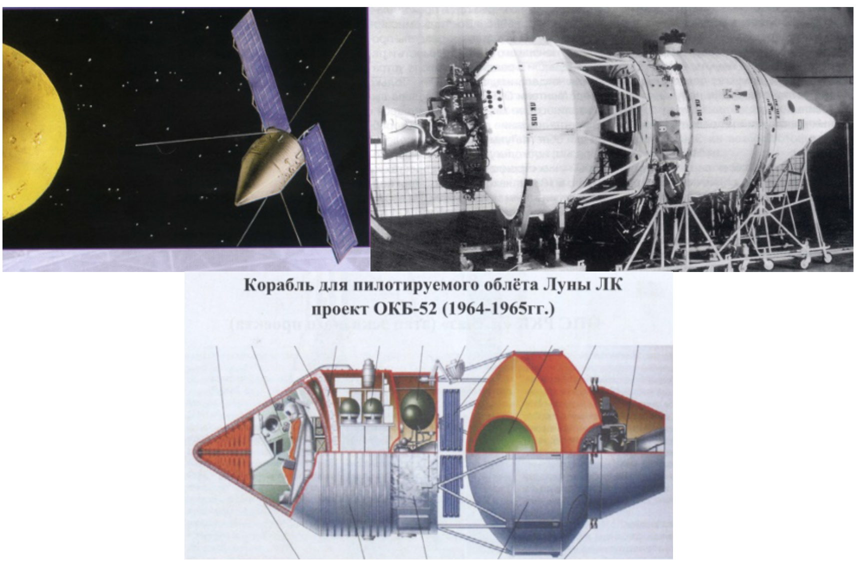


Figure 3.31. *The UR-500-LK-1 project (source: NPO Mash). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

On August 3, 1964, decree no. 655-268 officially began the Soviet lunar program. It awarded the flight over the moon to Chelomey: twelve UR-500s for lunar satellites (study on the space around the moon, photographing the Moon, and returning to Earth, orbiter) in 1966–1967 and 12 manned UR-500s to fly over the Moon in 1966–1967. Moreover, he ordered three to four UR-500s to launch the

Proton-1 satellite (study of elementary particles) in 1964–1965 and two other rockets for Proton-2 in 1966–1967.

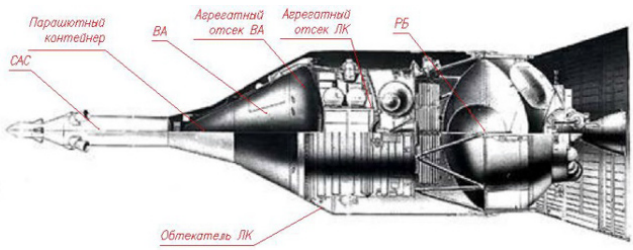


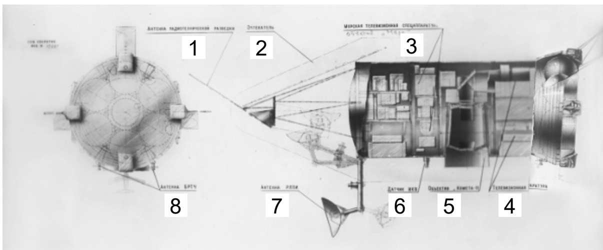
Figure 3.32. *The LK-1 spacecraft (source: NPO Mash)*

For the flight over the moon, he developed the three-stage, 17.87-ton LK-1 spacecraft launched by the UR-500. The vehicle was made up of an injection stage (12.28-ton Bloc-A), a service module equipped with an engine installation (2.73-ton Bloc-B), an Apollo type capsule (2.46-ton Bloc-V) and a rescue tower (1.2-ton Bloc-G). The flyby was ensured by a 5.19-ton spacecraft with a cosmonaut onboard.

On September 24, 1964, during the Kedr operation, the Head of State saw the launcher model on the launch platform and a silo model for the UR-500 with a diameter of 10 m and a width of 50 m. Three weeks later, he was fired. It was Keldysh who would save the situation. He would support the development of the Proton satellites as a payload for the first two-stage UR-500s.

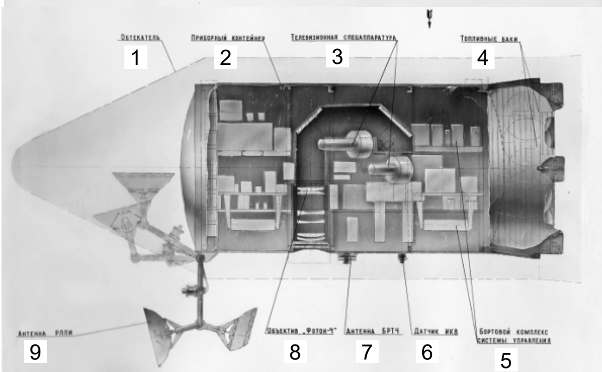
On March 2, 1965, the Ministry of General Machines (MOM) was created and the OKB-52, which had thus far depended on the Ministry of the Aviation Industry, was transferred to its first main directorate headed by N. D. Khokhlov, where it became the TsKBM. The MOM, directed by S. A. Afanaseyev, ran the rocket and satellite enterprises.

The draft of the LK-1 was presented during a meeting on November 11, 1964. Korolev was categorically against it. The project was ended on June 30, 1965. Its cost was estimated at 380 million rubels. In August 1965, it was evaluated by an expert commission headed by the academician Keldysh, then president of the Academy of Science. The commission recommended carrying out the project. However, among the 47-member commission, there were three people from Korolev's OKB-1 (K. D. Bushuyev, S. S. Kriukov and B. V. Raushenbakh) who considered it useless. On September 8, the OKB-1 and the OKB-52 met in the presence of Afanaseyev (MOM), Keldysh (Academy of Science), G. A. Tyulin (first deputy of MOM), G. N. Pashkov (VPK) and others. Three new variants of the flight over the moon were examined: a Bloc-D and a 7K spacecraft performed an orbital rendez-vous before going to the moon, a manned 7K spacecraft performed a rendez-vous with an unmanned Bloc-D + 7K ensemble (transfer of two men from one spacecraft to another), or a UR-500 rocket directly launched a Bloc-D + 7K ensemble without an orbital rendez-vous. On October 25, 1965, the LK-1 was abandoned and replaced by the third variant, which became the UR-500K-7K-L1. Its draft was ended on November 30 and adopted by Korolev and Chelomey on December 13.



TGR with the Kometa-11 objective

1) Electronic listening antenna
2) Nose
3) Marine Mars television device
4) Television device
5) Kometa-11 device
6) Infrared vertical sensor
7) Antenna
8) Antenna



TGR with the Photon-4 objective

1) Nose
2) Device container
3) Television device
4) Propellant reserve
5) Steering system
6) Infrared vertical sensor
7) Antenna
8) Photon-4 objective
9) Antenna

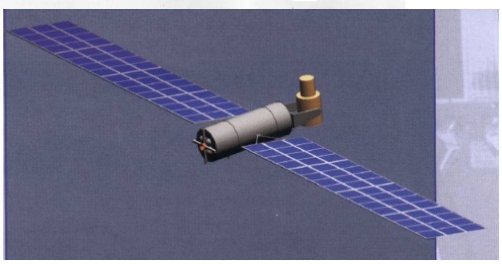


Figure 3.33. *The TGR satellite project (source: NPO Mash***)*

The OKB-52 had also studied a television global surveillance spy satellite (TGR) in 1963–1965, the N-2 geophysical satellite in 1963–1965, the Proton N-4 satellite in 1964–1965 and the Proton N-6 satellite in 1966–1968. The TGR was a 10.0-ton vehicle equipped with a TV system from the NII-380 and an optical-mechanical system from the Krasnogorsk factory (KMZ) and from the Vavilov Institute of Optics (GOI). This was a system of four satellites placed into orbit with a 97º inclination. There were two variants with solar panels and radio-isotopic generators (RTG). The steering system was created by Raspletin’s KB-1, whereas the data processing and transmission system came from Mnatsakanian’s NII-648. In 1965, however, the project was transferred to Yangel’s OKB-586 for the solar panel version (10.0-ton vehicle launched by the UR-500) and the KB-1 (Savin’s OKB-41) for the RTG version (5.0-ton vehicle launched by the R-7). The OKB-586’s project would be kept, then abandoned in favor of the Almaz orbital station program.

The N-2 was meant to allow a model of the Earth’s magnetic field to be constructed. The payload was provided by the IZMIRAN. However, the project was transferred to another OKB in 1967. The N-4 was decided on in August 1964: this was a 12.2-ton engine equipped with a 3.5-ton payload provided by the University of Moscow’s Institute of Nuclear Physics (NII YaF MGU), headed by S. N. Vernov. This payload was made up of an SEZ-14 ionizing calorimeter for very high-energy cosmic rays, an SEZ-12 device to study high-energy electrons, a Cherenkov SEZ-1 spectrometer for medium-energy cosmic rays and a GG-1 gamma telescope. The satellite was built under the direction of A. B. Bagdassarov. It was launched by the first UR-500K no. 207 on July 16, 1965 and worked for 43 days. The launcher was initially called Hercules, but after the success of its first flight, it assumed the name of its payload: Proton.

3.4. The UR-100

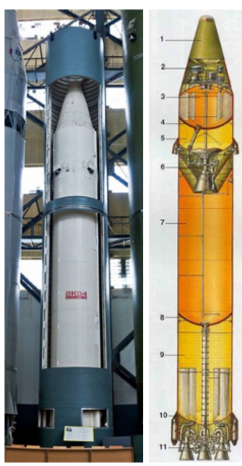
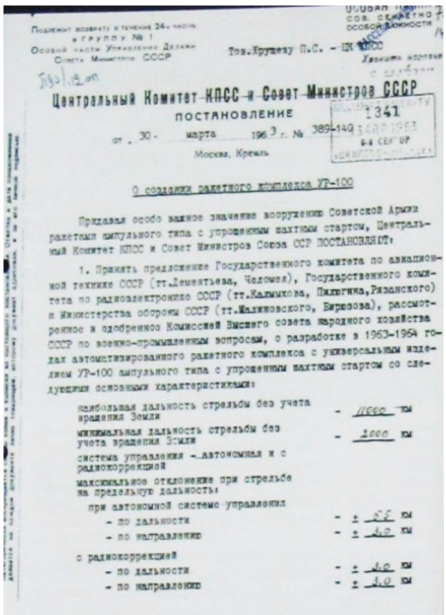


Figure 3.34. *The UR-100 (source: all rights reserved)*

In 1961, the USSR had the first generation of intercontinental missiles (ICBM): the R-7A and R-9A from Korolev and the R-16 from Yangel, the last two starting to be spread to silos, whereas more than 1,000 Minuteman missiles were being spread across the United States. A second generation of missiles was then decided upon: Yangel first proposed the 85.0-ton R-26 (8K66), then the 180-ton R-36 (8K67). Chelomey proposed a small polyvalent missile: the 42.0-ton UR-100 (8K84). It could serve as an ICBM, as an anti-missile interceptor and as a submarine launched missile (SLBM). It could be produced in large quantities like the Minuteman. Following in the footsteps of the naval missiles, it was launched from a container like a mortar. It kept its tanks filled with propellants (like in an ampoule) and did not require long preparations for launch (a few minutes warning). There were no umbilical connections and the launch was performed hot (engine ignited in the silo).


Тов. Хрущеву Н.С. – ЦК КПСС

Центральный Комитет КПСС и Совет Министров СССР

ПОСТАНОВЛЕНИЕ

от 30 марта 1963 г. № 389-140

Москва, Кремль

О создании ракетного комплекса УР-100

Придавая особо важное значение вооружению Советской Армии ракетами ампульного типа с упрощенным шахтным стартом, Центральный Комитет КПСС и Совет Министров Союза ССР ПОСТАНОВЛЯЮТ:

1. Принять предложение Государственного комитета по авиационной технике СССР (тт. Дементьева, Челомея), Государственного комитета по радиоэлектронике СССР (тт. Калмыкова, Пилюгина, Рязанского) и Министерства обороны СССР (тт. Малиновского, Бирюзова), рассмотренное и одобренное Комиссией Высшего совета народного хозяйства СССР по военно-промышленным вопросам, о разработке в 1963–1964 годах автоматизированного ракетного комплекса с универсальным изделием УР-100 ампульного типа с упрощенным шахтным стартом со следующими основными характеристиками:

наибольшая дальность стрельбы без учета вращения Земли – 11000 км

минимальная дальность стрельбы без учета вращения Земли – 2000 км

система управления – автономная и с радиокоррекцией

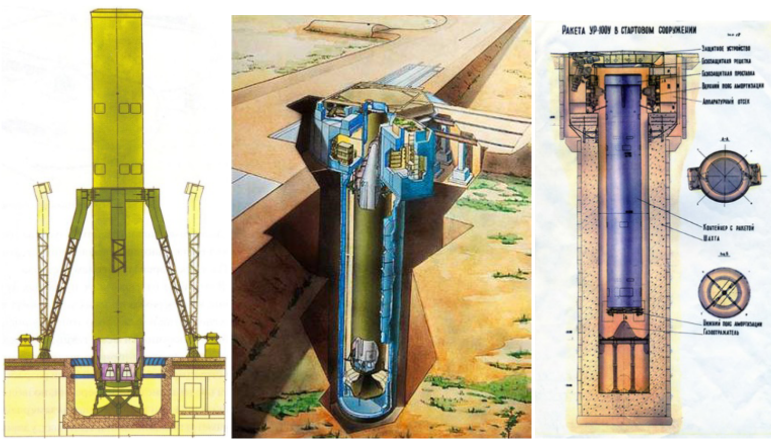
максимальное отклонение при стрельбе на предельную дальность:

при автономной системе управления
- по дальности – ± 5,5 км
- по направлению – ± 3,0 км

с радиокоррекцией
- по дальности – ± 3,0 км
- по направлению – ± 3,0 км

Figure 3.35. *The decree from March 30, 1963 (source: all rights reserved)*

The decree from March 30, 1963 ordered the creation of the UR-100. The subcontractors were Kosberg's OKB-154 for the first stage engine (15D1 including three RD-0216s and one integrated-flow RD-0217), Klimov's OKB-117 for the second stage engine (15D2 including one 15D13 and one derived-flow 15D14), I. I. Zverev's OKB-279 (which became Rubin) for the first stage's hydraulic steering actuators, O. V. Uspensky's OKB-118 (which became Avionika) for the second stage's electric steering actuators, I. I. Kartukov's OKB-81 (which became Iskra) for the stage-separating solid-propellant engines, N. A. Piliugin's NII-885 (which became RNIIKP) and V. I. Kuznetsov's NII-944 (which became NII PM) for the inertial guidance system with a gyrostabilized platform KI10-13 and KI25-10 calculator, Barmin's GSKB SpetzMash (which became KBOM) for the terrestrial complex (launch platform and silo) and OKB-52 subsidiary no. 2 of Baryshev's OKB-52 for the launch container.



a) b)

Figure 3.36. *a) Launch container and b) UR-100 and UR-100U silos (source: KBOM and NPO Mash). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

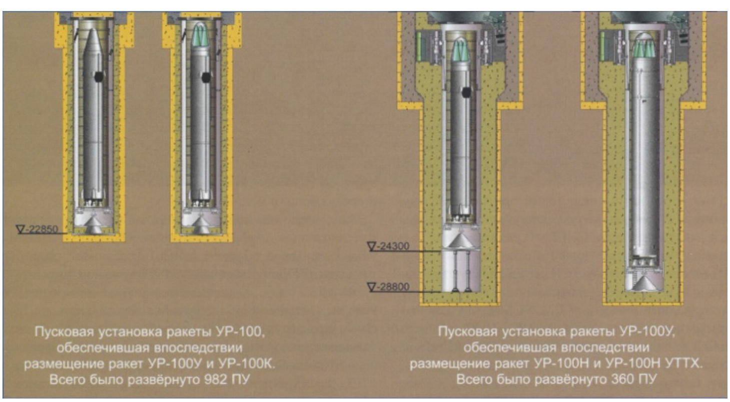


Figure 3.37. *The silos from different versions of the UR-100 (source: KBOM and NPO Mash). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

KBOM's subcontractors were N. A. Krivoshein's TsKB TM (silo cover opening in 30s), E. G. Rudyak's TSKB-34 for the launch post, V. K. Filippov's SPKB (which became KB TXM) for the fueling trucks, Nizhny-Tagil's wagon factory for the fueling wagons, the PKB-12 (which became ProyektMontazhAvtomatika) for the automation of the technological devices, factory no. 784 Arsenal's OKB from Kiev for the aiming system (S. P. Parnyakov), factory no. 686 Prozhektor's OKB for the electrical generators (V. A. Okunev) and the VNISI for the lighting means.

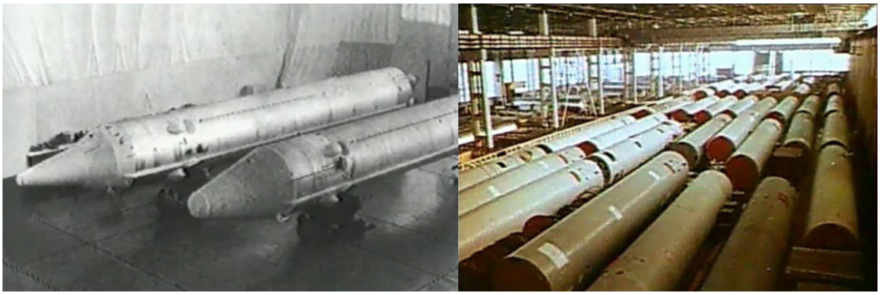


Figure 3.38. *Serial production of the UR-100 (source: all rights reserved)*

The UR-100 measured 16.8 m tall by 2 m in diameter. Given its 5-year service time (which was then extended to 7–10 years), the rocket could not use the hermetic, double-barrier joints. In fact, there was diffusion when the liquid flowed. Additionally, it was necessary to weld all the junctions (welding between aluminum and steel alloys). The silo was an OS type (10 silos spread apart from one another and controlled by a single launch post). The warheads, provided by Chelyabinsk's NII-1011, came in two types: light 15F842 of 0.5 megaton with a range of 10,000 km and heavy of 1 megaton with a range of 5,000 km. They were used with Palma lures from the TsNII-108 (V. M. Gerassimenko).

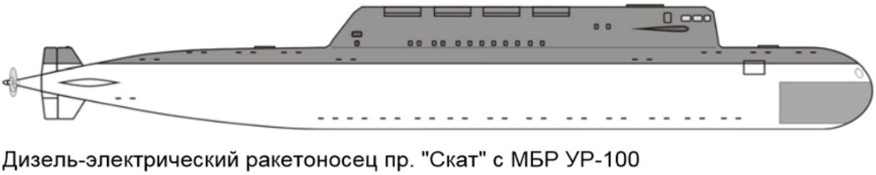


Figure 3.39. *The Skat submarine project equipped with UR-100 (source: all rights reserved)*

The missile was also planned to be loaded onto the Skat diesel submarine from P. P. Pustintsev's TsKB-18 Rubin (eight missiles). This was complex D-8. It competed with the Pr667B, equipped with the R-29 missile from Makeyev. However, this had finally won. The UR-100 was also proposed for the A-35 defense system from Moscow: the so-called Taran project. G. V. Kissunko (OKB-30 Vympel) had been working on the A and A-35 systems with missiles from P. D. Grushin for 7 years. For the A-35, it developed the 5V61/A-350. Chelomey prepared his project with Marshal Grechko and pushed his UR-100 (10-megaton nuclear warhead). The first deputy of the Ministry of the Aviation Industry, S. M. Leshenko, developed a plan so that Grushin's OKB would become a subsidiary of Chelomey.

The decree for the draft was signed on May 3, 1963. The council of general designers included Chelomey (president), G. V. Kissunko (deputy), P. D. Grushin (OKB-2), A. L. Mintz (Radiotechnical Institute), A. A. Raspletin (KB-1), V. P. Sosulnikov (NII-37), E. I. Zababakhin (NII-1011), S. A. Lebedev (ITM-VT), A. L. Livshitz (MNIIPA), S. A. Adzhemov (TsNII for communications), N. A. Piliugin (NII-885), Ya. I. Tregub (NII-2) and P. A. Khromov. Kissunko described this project as an adventure and did not wish to participate in the "game of state apparatus", but after Khrushchev was dismissed on October 12, 1964, the Taran project was abandoned. In the end, Grushkin's OKB would not become a subsidiary of Chelomey and the A-35 system would be equipped with the A-350 missile.

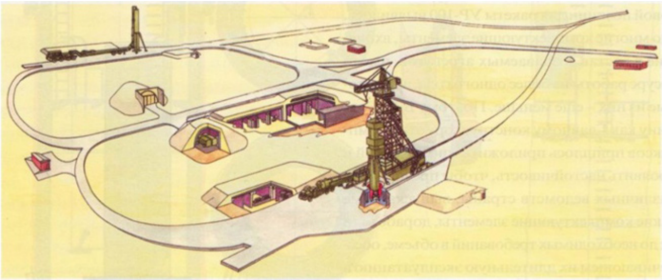


Figure 3.40. *Site no. 130 at Baikonur (source: KBOM). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

Management was created at Baikonur for the test flights on June 1, 1964. In 1964-1965, areas no. 130 (two terrestrial platforms), 131 (two OS silos) and 132 (two OS silos) were built. The first flight took place on April 19, 1965, lifting off from area no. 130. The president of the State Commission was General A. I. Sokolov. The first launch from a silo came on July 17. The test flights were finished by October 27, 1966 (15 launches). The UR-100 was declared operational on July 21, 1967. Serial production was organized in three factories: no. 23 Khrunichev (Moscow), no. 47 Strela (Orenburg) and no. 166 Polyot (Omsk). The missile was deployed in Baikonur (silos from areas no. 170, 171, 172, 173, 174, 175, 176, 177, 178, 179 and 180), but also to the Strategic Forces' bases (RVSN). In 1968–1971, the UR-100 was improved and became the UR-100M. It was tested from February 2 to November 24, 1971 (12 launches) and integrated into the armament on October 3, 1972.

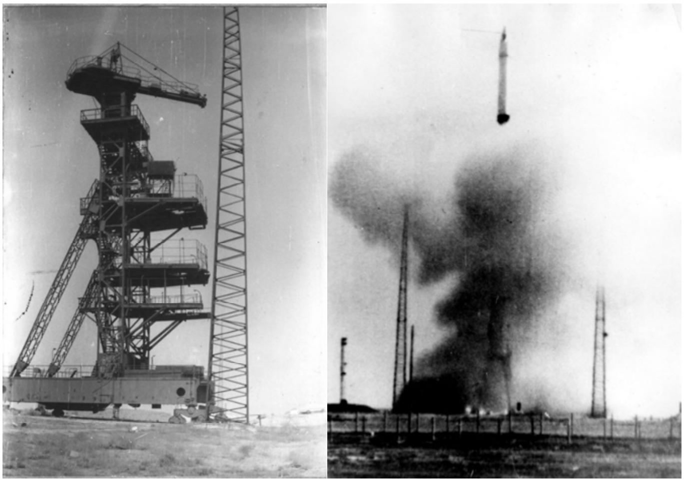


Figure 3.41. *The first launch in April 1965 (source: all rights reserved)*

Figure 3.42. *A UR-100N launch (source: all rights reserved)*

The decree from July 21, 1967 ordered the development of the UR-100K version (15A20). It was equipped with a 1-megaton warhead or three of 0.35 megatons each.

It was extended to 19 m to increase the propellant tank (mass: 50.0 t). The guidance precision was improved (gyrostabilized platform KI21-22 and KI25 calculator). The test flights took place from July 23, 1969 to March 11, 1971 (28 launches). The president of the State Commission was General V. P. Morozov (deputy of the GURVO). The UR-100K was declared operational on December 28, 1972.

The UR-100U version (15A20U) was decided on by the decree from August 19, 1970. It was a matter of hardening the silo with a highly resistant shock absorber in case of a nuclear explosion. The system was developed by subsidiary no. 2 of the OKB-52. The rocket was equipped with two shock absorbing belts for fixation in the container. The test flights took place from June 16, 1971 to January 30, 1973 (19 launches). Complex 15P120U was integrated into the armament on September 26, 1974.

A new generation was also developed in 1970-1973: the SS-11 (NATO code) then became the SS-19. The mass was more than doubled: 105 tons instead of 50.0 tons. The height rose to 24 m and the diameter to 2.5 m. The payload henceforth included six warheads of 500 kilotons. The first stage's engines were RD-0233 (15D95) and RD-0234 (15D96), with a total thrust of 188 tons at liftoff. The second stages were RD-0235 (15D113) and RD-0236 (15D114) with a total thrust of 24.0 tons in vacuum. The bus (third stage) was propelled by an RD-0237. The onboard computer guidance system was provided by V. G. Sergeyev's OKB-692 (which became Khartron) in Kharkov. The test flights took place from June 1973 to December 1974 (25 launches). The president of the State Commission was E. B. Volkov. Complex 15P130 was declared operational on December 30, 1975. An improved version, the UR-100NU (15A35), was tested from October 1977 to June 1979 (19 launches). Complex 15P135 was declared operational on December 17, 1980.

From then to 1999, there would be 182 UR-100/UR-100M launches, 97 UR-100K/UR-100U launches, 63 UR-100N launches and 74 UR-100NU launches from Baikonur. The UR-100/100M was deployed to 990 units, the UR-100K/100U to 420 units, the UR-100N to 180 units and the UR-100NU to 360 samples. In 1974, there was a maximum of 1,030 missiles in service. Today, there are still 70 in service with a lifetime that has been extended to 36 years.

In 1987–1990, the UR-100N was transformed into a space launcher (14A01). It was equipped with a Breeze upper stage and included the Nariad-V (14F11) anti-satellite system. Three launches took place on November 20, 1990 (area no. 131), December 21, 1991 (area no. 131) and December 26, 1994 (area no. 175-1). The first two were suborbital and the last sent the Radio-Rosto satellite into orbit.

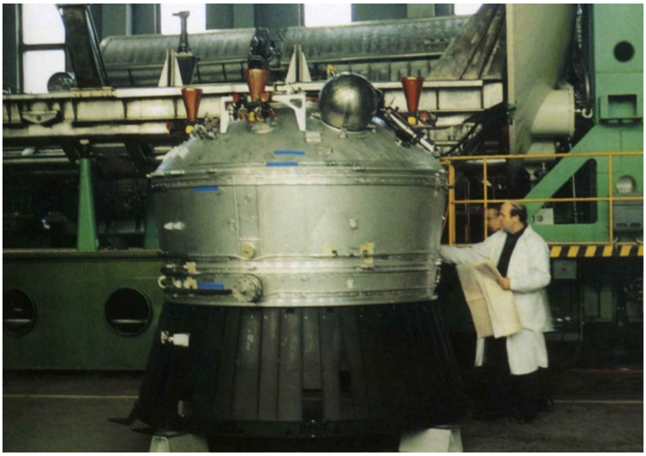


Figure 3.43. *The Breeze-KM stage (source: all rights reserved)*

Figure 3.44. *The Rockot launcher (source: Eurockot)*

In 1995, Khrunichev created the Eurorocket trading company the German DASA (49–51%). The Rockot launcher (14A05) was placed 1.8 tons into low orbit. Since May 2000, there have been 10 commercial launches and five federal flights from Plessetsk (area no. 133).

Figure 3.45. *The Strela launcher (source: Christian Lardier and NPO Mash)*

Following the decree from October 22, 1992, the Strela launcher (14A036) was developed from the UR-100NU. On December 5, 2003, it placed a model (978 kg) of the Kondor-E satellite (14F133) into orbit from Baikonur (area no. 175-1).

3.5. The UR-700

The UR-700 (11K87) was a super-rocket meant for manned flights to the Moon and Mars. The project was studied starting in 1962, in competition with Korolev's N-1. On October 29, 1965, it received the green light from Keldysh's Expert Commission and from the Ministry (MOM). The draft was performed in 1966. Decree no. 1070-363 from November 17, 1967 began the Galaktika program. The council of designers brought together Chelomey, Glushko, A. M. Isayev (OKB-2), F. D. Tkachev (NII of parachutes), S. G. Darevsky (NII AO), V. S. Avduyevsky (NII-1), N. M. Korneyev (KBOM), G. I. Voronin (OKB-124), A. S. Selivanov (NII-885), Yu. S. Bykov (MNIIRS), N. S. Lidorenko (VNIIT), A. S. Abramov (OKB-12), G. I. Severin (factory no. 918), O. V. Uspensky (OKB-118) and a deputy of V. G. Sergeyev (OKB-692). The rocket, weighing 4,823 tons at liftoff, was placed 151 tons into a low orbit and sent two men directly to the Moon.

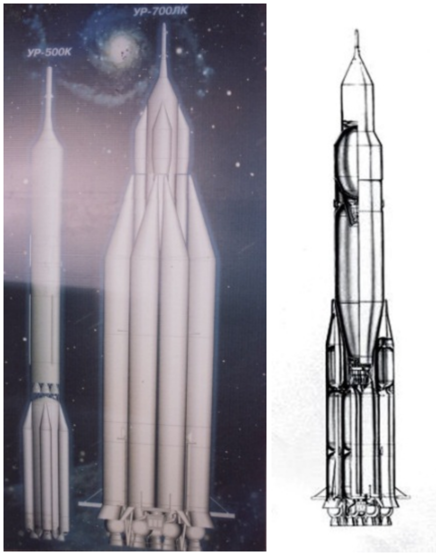


Figure 3.46. *a) The UR-700 launcher and b) the UR-700 with a RO-31 nuclear motor (source: NPO Mash)*

The first stage (lateral boosters) was propelled by six RD-270 engines (8D420) with 640 tons of thrust (three pairs). The second stage (central body) was propelled by three RD-270s. The first and second stages were ignited simultaneously. The first stage's engines were then fed by the propellants that were located in extra tanks placed on the lateral boosters. After dropping the boosters, the second stage continued with the propellants in the central body. The third stage was propelled by three RD-254s (11D44) with 175 tons of thrust in vacuum. All the stages, made up of blocks 4.1 m in diameter like the UR-500, worked with the amil-heptil couple. The LK-700 (50.0 tons) was made up of six blocks: the transfer stage (three RD-0217 with 23.5 tons of thrust, from Konopatov), the correction and brake stage (an RD-0217 engine and three 11D416 engines with 1.67 tons of thrust, from Isayev), the lunar landing stage (three 11D416 motors), the ascent and correction stage (15D13 motor with 13.4 tons of thrust, from Klimov), the capsule (3.13 tons) and the rescue system. The spacecraft weighed 17.0 tons on the moon. The project was ended on September 30, 1968. The cost of the program was estimated at 816 million rubels. It would not be financed however. The OKB-52 had studied evolutions of the third stage. An initial version with nine cryogenic 11D54 engines from Lyulka (360t of thrust) allowed 185 tons to be launched. A second version with three RD-350 hydrogen-fluoride engines from Glushko (450 tons of thrust) would go up to 215 tons. Lastly, a third version with seven nuclear RO-31 engines from Konopatov

(280 tons of thrust) went up to 250 tons. The solid-phase liquid hydrogen RO-31 was also known as the RD-0411 (11B97).

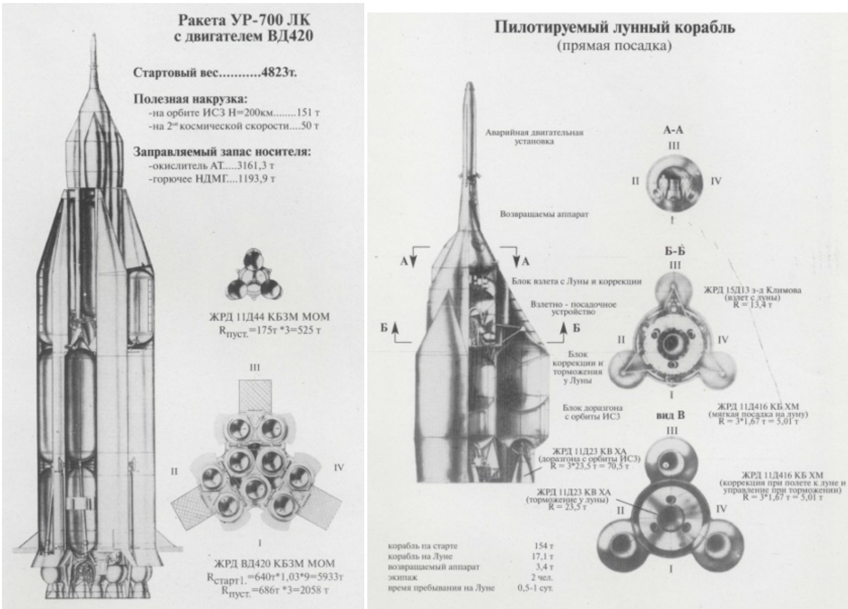


Figure 3.47. *The UR-700-LK-700 complex (source: NPO Mash)*

The draft for the Martian mission UR-700M-MK-700 was carried out in the framework of order no. 232 from the ministry on June 30, 1969. The rocket, weighing 16,000 t at liftoff, was capable of launching 750 tons. It had three stages: the first two were oxygen-kerosene stages, the third, cryogenic. The first stage was made up of eight lateral blocks 9 m in diameter, each equipped with eight RD-116 engines from Glushko (600 tons of thrust, chamber pressure of 200 atm, specific impulse of 333 s). The second stage (central body), 12.5 m in diameter, was equipped with 12 of these engines. The two stages were ignited upon liftoff, which provided a total thrust of 45,600 tons. Part of the first stage's propellants fed the second stage's engines. The third stage, also 12.5 m in diameter, was equipped with six cryogenic NK-35 motors from Kuznetsov (220 tons of thrust).

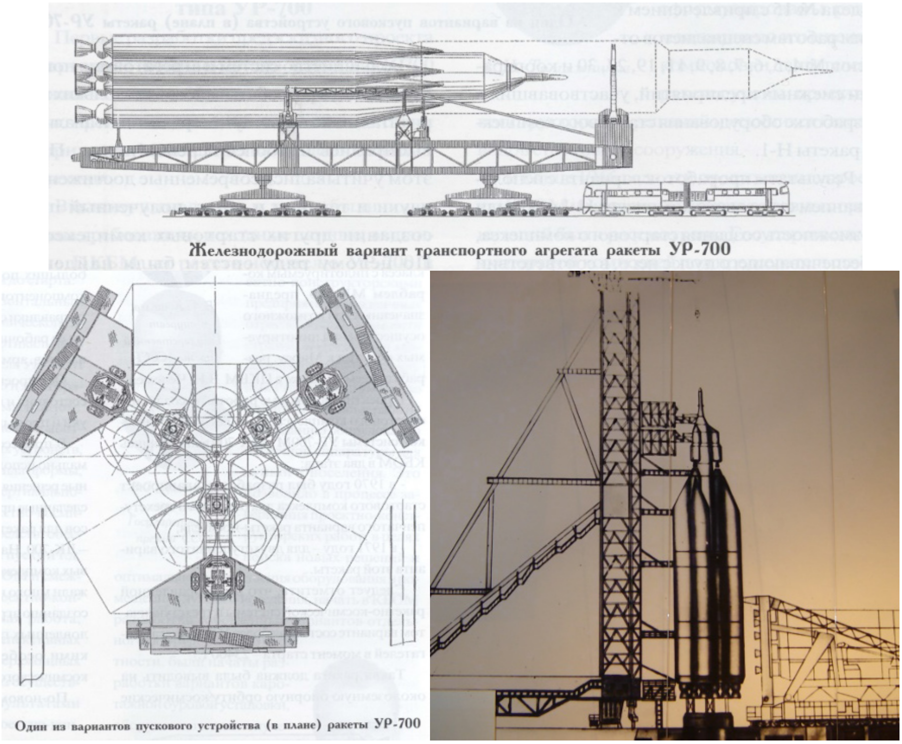


Figure 3.48. *The transport and launch table of the UR-700 (source: NPO Mash)*

Several versions of the Martian mission were planned. They were examined by an expert commission in 1972. It believed that 15–20 more years would be needed to realize such a mission. The preparation (long-term flights onboard orbital stations, development of nuclear propulsion, radiation issues, etc.) would require an investment of 30–40 billion rubels under the economic conditions of 1973.

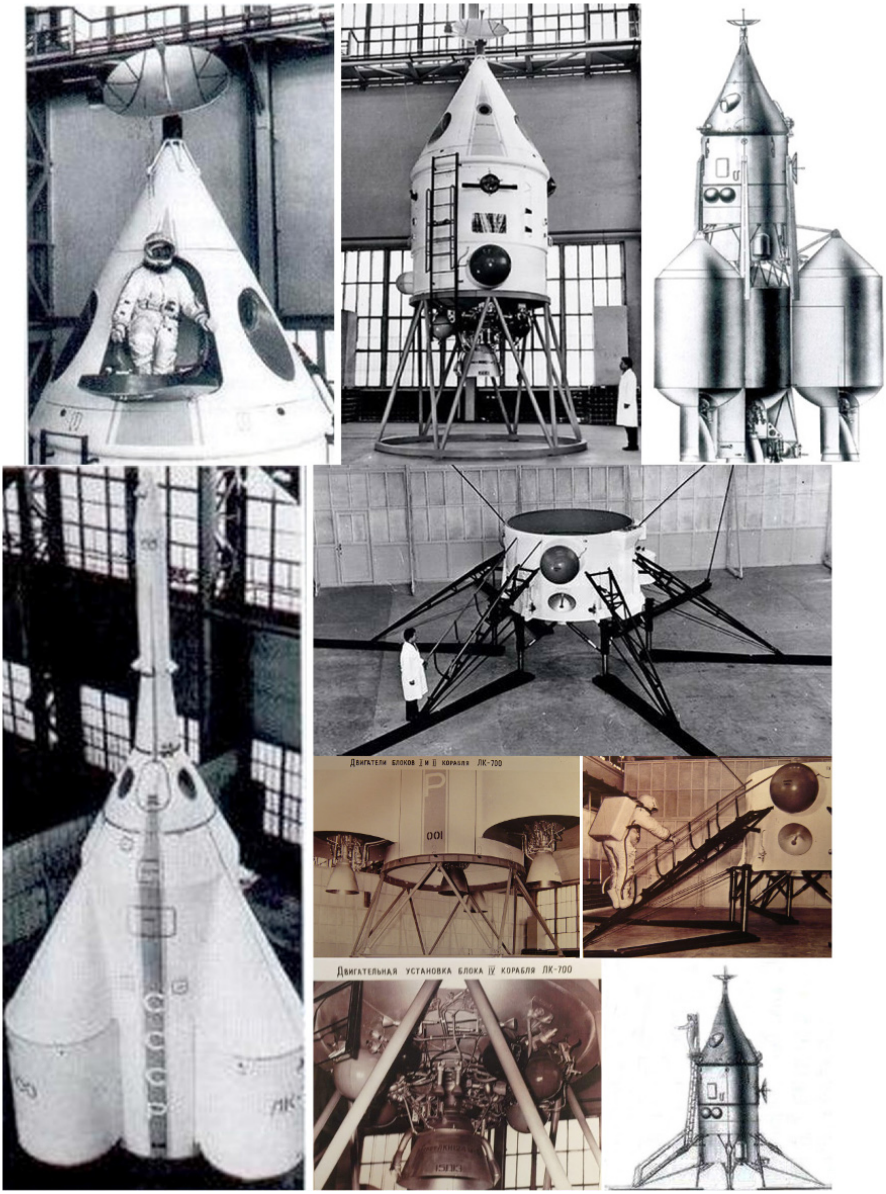


Figure 3.49. *The LK-700 lunar complex (source: NPO Mash)*

3.6. The UR-1000

This was a proposition from Glushko dating back to 1964. It was based on the schema of the UR-500. The first stage, with a maximum diameter of 10 m, was made up of a central body 6.5 m in diameter and lateral blocks 1.65 m in diameter. It had eight RD-270 engines. The second stage was equipped with an extended-nozzle RD-270 or four 11D44s (172 tons of thrust in all). Lastly, the third stage was a second stage from the UR-500. It was equipped with four engines from Voronezh's OKB-154. The launcher would be created in cooperation between Moscow's OKB-52 and Dnyepropetrovsk's OKB-586. The first flight would take place in 1967.

4

Versions of the UR-500

4.1. The two-stage version

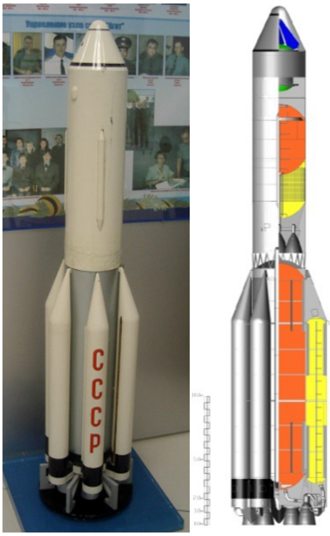


Figure 4.1. *UR-500K (source: Christian Lardier and Alexandre Chliadinsky). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

As we have seen, the first variant had two stages and the first model arrived in Baikonur on July 24, 1964. Six combined tests were run on the left platform of area 81. The first flight model, no. 20701, arrived in March 1965. The president of the State Commission was General A. G. Zakharov. On July 5, an initial tank fill-up was stopped after 120 s. In the end, the launch took place on July 16 at 5:16 pm (local time). The launch was originally planned to take place at 6:00 am. In the bunker,

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

there were 27 people, including the launch organizer, Lieutenant-Colonel A. I. Mogila. However, at liftoff time, the rocket stayed put. The problem came from the gyrostabilized platform (GSP) from Pilyugin. The service tower was reinstalled so action could be taken on the rocket. The chronology then started over again. The Proton-1 satellite (12.2 tons) was placed into orbit. This first success was repeated on November 2 with launcher no. 20901 and the Proton-2 satellite. However, the launch on March 24, 1966 (launcher no. 21101) failed after the second stage's engine broke down. Finally, on July 6, the fourth launch with launcher no. 21201 placed Proton-3 into orbit.

Figure 4.2. *Proton-1 launch (July 16, 1965) (source: all rights reserved)*

The launcher measured 42.3 m tall and 7.4 m in diameter at its base. It weighed 575 tons, 457 tons of this for the first stage and 105.8 tons for the second. The propellants were made up of nitric acid (then nitrogen tetroxide, or amil) located in the central tank (4.1 m in diameter) and UDMH (or heptil) in the boosters (1.6 m in diameter). The first stage (8S810), 21 m tall, was propelled by six RD-253s from Glushko. This was an integrated flow motor (gas-liquid mixture): before the pumps, approximately 75% of the propellants went through a gas generator that activated the turbine. The rest (UDMH) went into the walls of the combustion chamber to cool it. The gas leaving the turbine then entered the chamber, where it mixed with the liquid that had cooled it. The turbine had a force of 18,740 kW. For the six engines, this represented approximately 150,000 ch. The rotation speed was 14,000 rpm. The maximum pressure of the propellants in the tubes reached 400 atm. In the gas generator, this was 240 atm and in the combustion chamber, it was 150 atm. The temperature in the gas generator was 780 K, whereas it reached 3,400ºK in the chamber. This had an internal countersunk wall made up of bronze covered with a layer of thermic insulator made up of zirconium dioxide. The nozzle was an embossed wall for regenerative cooling. Igniting and extinguishing the engine was ensured by nine pyrovalves. Tank pressurization was performed with the help of gas coming, for the fuel, from a gas generator working with primary propellants, and for the oxidizer, coming from the turbine exhaust. At 600 ºC, these were cooled to 200 ºC in a mixer. The engine weighed 1,280 kg, 400 kg of which was the chamber. It had a thrust of 150 tons on the ground or 166 tons in vacuum. The specific impulse was 279 s on the ground or 310 s in vacuum. The perfection of this kind of engine had required the resolution of numerous problems by NII-1 and TsIAM (combustion instability, feed pressure of 400 atm, etc.). The on-ground tests at Glushko (stands no. 1 and 2) started in June 1962. There were a total of 191 tests with 119 motors. The interministerial tests (MVI) were carried out in three stages: the first in 1965–1966 (167 tests with 54 motors), the second in 1967–1968 (138 tests with 65 motors) and the third in 1969 (28 tests). Serial production was granted to Perm's factory no. 19 (later Perm Motor).

To increase the Proton's performance to 24.5 tons in a low orbit and launch Lavochkin's 5M Martian mission (sample recovery), the 11K88 version was decided on by decree no. 589-202 on July 24, 1969 and MOM's orders no. 247 from August 12, 1969, no. 87 from March 17, 1970 and no. 200 from July 1, 1971. The idea was to increase the mass of the first stage's propellants to 100 tons and to equip it with engines with 175 tons of thrust instead of 150 tons. This RD-256 (11D27) had an increased thrust of 16.6% (the pressure in the chamber rose from 150 to 172.8 atm). The project would be finalized in 1970 (first stage) and in the fourth quarter of 1971 (second stage). A model was built, but the work was stopped.

Figure 4.3. *RD-275 motor (source: Christian Lardier)*

Then, in 1974, the RD-253U would have a 7.7% increase in thrust (pressure rising to 160.5 atm). This work was also stopped, but then restarted in 1987 with the aim of improving Proton's performance. The motor then became the RD-275 (14D14), whose first flight was on October 11, 1995. Lastly, the final evolution was the RD-276 (RD-275M/14D14M) of the Proton-M. Its thrust was increased by 5.3% (pressuring increasing to 168.5 atm). The work started in 2001 and culminated in an initial flight on July 7, 2007. The performance was improved by 150 kg.

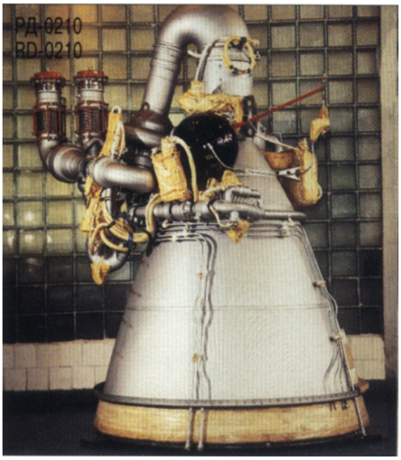


Figure 4.4. *RD-0208 motor (source: all rights reserved). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

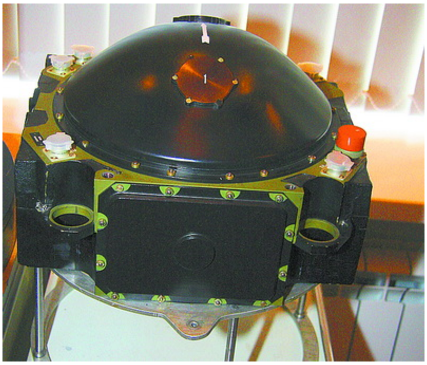


Figure 4.5. *The PV-300 guidance system (source: all rights reserved). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

The second stage (8S811) measured 9.62 m tall by 4.1 m in diameter. It was propelled by four steerable engines (3.15º angle) from Kosberg's OKB-154: this 8D410 included three RD-0208 (8D411) and one RD-0209 (8D412), each with 60.0 tons of thrust. Serial production was ensured by Voronezh's mechanics factory. The stage separation was performed hot. The functioning duration was 119 s. For the three- and four-stage version (UR-500K), the second stage was extended to 17 m and the motors changed to an 8D410K composed of three RD-0210 (8D411K) and one RD-0211 (8D412K).

The guidance system was developed by the automation and instrumentation NII (N. A. Pilyugin) and the NII-944 (V. I. Kuznetsov). However, the latter's activity was quickly transferred to the OKB of Kharkov's factory no. 897 Kommunar (L. L. Balashov). From 1946 to 1963, Pilyugin's NII had been a department of the NII-885. From 1963 to 1965, it was part of the NII-944. Then, upon the creation of the MOM, it became autonomous in 1965. As for the Kommunar factory's OKB, it was created in November 1951. The main designer was A. M. Ginzburg, a deputy of Pilyugin. Its successors were M. V. Ossipov in 1959–1964, L. L. Balashov in 1964–1983, A. G. Andrushenko in 1983–1986, V. M. Svich in 1986–2005 and S. Ya. Yatsenko since 2005. Factory no. 897, which would produce 80% of the Proton guidance system's equipment, was managed by V. N. Kulikov in 1965–1964, M. A. Kharchenko in 1964–1975, V. P. Ogolyuk in 1975–1979, V. E. Sokolov in 1979–1988, A. A. Asmolov in 1988–2006 and L. You. Sabadosh since 2006.

The hydraulic steering devices were manufactured by OKB-279 (which became Rubin), on behalf of I. I. Zverev (Balashikha), and OKB-467 (which became Voskhod), on behalf of F. F. Kupryanov (Pavlovo). The propellant consumption synchronization system (SOB-82K) was produced by OKB-12 (which became the instrumentation GNII). The launcher safeguard system (SBN) was provided by NII-137 (which became the precision mechanics NII), on behalf of S. E. Petrov (Saint Petersburg). The 8Ch122P aiming system was the work of factory no. 784 Arsenal's OKB, on behalf of S. P. Parnyakov (Kiev).

The 8P882K launch platform was produced by the GSKB SpetzMash (which became KBOM), on behalf of V. P. Barmin (deputies N. M. Korneyev and K. G. Khlamov), and subsidiary no. 2 of OKB-52 (which became Vympel), on behalf of V. M. Baryshev. It was installed in the "left" area of Baikonur, 20 km from the central area. It was built by the main directorate of special constructions (GUSS) of the Ministry of Defense (General M. G. Grigorenko in 1959–1971), the Institute of Design TsPI-31 (General M. P. Klimov in 1964–1973), regiment 130 UIR at Baikonur (General G. M. Shubnikov in 1955–1965), the 504th UNR (Colonel V. A. Sakharov, then Yu. G. Lobushkin), etc.

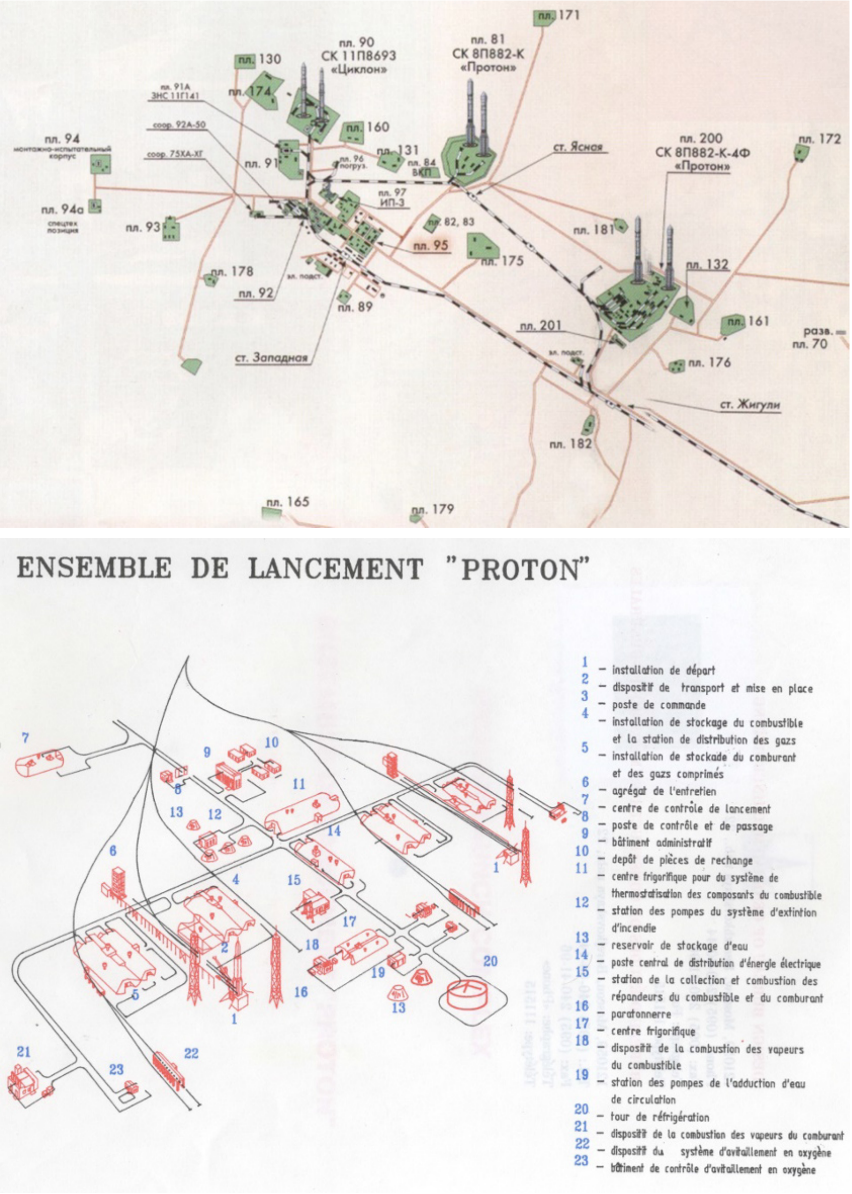


Figure 4.6. *The West zone of Baikonur (source: all rights reserved, KBOM and Jacob Terweij). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

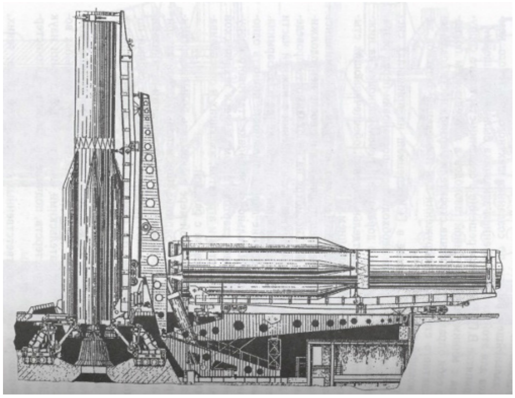


Figure 4.7. *The 8U260 fixed erector (source: all rights reserved, KBOM and Jacob Terweij)*

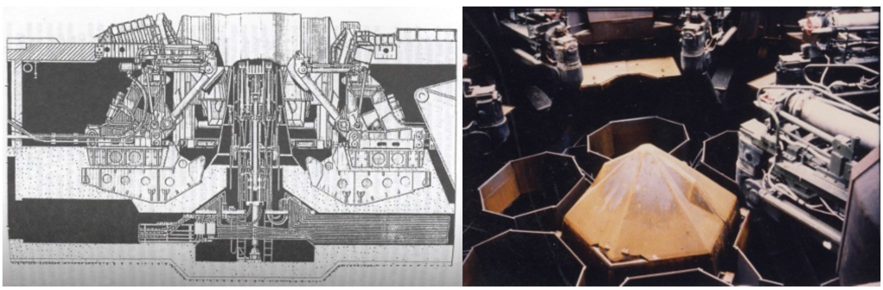


Figure 4.8. *The 8U259 launch table (source: all rights reserved, KBOM and Jacob Terweij)*

The center of life was in area no. 95. The MIK 92-1 allowed two rockets to be assembled in parallel. The first stage's barrel was assembled with the help of a "revolver" installation that was patented. The satellites were prepared in the MIK-92-50. The launcher was brought to the launch platform by rail (chariot 8T184). It was placed on the 8U260 fixed erector, which then verticalized it. The 8U259 launch table was a new type: all operations were performed without the presence of Man. The flue was dug 8 m deep, i.e. five times shallower than the R-7. It had six gas-ejection channels, one per motor. There was no umbilical mast because every connection (propellant feeds and drainage, electric and pneumatic connections) was produced by automatic mechanisms (one central and six lateral) that were located under the rocket on the launch table. Shortly before firing up the engines, the mechanisms were retracted in 1.8 s to be protected from the flames, which ensured multiple launches. These mechanisms had been developed by Kovrov’s KB Armatur. This enterprise had been firearms factory no. 575’s OKB-2, responsible for rockets since 1960. After the UR-500, it would make the same kind of mechanisms for Zenit and Energiya-Buran. Since May 1999, it has been the subsidiary of the Khrunichev Center. It was headed by A. M. Nikiforenko in 1956–1968, M. E. Vylyudnov in 1968–1970, O. S. Russakov in 1972–1988 and Yu. L. Arzumanov since 1988.

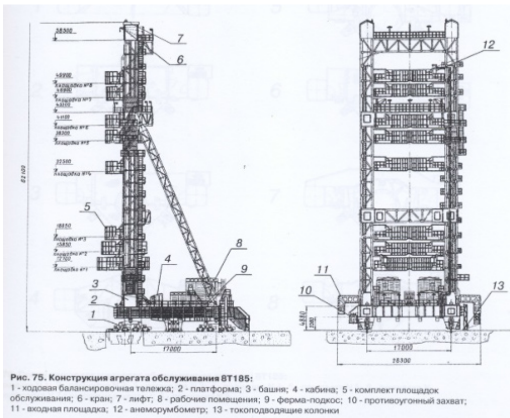
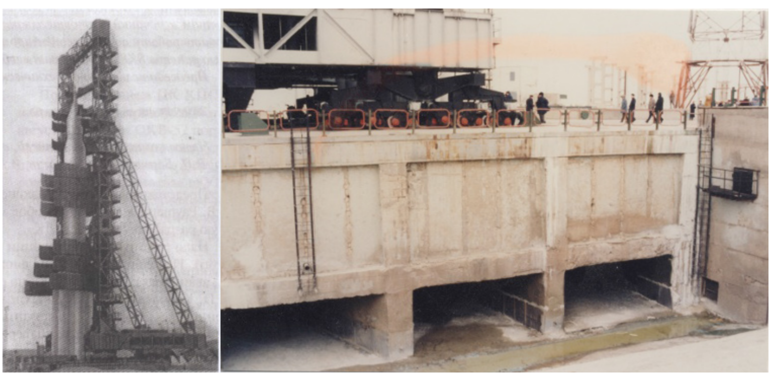


Figure 4.9. *The 8T185 mobile service tower (source: all rights reserved)*



a) b)

Figure 4.10. *a) Launcher in the mobile tower (source: all rights reserved) and b) the flue (source: Christian Lardier)*

The 8T185 mobile service tower measured 62 m high by 17 m wide (rail gauge). It weighed 1,600 tons and had five platforms (this number would then be increased to eight for new high parts). The platforms were protected by windbreakers. The test cycle on the launch platform, which had originally been 10–12 days, was reduced to 4–5 days. Before launch, it was moved back 300 m.

The propellants were stored in buried buildings (240 tons of fuel and 600 tons of oxidizer) located between the two launch platforms (no. 81L for "left" and 81R for "right"), separated by 600 m to avoid the effects of a launch failure. Fueling lasted approximately 60 min. In case of an aborted launch, the tanks were drained. There was also a gas-supply system (nitrogen, air, helium) and a thermic control station for the propellants and the payload. The bunker was located at least 1 km from the launch platform.

The KBOM's subconstractors were Krivoshein's TsKB TiazhMash, Novokramatorsk's machine factory (NKMZ), and the "Kirov" factory of transport devices and elevators for the 8U260 erector and the 8T185 service tower, V. A. Rozdov's Motor OKB and L. D. Novikov's wagon factory SKB (later TsKB TransMash) in Kalinin for the 8T184 chariot, the KB Armatur for the launch table, V. K. Filippov's SPKB (later KB TXM) and the M. N. Veremeyev's Ural wagons factory (UZV) in Nizhny-Tagil for propellant fueling, the Zhdanov heavy machines factory (JZTM, later AzovMash), the VNII KholodMash, the NIIKhimMash, the PKB-12 (later ProektMontazhAvtomatika), among others. A full-scale model of the platform was tested at the Leningrad metal factory (LMZ) and the erector at the NKMZ factory.

At Baikonur, the fourth IU management (unit no. 26360) in charge of the UR-500 was formed by decree no. 247-117 on March 2, 1962, the General Staff directive from September 19, 1962, and by order of cosmodrome manager A. G. Zakharov[1]. Then, on April 7, 1964, unit no. 93764 (19th OIITch) was formed to perform launches from area no. 81[2]. The 4th NIU also included unit no. 46180 (31st OIITch),

1 It was successively managed by Generals V. I. Menshikov (1962–1968), V. A. Nikolaenok (1968–1969), P. M. Katayev (1969–1974), A. I. Mogila (1974–1980), A. S. Sechkin (1980–1984), A. P. Zavalishin (1984–1986), V. I. Demidochkin (1986–1988), V. A. Grafinin (1988–1990), L. P. Goryushkin (1990–1992), L. T. Baranov (1992–1994), A. N. Glukhov (1994–1997), D. T. Chifin (1997–1999), V. N. Efimenko (1999–2001), S. Yu. Goncharov (2001–2005) and M. Yu. Vardanian in (2005–2006).

2 It was successively managed by Colonels (or Lieutenant Colonel) I. A. Pruglo (1964–1968), I. I. Stupanov (1968–1970), A. A. Kuzovlev (1970–1973), A. S. Sechkin (1973–1975), V. I. Polosin (1975–1980), V. I. Kostomyasov (1980–1986), S. V. Kopylov (1986–1988), A. D. Pavlov (1988–1991), D. T. Chifin (1991-1994), I. A. Forsyuk (1994–1997), S. A. Igonin (1997–2000) and Yu. V. Polikarpov (2000–2006).

which was responsible for launching the IS and US satellites with Cyclone rockets from area 90. Moreover, on April 18, 1973, unit no. 25921 (4th OIITch) was created to face the arrival of two new launch platforms on area no. 200[3]. In 1989, the 4th IU became the 2nd space means testing and usage center (TsIP KS)[4]. At different times, it included the first section for NPO Lavochkin's satellites, the second section for ISS Reshetnev's satellites, the third section for the Proton rocket, the fourth section for the preparation of launch platforms, the fifth section for telemetry, the sixth section for radiotechnical systems, the seventh section for propellants, the eighth section for early warning (Oko satellites), the ninth section for computers, the 10th section for PVOs (IS satellites) and the 11th and the 12th sections for the Navy (US satellites).

Area no. 92 included buildings 92-1 (MIK Proton), 92-2 (MIK for US satellites), 92-2V (MIK for Oko satellites), 92A-50 "Poltinnik" (MIK for satellites and their integration onto the Proton launcher), 92-223 and 92-224 (storage of IS and US satellites). The 92-1 measured 119 m long, 50 m wide and 23 m tall. The 92-2V measured 79.5 m long, 69.1 m wide and 22.2 m tall. The 92A-50 measured 229 m long, 145.8 m wide and 30 m tall. The last was destroyed in 1971–1980. It was then reconstructed in two stages in 1998–2000.

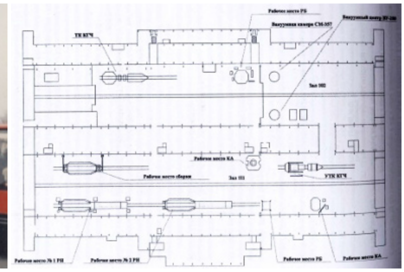
Area no. 81 (object 333) included platforms no. 23 (left) and no. 24 (right) built in 1963–1965. No. 23 served for 30 launches in 1967–1979, then it went 10 years unused. After reconstruction in 1987–1989, flights were started again on December 12, 1989. By August 18, 2011, 72 other flights had taken place. No. 24 served for 37 launches in 1965–1980, then it went 10 years unused. After reconstruction in 1997–1999, flights were started again on July 5, 1999. By August 18, 2011, 31 other flights had taken place.

---

3 It was successively managed by Colonels (or Lieutenant Colonel) V. A. Lenkevich (1973–1976), V. L. Golovachev (1976–1981), L. P. Goryushkin (1981–1983), V. S. Razin (1983-1987), V. A. Kuralekh (1987–1990), A. N. Glukhov (1990–1993), V. P. Kiryanov (1993–1995), G. A. Batishev (1995–1998), I. G. Zinovetz (1998–1999), M. D. Todorov (1999–2004) and A. I. Karpenko (2004–2006).

4 The first and fifth IU became the first TsIP KS (unit no. 44275). The third IU became the fourth TsIP KS. The sixth IU became the third TsIP KS. The seventh IU, created on September 22, 1987 to launch the Nariad-V satellites with the Rockot rockets from silos no. 131 and 175, included units no. 55056 (326th OIITch) and 46180 (31th OIITch). After performing three launches, unit no. 55056 was dissolved in 1994 and unit no. 46180 in 1998. The eighth IU, created on May 15, 1971 to launch the UR-100, was specialized in converted missiles (Dniepr, Rockot, Strela) in 1994. In 2008, the TsIP KS were dismantled when Roscosmos took the cosmodrome back from the Ministry of Defense.

a)



b)

c)

Figure 4.11. *a) Integration building no. 92-1 (source: Christian Lardier), b) the MIK 92A-50, and (c) integration building no. 92A-50 (source: all rights reserved)*

Area no. 200 included platforms no. 39 (left) and no. 40 (right) built in 1971–1976. These were models 8P82K-4F from KBOM. No. 39 served for 130 launches starting in February 1980 (Raduga). It was repaired from May to November 1986, then in 1999, with no pause in launches. No. 40 served for 66 launches starting in July 1977 (Raduga). The last launch took place in March 1991 (Almaz-1). Then, it was dismantled as part of the Kazakh Baiterek program (replacement with an Angara platform). Area no. 200 was transferred to Roscosmos in 1998 and no. 81 in 2006 (the 19th OIITch performed its last launch on December 25, 2005).

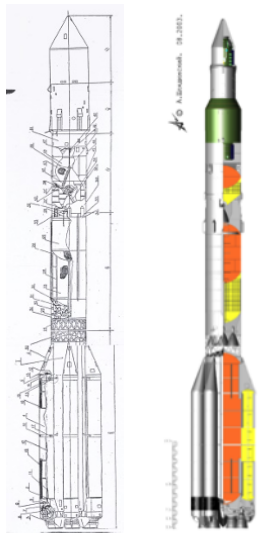
The fourth IU was dismantled in 2008. In fact, the Baikonur installations were progressively transferred from the Ministry of Defense to the Roscosmos space agency. Thus, the TsENKI was created on November 10, 1994. It was headed by A. S. Fadeyev. He received part of the installations in 1994, another in 1998, then became the holding of the terrestrial infrastructures including the KBOM, KBTM, KB TXM, KB Motor, OKB Vympel, Kosmotrans and the FKTs Baikonur. The last of these, created on May 18, 1999, was run by E. M. Kushnir, then D. I. Chistyakov. He ensured launches of Soyuz (E. A. Cherny, then V. R. Tomchuk), Proton (A. N. Glukhov, then S. I. Blyum), and Cyclone and Zenit (D. I. Chistyakov, then S. V. Sorokin).

Figure 4.12. *Proton assembly in the MIK (source: Christian Lardier)*

Figure 4.13. *A. S. Shekhoyan and building 11G141 (source: all rights reserved)*

The MIK 92A-50 was given to Khrunichev's subsidiary ZERKT (factory for the use of rocket-space technology), headed by I. S. Dodin. He succeeded the former deputies for test flights, Yu. V. Diachenko, then A. S. Shekhoyan in 1964–1980. A subsidiary of KBOM took over the use of the Soyuz (TsI-1) and Proton (TsI-2) launch platforms, whereas a TsEI subsidiary of KBTM took over the Cyclone and Zenit platforms. A TsEI subsidiary of the OKB Vympel was in charge of MIK no. 31-40 and 92-1. A TsEI subsidiary of KBTXM was in charge of the propellant fueling stations (ZSN) no. 11G12 in area no. 31 and no. 11G141 in area no. 91A. The latter had been retired in 1993 following damage to the building. Reconstruction, initiated in 2001, was finished in September 2011. It was to serve for fueling the Breeze and Bloc-DM upper stages, as well as all satellites launched from Baikonur. During this time, near the MIK 92A-50, a light station had been used to fuel the Breeze.

4.2. The three-stage version UR-500K



a) b)

Figure 4.14. *a) UR-500K (source: all rights reserved) and b) UR-500K-DOS-17K (source: Alexandre Chliadinsky). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

The UR-500K (8K82K) three-stage version was decided on by decree no. 532-205 on July 7, 1965. It made its first flight on November 16, 1968 to launch the Proton-4 (N-6) satellite, which weighed 17.0 tons. The 12.5-ton payload was an IK-15 ionization calorimeter (cosmic rays up to 1,015 eV), an SEZ-12M device to study high-energy electrons and an SEZ-13 device to detect quarks (fractional charge particles).

The third stage (8S812), with a diameter of 4.1 m, measured 4.15 m long (tanks) or 6.8 m with the engine, which was situated on the upper portion of the second stage. It weighed 4.18 tons and carried 46.6 tons of propellants. It was propelled by an 8D49 engine including an RD-0213 (8D48) with 60.0 tons of thrust and four RD-0214 (8D611) steering engines with 3.15 tons of thrust. The latter could pivot on 45º. On September 2, 2010, Voronezh's factory produced 16 8D410 and 1,436 8D410K engines for the Proton's second stages, as well as 359 8D49 engines for its third stages. During the separation of the second and third stages, six 8D84 solid-propellant engines slowed the second stage, whereas four 15D4 engines were used during the separation of the third stage and the payload (MKB Iskra's engines).

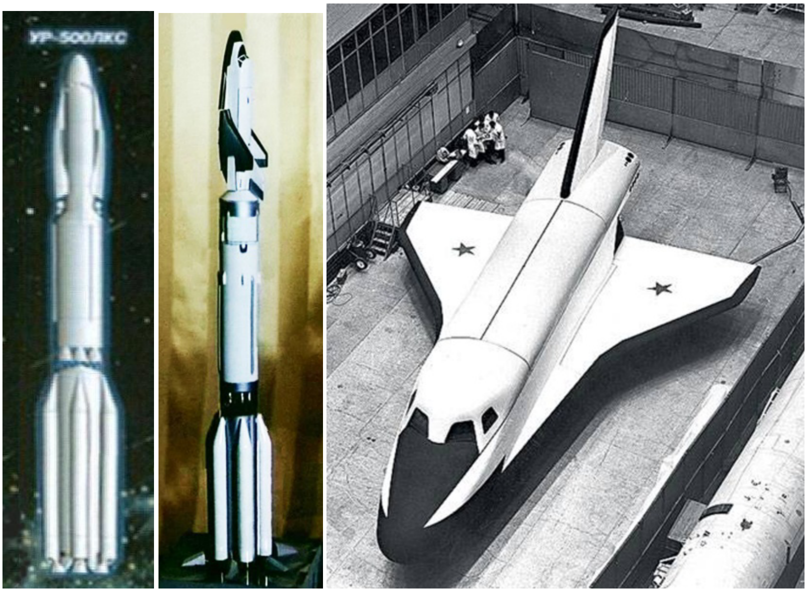


Figure 4.15. *The UR-500LKS and the LKS spaceplane (source: NPO Mash)*

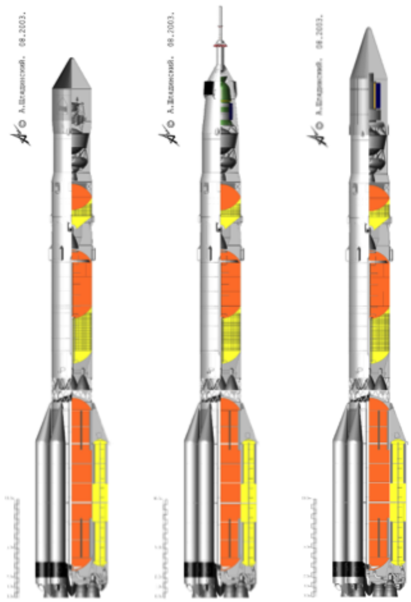
This version was used to launch orbital stations into terrestrial orbit: Chelomey's military Salyut (six Almaz stations, four TKS supply planes, four pairs of 82LB72 capsules), Mishin's civil Salyut (six DOS stations, Mir station, and Kvant, Kvant-2, Kristal, Spektr, Priroda modules), as well as the International Space Station's FGB/Zarya and SM/Zvezda.

This version would also launch the light LKS spaceplane. It was designed in 1975–1980 for strategic missions and to reach the Almaz stations. With a mass of 20.0 tons, it carried two cosmonauts and a 4.0-ton payload. It was a mini-shuttle capable of performing 100 flights using technology developed for Almaz's VA capsule. It could fly manned (10-day mission) or automatically (1-year mission). Its lateral offset was 2,000 km. A full-sale model was manufactured in 1980. For its strategic mission, Chelomey proposed putting a fleet of 360 LKS into orbit at a rate of 90 launches per year with the help of four launch platforms at Baikonur. This project had the support of the CPSU's Secretary for Space, Ya. P. Ryabov[5]. The project was presented on two different occasions to the VPK, but it was not accepted. In 1981, the State Commission, headed by deputy Minister of Defense

5 He occupied this position from 1976 to 1979.

V. M. Shabanov, examined the project, but it was once again rejected. At this time, the Buran shuttle was already being developed and the Spiral program had been abandoned.

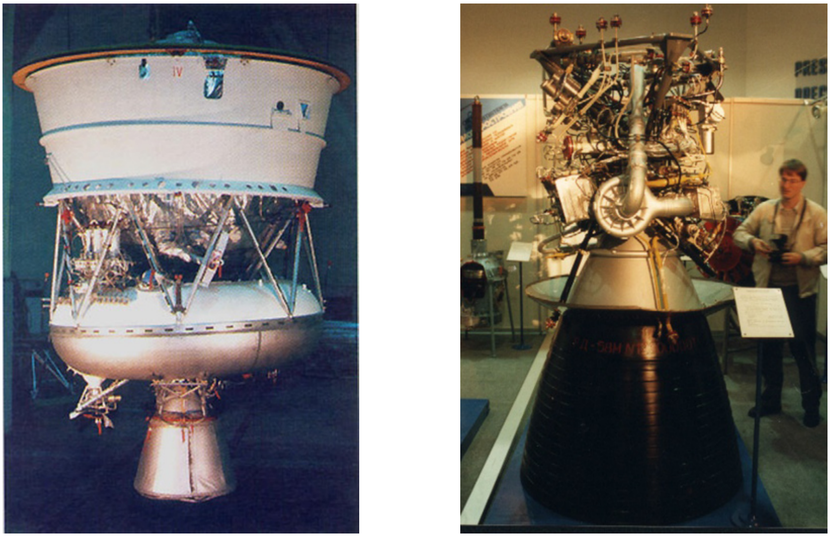
4.3. The four-stage version



a) b) c)

Figure 4.16. *a) UR-500K-7K-L1, b) UR-500K-E-8-5 and c) UR-500K-Raduga (source: Alexandre Chliadinsky)*

The Bloc-D (11S824) fourth stage had been developed by the OKB-1 for the lunar rocket N1-L3. Weighing 17.3 tons, it measured 5.5 m long with a diameter of 4.15 m. The guidance system included the L-300 GSP and the Argon-11 computer. It was equipped with an 11D58 integrated-flow engine with 8.6 tons of thrust developed by OKB-1's M. V. Melnikov and serially produced by Voronezh's mechanics factory. It was reignitable, with a working duration of 600 s. The reignition was ensured, after the ballistic phase, by the ignition system (SOZ) equipped with 11D79 engines from Turayevo's KB Soyuz.



a) b)

Figure 4.17. *a) The Bloc-D and b) the 11D58M motor (source: all rights reserved and Christian Lardier)*

In 1965, it was part of the UR-500K/7K-L1 complex. On September 21, 1966, the model of launcher no. 226-01 arrived in Baikonur for testing. On November 18 and December 9, 1966, the Bloc-D was tested on a test bench of the NII KhimMash in Zagorsk. It performed two ignitions each time. The first four-stage UR-500K launched Cosmos-146 in March 1967. From March 1967 to October 1970, 11 7K-L1 were launched with only four capsule recoveries (two ballistic returns and one crash landing). In 1968, for launches of interplanetary probes from the NPO Lavochkin, there were plans to use a new stage equipped with an oxygen-UDMH engine with 10.0 tons of thrust. In the end, the Bloc-D was used to launch the Mars-69 probes. However, the two launches failed in March and April 1969. From February 1969 to August 1976, the Bloc-D was used to perform two experimental launches, 16 lunar probes and 9 Martian probes. The experimental launches were meant to test a large number of reignitions in space: the first with short ignitions to perform a terrestrial orbit and the second to transfer a spacecraft into an interplanetary trajectory. The first launch of the 7K-L1E took place on November 28, 1969, but this was a failure. The 8D48 engine on the third stage exploded after 556.5 s of flight and the spacecraft landed 200 km north of Harbin, China. The second was launched on December 2, 1970 and became Cosmos-382. It went from an orbit at 196–276 km to 320–5,040 km, then 2,575–5,085 km. In total, the Block-D was launched 38 times with four failures attributable to it.

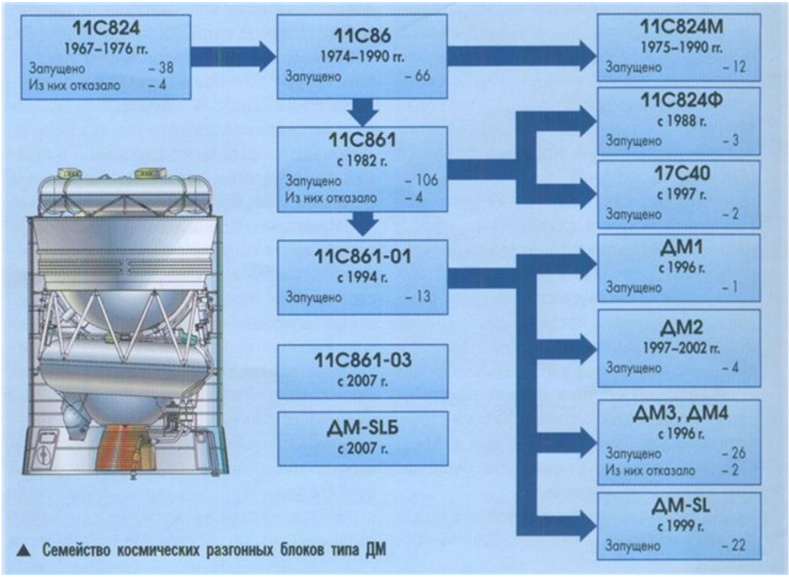


Figure 4.18. *The Bloc-D and DM versions (source: all rights reserved)*

In March 1969, a modification was made to the Bloc-D to place a direct television broadcast satellite (SNTV) from Reshetnev into geostationary orbit (GEO). It was equipped with an 11D58M engine and a ring-shaped compartment surrounding the guidance system (GSP MS-500 and S-530 computer). This guidance system received the State Prize in 1987. The engine used a synthesized hydrocarbon (syntin) instead of kerosene. The syntin was produced by the Salavat petrochemical combinate. It could be ignited up to seven times because of a new overpressure pump and a new start-up propellant. With a mass of 18.4 tons, it could place 2.6 tons into GEO. This Bloc-DM (11S86) competed with Reshetnev's fluorine 11S813. Six statistics tests were performed at the NII KhimMash from August 3, 1973 to July 30, 1975. The first flight took place on March 26, 1974 with Cosmos-637, a model of the Raduga satellite. It was launched 66 times by 1990 with no failures. The 11S824M (or D-1) version was an 11S86 with no control system (direction ensured by the payload) developed in the 1970s. It was launched 12 times from October 16, 1975 to December 1, 1989 (eight Venera, two Vega, Astron and Granat).

To launch Glonass satellites starting in October 1982, the Bloc-DM-2 (11S861) version, with a digital guidance system (GSP DS-300 and S-530 computer), was developed. It placed Glonass into circular orbit at 19,000 km or 2.4 tons into GEO. The first geostationary launch was performed on October 1985 (Cosmos-1700). To this day, it has served for 44 Glonass launches, two Tselina-2 satellites, and 70 geostationary satellites, i.e. a total of 116 launches with four failures. The last unit served to launch an Oko-2 satellite in 2012. The 11S824F (or D-2) version was developed for the two Phobos probes in 1988 and Mars-96 in 1996. This was an 11S861 with no control system. The Mars-96 launch failed and the probe fell into the Andes Mountains in Chile. The second ignition did not take place for unknown reasons. However, the propellant-consumption regulation system (RSKTK-52) of the NII-12 would be replaced by a new one (CUMD-58M).

In order to improve GEO performance, the Bloc-DM-01 (11S861-01) was developed: it was increased to 2.6 tons by adding 200–300 kg of propellants. The first launch took place with the Gals-1 satellite in January 1994. Then, it was used for the Express, Kupon, Yamal and Sesat, for a total of 13 launches by 2005. This stage would give rise to a series of versions meant for commercial flights. Thus, the Bloc-DM1 was used for the Inmarsat-3F2 satellite in September 1996. The Bloc-DM2 was used to spread the Iridium constellation (three flights) in 1997–1998 and to launch the ESA's Integral scientific satellite in October 2002. The Bloc-DM-3 was used to launch the Astra-1F satellite in April 1996. Then, it would serve for another 24 launches with two failures (notably causing the loss of the Astra-1K telecommunications satellite manufactured by Thales Alenia Space). The Bloc-DM-4 was used only once, to launch Telstar-5 in May 1997. The Bloc-DM-5 (or 17S40) was used to launch the Arkon imaging satellites into orbits of 1,500–2,700 km. To date, two have been launched: one in June 1997 (Cosmos-2344) and one in July 2002 (Cosmos-2392).

In the early 1990s, the serial production of the base model of the Bloc-DM was transferred to Krasnoyarsk's Krasmash factory. It has produced nearly 120 units to this day.

The Sea Launch and Land Launch launchers received dedicated versions of the Bloc-DM. The first was equipped with the Bloc-DM-SL (314GK) whose prototype no. 1TL launched a 4.5-ton DemoSat in March 1999. Next, a more powerful version, 314GK-A18, allowed the payload to be increased from 5.5 to 6.1 tons. Increases to the mass were made to the structure (155 kg), the propellants in the orientation and stabilization control system (57 kg), the BR-9DM-04 static-memory recorder (10.5 kg), the thermic protection suppression (15 kg), the new extended carbon–carbon nozzle developed by Perm's NPO Iskra (90 kg), etc. It was first used in June 2003 (Thuraya-2). To this day, 31 Bloc-DM-SLs have been launched. The Land Launch used the Bloc-DM-SLB (452GK). The first launch took place in April 2008. Five flights had taken place by 2011.

Figure 4.19. *Steps 1 and 2 of the Bloc-DM-03 stage (source: all rights reserved). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

The last version was the Bloc-DM-03 (11S861-03). The modifications, made to reduce the final mass to 2.35 tons, involved the use of a Biser-6 computer, the expandable nozzle on the 11D58M (also on the Sea Launch), and the replacement of the hermetic device container, yielding a 150-kg mass reduction. The performance then increased to 3.2–3.4 tons in GEO. The first launch took place on December 5, 2010, with a trio of Glonass-Ms. However, the stage was given too much propellant during fueling. Being too heavy, it fell into the Pacific. The next launch was to take place in 2012, once again with a trio of Glonass-Ms. During the second phase, the stage was to be given the new version of the 11D58MF engine by 2015. It would be equipped with new systems that would allow the SOZ and its two 11D79 with their extremely toxic fuels to be removed.

In total, 292 Bloc-D and DM were launched on the Proton and 35 Bloc-DM on the Zenit.

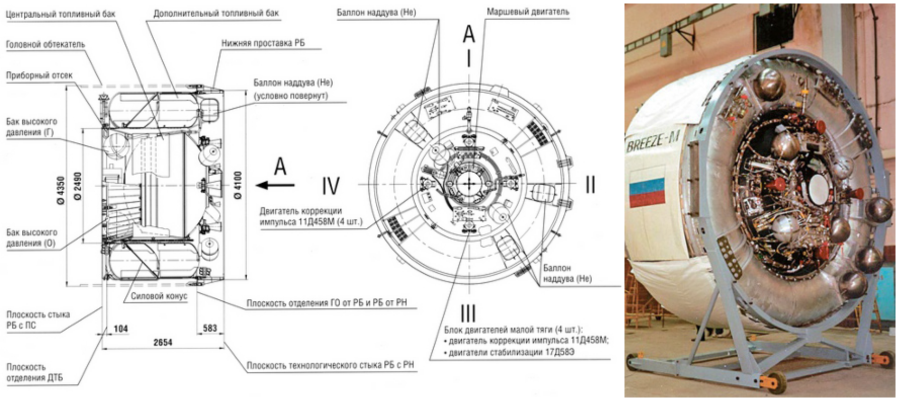


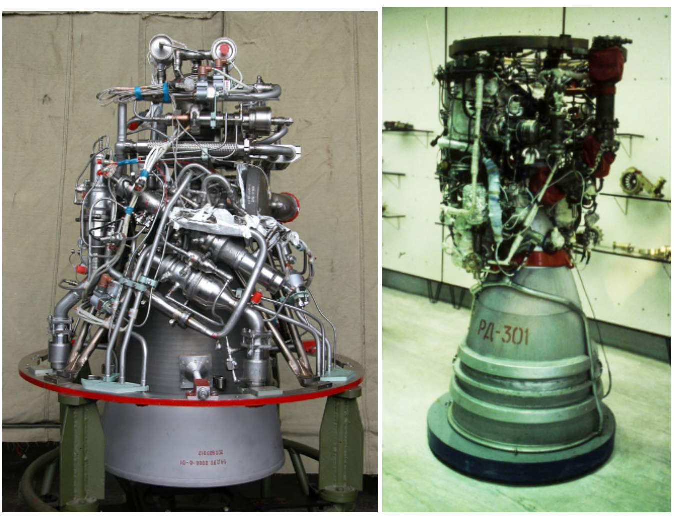
Figure 4.20. *The Breeze-M stage (source: all rights reserved and Khrunichev Center)*

In the 1980s, Khrunichev developed the Naryad-V anti-satellite system equipped with cosmos-cosmos rockets created by the main designer A. E. Nudelman from the OKB-16 (later the KB TochMash). The chief designer was E. G. Sizov, son of a CPSU Central Committee member. On the team was Boris Yeltsin's daughter Tatyana, who had worked at the KB Salyut from 1983 to 1994 (later the Khrunichev Center, headed by A. I. Kiselev in June 1993). Naryad-V was launched from a silo by the UR-100N missile with an upper stage: the Breeze (14S12). It was propelled by the S5-98 engine from KB KhimMash, with 2.0 tons of thrust and a working duration of 3,200 s. A model was presented to Gorbachev when he visited Baikonur in May 1987. The first launch took place on November 20, 1990 and the second on December 20, 1991 (suborbital flights). The program was abandoned, however, and the launcher was proposed to the cooperation. Thus, the German-Russian company Eurockot was founded in May 1994. The first orbital launch took place on December 26, 1994 (Breeze-K). In 1997–1998, the stage was modified into the Breeze-KM. The first Rockot launch took place on May 16, 2000 from Plessetsk (Iridium model). This stage would then give rise to the Breeze-M (14S43) meant for the Proton-M launcher. The guidance system was provided by the OKB Mars (A. S. Syrov) with a GSP from the Institute of Command Devices (V. P. Arefyev). The engine was an S5-98M (14D30) capable of igniting eight times. Orientation and stabilization were performed with the help of four 11D458 engines and 12 17D58E engines. The toric tanks contained 20.0 tons of propellants (N_2O_4-UDMH). The first flight (no. 88501) took place on July 5, 1999, but the launch failed after 427 s due to the second stage of the Proton-K. The Raduga satellite was lost. The second flight took place on June 6, 2000. The Proton-K successfully launched a Gorizont satellite. Finally, the third flight on November 20, 2001 was performed with the first Proton-M (no. 535-01). It placed the Ekran-M16 satellite into orbit. Since then, it was used

53 times on two Proton-Ks and 51 Proton-Ms up to 2011. It would continue to be used on Proton until 2017–2018, when the new Angara launcher would begin its commercial career. Breeze-M would then be part of the upper stages of the Angara-A3 and A5 versions.

4.4. The upper stage projects

On July 4, 1966, the MOM decided to develop ammonium fluoride third and fourth stages and also to create a draft with a hydrogen fluoride mixture. The engines were from Glushko's OKB-456. It had started using fluorine in 1958 at the Primorsk subsidiary (50 km from Vyborg, near Leningrad), which was headed by E. N. Kuzmin. The first projects (10.0 tons of thrust, specific impulse of 400 s) were the engines RD-303 or 8D21 (1960–1965) and RD-302 or 11D13F (1965–1968) for Yangel's rockets. The first firing took place in August 1963.



a) b)

Figure 4.21. *a) The 14D30 engine (source: all rights reserved) and b) the RD-301 (OKB-456 Museum) (source: Christian Lardier). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

In 1967, a decree launched the direct television broadcast geostationary satellite program. This satellite was powered by a nuclear reactor and launched by a Proton rocket equipped with an ammonia fluoride 11S813 fourth stage. The satellite and the stage were developed by M. F. Reshetnev's OKB in Krasnoyarsk. Production would be ensured by the Omsk Polyot factory, the Krasnoyarsk KrasMash factory and the Glushko factory in Khimki. The RD-301 or 11D14 was developed in 1969–1973, then underwent ground testing in 1973–1976. However, by limiting the power and frequency of the direct broadcasting, the IUT prevented the pursuit of this program. It was abandoned in December 1976. Half a billion rubles had already been spent and the engine was finishing its three-step tests with 200,000 s of operation.

In the meantime, on April 5, 1972, the Raduga satellite (11F638) was decided on with a launch on the Proton, equipped with a Bloc-D fourth stage from Energiya (11S86). The first geostationary launch took place on March 26, 1974 with a Raduga model. The second launch on July 29, 1974 was a geostationary Molnya-1 or Molnya-1S. The first Raduga was launched on December 22, 1975.

Furthermore, three experimental hydrogen fluoride engines had been studied: the RD-350 or 11D16 with 10.0 tons of thrust (1961–1967), the RD-351 with 25.0 tons of thrust (1967/?) and the RD-352 with 10.0 tons of thrust (?/1976). The specific impulse was to reach 465 s, but this work was also abandoned in 1976. Moreover, the use of fluorine posed serious safety issues.

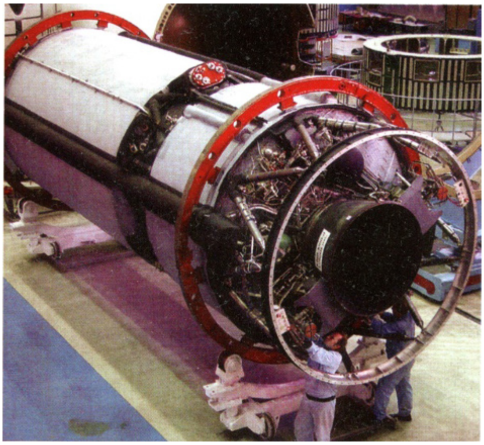


Figure 4.22. *The 12KRB stage (source: Khrunichev Center)*

In 1971, by initiative of the NII-88 (TsNII Mash) and the NII-1 (NII TP), the Proton-K was to be given a cryogenic third stage equipped with an 11D57 engine with 40.0 tons of thrust, manufactured by A. M. Lyulka. This was confirmed by a MOM decision on December 9, 1971, which requested a technical proposition by the first quarter of 1972.

However, it is not until 1982 that work started on the Shtorm stage (14S41) equipped with an 11D56U or KVD-1 engine with 7.5 tons of thrust, manufactured by Isayev's KB-2 (KB KhimMash). A decree from the minister was signed in August 1987 and decisions were made by the VPK in January and by the minister in February 1988 to create the stage in 1988–1992. It allowed up to 3.7 tons to be placed into GEO. However, work was stopped in 1991 during the collapse of the Soviet Union. They were nevertheless commercialized in India in seven cryogenic 12KRB stages meant for the GSLV launcher. Discussions between Glavcosmos and the ISRO had begun in 1989. At the time, this was a violation of the MTCR treaty on transfers of technology. France, which had sold the Viking engine to India, had not managed to sell it the HM-7. But the contract was finally signed on January 18, 1991. This is why the United States would later impose a quota on the Proton on the commercial market. On April 18, 2001, the first stage lifted off on the GSLV-D1, which launched the 1.5-ton Gramsat-1A satellite.

Since then, Khrunichev has not stopped proposing versions of Proton-K and Proton-M with cryogenic stages. This included the KVRB, which was first studied in 1995 and which had also been proposed for the Zenit and Ariane-5. The stage, 3.6 m in diameter, was equipped with a KVD-1 engine and a guidance system manufactured by the OKB Mars in Moscow. Furthermore, the KVTK stage, 4.0 m in diameter, is finally being developed for the new Angara launcher.

4.5. The UR-500MK

Figure 4.23. *The UR-500MK (source: I. Marinine Novosti Kosmonavtiki)*

Chelomey had proposed this oxygen-kerosene version in 1975. Equipped with NK-33 engines instead of RD-253, development would cost less. The NK-33 would become available after the end of the N1-L3 lunar program. Following in the footsteps of the RD-253, it had a thrust of 150 tons on the ground. Order no. 153 from MOM on April 29, 1975 asked Chelomey to study the rocket, capable of placing 25 to 30 tons into a low orbit. Two versions 11K98 (three lateral blocks) and 11K99 (six lateral blocks) were planned. The first, 590 tons at liftoff, could launch 15.0 tons, while the second, weighing 1,000 tons, could launch 30.0 tons. The central body, equipped with an NK-43 engine (altitude version of the NK-33), was surrounded by three or six boosters, all the engines being ignited at liftoff. The tanks were the same as those of the UR-500. Guidance was ensured by an onboard computer. However, these launchers competed with Glushko's projects: 11K37, Zenit (11K77) and Energiya (11K25). In 1976, the choice was made for Zenit/Energiya and the UR-500MK was abandoned.

4.6. The UR-530

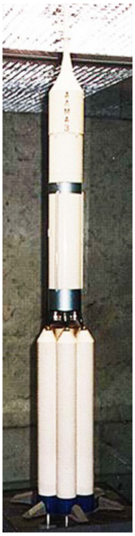


Figure 4.24. *The UR-530 (source: all rights reserved)*

In 1977, Chelomey proposed the UR-530, intended to launch an Almaz space station, equipped with a capsule for four or five cosmonauts, capable of being placed into polar orbit. To increase the payload from 20.0 to 35.0 tons, the lateral blocks were replaced by the first stages of the UR-100N (15A30) intercontinental missile. It was therefore the 30 from the 15A30 that gave its name to the launcher. It weighed 1,200 tons at liftoff. The first stage was a bundle including a central body and six lateral blocks. These were extended first stages (2.5 m diameter instead of 1.6 m) of the UR-100N (with additional propellants). They were equipped with 15D95 engines (3 × RD-0233 and 1 × RD-0234) with a unitary thrust of 210 tons (total thrust of 1,470 tons). The second stage was that of the UR-500, but it was also lengthened to hold more propellants. It was propelled by an 8D410K made up of three RD-0210 (8D411K) and one RD-0211 (8D412K). The guidance system came from the UR-100N. The launch platform was an 8P822K with some modifications. Furthermore, the ecological aspect had been dealt with through neutralization of the tanks of toxic propellants (N_2O_4-UDMH), the elaboration of UDMH processing and destruction methods, and calculations of the effects on the ozone layer. The project was submitted to the higher authorities. It had the support of CP Secretary Ya. P. Riabov, but it would be abandoned in 1978.

4.7. The Proton-M

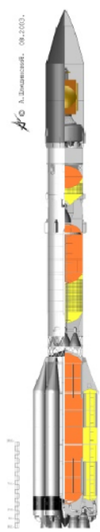


Figure 4.25. *Proton-M Breeze-M (source: Alexandre Chliadinsky). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

This project dates back to 1993. The main designer was G. A. Khazanovitch in 1993–2002, then L. I. Voloshin. It was first decided to reduce the mass of the structure, to improve construction, to use composite materials and to replace the guidance system (GSP PV-300 and Biser-3 computer like on the Sea Launch). A great deal of attention was paid to the ecological aspect: first- and second-stage tanks that emptied out in flight and reduction in the size of the stage fall out zones.

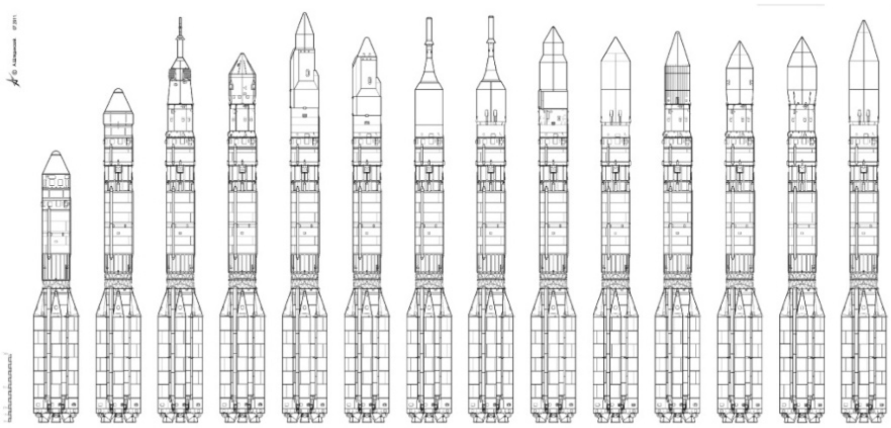


Figure 4.26. *Every version of the UR-500K Proton rocket (source: Alexandre Chliadinsky)*

In 1998–1999, the decision was made to replace Energiya's Bloc-DM with the Breeze-M. Financing was to come from their own funds, as there was no State money for the projects being developed (Proton-M, Angara, Monitor, Dialog). The Breeze-M first performed two flights on Proton-K, then, on April 7, 2001, the first Proton-M/Breeze-M launched Ekran-M16. The Breeze-M was more than a ton lighter than the Bloc-DM and its performance increased to 4.98 tons in geostationary transfer orbit (GTO) or 2.5 tons in GEO.

Modernization was pursued in four phases. Phase I from 2004 allowed the payload to be increased to 5.64 tons in GTO or 3.0 tons in GEO. Phase II started on July 7, 2007 with the introduction of the RD-276 (14D14M) engine with 170.4 tons of thrust (+5.2% in relation to the RD-275). The performance then reached 6.0 tons in GTO or 3.2 tons in GEO. Phase III started in February 2009 with the first double launch (Express-AM44 and Express-MD-1). The payload went from 6.15 tons in GTO or 3.25 tons in GEO. However, because of a specific launch method, a 6.3-ton satellite was placed into GEO in March 2010. Phase IV, the final one, involved reducing the stages' weight with new materials. It was to allow 150 kg to be gained so as to achieve a 6.3-ton performance in nominal mode. The first flight took place on June 9, 2016.

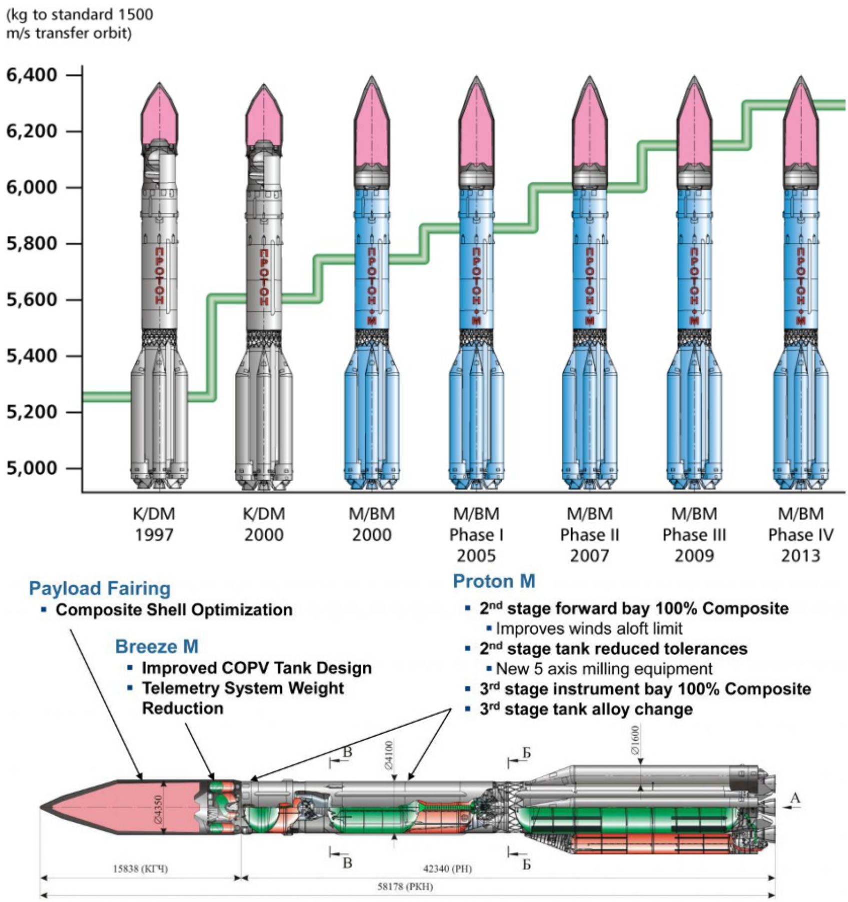


Figure 4.27. *Phase IV of the improvements to the Proton-M (source: Khrunichev Center). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

Proton's development had been rewarded with the State Prize in 1985. Proton-M was awarded with the State Prize in 2007. It was received by V. E. Nesterov (general director), L. I. Voloshin (main designer), I. S. Dodin (ZERKT director), V. N. Sychev (factory manager), Yu. A. Tsurikov (Khrunichev), I. A. Arbuzov (Perm Motors), S. A. Lyssenko (Space Forces), V. V. Morozov (NPO AP), G. G. Raikunov (TsNII Mash) and A. N. Chulkov (Roscosmos).

4.8. Proton medium and light

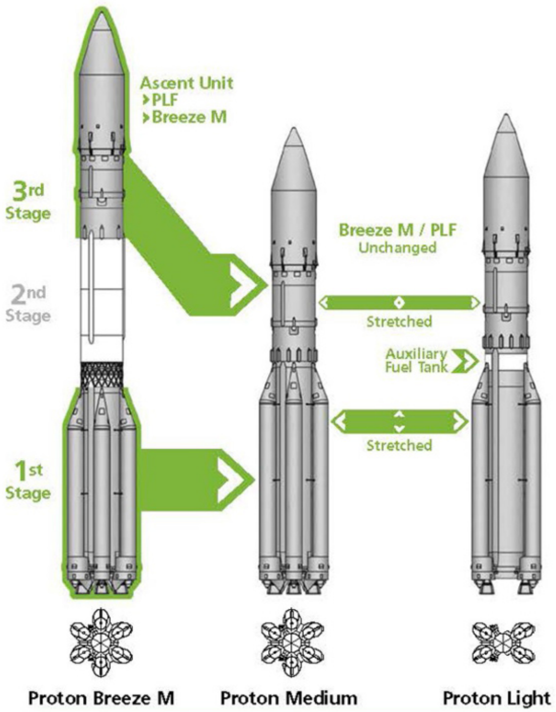


Figure 4.28. *The medium and light versions (source: Khrunichev Center)*

On September 12, 2016, at the World Euroconsult Summit in Paris, ILS unveiled the new medium and light versions. These involved eliminating the second stage of Proton-M, extending the first stage (addition of 35.0 tons of propellants) and extending the third stage (addition of 22.0 tons of propellants). Furthermore, for the light version, there were only four lateral boosters instead of six and a small supplemental tank at the top of the central body. The Breeze-M and the fairing remained unchanged. Its performance, with a delta V of 1,500 m/s, is 3.6 tons for the light, 5.0 tons for the medium, 6.3 tons for the Proton-M Phase IV and 7.0 tons for a future Proton-M+. This family of launchers allows it to be competitive with the expendable and recoverable Falcon-9 from Space X. The medium should fly in 2018 and the light in 2019.

4.9. Angara

a) b)

Figure 4.29. *a) 1995 project (source: Khrunichev Center) and b) 1997 project (source: Christian Lardier). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

The project for a Proton successor dates back to late 1993. It was launched following a decision by President Yeltsin on April 18, 1994. Two projects were competing: Khrunichev's Angara-2 and RKK Energiya's Energiya-3. At the time, Polukhin, Karrask, Dermichev and others proposed an initial project with lateral tank stages from Makeyev and a second cryogenic stage from Energiya. It was equipped with the RD-170 engine on the first stage and the RD-0120 on the second stage. The launch platform was created by the KBTM. This project was kept. It was the subject of a decision by the Space Forces and Roscosmos on August 12, 1994, then a presidential decree on January 6, 1995, as well as government decree no. 829 from August 26, 1995. The test flights were then planned for 2005, but the concept was then revised: the lateral tanks were abandoned. The vehicle became modular with a universal URM block for a family of launchers of all sizes: small (Angara-1.1 and 1.2), medium (Angara-A3) and heavy (Angara-A5 and A7). Unlike the Proton, Angara used ecological propellants (oxygen, kerosene, hydrogen). The URM was propelled by the new RD-191 engine from EnergoMash (196 tons of thrust on the ground). The upper stages would be Soyuz-2's Bloc-I (RD-0124 with 30.0 tons of thrust), Fregat-SB (2.0 tons of thrust), Breeze-M (2.0 tons of thrust) or the cryogenic

KVTK (RD-0146D with 7.5 tons of thrust). The guidance system was created by the NPO AP in Moscow (GSP PV-300 and Biser-3 computer).

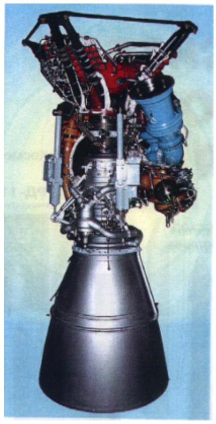


Figure 4.30. *RD-191 (source: all rights reserved)*

The new project was presented at the International Aviation and Space Salon MAKS in Zhukovsky in August 1997. It was the subject of a new decision by the Space Forces and Roscosmos on September 3, 1997. Another decision on January 12, 1998 fixed financing for eight years: it was ensured 68% by Khrunichev, 16% by Roscosmos and 15% by the Ministry of Defense.

a) b)

Figure 4.31. *a) RD-0146 and b) RD-0146D (source: all rights reserved). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

The main designer of Angara was G. V. Kleimenov. The Angara-1 was presented at the Paris Air Show in June 1999. This was a 171-ton launcher capable of placing 3.8 tons into a low orbit. The first stage was sold to South Korea, which made it into its national launcher, KSLV-1 (three flights in August 2009, June 2010 and January 2013). The Angara-A3 (three URM) was a 481-t launcher capable of placing 14.6 tons into a low orbit. The Angara-A5 (five URM) was a 773-ton launcher capable of placing 24.5 tons into a low orbit or 6.6 tons into GTO. It was sold to Kazakhstan as the national launcher, Baiterek. Lastly, the Angara-A7 was a 1,133-ton launcher capable of placing 35.0 ton into a low orbit.

Figure 4.32. *The reusable Baikal booster from 1999 (source: all rights reserved)*

Figure 4.33. *The Angara with reusable boosters (source: Christian Lardier)*

Figure 4.34. *The Angara family in 2011 (source: Christian Lardier)*

The cryogenic KVTK stage is to be used on Angara-A5 starting in 2021. Financing has been ensured since 2006 in the framework of the federal Dvina-KVTK program. Its RD-0146D from the KB KhimAvtomatiki in Voronezh was an Expander engine with 7.5 tons of thrust and 470 s of specific impulse. The first firing of the RD-0146 took place on October 9, 2001. The stage was developed in five versions: KVSK for the Angara-A3, KVTK for the Angara-A5 and A7, and KVTK-2 and 2B for the Angara-7V. The KVSK, with a mass of 13.84 tons, placed 3.5 tons into GTO or 2.0 tons into GEO. The KVTK of the Angara-A5, with a mass of 23.53 tons, placed 7.5 tons into GTO or 4.5 tons into GEO, while the KVTK of the Angara-A7, with a mass of 31.25 tons, placed 12.5 tons into GTO or 7.2 tons into GEO. The KVTK-2, with a mass of 43.31 tons, placed 19.0 tons into GTO or 11.4 tons into GEO. Lastly, the KVTK-2B, with a mass of 48.56 tons, could place 19.0 tons into lunar orbit after a rendezvous with the payload in terrestrial orbit.

Figure 4.35. *Initial flight of Angara-1.2PP (source: all rights reserved)*

The launch platform was built on the site previously planned for the Zenit launch in Plesstsk: area no. 35. However, the work would be very slow. The inaugural flight of Angara-1.2PP (first flight) took place from the Plessetsk platform on July 9, 2014, and that of the Angara-A5, on December 23, 2014. The Angara-1.2PP (14A125-01 no. 71601), with a URM-2 upper stage with an RD-0124 motor, had performed a suborbital flight. The Angara-A5 no. 1L (14A127 no. 71751), with the third stage Breeze-M no. 88801, had placed the IPM model weighing more than 2.0 tons into GEO. The second Angara-A5 no. 752 was planned for mid-2017 with the Bloc-DM-03 upper stage and the Angosat-1 telecommunications satellite from Energiya. In January 2015, EnergoMash announced the production of 10 RD-191s for the Angara-A5 no. 3 and 4 in 2015 and 2016. In June 2016, the company planned to double production: 22 motors in 2016 and 40 in 2017. Moreover, in August, the transfer of production to the Proton-PM factory in Perm was canceled to leave it in Moscow.

In December 2015, the Omsk factory announced the production of the Angara-1 no. 602 and Angara-5 no. 753, 754 and 755 in 2016. The Angara-1 no. 602 is to fly in 2017 (version 1.2/AM), then launch trios of Gonetz satellites by 2025. An initial commercial launch was sold to South Korea: the Kompsat-6 would be launched in 2020. As for the Angara-5 no. 753, it is meant to launch a military satellite in 2018. A second launch platform is to be brought into service in Plessetsk in 2019. Then, Vostochny’s should be inaugurated in 2021 to launch a Luch-5M satellite relay.

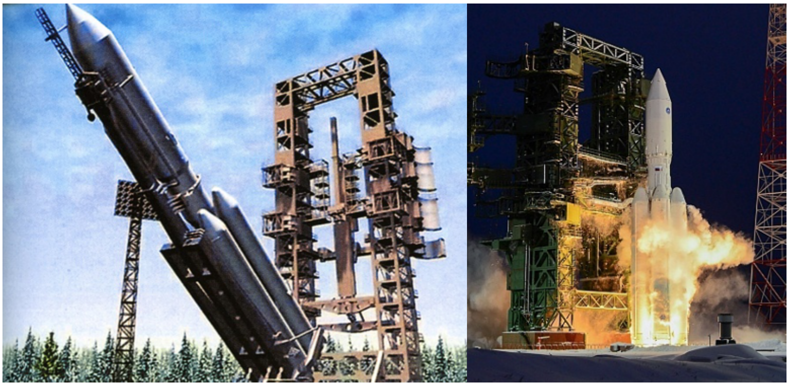


Figure 4.36. *Initial flight of the Angara-A5 on December 23, 2014 (source: KBTM and all rights reserved)*

The test flights include 10 launches. In 2018, serial production is to start at the Omsk factory (URM-1 and URM-2) and at the Khrunichev factory (upper stages): two rockets per year in 2018–2020, four per year in 2021–2022, six in 2023, then seven per year starting in 2024. The Omsk factory is planned to produce up to 100 URM per year. Angara's price on the commercial market will be less than that of the Proton.

In 2011, Roscosmos decided to replace the Rus-M launcher project, which was supposed to be launched from the new Svobodny/Vostochny cosmodrome starting in 2015, with the Angara-A5P (piloted), which would, for the first time, be a Khrunichev launcher authorized to make manned flights. This would launch the future new-generation manned spacecraft, PTK-NP "Federatsia", which would replace the Soyuz-TMA, a historic comeback, given that the Proton had never been authorized to do this. The prototype is to fly automatically in 2021 and the first manned flight is planned for 2023 (flight to the ISS).

In early 2015, Roscosmos adopted the new 2016-2025 Federal Space Program. It abandoned the super-launcher project for Moon conquest and replaced it with the Angara-A5V, which allowed flights over the moon in two launches and lunar landing in four launches. It had the same performance capabilities as the Angara-7, but it had four boosters instead of six. The first stage was equipped with RD-191M (+10% thrust), the URM-2 second stage was replaced by a cryogenic stage with RD-0150 and the Breeze/Bloc-DM stage was replaced with another cryogenic KVTK stage with RD-0146. The first flight, for an automatic flight over the Moon, is planned for 2026. Lunar landing is projected for 2030.

a) b)

Figure 4.37. *a) The cryogenic stage projects: Shtorm (1980s), heavy stage for Proton, 12KRB for GSLV, KVTK for Angara-5. b) The cryo stages of Angara A3, A5 and A7 (source: all rights reserved). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

The first Angara-A5 with the KVTK cryogenic stage should launch the Luna-29 interplanetary probes (lunar sample returns) and Expeditsia-M, a.k.a. Phobos-Grunt-2 (Martian sample returns) in 2024, then the pair of Laplace probes to Jupiter in 2026. Starting in 2025, the Angara-A5 with the Bloc-DM-03 stage will launch the Elektro-M meteorological satellites. Later, it will launch the telecommunications satellites Enessei-A1 (mobile communications) and Ellipse (special communications).

The Baiterek version is intended for Kazakhstan. For this, platform no. 40 in area no. 200 (Proton) must be rebuilt. Initially, the cost of approximately 200 million dollars was to be financed 50% by Russia and 50% by Kazakhstan. For a while, there were plans to use the Zenit from platform no. 45 instead of Angara so as to reduce the project cost, but after the Russian-Ukrainian crisis, it was decided that the Sunkar launcher, a derivative of Zenit, would be produced instead. It is meant to fly around 2024.

Finally, Khrunichev studied versions of Angara equipped with recoverable Baikal boosters (VRE-PK). These studies had started with NPO Molnya in the 1990s. In the perspective of a lunar and Martian exploration program planned for 2030–2040, this launch method would cost 1.5 times less than a classic launcher. In addition, Roscosmos planned to develop a reusable MRKS-1 launcher in the future. An initial stage would consist of a VRB-TK reusable stage demonstrator. Unfortunately, the financing planned in the 2016–2025 Federal Space Program was abandoned in January 2016.

5

The Uses of the Proton

5.1. NPO Mashinostroyenie: the Almaz program

Figure 5.1. *Almaz station project with a VA capsule (source: NPO Mash)*

The OPS orbital station project (11F71) from the OKB-52 dates back to October 1964. Launched by the UR-500K, it had a lifetime of 1–2 years and could be occupied by two to three men. With a diameter of 4.1 m, it weighed 15.0 tons and possessed a 4.9-ton VA capsule (11F74). At first, it was serviced by the Soyuz spacecraft, then by the 20.0-ton TKS cargo spacecraft (11F72). It included the FGB module (11F77) and a VA capsule. For the first time, it was a matter of sending men into space with the Proton rocket. This would also be the case with the 7K-L1 program in 1967–1968. However, this would never come to fruition. An equivalent to the United States' MOL, it would be equipped with a camera, television, radar and radiotechnical means to localize strategic points to target them with the ICBM (enemy silos, factories, towns, etc.).

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

Figure 5.2. *TKS project based on the 7K-VI vessel (source: NPO Mash)*

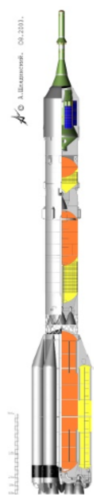


Figure 5.3. *UR-500-TKS (source: Alexandre Chliadinsky). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

This decision dates back to a decree from July 1, 1966. The project was examined by a commission led by General V. P. Morozov (NTK RVSN) in 1967. The station was equipped with an Agat-1 camera from Krasnogorsk's factory (Kometa-11A lens from LOMO). The resolution was 3 m. The camera had three channels. One of the films was processed in orbit with the Peshora device and transmitted back to Earth via television (VNII Television and TsNIRTI). The other films were brought back in small KSI capsules (11F76) weighing 360 kg. The TKS could be occupied by three cosmonauts and carried eight KSI capsules. It allowed the electrical power to be increased and the complex's orbit to be raised again. For its protection, the station was equipped with an NR-23 cannon from Nudelman (Schit-1 program). To use this cannon, the cosmonauts had a Sokol-1 periscope and the Yantar-P infrared detector to discover targets in the lower atmosphere. In a second stage, there were plans to use cosmos-cosmos rockets (Schit-2 program).

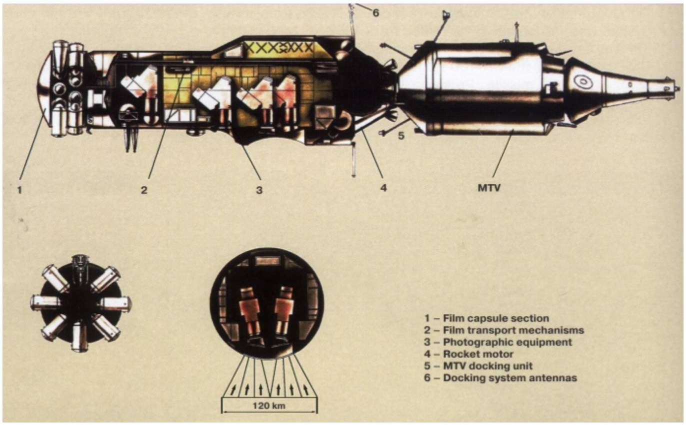


Figure 5.4. *The Almaz station with the TKS supply ship (source: NPO Mash)*

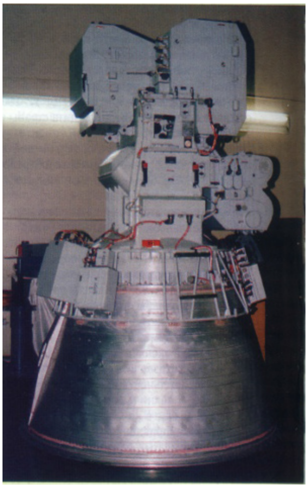


Figure 5.5. *The Agat-1 camera (source: all rights reserved)*

In September 1966, a group of cosmonauts from Almaz was formed at the Zvyozdny Gorodok (headed by Belayev in 1966–1969, Popovich in 1969–1970, Shonin in 1970–1973 and Artiukhin in 1974–1982). The group was joined by a large number of military cosmonauts chosen in 1963, 1965 and 1967. This included a maximum of 28 cosmonauts. In parallel, the OKB-52 had recruited its own cosmonauts in 1968 (Makrushin, Sukhanov, Eremich, Berkovich, the last of whom was replaced by Smirnichevsky in 1969). They were joined by Yuyugov and Romanov in 1973; Grechanik, Gevorkian and Khatulev in 1978; and then Chelomey (Sergey, the son of the general designer) in 1981.

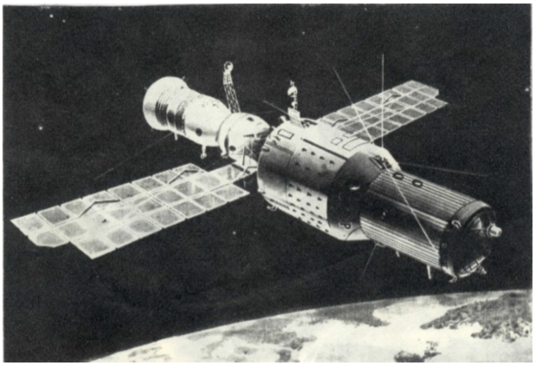


Figure 5.6. *The Almaz station with the Soyuz spacecraft (source: NPO Mash)*

Figure 5.7. *The Almaz cosmonauts (source: all rights reserved)*

In 1966, an anechoic chamber from NIIAiKM was equipped with an OPS interior for a 70-day simulation. In 1970, three crews were formed to train on the VA capsule: Fedorov-Demin-Preobrazhensky, Yakovlev-Zholobov-Stepanov and Zudov-Glazkov-Lissun. Next, three simulations lasting 36 days (December 1971–January 1972 with Panchenko-Alyev), 35 days (September–October 1972 with Lissun-Preobrazhensky) and 94 days (November 1972 to February 1973 with Glazkov-Khludeyev) took place in the analogue to the OPS (no. 0100).

Manufacturing began in 1968–1969 at the Khrunichev factory. The first flight was planned for April 22, 1970 to commemorate Lenin's 100th birthday. However, delays in the delivery of equipment began to add up. In December 1969, the modules were granted to the OKB-1 for the DOS program. However, the OPS + TKS + VA system was confirmed by the June 16, 1970 decree. The first OPS-1 no. 0101 flight module (with no VA capsule) was to be launched with the Skylab planned for April 1973. The delivery of equipment, particularly the Agat-1 camera, was delayed. Chelomey sent letters to the minister and the Central Committee's sector to accelerate things. The OPS-1 was delivered to Baikonur on December 25, 1972. Two days later, the State Commission was formed by decree no. 888-303. The president was Colonel General M. G. Grigoriev, first deputy of the RVSN. The deputies were A. G. Karas (GUKOS), M. N. Mishuk (VVS), M. A. Brezhnev (MOM), Chelomey (technical director), A. G. Zhamaletdinov (OPS station), D. A. Polukhin (Proton rocket), Yu. P. Semenov (7K-T spacecraft) and A. M. Soldatenkov (Soyuz rocket). The OKB-1 had developed version 11F615A9 of the Soyuz 7K-T for this program. The Igla rendez-vous and docking system was modified to tilt backwards to avoid colliding with elements of the station. However, spacecraft no. 61 was not ready: additional work on the new primary parachute was necessary. The station launch was initially planned to take place between May 19 and 25, 1973, but work on the parachute dragged on and the decision was made to return to the old model. The Soyuz launch was then rescheduled for April 7–8, then May 8. In the end, it was launched on May 27 for a 2-day test flight (Cosmos-656).

In the meantime, the OPS-1 (Salyut-2) station was launched, on April 3. It then had to make an autonomous 37-day flight instead of a 10-day one. However, on day 34 (188th orbit), the pressure in the airtight compartment dropped by half. An inquiry committee was formed, headed by Karas. It appears that debris from the explosion of the Proton's third stage had struck the station and caused the depressurization. It was then decided that valve would be added to evacuate the remaining propellants in the stage's tanks.

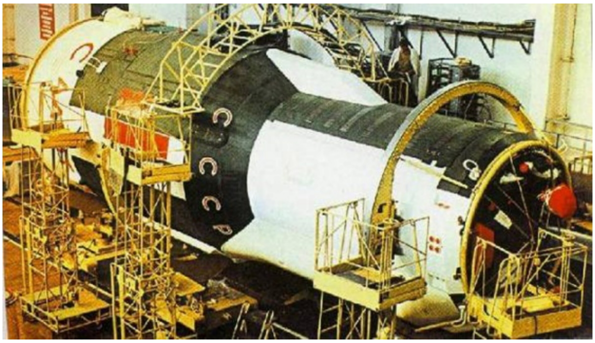


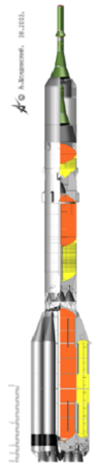
Figure 5.8. *The Salyut-3 station (OPS no. 0101-2) (source: all rights reserved)*

Figure 5.9. *Popovich and Artiukhin in Salyut-3 (source: all rights reserved)*

The second flight model, OPS-2 no. 0101-2 (Salyut-3), was launched on June 25, 1974. On July 3, the Soyuz 7K-T no. 62 (Soyuz-14) was launched with the Popovich-Artiukhin crew, which performed a 2-week mission on board the station. They placed the KSI capsule in the airlock. On August 26, a second crew (Sarafanov-Demin) was launched on board the Soyuz no. 63 (Soyuz-15), but the failure of the Igla system prevented meet-up with the station. They had to return to Earth. Finally, KSI capsule no. 506 was recovered despite the failure of the parachute system on September 23.

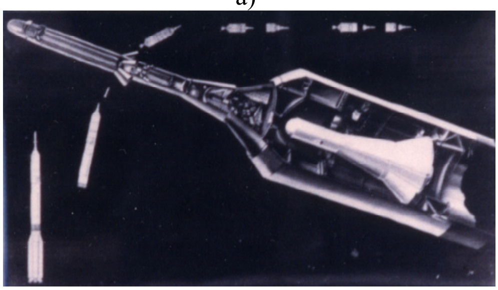
Figure 5.10. *The Soyuz-14 State Commission (source: all rights reserved)*

The third flight model, OPS-3 no. 01013 (Salyut-5), was launched on June 22, 1976. On July 6, the Soyuz 7K-T no. 41 (Soyuz-21) was launched with the Volynov-Zholobov crew, which was to perform a 64-day mission on board the station. However, Zholobov suffered from nausea and vomiting starting on day 44. The decision was made to bring them back to Earth on day 48. The State Commission asked them to take air, condensate and dust samples for toxicological analyses. No toxic particle was discovered. According to Oleg Gazenko, director of the Institute for Medical-Biological Problems (IMBP), the cause was emotional tension and a work overload. In addition, for the following flight, psychological support and a modification of the work–rest regime was decided. The Soyuz 7K-T no. 65 (Soyuz-23) was launched on October 14, 1976 (Zudov-Rozhdestvensky). This crew brought an air analysis laboratory, but a rendez-vous was not possible and the equipment returned to Earth after 2 days. It landed in Lake Tengiz, where an emergency evacuation was performed.



a)

b)



c)

d)

Figure 5.11. *a) UR-500-82LB72 (source: Alexandre Chliadinsky), b) the 82LB72 capsule test program, c) the VA capsule (source: Christian Lardier) and d) 82LB72 launch (source: all rights reserved)*

The Soyuz 7K-T no. 66 (Soyuz-24) was launched on February 7, 1977 (Gorbatko-Glazkov). It replaced one of the computers at the station, placed KSI capsule no. 507 into the airlock and proceeded to a replacement of the atmosphere during a 17-day flight. The day following their return to Earth, the KSI capsule was recovered. Two other crews prepared to join the station: Berezovoy-Lissun and Kozelsky-Preobrazhensky. However, the Soyuz 7K-T spacecraft no. 67 was not ready and the station did not have enough propellant reserves. It was destroyed on August 8, 1977 (the 7K-T no. 67 would serve for the Soyuz-30 mission in June 1978).

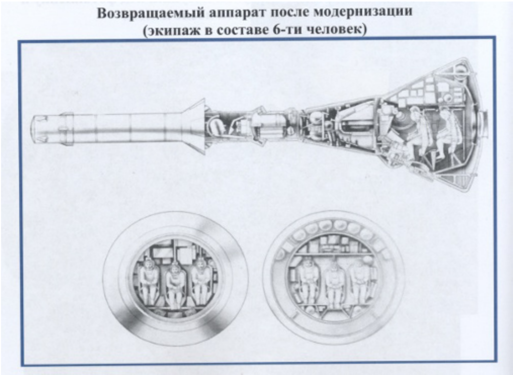


Figure 5.12. *Six-cosmonaut version (source: NPO Mash)*

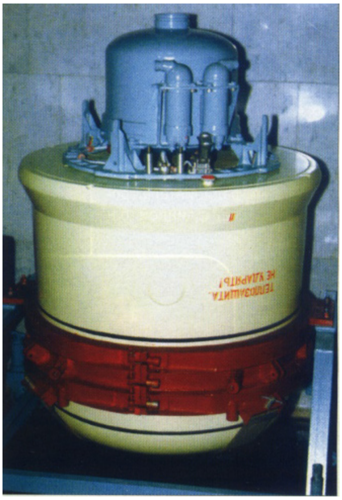


Figure 5.13. *The KSI capsule (source: NPO Mash). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

The OPS-4 station (no. 104) was ready in 1978. It was to be joined by a TKS. The decree from January 19, 1976 indicated that the TKS test flights would include two automatic flights starting in 1976 and five manned flights starting in 1978. The VA capsule had undergone autonomous tests in area 51 at Baikonur (failure of capsule rescue tower no. 005 in October 1979). It was then the subject of the 82LB72 program: launching pairs of capsules with the UR-500K rocket. The State Commission was headed by General G. S. Titov. The first LVI-1 launch (Cosmos-881 and 882) took place on December 15, 1976 with capsules no. 009 (lower, with no rescue tower) and no. 009A (upper, with rescue tower). The second LVI-2 launch took place on August 4, 1977 with capsules no. 009P (lower, with no rescue tower) and no. 009A/P (upper, with rescue tower). However, the Proton rocket failed after 49 seconds of flight (problem with the RD-253 engine) and capsule no. 009A/P was recovered. The third LVI-3 launch (Cosmos-997 and 998) took place on March 30, 1978 with capsules no. 009P/2 (lower, with no rescue tower) and no. 009A/P2 (upper, with rescue tower). Finally, the fourth LVI-4 launch (Cosmos-1100 and 1101) took place on May 23, 1979 with capsules no. 0102 (lower, with no rescue tower) and no. 0102A (upper, with rescue tower). However, the return was ballistic and the two capsules were lost. Capsule no. 009A had flown three times (LVI-1, LVI-2 and LVI-3).

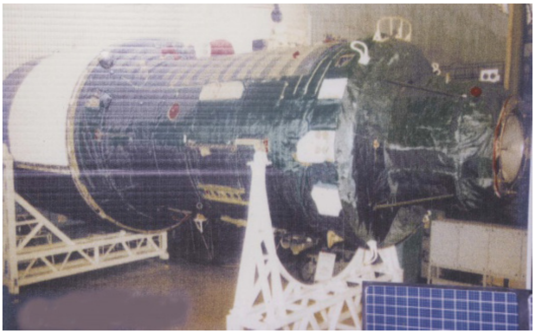


Figure 5.14. *Almaz station no. 104 (source: all rights reserved)*

The first TKS no. 16101 (Cosmos-929) was launched on July 17, 1977 with capsule no. 009A/2. The capsule was recovered after 1 month. Then, the TKS performed orbital maneuvers and reentered the atmosphere on February 3, 1978. From 1979 to 1982, three crews were trained to fly on the TKS: Glazkov-Makrushin-Stepanov, Sarafanov-Romanov-Preobrazhensky and Artiukhin-Yuyugov-Berezovoy. They each performed an 8-day simulation on an analogue of the TsNII-30. The second TKS no. 16301 (Cosmos-1267) was launched on April 25, 1981. Once again, the capsule was recovered after 1 month. Next, the TKS was docked to Salyut-6 on June 19 and reentered the atmosphere on July 29, 1982. However, a decree forbade manned flights with the TKS, which became a module of the DOS program. The OPS-4 would remain on the ground and the TKS-3 would not make the first manned flight.

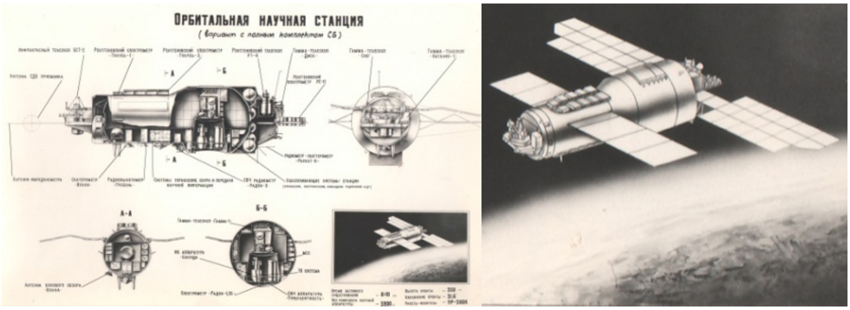


Figure 5.15. *The Almaz-N project (source: NPO Mash***)*

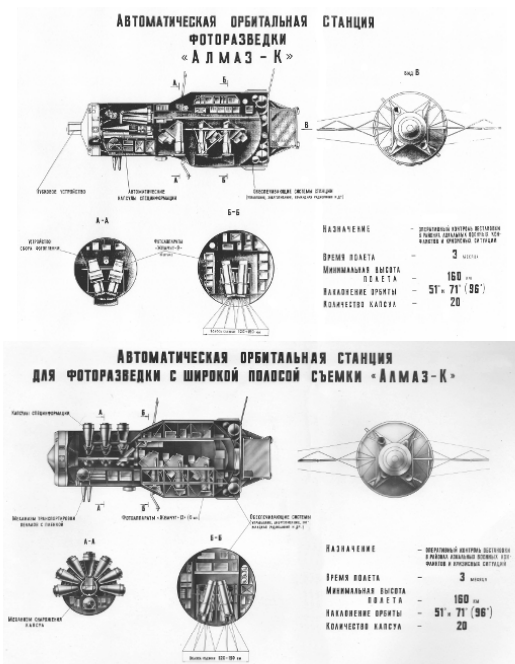


Figure 5.16. *The Almaz-K project: variants from 1974 to 1975 and 1976 (source: NPO Mash***)*

In parallel, a MOM decision from June 15, 1972 requested the creation of a scientific version of Almaz: Almaz-N. The project was ready in late 1974 and sent to MOM and the IKI (R. Z. Sagdeyev). The payload had a mass of 6.0 tons, 5.0 tons of which was for the astrophysical part and 1.0 tons for remote sensing. In astrophysics, the plan was to bring four gamma telescopes (1.4-tons Gamma-1, Natalia, Disk and Sneg-2), three X spectrometers (PS-17, Golub-3, Golub-1), the X RT-6 telescope and six radiometers (frequencies of 0.2518 cm). In remote sensing, the Priroda complex worked in microwaves (10 cm) and infrared (3–12 μm). The first flight models were meant to be ready in 1979 and 1980, but the project was abandoned in 1978.

Figure 5.17. *The Almaz-T station (source: Christian Lardier)*

On January 19, 1976, a decree decided on the Almaz automatic missions program: the Almaz-K for optical imaging and the Almaz-T (11F668) for radar imaging. The first, with a 3- to 6-month lifetime, was to be equipped with four to six Zhemchug-12 cameras from KMZ with the TeleGOIR-12MK lens with a 3-m focal length. The targeted resolution was 1.2 m. The films were returned to the ground by 20 KSI capsules. The cost of the program was estimated at 180 million rubles. The test flights (LKI) foresaw three Almaz-K flights in 1978–1979, followed by serial vehicles starting in 1979. However, a decision from September 9, 1977 requested an improvement of the resolution to 0.8–1.0 m. The Almaz-K was then equipped with four Zhemchug-12CH cameras with the APO-TeleGOIR-3 lens. The first flight model was planned for the first quarter of 1980, but the program was abandoned. The Almaz-T was to be equipped with an SAR Mech-A radar (20–30 m resolution) from the instrumentation NII. Flight models no. 303 and 304 were manufactured: the first arrived in Baikonur in November 1980. The launch was planned for July 1981, but the December 1981 decree brought the program to an end. Station no. 303 was stored in area no. 92 until 1986. With the deaths of Ustinov and Chelomey in 1984, a 25-year-old conflict came to an end. In addition, the decision was made to restart the program. Model no. 303 was launched on November 29, 1986, but the launch failed due to a failure of the Proton's second stage.

Figure 5.18. *Cosmos-1870 launch (source: all rights reserved)*

Model no. 304 (Cosmos-1870) was launched on July 25, 1987 and worked for two years. It was equipped with a Mech-K/Ekor-1 radar (20-m resolution) and a high-resolution Leader television. The images were retransmitted via Geizer satellite relays. Finally, model no. 305 (Almaz-1) was launched on March 31, 1991. It also worked for 2 years. It was equipped with the Mech-KU/Ekor-A1 radar (10–12 m resolution) and the Omega-SK scanning radiometer. An Almaz-1B with a 5–7 m resolution was planned but, unfortunately, the financing could not be found.

5.2. RKK Energiya

5.2.1. *The 7K-L1 program*

On August 3, 1964, the UR-500K was meant to launch Chelomey's LK-1 lunar spacecraft. It included a Bloc-A (injection stage), a Bloc-B (service compartment), a Bloc-V (VA capsule) and a Bloc-G (rescue tower). The cost was estimated at 380 million rubles. However, on October 12, with the dismissal of Khrushchev, Chelomey lost his greatest support. On November 11, he presented his draft, but Korolev was opposed and proposed replacing it with a Bloc-D fourth stage (11S824) and an L-1 spacecraft (11F91). This was a 5.35-ton Soyuz with no orbital compartment. An expert commission presided over by Keldysh and including 47 people had examined the project from August 5 to 19, 1965. On September 8, the two OKB got together and on October 25, the LK-1 was stopped and replaced by the 7K-L1. The draft of the 7K-L1 was presented by Korolev on November 30. On December 13, the UR-500K-7K-L1 was signed by the two designers. The goal was to fly over the Moon with two cosmonauts in November 1967.

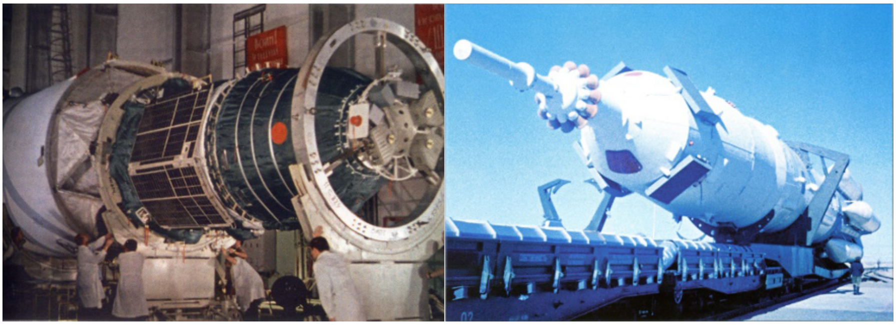


Figure 5.19. *The Zond spacecraft (7K-L1) (source: RKK Energiya)*

Figure 5.20. *Zond launch (source: RKK Energiya)*

The first 7K-L1 spacecraft (model no. 2P, Cosmos-146) arrived in Baikonur on January 1967. The launch took place on March 10, 1967, but the spacecraft was placed in solar orbit and did not come back to Earth. The second flight (model no. 3P, Cosmos-154) took place on April 8, but following a failure of the guidance system, the main engine (11D58) did not ignite and the spacecraft remained in terrestrial orbit. Spacecraft no. 4L (first flight model) was launched on September 28, but one engine (11D43) from the rocket's first stage broke down (injection of a rubber plug in the pump) at 97.4 s. The rescue tower was activated and the spacecraft fell back 20–30 km from the launch platform. Spacecraft no. 5L was launched on November 22 but this time, the failure was due to the second stage. The nozzle in one engine (8D412K) had been destroyed after 125.5 s. The spacecraft was recovered 110 km from Jezkazgan.

Spacecraft no. 6L (Zond-4) was launched on March 2, 1968. It performed a 1-week flight in an orbit peaking at 354,000 km. During the return, however, it performed a ballistic reentry following a failure of the orientation system. The capsule was voluntarily destroyed over the Bay of Biscay. Spacecraft no. 7L was launched on April 23, but a short circuit in the second stage's guidance system caused the ignition of the rescue tower. On July 14, during the preparation of spacecraft no. 8L, a problem arose while fueling the Bloc-D with oxygen and it was destroyed, causing the death of I. F. Khridin. The cause of this incident was an undocumented modification to the stage. This problem between the OKB-1 and OKB-52 was identical to the one that had taken place between the OKB-1 and TsSKB in September 1962 concerning Bloc-E.

Spacecraft no. 9L (Zond-5) was launched on September 15. It flew over the Moon at a distance of 1,960 km and, for the second time, performed a ballistic return. The capsule landed in the Indian Ocean, where it was recovered with its passengers (turtles, insects, plants, bacteria). Spacecraft no. 12L (Zond-6) was launched on November 10. It flew over the moon at a distance of 2,420 km. This time, the return was nominal: it landed in Kazakhstan, but the parachute detached at an altitude of 5 km and the capsule crashed: a small portion of the lunar images were saved. It was too late to perform a piloted flight before the December 1968 Apollo-8 mission. Spacecraft no. 13L was launched on January 20, 1969. Unfortunately, one of the second stage's engines (8D411K) broke down after 313 s, then a third-stage engine (8D48) did the same at 500 s. Spacecraft no. 11L (Zond-7) was launched on August 7. It flew over the moon at a distance of 1,200 km. For the second time, the return was nominal: the capsule landed near Kostanay, Kazakhstan. The UR-500K rocket was declared operational in February 1970. Lastly, spacecraft no. 14L (Zond-8) was launched on October 20, 1970. It flew over the moon at a distance of 1,200 km. However, following in the footsteps of Zond-5, the return into the Indian Ocean was ballistic. Spacecraft no. 10L was not launched. The program was ended on March 3, 1972.

5.2.2. *The DOS program*

After the failure of the N1-L3 program, priority was given to the orbital stations. NASA was then planning the Skylab for 1973. In December 1969, Mishin's OKB-1 decided to make a station for the Academy of Science, while Chelomey was making a station for the Ministry of Defense. The latter, Almaz, was a response to the United States' MOL, which had been abandoned in 1969. The KB Salyut had already performed eight Almaz units (OPS, 11F71) in the Khrunichev factory's workshops. Decree no. 105-41 from February 9, 1970 ordered an alliance between the OKB-1 (Mishin, K. D. Bushuyev, K. P. Feoktistov, Yu. P. Semenov, V. V. Ryumin, A. V. Pallo, etc.), the OKB-52 (Chelomey), the KB Salyut (V. N. Bugaysky, V. V. Pallo) and the Khrunichev factory (M. I. Ryzhikh). The OPS was equipped with elements from the OKB-1 (docking unit, passage compartment, propulsion unit, etc.).

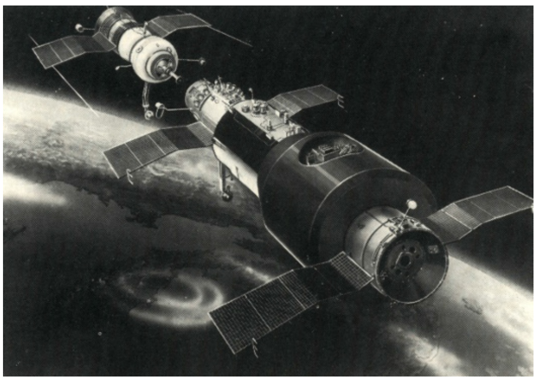


Figure 5.21. *The DOS orbital station (source: RKK Energiya)*

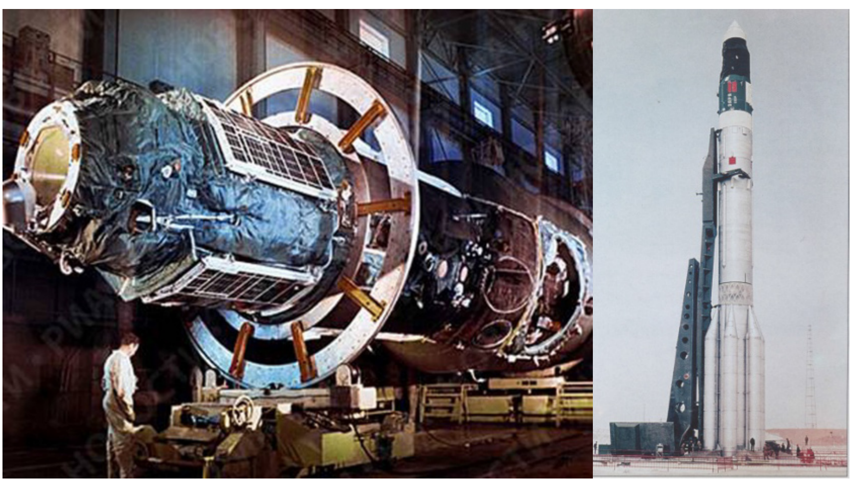


Figure 5.22. *The Salyut-1 Zarya station (source: RKK Energiya)*

The 18.9-ton station was to be launched by the UR-500K and served by the Soyuz spacecraft (7K-T, 11F615A8). The main payload was the OST-1 solar telescope from the Crimean observatory. The station (DOS-1, 17K no. 121), named Zarya or Salyut-1, was launched on April 19, 1971. The first crew did not manage to enter the station following an airtightness problem in the docking unit. The second crew spent 24 days onboard, but during their return to Earth, the cosmonauts died due to capsule depressurization.

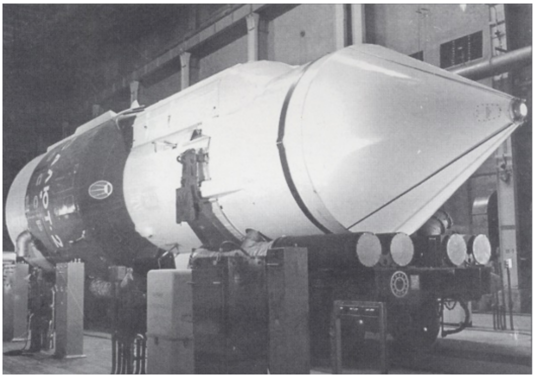


Figure 5.23. *The Salyut-2 station (source: RKK Energiya)*

The second station, DOS-2 (17K no. 122, Salyut-2), was launched on July 29, 1972, but the launcher was unstable and the rocket's second stage was cut off after 180 s of flight. The whole vehicle fell back to Earth 536 km from the launch platform.

The third station, DOS-3 (17K no. 123, Cosmos-557), was launched on May 11, 1973. It had three large solar panels that could be rotated toward the sun instead of four small panels like the previous stations. However, during the very first orbit, there was an ionic orientation system failure leading to the loss of propellants. The station was adrift. On May 14, the Skylab station was launched from Cape Canaveral. Due to disagreements between Feoktistov from the OKB-1 and Bugaysky from the KB Salyut, the latter resigned and was replaced by Polukhin.

The DOS-4 station (17K no. 124, Salyut-4) was launched on December 26, 1974. The first crew occupied it for 1 month. The second crew's launch, on the other hand, failed in April 1975: it performed a suborbital flight. The third crew performed a 63-day flight.

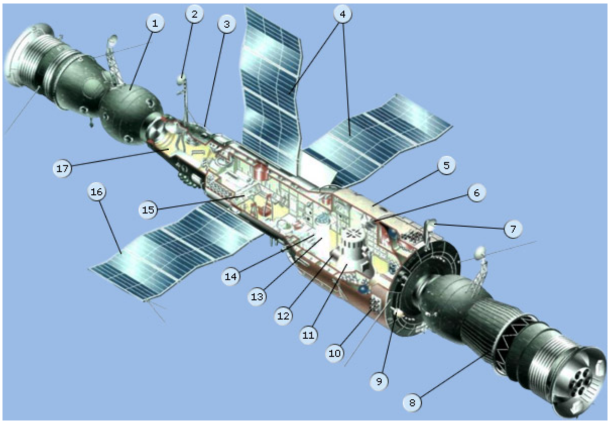


Figure 5.24. *The Salyut-6 station (source: RKK Energiya)*

The DOS-5 station (17K no. 125, Salyut-6) was launched on September 29, 1977. It was a new generation station: it was equipped with a second docking unit and it could be refueled by Progress cargo spacecraft (11F615A15). The main payload was the submillimetric BST-1M telescope (650 kg) from the Lebedev Institute of Physics and Kazan's TsKB Photon. The first crew occupied it for 96 days, the second for 140 days, the third for 175 days, the fourth for 185 days, the fifth for 12 days (maintenance mission) and the sixth for 75 days. In the end, the station was joined by the Cosmos-1267 module (TKS 11F72 no. 16301) in June 1981. The docking units being different, the crew had used an adapter to ensure docking without mechanical locking. The 35.0-ton orbital complex was destroyed in the atmosphere in July 1982.

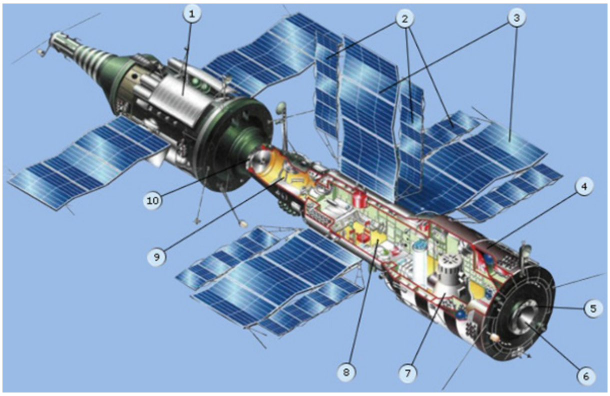


Figure 5.25. *Salyut-7 with Cosmos-1443 (source: RKK Energiya)*

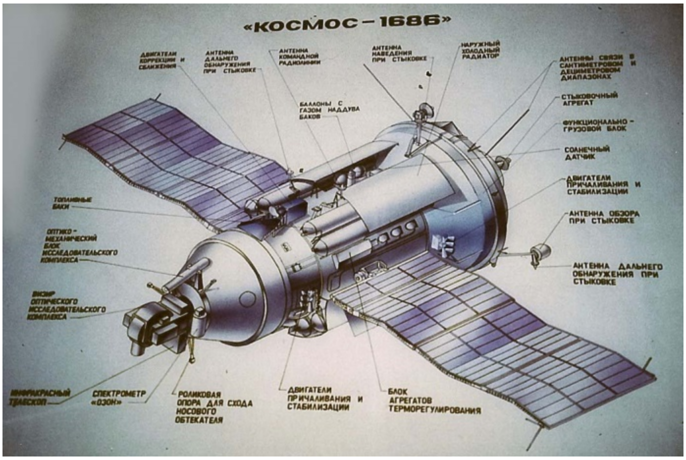


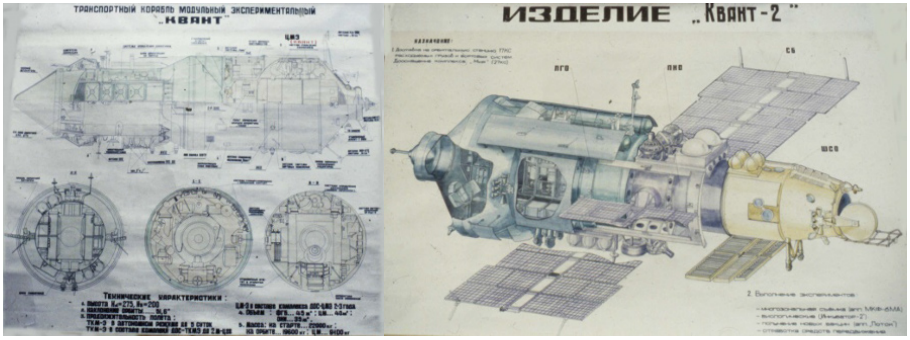
Figure 5.26. *The Cosmos-1686 module (source: Christian Lardier)*

The DOS-5-2 station (17K no. 125-2, Salyut-7) was launched on April 19, 1982. It was the understudy of Salyut-6. The main payload was a set of Roentgen SKR-02M and RT-4M telescopes (500 kg). The first crew occupied it for 211 days, the second for 150 days, the third for 237 days, the fourth for 112 days (station reviving mission), the fifth for 65 days (flight shortened due to Vassyutin's illness) and the sixth for 50 days. The station was joined by the Cosmos-1443 module (TKS 11F72 no. 16401) in March 1983. This time, the docking units were identical and the crew could enter the module. The module separated on August 14 and the VA capsule returned to Earth with a 350-kg load on August 23. The module reentered the atmosphere on September 19. Next, the station was joined by Cosmos-1686 (TKS-M 11F72 no. 16501) on October 2, 1985. This time, the capsule was replaced by the Pion-K optical complex (900 kg) from the TsKB Photon. It was used by the fifth and sixth expeditions. After that, the orbital complex was destroyed in the atmosphere in February 1991.

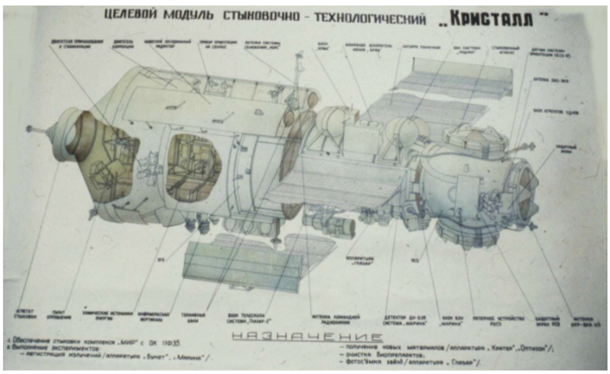
The following modular station was launched on February 20, 1986. This was the Mir (27K) station, made up of a base module (17K no. 12701) weighing 20.9 tons and five modules developed by the KB Salyut, which had recovered all the work on this subject by becoming a subsidiary of NPO Energiya between 1981 and 1988. In fact, a decree from December 19, 1981 stopped the Almaz program's manned flight, the

OKB-52 reorienting it toward automatic station programs. The KB Salyut then came up with the 37K module, made up of a 10.0-ton TKM tug and the 11.0-ton TsM module. The TKM (or FGB, functional cargo bloc) was derived from the TKS. The TsM had two docking units. Initially, the first 37KE model (Kvant-1) was planned for Salyut-7, but delays in manufacturing pushed it back on Mir. In the end, it was launched on March 31, 1987. The TsM-E was a Roentgen astronomy module that would record the explosion of supernova 1987A. A similar module, the 37KB no. 37070 (or BDP, additional device bloc), weighing 7,150 kg, was located in the Buran shuttle's hold in 1988. A second module no. 37071 had been manufactured and a third, no. 37072, was in the plans. They were meant to be docked to the Mir station, but the program was stopped.

Figure 5.27. *The Mir station with all its modules (source: RKK Energiya)*



a) b)



c)

Figure 5.28. *a) The Kvant-1 module, b) the Kvant-2 module, and c) the Kristall module (source: Christian Lardier)*

Four other modules of this kind were studied as follows: 37K (cargo), 37KD (logistics), 37KT (microgravity) and 37KP (remote sensing). In 1984, however, they were transformed into derivatives of the TKS-M and became the 77KSD no. 17101 (Kvant-2, logistics), 77KST no. 17201 (Kristall, microgravity), 77KSO no. 17301 (Spectre, optics) and 77KSI no. 17401 (Priroda, remote sensing). They were launched in November 1989, May 1990, May 1995 and April 1996, respectively. Initially, the Spectre module was meant to board TsNPO Kometa and Kazan's optical-mechanics factory's Oktava optical system. It was meant to detect rocket launches and to follow them into space. For its calibration, small targets were to be released by three launch devices placed outside the module. For larger targets, an airlock was necessary.

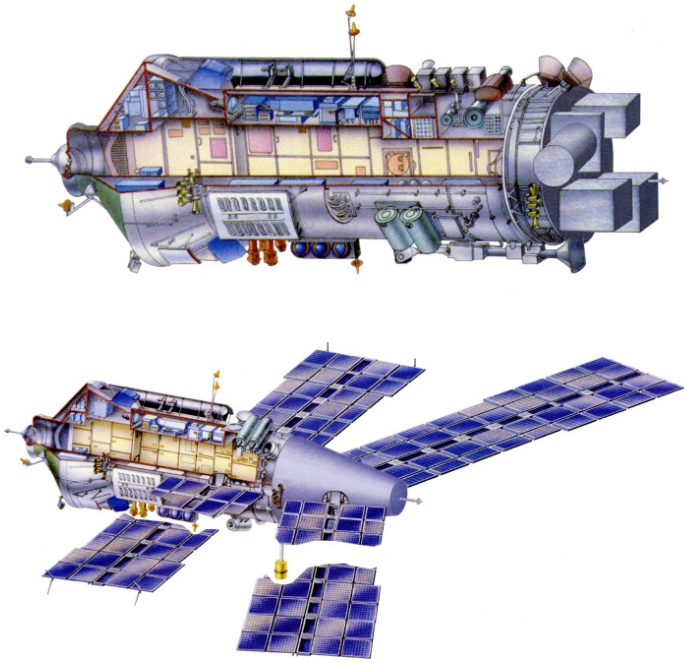


Figure 5.29. *Above: the Prioroda module; below: the Spectre module (source: RKK Energiya)*

However, with the end of the Soviet Union, the program was modified. In July 1993, the decision was made to board 600–700 kg of devices from the United States. The first crew occupied it for 50 days, the second for 326 days, the third for 365 days, the fourth for 151 days (Polyakov's 240-day flight), the fifth for 166 days, the sixth for 179 days, the seventh for 130 days, the eight for 175 days, the ninth for 145 days, the 10th for 175 days, the 11th for 145 days, the 12th for 188 days, the 13th for 179 days, the 14th for 196 days, the 15th for 182 days, the 16th for 125 days, the 17th for 169 days (Polyakov's 437-day flight), the 18th for 115 days, the 19th for 75 days, the 20th for 179 days, the 21st for 193 days, the 22nd for 196 days, the 23rd for 184 days, the 24th for 197 days, the 25th for 207 days, the 26th for 198 days, the 27th for 188 days and the 28th for 72 days. The Mir station was destroyed on March 23, 2001.

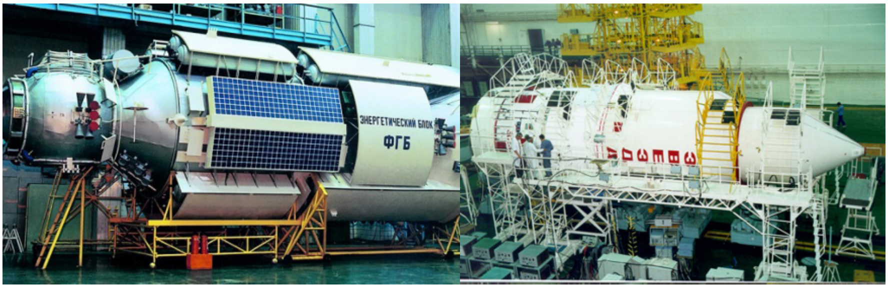


Figure 5.30. *The FGB Zarya and the Zvezda station (source: RKK Energiya)*

Figure 5.31. *Zarya launch (1998) and Zvezda launch (2000) (source: Khrunichev Center)*

A Mir-2 station was decided in December 1989. It was based on the manned 17K no. 128 module (DOS-7K no. 8). The launch was then planned for 1996, but the project was abandoned in favor of the International Space Station (ISS). The first module was the FGB Zarya (77KM no. 17501), which was launched in November 1998. NASA had bought it for approximately 300 million dollars. Then, the manned Zvezda module (17KSM no. 12801) was launched in July 2000. The construction of the FGB-2 started in 1995. It became the MLM module, which was meant for launch in 2015.

5.3. NPO Lavochkin

5.3.1. *The Luna program*

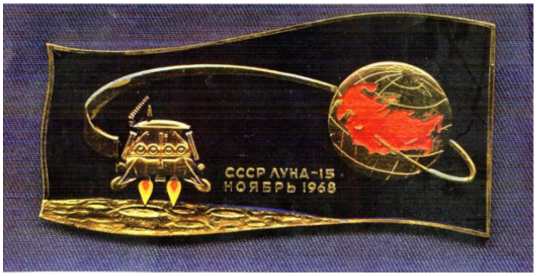


Figure 5.32. *Luna-15 was planned for November 1968 (source: Christian Lardier)*

In late 1965, the UR-500K was available to launch interplanetary probes weighing 5.5–7.5 tons. The designer, G. N. Babakin from the NPO Lavochkin, started designing a second generation of lunar probes (E-8), Venus probes (V) and Martian probes (M).

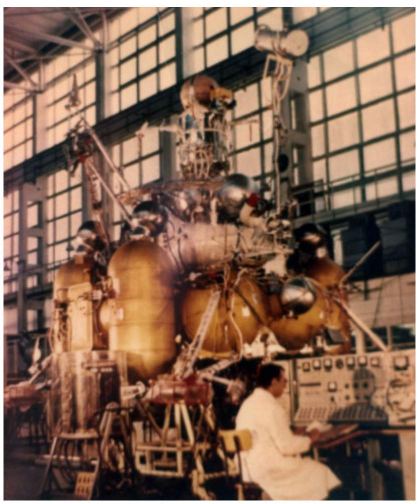


Figure 5.33. *Luna-16 (E-8-5) (source: NPO Lavochkin)*

The E-8 program included a Lunakhod lunar rover version (E-8), a lunar sample return version (E-8-5) and an orbital version (E-8LS). The E-8 had been studied by Korolev since July 1963 with the VNII TransMash (VNII-100) in Leningrad. It was initially meant to be launched in two pieces by Soyuz rockets and to perform an orbital rendez-vous. The injection stage on a lunar trajectory was a Bloc-M (reduced Bloc-D model) and the E-8 complex included a Bloc-N propulsion module and the 640-kg L-2 rover. With the Proton, however, it was possible to launch it with a single rocket. The draft was finished on May 18, 1966, and decree no. 115-46 was signed on February 4, 1967.

In late 1967, the technical documentation for the propulsion module (KT) equipped with the 11D417 engine and the Lunakhod (8EL) was ready and the chassis was delivered to Lavochkin. In April 1968, the KIK proceeded to the selection of the group of drivers for the Lunakhod and to the construction of a remote guidance center at Simferopol's station no. 10 (NIP-10) of the tracking network (KIK).

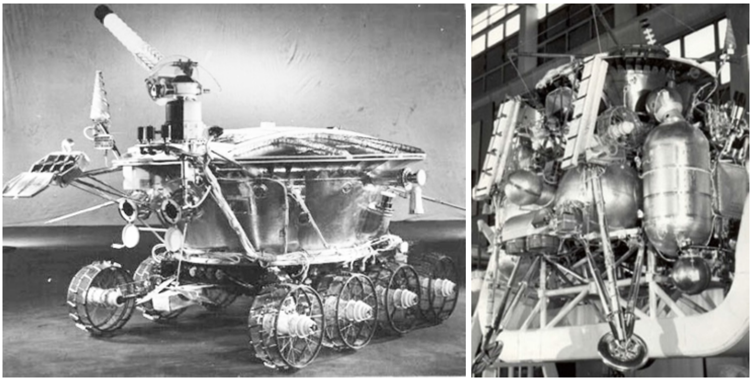


Figure 5.34. *Lunakhod-1 and Luna-17 (source: NPO Lavochkin)*

Decree no. 19-10 from January 8, 1969 set the time frame for the launches in 1969: three E-8 in February, October and November and five E-8-5 in April, May, June, August and September. The first Lunakhod (E-8 no. 201) was launched on February 19, 1969, but the Proton's first stage failed. A 200 mm fissure on one of the fuel tanks had been discovered. The problem was fixed and the launch took place the next day, but this was a failure after 50 s, with an explosion around the fairing, the extinction of the first stage's engines, and the destruction of the launcher with a cloud and toxic propellant vapors (the birds that flew into the cloud dropped dead). The order to stop had been sent by the upper composite after the destruction of the fairing. The second E-8 vehicle no. 203 (Luna-17) was launched on November 10, 1970. This time, it was a success: Lunakhod-1 (756 kg) traveled 10,540 m in 321 days in the Mare Imbrium.

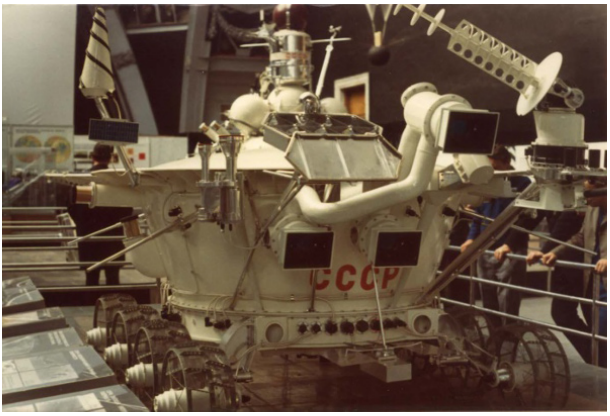


Figure 5.35. *Lunakhod-2 (source: Christian Lardier)*

The third E-8 vehicle no. 204 (Luna-21) was launched on January 8, 1973. Lunakhod-2 (840 kg) traveled 37,000 m in 120 days in the Mare Serenitatis.

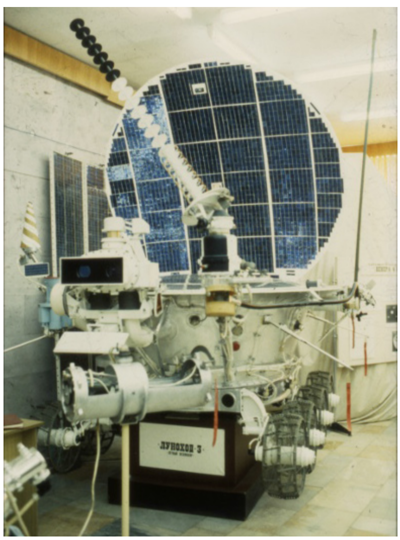


Figure 5.36. *Lunakhod-3 (source: Christian Lardier)*

A Lunakhod-3 was being prepared at Lavochkin, but it would not be launched and was later placed in the company's museum.

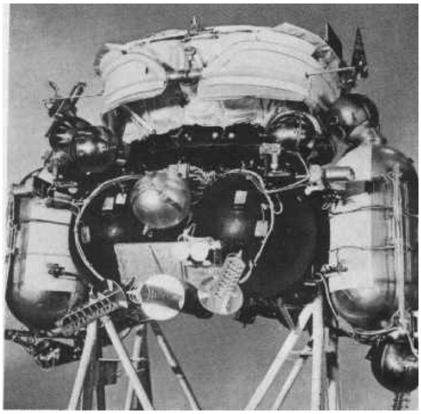


Figure 5.37. *Luna-19 (source: NPO Lavochkin)*

In early 1969, it seemed obvious that the race to the Moon against the United States had been lost. To pre-empt them automatically, the E-8-5 probe became priority no. 1. The KT module was surmounted on an ascent stage equipped with an S5-61 engine ordered by MOM decree no. 31 from January 23, 1968. It was also equipped with a 34-kg spherical recovery capsule. The samples were taken by a drilling device. The first E-8-5 probe, no. 401, was launched on June 5, 1969, but it experienced a failure of the Bloc-D fourth stage. Three days before the launch of Apollo-11, the second E-8-5 no. 402 (Luna-15) was launched successfully. However, on July 21, when it ignited its motor to land on the Moon, it apparently crashed into a mountain in the Mare Crisium. The third E-8-5 no. 403 was launched on September 23, 1969. Once again, though, there was a failure of the Bloc-D fourth stage and it became Cosmos-300. The fourth E-8-5 no. 404 was launched on October 22, 1969. The Bloc-D still did not work and it became Cosmos-305. On February 6, 1970, it was E-8-5 no. 405's turn: this time, it was the first stage that broke down after 128 s of flight due to a false indication provided by a pressure sensor. A modification of these sensors was decided on for the subsequent flights and a first test stage was launched on August 17, 1970 to test them in flight. The upper part of the launcher was replaced by a GBM 82EV model (equivalent size). The suborbital flight was a success. Flights could then be restarted. The sixth E-8-5 no. 406 (Luna-16) was launched on September 12, 1970: it was finally a success. The probe brought 105 g of samples back from the Mare Fecunditatis. On August 3, 1971, the designer Babakin died after this exploit. On September 2, 1971, the same old story came back with the E-8-5 no. 407 (Luna-18), which crashed into the mountains of the Mare Fecunditatis. The eighth attempt came on February 14, 1972 with the E-8-5 no. 408 (Luna-20) probe. It brought back 55 g of samples from a site approximately 1.8 km from the site where the Luna-18 had crashed.

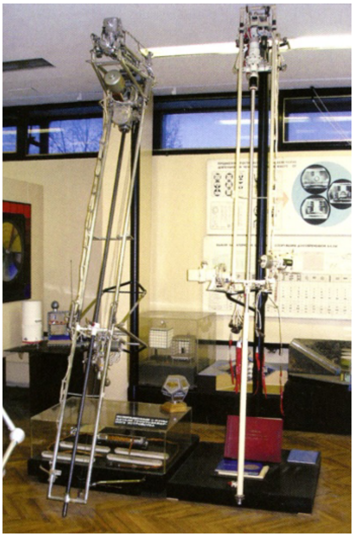


Figure 5.38. *The LB-09 lunar system (left) and the Martian MB-01 (right) (source: KBOM)*

MOM decree no. 337 from November 13, 1969 created the KB Mash in Tashkent (Uzbekistan), a subsidiary of V. P. Barmin's KBOM. Barmin assigned them the creation of a new drilling system, LB-09, capable of removing samples from a depth of 2.7 m. It was mounted on three modified probes. The first E-8-5M no. 410 (Luna-23) was launched on October 28, 1974, but it crashed into the Mare Crisium. The second, E-8-5M no. 411, launched on October 16, 1975, was a failure (breakdown of the Bloc-D fourth stage). Finally, the third was a success: the E-8-5M probe no. 412 (Luna-24) was launched on August 9, 1976. It brought 170 g of samples back from the Mare Crisium. A fourth mission was in the works, but it would never be launched.

The orbiter program only had two missions: E-8LS no. 202 (Luna-19) launched on September 28, 1971 and E-8LS no. 220 (Luna-22) launched on May 29, 1974. The former (5,330 kg) worked for 13 months in lunar orbit until November 1, 1972, while the latter (5,700 kg) worked for 18 months until November 1976.

5.3.2. *The Mars program*

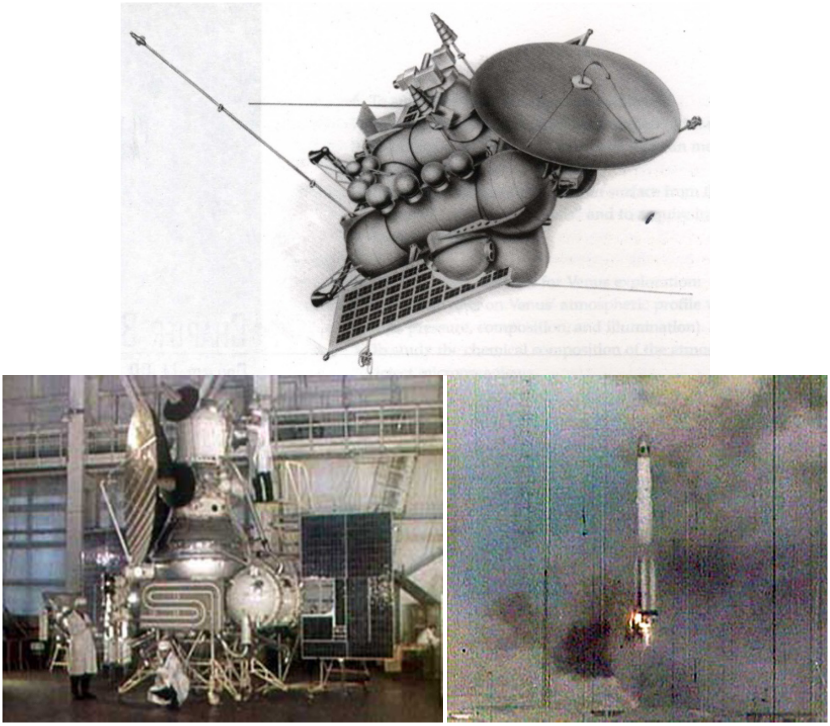


Figure 5.39. *The 1969 Martian mission (source: NPO Lavochkin)*

In mid-1966, Babakin developed a plan to explore Mars and Venus with the help of second-generation probes launched by Proton. Until then, the USSR had used the Martian windows in October 1960, November 1962 and November 1964, but the decision was made to skip the January 1967 window to develop the Mars-1969 mission in the following 20 months. In November 1967, the preliminary project was ready. The propulsion module was derived from that of the lunar probes. The spacecraft included an orbiter and a landing capsule. However, throughout development, it was discovered that the elastic membrane of the propellant tanks did not resist a multi-month flight. 13 months before the launch, it was decided that a new propulsion system would be made. The probe then weighed 3,834 kg, 260 kg of which was the capsule. The scientific instruments, provided by the Institute of Cosmic Research (IKI), weighed 99.5 kg, 15 kg of which was on the lander (gas analyzer, pressure, temperature, density analyzer). In late 1968, however, the program was behind and teams were working 24 h a day. The two probes, no. 521

and 522, were sent to Baikonur. The first was launched on March 27: the Proton's third stage broke down after 438 s of flight, and the probe fell into the Altai Mountains. The second was launched on April 2: this time, it was an 11D43 engine on the first stage that broke down (N_2O_4 pump) during liftoff, causing the rocket to explode 1.5 km from the launch platform. The probes were meant to arrive at their destinations on September 11 and 15.

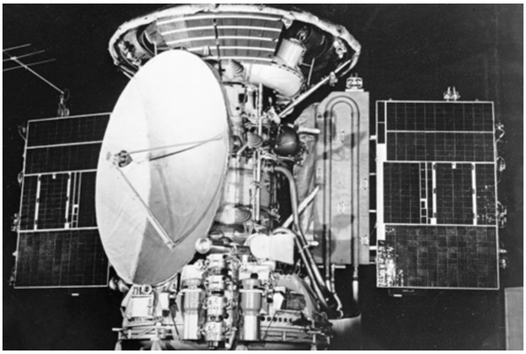


Figure 5.40. *The 1971 Martian mission (source: NPO Lavochkin)*

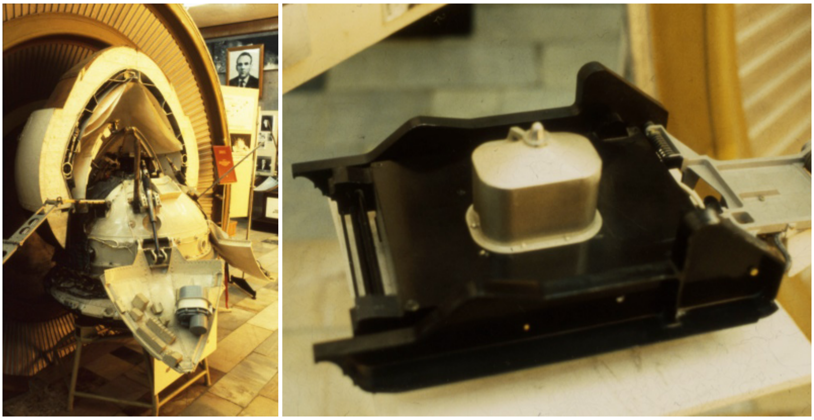


Figure 5.41. *The Mars-3's capsule and PrOP mini-rover (source: Christian Lardier)*

At the end of May 1969, Keldysh led a meeting concerning the May 1971 window. The participants were G. A. Tyulin and E. N. Bogomolov (MOM), G. N. Babakin and V. G. Perminov (NPO Lavochkin), M. S. Riazanky and

Yu. F. Makarov (NII-885), A. P. Vinogradov and Yu. A. Surkov (Geokhi), V. I. Moroz and E. M. Vassilyev (IKI), and M. Ya. Marov (secretary). It was decided that three probes would be launched, the first of which (M-71S) would serve as a relay for the other two, equipped with a landing capsule. It was meant to carry 800 kg of propellants and the tanks were supposed to be modified. Once again, the probe's configuration was changed, but it would then be maintained for all the Martian and Venus missions until 1984. The new guidance system, developed by Pilyugin's NPO AP, allowed the probe to control the Bloc-D fourth stage. In February 1970, the preliminary project was ready. The M-71S no. 170 weighed 4,549 kg, 2,385 kg of which was propellants and gas, while the M-71 no. 171 and 172 weighed 4,650 kg, 1,000 kg of which was the capsule. The M-71S was launched on May 10, 1971, but the fourth stage did not work and the probe remained in terrestrial orbit (Cosmos-419). The two M-71 were launched on May 19 and 28; they became Mars-2 and Mars-3. The capsules were released on November 27 and December 2. Unfortunately, the Mars-2 capsule remained silent, while that of the Mars-3 positioned itself in the Phaetonis region and only transmitted for 20 s. In fact, it was a victim of the dust storm that struck at that time of year. The capsule, derived from that of the Luna-9 and 13, weighed 355 kg on Mars' surface. It was equipped with a 4.5-kg Prop-M minirover developed by VNII TransMash's A. L. Kemurjian. It was meant to move with the help of two lateral skis and remained attached to the capsule by a 15 m long cable. It was equipped with a penetrometer and a densitometer. Mars-2 was placed into an orbit at 1,380/25,000 km, while Mars-3 was in an orbit of 1,500/200,000 km described in 12 days and 19 h. Initially, a 25-h period is planned, but the guidance system miscalculated the breaks and the motor was extinguished prematurely. Nevertheless, until the end of the mission in August 1972, Mars-2 performed 362 orbits and Mars-3 performed 20, transmitting excellent scientific results.

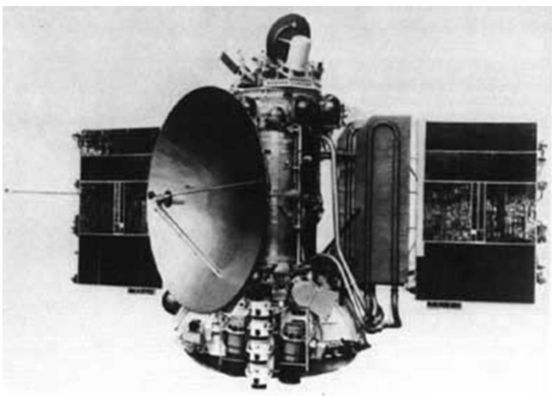


Figure 5.42. *Mars-4 and 5 (M73S) from 1973 (source: NPO Lavochkin)*

In the meantime, on August 3, 1971, Babakin passed away. He was replaced by his first deputy, S. S. Kryukov, who had worked at Korolev, then became first deputy of the NPO Lavochkin on March 30, 1970.

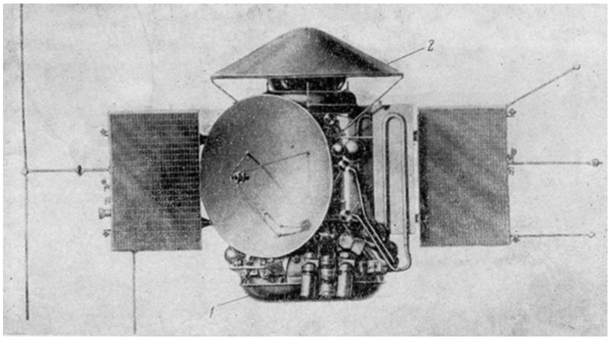


Figure 5.43. *Mars-6 and Mars-7 (M73P) from 1973 (source: NPO Lavochkin)*

The 1973 Mars window was not favorable and it was decided that a four-probe mission would be performed: two 3,200-kg orbiters and two 4,600-kg landers. However, throughout the testing of the power system, it was found that an electronic part (transistor 2T-312 from the Voronezh factory) broke down. It was located in most of the onboard equipment. An analysis showed that it did not work for more than 1.5–2.0 years after production. The chance of the mission succeeding was 50%. Six months were needed to replace them with other, more reliable transistors. However, it was decided that the program would go ahead as planned. The Mars-4 and 5 were launched on July 21 and 25, while the Mars-6 and 7 were launched on August 5 and 9. Unfortunately, they all broke down: Mars-4 flew 2,200 km from the planet on February 10, 1974, Mars-5 was placed into orbit on February 12 but only broadcasted for 16 days, Mars-6 arrived on March 12, but communication with the capsule was cut off 5 s before landing and Mars-7 arrived on March 9, but the capsule went past the planet without being able to transmit scientific information. This failure would cost the president of the State Commission, G. A. Tyulin, his job. He had been the first deputy of the MOM and headed several state commissions (manned flights in 1963–1965, 7K-L1 in 1967–1970, Luna in 1965–1974, Mars in 1962–1974, Venera in 1962–1972 and Apollo-Soyuz in 1972-1975). He was replaced by K. A. Kerimov for the interplanetary flights in 1974–1991.

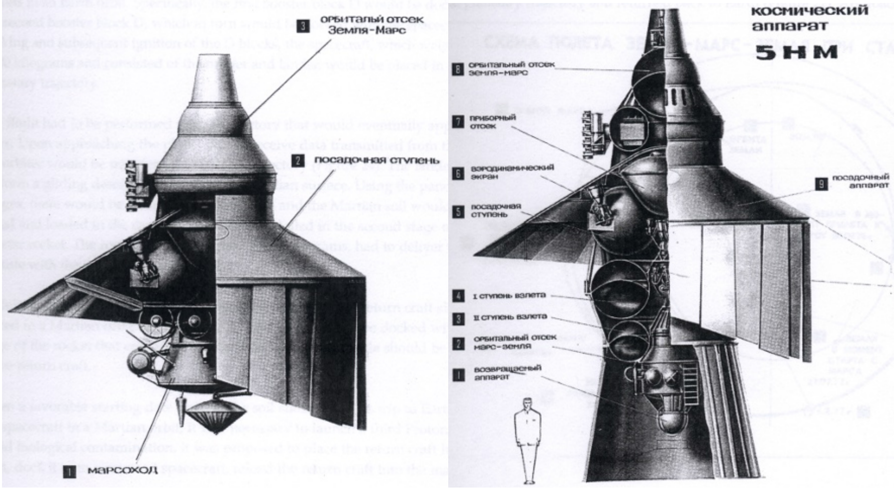


Figure 5.44. *The 4NM probe (Marsokhod) and the 5NM probe (sample return) (source: NPO Lavochkin)*

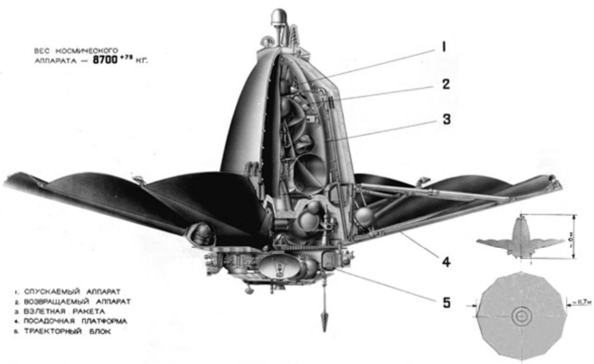


Figure 5.45. *The 5M probe (M-79) from 1974–1977 (source: NPO Lavochkin)*

In the summer of 1970, the 5NM (M-75) project was designed to launch a Martian probe weighing 98.0 tons with the N-1 rocket in September 1975. It was a sample return mission (200 g). The arrival to Earth was meant to take place on May 14, 1978 in the 15-kg capsule. The 4NM mission was designed in 1973 to test the different systems and explore Mars with a rover. However, the N-1 was abandoned in 1974 and replaced by the Proton. The decision was made to perform a 5M (M-79) mission with three launches: the first with a Bloc-D, the second with an 8.5-ton probe (cruiser and lander module), and the third with the orbiter that recovered the samples and brought them back to Earth. The mission required three orbital rendezvous. To reduce the number of Protons to two, the probe and the orbiter were combined into a single 9.1-ton spacecraft: 1.68 tons for the orbiter and 7.45 tons for the lander. The latter included the 3.19-ton ascent stage and the 7.8-kg return capsule. To launch the mission, the 11K88 version of the Proton, decided on by decree no. 589-202 from July 24, 1969, was to be used. Decree no. 379-115 from December 4, 1975 defined NPO Lavochkin's work in the study of the Moon and the planets of the solar system. It planned the 5M expedition in 1981. In January 1976, the preliminary return vehicle project was adopted. Sterilization was to be performed in flight, which fixed the problem of biological contamination on Earth.

In March 1976, Kryukov took Y. N. Trufanov on as his first deputy (he would remain in this position until 1980), who replaced A. G. Chesnokov. In December 1977, he left Lavochkin to become first deputy of Gluchko at RKK Energiya. In 1978, the TsNII Mash published a report that doubted the feasibility of the project due to its complexity, cost, and the low likelihood of success. Based on this report, the project was abandoned.

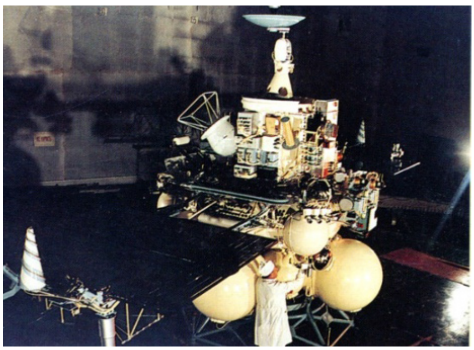


Figure 5.46. *The 1F Phobos probe from 1988 (source: NPO Lavochkin)*

Figure 5.47. *The Phobos Proton from 1988 (source: Khrunichev Center)*

Kryukov was replaced by V. M. Kovtunenko. He came from the NPO Yuzhnoye in Dniepropetrovsk, Ukraine, where he had developed a large number of Cosmos satellites. The Mars windows in 1975, 1977 and 1979 were not used. In 1979, he designed the UMVL (Universal Mars, Venera, Luna) platform. Its first use would be the Phobos mission in 1988. Two probes (1F no. 102 and 102) weighing 6,220 kg were built to be placed in orbit around Mars and place landers (55-kg fixed LAL and 43-kg mobile Hopper) on its satellite Phobos. For the launch, the fourth stage was an 11S824F (or D-2). It had no toroidal instrument compartment because steering was ensured by the probe's onboard computer. The two probes were launched on July 7 and 12, 1988. On September 1, following a remote control error, contact with the first was lost. The second was sent into orbit on January 29, 1989. It came within 200 m of Phobos and stopped transmitting on March 29, after 2 months in orbit.

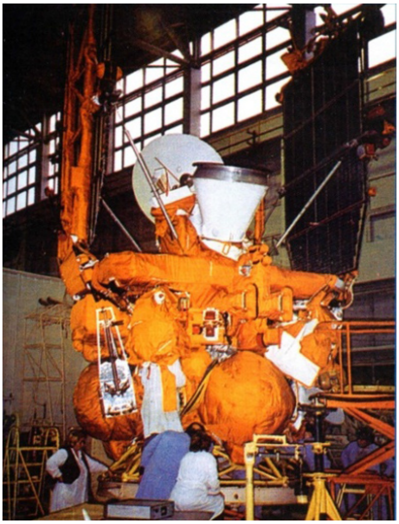


Figure 5.48. *The Mars-96 probe (source: NPO Lavochkin)*

In 1985, France and Russia were studying the Vesta mission initially meant to study Venus' atmosphere with the help of balloons or airships, then the Vesta asteroid by flying over it or landing on it with the help of a French probe. In 1986, it was replaced by a Martian mission, as well as two probes meant to fly over several asteroids and comets. Finally, in 1987, it was the Mars-94 that was meant to place a French solar hot air balloon into the planet's atmosphere, while the Vesta mission was the object of a complementary study. In April 1991, instead of launching two probes equipped with a French balloon and a Russian rover (Marsokhod), the decision was made to separate them into Mars-94 and Mars-96, which, in April 1994, became Mars-96 and Mars-98. Finally, in June 1995, the economic difficulties forced the Mars-98 to be abandoned. On November 16, 1996, the Martian probe Mars-96 (or M1 no. 520 or Mars-8), which carried out nine French experiments, was launched from Baikonur, but the 11S824F stage did not work correctly and it fell back into the Pacific Ocean.

5.3.3. *The Venera program*

The second-generation Venera (4V) was developed by Kryukov starting in 1971. It was launched by Protons equipped with the 11S824M fourth stage.

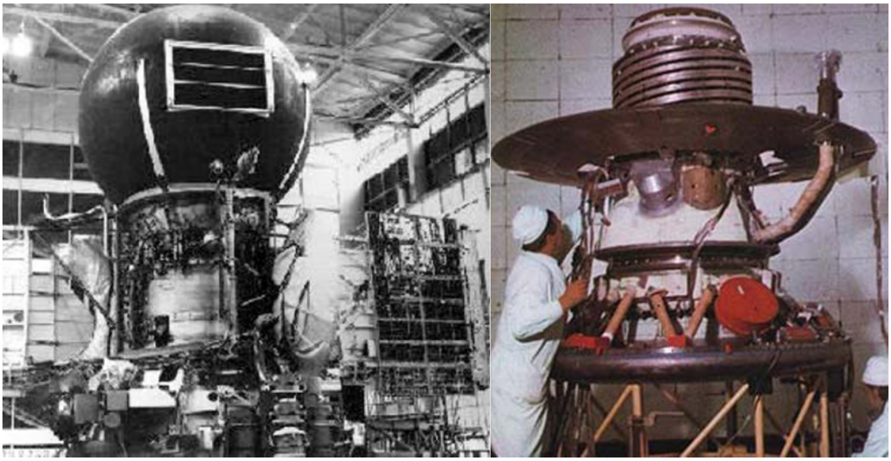


Figure 5.49. *The Venera-9 probe and the landing capsule (NPO Lavochkin)*

The first mission was launched in June 1975: Venera-9 (4V-1 no. 660), weighing 4,936 kg, and Venera-10 (4V-1 no. 661), weighing 5,033 kg, released their capsules into Venus' atmosphere on October 22 and 25. From the surface, they broadcasted for 53 and 65 min, respectively, and sent the first panoramas of the planet's ground. This success earned Kovtunenko the 1978 State Prize.

The operation was repeated in September 1978: Venera-11 (4V-1 no. 360), weighing 4,450 kg, and Venera-12 (4V-1 no. 361), weighing 4,461 kg, released their capsules into Venus' atmosphere on December 21 and 25. From the surface, they broadcasted for 95 min and 110 min, respectively. This time, however, there were no images of the ground because the camera shutters did not open.

The final operation was performed in November 1981. Venera-13 (4V-1M no. 760) and Venera-14 (4V-1M no. 761), which both weighed 4,463 kg, released their capsules into Venus' atmosphere on March 1 and 5, 1982. From the surface, they broadcasted for 127 min and 57 min, respectively. This time, the panoramas were in color. Soil samples were analyzed on site.

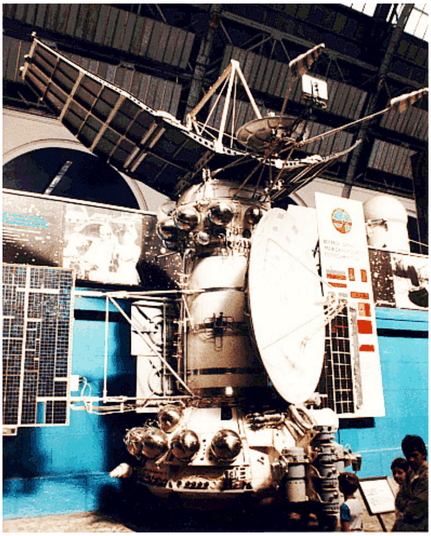


Figure 5.50. *The Venera-15 probe (source: all rights reserved)*

The June 1983 mission was different: the goal was to perform a radar cartography of the planet hidden under its layer of clouds. Venera-15 (4V-2 no. 860), weighing 5,250 kg, and Venera-16 (4V-2 no. 861), weighing 5,300 kg, were equipped with a lateral vision radar from the OKB MEI (A. F. Bogomolov) with a resolution of 1–2 m. The probes were placed in Martian orbit on October 10 and 14; from November 11 to July 10, 1984, they mapped 115 million km^2 of the northern hemisphere and a map was created on a scale of 1/10,000,000.

The decision to make the 5V probe to study Venus dates back to August 1977. The target window was 1985. In 1978–1979, the use of a French balloon (EOS-Venus) to study Venus' atmosphere was planned: in the end, it would be created by the IKI. In July 1980, the decision was made to fly over Venus, then Halley's comet in March 1986: this was the Venera-Halley (Vega) mission. The president of the State Commission was Major General G. M. Tamkovich. The two probes Vega-1 (5VK no. 901) and Vega-2 (5VK no. 902), both 4,920 kg, were launched on December 15 and 21, 1984. The capsules (750 kg) were released while flying over Venus on June 11 and 15, 1985. They first released balloons, 3.4 m in diameter, which drifted for 46 h at an altitude of 54 km. The Vega-1's lander trigged the landing signal at an altitude of 18 km and only broadcasted from the ground for

20 min. The Vega-2's broadcasted for 56 min. It then proceeded to analyze the soil. The orbital modules followed their path to the Halley's comet, which they flew over on March 6, 1986 at a distance of 8,890 km and on March 8 at 8,030 km. Important scientific results were obtained and R.Z. Sagdeyev, director of the IKI, received the Hero of Socialist Labor medal.

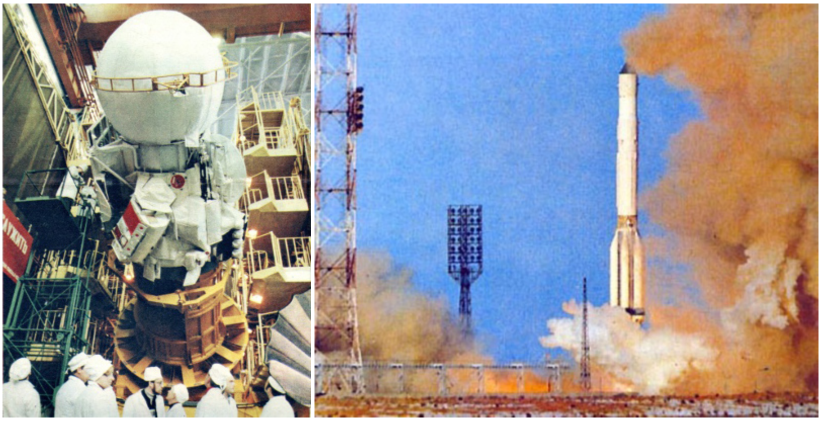


Figure 5.51. *The VEGA probe and its 1984 launch (source: NPO Lavochkin, all rights reserved)*

5.3.4. *Scientific probes*

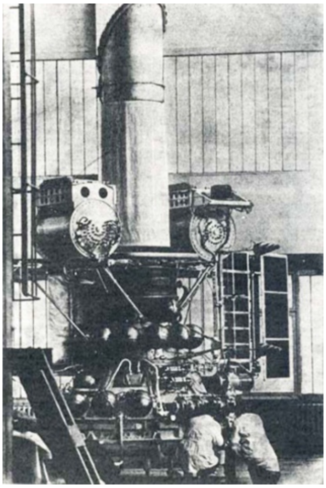


Figure 5.52. *The Astron satellite (source: NPO Lavochkin)*

The Astron (1A) project was proposed in cooperation with France in 1977 and adopted in 1979. The idea was to use a Venera platform (4V-1, 4V-1M) to bring a UV telescope 80 cm in diameter developed by the Crimean observatory (KrAO), associated with a spectrometer from the Laboratoire d'astronomie spatiale in Marseille. The satellite weighed 3.5 tons and the payload 450 kg. It was launched on March 23, 1983 and worked until 1989.

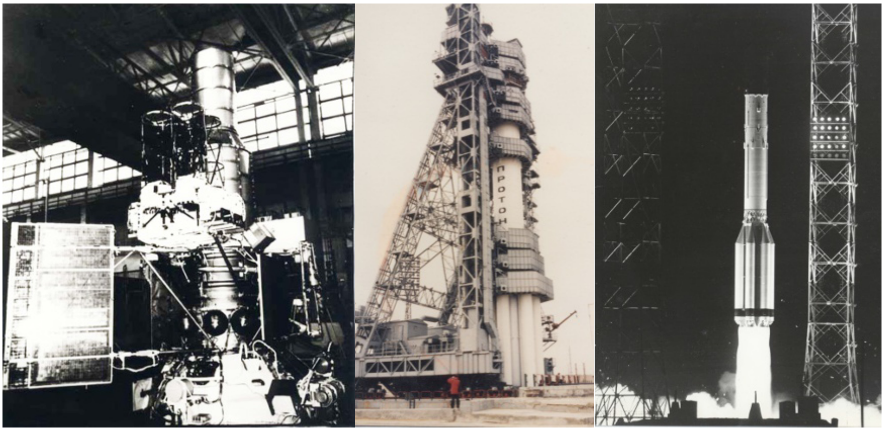


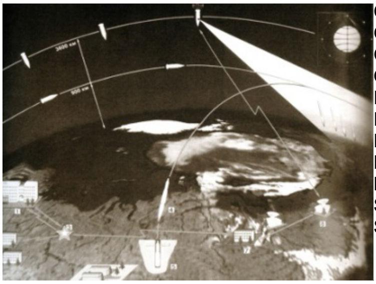
Figure 5.53. *The Granat satellite and its 1989 launch (source: Lavochkin, Christian Lardier; all rights reserved)*

The Granat (1AS) project was proposed in 1982 and adopted in 1983. This time, the focus was a gamma telescope with a coded Sigma mask provided by France (CNES, CESR, CEA). It was also equipped with X APT-P and ART-S telescopes from the IKI and Phebus, Watch, Conus and Podsolnukh experiments. The State Commission was headed by General G. M. Tamkovich. The launch took place on December 1, 1989. The observatory successfully worked until 1999.

The 1A were then replaced by the 2A, the first of which, Radio-Astron/Spectre-R, was launched by Zenit-3F on July 18, 2011.

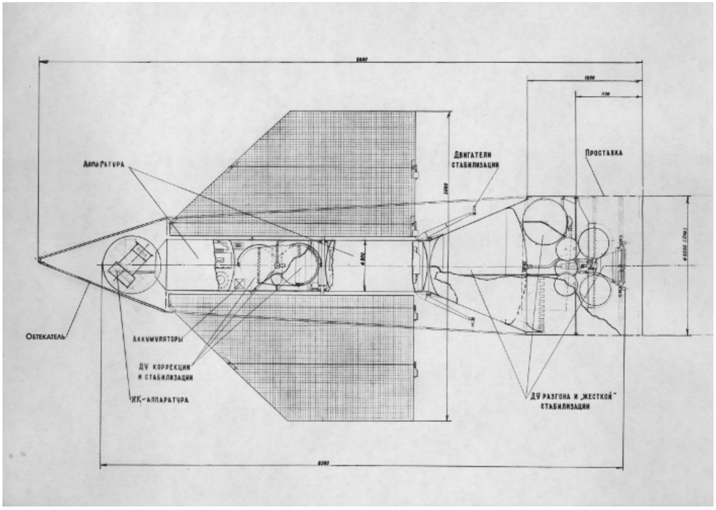
5.3.5. *The Oko early warning satellites*

The Oko early warning satellites were manufactured by the NPO Lavochkin in cooperation with A. I. Savin's OKB-41 (which later became TsNII Kometa). The first generation, US-K (Kontinent), was launched by 8K78M Molnya-M rockets on 12-h orbits. The first model (5V95) was placed in orbit on September 19, 1972 (Cosmos-520). The system was declared operational on December 27, 1982.

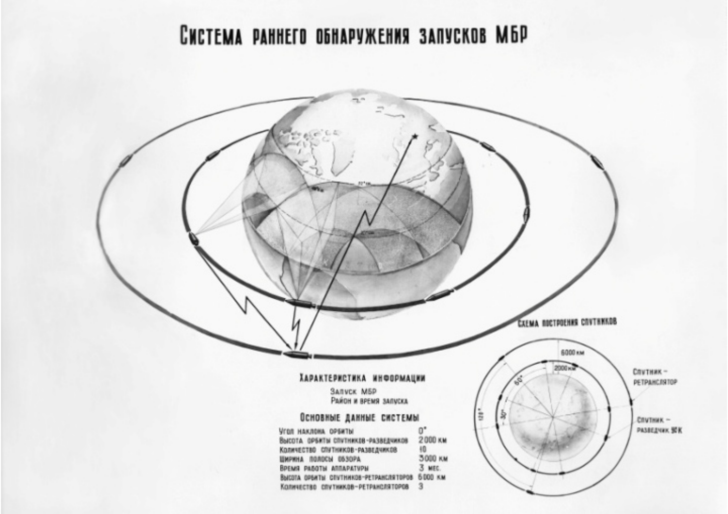


Characteristics of the US-K system
Orbit angle: 0°
Orbit altitude: 2,000km
Quantity of satellites: 10
Field of vision: 3,000km
Functioning time: 3 months
Relay satellite orbit altitude: 6,000km
Number of relay satellites: 3
Launcher: UR-200
Satellite mass: 6.3-6.4t
Size: 8.3m long x 2.2m in diameter

a)



b)



c)

Figure 5.54. *The US-K system of Chelomey in the 1960s (source: NPO Mash***)*

In 1975, however, the US-K started to be placed into geostationary orbit, while the study of the US-KMO (Kontinent, Morey i Okean) system was just starting. The US-K became the UK-KS (stationary). The geostationary positions were reserved for the IUT under the name Prognoz. The first model (5V95) was placed into orbit on October 8, 1975 (Cosmos-775), then the second model 75X6 from March 1984 to August 1997 (Cosmos-1546, Cosmos-1629, Cosmos-1894, Cosmos-1940, Cosmos-2155, Cosmos-2209, Cosmos-2345).

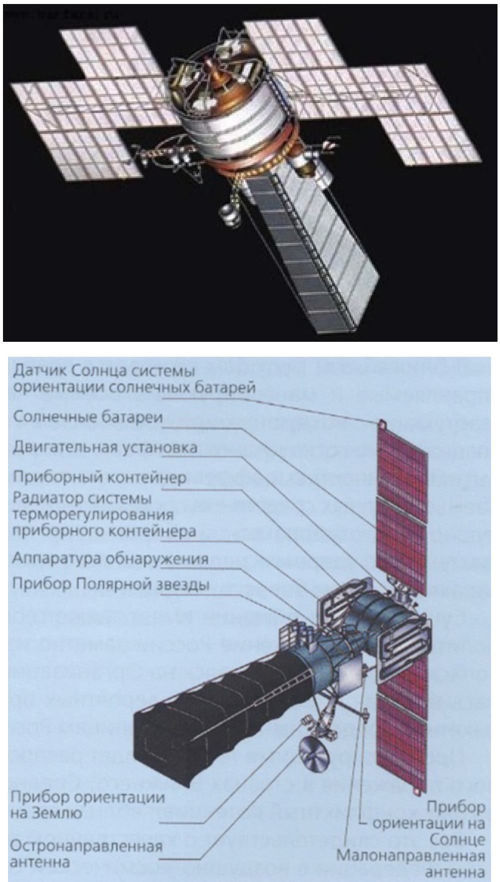


Figure 5.55. *The Oko-1 (US-KS) and Oko-2 satellites (US-KMO) (source: NPO Lavochkin)*

The US-KMO was developed by Kometa and Lavochkin. The payload (BAO) included a heat sensor (TP) from the GOI Vavilov (beryllium mirror 1m in diameter) and a television system (TV) from the VNIIT in Leningrad. The BAO was verified on a satellite placed into a 12-h orbit in August 1985 (Cosmos-1675).

Decree no. 465-150 from 1985 set the schedule for creating the system. The first stage included two GEO satellites and one station, observing the West, for test flights (LKI). The second also included the observation of the East. The third stage included the full system with eight GEO satellites, four HEO and two management stations.

The first Oko-2 satellite and the first station were ready in 1990. Cosmos-2133 (71X6 no. 7120) was launched by Proton on February 14, 1991. It worked in orbit for 4 years, but its BAO had a problem with static electricity that prevented it from calculating the necessary statistics. A modification was made before the second satellite, Cosmos-2224 (no. 7121), was launched on December 17, 1992. It worked for 6.2 years, detecting a certain number of rocket launches. With the Cosmos-2282 (no. 7123) from July 1994, two satellites were at work at the same time and State tests could begin. The system was integrated into the armament on December 25, 1996. From April 1998 to February 2012, five other satellites were launched: Cosmos-2350 (71X6 no. 7122) worked from 1998 to 2000, Cosmos-2379 (71X6 no. 7124) from 2001 to 2006, Cosmos-2397 (71X6 no. 7126) from 2003 to 2005, Cosmos-2440 since 2008 and Cosmos-2478 since February 10, 2012.

5.3.6. *The Araks/Arkon optical imaging satellites*

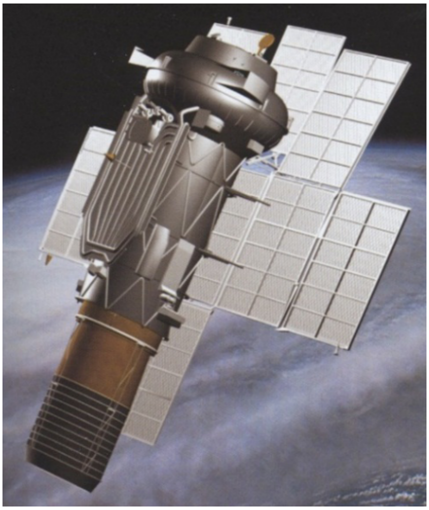


Figure 5.56. *The Arkon-1 satellite (source: NPO Lavochkin)*

In 1983, a decision called for the development of the Sapfir-V system by TsSKB (two to three satellites in orbit at 300–500 km) and that of the Arkon by NPO Lavochkin (two to three satellites in orbit at 4,000 km). The two types of spacecraft were to be equipped with optoelectronic telescopes with large-scale lenses from LOMO. However, due to financial difficulties, these programs were put on hold during the 1990s. At the TsSKB, the Sapfir project was 70–75% ready. As for the Arkon (11F664), it was finished and two models were launched: Arkon-1, placed into a 1.1513 × 2.745 km orbit at a 63.4º incline, worked from June 6 to October 1997, while Arkon-2, placed into a 1,513 × 1,841 km orbit at a 63.4º incline, worked from July 25, 2002 to August 10, 2003. The Arkon was also known by the name Araks-R (Razvezdka). It would give rise to the Araks-N (Nauka): the Lomonossov astrometry satellite project was studied by the Sternberg Institute of Astronomy at Moscow State University in 1987-2004.

5.4. Applied mechanics NPO

5.4.1. *Telecommunications satellites*

The first generation of telecommunications satellites, built by the NPO PM in Krasnoyarsk, was launched by 8K78M Molnya-M rockets into 12-h orbits. However, a 1967 decree ordered the development of a direct television broadcasting satellite, Ecran-AM, fed by a nuclear generator. To launch it, the Proton was to receive a new upper stage, 11S813, fueled by ammonium fluoride. However, the meeting about the frequencies of the IUT in Geneva forbid the use of amplitude modulation in 1971 and the project was abandoned.

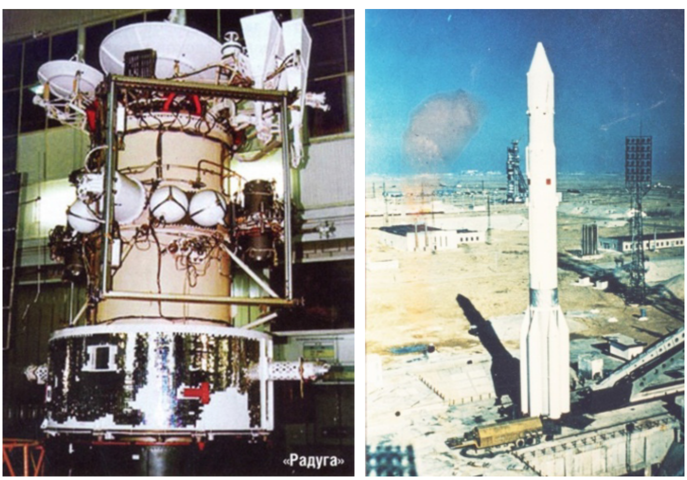


Figure 5.57. *The Raduga satellite and its launch (source: all rights reserved)*

On April 5, 1972, a decree requested a unique satellite communication system (ESSS). The geostationary positions were reserved for the IUT under the name Stationar. NPO PM then developed the Raduga satellite (11F638), which weighed 2.0 tons and was to be placed into geostationary orbit by the Proton with a Bloc-DM (11S86). The platform was a KAUR-3. The payload in C band included the three military repeaters Delta-1 (or Gran) from V. I. Moguchev from the MNIIRS and the three dual repeaters from M. V. Brodsky from the Radio NII. The guaranteed lifetime was 3 years. A Raduga model was launched on March 29, 1974 into geostationary orbit (Cosmos-638). Then, the Molnya-1 no. 38 followed on July 29, 1974 and became Molnya-1S (Stationar). The Raduga no. 11L was launched on December 22, 1975, but it only worked for 3 months due to an electrical feed malfunction. The no. 12L was launched on September 11, 1976 and this time, it worked for 3 years and 8 months. Three launch failures occurred on December 24, 1982 (second stage after 230 s due to HF vibrations in the engine), February 19, 1996 (absence of the fourth stage's second ignition due to a problem with the valve bringing ignition propellant to the gas generator) and July 5, 1999 (second stage after 277 s due to particles in the turbopump). All in all, 35 Raduga were launched until 1999. The State Commission was headed by General A. A. Maximov, then by General N. F. Shlygov starting in 1978.

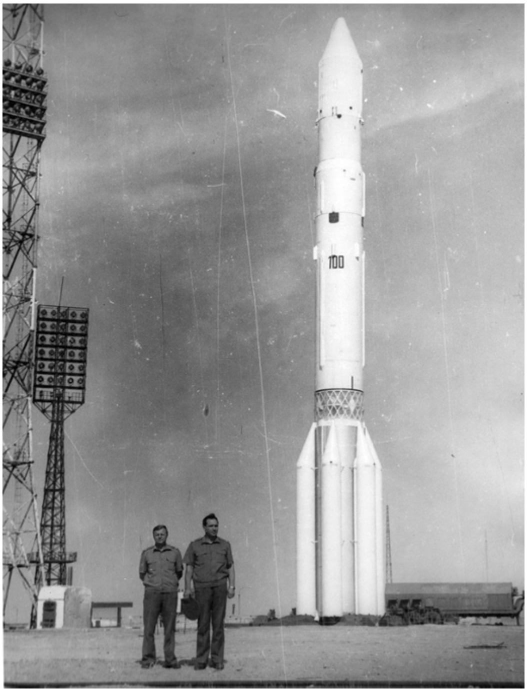


Figure 5.58. *The 100th Proton with a Raduga in November 1982 (source: all rights reserved)*

In 1985, NPO PM began developing the Raduga-1, a.k.a. Globus (17F15), the first model of which, no. 11L, was launched on June 22, 1989. The 2,420-kg satellite was equipped with Delta-1 (X band), Delta-2 (C band), Volna (L band) and Tor (K_a band) repeaters. With its entry onto the playing field on March 3, 1996, the second stage of the ESSS began. All in all, eight Raduga-1 were launched until 2009. The final version, Raduga-1M, was launched in two units: no. 1 on December 9, 2007 and no. 2 on January 28, 2010.

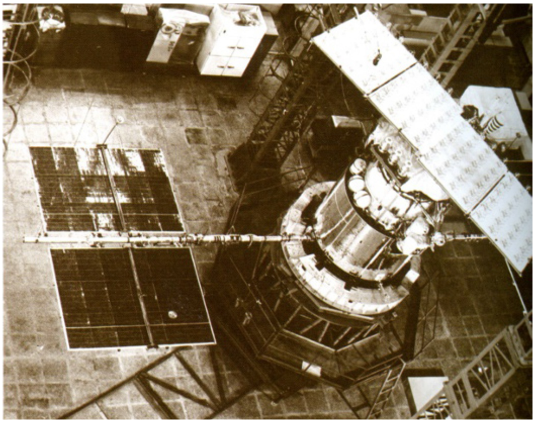


Figure 5.59. *The Ecran satellite (source: ISS Reshetnev)*

The first television broadcasting satellite Ecran no. 11L was launched on October 26, 1976. The payload, developed by the Radio NII, included two 200-W repeaters. The main antenna was an active antenna. The solar panels provided a power of 2 kW. It was placed on the Stationar-T position at 99º east. The second satellite was launched on September 20, 1977, but the system stopped working in 1978 due to three successive failures: May 27 (loss of the first stage's stability after 87 s due to a heptil leak, destruction after 119.51 s, and fall back to Earth 600 km from the launch platform), August 17 (second stage after 242 s due to a hot gas leak, destruction after 259.1 s, and fall back to Earth 136 km from Karaganda) and October 17 (second stage after 236 s due to foreign particles, fall back to Earth 86 km from Karaganda). With the successful launch on February 21, 1979, service could resume and use began in 1980 (3,000 subscriptions in 1982). A fourth launch failure took place on July 23, 1982; after 8 s, the first stage's actuator failed and the launch fell back to Earth 55 km from the launch platform. All in all, 21 Ecran were launched until 1988. The State Commission was headed by General Yu. F. Kravtsov.

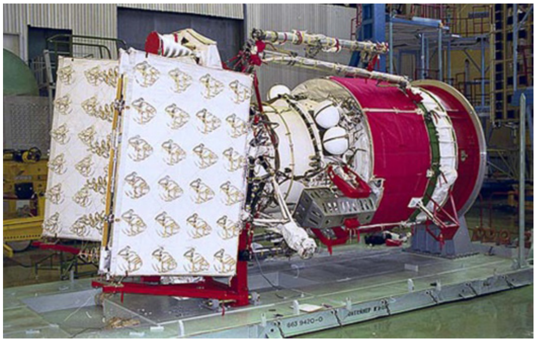


Figure 5.60. *The Ecran-M satellite (source: ISS Reshetnev)*

In 1984, NPO PM started developing the Ecran-M, the first copy of which, no. 11L, was launched on January 30, 1987, but there was a failure of the fourth stage and it became Cosmos-1817. A second launch failure occurred on August 9, 1990: the third stage stopped working after 349 s when the propellant feed stopped due to a rag in the piping. The vehicle fell into the Pacific. All in all, six Ecran-M were launched until April 2001.

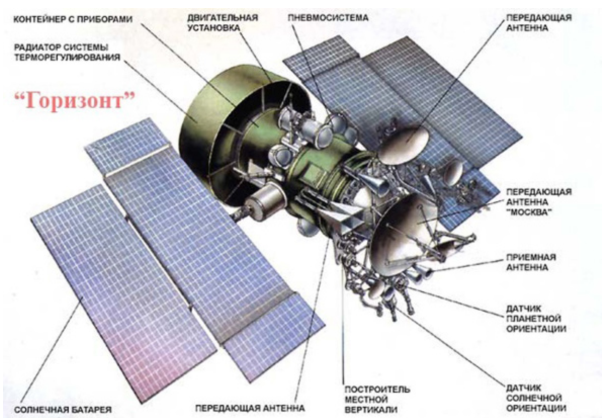


Figure 5.61. *The Gorizont satellite (source: ISS Reshetnev)*

The Gorizont civil satellite was created to ensure communications during the Olympic Games that took place in Moscow from July 19 to August 3, 1980. The payload included six C band repeaters, one in L band for Morflot and one in Ku band for the presidential airplane (MNIIRS). The first four satellites were launched on December 19, 1978 (bad orbit at 22,581/48,365 km), July 6, 1979, December 28, 1979 and June 14, 1980 before the Olympic Games. Use began in 1981 with more than 500 Moskva stations. Two launch failures occurred on January 18, 1988 (third-stage failure after 549 s due to an issue with the propellant piping construction) and on May 27, 1993 (the second stage was not completely filled with propellants due to a storage problem that was beyond the authorized limits). All in all, 35 Gorizont were launched until 2000.

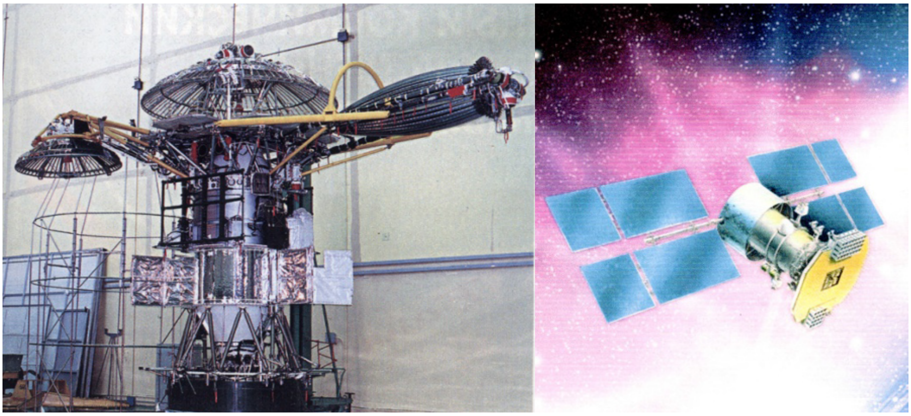


Figure 5.62. *The Luch-Altair and Potok-Geizer satellites (source: ISS Reshetnev)*

Next, the KAUR-4 platform was developed for the GKKRS relay satellite system (global retransmission and space command system), a decision made on February 17, 1976. For the first time, there was an onboard computer and electric propulsion (SPT-70 engines from the OKB Fakel) for position maintenance. The geostationary positions were reserved at the IUT under the name Potok (Geizer satellite) and Luch (Altair satellite). Geizer (11F663) was meant for Yantar and Tselina spy satellite date relays. It was equipped with Splav-2 and Synthesis payloads from NPO Elas, which would be used in January 1986 and February 1991, respectively. The first satellite was launched on May 18, 1982 (Cosmos-1366). All in all, 10 Geizer were launched until 2000. Its successor, the Garpun (14F136), was launched on September 21, 2011. As for the Altair (11F669), it served as a relay between tracking ships and manned spacecraft and orbital stations. It was equipped with the Arkion payload from the NPO Radiopribor. The first satellite, no. 11L, was launched on October 20, 1985 (Cosmos-1700). Four other satellites were launched until 1995 (Cosmos-1897, Cosmos-2054, Luch-1 and Luch-2/Helios). The successor, Luch-5A, was launched on December 11, 2011. The Luch-5B was planned for 2012 and the Luch-4 for 2014. The Potok and Luch State Commission was headed by General N. F. Shlygov, then by General N. A. Borissyuk.

Moreover, in the early 1980s, NPO PM studied the possibility of placing a 300-kg nuclear generator on the Molnya satellite: this was the Estafette project. However, the generator, studied by the TsKBM in Saint Petersburg, became heavier: it increased from 300 to 800 kg. In the end, this generator, named Topaz-2, would be sold to the United States.

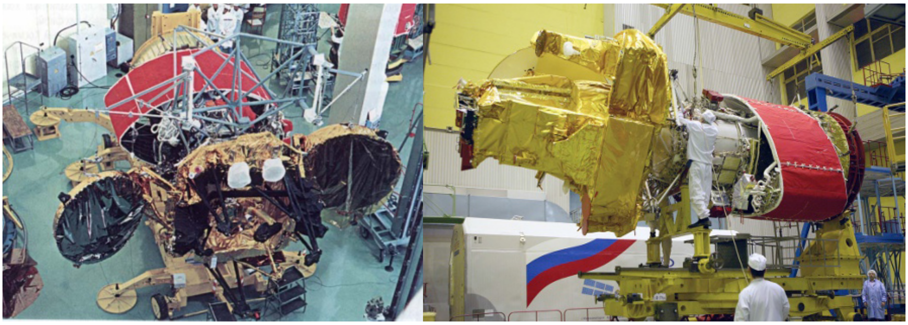


Figure 5.63. *The Sesat-1 and Express-AM44 satellites (source: ISS Reshetnev). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

With the end of the Soviet Union, a new generation of telecommunications satellites, more in line with Western standards, made their appearance. They weighed 2.5 tons, had a power of 2.4 kW and had a lifetime of 5 years. They were launched with the Bloc-DM 11S861-01. The first launch took place on January 20, 1994 with the direct television broadcasting satellite Gals-1 (17F71 no. 11L), which was equipped with three Ku band repeaters. The second satellite (no. 12L) was launched on November 17, 1995. Next, the Express (11F639), a successor of the Gorizont equipped with 12 K_u band repeaters, was launched on October 13, 1994 (no. 11L) and September 26, 1996 (no. 12L). Their performance was insufficient, and NPO PM decided to cooperate with Western companies. The first contract was signed on August 4, 1995 with Alcatel Space and Eutelsat for the Sesat satellite (Siberia-European Satellite) equipped with 18 K_u band repeaters. It was launched on April 17, 2000. This cooperation gave rise to the Express-A (A for Alcatel), equipped with 12 repeaters provided by the French manufacturer. Four satellites were launched on October 27, 1999 (second-stage failure after 222 s due to particles in the turbopump), March 12, 2000, June 22, 2000 and June 10, 2002. The following generation brought the Express-AM. These were 2.6-ton satellites with a power of 7.3 kW and a lifetime of 12 years. The first, Express-AM22, was launched on December 28, 2003. It was equipped with a Thales Alenia Space payload (24 repeaters). The NPO PM (later ISS Reshetnev in 2008) and Thales Alenia Space team would also make the Express-AM11 (2004), Express-AM2 (2005), Express-AM3 (2005), Express-AM33 (2008), Express-AM44 (2009), Express-AM8 (2013), Express-AT1 (2013) and Express-AT2 (2013). The Express-AM1, launched in 2004, was equipped with a payload from NEC-Toshiba (Japan), while the Express-AM5 and AM6, planned for launch in 2012 and 2013, would have payloads from MDA (Canada).

5.4.2. *The Glonass navigation satellites*

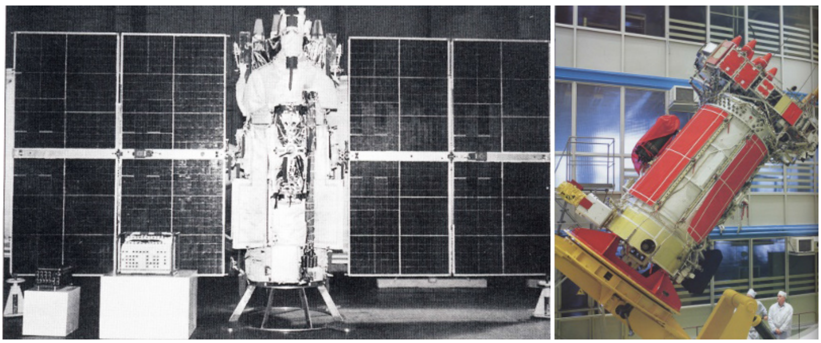


Figure 5.64. *The Glonass and Glonass-M satellites (source: ISS Reshetnev). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

The Glonass global navigation system was decided on by decree in December 1976. To obtain a perfect trajectography of the satellites, it was necessary to improve the terrestrial geoid, and two geodesic Sphera satellites were launched in July 1976 (Cosmos-842) and May 1977 (Cosmos-911). In 1978, NPO PM submitted its project to a commission headed by General I. V. Mesheryakov, deputy head of the TsNII-50. A new decree on August 29, 1979 asked for a constellation of 24 satellites to be put into service in 1987. The Uragan satellite (11F654), which weighed 1,415 kg, was to be launched in a triplet by a Bloc-DM Proton 11S861. They were placed into circular orbits at 19,100 km at a 64.8º inclination. The onboard atomic clocks were created by A. G. Gevorkian at the Institute of Radio Navigation and Time (LNIRTI, later RIRV) in Saint Petersburg. The serial production of the satellites was granted to the Polyot factory in Omsk. However, payload production was slower than planned and deployment began with triplets including models. The first launch took place on October 12, 1982 with one satellite and two models. Then, the next six launches were made up of two satellites and one model. The eighth launch finally included three satellites. In 1989, two launches included two satellites and one Etalon passive geodesic satellite. The satellites were initially deployed in two orbital planes: one 12-satellite constellation was in use starting in September 24, 1993. Then, they were deployed in the third orbital plane. On the occasion of the 27th launch on December 14, 1995, the 24-satellite constellation was declared operational. Throughout this launch, two of the three guidance systems had broken down. Three launches also failed: April 24, 1987 (the second ignition of the Bloc-DM failed to occur and the satellites were placed into orbit at 211 × 17,550 km), February 17, 1988 (the Bloc-DM did not ignite and the satellites were not separated) and December 5, 2010 (the Bloc-DM 11S861-03 no. 1L had been overfilled with propellants. Being too heavy, satellization could not take place). All in all, 85 Uragan were launched until December 2004. Starting in 2001, an improved version, Uragan-M (14F113), was launched in four triplets. Then, starting with the 34th launch on December 25, 2005, the triplets began to only include Uragan-M. All in all, 37 Uragan-M were launched until 2011. Since 1982, 42 Protons have been used to deploy the Glonass (122 Uragan and Uragan-M satellites, nine of which were lost during launch).

5.5. Other satellites

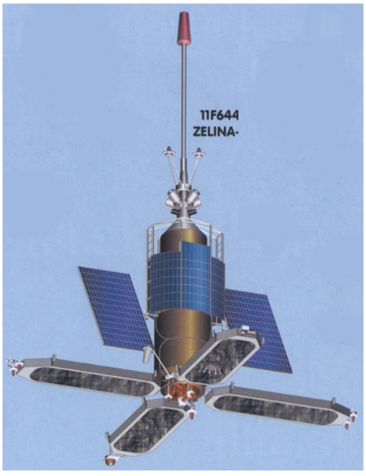


Figure 5.65. *The Tselina-2 satellite (source: NPO Yuzhnoye)*

The electronic intelligence satellite Tselina-2 (11F644), built by the NPO Yuzhnoye in Dniepropetrovsk, Ukraine, was meant to be launched by the new Zenit-2 rocket starting in 1984, but the launcher was not ready for its inaugural flight until April 13, 1985. In addition, the decision was made to launch the first two satellites with Proton equipped with a Bloc-M 11S861. The first launch took place on September 29, 1984 (Cosmos-1603) and the second on May 30, 1985 (Cosmos-

1656). The spacecraft, with a mass of 3.2 tons, was placed into a circular orbit at 850 km with a 71° inclination. The first Tselina-2 launched by a Zenit-2 was Cosmos-1833 on March 18, 1987.

When commercial telecommunications satellites made their debut in Russia, most of the general contractors jumped into the fray. Thus, the NPO Lavochkin developed the Coupon satellite (K95K), which weighed 2,650 kg, and was meant for the Bankir system (satellite banking network). The satellite was launched on November 12, 1997, but it quickly broke down and had no successor. RKK Energiya developed the Yamal platform (1,360 kg) for the Gazprom consortium. The first generation of Yamal-101 and 102 were equipped with a payload from Loral (12 C band repeaters). They were launched on September 6, 1999, but Yamal-101 quickly ran into electrical feed issues while in orbit. The Yamal-201 and 202 were launched on November 24, 2003. The payload was provided by Alcatel and Alenia Spazio. Next, RKK Energiya lost the contracts for the successors, which went to ISS Reshetnev (Yamal-300K with an Express-1000 platform, Yamal-401 with an Express-2000 platform and Yamal-402 with a Spacebus-4000C3 platform).

Finally, the Khrunichev Center developed the Yakhta platform (1,140 kg), which was used for the Express-MD-1 and MD-2 satellites, equipped with Thales Alenia Space payloads. The first was launched on February 11, 2009, and the second was planned for 2012. Khrunichev had also received the contract for the Express-AM4 and granted it to Astrium (Eurostar-3000 platform). However, the 18 August, 2011 launch failed due to a flight programming problem. Its understudy, Express-AM4R, was launched on May 15, 2014, but it was also lost due to a problem with the turbopump in the third-stage motor.

5.6. The centennial celebration of V. N. Chelomey's birth

June 30, 2014 marked the centennial of Vladimir Chelomey's birth in Sedletz. There was henceforth a commemorative plaque at school no. 10 in Poltava, where he had studied in 1922–1926. There was also a plaque where he had lived in Kiev in 1926–1941 and a bust at the Polytechnic Institute of Kiev, which he finished in 1937.

Parallel to his work as a designer, he was named head of section no. 6 of laboratory no. 3 of TsIAM in 1948. There, he studied pulsejets with N. Ya. Litvinov, R. I. Kurziner and others in 1949. However, this work would be abandoned in the end.

In 1951, he became a doctor of technical science and 1 year later, professor at the Bauman Technical University of Moscow (MVTU). On July 2, 1960, he created the chair for winged rockets (M-10, then M-2 in June 1961), which he headed until 1984. The chair was also responsible for satellites starting in 1964. His successors were I. M. Shumilov in 1984–1992, followed by his son S. V. Chelomey in 1992–1999, and then O. N. Tushev since 2001. In June 1984, a second bust of Chelomey was installed on the grounds of the MTVU. In 1958, Chelomey was elected as a corresponding member of the Academy of Science. Four years later, he became an academician. On July 4, 1963, he was a member of the Academy's presidium. The Academy awarded him the Zhukovsky medal in 1964 and the Lyapunov medal in 1977. He was also a member of the National Committee for Theoretical and Applied Mechanics. In 1974, he was elected member of the International Academy of Astronautics (IAA).

On the occasion of his 60th birthday, the book *Selected Problems of Applied Mechanics* was published in 1974. Next, along with his co-authors, Chelomey published *Pneumo-Hydraulic Systems of Motor Installations in Liquid Rocket Engines* in 1978. In 1981, he published *Vibrations in Technology* (six volumes). Finally, in 1989, Chelomey's *Selected Works* was published 5 years after his death.

On the political side of things, he participated in all of the PCUS congresses starting in 1961. However, he would never become a member of the Central Committee (which included P. D. Grushin, V. P. Makeyev, V. F. Utkin, V. P. Glushko and Yu. P. Semenov). Moreover, starting in 1974, he was a deputy of Chuvashy at the Supreme Soviet. However, in his career, he made both friends and enemies. In 1953, his OKB-51 was closed by Beria in favor of his son, who was working on the Kometa missile with aircraft designer Mikoyan (brother of the deputy president of the council of ministers).

Figure 5.66. *Keldysh and Chelomey (source: all rights reserved)*

In 1958, however, he appointed Nikita Khrushchev's son and thus benefited from the support of the Head of State. When Khrushchev was fired in October 1964, he lost a large share of his contracts: the flight over the moon was granted to Korolev, the UR-200, GFS satellites and Plazma, the Raketoplan, the P-25 naval missile were abandoned, and the US-K early warning satellite was transferred to Kometa and the TGR satellite to the OKB-586 (Yuzhnoe). Among his supports, he could count on A. A. Grechko, Minister of Defense in 1967-1976, P. V. Dementyev, Minister of the Aviation Industry in 1953–1977 (on which the OKB-52 depended in 1954–1965), S. A. Afanaseyev, Minister of General Machines in 1965–1983 (on which the OKB-52 depended in 1965–1991), academicians M. V. Keldysh, L. I. Sedov, V. S. Avduyevsky (TsAGI, TsIAM, NII-1), etc. His adversaries were D. F. Ustinov, head of the VPK in 1957–1963, and L. V. Smirnov, head of the VPK in 1965–1985, both who had come from the Ministry of the Defense Industry (armament), which supported his competitor, Korolev. The situation became critical for Chelomey when Ustinov became Minister of Defense in 1976–1984. On December 19, 1981, a decree decided to stop all space programs at the OKB-52. On January 28, 1983, it became the NPO Mash with E. A. Verbin as the general director and Chelomey as the general designer. From 1989 to 2007, the general director and designer was G. A. Efremov. Born in 1933, he finished his studies at the Institute of Military Mechanics in Leningrad in 1956, then went to the OKB-52. He was head of the KB in 1964, then deputy in 1971. He was granted the Hero of Socialist Labor in 1963, the Lenin Prize in 1982 and the State Prize in 1974. In 2007, he was replaced by A. G. Leonov. Born in 1952, he finished his studies at the Institute of Aviation in Moscow in 1975. He joined the OKB-52 and managed the programs performed in cooperation in 1999 (notably in BrahMos with India). He became a doctor of technical science in 2009.

a) b) c)

Figure 5.67. *a) Vladimir and Ninel, b) Sergey and c) Evgenya (source: all rights reserved)*

Chelomey was married to Ninel Vassilyevna. They had two children together: a son, Sergey, and daughter, Evgenya. Sergey (April 2, 1952–March 6, 1999) finished his studies at the MFTI in 1976, then joined his father's company. There, he was a cosmonaut candidate from March 1981 to April 1987. He was part of a team who was meant to fly to the Almaz orbital station (Zudov-Glazkov-Chelomey). Then, he received his doctorate in mathematics and physical sciences. After becoming a professor, he followed in his father's footsteps as the M-2 chair of the MVTU in 1992. Unfortunately, he died young, leaving behind a son (Vladimir, named after his grandfather) and a daughter (Anastasia). Chelomey's daughter, Evgenya, married the son of N. V. Talyzin, main designer of the satellite communication systems at the Radio Institute, deputy, first deputy, then Minister of Communications in 1965–1980 and deputy, then first deputy of the Council of Ministers and president of the Gosplan in 1985–1988.

12 декабря 1984 года ● 3

Академик

Владимир Николаевич ЧЕЛОМЕЙ

8 декабря 1984 г. в Москве на 71-м году жизни скоропостижно скончался выдающийся ученый и конструктор в области ракетной техники, член КПСС с 1941 года, депутат Верховного Совета СССР, дважды Герой Социалистического Труда, лауреат Ленинской и Государственных премий СССР, академик Владимир Николаевич Челомей.

Владимир Николаевич Челомей был выдающимся конструктором советской ракетной техники и летательных аппаратов, выполнял важные научные работы в области механики, воспитал многочисленные кадры ученых и инженеров, работающих во многих институтах и конструкторских бюро.

В. Н. Челомей родился 30 июня 1914 г. в семье учителя. После окончания Киевского авиационного института имени К. Е. Ворошилова и аспирантуры Академии наук УССР с 1939 года работал научным консультантом и начальником отдела Центрального института авиационного моторостроения, главным конструктором и директором завода.

Последние двадцать девять лет В. Н. Челомей возглавлял крупную научно-исследовательскую и конструкторскую организацию. Яркий талант ученого и конструктора, глубокие теоретические знания и большая эрудиция позволили ему создать высококвалифицированный коллектив и успешно выполнять сложные научно-технические задачи.

Владимира Николаевича отличали кипучая энергия и неутомимый поиск новых решений, творческая смелость в сочетании с большими организаторскими способностями, внимательное отношение к людям.

За выдающиеся заслуги перед Родиной он был дважды удостоен звания Героя Социалистического Труда, награжден пятью орденами Ленина, орденом Октябрьской Революции и многими медалями. Ему были присуждены Ленинская и Государственные премии СССР. Был делегатом XXIV, XXV и XXVI съездов КПСС, избирался депутатом Верховного Совета СССР ряда созывов.

Светлая память о выдающемся ученом и конструкторе Владимире Николаевиче Челомее — верном сыне Коммунистической партии и советского народа, отдавшем все силы служению своей Родине, навсегда сохранится в наших сердцах.

К. У. Черненко, Г. А. Алиев, В. И. Воротников, М. С. Горбачев, В. В. Гришин, А. А. Громыко, Д. А. Кунаев, Г. В. Романов, М. С. Соломенцев, Н. А. Тихонов, Д. Ф. Устинов, В. В. Щербицкий, П. Н. Демичев, В. И. Долгих, В. В. Кузнецов, Б. Н. Пономарев, В. М. Чебриков, Э. А. Шеварднадзе, М. В. Зимянин, И. В. Капитонов, Е. К. Лигачев, К. В. Русаков, Н. И. Рыжков, Л. В. Смирнов, Г. И. Марчук, Н. В. Талызин, А. П. Александров, И. Ф. Дмитриев, В. А. Медведев, О. Д. Бакланов, И. С. Силаев, И. С. Белоусов, В. В. Бахирев, Е. П. Славский, А. И. Шокин, С. А. Афанасьев, Б. В. Бальмонт, В. И. Коновалов, Н. С. Строев, В. В. Козлов, Б. А. Комиссаров, С. Л. Соколов, С. Ф. Ахромеев, В. Ф. Толубко, С. Г. Горшков, В. М. Шабанов, А. А. Максимов, В. Н. Коновалов, А. С. Матренин, В. Н. Иванов, Е. П. Велихов, В. А. Котельников, В. П. Глушко, В. Ф. Уткин, В. И. Кузнецов, Д. А. Полухин, А. И. Киселев, Д. А. Тараков, Г. А. Ефремов.

Figure 5.68. *Obituary published in Pravda on December 12, 1984 (source: Christian Lardier)*

Chelomey received the 1967 State Prize for the UR-100, the 1974 State Prize for the UR-100U, the 1982 State Prize for the UR-100NUTTX, the Order of Lenin in 1974 for his 60th birthday and again in 1984 for his 70th birthday. He died in an automobile accident on December 8, 1984. He was buried at the Novodevichy Cemetery. After his death, a third bust was placed on the company's grounds in Reutov (1988) and a fourth in a school of the cosmodrome in Baikonur (1991).

закрылся из-за финанс. затруднений.

ЧА́СТНЫЙ ПРИ́СТАВ, полицейский чин, начальник *части*. Должность введена Уставом благочиния 1782. Ч. п. подчинялись *Управе благочиния* (непосредств. начальник — полицмейстер), под их началом были квартальные надзиратели. Ч. п. следили за «охранением тишины и спокойствия», вели регистрацию строений и жителей, давали разрешения на проживание в М. и выезд из неё, надзирали за гостиницами, трактирами, ресторанами, исполняли суд. решения. В 1881 в связи с реформой моск. полиции должность Ч. п. упразднена.

ЧАСЫ́ ГОРОДСКИ́Е. Первые Ч. г. в Москве сооружены в 1404 Лазарем Сербиным на одном из зданий Кремля вблизи Благовещенского собора. В 15—18 вв. сооружено несколько солнечных Ч. г., нек-рые из них сохранились: на зданиях МГУ (просп. Маркса, 18), Историко-архивного ин-та (ул. 25 Октября, 15) и др. Начиная с 15 в. устанавливались башенные механич. Ч. г., в т. ч. в Кремле, монастырях, на церквах и больших гор. зданиях. В 1621 были изготовлены *Кремлёвские куранты*, к-рые в 1625 установили на Спасской башне. Башенные часы стояли до 1933 на *Сухаревой башне*. В 19 в. существовало неск. крупных предприятий по изготовлению башенных Ч. г.,

654

Часы на здании Центрального театра кукол.

Памятник-бюст П. Л. Чебышёва.

ми вопросами естествознания и техники. Памятник-бюст (скульп. И. А. Рабинович, 1953) у здания МГУ на Ленинских горах.

ЧЕЛОМЕ́Й Владимир Николаевич (р. 1914), учёный в области механики и процессов управления, акад. АН СССР (1962), дважды Герой Соц. Труда (1959, 1963). Чл. КПСС с 1941. Окончил Киевский авиац. ин-т (1937). В 1941—44 работал в Центр. ин-те авиац. моторостроения им. Баранова. С 1959 ген. конструктор. Создал первый в СССР пульсирующий возд.-реактивный двигатель (1942). Под рук. Ч. разработаны ракета-носитель и спутники «Протон», искусств. спутник Земли «Полёт». С 1952 проф. МВТУ им. Баумана. Деп. Верх. Совета СССР с 1974. Ленинская пр. (1959), Гос. пр. СССР (1967, 1974).

ЧЕЛЮ́СКИНЦЫ, участники экспедиции по Сев. морскому пути на пароходе «Челюскин» (1933—34). Руководитель — О. Ю. Шмидт. 13 февр. 1934 пароход, раздавленный льдами, затонул в Чукотском м., участники экспедиции (104 чел.) высадились на лёд и в течение двух месяцев в труднейших метеорологич. условиях героич. усилиями лётчиков были эвакуированы на материк (последняя группа — 13 апр.), самолёты сделали 24 рейса. 19 июня Ч. прибыли в Москву на Белорусский вокзал; ул. Горько... по к-рой следовали машины с Ч., бы

Figure 5.69. *Chlomey's first appearance as the Proton and Polyot designer in the Encyclopedia of Moscow, published in 1980 (source: Christian Lardier)*

Figure 5.70. *Busts in Kiev, Baikonur, MVTU, NPO Mash, and tomb in Novodevichy (source: all rights reserved)*

In the West, his identity was revealed by Oleg Penkovsky (the book *The Penkovsky Papers*) in 1965, then by the defector Leonid Vladimirov (the book *Russian Space Bluff*) in 1971, and then by Khrushchev (the book *Khrushchev Remembers*: *The Last Testament*) in 1974. Theodore Shabad, *New York Times* correspondent in Moscow, cited him as the head of the Soviet space program on July 14, 1974, but this information was incorrect. It would not be until the publication of the Moscow Encyclopedia in 1980 that the true nature of his activity would be known: designer of the Polyot and Proton. This information would be brought to the Western public's eye by Claude Wachtel on June 1 and 2, 1984 (an article in the *JBIS* in 1985), then by myself (an article in *Aviation Magazine*, January 15, 1985). Chelomey's obituary in December 1984 would provide no complementary information, but the biography published in the *Encyclopedia of Cosmonautics* in March 1985 also referred to him as the father of the military orbital stations (Salyut-3 and 5, Cosmos-1267, etc.).

a) **b)**

Figure 5.71. *a) Order of Lenin awarded by N. S. Khrushchev to the OKB in 1959 and b) Order of the Red Banner awarded by P. V. Dementyev to the OKB in 1963 (source: all rights reserved)*

a) **b)**

Figure 5.72. *(a) Chelomey, Khrushchev, Korolev, Pilyugie, Barmin in Crimea in 1961 (source: all rights reserved) and (b) from left to right, Glushko, Trufanov, Tyulin, Kaidalov, Barmin, Pruglo, Konopatov, Kurushin, Chelomey, Druzhinin, 1965 (source: all rights reserved)*

a) **b)**

Figure 5.73. *a) Chelomey in Baikonur in 1970 (source: all rights reserved) and b) M. G. Grigoryev and V. N. Chelomey in 1974 (source: all rights reserved)*

a) **b)**

Figure 5.74. *a) I. S. Belussov, Chelomey, S. A. Afanaseyev, S. G. Gorshkov and P. G. Kotov, and b) V. S. Avduyevsky, V. P. Mishin, E. P. Velikhov, Chelomey, and A. P. Alexandrov (source: all rights reserved)*

PART 2

The Proton in the West

6

Saturn's Rival

On October 4, 1957, the Redstone Arsenal team from Huntsville (Alabama), led by Wernher Von Braun, had experienced the humiliation of seeing the world's first artificial satellite put into orbit by the Soviets. If the father of the German V-2 had been allowed to continue working, the team could have done the same with the support of a modified Jupiter-C missile as soon as January 1957. The subtleties of the Eisenhower administration's space policy had at that time given priority to the Vanguard program since it was based on a sounding rocket design rather than a weapon system. The White House's objective was to create a legal precedent when the scientific satellite had flown over numerous sovereign nations, including the Soviet Union, without arousing official protest. This could have paved the way to fly over again in the future with useful and much less innocent intentions, as was the concept of the WS-117L spy satellite, secretly studied at Lockheed since February 1956, which would later give rise to the Corona military observation program.

After the spectacular failure of the Vanguard's inaugural launch on December 17, 1957, Von Braun's team would take its revenge on February 1, 1958 when it sent the Explorer-1 into orbit, the very first US satellite, atop the Juno-1 launcher, a variant of the Jupiter-C missile. However, in the public eye, the damage was already done. The Soviet Union had taken the first steps into space and was ahead in the race that had started by collecting the big "firsts". These were skillfully staged under the guidance of Nikita Khrushchev, enthusiastic First Secretary of the CPSU: the first living creature in orbit, the first flight over the Moon, the first impact and first images of its far side, the first interplanetary probe, the first man in space, then the first woman and, finally, the first team, on October 12, 1964, with the Voskhod-1 manned spacecraft whose 5,320 kg weight set a new record for a satellite's mass (excluding the launcher's upper stage). Ironically, the same day as this record, Nikita Khrushchev was dismissed of his duties by Leonid Brezhnev and Nikolai Podgorny.

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

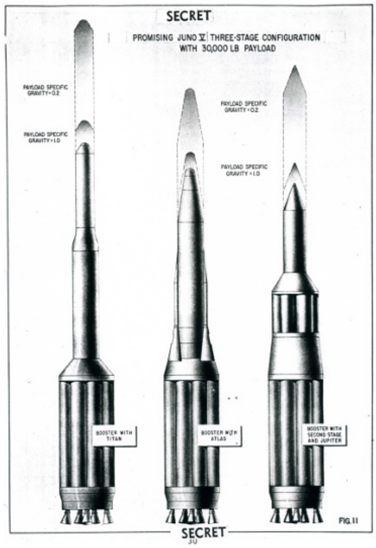


Figure 6.1. *First concepts of the Juno 5 (source: ABMA)*

Nevertheless, the US counterattack was underway. Through his historic speech given on May 25, 1961, US President John F. Kennedy gave it a goal: "landing a man on the Moon and returning him safely [before] this decade is out". Three primary programs were at work to achieve this goal. Gemini, a two-seated capsule developed from the Mercury, aimed to master basic orbital rendezvous and docking techniques, as well as extravehicular activities, which should allow them to beat the Soviets to some "firsts". Apollo would be the spacecraft for manned lunar missions and Saturn would become the family of launchers that would make these missions possible.

At the origin of the Saturn is actually a concept studied by Wernher Von Braun and his team: the Juno-5 launcher, whose development was authorized by the Advanced Research Projects Agency starting in August 1958. The basic idea was to create a propellant stage with a 700-ton thrust made up of a Jupiter missile surrounded by eight Redstone missiles from which the Jupiter-C and the Juno-1 were derived. The project quickly evolved into a multistage rocket to place heavy military loads into orbit, but the configuration of the first "barrel" stage would remain, the central shaft and four outside shafts being filled with liquid oxygen, while the four other outside shafts were filled with kerosene. The Juno-5 was renamed the Saturn-1 in February 1959 and proposed to NASA, which finally took control of it in July 1960. Saturn was thus the very first launcher developed under the direction of the US space agency, which would make it greatly symbolic.

6.1. Records to break

Figure 6.2. *Launch of the Saturn SA-1 (source: NASA)*

On October 27, 1961, the first Saturn-1 (SA-1) launcher took off from Complex 34 at Cape Canaveral in Florida. Only the first stage was active. The second and third were inert models filled with water and mounted on the upper cone of a Jupiter missile. Fifty meters tall and with a total mass exceeding 400 tons, all propelled by eight motors with a combined thrust of 5,800 kN at liftoff: never before had such a powerful launcher been seen in the West! Nor in the East, but Westerners did not yet know that. For this first suborbital flight, the Saturn SA-1 launcher reached an altitude of 134 km before falling back, as planned, into the Atlantic.

Three other suborbital flights would follow in 1962 and 1963 before the first orbital flight on January 29, 1964. On that day, taking off from Complex 37B of Cape Canaveral, the Saturn SA-5 launcher placed a load of 16,965 kg into orbit, made up of its S-4 upper stage and a Jupiter missile nose cone loaded with 5,260 kg of sand serving as a ballast. This was a record, even if it was not a satellite, strictly speaking.

For the United States to finally pocket the record for the largest satellite ever placed in orbit[1], it would have to wait until February 16, 1965 and the eighth flight of the Saturn-1 (SA-9, because the order of launcher manufacturing was jostled). For this mission, considered the first operational flight of the Saturn launcher, the payload was made up of a model of the Apollo command module and Pegasus-1, a satellite equipped with detector panels that gave it a span of 29 m once deployed. This would serve to measure the density of micrometeorites around the Earth. The satellite itself only weighed 1,805 kg, but because it was designed to remain attached to the S-4 stage, its official mass reached 10,297 kg. The Voskhod-1 record was thus crushed.

In orbit, for the first time, a television camera retransmitted the deployment of the detector panels. On the ground, observers had no problem seeing the satellite, whose magnitude sometimes rivaled that of the brightest stars.

Figure 6.3. *Launch of the Saturn SA-8 (source: NASA)*

1 To be honest, we must not forget that the United States had already landed this record on December 18, 1958 with the SCORE (Signal Communications by Orbiting Relay Equipment) satellite whose mass officially reached 3,969 kg. In reality, this was the central body of an Atlas B missile that had itself been placed into orbit and on which a 68 kg case was fixed; this case contained an emitter powered by batteries to retransmit President Dwight Eisenhower's pre-recorded Christmas wishes for 12 days. Some wasted no time in presenting this propaganda operation as the "first telecommunication satellite in history", even if the signal was actually so weak that only a few radio amateurs could capture it. This record really was not a record given that, in November, 1958, the Soviet Sputnik-2, weighing in at 508 kg, had also remained attached to the central body of its launcher, with a total mass of more than 6.0 tons. It would nevertheless remain official until May 15, 1960 and the launch of the 4,600 kg first Vostok prototype.

The operation was renewed on May 25 with the Saturn SA-8, which launched Pegasus-2. Nine days later, the astronaut Edward White crawled out of the Gemini-4 capsule and performed a 20-min walk in space, reproducing and exceeding the 8-minute exploit of Alexey Leonov less than 3 months earlier. Although the Soviet cosmonaut had seemed like a clumsy puppet in the low-quality images, the American astronaut seemed at ease and the photographs were splendid. A little more than 1 month later, on the night of July 14/15, NASA's Mariner-4 probe was the first to fly around Mars and send back images, whereas the Soviet Zond-2 probe, which followed it, broke down in May. For the first time since the start of the "space race", the United States seemed to be well ahead of its rival. This impression would only last a few hours.

On July 16, the announcement of the Soviet launch of a 12,200 kg satellite – excluding the upper stage – fell like thunder and reset the counters at zero.

Named the Proton-1, this giant satellite was presented by the astrophysicist Sergei Vernov, correspondent of the USSR Academy of Sciences, as "a station for the study of cosmic rays and high-energy particles". As some US analysts were sure to point out, including scientific consultant Frederick I. Ordway III from Von Braun's team in Huntsville, "this mission would not require the use of such a massive spacecraft, *a priori*". Furthermore, the term "station" did not go unnoticed and commentators immediately imagined that it was a prototype of a manned vehicle, probably a manned module that could be used as a relay by Soviet cosmonauts on their way to the Moon.

The communiqué from the official press agency TASS remained evasive concerning the launcher that had allowed this exploit, as was traditional: "in order to ensure the foreseen development of the research program, a new high-power launcher has been developed in the Soviet Union". Nothing more would be known. The communiqué also did not specify the total mass placed in orbit, but for US analysts, it seemed reasonable to estimate 20.0 tons, i.e. a performance coming close to that of the future Saturn-1B, an improved version of the Saturn-1 that would debut in 1966 and place 18.6 tons into orbit. It was only long after the end of the Cold War that it would be discovered that the announced mass of 12.2 tons for the Proton-1 was actually made up of 8.3 tons for the satellite itself[2] and 3.9 tons of ballast to achieve the maximum performance allowed by the staging of the UR-500 missile, a two-stage missile that served for launching and was absolutely not optimized to achieve orbit[3].

2 3.5 tons of which was actual science payload.

3 Paradoxically, if the empty mass of the second stage of the UR-500 (13,180 kg) was added to the satellite's real mass, it would reach a total of approximately 21.5 tons in orbit, close to the American estimate. With the ballast, however, it would reach 25 tons.

In the meantime, extrapolations allowed the new Russian launcher to be attributed a liftoff thrust of the order of 1,000 tons, which would have made it the most powerful launcher in the world, awaiting the appearance of the giant Saturn-5, which was still 2 years in the future.

Concerning its configuration, "it is very difficult to escape speculation", Frederick I. Ordway III would write a few months later. "If Proton-1 truly represented the maximum mass that could be put into orbit, substantial improvements to this rocket will have to be expected. It could even be a prototype of the vehicle that the Soviets propose using for Man's voyage to the Moon".

That summer, 1965, one thing seemed sure for Westerners: if the Soviets also had a launcher similar to the Saturn, they were following a parallel path and thus participating in the race initiated by Kennedy. The launches of the Proton-2 on November 2 and Proton-3 on July 6, 1966 would only confirm this idea.

6.2. Target: Moon

While months went by without the Soviets launching new manned missions following the Voskhod-2 in March 1965, the appearance of the Proton awakened the imagination of observers, even more so given that on August 25, General Nikolai Kamanin, head of the Center for Cosmonaut Training, announced that the Soviets "would leave for the Moon on board a giant rocket assembled in orbit by workers of the cosmos".

In France, the famous popularizer Albert Ducrocq glimpsed a lunar spaceship weighing some 50.0 tons, made up of 12.0 tons elements assembled in orbit. In the United States in mid-1966, the weekly magazine *Aviation Week & Space Technology* believed – due to a series of reports published in the Russian newspapers *Krasnaya Zvezda* and *Komsomolskaya Pravda*, as well as those in the Czechoslovakian press – that the Soviets were preparing a spacecraft capable of taking six to eight cosmonauts around the Moon. It would take time to perfect it, which would explain this parenthesis in manned flights. This final assertion was refused – which was rather rare – by General Kamanin during a new press conference in Warsaw on March 10, 1967: "the Westerners often lend us possibilities exceeding our current means". At the same time, he maintained that the Soviets would soon have a launcher more powerful than the Saturn-5.

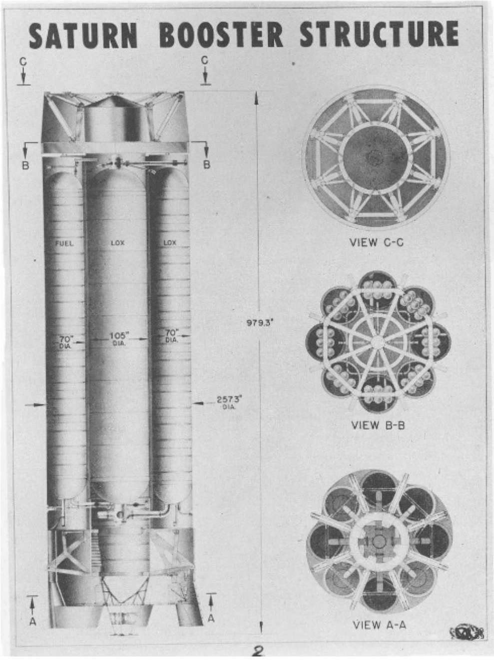


Figure 6.4. *The barrel from the Saturn-1's first stage (source: NASA)*

Figure 6.5. *Without knowing it, the Americans were using the same barrel configuration as the Soviets (source: NASA)*

Yet, that same day, March 10, 1967, a launch went nearly unperceived in the long litany of missions that the Soviets gave the general name "Kosmos". This Kosmos-146 was launched into orbit at 51.5º, a rather unusual inclination that generally seemed to be reserved for missions of "great astronautics". This is indeed one of the weakest inclinations that can be obtained from the Tyuratam station (aka Baikonur) without flying over China. This is thus the one that allowed the heaviest payloads to be launched and notably served for the parking orbits of lunar and interplanetary probes.

Very quickly, it was apparent that this satellite was very large. It was clearly visible with the naked eye and presented strong variations of luminosity. According to the first statements from US radar networks surveying the sky, it could have had a mass of 25 to 30 tons. A few hours after its launch, two objects broke off from it and were quickly lost sight of. Two others would be followed until they reentered the atmosphere 8 days later. Every analyst was convinced: this was truly the first test flight of a new spacecraft, accompanied by the upper stage of an even more powerful version of the Proton satellite launcher and maybe even of small individual pods to assemble larger space structures[4]. Celestial mechanics is formal, however; for this first attempt, it was not yet a matter of reaching the Moon.

Figure 6.6. *Proton-1 satellite in Le Bourget in 1967 (source: rights reserved)*

4 Not every object connected to this launch was formally identified, but Kosmos-146 was primarily made up of an L1 model, a Bloc-D upper stage, and the new third stage of the Proton launcher.

The operation was renewed on April 8 with Kosmos-154, whose failure went unnoticed[5], in addition to being quickly eclipsed, two weeks later, by the drama of the Soyuz-1 mission and the death of cosmonaut Vladimir Komarov in the crash of his capsule. After a flight abounding in onboard failures and glitches, it took two attempts to deorbit. Although the reentry through the upper atmosphere had gone well, the parachute failed to deploy and the capsule crashed into the steppe at more than 120 km/h.

The following June, the Soviets unveiled the architecture of the Vostok launcher by exposing a full-scale model at the Paris Air Show in Le Bourget. They also presented a model of the Proton satellite, whose 4.5-m diameter greatly impressed visitors, but not specialists, who had already assumed this based on the few photos that had previously been broadcasted. As for the launcher that put these giants into orbit, however, nothing was revealed. The only number that the Soviets really wanted to communicate up to that point was a power at liftoff of 60 million horsepower, very difficult to convert into thrust. However, British analyst John A. Parfitt from the Guided Weapons Division of the British Aircraft Corporation would deduce from this that the maximum payload capacity of the Proton reached 14.0 tons.

Figure 6.7. *First liftoff of the Saturn-5 (source: NASA)*

5 The Bloc-D upper stage could not be restarted to reach a higher orbit.

On November 9, 1967, the success of the giant Saturn-5 launcher's inaugural flight shadowed the Soviets' mysterious lunar plans. The mass sent into orbit amounted to 127 tons, i.e. more than everything that the United States had sent into space for the past 10 years. After having been greatly shaken by the January 27 accident that caused the death of the first crew – Gus Grissom, Edward White and Roger Chaffee – during rehearsal, the Apollo program was once again on track.

March 2, 1968, TASS announced the launch of a Zond-4 probe. Since the previous probes launched under this name were meant more for distant space, it did not really attract attention at first. However, rumors from Moscow left people to understand that the probe could leave Earth orbit to fly beyond the Moon. For Heinz Kaminski, director of the Institute for Space Research in Bochum, Germany and the first man to have captured the "beep-beep" of Sputnik outside the USSR, there was no doubt that the Soviets were testing an empty spaceship, later to be manned, derived from the Soyuz to reach the Moon, which implied that the Proton satellites' launcher had been used again. Other commentators, notably in the United States, thought rather that it was an experimental probe of around 1,500 kg, put into orbit by a derivative of the Vostok launcher. When Zond-4 was boosted into an elliptical orbit seven days before the opening of a true lunar window and reached a distance of 330,000 km from Earth, but in the opposite direction of the Moon, opinions remained divided and they would remain so after the probe had been destroyed during its return over the Atlantic Ocean, where a Soviet recovery fleet, if there was one, failed to be spotted. No one imagined then that this return was a fiasco and that the probe had been destroyed by a system sent so that it would not fall into the wrong hands.

One month later, during its second flight, the giant Saturn-5 launcher lifted the Apollo-6 capsule to an altitude of 22,209 km before its return and recovery in the Pacific Ocean, 500 km north of Honolulu. The same day, pastor Martin Luther King was assassinated in Memphis. Robert Kennedy's turn would come 1 month later. Problems would also break out in America, Europe and even in Japan, whereas the Warsaw Pact would crush the "Prague Spring". For a while, the Apollo program and the race to the Moon would no longer make the headlines.

As for NASA, it saw a crisis of its own.

During the summer of 1967, it launched a step-by-step program to prepare the lunar landing. The goals were designated by letters and as many missions as were necessary would be attributed to each before moving on to the next stage:

– A: qualification of the Saturn-5 launcher;

– B: qualification of the manned lunar module in a low orbit;

– C: qualification of the Apollo spacecraft with a crew in a low orbit;

– D: qualification of joint operations of the Apollo spacecraft and the lunar module with a crew in a low orbit;

– E: joint operations of the Apollo spacecraft and the lunar module with a crew in a high orbit;

– F: dispatch of a crew to a lunar orbit;

– G: lunar landing.

In July 1968, goals A and B had been fulfilled and the Apollo-7 mission, planned for the fall, was to fulfill goal C. Starting April 27, based on the results from the Apollo-6 mission, NASA's administrator, James E. Webb, had approved the use of the third Saturn-5 launcher for a manned flight at the end of the year, which would allow goal D to be achieved. However, keeping this schedule to achieve goal G before 1970 seemed unrealistic, even with the optimistic hypothesis that none of the missions would face major problems and voices would rise up within the agency to "skip" steps.

Yet the CIA and its military counterpart, the Defense Intelligence Agency (DIA), then suddenly warned NASA that the Soviets had decided to attempt a manned circumlunar flight before the end of the year. The efficiency of these secret services would later be admired, because the meeting in Moscow where this decision took place only dated back to June 26. Although civil observers had been lost in conjectures about the mysterious large Soviet launcher and fantasizing about a hypothetical giant launcher equivalent to the Saturn-5 for 3 years, the CIA was far beyond wild guessing and had much more precise information.

6.3. Under a shroud of secrecy

In the heroic era of Sputnik and the fantasy of the "missile gap" where Nikita Khrushchev's saber-rattling was taken at face value when he proclaimed that his factories were making missiles "like sausages", US intelligence agencies could hardly count on just some dangerous aerial reconnaissance to get an idea of what the Soviets were plotting.

This era ended with the arrival of spy satellites. After erratic beginnings, secret satellites from the Corona program regularly observed the entire Soviet territory after 1961–1962 and those of the Gambit program did so starting in 1963. The latter in particular made shots with a 1.2-m resolution possible, even increasing to 60 cm in 1966. This was more than enough to monitor the evolution of work on the different launch infrastructures in Baikonur and to have a rather clear idea of what was being prepared there. By completing this so-called "IMINT" (Imagery Intelligence) information with those gleaned by more traditional "HUMINT" (Human Intelligence) spying, the CIA thought it could determine the nature of Soviet projects with rather high precision. However, the absence of infiltration at the highest levels made it difficult to interpret the political prevarications that presided over the future of Soviet cosmonautics.

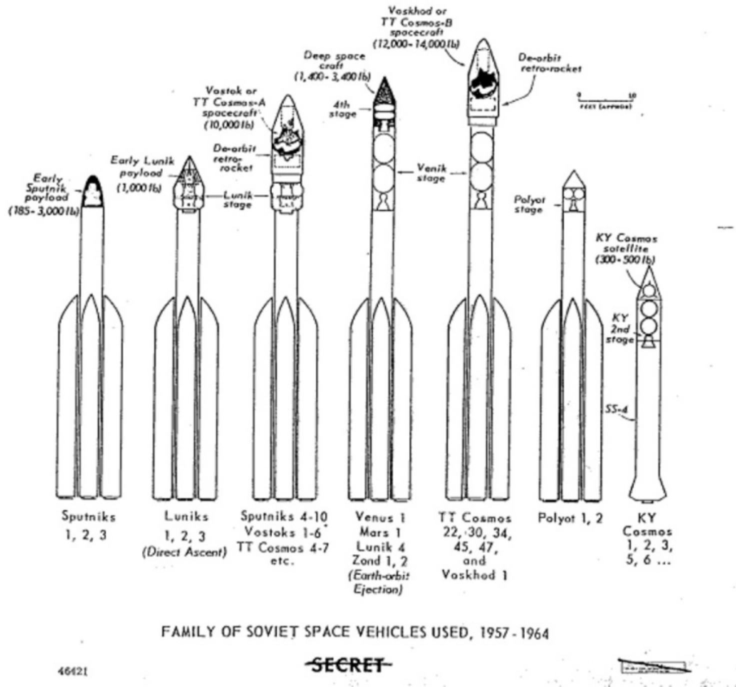


Figure 6.8. *The Soviet launchers known to the CIA in 1965 (source: CIA)*

Thus, in its National Intelligence Estimate (NIE) from January 27, 1965 on the Soviet space program, the CIA stated that there was no indication that the Soviet Union had started a competition with the United States for the race to the Moon. The cause of this was simple: although Khrushchev had explicitly mentioned this in November 1963 and July 1964, the Soviet equivalent of the Apollo program was not approved until August 1, 1964, once the highest authorities had understood that the Americans were not ready to give up Kennedy's crazy bet, particularly after he had been assassinated and the construction work on the N-1 launcher complex had started just 1 month later.

Likewise, the CIA announced that a launcher with 2 million pounds of thrust (900 tons) was being developed for introduction that year. Its payload capacity was then estimated at 50,000 lb (22.5 tons) in a low orbit. Comparable in size to the US Saturn-1, this new launcher could serve for manned missions as early as 1966, then 1 year or 2 years later, to launch elements for a large, manned orbital station whose mass could quickly exceed 100,000 lb (45 tons) and welcome rotations of crews of 5–10 people.

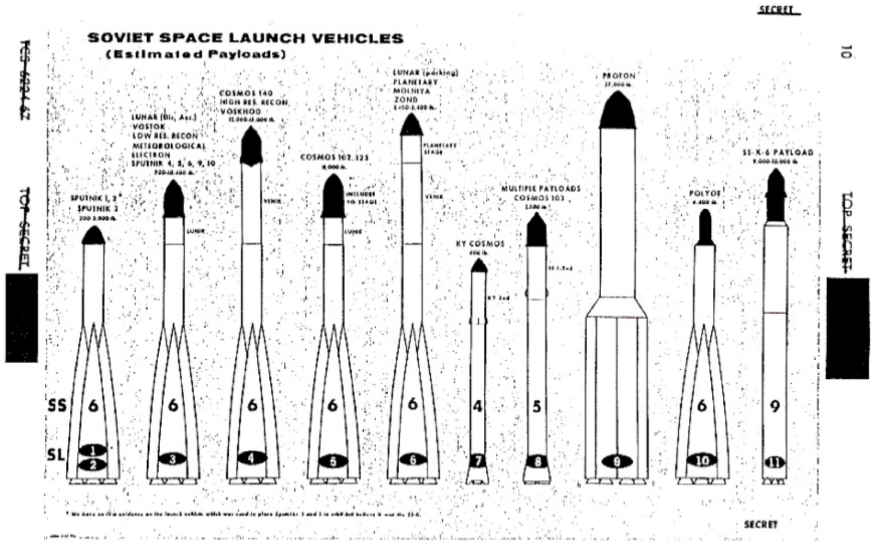


Figure 6.9. *The Soviet launchers known to the CIA in 1967 (source: CIA)*

The CIA also realized that this new launched could rather quickly make it possible to fly around the Moon, maybe even as early as 1967, beating the Americans to the punch without having to run risks and particularly take on the costs of landing. The date 1968 seemed rather credible, however, "even later if the project must incorporate advanced technologies in view of their later application to a true manned lunar landing mission".

The following September, i.e. 2 months after the CIA's previsions found themselves confirmed by the launch of the Proton-1 and the idea of a race was reintroduced to the general public, James Webb addressed the CIA to ask for an update on "the likelihood and consequences of a Soviet program to put a man on the Moon competing with Apollo". NASA's budget then reached a historic amount – nearly 5.5% of the federal budget – that needed to be justified. In response, Sherman Kent, in charge of the NIE, wrote a memo in which he explained that no new element collected over recent months had modified the conclusion from the January report. “The Soviets’ obvious interest for lunar exploration was a factor that was taken into consideration in our estimation that they intend to undertake a manned lunar landing project at some time or another in the future. However, the pace at which this program has been progressed by the Soviets has been irregular and generally not crowned with success”. As Sherman Kent emphasized, the CIA then believed that the Soviets had launched 18 probes to the Moon since 1958 and that only three had seen success[6]. Furthermore, he believed that the change in direction at the Kremlin brought about a reinforcement in military expenses that could notably be directed toward the space effort. He noted, however, “if the Soviets chose not to participate in the race to the Moon, it could be expected that they would work to diminish the impact of the Apollo program’s success through the accomplishment of other efforts of their choice. They openly challenged the scientific impact and interest of the landing of astronauts on the Moon and likely opposed it to goals to which they attributed greater importance”. Among these, he cited the implementation of an operational orbital structure with the support of space stations around the Earth or a robotic lunar exploration program, or even the flight of a crew on a circumlunar trajectory “in order to reduce the significance of Apollo’s success and to reinforce the role of the Soviet Union in the beginnings of lunar exploration”. Strangely, this memo, addressed to Vice-Admiral William Raborn, then director of the CIA, would not be sent to James Webb[7]. Instead, William Raborn would bring together a committee on space intelligence (the Space Intelligence Panel) that would deliver a short statement at the end of October.

> “It is clear that the Soviet space program is significant, generally competitive, and polyvalent. Its primary goal is to improve the USSR’s image in relation to the United States in technological and military terms through important accomplishments in space. It is not currently possible to determine with certainty the specific direction that the Soviets will choose in an attempt to achieve this primary goal. Remembering Soviet advances in terms of spatial propulsion and the absence of development indices for a program similar to Apollo, the committee concludes that ‘if the Soviets are in fact pursuing a manned lunar mission, this is not ahead of the American program, but points to a delay that could reach up to 18 months’”.

---

6 From September 23, 1958 to July 20, 1965, there were actually 19 Soviet missions to the Moon, seven of which were recognized as such and four of which achieved their goals.

7 William Raborn would retire in June 1966 and intelligence historians agree today in estimating that he was inept in this position.

The analysis proved to be right concerning the delay, even if it was based on a lack of knowledge of the Soviets' real projects and of the premature demise of their primary general contractor Sergey Korolev the following January which would play a large role in their failure.

The Moon was likely not the primary concern of the CIA at that time, because it apparently did not know the bellicose origins of the Proton-1 launcher. On October 7, 1965, it published a top-secret document entitled "Soviet capacities for a strategic attack", in which it analyzed the consequences of the change in direction undertaken at the Kremlin 1 year earlier. It concludes that if the era of demagogy embodied by Khrushchev had ended, his successors remained involved in ambitious programs, particularly with the creation of a ballistic dissuasion force with a sufficiently consequent magnitude to be credible and in relation to which the Proton-1 launcher could play a significant role. This was presented as a missile with an estimated initial thrust of 2.5 million pounds (1,150 tons) capable of carrying 13.5 tons over 12,000 km. The CIA then believed that the deployment of a small number (up to 6) of very large vector ballistics – capable of serving as a "global missile" or carrying a giant 100-MT thermonuclear charge – was within the Soviets' reach by 1967. The missile would then be a logical consequence of the test of the "Tsar Bomba" that took place on October 30, 1961. This experimental 57-MT aerial bomb – the most powerful in history – was released over Novaya Zemlya. Its explosion created a flash of light visible 1,000 km away and a mushroom cloud more than 60 km tall and 30 km in diameter, obliterating everything in a 25 km radius. The exact architecture of the missile was unknown at the time. It was imagined to be multistage, but with non-storable propellants. It also did not receive the definitive "SS" designation like every identified surface-to-surface missile and only appeared as "SS-Very Large" in the synthesis of the report. The lack of technical knowledge about the launcher became apparent when the report questioned the role of two new launch pads whose construction was detected in Tyuratam. It was not certain that they were meant for this system that could possibly reuse the old SS-6 (R-7) launch pads after they were withdrawn. Moreover, the rumor of deploying orbital weapons led the CIA to believe that a satellite the size of the Proton-1 (estimated at 12.25 tons) could very likely carry an 8.6-ton weapon, but that the Soviet military authorities likely would not take such a risk of worsening East-West relations with a weapon whose efficiency was so dubious.

Figure 6.10. *The Tsar Bomba tested in 1961 (source: VNIIEDF)*

One year later, an update of this document attested to a total reversal of the analysis that henceforth showed greater concern for the multiplication of SS-9 missiles and their use to launch Fractional Orbit Bombardment System orbital weapons, whose tests seem to have started with putting an undeclared satellite in space in September 1966, as well as for a potential giant missile: “nothing allows the development of the Proton launcher (SS-X-5) into a very high capacity intercontinental ballistic missile to be confirmed”. The report mentioned four space launches, including a failure unknown to the general public, and found that the slow pace at which they took place did not correspond to the development of an operational weapon system. “Even if the Soviets decided to develop a military ballistic version, there would likely be no very high capacity intercontinental ballistic missile in the next two years”.

The report also noted that the payload capacity of the Proton launcher, which had “an adapted third stage”, could reach 22.5 tons in a low orbit. In October 1966, the CIA thus knew that the version that had flown to that point only had two stages.

The 1967 edition of the NIE on the Soviet space program was published on March 2, i.e. a week before the launch of the Kosmos-146. The Proton launcher, which received the SL-9 designation, was presented as the first Soviet launcher dedicated to space missions, even if its original development as a missile associated with a 100-MT bomb was recognized. The thrust of its first stage was estimated to be between 1,100 and 1,400 tons, which proves this time that the CIA knew that the Proton was not using a cluster design like the Vostok launcher. This information could not come from satellite imaging alone.

Once again, there was mention of a future third stage capable of increasing the cargo capacity between 22.5 and 27.0 tons, or even 30.0–35.0 tons with an upper stage filled with liquid hydrogen and oxygen. Because of a fourth stage and without the use of cryogenic propellants, it would be possible to send approximately 7.0 tons to the Moon, which would allow a piloted flight around the Moon to take place, probably in 6–12 months after the first flight of the tri-stage version.

The report also imagined the possibility of using stages from the SL-9 in the upper parts of the new giant launcher for which the Soviets were building a gigantic preparation and launching infrastructure in Tyuratum – the "J complex" – whose progress was closely followed by American satellites. Maybe incomplete information and a relative incomprehension of the political rivalries between the different Soviet builders led CIA analysts to mix up concurrent projects: Chelomei's UR-700, which used part of the Proton's architecture, and Korolev's N-1, which would provide the Proton with its fourth stage.

Lastly, the report stated the belief that the Soviets did not have all the technical and economic resources necessary to work on all of their projects simultaneously. "As a result, we believe that some foreseeable projects will not be attempted; others will proceed at a slow pace and substantial resources will only be allocated to only a few of them". It also mentioned the countless failures that had gone unmentioned by Moscow, often leading to significant delays in programs.

One year earlier, in March 1966, the CIA's Information Management Office had published a comparative report on the size of the US and Soviet space programs. The CIA then believed that the US space budget had reached a ceiling at 7 billion dollars due to Apollo and should then decrease; it thought that the equivalent Soviet budget should be around 5 billion dollars, but was in all likelihood regularly growing in the hypothesis of a lunar landing by 1970 and the development of an orbital station program. It is important to note that at that time the CIA believed the military space budgets to be equal to one another, each amounting to 1.5 billion dollars, civil programs taking the lion's share in both the USSR and the United States.

In its March 1967 report, the CIA believed that the Soviet manned lunar program was likely not first designed to compete with Apollo and that it likely still was not intended to. "There is the possibility, however, that, according to the current vision the Soviets have of the Apollo mission timeline, they may think they have a chance of reaching the Moon first and they could accelerate their program with the hope of achieving this".

Barely 1 month after the death of the Apollo-1 astronauts and 1.5 months before that of Komarov, the Soviets had good reason to believe that the Americans could not possibly keep up their intended pace. The CIA then believed them capable of landing on the Moon by 1970 or 1971. In the mean time, it expected a 20-ton space station to be launched by a tri-stage Proton in the first half of 1968 and that it could be visited by the new manned spacecraft under development (the Soyuz).

Most of all, the CIA's report developed the idea that the Soviets could attempt a manned flight around the Moon as soon as possible, primarily to garner "important dividends in terms of prestige" and to diminish the impact of the propaganda concerning potential success of the Apollo project. Analysts even imagined possible architectures for such a flight, like the addition of a "Venik stage" (the Molniya launcher's Block-I) to the SL-9 (the two-stage Proton) and the SL-8's final stage (the small Kosmos-3 launcher) to launch a modified two-seater Voskhod on a circumlunar trajectory, unless they turned to a new third stage and the new spacecraft being developed. Obviously, before attempting the mission with a crew, the Soviets should attempt at least one unmanned flight, and it would then take them around 6 months to qualify the system and "test the equipment and techniques for sea recovery, which could be necessary upon returning from a circumlunar flight". The CIA then predicted that the best period for such an operation would be during the first half of 1968, when the Moon would present a declination toward the north.

Figure 6.11. *N-1 preparations photographed by a KH-8 on September 19, 1968 (source: NRO)*

Thirteen months later, on April 4, 1968, i.e. 1 month after the Zond-4 flight, the CIA published a new update on its analysis of the Soviet space program. This time, the piloted lunar landing was no longer expected to be late 1971; much more likely was 1972. The failure of an unmanned circumlunar launch in November 1967 is mentioned[8] and the flight of cosmonauts around the Moon was expected for the second half of 1968 or in 1969. It was expected that a space station would be launched in 1969 or 1970. The tri-stage Proton launcher used for these missions received the "SL-12" designation and its cargo capacity was estimated to be between 18.0 and 27.0 tons. For the CIA, the launches of the Kosmos-146 and 154 were failures, whereas that of the Zond-4 was a success – except the recovery – and was correctly attributed to the Proton. Finally, a schematic architecture of the launchers was proposed. The Proton SL-9 and SL-12 appeared with a first stage whose conception with cylindrical barrels with a diameter of 3 m recalled that of the Saturn-1's S-1 stage. Its diameter appeared to be greater than that of the Soyuz launcher bases (i.e. around 10–12 m), which was exaggerated, but its height between 20 and 23 m was a good approximation. In reality, the first stage of the Proton measured 21.2 m tall and 7.4 m in diameter.

6.4. No second place

In the summer of 1968, the last news from the CIA and the DIA lent more weight to the arguments of those at NASA who wanted to accelerate the program. After the Apollo-6 operation, three flights still remained to be completed before the end of the year, including Apollo-7, the first manned flight, with a launch on Saturn-1B and probably another unmanned Saturn-5 flight, in order to resolve pogo oscillation problems that nearly made the previous flight a disaster. After that, five to six missions were foreseen in 1969 before the potential landing of a team on the Moon.

Moreover, it seemed that the lunar module would never be ready to fly before the end of the year. However, on August 7, George M. Low, director of the Apollo vehicle program, asked flight director Christopher C. Kraft to study a flight plan for an Apollo mission around the Moon at the end of the year. A meeting was organized for all those in charge of the program two days later at the Marshall Spaceflight Center in Huntsville. Everyone agreed that it was possible to be ready for such a mission in December with ballast instead of the lunar module. Work would be done to resolve the pogo problem on Saturn-5. The project would have to remain secret, however, until a decision was made by NASA's director. In the meantime, its instigators would refer to it with the code name "Sam's budget exercise". One week later, they obtained the support of NASA's administrator, James Webb. A mission was added to the planning for December 6 and it would bear the name Apollo 8.

---

8 This is mission L1 no. 5 of the giant N-1 launcher. The previous failure of the L1 no. 4 in September went unnoticed.

On September 14, a Proton launcher sent Zond-5 to the Moon. The probe was followed by the British Jodrell Bank Observatory as it went 1,950 km from the Moon on September 18. The director of the observatory, Sir Bernard Lovell, announced that it was a very large object and likely even a test flight for a manned mission. “I expect a human being to be placed in a similar vehicle in the coming months”, declared the famous astronomer. The probe performed the first atmospheric reentry at the second cosmic velocity and was recovered by a Soviet ship after landing in the Indian Ocean. “The space research program and that to research the systems and elements of the spacecraft were performed successfully”, broadcasted TASS. “The success of the Zond-5 flight on an Earth-Moon-Earth trajectory and its return to Earth in a predetermined area are an exceptional success lending credit to Soviet science and technology”. The Soviets would later reveal that this unmanned flight had recovered passengers safe and sound: a couple of turtles, flies and maggots.

Incidentally, as the Soviets were adding another first to their record, NASA’s administrator James Webb resigned on September 16, while the Apollo-7 launch, planned for September 20, had to be postponed. However, NASA did not have only bad news: on September 19, its Saturn-5 launcher was declared ready for a manned flight.

On October 11, a Saturn-1B placed Apollo-7 into orbit with three astronauts on board. The nearly 11-day mission around the Earth was a total success that ensured the qualification of the Apollo spacecraft. On November 10, a new round table of the Apollo program’s management approved the launch of Apollo-8 to the Moon and the next day, NASA’s new interim administrator, Thomas O. Paine, unveiled the new goal to the general public.

The day before, at the very same time that the Apollo management was convened, a Proton launcher lifted off from Baikonur to send Zond-6 to the Moon in an exact replica of the Zond-5 mission. After a pass behind the Moon on October 13, Zond-6 returned to Earth on the October 17 with a daring two-part maneuver: first, an initial entry into the atmosphere above the Indian Ocean to decelerate and then a slower reentry that allowed a more traditional recovery in Soviet territory.

After this new success, professor Leonid Sedov confirmed on November 21 that it would be “probably a year or more” before the USSR attempted a manned lunar flight. Everyone had their eyes peeled the week from December 2 to 8: the next favorable window for the Soviets to attempt the third flight over the Moon, this time with men on board and thus to beat NASA's Apollo-8 to the punch, as its window would not open until December 20.

Figure 6.12. *Apollo-8 puts an end to the Soviets' lunar aspirations (source: NASA)*

The Soviet window finally opened, then closed again without any launch being announced or detected. On December 21, the third Saturn-5 launcher sent Apollo-8 to the Moon for a mission that would be greatly successful and would speed up the Apollo's accomplishment with the first manned lunar landing in history, barely seven months later. Two other unmanned Zond flights would go around the Moon in August 1969 and October 1970 before the program ended. Westerners would not discover underlying secrets of this strange program and the reasons for its failure until 20 years later.

The Proton would be used one last time in an attempt to beat NASA in the last straight line. On July 13, 1969, 3 days before Apollo-11's liftoff, a Proton sent a new kind of probe to the Moon. The most daring analysts then imagined that it could beat the American astronauts to their lunar landing site and film their arrival to prove that "the Soviets were there first". Others who were more reasonable preferred to think – and rightly so – that it was a sample return mission, allowing Moscow to demonstrate the waste represented by the costly American program, while the same scientific results could be obtained with a robot. This attempt to bring back a few grams of lunar regolith before Apollo would fall short when the Luna-15 probe crashed into the Mare Crisium, 13 hours after Neil Armstrong left his boot prints in the dust of the Mare Tranquillitis. The operation was renewed with greater success thanks to the Luna-16 in September 1970 in the Mare Fecunditatis. The drill removed a sample before hitting a rock 35 cm deep. Part of the sample was then lost during the transfer to the return capsule, but 101 g was brought to Earth. This was the first automatic return of samples from another celestial body in history. This exploit would be repeated by the Luna-20 in February 1972 and Luna-24 in August 1976, but the total 326 g brought back paled in comparison with the 382 kg selected and returned to Earth by Apollo's astronauts.

Apollo's insolent success thus eclipsed those of the Proton, which nevertheless deployed two remote-controlled Lunakhod rovers on the Moon and afforded itself the luxury of performing another first before its rival, Saturn: placing the first habitable space station into space, Salyut-1, on April 19, 1971, more than 2 years before NASA's Skylab. While America abandoned the Moon and the final Saturn flew in July 1975, the Proton would remain the preference for the Soviets' large space missions, placing civil and military stations into orbit or launching planetary exploration missions that would succeed on Venus and fail on Mars.

The giant N-1 launcher that was to compete with the Saturn-5 discretely suffered four failures in four launches from February 1969 to November 1972 before the program was abandoned in 1974. The Proton would thus remain the most powerful launcher in the Soviet arsenal until 1987 and its design would remain secret practically until that date.

7

Commercial Prehistory

Throughout those same years that saw the Soviet Proton and the US Saturn compete in the race to the Moon, the Europeans were attempting to develop their own launcher, at a much more modest scale, the initial capacity of the Europa (850 kg in a low polar orbit of 500 km) approximately corresponding to that of the Delta-M in the United States or the Kosmos-3M in the USSR. To avoid straining any national sensitivity, the Europa's first stage was British, its second French, its third German and its payload fairing Italian. If all of these operated well separately, their combination suffered four failures in four orbital attempts between 1968 and 1971. Following this fiasco, the countries of Western Europe began a profound restructuring of their space cooperation policy, which led them to decide on the creation of the European Space Agency (ESA) in 1973 and to assign as one of its first tasks the development of a new European launcher, under French project management. This would become the Ariane-1 and it would fly on Christmas Eve 1979.

In the meantime, however, the European states created a series of satellites designed to be launched by Europa and which would henceforth need to be given new launchers. Among these were scientific satellites such as Cos-B for gamma ray astronomy and Geos-1 for the study of the Earth's magnetosphere, the Italian Sirio experimental satellite, as well as two Franco-German Symphonie telecommunications satellites.

At that time, only the United States and the Soviet Union had the adapted launching means for these missions and the latter had not yet launched even the smallest geostationary satellite[1]. From 1962 to 1972, Italy, Great Britain, France, Germany and the European Space Research Organisation (ESRO, a precursor of the ESA) had NASA place 18 small scientific or technological orbits into space with the

1 This would take place in March 1974 with the Kosmos-637 on Proton.

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

small Scout and Thor Delta launchers. As for France, it was the only one to have established a partnership agreement with the USSR during General Charles de Gaulle's journey to Moscow and Baikonur – which he would be the first Westerner to visit[2] – in June 1966.

It was within the framework of this agreement that the National Center for Space Studies (CNES) sent hosted payloads on Soviet missions – laser reflectors on the Lunakhods or scientific experiments on Martian probes – and, in 1972, it even had a small technological satellite launched on a Molniya vehicle from the Plesetsk spaceport, whose existence Moscow had not yet officially recognized. The conditions imposed by the Soviets were very strict then. When they asked their Soviet counterparts how it was possible to access the instruments during their integration or preparation for the launch, the French scientists plunged them into an extremely uncomfortable situation. The Soviet scientists eventually admitted that even they did not have access to their own devices, either; soldiers were in charge of all operations in the launch base.

Figure 7.1. *The Franco-German Symphonie satellite (source: MBB)*

In these conditions, it was impossible for a Western team to accompany its satellite to the launch site[3]. Yet, what was acceptable for a small technological

2 Along with his aide-de-camp, Admiral François Flohic and the French Minister of Foreign Affairs, Maurice Couve de Murville.

3 The first that would be authorized to do this was a French CNES team, in 1977, for the launch of the small Signe-3 scientific satellite, which would be placed in orbit from the small, relatively unhidden Spaceport of Kapustin Yar, near Volgograd.

payload or a scientific experiment no longer was for an entire satellite, generally at the cutting edge of technology at the time.

The United States was thus the only path for Europeans to access space and the Nixon administration was fully aware of this. On October 9, 1972, the US president summarized his doctrine in the following way: “the United States will provide their assistance to space launches of every nation and every international organization that is interested, for satellite projects meant for peaceful ends and which will respect the obligations of the concerned treaties and international agreements”.

In practice, for the Europeans, this meant the obligation to limit the use of the geostationary telecommunications satellites, Symphonie, to an experimental mission, to avoid detracting from the monopoly on international space telecommunications guaranteed by treaty to the intergovernmental organization Intelsat, dominated by the US Comsat, whose contribution could not – according to the 1964 treaty – fall below 50.6% of the capital. This argument had already been presented to the Europeans in 1968.

After having explored the possibility of a launch with the Soviets – “not before 1976” responded Interkosmos – France and Germany resolved to accept the United States’ humiliating terms so that the Symphonie-1 and Symphonie-2 would be placed in orbit by the Delta launchers in December 1974 and August 1975, respectively.

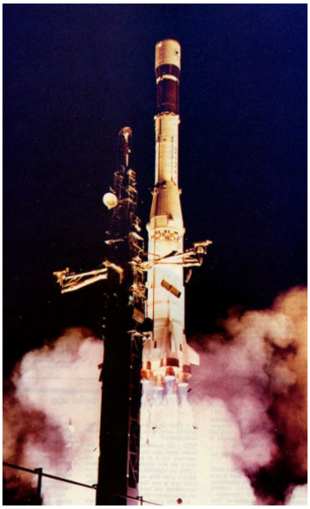


Figure 7.2. *First launch of an Intelsat satellite by Europe’s Ariane in 1983 (L7) (source: Arianespace)*

Later, when the Europeans were developing the Ariane to ensure their autonomous access to space, they realized that their institutional market – estimated at around two launchers per year in the 1980s – would not allow them to maintain a fast enough pace to ensure industrial production and reliable use of the system. It would thus be necessary to open the system up to commercial launchers. Yet, ESA's rules of operation, with the need for unanimous decisions, were not well suited to these activities. On December 15, 1977, Frédéric d'Allest, then director of the launchers at CNES, to which the ESA had delegated the development of the Ariane, suggested the creation of a commercialization business whose capital would be divided between CNES and the program's industrial suppliers. One year later, when he called on potential clients, he found his initial success with… Intelsat, who agreed to choose Ariane to launch some of its Intelsat-5 generation satellites. A previous memorandum of understanding was signed between CNES and the industrialists on June 12, 1979, during the Paris Air Show, for the creation of the company Transpace, which would promptly be renamed Arianespace. The first private space transportation company was officially founded on March 26, 1980. Initially decried for the lack of control that it imposed on foreign operations, this new commercial model would inspire the liberalization of the launching market in the United States. The commercial Space Launch Act was announced on October 30, 1984 by President Ronald Reagan, and it would lead to the creation of companies meant to compete with Arianespace: General Dynamics Commercial Launch Services in 1985 for the Atlas launcher, Martin Marietta Commercial Titan Inc. in 1987 for the Titan and McDonnell Douglas Commercial Delta Inc. in 1988 for the Delta. The space sector entered a new era: conquest was over; it was now time for exploitation.

7.1. Swiss francs for invisible launchers

Even if they remained discrete during this period, the Soviets closely followed this evolution, more for its geopolitical implications than the economic ones; anything that could minimize the United States' dominance in the space sector was welcome, particularly on the eve of the space shuttle's birth, which promised to revolutionize access to space and to render all consumer launchers obsolete.

Thus, in September 1979, when Inmarsat (International Maritime Satellite Organization) was founded in London and the first Ariane launch was being feverishly prepared, Moscow discretely contacted ESA, proposing to provide the launch of the maritime telecommunications satellite Marecs 3 – which had to be rented to Inmarsat – in case Ariane was not available to perform this mission in time. Five months earlier, Leonid Brezhnev had offered French President Valéry Giscard d'Estaing to send a French astronaut on a Soviet Soyuz spacecraft. Here, it was not a matter of money, but of guaranteeing the Europeans access to space that

Washington was selling at a high price. The French accepted concerning the astronaut[4], but ESA did not follow up regarding the satellite, particularly as the production of the Marecs series had to be limited in the end to two flight models – Marecs-A and Marecs-B – that were launched on Ariane. The first reached geostationary orbit in December 1981 and the second crashed into the Atlantic Ocean the following September. A third model was then integrated to replace it. This Marecs-B2 was successfully launched in November 1984, still by Ariane.

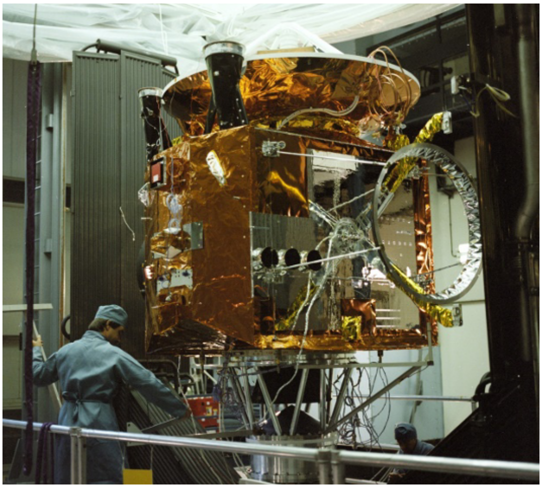


Figure 7.3. *Marecs-B2 in preparation (source: ESA)*

In the meantime, the Soviets once again attempted to place their launcher in mid-1983, when Inmarsat, who had recently begun to operate the first Marecs and the US Marisat satellites, was preparing a call for tender for its second generation of satellites. The Inmarsat-2s would be launched starting in 1988. The USSR was then the organization's fifth largest financial contributor and the given price for the launch, 24 million dollars, was "competitive" according to Inmarsat's management. The Soviets proposed a four-time payment: 10% one month after signing the contract, 25% five months later and 40% one year later. The final 25% was payable upon launching and in case of failure, a replacement launch would be provided at half price. The settlement would have to be paid in Swiss francs through a Swiss banking establishment.

These original methods of payment worried the Inmarsat management less than the opacity that remained in the program. The Soviets' approach was rather nonchalant: "you provide the satellite and we'll launch it", which more or less indicated a delivery

4 Jean-Loup Chrétien flew on board the Soyuz T-6 mission from June 25 to July 2, 1982.

of the satellite to a Western airport to be taken away by an Aeroflot cargo plane and the later announcement of the launch by the Soviets so that the operator could take delivery of it once in orbit. The demands for technical information on the launcher, not only on the interfaces with the payload, but also on its design and reliability, went unheeded. These were details that the Soviets had managed to keep secret for nearly 20 years.

7.2. Curtain raiser

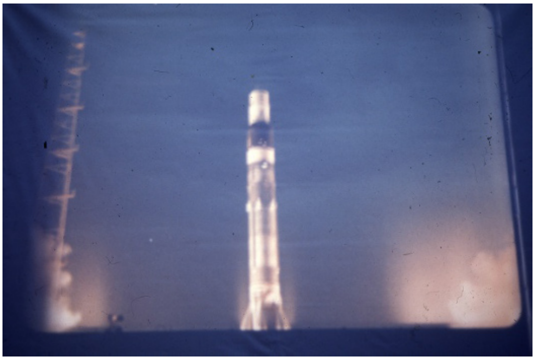


Figure 7.4. *Launch of the Salyut-1 in 1971 (source: Christian Lardier)*

The only image then available in the West came from a 1972 Soviet documentary, "Steep Road of Cosmos". It shows the upper part of a three-stage Proton during the launch of the Salyut-1 station. At the bottom of the image, the viewer can just barely discern what seem to be conical lateral booster attachment points. Western illustrators and analysts needed nothing more to attribute to the Proton a design similar to that of Korolev's R-7, imagining it to have six releasable boosters with length of as much as 40 m. This would have made the Proton a giant more than 80 m tall with a base diameter of 12 m. The satellite orbit analysis also led them to imagine several variants of upper stages, some of them cryogenic, but in reality, it had to be acknowledged that very little was actually known.

The exact name of the launcher was also unknown. Westerners referred to it using two nomenclatures coming from the United States' information community and in use for more than 20 years. The Pentagon had its own naming system, which spread to NATO. It was inspired by a practice introduced during World War II with Japanese material and consisting of giving a code name to enemy devices for on-site taxonomical and identification ends. In this system, surface-to-surface missiles were given the denomination "SS" without any real distinction of range, while space launchers were given the sign “SL”. The Proton, whose missile version was identified as “SS – Very Large” or “SS-X-5” [5] was thus stamped “SL-9” for its two-stage version, “SL-12” for the four-stage variant that launched lunar and interplanetary missions and “SL-13” for the three-stage version introduced in November 1968 with Proton 4 and dedicated at the launch of the Salyut stations.

The second nomenclature, civil in nature, was updated starting in 1962 and published in 1968 by Charles S. Sheldon, an analyst of the Library of Congress. This attributed a letter to each family of launchers: “A” for the Semyorka family derived from Korolev’s R-7, “B” and “C” for the two families of Kosmos launchers, “D” for the Proton and “F” for the Tsyklon launchers. If necessary, this letter was followed by a number designating an upper part version then possibly a letter to clarify the system’s particular capacities: “e” for an interplanetary stage, “h” for a cryogenic stage, “m” for a maneuvering stage, “r” for a reentry system and “s” for a station-keeping system. In the Sheldon nomenclature, the initial two-stage Proton was thus a “D”, its lunar and interplanetary version a “D-1e”, while the three-stage Salyut launcher was a “D-1”.

The veil over the reality of the Proton was eventually raised in two stages.

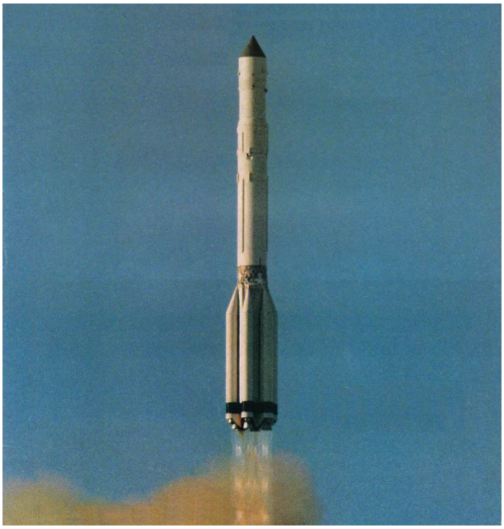


Figure 7.5. *Launch of the Vega-2 in 1984 (source: all rights reserved)*

5 Not to be confused with the mid-range SS-5 “Skean” (R-14 “Chusovaya”) that served as the Kosmos-3 launcher’s base.

On December 15 and 21, 1984, two Proton launchers took off from Baikonur to place the two probes from the Vega program (Venera-Gallei) on interplanetary trajectories so they would release landers onto Venus before flying over Halley's comet during its great return to the inner solar system. This mission was largely international cooperation, with notable participation from the "brother countries" (Bulgaria, Czechoslovakia, East Germany, Hungary, Poland), but also Western partners: Austria, France, Italy, the United States, West Germany and the ESA, who would use the data provided by the probes to direct the approach of its own probe, Giotto, as close as possible to the comet's nucleus. To emphasize the importance of this mission, the Soviets broadcast images of the first 50 s of one of the launches, which allowed people to see the whole launcher for the first time, nearly 20 years after its first flight. Western analysts immediately noticed the presence of six cylinders around the first stage, which turned out to be much shorter than they had imagined. Nevertheless, there was no doubt in their minds that these were releasable accelerators with a "cluster" design similar to that of the R-7, as witnessed by the articles published in 1985, including the one written by Alan Bond and John A. Parfitt in the British magazine *Spaceflight* in July–August, which indicated that "the central stage is not activated on the ground; this is shown clearly when the launcher pulls away by the light of six motors on lateral accelerators surrounding the dark central stage". They imagined that the launcher had a seventh RD-253 motor activated in flight, which would give it a thrust of around 1,400 tons for a mass around 800 tons at liftoff.


ORBITE

LE BULLETIN DU COSMOS CLUB DE FRANCE — 18 rue Saint-Benoit, 75006 PARIS

NUMERO SPECIAL — JANVIER 1986

special urss

La reproduction partielle des informations contenues dans ce numéro est autorisée sous réserve de citer la référence " journal Orbite - organe du Cosmos Club de France ".

La "Proton" décolle à Baikonour

VINGT ANS APRES

Une étonnante fusée – la Semiorka de Serguei KOROLEV – avait constitué le secret de la série de succès remportés par les Soviétiques dans la phase héroïque de la conquête spatiale. Alimentée par kérosène et oxygène liquide, cette fusée se caractérisait tant par des moteurs au rendement exceptionnel que par une structure pyramidale dont la révélation fit sensation au Bourget, en 1967 lors du Salon de l'Aéronautique.

C'est à différentes versions de cette Semiorka – toujours utilisée aujourd'hui pour la mise en orbite de vaisseaux Soyouz – qu'avaient échu le lancement des Spoutnik, du Vostok de Youri Gagarine et des premiers Luna.

Cependant, dès 1965, les Russes mettaient en service une fusée plus puissante, due à un autre constructeur, Vladimir CHELOMEI, une fusée à laquelle on prit l'habitude de donner le nom des satellites scientifiques Proton à la mise en orbite desquels elle fut en premier lieu affectée.

Par la suite, cette fusée Proton allait devenir le grand cheval de bataille de l'astronautique russe, les Soviétiques l'ayant retenue pour lancer aussi bien leurs Luna et engins planétaires de seconde génération que des satellites géostationnaires ou des stations Saliout.

Mais vingt ans durant, aucune photographie n'en fut publiée, aucune description technique n'en fut donnée. Après avoir autrefois fourni les premières informations sur la fusée de Korolev, le COSMOS CLUB DE FRANCE est très heureux de pouvoir, sous la plume de ses excellents spécialistes de l'espace russe – Boris STERNIKOV et Christian LARDIER – vous offrir, avec ce bulletin spécial, la primeur d'informations techniques, émanant notamment du constructeur Valentin GLOUCHKO, qui concernent à la fois la fusée Proton et les nouveaux moteurs spatiaux de l'URSS.

A.O.

Faits et commentaires

L'AFP passe au satellite

Les secrets de la fusée « Proton »

NOTES

Faits et commentaires

Le lanceur soviétique Proton, fer de lance de Baïkonour

Figure 7.6. *Orbite newspaper from January 1986, the AviMag reviews from February 1, 1986 to May 1, 1986 (source: Christian Lardier)*

The true barrel design of the first stage – which had already been presented theoretically by Chelomey in his work *Pneumohydraulic Systems of Motor Installations with Liquid Propellant Rocket Engines* in 1978 (Sviazka schema) – was discretely revealed in the new Russian edition of the Soviet encyclopedia of world astronautics (*Encyclopedia Kosmonautika)* by Valentin P. Glushko[6], secretly published in Moscow in December 1985, but of which two members of the Cosmos Club de France (C2F), Claude Wachtel and Christian Lardier, immediately procured a copy. They published the first analysis on the real design of the Proton in January 1986 in *Orbite*, the C2F's bulletin. In particular, they revealed the overestimation of the launcher's initial thrust, which was only 900 tons, whereas it had to that point been estimated to be between 1,250 and 1,500 tons. This information would be widely spread by the specialized press, which would quite often omit to cite the original source.

7.3. Regime change

This opacity greatly harmed the Soviets in their first attempts at commercializing their launchers. No Western satellite builder then foresaw developing a satellite compatible with the interfaces of an unknown launcher. But this was not the only obstacle. The US Department of State, in charge of monitoring all exports of sensitive technologies, was strongly opposed to sending satellites or satellite components to the Soviet Union, for fear of undesired technology transfers. The term "technological theft" was even used.

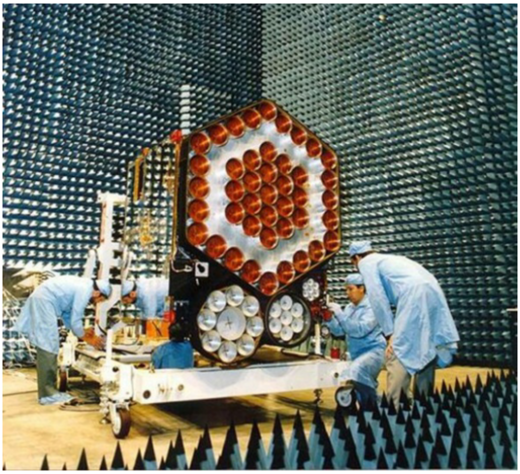


Figure 7.7. *Inmarsat-2 (source: Airbus DS). For a color version of this figure, see www.iste.co.uk/lardier/proton.zip*

6 The 1971 edition of this same encyclopedia had no qualms about presenting the Proton as a "powerful multi-stage rocket propelled by several motors".

To quiet these fears, when the Soviets returned to the head of Inmarsat in March 1985, during the conferral of the project management contract for the Inmarsat-2 series to British Aerospace, they ensured that the owner of the satellite could accompany it to the launch site and stay there until the launch itself. Furthermore, communications sessions would be possible with the satellite during the fourth stage's flight phase.

The fees did not change, or barely: 24 to 26 million dollars (in Swiss francs) for a single launch directly into geostationary orbit. The fee fell to 12 million for a triple launch. And in case of failure, another launcher would be available 10 days later at half price. The Soviet offer also contained a veiled threat: if Inmarsat did not select the cheapest launch offer on the market, the organization could be accused of violating its own constitution.

This offer would be no more successful than the previous one, but in the Soviet Union, the situation would quickly evolve and open new doors for the Proton.

March 11, 1985 marked Mikhail Gorbachev's rise to power as he was named General Secretary of the CPSU at the young age of 54, which constituted a radical change in relation to his predecessor, Konstantin Chernenko, 20 years older than him, who embodied an aging Brezhnevian line of orthodoxy. The new head of the Communist bloc was aware that the system was running out of steam and his priority would be to quickly bring about reforms that would allow him to save what could still be saved, even if it meant questioning countless dogmata inherited from the Stalin era, which Yuri Andropov, Chernenko's own predecessor who had briefly occupied the Kremlin after Leonid Brezhnev's death in November 1982, had not dared – or had not had time for.

Gorbachev's first priority was to launch an economic reconstruction policy, "Perestroika" which began in April 1985. It aimed to liberalize domestic commerce and particularly large state enterprises' activity. The Party thereby lifted its stranglehold on production and services, such that the managers of large conglomerates would have to take responsibility for their results. One corollary of this system reform was to end the opacity of the cogs of the country's industry and economy, which had until then been hidden from the eyes of everyone, including the Soviet people, behind the bureaucracy of the State apparatus and its countless ministries, commissions and committees.

In Russian, this transparency was called “Glasnost” and it would progressively spread to various domains, revealing to outside observers the inner workings of the USSR’s industrial complex and its structures, which were so different from those that existed in the West.

In the space domain, this was illustrated at first by the formation of Glavkosmos[7] in October 1985. It was Division No. 13 of the top secret MOM (*Ministervo Obshcheye Mashinostroeniye)*, the federal Ministry of General Machine Building, created by Brezhnev in 1965 to head the Soviet military-industrial complex’s activities in the space and ballistics domains. However, the new structure was presented to the outside world as an interministerial agency responsible for administering the whole Soviet civil space program and serving as a façade for the ministry[8]. Alexander Dunaev, who managed Glavkosmos, had the rank of delegated minister to the first vice-minister in charge of the space program at MOM, but he could not manage to obtain the budgets that were meant to be his. The MOM maintained complete control over the entire program and despite its attempts to impose itself as a true space agency, at least in appearance, Glavkosmos’ role was limited to that of the only intermediary for all international cooperation in the space domain and more particularly as the one-stop shop for the commercialization of all Soviet launch services abroad.

Figure 7.8. *Alexander Dunaev (source: all rights reserved)*

7 Glavnoye Upravleniye po Sozdaniyu i Ispolzovaniyu Kosmicheskoy Tekhniki dlya Narodnovo Khozyaystva i Nauchniy Issledovaniye – Primary direction for the design and use of space technologies for the economy and scientific research.

8 To preserve the illusion of an independent agency and the secret that had to continue enshrouding the entire existence of the MOM, the Glavkosmos headquarters was placed in Moscow at Krasnoproletarskaya Street 9, while the ministry was located on Muiskaya Square, a kilometer away.

Figure 7.9. *Launch of the IRS-1A (source: Glavkosmos)*

Less than a year later, in September 1986, Glavkosmos recorded its first success with the signing of a semicommercial agreement to place the very first Indian remote sensing satellite, IRS-1A, in orbit with a Vostok-M launcher for the Indian Space Research Organization (ISRO).

7.4. A market to be cornered

In the meantime, a catastrophe had come to upset the world of space transport. On January 28, 1986, the in-flight disintegration of the US space shuttle Challenger after 73 s in flight tolled the bells on its commercial exploitation, the end of which was officially announced in June. This halt came at the worst time: when the geostationary telecommunications satellite sector was rising with the emergence of new national, regional and even international operators whose existence was made possible by the end of the United States' monopoly on space access. With the European launcher Ariane unable to ensure all commercial missions on its own, the market would need new expendable launchers and fast. The production lines for US launchers, which had been interrupted, were relaunched. In September 1986, Martin Marietta announced its Commercial Titan 3, available starting in 1989. In October, the line of Deltas, stopped 4 years prior, urgently restarted at McDonnell Douglas, while General Dynamics relaunched the Atlas Centaur line in June 1987.

This was also a chance for Glavkosmos, which had a proven, competitive launcher and could therefore play an important role by imposing itself against MOM by bringing back cash flows as the Soviet Union was facing its first great structural crisis of the Gorbachev era. Indeed, while Perestroika was upsetting the fossilized economy of the Soviet giant, it was hit head on by the collapse of the prices for oil, the country's primary natural resource and a large source of cash. In 1988, the oil barrel fell to 15 dollars, i.e. half its value in 1985. The sale of space launchers then seemed to be one of the good ways to help fill the abysmal deficit that had appeared.

Figure 7.10. *Licensintorg ad (source: Licensintorg)*

To introduce itself into this market, Glavkosmos teamed up with the import–export organization V/O Licensintorg and Ingostrakh, which would provide insurance services. The aim was to propose the whole range of Soviet launchers in production to satellite operators: Proton, of course, but also Vostok, Soyuz, Molniya, Kosmos, and Tsyklon. Thus, in June 1987, at the Paris Air Show, the first commercial brochures (under Licensintorg's name) about Soviet launchers and particularly the Proton appeared.

Figure 7.11. *The first photographs of Proton published in 1986 (source: all rights reserved)*

Aware of the lack of trust they faced in an ever-bipolar world where "glasnost" was still regarded with suspicion, the Soviets attempted to play the game of competitive economics and proposed an attractive price "20–50% cheaper than Ariane or the US Shuttle" (between 18 and 20 million dollars). Furthermore, they promised that the satellites they would be given would not be inspected. On the Western side, the concerns expressed by the Department of State had become a generalized fantasy. Everyone feared that once they were left alone with Western satellites, the Soviets would go so far as to partially dismantle them to seize the technology, which, moreover, would endanger missions[9]. Dmitri Poletaev, head of launchers at Glavkosmos, attempted to reassure potential clients by multiplying guarantees: "the representatives of the producer will be able to accompany their satellite throughout its transfer through the USSR and until it takes off from the launch platform". As a joke, it was even proposed that security agents might be "handcuffed" to satellites exported to the USSR.

9 During French astronaut Jean-Loup Chrétien's extravehicular activities on December 9, 1988, the ERA antenna structure, built by Aérospatiale, failed to deploy and required "muscled" intervention on the part of cosmonaut Aleksandr Volkov (a kick). The mishap was attributed by rumors of an "imperfect remounting" by the Russians. No formal proof was ever given to validate this theory.

Strengthened by these guarantees and succinct technical documentation that henceforth presented all necessary information concerning the environment of the payload and the interfaces with the launcher, in early 1986, Glavkosmos proposed its Proton to the organization Eutelsat to launch one of its Eutelsat-2 satellites for 50 million Swiss francs. However, in May, the pan-European operator preferred to sign for two launches with Arianespace and one with General Dynamics. By fall, Glavkosmos proposed its launch services to Siam Satellite, the new Thai operator, but the company would never obtain the funding for its satellite. A similar offer was made to Indonesia in 1987 for its Palapa-B2R satellite. This had been launched for the first time by the Challenger space shuttle in February 1984 and was recovered the following November by the Discovery shuttle after its perigee motor failed to ignite. The Indonesian government then reacquired it from SatTel Technologies, which had itself bought it from the insurer Meryll, who had become the owner after the first launch's failure. Apart from a very competitive fee of 40 million dollars, Glavkosmos proposed the bonus of letting an Indonesian astronaut fly to Mir if Palapa-B2R launched from the Proton. The offer was tantalizing since an Indonesian astronaut, biologist Pratiwi Sudarmono, had been selected in October 1985 to accompany the Palapa-B3 satellite on board the Columbia space shuttle, but the dream of seeing an Indonesian fly in space had vanished with the Challenger catastrophe. However, Indonesia eventually preferred to entrust its launch to McDonnell Douglas.

a) b)

Figure 7.12. *a) Ill-fated Indonesian astronaut Pratiwi Sudarmono and b) Palapa-B2 and Westar-6 brought back to Earth by Discovery in 1984 (source: NASA)*

7.5. The American friend

Figure 7.13. *Arthur M. Dula (source: all rights reserved)*

It was at that point that a 40-year-old corporate lawyer from Texas, Arthur M. Dula, came onto the scene. This lawyer, specializing in the space sector and questions of intellectual property, had already made his name upon opposing the 1967 Space Treaty and as the cofounder of several companies in the space sector, including Space Services Inc. (SSI), headed by former astronaut Donald "Deke" Slayton. Because of the efforts of Art Dula, SSI was the first company to receive a federal license to perform a private space launch in September 1982 with the sounding rocket Conestoga from Matagorda, an island on the Texas coastline kindly loaned to them by an oil magnate. The Conestoga had been developed by Space Vector and Eagle Engineering, another company founded by Art Dula. He was also among the founders of Spacehab Inc., which would provide pressurized modules for the space shuttle.

Art Dula was a close friend of famous science fiction author Robert A. Heinlein[10], who in 1950 penned a vindication of the spatial conquest led by the private industry entitled *The Man Who Sold the Moon*[11], and like Heinlein, he strongly believed that the private sector would have to play a major role in the exploitation of space. "I consider space to be the next logical frontier of capitalism," he said. As such, he saw the release of Soviet launchers onto the market as a chance to break away from the *de facto*

10 He would become his executor upon his death in May 1988.

11 Immediately brought to the big screen by Irving Pitchel with the title *Destination… Moon*. This film became a science fiction standard in the 1950s and its imagery would serve as a popular reference until the start of the space age, notably inspiring Belgian cartoonist Hergé for his works *Destination Moon*, released in 1953, and *Explorers on the Moon*, from 1954.

monopoly exercised by the US government on the United States launcher market and which had led, with the Challenger fiasco, to abandoning the world market to Arianespace. He thought that only the liberalization of the market would allow the competitiveness of the United States' space industry to be restored and that this would give US satellite producers a chance to retain their predominant share of the market. If the United States continued in their protectionist approach, he stated, the Europeans, Japanese and Russians would seize the whole global market.

By summer 1986, he had gathered several investor friends in Houston and after a few market analyses and a study of the legal aspects, he founded the Space Commerce Corporation (SCC) with them with the goal of commercializing Soviet space capacities in the West. The following October, during the International Astronautical Congress, which took place that year in Innsbruck (Austria), he met Alexander Dunaev. In the preceding months, Dunaev had attempted to bypass the export problem by asking the US government about the possibility of launching the Proton from Cape Canaveral. This request went unheeded. The two men then started working on the modalities of an agreement that would give Glavkosmos an exclusive agent in the United States, and moreover give in-depth knowledge of US legislation and lobbying power with the responsible authorities. Led by Dmitri Poletaev, a Glavkosmos delegation came to Texas in May 1987, accompanied by Valery Mechkov, general director of V/O Licensintorg, to complete the negotiations.

Figure 7.14. *Glavkosmos' stand in Bourget in 1987 (source: Christian Lardier)*

On November 23, 1987, Art Dula and two of his associates, Dan Cassidy from the Marsh & McLennon insurance broker and Robert Citron, the creator and founder of Spacehab, set off for the Baikonur cosmodrome. They were the first people from the United States to visit the site since the NASA crew's trip in 1975 during preparations for the Apollo-Soyuz mission. They were invited by Glavkosmos, but the military authorities remained very strict about their movements and forbid them from taking a single picture or video. Throughout their round inspecting the Proton preparation and launch installations, one particular place they visited was launch complex no. 200/39 and integration hall no. 92, where preparations were being made on the Proton launcher that would place the military relay satellite Kosmos 1897 into orbit 3 days later, as well as the adjoining installations for satellite fueling. The three men could not stay on-site long enough to witness the launch. Nevertheless, throughout this voyage, Oleg Firsiouk, vice president of international affairs at Glavkosmos, proposed to them not only the commercialization of the Proton, but also that of Gorizont telecommunications satellites, which could be launched at a symbolic cost and paid through a percentage of revenues. Use would be guaranteed for 10 years, even if it meant launching a second satellite if the first failed on orbit. Cargo capacities were also mentioned for experiments on board the Mir station or on manned Soyuz missions meant to elaborate materials in microgravity. He even discussed the possibility of commercializing launches on board the new giant Energiya launcher, which had performed its first flight in May 1987.

The hardest work still remained: convincing the Department of State to lift its sanctions on exports by showing it that, as US satellite producers thought, "there's nothing particularly secret about telecommunications satellites, their characteristics are freely available in the technical literature, most of their components are available in large industrial nations, and only the integration and testing processes are slightly sensitive, but they cannot be proven through reverse engineering". Art Dula, who shot to the foreground in the Western press, insisted that an agreement with Glavkosmos would stipulate being able to transfer satellites in the Soviet Union in sealed containers and having his own security service guard the preparation installations so that no Soviet would come close to the satellites and only the client's crews could access them. The agreement with Glavkosmos even stipulated that the SCC would benefit from secure channels directly linked to the United States via an Intelsat station.

The arguments set forth by Art Dula were simple: if the United States continued to keep the Proton far from the market, the economic constraints would force operators to have their satellites manufactured outside the United States so they could launch them in Russia at a competitive price, with a true risk of technological transfers. However, by accepting some exemptions so that satellites could fly on the

Proton while the United States rebuilt their fleet of consumer launchers, the US satellite industry could be saved and healthy competition on the international level could be ensured.

The Department of State had a different take on things. In July 1987, it very clearly stipulated that the demands for export licenses for satellites that would be launched in the USSR would be denied “with no exceptions”.

7.6. Short-lived contracts and seduction operations

In the final weeks of 1987, the SCC’s position was supported by the largest satellite manufacturer of the time, California-based Hughes Satellites, who booked a launch on the Proton to put an HS-393 satellite into orbit. This satellite had been ordered in 1985 by Satellite Transponder Leasing Corp. (STLC), an affiliate of IBM which eventually did not succeed in raising its long-term financing. The satellite was being built but therefore had not been allocated and thus became what was usually called a “white tail”, by analogy with the aeronautical terminology referring to an airplane in the process of being assembled, even finished, which had not yet been definitively bought by an airline and thus bore no logos on its tailfin. In 1986, Intelsat booked a half-million dollar option for the satellite and it was in order to launch it that Hughes had decided to reserve a time slot on the Proton. This was the subject of an official agreement protocol with SCC in early 1989, Art Dula’s company undertaking to obtain an export license before the summer of that year. Unfortunately, the Department of State remained inflexible and the international operator could not proceed. The booking thus became null and void without an actual contract being concluded and signed[12].

In the meantime, Glavkosmos organized a large communication operation around the launch of Phobos probes in July 1988. Since 14 countries had provided experiments for the two orbiters meant to explore the largest satellite around the red planet, official representatives and journalists from these nations were invited to Baikonur for the launch of Phobos-1 on July 7. The European delegation was led by ESA’s general director Reimar Lüst from Germany, accompanied by Roger-Maurice Bonnet from France, ESA’s director of scientific programs, whereas the French delegation was led by the French Minister of Space, Paul Quilès, accompanied by

12 The satellite was eventually launched on Ariane-4 under the name SBS-6 in October 1990 on behalf of Hughes Communications.

Jacques-Louis Lyons, president of CNES. Lennard A. Fisk, adjunct administrator of NASA, headed the US delegation. The guests had the right to visit the assembly halls and particularly the MIK-92, where the Phobos-2 launcher, entirely integrated, was waiting to take its turn on the launch pad.

Figure 7.15. *Advertising at the Phobos launch in 1988 (source: all rights reserved)*

Light gains make a heavy purse. This launcher, which would be the most-photographed Proton by Westerners until 1996, bore surprising markings: Glavkosmos had sold advertising space to two European steelworkers, large providers of steel to the Russian industry, the Italian Danieli and Austrian Voest-Alpine. This was the first time that a space launcher was used in this way for advertising. Glavkosmos went even further, since the control room of the TsOuP in Kaliningrad (today Korolev), near Moscow, images of which would be broadcasted around the world, was also covered with advertising for Soviet companies.

Half an hour before the launch of Phobos-1, observers were given a new surprise as a delegation from the Pentagon, made up of generals and high-ranking officers from the U.S. Air Force, led by General Donald L. Cromer, head of the Space Command, arrived. The liftoff was a success, as was that of the Phobos-2 on July 12[13], and delegations would be able to return to their countries and testify about the Soviets' technical mastery, and also about their new desire for openness.

13 Unfortunately, the mission ended in a double failure, since contact with the Phobos-1 was lost on September 2 following a human error, as the probe was on its way to Mars. Phobos-2, on the other hand, succeeded in reaching orbit around Mars on January 29, 1989, but all contact was then lost on March 27.

Figure 7.16. *Visit of the MIK 92 in Baikonur (source: Christian Lardier)*

Starting in January 1989, SCC reinforced its cooperation with Glavkosmos and its activities include the commercialization of the whole range of services offered by the Soviets: not only launches, data, materials and technologies, but also conferences, training and even organized trips. The Proton was proposed commercially between 28 and 35 million dollars, depending on whether the launch was to a geostationary transfer orbit (5.5-ton capacity) or a sun synchronous orbit (2.8 tons). Glavkosmos requested 120,000 dollars for a reservation, whereas the SCC requested 200,000 dollars.

It required some wait until the second reservation went onto the books on November 14, 1989. This time, the customer was a newly created operator, Energetics Satellite Corp., an affiliate of Energetics Inc., a drilling company based in Englewood, Colorado. It planned to launch a constellation of geostationary Sat/Track satellites for beacon geolocalization. The contract, which valued 13 million dollars, only dealt with two auxiliary passenger launches, but it contained options for six additional launches, which would bring its total value to 54 million dollars. The project, like many similar systems proposed in the same time period, would never see the light of day[14].

In 1990, SCC fired up all cylinders to successfully sell launches on the Proton, but the US launch capacity was once again operational. Martin Marietta, with his Titan 3 Commercial had even already decided to throw in the towel and leave McDonnell Douglas with their Delta and General Dynamics with their Atlas face Arianespace, on their own. The argument that the Proton was the intermediary launcher for the United States no longer held water. However, SCC continued its efforts with the Department of State and once again proposed to bypass the problem by launching the Proton from Cape Canaveral. For this, an attempt was made to approach the Florida

14 The US Geostar, which had launched a dedicated payload on board the Spacenet-3R satellite in March 1988 and was planning two satellites in 1990, declared bankruptcy in February 1991. Its European equivalent, Locstar, which had ordered two satellites from Matra Marconi Space in November 1989, canceled its program in July 1991 before being liquidated in 1993.

Space Authority, an entity created the previous year by Governor Bob Martinez and the Florida Congress to encourage the development of space transport activities in the state. In order to insist on the opening of the East, SCC would even organize a traveling exposition of Soviet space material throughout the United States starting in May 1990. In competition to launch Mexico's Solidaridad satellites, the Proton was quickly eliminated and the satellites allocated to Arianespace in September 1991.

Meanwhile Glavkosmos was also working to expand the Proton's market through other means by encouraging the creation of new satellite projects combining manufacturing by NPO Prikladnoy Mekhaniki (NPO PM), the great producer of Russian telecommunications satellites based on Krasnoyarsk in Siberia, with a Western payload and financing. The satellites would be launched by the Proton. In 1989, an agreement with Deutsche Aerospace and ANT in Germany and the Soviet bloc operator Intersputnik allowed studies to be conducted on the Romantis project. A more ambitious agreement was signed in November 1990 with the Canadian companies Spar Aerospace, Canadian Satellite Communications and General Discovery to establish the SovCanStar Communications company, in which they promised to invest approximately 100 million Canadian dollars. None of these projects would succeed in this form. In 1992, Romantis was returned to the level of a communications network using existing satellites, while SovCanStar threw in the towel after a loss at the launch of a Gorizont satellite that should have started a temporary service on May 27, 1993.

Faced with the inability of Glavkosmos and SCC to garner significant contracts, the primary Soviet space enterprises such as NPO Energiya or NPO PM, which had started to be known in the West, decided to proceed without its services and attempt to negotiate directly with Western partners as MOM had authorized since 1988. Thus, in March 1990, the Proton was proposed to launch the Lunar Prospector project. This "commercial" lunar probe was studied by two private associations, Lunar Exploration Inc. in Texas and the Space Studies Institute in New Jersey, with the support of Lockheed Missiles & Space Co., in anticipation of a launch announced for 1992. But the agreement was signed directly at the end of the year with NPO Energiya for a launch on Molniya in 1993. In the end, the Russian giant could not pull it off because the program had faced numerous delays due to a lack of financing before finally being taken over by NASA in February 1995; the probe was sent toward the Moon in January 1998 on a small Athena-2 launcher from Lockheed Martin.

7.7. The end of an era

In November 1990, Washington's official position was slightly modified with the signature of a presidential mandate that transferred the authority to export telecommunications satellites from the Department of State to the Department of Commerce. Satellites were thus removed from the list of weapons to join that of articles whose commerce was controlled. Faced with pressure from the industry, which wanted access to Soviet and Chinese launchers, a first step had just been made, but there would be nearly a two-year wait before the Department of Commerce provided adapted regulation on this matter.

Figure 7.17. *MIK-92 visit in Baikonur (source: Christian Lardier)*

It was already too late for Glavkosmos, whose final large-scale operation took place on January 18, 1992 with its traditional partner: India's ISRO. After the launch of IRS-1A in March 1988 and the launch order for IRS-1B, which would fly in August 1991, both on the last Vostok-M vehicles, India signed a long-term agreement with Russia. This included a firm launch for IRS-1C, which flew on a Molniya launcher on December 28, 1995, accompanied by two options for IRS-1D on Molniya and most importantly for the Insat-2A telecommunications satellite on the Proton. Unfortunately, the IRS-1D launch was canceled in April 1996, as IRSO decided to allocate the satellite to its national launcher, PSLV, whereas the Insat-2A would finally be the object of a contract with Arianespace, the European Ariane becoming the go-to foreign launcher for Indian geostationary satellites (13 launches from 1992 to September 2012). Another part of the agreement asked for the delivery by KB Salyut of seven 12KRB cryogenic stages designed for the future Indian Geosynchronous Satellite Launch Vehicle (GSLV) launchers, which would lead to a violent reaction from Washington when the ways and means became known: it included a technology transfer of cryogenic propulsion to India. On May 11, 1992, the Department of State imposed an embargo on Glavkosmos' activities, considering that its agreement with ISRO on the delivery of cryogenic stages ran contrary to the rules of nonproliferation of ballistic technologies as supported by the Missile Technology Control Regime (MTCR), without paying great attention to the fact that neither Russia nor India were signatories, nor even that cryogenic technology is not at all adapted to missile propulsion. For Glavkosmos, this meant the impossibility of signing any contract at all with the United States, but this no longer made a great difference, given that the marketing of the Proton had not been its responsibility for several months by that point.

Figure 7.18. *MIK-92 visit in Baikonur (source: Christian Lardier)*

In the meantime, the face of the world had changed. Fundamentally weakened by the dispersion of the Eastern bloc and the profound consequences of Perestroika, the Soviet Union received its *coup de grâce* with the conservative putsch that attempted to overthrow Mikhail Gorbachev on August 19, 1991 and only succeeded in definitively sapping the credibility of all federal institutions in fewer than 72 h.

In the institutional maelstrom that ensued, Glavkosmos escaped the influence of MOM in September 1991 to become the commercial representation agency of various Russian manufacturers. At that point, most of its activities had already been directly recovered by the great names of the military-industrial space and ballistic complex, that decided to adopt their own structure to commercialize their production by creating the association Rossobshchemash, which presented itself as a "private" Russian version of MOM, itself dissolved shortly thereafter. Rossobshchemash included a space division – the "Kontsern Kosmos" – which gathered 30 of the biggest names in the space industry[15] and would generate a series of commercial representation agreements in Europe and the United States before being wiped out in turn by the commercial initiatives taken directly by its members.

Soviet power crumbled, the former Soviet republics proclaiming their independence, and in barely 4 months, the USSR had dissolved. On Christmas Eve 1991, the Russian tricolor flag flew in the towers of the Kremlin, where Mikhail Gorbachev had just resigned. The next day, the Supreme Soviet scuttled what remained of the Soviet Union as a political entity.

15 Among these were: the guiding equipment provider NPO Avtomatiki i Priborostroeniye; the engine manufacturer NPO Energomash; NPO Energiya (associated member); the material and optics provider NPO Kompozit; the MZ Khrunichev and MZ Progress factories that manufactured the Proton and Semyorka launchers; the KB Salyut and TsSKB study offices associated with them; the space satellite manufacturer NPO Lavochkin; the satellite manufacturers NPO Mashinostroeniye and NPO Prikladnoy Mekhaniki; testing facility TsNII Mashinostroeniye; the MAI (Moscow Aviation Institute); APO Polyot which produced the Kosmos launchers; the research center NII-TP; the metallurgist NPO Tekhnomash and the supplier NPO Tochnekh Proborov. There were also non-Russian members, such as the Estonian Space Agency, the Ukrainian supplier NPO Khardron and the UzbekTashKB Mashinostroeniye.

8

Friends or Foes

During the failed putsch of August 1991, the military-industrial complex in general and its space component in particular were tarnished, because one of the eight leading putschists was none other than minister Oleg Dmitrievich Baklanov, vice president of the Defense Council, who had been one of the political craftsmen of the program who designed the giant Energiya launcher, the Buran shuttle and the Polyus combat space station, which he considered to be a means of fighting against the Strategic Defense Initiative (the "Star Wars") started by the Reagan administration. This old-fashioned vision was now obsolete. The future was opened to cooperation. Twenty days before the putsch, on July 31, Gorbachev met with President George H.W. Bush to sign a Soviet-American cooperation agreement that would prepare the flight of a US astronaut on board Mir and that of a Soviet cosmonaut to the Spacelab laboratory on board the space shuttle, beginning a partnership that would lead to the birth of the International Space Station.

Figure 8.1. *Sergey Krikalev on STS-60 in February 1994 (second from the left) and Norman Thagard on Mir in March 1995 (left) (source: NASA)*

However, the implosion of the USSR and the slow gestation of a post-Soviet Russia left room for a period of chaos. The inherited MOM system was ill-adapted to change and the political situation was difficult to define from day to day, so much so that representatives multiplied but no responsibility was definitively attributed. At

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

the same time, Russian space budgets, already frozen since 1990, faced a 40% drop in rubles while inflation multiplied prices eightfold between 1990 and early 1992 and another fivefold throughout that same year. If the 2 years are totaled, the affected resources of the space sector fell by 95% and Gorbachev had started to cut that budget well before then. In practice, some crews, even entire factories, were not paid for several months and had no idea what the future – formerly planned – held in store. The imperative need to find means of survival and the lack of knowledge and understanding concerning Western commercial practices then led to an anarchical effervescence of demand in the sector, which sometimes led to black market sales. Westerners, often ill-informed about the internal structures of the Russian industry, had a hard time navigating this situation.

The Soviet system passed down a terribly complex organization. Traditionally, the industrial responsibility for programs belonged to design bureaus ("KB") with no production capacities beyond a few workshops to design demonstrations and prototypes. These design bureaus used to delegate actual production to a network of factories ("MZ"), which in turn depended on the government and received their financing from one or several ministries. As such, it was not uncommon to see three or four representatives simultaneously attempting to sell worldwide exclusive rights to the same product within one administration – old or new – a design bureau or even one or several production plants, when it was not the engineers or technicians themselves offering to sell the highest bidder launchers, motors or all sorts of other equipment stored in warehouses that they had the keys to. In the case of the Proton, the design bureau was the KB Salyut and the integration of the launchers was performed by the MZ Khrunichev[1], both located in Fili to the west of Moscow. Salyut was an affiliate of NPO Machinostroeniye in Reutov from 1960–1981, an affiliate of Energiya from 1981–1988, then autonomous in 1988, while the factory had always been independent: the KB and the factory fused to form the Khrunichev center in 1993. Adding in Glavkosmos and the brand new Russian space agency, RKA, there were a lot of people hoping to sell the most coveted launcher from the old Soviet arsenal.

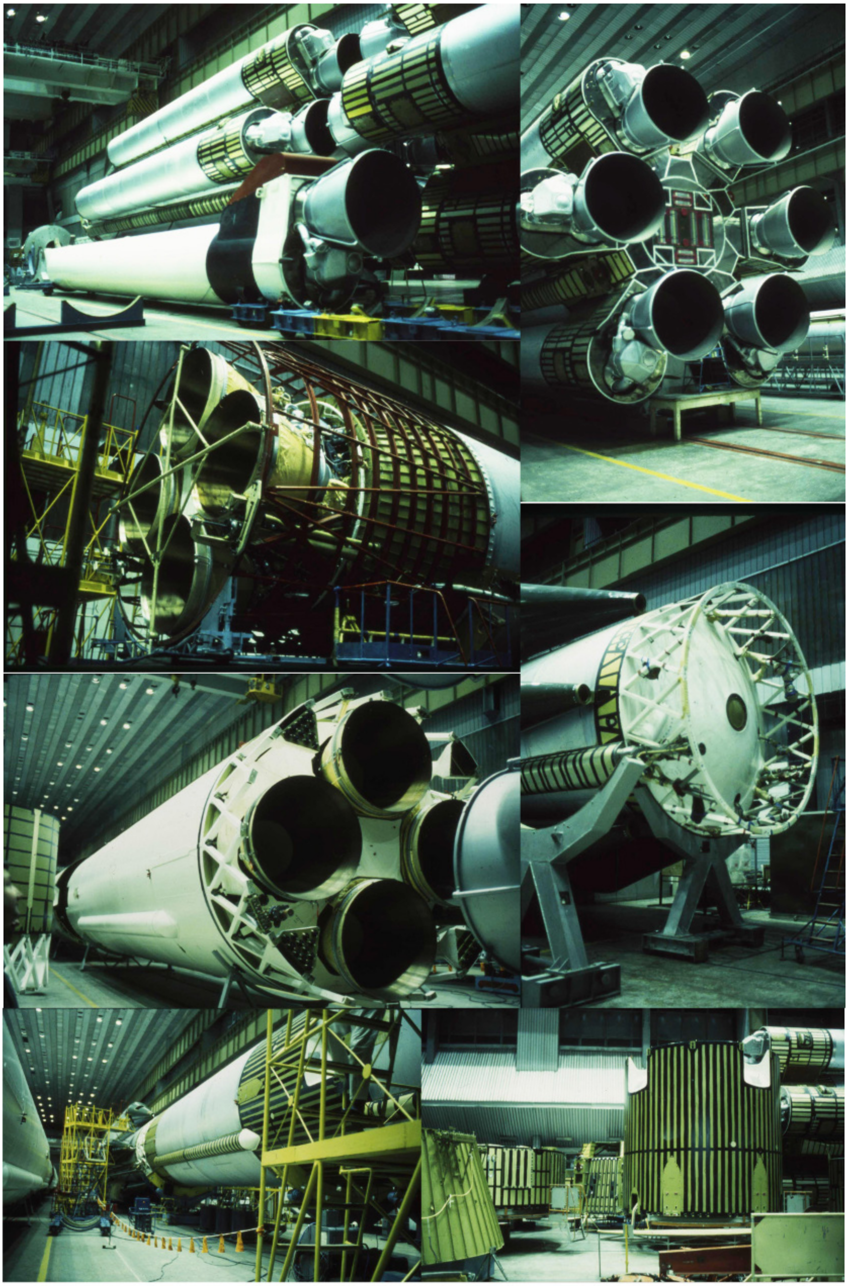
8.1. First hope for success

In March 1992, Glavkosmos' efforts eventually paid off, but it was the KB Salyut that would reap the benefits. The Proton, which had once again been proposed to Inmarsat in mid-1990, this time to launch its third-generation satellites, was finally among the finalists. Of course, the international maritime satellite operator had first booked General Dynamics' Atlas for the first two satellites, but for the next two, it would be a competition between Ariane and the Russian launcher,

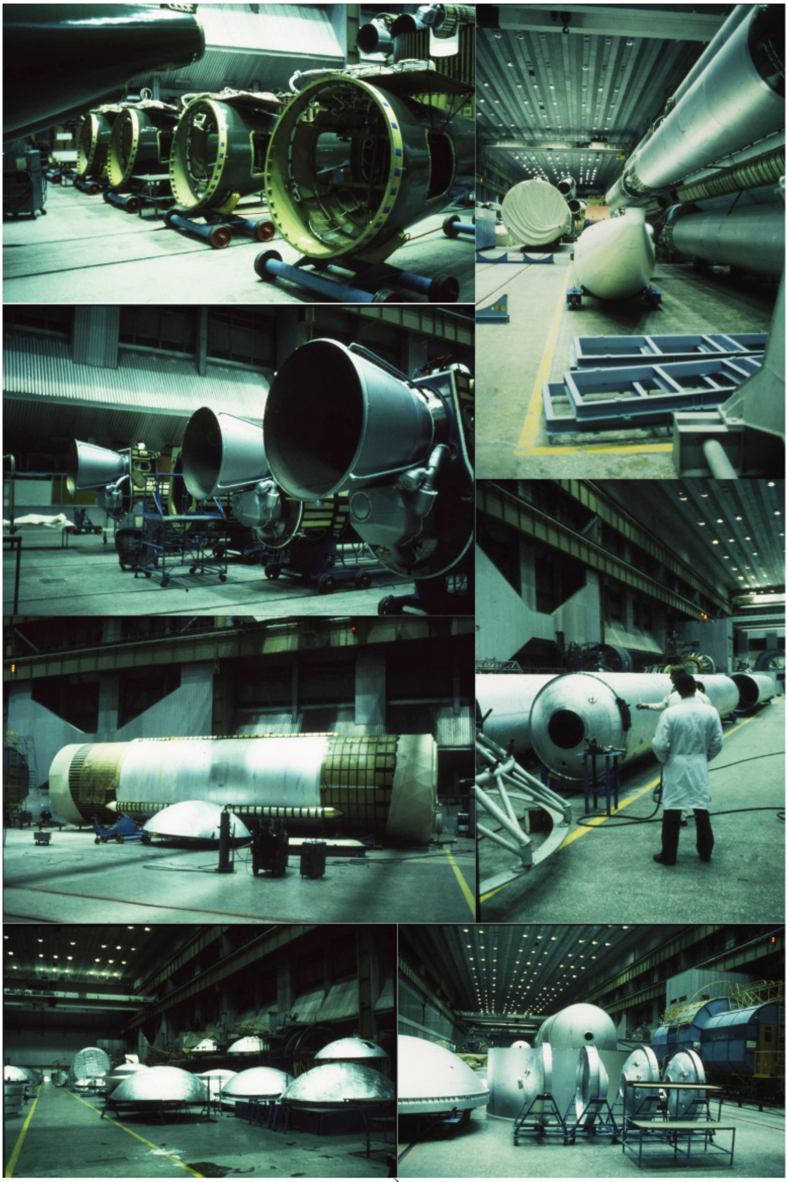
1 Machinostroeniye Zavod imeni Khrunicheva – Khrunicheva production factory, sometimes also known as ZiKH.

Japanese and Chinese offers having been turned down. A final decision had to be made by Inmarsat's Council during its next meeting in July. This would give the Russians 4 months to work toward an agreement with Washington for the export of the satellite. The US Department of Commerce, which had overtaken this responsibility from the Department of State 15 months prior, had not yet decided on this point.

a)



b)



c)

Figure 8.2. *Khrunichev visit in 1991 (source: Christian Lardier)*

On June 17, 1992, Russian president Boris Yeltsin arrived in Washington to meet his US counterpart and to agree with him on the defeat of the Communist bloc. On the agenda that day: US participation in a 24-billion dollar aid package. After successfully containing the collapse of Russia with the signature of the Federation Treaty by 18 out of 20 republics on May 31, the new ruler of the Kremlin took advantage of this to negotiate a two-thirds reduction of nuclear arsenal. The two presidents also signed a cooperation agreement regarding space research with peaceful ends. This included a section on commercial space transport, which sanctioned Russia's acceptance of the market rules and particularly the renunciation of disloyal practices. Russia and the United States furthermore agreed to open up negotiations to develop international directives regarding competition on the commercial satellite launching market, thereby allowing Russian launchers to participate. Finally, an exemption was already agreed upon to allow the Proton to be a candidate for the launch of one of Inmarsat's third-generation satellites. The conferment of an export license would, however, be dependent on the conclusion of a Technology Safeguard Agreement.

The Department of Commerce would not finalize its regulation on the export of telecommunication satellites until the following October, but Inmarsat's Council had accepted to postpone its decision until November.

Before the fall of the Berlin Wall on November 9, 1989, the heads of the military-industrial complexes on both sides of the Iron Curtain had clearly understood that the coming end of the Cold War would have a large impact on their budgets and that they would need to cooperate with their former enemy to survive.

In 1990, the MZ Khrunichev factory established a department of foreign commercial relations, headed by Arkadi Y. Zimmerman. Specialized engineers from the factory were sent to the United States, but also to France and Germany, to perform internships and become familiarized with Western methods. In 1992, Alexander V. Lebedev was named deputy director of foreign commercial relations and Alexander S. Kondratiyev became head of the department. They would play an essential role in negotiations with foreign partners. Solutions had to be found, because on the Russian side, all that was proposed to Khrunichev was to diversify by producing automatic milking machines, foldable bicycles, camping material and even saucepans.

The Khrunichev team also benefited from the expertise of Andrei A. Kokoshin[2], deputy director of the ISKAN (Institute for US and Canadian Studies) and strategy and defense expert renowned in both the East and the West. In his opinion, it was worthless to start working with international clients who had no previous knowledge of Western commercial practices and no connection to a US manufacturer large enough to provide credibility, because otherwise, there was a risk of ending up alone, "stuck with a bunch of missiles nobody wants".

8.2. Lockheed joins the fray

What was hard to endure on the Russian side was equally unbearable on the United States' side, where manufacturers complained to the Pentagon and the National Space Council that after "having won the Cold War", their only reward was cuts in their orders. "The Defense budget will be reduced by 10% over 5 years," announced Secretary of Defense Dick Cheney on June 18, 1990. The dividends of peace could not compare to those of shareholders.

Among the primary victims of this situation was Lockheed Corp., one of the largest names in defense since World War II. It was in its design bureaus and its factories that legendary aircraft were born, like the P-38 "Lightning" or the P-80 "Shooting Star" and more recently the fabulous SR-71 "Blackbird" Mach 3 spy plane or the F-117 "Nighthawk" stealth plane, the F-104 "Starfighter" interceptor or the cargo planes C-130 "Hercules" and C-5A "Galaxy". Its Lockheed Missile & Space Co. (LMSC) division, based in Sunnyvale, California, had previously developed the very first spy satellites, even before Sputnik. It was involved in naval ballistic missile programs – primarily the Trident missiles that armed US and British nuclear submarines. According to estimates from the Lockheed management, the end of the Cold War should translate into a 50% drop in their revenue, because the company had withdrawn from the civil aerial sector after the commercial failure of its L-1011 Tristar, which had already nearly caused it to collapse in 1971. It had also left the space transport sector when it stopped producing Agena upper stages, more than 350 copies of which had been placed on the Thor, Atlas and Titan launchers for more than

2 Boris Yeltsin's future Vice Prime Minister of Defense from April 1992 to May 1997, then head of the Defense Council and the State Military Inspection, then in March 1998 head of the Security Council, a position he would be dismissed from 5 months later during the great governmental and economic crisis of 1998.

30 years[3]. Between 1987 and 1991, the number of technicians and engineers employed by the LMSC division dropped from 11,526 to 9,636, and this decrease would continue over time. In an effort to face this lean period that was coming about and the "new global economic order" that would result from the end of the East-West conflict, Lockheed's management was attentive to every opportunity that could present itself, even those that would imply shaking hands with old adversaries.

The Russians themselves had not expected the collapse of the USSR and thus had not sought out new contacts in the aeronautics or the space sectors. "They had respect for our performances and particularly for the U2 spy plane, through which we had stolen their air space", would later declare H. Hollister Cantus, then vice president of LMSC for government orders. He thus remembered having received a trio of representatives of the Soviet industry in his Washington office around 1990: "They were hoping to collaborate with us in the domain of submarine-launched ballistic missiles and they were very impressed by our Trident missile, but I quickly understood that they also wanted to learn more about our system than they were willing to reveal about their own". Through a secure telephone line, he then referred this matter to the president of LMSC, John McMahon, a former CIA officer who had made his debut on the U2 before climbing all the way to the top and becoming deputy director of the agency under Reagan and leaving it before his reputation was sullied by the scandals of that era. The discussions on missiles would be cut off short, but the contacts would be pursued for more civil operations, less involved in "secret defense". Several Russian delegations would visit Lockheed, notably representatives of NPO Energiya. However, nothing conclusive would come of this until the Bush-Yeltsin summit in June 1992.

In July, at Yeltsin's invitation, the new NASA administrator, Daniel Goldin, and the new director of the National Space Council, Brian Dailey, paid a visit to the principal industrial sites of the Russian space sector. The 21-person delegation also included representatives of the Department of State, the US Air Force, the CIA and the NSA. Most expected to find sites in a state of disrepair, but they came back very impressed by the quality of the equipment and installations presented to them. This visit would play an important role in the US-Russian rapprochement that would result in the creation of the International Space Station. Most importantly, the members of the delegation would talk to those around them about what they had seen.

3 Lockheed would nevertheless initiate the development of a family of small launchers in mid-1993. These LLV (Lockheed Launch Vehicles) would fly from 1995 to 2001 under the name LLV, then LMLV (Lockheed Martin Launch Vehicles), and finally Athena.

The following month, Professor James F. Gibbons, Dean of the School of Engineering at Stanford University, questioned Daniel Tellep, the CEO of Lockheed Corp., on the subject of potential cooperation with the “new Russia” in the space sector during an administration council meeting. This specialist in semiconductors and a pioneer in distance learning, had participated in numerous scientific policy advisory committees under the President of the United States since the Nixon era. He had no difficulty convincing Dan Tellep, especially since before presiding over the group’s destiny, he was John McMahon’s predecessor as the head of LMSC. A team was soon assembled to prepare a commercial agreement under the leadership of LMSC’s new vice president for advanced programs, Melvin R. Brashears, as well as with the help of Professor William J. Perry, co-director of the Center for International Security and Arms Control (CISAC) at Stanford University. He had also been the Under Secretary of Defense for Research and Engineering under Jimmy Carter, a position in which he played an important role for the development of stealth plane technology developed by Lockheed[4].

Although KB Salyut had been in the front line to win an Inmarsat 3 satellite launch contract, Lockheed’s team was focused on MZ Khrunichev, the Proton’s manufacturer, whose potential seemed the most interesting and the most complementary to Lockheed’s own capacities in the field of satellites and operations. Furthermore, under the responsibility and technical control of a large name in the US space sector, whose skills were world renowned, the Proton would start having the credibility that it had lacked on the international market.

However, Lockheed was not the only US manufacturer who had his heart set on Khrunichev. Rockwell, the prime industrial contractor of the space shuttle, was also in the running. The former North American whose past accomplishments included the Apollo command module or the propulsion for the Saturn launchers was marginalized in space transportation. Of course, he was in charge of the maintenance and operations of the shuttle, but since the Challenger accident, prospects were limited. Its launch rate, which was thought to be able to reach up to 18 flights per year before the incident, would not exceed eight or even six per year in the years to come. Moreover, the introduction of the fifth orbiter, Endeavour, to replace Challenger, would mean the closure of the assembly line. To diversify, Rockwell thus attempted to get involved in former Soviet launch systems, notably the Proton and the Tsyklon.

This competition between Lockheed and Rockwell would end shortly after a ludicrous incident during the World Space Congress that took place in Washington from August 28 to September 5, 1992. To celebrate the spirit of exploration on the

4 He would be named Secretary of Defense in January 1993 at the start of Bill Clinton’s first term.

500th anniversary of Christopher Columbus' first voyage and at the invitation of NASA and the American Institute of Aeronautics and Astronautics (AIAA), the International Astronautics Federation (IAF) and Cospar (Committee on Space Research) had decided to bring their respective congresses together. The combination of these two annual gatherings, both highly renowned in the space community, led to an exceptional event bringing together more than 8,000 delegates from around the world. The ideal location for networking.

One of the receptions, which are usually organized on the fringe of this kind of congress, took place in Mount Vernon and included a cruise on the Potomac onboard the "Cherry Blossom", a reproduction sternwheeler, a typical 19th-Century paddle steamer. Lockheed's crew hoped to meet its Russian contacts onboard, but Rockwell beat them to the mark by inviting the Russians onto a yacht reserved for the occasion in order to impress them. Unfortunately, the best plans never go as planned, and when the "Cherry Blossom" cast off from the Alexandria dock, Lockheed's representatives, leaning on the railing, could watch their rival's misfortune as they were unable to start the yacht's motor, much to the chagrin of the Russians.

8.3. Voyage to Moscow

These incidents were the obvious sign that there was no time to lose. Bill Perry suggested they immediately go to Moscow to negotiate directly with Khrunichev's management. Mel Brashears completed his agreement project and had it approved by John McMahon, then by Dan Tellep. Before going to submit it to the Russians, he would first have to receive the approval of the National Security Council, the National Space Council, the Department of State, the CIA and the Pentagon. He managed to convince all of them in less than a 2-week time period.

In late September, Mel Brashears and Bill Perry, accompanied by a group of Lockheed specialists and a consultant team from the Aspen Institute, who were at that time working with the Dean of the School of Engineering at Stanford, flew off to Moscow. Mel Brashears would later describe this voyage as a mixture of a tourist trip, undercover espionage and business negotiations. The US delegation was welcomed enthusiastically at Khrunichev on September 21, 1992, where it was invited to visit the impressive factory that produced both the Proton launchers and the Mir station modules. Like the delegation led by Goldin 2 months earlier, they were guided by the director of MZ Khrunichev himself, Anatoli Ivanovich Kiselev, and for 3 hours, they toured the integration halls, manufacturing workshops, and test assemblies, not to leave out the component assembly lines. They were so impressed by the enormity and efficiency of the assembly lines, as well as by the combination of high technology and working conditions that never would have been approved back home by the Occupational Safety and Health Administration (OSHA), the agency responsible for monitoring employee health and the safety of working conditions: workers several meters off the ground without protection harnesses and moving around on tiny walkways with no railing. When Mel Brashears asked if accidents ever happened, Anatoli Kiselev answered without mischief: “the workers have to be careful; else, we can replace them”.

The presence of cats in the factory was another source of amazement for the US delegation. They were no less surprised upon learning that these were responsible for keeping mice out of the equipment.

These cultural differences would take a dramatic turn when the delegation took a seat at the negotiation table across from Anatoli Kiselev and the other leaders at Khrunichev. After thanking their hosts for the fascinating visit of their site, Mel Brashears made the mistake of presenting his agreement project as if he were dealing with a Western business leader familiar with the legal and financial terminology of the market economy.

What he proposed was the start of a joint venture between Lockheed and Khrunichev, for which Lockheed would provide the initial capital, while Khrunichev would provide Proton launchers, their infrastructure and the associated operations. The company would benefit from Lockheed’s international commercial network and its expertise to sell to customers around the world. The shares would be equal, but the contract revenue would be shared according to a price scale negotiated beforehand by the two partners. Each would be responsible for managing its own part of the activity: selling launchers for Lockheed, manufacturing them for Khrunichev. The new company itself would thus only be a coordination structure; it would have no revenue and would not distribute any dividends, which would allow issues of governance to be simplified to their simplest expression. Each would also be responsible for its own internal accounting, in its own way, and for making regular profits.

Born in 1938 in a working-class family, Anatoli Kiselev had not lived in a world where companies were bought and sold, where they were designed like shells in which activities could be dispatched so that the risks of some would not affect the success of others. He had lived in a world where factories were given tasks by order of the central government and had to manage every aspect of workers’ daily routines, from food to shelter, from daycare to children’s schooling. He was a perfect product of Soviet education, in which some ideas had not crossed the Iron Curtain unscathed, as witnessed by the definition of the word *businessman* in the famous Explanatory dictionary of foreign words (Tolkovyi slovar inoyazychnikh slov), a Soviet era reference book: “a capitalist, cunning merchant, determined to profit from everyone and willing to do anything to fill his or her pockets”.

Anatoli Kiselev had grown up under Stalin, studied at school no. 590 in Fili in the west of Moscow, before turning to aeronautics factory no. 23 at the age of 18 as an electrician. In 1960, the factory had begun the production of Chelomey’s OKB-52 missiles. Thanks to night classes at the MATI (*Moskivskovo aviatsionno-tekhnologicheskovo instituta*), he received his engineering degree at 26. He worked on UR-200, UR-100 and UR-500 missiles, which led him to take part in the very first flight of the Proton in 1965. Working relentlessly to make intercontinental missiles at remote sites operational, he climbed the business ladder and in February 1968, at the age of 29, became the deputy director of the factory. He thus was finally able to offer his wife and daughter the luxury of separate bedrooms in their apartment. Having become the friend and protégé of Minister Sergey Afanasyev, he spent 3 years at MOM before being named head of Khrunichev and its 24,000 employees in February 1975 at the young age of 36. Besides the Proton launcher, he had also had to manage the manufacturing of Salyut, Almaz and Mir space stations. He received numerous decorations: two Orders of Lenin (1983 and 1990), one Order of the Red Banner (1975), and was crowned with the Lenin Prize in 1978 and was the Hero of Socialist Labor in 1990.

Mel Brashears, on the other hand, was born post-war in Missouri. He grew up there when the “Golden Age of Capitalism” was at its peak and received his engineering degree at the local university, while NASA astronauts were examining the Moon’s surface. Then he joined LMSC, where he made his way from research programs to development programs.

While Brashears, with all his typical candor of the Midwest, which could just as easily have been taken for arrogance, explained his proposition, relayed by an interpreter, Kiselev squirmed in his chair. Finally, when it was explained that Lockheed, as the principal investor, would possess 51% of the shares of the new company, Kiselev interrupted brutally:

> “So what you are telling us is that our Proton is a superb launcher and that you want it to be the star of our joint venture?”

He then removed his jacket and asked Mel Brashears:

> “Is this my jacket?”

Discomfited, Brashears could only agree.

> "And you want half and even more than half of my jacket?" he exploded, pulling on it as if he were going to tear it apart, to the great alarm of the US delegation.

Valery Pivarov, the interpreter, intervened immediately and explained to the two men that they were not understanding one another. Apparently, the US proposition had been interpreted by the Russians as an attempt to transfer the production of the Proton under Lockheed's control and share it 51/49 as an effective takeover, with part of the launch revenue being Khrunichev's only compensation. Once the concept of *joint venture* had been correctly explained, Anatoli Kiselev was once again all smiles. In reality, it was quite likely that he had understood everything even before his outburst, but after having stupefied the US delegation, he could profit from the relief that they started feeling to push his advantage by suggesting that on top of the 15 million dollars that Lockheed proposed to invest in the joint venture, another 5 million dollars would be given to Khrunichev before the end of the year to finance work modernizing the Proton. Lockheed's crew, dumbstruck, then responded that it did not have the authority to negotiate more than the initial sum, to which Anatoli Kiselev responded, without missing a beat, that countless telephones were available both at Khrunichev and at the hotel, or even at the United States embassy, for them to get in touch with Sunnyvale, and the day was far from over. In fact, in California, it had not even begun. The 5 million dollars was the condition for any agreement and Kiselev even pushed his bluff further, saying that if Lockheed hesitated, the representatives of Boeing could be there "in minutes".

Figure 8.3. *Melvin Brashears and Anatoli Kiselev (source: Khrunichev Center)*

The meeting was adjourned and the next day, it was a beaming Anatoli Kiselev who welcomed Mel Brashears and his crew when they announced that his conditions had been accepted. An initial memorandum of understanding was signed on September 22. One week later, they would all meet again at Lockheed in Sunnyvale to sign the final agreement, effective on October 30.

The news would not be revealed officially until 2 months later, the time to obtain the necessary authorizations on both the Russian and US side. This time period would also allow Lockheed to prepare its first client, with a slightly peculiar contract.

8.4. Telephony in the sky

The commercialization of the Proton was not the first path explored by Lockheed to diversify its space activities. A year earlier, the manufacturer had been approached by Motorola, which was at the time the giant in mobile telephony with a burning desire to revolutionize the concept.

In 1984, Motorola had developed the first cell phone to receive the approval of the Federal Communications Commission (FCC), which allowed networks to be opened in the United States. This technology had been available in Japan since 1979 and since 1981 in Scandinavia. However, these first cell phones were still analog, heavy and with very limited autonomy. Moreover, the networks had coverage reduced to a few large agglomerations and compatibility between networks was nearly inexistent. The cell phone remained limited to an urban elite and Motorola planned to remedy this, though it was not the only one dealing with this issue: from 1982 to 1987, a digital norm had been identified in France by the GSM committee (Groupe Spécial Mobile) and was to be introduced across Europe starting in 1991, which would kick off modern digital cell phones that would become generalized and then democratized in a few years.

On June 26, 1990, Motorola organized a large media "hit" with an international press conference held simultaneously in London, New York, Beijing and Melbourne to unveil the revolutionary concept its teams had been working on for 2 years: a constellation of 77 low-orbiting satellites gravitating from pole to pole to ensure global coverage and to relay cell phone calls to the most remote corners of the planet. The mining prospector deep in the Andes, the vacationer on a deserted island[5], the technician on an oil platform, the scientist crossing the Antarctic or the mountaineer climbing a Himalayan summit, as well as any traveling businessman across the Midwest, anyone could have access to cell phone services via satellite. Calls would rise directly to the satellite of the closest network and would be retransmitted from satellite to satellite until it was transferred to a

5 The legend goes that Iridium was founded because the wife of an executive at Motorola, Karen Bertiger, had complained that she could not use her cell phone during her vacation in the Bahamas in 1985.

station connected to the public network or directly to another user. The project was called Iridium, referring to chemical element 77[6].

After consulting seven satellite manufacturers in the United States and 10 more around the world, Motorola, which hoped to remain the program's prime contractor, determined that having produced 350 spy satellites in its factories, Lockheed was the ideal partner for its project. A letter of intent was signed on April 1, 1991 between Motorola and LMSC, which made Lockheed's subsidiary the first industrial partner for the Iridium system, whose total cost was then estimated at 2.3 billion dollars. For Lockheed, this was a first venture into the juicy market of space telecommunications and a new subsidiary was created for the occasion – Lockheed Commercial Space Co. – which would take part in the project. At the time, it was imagined that satellites would only weigh 350 kg and cost 30 million dollars apiece. Since their lifespan should be 5 years, this meant that maintaining the constellation would imply launching approximately 15 per year, i.e. an annual cost of around 450 million dollars that would allow LMSC to save most of its jobs. The company Iridium LLC was founded in June.

In the launcher sector, this new market also aroused interest, especially as competing projects would not take long to appear. By late 1991, Globalstar (48 satellites), Ellipsat (24 satellites), Odyssey (12 satellites), Aries (24 satellites) and a mysterious "Project 21" from Inmarsat (35–40 satellites) were already announced, as well as a plethora of radio messaging satellite constellations. In a few months, every manufacturer, design bureau or organization on the planet that was closely or not so closely linked to a launch or missile system would come to present its system to place small satellites – one by one – into orbit. This effervescence would only grow when Daniel Goldin, former employee of TRW and champion of small, low-cost missions according to his definition of "faster, better, cheaper," [7] rose to the head of NASA in April 1992.

On January 16, 1992, Iridium LLC announced that its satellites, which had a weight of 430 kg, would not be deployed individually but in clusters of 11 or 12 on Ariane launchers or 6 on Delta launchers. In case of emergency, an individual replacement could be launched "in 36 hours" by a small, light Pegasus launcher. The satellites would be assembly-line products "based on a platform designed for the needs of the US Air Force". The first launches were planned in 1994 with the initial start of

6 This name would even be kept after the concept was revised in 1992 and reduced to 66 satellites.

7 Slogan to which his detractors would add "pick two", because "out of three, only two could be achieved".

service in 1997. In September, the program was revised with a change from seven to six orbital planes for the constellation, which would consequently include no more than 66 satellites, whose mass at that time was 689 kg. The total cost of the project had been brought up to 3.37 billion dollars with launches pushed back to 1996 to provide services in 1998.

Figure 8.4. *From left to right, Vice President and President of Motorola, A. I. Kiselev, Minister of Science and Technology A. A. Kuzmitsky (source: all rights reserved)*

The rapprochement with Khrunichev allowed Lockheed to propose a new means of launching satellites to Motorola. At first, the performances announced for the Proton-K in the Sun-synchronous orbit (2,800 kg) barely allowed an Iridium triplet to be launched with their adaptor, but it very quickly seemed that the use of a Block-DM adapted for the mission would allow the five experimental satellites for which Motorola had obtained a license to be transported together. This was awarded by the FCC after the allocation of the first frequencies for this type of system during the World Administrative Radio Conference (WARC 92) that took place in Torremolinos (Spain) in February. Subsequently, launches in clusters of seven or even nine satellites were possible.

In the end, on December 16, a decree by Prime Minister Viktor Chernomydin (governmental decree no. 2349-r) gave the green light for the strategic rapprochement between Khrunichev and Lockheed and for the commercial use of the Proton launcher. It authorized the preparation of three launches for Iridium and also planned for 40 million dollars, taken from the profit made on these launches, to be invested in the Iridium project, of which Khrunichev would then become a partner of up to 1.2%. The RKA, the Ministry of Defense and the Ministry of Post and Telecommunications would be responsible for defining the arrangements for using Iridium in Russia.

On December 23, it was the US Department of State's turn to endorse the US-Russian industrial agreement, which took effect on December 28. This was the start of Lockheed Khrunichev International (LKI), an equally owned joint venture that would have the exclusive right to commercialize the Proton launcher outside the former USSR.

Two days later, on December 30, Khrunichev received its 5-million dollar (2 billion rubles) payment as expected. Two days after that, on January 1, 1993, the Russian federal government, incapable of paying its employees, reported the transfer of these salaries across the industry, and because of the godsend from the United States, they would all continue to receive regular pay.

8.5. Khrunichev, Salyut and Energiya

Khrunichev signed its very first contract with Motorola on January 12, 1993, concerning three launches to put 21 Iridium satellites into orbit starting in 1996. The total amount of the transaction reached 166.5 million dollars and the contract included a risk-sharing partnership clause stating that Khrunichev would invest 40 million dollars in the Iridium project. This sum would later be reassessed at 82 million, for 5% of the project shares. The contract was publicly announced in February[8].

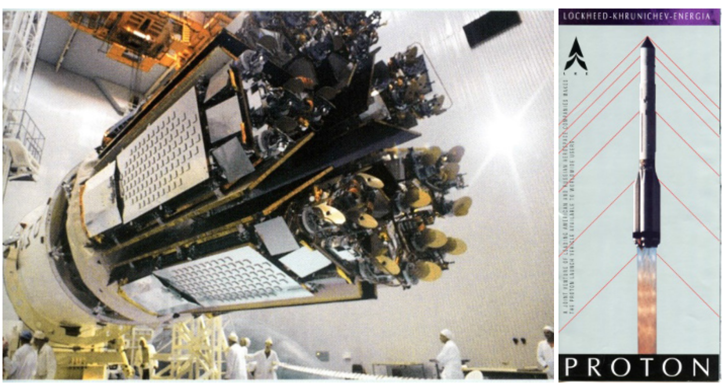


Figure 8.5. *Iridium on Proton (source: Khrunichev Center, LKEI)*

8 Lockheed would receive an order for 120 platforms for the satellites the following August. All in all, 95 satellites would be launched from May 1997 to June 2002.

This was not, however, Proton's first commercial success. After having accepted to postpone its decision on the choice of launchers for its Inmarsat-3-F3 and F4 satellites, in order to give the Department of Commerce the time it had stipulated for the regulation to be applied to Proton, Inmarsat's Council of Commerce met again on November 9 and reached its verdict: the launches would go to Proton and Ariane. For Proton, the signatory of the contract with an announced value of 36 million dollars would be KB Salyut. This contract was officially signed on March 19, 1993 and in no way involved LKI. It would not be publicly announced until April 13. KB Salyut had even gone to consult Aérospatiale in France to define the characteristics of a special adapter so that this satellite, designed in the West, could be placed atop a Russian launcher. This adapter and a separation system would be ordered from the Swedish SAAB Ericsson Space in June, for 1 million dollars, which represented a nearly two-thirds reduction compared to the initial cost of 2.8 million dollars, obtained primarily through very strong re-subcontracting of the work to KB Salyut workshops. Also in June, the Inmarsat contract received the guarantee of BERD (European Bank for Reconstruction and Development) that would agree to reimburse half of the funds provided to KB Salyut in case the satellite could not be put into orbit[9].

Following Inmarsat's announcement in November, Anatoli Kiselev made the firm public declaration that Khrunichev would not deliver the launcher for the mission, denying KB Salyut the right to sign contracts involving the Proton. The question of the final responsibility for the Proton could no longer be delayed, because KB Salyut had also been contacted in September by Intelsat's Council of Governors as part of a call for tenders for the launch of an Intelsat-7A satellite and two Intelsat-8 satellites, with options for two additional launches.

The issue would escalate even more quickly up to the Kremlin, given that Boris Yeltsin's very own daughter, Tatyana Dyachenko, after having worked as an engineer at KB Salyut, started working at Khrunichev. To demonstrate his opposition, Kiselev worked to create a new design bureau, KB Khrunichev, within MZ Khrunichev to do away with KB Salyut definitively. To deal with matters of trajectography, monitoring, and flight programs, which generally fell upon the KB, he called on NPO Machnistroenye specialists in Reutov[10], but in his opinion, even this solution was not satisfactory.

Anatoli Kiselev's lobbying with Yeltsin ended up paying off, however. After having met the main heads of the Russian space industry, the president made him

9 A 10.3-million dollar credit would be provided in April 1994 to allow the export of the Inmarsat-3-F3 satellite and to cover its launch by the insurers.

10 Which MZ Khrunichev officially depended upon.

personally responsible for writing the decree that would bring MZ Khrunichev and KB Salyut together in a single center. This presidential decree was published on June 7. It merged the two entities into a new whole that would take the name "GKNPTs Khrunichev"[11] and would be presented to the West under the name "Khrunichev Enterprise". It was, of course, under the direction of Anatoli Kiselev, who would not report to the RKA but directly to the Kremlin. This position as the general manager would be conferred, incidentally, by presidential decree. The design bureau of this new structure kept the name KB Salyut but would focus on new developments. Moreover, Khrunichev was required to remain a state enterprise and its name was added to the list of companies that could not be privatized or merged, all while receiving the right to form partnerships abroad and manage its revenue as it saw fit.

In the meantime, the partnership with Lockheed had benefited from a new partner as it was joined by NPO Energiya, which provided the Block-DM upper stage. The negotiations had been difficult because Energiya's management was fully aware that it had an essential element for both the launch of Inmarsat's satellite and for the three clusters of Iridium satellites. Anatoli Kiselev would even be forced to call upon Dan Tellep for assistance, but on April 15, Mel Brashears and Alexander Lebedev, along with Energiya's representatives, could finally sign the documents that would create Lockheed Khrunichev Energiya International (LKEI), which succeeded the short-lived LKI for the commercialization of the Proton outside the former USSR. The new structure's board of directors would be headed by Anatoli Kiselev. At his sides were Alexander V. Lebedev and Alexander S. Kondratiyev from Khrunichev, as well as Yuri I. Semenov from Energiya. On the US side, Lockheed named a CEO for LKI, then one for LKEI in February: Charles H. Lloyd, former director of commercial launches at General Dynamics Space Systems. This was an experienced man who had helped the Atlas launcher make its entry onto the international market.

Lockheed's 15 million dollars were finally released. They would allow funds to be advanced to subcontractors, primarily the engine manufacturers PO Motorostroitel in Perm (RD-253 engines from NPO Energomash) and PO VMZ in Voronezh (RD-0210, RD-0211 and RD-0212 engines from KB KhimAvtomatiki), as well as the guidance equipment provider, NPO AP from Moscow and that of gyrostabilized platforms, PO Korpus in Saratov. For each commercial Proton mission, Khrunichev would reimburse 1 million dollars to Lockheed, which, incidentally, would receive a 15% commission on profits.

---

11 "Gossudartsveniy Kosmicheskiy Nauchno-Proizvodstvenniy Tsentr imeni Khrunicheva" – Khrunichev State Research and Production Space Center.

8.6. The Indian obstacle

However, a final step remained to be taken so that the Proton could be definitively placed in the international commercial market: the US Department of State had to give it permission. Yet, in spite of the approval granted in June 1992, the situation was relatively tense due to the January 1991 agreement with India to provide 12KRB stages to ISRO to equip its GSLV launchers (see Chapter 7). The Kremlin having refused to back down on this transfer of technology to one of its most loyal partners, after a warning from Secretary of State James Baker in January 1992, Washington retaliated with sanctions in May, which took the form of a 2-year embargo on contracts with Glavkosmos, the contract signatory, KB Salyut and MZ Khrunichev; however, the designer and the manufacturer, respectively, of the 12KRB stages were not threatened[12]. In fact, the Department of State ruled the carrot and the stick, because it hoped, before all else, to avoid the collapse of the Russian industry, which would risk causing a "brain drain" to states seeking to develop ballistic capabilities while also not running contrary to the plans of the White House, which would love to use the Russians' capabilities for itself to save NASA's orbital station program.

For a few months, the Russians would play for time and George Bush's unexpected loss to Democrat Bill Clinton would allow them to not question their contract with India until early 1993. The case finally ended up on the desk of Anthony Lake, the new president's national security counselor. Concerned with resolving at best the different space issues put on hold, whether it was the fight against proliferation, cooperation in the area of manned flights or the Russian industry's access to the international market, he started setting up the Space Cooperation Working Group within the White House as soon as February 1993. The idea of the group was to connect all these questions to convince Russian partners that they had more to gain by cooperating than by opposing the United States and for this, he proposed opening doors to Russian launches on the condition that the contract with India be revoked. In early April, the proposition was made to Boris Yeltsin during his first meeting with Bill Clinton. The summit took place in Vancouver and primarily revolved around an immediate aid plan for Russia amounting to 1.6 billion dollars. At the same time, NASA was working on the possibility of merging the US Freedom and the Russian Mir-2 space station projects into a true international space station. It lured the head of the RKA, Yuri Koptev, with the promise of an initial prospective market of 400 million dollars (305 for spacecraft flights to Mir and 95 to start work on the future joint space station)…

12 At the same time, the US industry was building a cryogenic propellant factory for ISRO in Mahendragiri, in Karnataka, without any concern.

under the condition that the Indian contract, the value of which was evaluated between 250 and 350 million dollars, is cancelled.

In May, the Department of State leaked that negotiations with Russia could lead to a quota agreement that would give Russia the ability to sign eight new contracts for geostationary launches from then to 2000. A similar agreement had been in effect with China since September 1988. On June 17, in a speech on space policy, Bill Clinton mentioned cooperation with Russia on the Space station program for the first time. However, the Russians still had not amended their contract with India.

In the days that followed, the US president and his vice president, Al Gore, personally wrote to Boris Yeltsin and Viktor Chernomyrdin. The message was clear and incontrovertible: if they did not act by mid-July, the sanctions would be extended. Secretary of State Warren Christopher had already warned the Minister of Foreign Affairs, Andrey Kozyrev: this time, they would involve entire sectors of the Russian space industry, putting an end to cooperation and the agreements signed with partners in the United States. These threats were enough to convince Koptev, Kiselev, and Semenov, who saw Glavkosmos as an obstacle to their interests that had to be removed. Koptev also received the support of Kozyrev and Chernomyrdin, which helped him convince the head of the Kremlin. Yeltsin then entrusted the renegotiation of the Indian contract to Koptev. It would henceforth only concern the delivery of stages ready to be launched, with no transfer of technology to India. On July 16, a Russian delegation signed a protocol in Washington, confirming this agreement and Russia's acceptance of the MTCR clauses.

8.7. Detour through France

The agreement allowing the Proton to enter the commercial market was finally signed on September 2 by Al Gore and Viktor Chernomyrdin. It specified that only launch contracts for a total of eight geostationary satellites could be signed until December 31, 2000, not counting the contract already signed with Inmarsat. Moreover, to avoid destabilizing the market, it was proposed by Russia that their launch services would have to be at prices similar to those of their Western competitors. Regarding international competition, Russian launchers could not be proposed at a discounted fee more than 7.5% below the lowest offer of a Western competitor. Finally, Russia could not sign more than two contracts over a 12-month period. This agreement could be revised after a mid-term reexamination of the market in 1997. At a press conference, Yuri Koptev allowed himself a bitter comment: "it's a bit like 'allowing' a champion to enter the ring against a novice boxer. I regret that we must enter the market with an agreement on quotas, but we have no other choice".

Another man was bitter when the signing of this agreement was announced: Arianespace CEO Charles Bigot. For more than a year, he had been concerned about the United States' maneuvers to pit Ariane against Chinese and Russian launchers to bar it from the international market, whereas unlike its competitors in the United States, it had no captive institutional market significant enough to survive. On October 1, 1992, at a press conference, he wasted no time in denouncing the role played by Comsat, US signatory of Intelsat and Inmarsat, in these maneuvers and the absence of European desire to counter it, although it only possessed 20% of the organization's shares. "The power of Comsat is the agreed-upon weakness of its adversaries". He rose against "a shameless campaign between the two other primary signatories of Inmarsat, which are Great Britain (13%) and Norway (12%) to buy the Proton. With 46% of the shares, however, Europe should have had no difficulty making its voice heard". He even went so far as to recall that half of the Inmarsat-3 satellites were manufactured in Europe (the payload was produced by Matra Marconi Space UK[13]) and that, therefore, Europe could also prevent its export to Russia.

This offensive strategy was not to the liking of Michel Delaye, who headed the Space & Defense branch of Aérospatiale, the primary manufacturer of the Ariane launch system. For this École Polytechnique graduate, coming from the field of ballistic missiles and already having made contacts in Russia for several years, this goes against history. Therefore, in fall 1992, he organized a dinner with Claude Goumy, CEO of Matra Marconi Space, and Jean Sollier, CEO of the SEP[14], to bring up Ariane's situation faced with the coming entry into the market of the former USSR's launchers, particularly the Proton. The agreement that was made at that time with Lockheed posed no real problem, for the US manufacturer was then absent from the launcher market beyond its Russian initiative. An alliance with Arianespace thus had to be possible to avoid the emergence of a potentially uncontrolled competitor, with strong growth potential and that could, in the long term, cause a great prejudice to the European launcher industry. The three men who, at that time, represented the essence of Arianespace's French industrial shareholders, made a great effort to convince Charles Bigot to give in to Russia to negotiate with Khrunichev's executives.

One of the last French space pioneers who was still at the helm of one of the largest players in the sector at the start of the 1990s, Charles Bigot had greatly contributed to the creation of the European launcher industry. Along with his predecessor Frédéric

13 A group born out of the merger between the French Matra Espace and the British Marconi Space in 1990. It would absorb British Aerospace in 1993 before merging with DASA in 2000 to form Astrium.

14 An Ariane propulsion provider absorbed by Snecma in 1997.

d'Allest, he was one of the principal architects of Ariane's success on the international market and, as such, he made it his priority to protect the European launcher and his industrial subsidiary at any cost. In fact, he too assessed the Russian threat and concluded that Ariane's share of the market would be the first to suffer from an uncontrolled ramp up of Proton. In his eyes, the United States was worried about seeing "their launcher industry run out of steam" and to maintain it, "they are seeking to drown their adversaries".

Charles Bigot thus made a series of trips to Moscow to meet high ranking executives, including Yuri Koptev and Anatoli Kiselev. First and foremost, this contact seemed positive and in a few months, the bases of commercial cooperation were in place. Technical cooperation on common upper parts for both Proton and Ariane was even mentioned and the statutes of a joint venture, called Ariane Proton International, were drafted. For a while, the official signature of the agreement was even planned for June 1993 at the Paris Air Show, but in reality, it would never take place. The reason officially given by the Russian partners for abandoning negotiations dealt with the limited number of launchers reserved for the Proton during the first years. According to the initial agreement, there would have only been one per year.

One per year from 1993 to 2000 made eight, the exact number granted by the quota agreement signed with the United States. Charles Bigot would later attribute this failure to his "naivety" faced with the United States' aggression. As for Anatoli Kiselev, he believes today that the French's idea was to "make Khrunichev a 'younger brother' of Arianespace and not a true partner". Furthermore, he notes, with more than 70% of satellites on the market being products of the United States, in order to succeed, it would have been better to ally with the United States than with Europe.

This was felt as a slap in the face by the French. At nearly the same time, the European Space Agency was selecting a new scientific mission in the scope of its Horizon 2000 program. The Integral (International Gamma Ray Astrophysics Laboratory) space observatory had to scrutinize the hottest points in the universe in X-ray and gamma ray spectrums. In exchange for observation time, NASA participated in the program by offering its Deep Space Network tracking system and the IKI[15] even participated, offering a launch on Proton. The general director of CNES, Jean-Daniel Lévi, then announced that CNES would veto this launch, considering that "all the satellites of the European agencies had to be put into orbit

15 "Institut Kosmicheskikh Issledovaniy" – Space Research Institute of the Russian Academy of Sciences.

by European launchers". This threat was not followed by any actual consequence[16], but it illustrated the feeling in Europe at the time.

8.8. First steps on the market

In the United States, as well, this quota agreement aroused mixed opinions. In October, during an international conference organized by Inmarsat on "mobile communication via satellite", Michael R. Wash, president of General Dynamics Commercial Launch Systems (CLS), which commercialized the Atlas launcher, interpreted the agreement in his own way. Notably, he believed that Russian-manufactured geostationary satellites that were meant to be used by an operator outside the former USSR also had to be taken into account. Yet, three Express satellites to be launched starting in 1994 had to be leased by Intelsat, whereas a Gorizont and four more Express satellites were planned for the US operator Rimsat Ltd., which used orbital slots booked by the island kingdom of Tonga. If this was added to the five satellites from the Russian-Canadian SovCanStar project (see Chapter 7), for Michael Wash, the quotas were already exceeded with 13 satellites planned on Proton.

This biased reading of the agreement did not stop LKEI from signing its first agreement since September 20 with the satellite manufacturer Space Systems/Loral, for a firm launch on Proton starting at the end of 1995 and four options until 1998[17]. This was only the first. Since then, satellite manufacturers and large operators would approach LKEI and include the Proton in their calls for tenders for launch services. In early 1994, Anatoli Kiselev would announce that he had nine launches worth a total amount of 600 million dollars on his order book, without giving further information about who his clients were. It is very likely that these were just the Inmarsat launch, three Iridium launches and the five Loral launches again. However, in March 1994, Charles Lloyd announced that he had signed a contract with the Société Européenne des Satellites (SES) for the launch of its Astra-1F television satellite in 1996, coupled with four options. "This contract is very important because

16 Primarily due to the excessive cost that an 870-million franc Ariane-5 launch would have represented for a program whose budget was limited to 2 billion francs, but also because Ariane-5, in its definition at that time, did not allow the 72 h, 115,000 km orbit planned for the mission to be reached. Only a 24 h, 68,000 km orbit would have been possible, dramatically reducing the satellite's observation time. The satellite could only be operational beyond 40,000 km, far from the disturbances caused by the radiation belts surrounding the Earth.

17 This contract was for the launch of the Tempo-1 television satellite planned for 1996, but which would be postponed until 2002 due to financing and licensing issues.

we are fighting Arianespace with a European client", he stated with great pleasure. From its Luxemburg headquarters at Betzdorf Castle, SES denied having made its choice and stated that it was still negotiating with several potential providers[18]. This firm contract – amounting to 49 million dollars – would not officially be confirmed until February 1995, SES explaining its choice by the need to have an "alternative source" for its launches. In December 1994, PanAmSat, a US operator competing with Intelsat, ordered a launch in late 1996 for its PAS-5 satellite for 47 million dollars. In March, it was the number one satellite manufacturer in the world, Hughes Space & Communications, that would decide to book an undisclosed number of launch slots on the Proton starting in 1997. In June, US operator Echostar ordered two back-up launches in late 1996 and early 1998 in case its previously ordered launches on Chinese launchers ran into difficulties[19].

These contracts would allow LKEI to invest 25 million dollars in the modernization of the Baikonur launch site in Kazakhstan to welcome Western clients. This would include an update to Western standards of installations for the preparation and fueling of satellites, with an uninterrupted power supply. Approximately 5 million dollars would be allotted to on-site communication systems. An effort would also be made to host client teams and to refurbish the runway of the Yubileniy ("Jubilee") airfield that had previously been used by the Buran space shuttle.

After being uncertain for a while after Kazakhstan's independence in April 1990, the situation of the Baikonur cosmodrome had to be brought up to norms. A presidential decree from Boris Yeltsin, dated October 24, 1994 had just placed the site under the joint control of the Ministry of Defense and the RKA. A rent agreement had also been signed on December 10 between Viktor Chernomyrdin and his Kazakh counterpart, Akezhan Kazhegeldin, for a 7,000 km^2 enclave (about half the size of Connecticut), including the cosmodrome and the adjacent town of Leninsk that would be placed under Russian federal control for 115 million dollars per year. The lease ran until 2015. This agreement was ratified on April 18 by Kazakh President Nursultan Nazarbayev, who was given extraordinary powers after

---

18 Until December 1994, SES was negotiating with Arianespace to launch Astra-1F at a promotional fee of approximately 40 million dollars on Ariane-5's second test flight, then planned for April 1996 (it would get pushed back to October before being postponed by a year after the failure of Ariane-5's first flight).

19 Trust in Chinese launchers was losing speed since, in January, the Apstar-2 satellite had been lost for unknown reasons during its launch by a Chinese CZ-2E. It seems that the satellite had been destroyed following the dislocation of the payload fairing, or that the shroud itself was blown away by the satellite's explosion. A similar accident took place in December 1992 with Optus B2 and a highly controversial investigation commission cleared both the launcher and the satellite's name.

the dissolution of the Kazakh parliament. Three days later, the Russian Duma ratified it too.

Figure 8.6. *A. Kiselev with D. Tellep and N. Augustine in June 1995 (source: Khrunichev Center)*

However, before LKEI could perform a single launch, its structure would undergo a brutal evolution, an ultimate consequence of the wave of mergers and acquisitions that would drastically reduce the number of players in the US military-industrial complex during the 1990s, itself a consequence of the contraction of the military markets. In the launcher sector, this started with the acquisition of General Dynamics Space Systems, which produced Atlas launchers and Centaur upper stages, by its rival Martin Marietta Corp., which produced Titan launchers. Martin Marietta, which had left the commercial launcher market upon retiring its Commercial Titan from the circuit in 1992 came back because of GD's subsidiary CLS. The transaction, amounting to 208.5 million dollars, was announced on December 23, 1993, but would not be effective until May 2, 1994. Four months later, on September 1, it was Lockheed Corp. and Martin Marietta Corp.'s turn to announce their engagement to create a giant boasting 22.5 billion dollars in revenue, 30% of which was in the space sector.

Figure 8.7. *Creation of ILS in Bourget in June 1995 (source: Khrunichev Center)*

Concretely, this merge, effective on March 15, 1995, would place two of the main launchers on the market under the same roof: Proton and Atlas. A single structure would therefore be implemented to commercialize the two launchers together, one backing up the other and vice versa. The creation of International Launch Services (ILS) was officially announced on June 10, 1995 at the Paris Air Show. For Vance Coffman, who was then head of the Space & Strategic Missiles sector of Lockheed Martin, ILS's goal would be to "conquer more than 50% of the market by 2000".

9

The Transatlantic Alliance

Thirty years after having been the Soviet rival of NASA's Saturn launchers, with the creation of ILS, the Proton became the ally of the Atlas, once the US rival to Korolev's Semyorka launchers. Since the R-7 was the first intercontinental missile developed in the "Eastern Bloc", the Atlas had started its career as the first intercontinental missile developed in the "free world". Designed for the US Air Force by Convair, a division of General Dynamics based in San Diego (California), it was the result of the MX-774 ballistic vector program initiated in 1945, abandoned in 1947, and then relaunched in 1951. Its main designer was Belgian engineer Karel J. Bossart. An immigrant who came to the United States in 1930, he was the creator of its "1 ½ stage" design. In fact, the Atlas was based on a single stage with a very low structural ratio thanks to "balloon tank" technology. The rigidity of propellant tanks is ensured by internal pressurization, which allows the thickness of the walls to be reduced and consequently also the dry mass. This stage is powered by three engines at liftoff, two of which – the so-called "booster engines" – are ejected after 150 s with their assembly and the launcher's lower skirt. The third engine – the so-called "sustainer engine" – ensures propulsion during the rest of the flight until the payload is released. This may be made up of a nuclear warhead, a manned capsule or an upper stage satellite composite.

The Atlas made its first flight on June 11, 1957, from Cape Canaveral. That same day, in Kazakhstan, the second launch of the Soviet R-7 took place. The two flights resulted in failures, after 23 s for the Atlas, 103.6 s for the R-7. The Atlas and the R-7 met with success for the first time during their third attempts, on August 21 for the Soviet Union and December 17 for the United States, i.e. 11 days after the Vanguard's spectacular failure. The developmental versions Atlas A, B and C made way for the operational Atlas D in 1959. It flew together with the E and F versions starting in 1960 and 1961. The deployment of missiles on operational sites would be spread out from February 1960 to December 1960 and their withdrawal from June 1964 to April 1965.

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

Like the R-7, the Atlas was not a missile with immediate launch capacity. Kerosene and liquid oxygen fueling did not allow a launch in fewer than 15 min from a half-buried, horizontal “casket” or 8 min from a silo with a launch pad on an elevator for a liftoff from the surface.

However, following in the footsteps of its Soviet counterpart, it proved to be a superb space launcher. Starting in 1959, an Able stage was added to the Atlas C and later to the Atlas D to send Pioneer lunar probes, and the Atlas D was adapted to send the first US astronauts into orbit with manned capsules as part of the Mercury program. This variant would receive the designation LV-3B. The LV-3A would be equipped with an Agena upper stage – developed by Lockheed – for a wide variety of missions, primarily the launch of spy satellites, but also to send Ranger or Lunar Orbiter lunar probes and Mariner interplanetary probes. Starting in 1962, the introduction of the first cryogenic stage in history, the Centaur, also designed by Karel Bossart and manufactured by Convair, would give rise to the Atlas Centaur (LV-3C). This version carried Surveyor probes that would gently land on the Moon starting in 1966, before becoming the reference launcher to carry large geostationary telecommunications satellites in the 1970s, because of the Atlas stage being stretched by 1.3 m starting in 1967 (SLV-3C), as well as remotorization and the integration of the Atlas’ avionics on the Centaur in 1972 (SLV-3D), which allowed the combination of two independent stages to be turned into a modern integrated launcher capable of placing 2,040 kg into geostationary transfer orbit with a 28º inclination relative to the equator. It was to compete with this specific version that the Europeans gave their Ariane 1 launcher a carrying capacity of 1,700 kg to a geostationary transfer orbit with a 6º inclination in 1973. In 17 flights of the SLV-3C version and 32 of the SLV-3D (2 failures for each), the Atlas Centaur would launch the first probe to be placed in orbit around Mars (Mariner 9 in 1971) and the first two probes to fly over Jupiter (Pioneer 10 and 11 in 1972 and 1973, respectively), but also five astronomical observatories from NASA (two OAO and three HEAO) and, most importantly, 20 generation 4, 4A and 5 Intelsat satellites, four Comstar satellites and five Fleetsatcom from the US Navy between 1971 and 1983.

The beginning of operation of the Space Shuttle that was initially meant to replace all consumer launchers led to the end of chain production. However, the shuttle was far from keeping its promises, and after the Challenger catastrophe in 1986, it was banned from the commercial market. General Dynamics relaunched production of the Atlas G Centaur in June 1987 and directly began its commercialization – in compliance with the 1984 Commercial Space Launch Act – under the name Atlas 1 (2,335 kg in geostationary transfer orbit). Improved versions were quickly introduced: Atlas 2 (2,812 kg) for the US Air Force, Atlas 2A

(3,045 kg) for the commercial market and Atlas 2AS (3,700 kg) with solid boosters introduced for the first time.

Figure 9.1. *Atlas-2AS (source: Lockheed Martin)*

9.1. Reduced quotas

When the creation of ILS was confirmed, only the Atlas 2A and 2AS versions were still available. The best capacity offered by the Atlas was only 75% that of the Proton, but this did not stop ILS from announcing a "mutual backup" policy to its clients: a contract signed with Atlas capable of being performed on Proton or vice versa, in case of the unavailability of the initially chosen launcher. This notion was rather theoretical at first, because even if there was no doubt that all satellites allocated to the Atlas could be launched by the Proton, the latter could carry satellites weighing more than four metric tons which Atlas was not yet powerful enough for. However, by blurring the boundary between launches allocated to the Proton and the Atlas, ILS gave itself the chance to circumvent the quota policy that still only allocated Proton eight launches until 2000 (excluding Inmarsat 3-F2), three of which had already been the object of firm contracts (Astra 1F, Telstar 5, PAS-5) signed by LKEI.

However, the geostationary launch market seemed to be in an expansionary phase. Several phenomena were at work. On the one hand, the appearance of the digital television would require simultaneous broadcasting to analog and digital channels (“simulcast”), while users were switching from older generation television sets to new ones. The result was that even if the initial goal of the digital technology was to reduce bandwidth consumption, at first, it translated into an increase in the demand in bandwidth. Moreover, as digital compression allowed reduced broadcasting costs, the number of channels would literally explode. On the other hand, the Internet, limited to confidential use for 20 years, had opened to the public in 1993 and initiated vertiginous growth that would arouse operators’ appetites. These operators would rush to present high-speed satellite projects using the K_a band (20–30 GHz) and to obtain an operating permit from the Federal Communications Commission (FCC).

Figure 9.2. *Yuri Koptev, Anatoli Kiselev and Al Gore at Khrunichev in 1995 (source: Khrunichev Center)*

In September 1995, when the World Wide Web had only been in the public domain for two years and still had fewer than 20,000 sites, requests for permits had already been submitted by Hughes Communications for its Spaceway project (15 geostationary satellites), AT&T for VoiceSpan (12 satellites), Lockheed Martin Astro Space for AstroLink (nine satellites), GE Americom (nine satellites), Motorola for Millenium (four satellites), Loral Corp. for Cyberstar (three satellites), Echostar Communications (two satellites), NetSat 28 (one satellite), not to mention Teledesic for its astounding constellation of 840 low-orbit satellites. Ka Star Communications, Morningstar satellite, VisionStar, Orion Network Systems, PanAmSat and TRW were also in the running.

Faced with this increase in launch demands, Washington accepted a slight ease up of the bridle on the Proton by loosening the quota policy 1 year earlier than planned. On January 31, 1996, a new agreement was signed between Al Gore and Viktor Chernomyrdin henceforth authorizing Russian launchers to place up to 16 satellites into geostationary orbit by December 31, 2000. This number could even increase to 20 if the commercial market ever exceeded the 80 satellites to be launched between 1996 and 2000.

This was a new victory for the Proton but, to finalize this, it needed to pass its "final exam" by successfully performing its first commercial flight in the best conditions possible so as to definitively ascertain the trust of operators and their insurers.

9.2. Baptism of fire

The first satellite to fly on the Proton would be Astra 1F, a direct television satellite from the Société Européenne des Satellites (SES), a private European operator based in Luxemburg. This was an HS-601 bus from Hughes Space & Communications, the most popular model from the largest satellite manufacturer of the time (73 units launched from 1992 to 2010). On February 12, it left Hughes' workshops in El Segundo, a neighborhood in Los Angeles, to board a Boeing 747 cargo plane destined for Baikonur, where it arrived on the February 14. For the first time, a satellite manufactured in the United States would be prepared for launch at the Kazakh cosmodrome, in the new installations modernized by ILS and used jointly with the Russian Space Forces. Initially planned for March 1, the launch was moved to March 28. Placement into orbit and the first operations were covered by an insurance evaluated at approximately 200 million ECU (258 million dollars), established at 18.4%.

Unfortunately, the satellite had barely left its container when operations had to be interrupted. On February 19, a Proton K launcher, equipped with a Block-DM-2 from RKK Energiya as a fourth stage, could not place its payload – the military telecommunications satellite Raduga 33 – into geostationary orbit. The three stages of the Proton managed to place the Block-DM-2 and the satellite into parking orbit at 185 km with a 51.6º inclination and an initial ignition of the Block-DM-2 transferred the composite to an elliptical orbit (231.4 × 36,509.7 km) at a 48.33º inclination. However, at its apogee, it could not reignite to circularize the orbit. Even worse, the stage exploded after separating its payload, creating more than 200 pieces of debris.

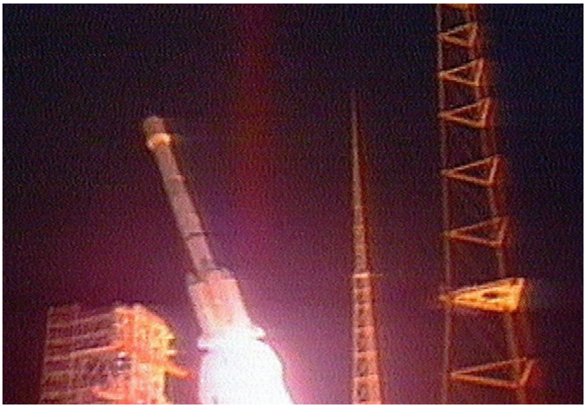


Figure 9.3. *Failure of Intelsat-708 on 2/14/1996 (source: Wikipedia)*

This failure, the first for the Block-DM-2 since 1988, could not have come at a worse time. The Proton absolutely had to demonstrate its reliability, even more so as one of its most dangerous adversaries, the Chinese CZ-3B launcher, had just suffered a terrible failure during its inaugural flight on February 14 at the Xichang site, with the Intelsat 708 satellite onboard. Before even having passed the launch tower, the vehicle had nosed up and left to crash into a neighboring hill, destroying a village that had not been evacuated despite its dangerous proximity to the launch pad. Officially, only six people died and 57 were injured. Unofficially, it was much worse. The credibility of launchers coming from planned economies could quickly come into question, so the Proton needed to make its difference fast.

The cause of the Block-DM-2's failure was quickly attributed by RKK Energiya to a lack of pressure in the 11D58M engine's gas generator, which prevented reignition. This lack of pressure was caused by a leak in the hypergolic start circuit near the solenoid valve controlling feed from the gas generator and engine injection. For Yuri Semenov, president of Energiya, the problem was not a result of the stage's design, which had proven reliable 96.7% of the time since its introduction in 1974, but rather was a question of procedure[1]. In his opinion, this failure would not lead to any significant delay. The Astra 1F launch campaign was therefore pursued with an aim to liftoff on the night of April 8/9. Incidentally, this postponement was not officially due to the Proton's failure, but was the result of leak in one of the satellite's helium tanks.

1 A break wire was improperly installed on a nut fixing the propellant line's joint, which then came loose due to vibrations. On the following flights, a break wire with a greater diameter would be used and it would be doubled.

Figure 9.4. *Vance Coffman, Anatoli Kiselev and Romain Bausch, head of SES (source: all rights reserved)*

For this baptism of fire, ILS and particularly SES did not skimp on means. One hundred journalists were invited to Moscow, where a large reception was organized at the Luxemburgish Embassy. The management of Lockheed Martin and Hughes came in private jets. Even the Grand Duke of Luxemburg, Jean, made the trip. Before the launch, visits were organized to Khrunichev and Energiya, which had opened its private museum for the occasion.

Since the liftoff was planned for 3:09 AM (Moscow time) and there was no quality lodging in the town of Baikonur[2] to host everyone, a Transaero Airlines charter flight was organized to make round trips over night. It landed at the very heart of the cosmodrome, on the Yubileny Air Field, where the Buran spacecraft had landed too in 1988 after its first and only flight. Four packed buses took visitors to launch pad no. 81/23, 30 km away, on bumpy roads across the steppe. The observation site was located barely 2 km from the launcher, which had been released freed from its service tower and stood on the launch pad, brightly illuminated. Its sides were decorated with a Russian flag, a US flag, and a Luxemburgish flag. As the temperature was –5 ºC, a tent had been set up with a loudspeaker reporting operations in Russian.

2 This secret town, which was later named Zarya in 1955, Leninskiy in 1958 and Leninsk since 1966, came to be renamed Baikonur the previous December 20, although a town with the same name already existed 250 km away.

Figure 9.5. *State Commission for the Astra-1F launch (source: Khrunichev Center)*

To perform this launch, the pad had to be modified in order to install computers and network connections required by the satellite manufacturer. In order to shield them from the hardships of the climate and the effects of liftoff, a concrete protective structure was built around cable encasements and ran across the site. Since this era, it has born the nickname “Astra wall”.

Figure 9.6. *Astra-1F launch on April 9, 1996 (source: Khrunichev Center)*

In the absence of a countdown, which they had become accustomed to at US or European launches, the guests were surprised when the launcher base lit up. Some, hidden in the tent to escape the cold, did not even realize that the launcher was lifting off. It was 11:09 pm GMT on April 8, or 5:09 am in Baikonur on April 9. The first commercial Proton lifted off in the night and turned eastward. The sky was clear and the observers witnessed the ignition of the second stage, then the third, and they could even follow the second stage's reentry into the atmosphere. The third stage placed the Block-DM-2 (in commercial "DM3" configuration with a special adapter for the HS-601 platform) and Astra-1F into parking orbit (213 × 219 km, 51.6º). An initial ignition of the Block-DM-2 transferred the composite into orbit reaching a geostationary altitude with a 48º inclination. When the composite reached its apogee, the second ignition played out perfectly, reducing the inclination and raising up the perigee. After 6 h and 41 min of flight, Astra-1F was separated on a geostationary transfer orbit with a very high perigee (11,970 × 35,936 km, 6.95º) as planned. It was a total success[3].

SES was satisfied with the result, particularly as the very high perigee of the transfer orbit would allow money to be saved on propellant for the satellite, whose lifetime had been reevaluated at 23 years. Starting in June, the Luxemburgish operator exercised one of its options from its contract with ILS to order a Proton launcher for its Astra-1G satellite.

In the weeks preceding the launch, ILS had already improved its order list with the confirmation of one of its reservations taken by Hughes to launch the Chinese Asiasat-3 satellite on Proton in 1997[4] and with the Japanese JCSAT-4 satellite on Atlas-2AS. The Japanese JSAT-4 operator was the first to sign a contract with a backup clause on Proton. Parallel to this, ILS received new orders on Atlas-2AS for two Intelsat-8A satellites initially planned to liftoff from Chinese launchers, but these were chained to the ground after the February 14 failure. On May 30, the United States' Echostar Corp. – another former client of the Chinese launchers – signed the very first mixed Atlas/Proton contract with ILS to put the Echostar-3 and Echostar-4 into orbit. The first was planned on Atlas-2AS in late 1997 and the second on Proton in early 1998. One year after its creation, ILS announced that the combined order lists of the Atlas and the Proton exceeded 2.5 billion dollars with 23

3 In 2013, it would be revealed that the SES had sent its own experts to Khrunichev as part of the US technical team to achieve an independent view of procedures and the material used. Armed with this information, the SES could discard the first launcher that had been proposed to it. This "failed" launcher would later have been used for the Asiasat 3 launch, which would result in failure.

4 Although it was announced after the failure of the CZ-3B, Asiasat's decision to choose the Proton over a Chinese launcher had taken place before this.

launches on Atlas and 16 on Proton. At the same time, Arianespace's order list included 47 satellites to be launched. The goal to surpass the Europeans before 2000 started to seem possible, particularly after the spectacular failure of the new Ariane-5 launcher during its inaugural flight on June 4, 1996.

9.3. A "Russified" Atlas

Beyond the difference in capacity between the Atlas and the Proton, the signing of this series of contracts demonstrated another major imbalance between the two launchers, which would make managing the "mutual backup" policy difficult. While the Atlas contracts were signed for sums in the order of 90 million dollars, the Proton launches were commercialized for between 50 and 60 million dollars. If a Proton client had to lift off on top of an Atlas, who would be responsible for the override?

Among the planned solutions to rebalance ILS's offer, Lockheed Martin prepared a new evolution of the Atlas launcher designed to reduce launch costs by 25% at nearly the same capacity as Atlas-2AS, but without using solid boosters. The project – valued at 30 million dollars – had been studied since 1994, but was made public for the first time in September 1995 under the name Atlas-2AR (reengined). It primarily involved replacing Rocketdyne's MA-5A thrust pack (made up of an RS-56SA engine and two extendable RS-27 booster engine) with a new, more powerful propulsion. The Atlas-2AR was to be available in September 1998 and would also serve as the basis for the future family of expendable launchers that Lockheed Martin had been studying in the framework of the Evolved Expendable Launch Vehicles (EELV) call for tender from the US Air Force[5]. Lockheed Martin was among the four manufacturers preselected on August 24, 1995 alongside Alliant Techsystems, Boeing and McDonnell Douglas for 15-month study contracts.

At first, three propulsion designs were envisioned: Rocketdyne's MA-5D (an improved version of the MA-5A), NPO Energomash's RD-180 (a two-chamber version of the four-chamber RD-171 of the Zenit's first stage) and a pair of KNPO Trud's NK-33 (renamed AOOT SNTK Dvigateli NK in 1994, then SNTKP Kuznetsov in 1996),

---

5 The EELV program was launched in November 1994 by the Pentagon in the wake of a report on the modernization of its space activities presented in May 1994 by General Thomas S. Moorman. It aimed to develop a new family of expendable launchers that were to bring about 25–50% cost reductions in relation to the Delta, Atlas, and Titan launchers. Congress financed it for the first time in September 1994. It followed the ALS (Advanced Launch System) program in 1987–1989 and the NLS (National Launch System) program in 1991–1993, which never made it past the study stage.

initially developed for the Soviet N1 lunar launcher and commercialized by Aerojet under the label AJ26. Rocketdyne quickly left the competition because its MA-5D could not be ready without delays. The RD-180 was finally selected in January 1996.

In October 1992, NPO Energomash was the first former USSR manufacturer to sign an exclusive commercial partnership agreement with a counterpart in the United States – Pratt & Whitney Space Propulsion Operations (SPO), a subsidiary of United Technologies Corp. (UTC). Pratt & Whitney thus became the exclusive distributor of its engines outside the former USSR, and it was through its intervention that Lockheed Martin would be provided with RD-180. A production line could even be installed at Pratt & Whitney in West Palm Beach in Florida to manufacture engines meant for the EELV. In Moscow, this was seen in a very different light. On January 3, 1996, the Russian Federation's Committee of State on Defense-Industrial Questions (GosKomOboronProm) officially opposed granting a permit for the RD-180 to the US engine manufacturer. For President Viktor Glukhikh, this transfer of technology "would cause irreparable damage to Russia's defensive capacities". With its specific impulse of 311 s and its variable thrust, the RD-180 was actually one of the best performing kerosene and liquid oxygen engines ever developed. At the same time, the Ministry of Defense refused to grant an export permit to the first 21 NK-33 engines ordered by Aerojet, apparently to favor the RD-180 in the competition, because its production would bring industrial activity to Russia, while the NK-33 had been manufactured in the 1970s and kept in storage since that time. Moreover, recalls Boris Katorgin, General Director of Energomash: "the development of the RD-180 will not be paid by Russia, but it will be available for the Russian space program". The export of the RD-180 to the United States was finally approved in April. Engines manufactured in Russia would equip the first 18 Atlas-2AR. Engines manufactured under license in Florida had to be available starting with the 19th flight. This production on US soil was indispensable if Lockheed Martin hoped to be competitive for the EELV, because due to their strategic importance, future military launchers in the United States would have to be produced completely on US soil[6]. The Atlas-2AR's preliminary design review took place in May and Space Systems/Loral made a firm order for two missions on the new launcher starting the following month. In November, the RD-180 performed its first bench tests in Khimki in Russia, and on December 20, Lockheed Martin and McDonnell Douglas were selected for a complementary 17-month study phase to finalize the design of their launchers that were candidates for the EELV program. In June 1998, one of the two would be

6 In the end, the Atlas-5 would fly with RD-180 engines manufactured in Russia, structural elements made of composite elements made in Spain and, for some versions, a payload fairing designed and manufactured in Switzerland, derived from Ariane-5's fairing.

selected for a 1.6 billion dollar development phase. NPO Energomash and Pratt & Whitney created a joint venture in January 1997, RD Amross LLC, in order to produce and commercialize the RD-180 together. A first prototype of the engine was delivered to Lockheed Martin Astronautics in Denver, Colorado for compatibility tests with the first stage of the Atlas-2AR, whose performance in geostationary transfer had been reevaluated at 4,045 kg. More powerful variants were planned, like the Atlas-2ARS with a set of Castor-4A solid propellant motors as strap-on boosters (4,260 kg in geostationary transfer), or versions with an extended first stage (4,318 kg, even 4,545 kg with solid boosters). Such evolutions would bring the Atlas' capacity near to that of the Proton.

On April 23, the first flight model for the RD-180 was destroyed during a bench test in Khimki. A mixture with too much kerosene caused it to overheat during a voluntarily downgraded ignition sequence. The intake valves would be modified for the following models. On May 20, the failure of an RD-171 engine, from which it was derived, caused a Zenit launcher to fail in Baikonur. The engine, which had been stored for 7 years, was said to have suffered from the obstruction of one of its liquid oxygen feed lines. The engine's design was not questioned. During the following Paris Air Show in June 1997, Lockheed Martin had enough trust to place an order with RD Amross for 101 RD-180 engines.

9.4. Discrete success and a spectacular failure

Figure 9.7. *Inmarsat-3F2 on Proton (source: Khrunichev Center)*

During this time, the Proton had pursued its launches and signed one contract after another. Inmarsat-3-F2 was placed directly into geostationary orbit on September 6, 1996. The 65.7 million dollar insurance that covered the launch and the first operations had been contracted with a 16.5% premium rate. The operator PT Asia Cellular Satellite System (ACeS) signed the launch of its mobile telephony satellite Garuda-1 in 1998 and Hughes ordered three launches for the ICO mobile constellation.

Figure 9.8. *Commission of State for Inmarsat-3F2: Semenov–Kiselev–Shumilin (source: Khrunichev Center)*

On November 16 at 8:40 pm GMT, a Proton-K was launched with an international load, but this had nothing to do with ILS. It was the last of the large interplanetary probes whose development had started during the Soviet era. This 6,852 kg monster, built by NPO Lavochkin, was the most ambitious of all the Martian missions ever attempted. Initially planned for the 1994 Martian launch window, it had to be postponed due to difficulties financing the space program during the collapse of the USSR and the mission could only be saved because of significant international investment. France, Germany, and the ESA thus provided for 200 million dollars in equipment, services and direct financial support so that this "Mars-96" probe would fly[7]. Derived from the Phobos probes, the orbiter included – beyond Russian scientific instrumentation – an important scientific payload from Europe with no less than six French instruments, two German, one British, one Irish, one Swedish and one from the ESA. Two small autonomous landers would be placed on the surface of the red planet, each including four French instruments, one German, one Finnish and one from NASA. Moreover, two penetrators would be

7 If it succeeded, the probe (objet M1 no. 520) would have been renamed Mars 8. A large part of the orbiter's European payload, reconstituted from spare parts, eventually reached orbit around Mars on Christmas Eve 2003 onboard the European Mars Express probe.

stuck in the soil. Their payload had been developed in cooperation with Russia, Germany and Great Britain, with Czech, Bulgarian, Japanese and Finnish contributions. In total, besides Russia and the ESA, 18 countries were involved in the mission.

Once again, the three-stage Proton functioned perfectly and an initial ignition of the Block-D-2 upper stage placed the probe (11S824F) into parking orbit (148 × 158 km, 51.5º). A second, 8-min ignition had to transfer the probe to a highly elliptical orbit, reaching 314,000 km – nearly the altitude of the Moon – but it would take place out of visibility from the tracking stations. Due to the limited budget, the RKA had been unable to deploy tracking ships in the Pacific. At the planned time to regain contact, the probe was not at the rendezvous point. The ignition apparently had not taken place or it had only lasted a few seconds. Controlled by its internal clock, the probe had been separated from the launcher 66 min after liftoff and had ignited its own thruster for 3 min, placing itself on a trajectory reaching an altitude of 1,500 km before reentering the atmosphere over the border between Peru and Bolivia, right in the middle of the Atacama Desert. The Block-D-2, which remained in parking orbit, would disintegrate 25 h later, 560 km southeast of Easter Island. In the absence of telemetry, the real cause of this failure would never be fully identified. The official investigation commission would submit a report with no conclusion after 2 months of fruitless investigations.

This spectacular and broadly mediatized failure grounded the Proton for 6 months. Flights did not resume until May 24, 1997 when the US telecommunications satellite Telstar-5 was placed in orbit on behalf of Loral. The first cluster of Iridium mobile telephony satellites followed less than 1 month later on June 18.

Contracts for Proton launches also took off again. Options were raised in May for the launches of Astra-2A and Echostar-4. With a mix of electrical and chemical propulsion, Astra-2A could take full benefit from the high-perigee injection provided by the Proton but inaccessible to Ariane-4. At the same time, Lockheed Martin associated with the Russian operator Intersputnik to create a new international operator based in London: Lockheed Martin Intersputnik (LMI). This new entity's first satellite would be produced in Lockheed Martin's brand new installations in Sunnyvale where the manufacturer had reassembled teams formerly spread across Lockheed and Martin Marietta. The construction of two generic satellites, with no allocated client, had been launched in late 1995 to qualify the new lines. The first of these would become LMI-1 and would, of course, be launched with Proton in 1998. The second satellite would follow in 1999 and two more in 2000[8].

9.5. Keeping pace with Ariane

Figure 9.9. *Charles H. Lloyd (source: all rights reserved)*

Since the creation of ILS, Charles H. Lloyd had remained in charge of Russian activities as the president of ILS's Proton Division in the continuity of his position as the CEO of LKEI. At the same time, the Atlas division returned to Michael R. Wash, CEO of Lockheed Martin Commercial Launch Services. Both were placed under the authority of James McAnally, head of Lockheed Martin Astronautics and ILS. After his retirement in January 1997, it was Charles Lloyd who succeeded him as the head of ILS. During the 1997 Paris Air Show, i.e. 2 years after the creation of the commercial alliance of the Proton and the Atlas, he was proud to announce that one of the goals set in 1995 had been achieved: the US–Russian alliance was keeping pace with Arianespace, the market leader for 10 years. While the European company had an order list with 44 firm contracts, ILS announced 49. Beyond the effects of this announcement, the reality was a bit subtler. Of the 44 contracts garnered by Arianespace, 38 came from the open commercial market. Only six government payloads constituted the European launcher's captive market. ILS's order list, on the other hand, only numbered 34 commercial payloads (14 on Atlas, 20 on Proton) and

8 Intersputnik had initially planned to associate with the French manufacturer Aérospatiale Satellites, but was forced to withdraw due to the latter's inability to invest in a joint venture. LMI-1 would be launched on September 27, 1999 on Proton, but none of the following satellites would be built. LMI and its satellite had been resold in September 2006 by Asia Broadcast Satellite from Hong-Kong. LMI-1 was renamed ABS-1.

15 US government payloads (all on Atlas). Moreover, among the so-called "commercial" contracts, seven came from Lockheed Martin or its subsidiaries (one on Atlas, six on Proton). The other large manufacturers (Hughes, Loral) and operators (Eutelsat, Intelsat, SES) chose to mix their orders between the providers. The fact remains that in that year in early summer, ILS had a workload management schedule comparable to that of Arianespace and the Proton was its primary launcher for commercial missions.

That Paris Air Show was also the occasion for ILS to officially launch the commercialization of the modernized version of the Proton, the Proton-M, whose development had begun in 1992. It would be given a more compact and more maneuverable upper stage, the Breeze-M, an evolution of the Breeze-K that had already been flying on Rockot since 1994. Planned to be available starting in late 1998, the combination Proton-M-Breeze-M would be capable of placing 5.5 tons into geostationary transfer orbit, i.e. 500 kg more than the most powerful version of Ariane-4. If the calendar was respected, the Proton-M would arrive at the perfect time to compete with the new Ariane-5, as soon as it was qualified for commercial flights.

A second launch complex in Baikonur would, furthermore, be brought to the Western standard and be available in early 1998, while a second preparation room for commercial satellite payloads would be available starting in fall 1997 for ILS clients.

Figure 9.10. *ILS meeting in 1996 (Kiselev–McAnally) (source: Khrunichev Center)*

However, it was not all a bed of roses in ILS-client relations. On June 23, 1997, Hughes Space & Communications International, the main satellite manufacturer of the time, filed a complaint with the Los Angeles County Superior Court against Lockheed Martin Corp., Lockheed Martin Commercial Space and ILS, for a "breach of contract, dishonest commercial practices and devious interferences with a contract" and demanded 550 million dollars of indemnification. HSCI claimed to have signed a launch service agreement (LSA) with LKEI on November 11, 1994, through which it agreed to buy one Proton launch per year at a fixed price from 1997 to 2000. In return, LKEI agreed to guarantee Hughes access to the launches available on Proton until the end of 2001, at a fixed price, renegotiable beyond that date. Covered by an "absolute and unconditional" guarantee from Lockheed Commercial Space and Lockheed Missiles & Space, the agreement also foresaw LKE being able to propose launches on both Proton-K and Proton-M, but that Hughes had the possibility to expressly ask for a launch on the Proton-K version, already demonstrated in flight. According to Hughes, LKE had then refused to respond to Hughes' demands, arguing that it no longer had available timeslots on the Proton, while a schedule of eight launches per year had previously been announced. On May 9, 1996 – 1 month after the launch of Astra-1F – Hughes had asked ILS to sign a contract for all optional launches that would become available. The following August 2, ILS had proposed four timeslots, two in 1998 and two in 1999, but at a "much greater [price] than the one negotiated in the scope of the LSA and in much less favorable conditions". According to Hughes, the next September 17, ILS had confirmed its refusal to use the prices provided for in the LSA and asked for another several million dollars to perform modifications on the installations in Baikonur, while it had previously been promised that these updates would not be imposed upon the satellite's manufacturer. Finally, ILS had announced to Hughes its intention to retire the Proton-K from service and not to provide the Proton-M to Hughes in the scope of the LSA. Despite Hughes' repeated demands to stick to the initial conditions, the price asked by ILS for the four launches had exceeded a total of 80 million dollars. As a result, Hughes demanded 250 million dollars from Lockheed Martin and Lockheed Martin Commercial Space, ILS's guarantors, for a breach of contract and 300 million more from the three companies, believing that they had intentionally maneuvered to cause a "financial injustice" to the satellite manufacturer, which had become direct competition since the fusion of Lockheed and Martin Marietta's activities in early 1995. The issue would be resolved outside the courtroom.

ILS continued its launches, which were starting to become more numerous than those that Khrunichev continued to perform for the government. After a Kosmos-2345 anti-missile alert, PAS-5 was launched on August 28 for PanAmSat and followed by an Iridium cluster on September 14. On November 12, it was Russian satellite Kupon's turn, which would vainly attempt to establish the Bankir network to modernize banking exchanges in Russia. Astra-1G was a new success for SES on December 2. The first contract allocated to Proton-M was signed on November 5 to place the Intelsat-901 into orbit in mid-2000.

Figure 9.11. *Asiasat-3 launch on December 25, 1997 (source: ILS)*

This beautiful success did not last. During the night of Christmas – which the Russians would not celebrate for another 2 weeks, according to the Julian calendar – a Proton-K lifted off from Baikonur with a Block-DM-2M stage at its peak and the Asiasat-3 satellite, produced by Hughes Space & Communications on the foundation of its star HS-601 platform. The three-stage Proton provided total satisfaction and Energiya's stage performed its first ignition with no issues. Unfortunately, the second ignition only lasted one second instead of the expected 110. The 220 million dollars satellite was stranded in an orbit improper for any use: 203 × 26,008 km, 51.37º. As if this pitfall were not enough, Asiasat, which was counting on this satellite to compete with the one its rival APT Satellite had launched two months earlier, saw its stock value drop by 42%. The damage declared to the insurance companies exceeded 200 million dollars.

Asiasat-3 would, nevertheless, end up reaching geostationary orbit, but by a detour and with another name.

While the satellite's property was transferred to Hughes Global Services (HGS) with the promise to share all the profits that could be made if it provided possible to use it for another application, Edward Belbruno, a former JPL worker and great specialist in orbits, proposed a revolutionary idea to save the mission. By using the propellants from the satellite – provisionally renamed HGS-1 – it was impossible to circularize the orbit at the geosynchronous altitude and to reduce the 51º inclination. However, by using these propellants to place the satellite into translunar orbit, it became possible to perform gravitational assistance maneuvers, and to reduce the inclination, all that was needed was to increase the perigee. Two passes near the moon took place on May 13 and June 6, 1998 at a distance of 6,200 and 34,300 km, respectively. HGS-1 finally arrived in geosynchronous orbit with an 8.7º inclination a few days later. One of its solar panels – closed since the launch – refused to deploy after having undergone thermic cycles for which it had not been designed. Sold to the private US operator PanAmSat, the former Asiasat-3 would be used with the name PAS-22 until July 2002.

After having been grounded for 4 months, the Proton flew again in April 1998 to launch the third and final pair of Iridium satellites. Three other launches for ILS followed that year – Echostar-4, Astra-2A and PAS-8 – and on November 20, a three-stage Proton-K was launched from Baikonur with an exceptional payload: Zarya, the very first module of what would become the International Space Station (ISS). Built by Energiya and Khrunichev, under the contracting authority of Boeing on behalf of NASA, it marked the beginning of the most important space cooperation of all time.

The most powerful launcher in the Russian arsenal would only be used, however, on two occasions in the assembly of the ISS. The second time would be July 12, 2000, when a Proton-K launched the Zvezda module, built from the core module of what should have become the Mir-2 station. However, what would have the biggest impact for the outside world on this launcher was the fact that it served as an advertising support. The famous US restaurant chain Pizza Hut had paid a million dollars for its logo to be placed on the second stage, quite visible at 3 × 3 m. This was the second time that the side of the Proton had been used as advertising space after the launch of the Phobos-2 probe in 1988.

Officially, Pizza Hut's advertising aimed to provide funds for Khrunichev, but only 15% of the amount had been invested in the manufacturer. The rest went to the Russian publicity agency Space Marketing Inc. and Globus Space, which had organized the communication campaign around the event. The operation would never be renewed.

9.6. Energiya's game

When the USSR collapsed, Lockheed was not the only US manufacturer to become interested in Soviet technologies to get into the commercial launcher market. Boeing was also waiting in the wings. The aeronautic giant's activities in space transport were at that time limited to the maintenance of the NASA spacecraft's orbiters and the integration of Inertial Upper Stages designed to transfer heavy payloads from a low orbit to a geostationary orbit after a launch by the spacecraft or Titan-34D launchers, then Titan-4. However, Boeing's role as the project manager on the Freedom space station and later on the Western segment of the future ISS made it a privileged spokesperson of its Russian counterpart, NPO Energiya, then RKK Energiya.

Starting in March 1993, the discussions revolved around the possibilities offered by the technologies in Russia's possession. Its Energiya-M launcher project, derived from the technology of the giant Energiya launcher, would require an excessive investment and one that was also legally impossible to implement. Boeing, on the other hand, was greatly interested in the possibilities offered by the Block-DM stage, already available and qualified. An adaptation of this stage to the Zenit launcher had already been studied, as had the creation of a launch pad for it from the Cape York region in Australia so as to make the most of the Earth's rotation to improve performances towards geostationary orbit. Nevertheless, this project required the creation of a launch site in a subtropical area, with infrastructures for payload processing, a runway to receive cargo planes, and a deep-water port to land launcher elements. In 1989, the investment was estimated at 470 million dollars.

Another option had already been explored by the Soviets: launching from a platform at sea. KBTM, which had designed and created launch infrastructures for Soviet cosmodromes and thus studied concepts for platforms adapted to the Soyuz launchers and particularly for the Tsyklon, derived from the R-36 missile and whose implementation was highly automated. This simple application was found on the Zenit launcher, which was designed like a missile to perform launches with short notice in order to maintain an orbital infrastructure even in case of a space war with the United States. Starting in 1977, the commission of military-industrial affairs of the council of Soviet ministries had asked for a study to be performed on a maritime launch platform for the Zenit.

This solution was mentioned with representatives of Boeing, because it would allow them to make the most of an equatorial launch site without having to invest in a complete base on foreign soil while maintaining the totality of payload operations in the United States, which would greatly simplify export procedures.

Building a dedicated offshore platform would be long and costly but, luckily, it happened that one of the largest mobile drilling platforms ever built was available for such a conversion. Produced in 1983 at Sumitumo Heavy Industries' Oppama naval workshops in Yokosuka, Japan, the "Ocean Odyssey" was created for the ODECO (Ocean Drilling & Exploration Company). It weighed more than 36,500 tons and measured 120 m long and 69 m wide. Equipped with two submersible hulls, which allowed it to stabilize for drilling by filling its ballasts with more than 20,000 tons of water, it was propelled by 12 motors. On September 22, 1988, during prospective drilling in the North Sea, a natural gas explosion was set off by a fire that had ravaged its superstructures. Towed to the port at Dundee, it had spent the last 5 years rusting there, but the structure was intact, which took no time at all to draw the interest of Energiya's engineers. Boeing had studied the possibility of transforming a supertanker into a launch platform, but the idea was quickly abandoned.

Figure 9.12. *The Boeing-Kvaerner-Yuzhnoe, YuzhMash and Energiya Sea Launch (source: Sea Launch)*

On November 25, 1993, in Turku, Finland, representatives of Boeing, RKK Energiya, and Norwegian ship-owner Kvaerner, which owned the platform, agreed on its reconversion. The following February, KB Yuzhnoye and MZ Yuzhmash, general contractor and Zenit launcher manufacturer, respectively, joined the project. Equipped with Energiya's Block-DM stage and launched from the Odyssey platform anchored on the Equator in the middle of the Pacific Ocean, the Zenit-3 could put up to 5.9 tons into geostationary transfer orbit.

The partners signed a memorandum of understanding to create the company Sea Launch in Baikonur in May 1994. At that time, Energiya had already been partnering with Lockheed and Khrunichev in LKEI to commercialize the Proton for a year, but its first commercial flight was planned in 2 years. In November, in Oslo, the partnership agreements were signed and Sea Launch was officially created in May 1995 on the Caiman Islands, one month before the official announcement that ILS had been founded and Energiya's interests in the partnership between Lockheed Martin and Khrunichev faded.

At first, Energiya's activities with Sea Launch did not seem to endanger the commercialization of the Proton. First, Zenit's arrival was not planned until 1998 at the earliest, which left the Proton time to impose itself. Moreover, the Zenit being above all else a Ukrainian launcher, it would not use the Russian quotas[9]. Sea Launch being a US company, some even considered – wrongly – that it could not be submitted to any quota. Then, the low announced costs (less than $15,000/kg in geostationary transfer) should first and foremost jeopardize the most expensive provider on the market, i.e. Arianespace. Finally, a new opening for the Block-DM stage should allow economies of scale and thus benefit the Proton's competitiveness.

However, Energiya's involvement in another partnership with a more significant share (25%) risked bringing about a conflict of interests in the long term. Moreover, relations with Khrunichev were regularly becoming strained, because Energiya's upper stages were undeniably the Proton's Achilles heel, as was shown by the loss of Mars-96. In 10 years, the Proton had experienced nine failures, five of which were linked to the Block-D-2 or DM stages. A replacement plan was necessary and Khrunichev had been working on it for several years, with an adaptation to the Proton of the Breeze maneuverable stage, whose prototype had flown on the first small Rockot launcher in 1994. In 1994, when the Proton successfully launched its first commercial satellites, Anatoli Kiselev committed to an extravagant benefits goal of 1.5 billion dollars per year with Russian banks to finance the investments necessary for the modernization of the Proton and the industrialization of the Breeze, which would allow Energiya's stages to be replaced.

The Asiasat-3 launch's failure on December 24, 1997 would confirm the urgent need for an alternative.

9 Quotas for Ukrainian launchers had been established on February 21, 1996 and fixed at twenty geostationary contracts until the end of 2001, with a possible extension of three if the market grew and five more for non-geostationary launches.

9.7. Opening up to the market

As the 1990s reached their end, the final major obstacle facing the Proton's promoters was the US quota policy that bridled its commercialization, while the market was booming. In 1995, analysts anticipated an increase in the number of geostationary satellites to be launched from 20 to 25 or 30 per year, with the rise of digital television and the growing fleets of international operators. In a few months, these perspectives would explode with the exponential growth of the Internet, which had been the new El Dorado of investors of all types. Their projections would make the market prospective climb from 25/30 to 40 or 50 satellites to be launched per year as the craziest projects were put forth by manufacturers and operators[10]. To grab the radiofrequency resources required for all these systems, a veritable rush began across the spectrum. Throughout the summer of 1997, after having granted fifteen licenses in the K_a band for projects that would represent some 52 billion dollars of investments if they were successful, the FCC proposed opening frequencies in the K_a and V bands (between 37.5 and 50.2 GHz). The license requests immediately flowed in: PanAmSat presented its V-Stream project (12 geostationary satellites), Loral its CyberPath (10 satellites), Lockheed Martin Telecommunications had its own project with nine satellites, Hughes Communications proposed its ExpressWay (14 satellites) and Orbital Sciences its OrbLink (seven satellites in medium Earth orbit), Motorola went further with its Celestri project made up of 63 large satellites in low orbit and nine in geostationary orbit, while TRW imagined a Global EHF Satellite Network (GESN) made up of 15 satellites in medium Earth orbit and four in geostationary orbit. In total, these systems would represent more than 30 billion dollars in investments.

The end of the quotas imposed on the Chinese since 1988, on Russian launchers since 1993 and on Ukrainian launchers since 1996 had long since engrained itself in White House thinking. Starting September 19, 1996, it was expressed in the National Space Policy published by the US executive branch, which proposed "a transition toward a free and honest commercial launch services market". In fact, it was thought at that time that Russian and Ukrainian launchers, commercialized via joint ventures piloted by US manufacturers, were perfectly under control and that the US launcher industry, restructured and reinforced by the EELV program, had nothing to fear. On the contrary, the primary victim of this lifting of the quotas would be Arianespace, which would be pushed out of the market.

10 Previsions of 100 satellites per year for the decade from 2000 to 2010 were also mentioned by the ITRI (International Technology Research Institute) in its evaluations for the US government.

In fact, starting on January 30, 1996, the Russian quota had been raised from eight to 16 geostationary contracts until December 31, 2000 with a maximum difference of 15% compared to the cheapest Western launcher, as opposed to the 7.5% from before. The agreement foresaw the possibility to increase to 18 then 20 contracts if the annual market exceeded 24 satellites per year. That quota extension to 20 contracts would be granted in early 1998. For operators seeking ever-freer access to space, this was not enough. In February, the Satellite Industry Association (SIA) sent a letter signed by its most influential members to Vice-President Al Gore asking for the abandonment of the quota regime and allow operators to respond to the endlessly growing demand for orbiting capacity, citing the success of the international joint-ventures ILS and Sea Launch to justify this.

Figure 9.13. *ILS meeting in 1999 (Kiselev-Trafton)*
(source: all rights reserved)

However, it was not the competition of Russian launchers that worried Washington's executive and legislative branches the most, but the involvement of manufacturers from the sector in transfers of technology with rather unwelcome old partners from the former USSR – such as Iran and North Korea – that could reinforce the risks of ballistic missiles proliferating despite the MTCR that Russia had nevertheless joined in August 1995. Notably, since January 1997, the United States had received unsettling reports concerning the Russian industry's involvement in the Islamic Republic of Iran's ballistic and nuclear program. The quota policy was also meant to prevent that.

On January 28, 1998, seven Russian entities suspected of having supported Iran in its missile program were sanctioned. Among these were the engine manufacturers NPO Energomash and NPO Trud. Six days earlier, Viktor Chernomyrdin had published a decree to increase monitoring on the export of “sensitive” technologies that Boris Yelstin had reinforced through “executive orders” imposing the creation of the necessary monitoring authorities. Blowing hot and cold, the Kremlin, through the voice of its Minister of Foreign Affairs, Yevgeny Primakov, announced that maintaining a sanctions policy could lead to a non-ratification of the Start 2 disarmament treaty by the Duma.

On January 12, 1999, three more organizations – including the MAI – would be the targets of US sanctions.

These questions were part of numerous issues, which Yevgeny Primakov – who had become Prime Minister in September 1998 – wished to discuss with the US administration when he took off for Washington on the evening of March 23, 1999. Unfortunately, his plane would have to turn around, because this was also the evening that NATO had chosen to begin bombarding Serbia as part of the “Allied Forces” operation following the failure several days earlier of the Rambouillet Conference on Kosovo’s status. The question of quotas would have to wait until the gunshots were silenced.

The following June, ILS exhausted the quota of launch contracts that it had been granted and theoretically had to wait until 2001 for more.

On July 21, Wilbur C. Trafton, who had succeeded Charlie Lloyd as the head of ILS at the start of the year, testified before the Senate’s subcommittee in charge of International Security and Proliferation. Before him, George Tenet, head of the CIA, had insisted on the catastrophic situation of the Russian economy and the undeniable appeal of transfers of sensitive technologies to Iran to bring fresh cash into the industry. Trafton recalled that neither Khrunichev nor Energiya were involved in the proliferation activities and had implemented very strict control procedures. According to him, if the quota regime was not lifted, the US space industry could lose its preeminence in favor of international competitors: “if LKEI [in ILS] cannot guarantee the availability of its launch services to its clients, the United States’ industry is preparing to lose hard-earned market shares from the last 13 years to foreign competition (…) The primary beneficiary would be the French Ariane program (*sic*) and the United States would lose ground on the highly competitive launch market”. Furthermore, if the quotas were not lifted, he believed that the support provided to some 100,000 Russian engineers and technicians by the sale of Proton launchers would be lost, which would increase the risk of proliferation and also endanger the production line for the RD-180 engine selected for Atlas-5 in the scope of the EELV program.

More would be needed to convince Congress.

The quotas on Ukrainian launches would be lifted on June 5, 2000, when it seemed obvious that Sea Launch would never reach its limit before the end of the year.

Efforts to accelerate an end to the quotas with Russia would be in vain. Nevertheless, as planned, this regime would end on December 31, 2000 and would not be renewed.

On January 1, 2001, the Proton could finally be freely commercialized, but the market that it had to conquer had been collapsing since the explosion of the “Internet bubble” in spring 2000.

10

Standing the Test of the Market

At the turn of the century, the day after the explosion of the speculative Internet bubble and on the eve of the crisis that would strike the aeronautics and space sector after the September 11 attacks, the space transport sector was being structured for the long term. The effervescence that had characterized it in the 1990s had calmed down and lasting industry actors were clearly identified.

Figure 10.1. *Atlas-3A launch on May 24, 2000 (source: Lockheed Martin)*

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

The International Launch Services (ILS) aligned its Proton-K launcher, finally cleared from the stranglehold of quotas, and commercialized it alongside the US Atlas-2A and 2AS launchers. The Atlas-3 range, with Russian first stage engines, was the first model to be flown successfully, on May 24, 2000. In parallel, partners Khrunichev and Lockheed Martin actively prepared the arrival of their new battle horses: a modernized Proton-M and a modular Atlas-5, from which the notion of reciprocal backup would eventually get its full meaning.

In Europe, Arianespace faced a difficult transition. On June 4, 1996, the dramatic failure of Ariane 5's inaugural flight dissipated the trust acquired by the Europeans with the Ariane 4 series. They had put all their hopes in this new launcher, due to become the first member of a new family. In the end, Ariane 5 could only be qualified following its third flight on October 21, 1998. Its first operational flight did not come until a year later, on December 10, 1999, 3 years behind the original planning. In the meantime, however, the average mass of satellites had increased and here we had a launcher, formerly labeled too powerful for the market, with its 5,970 kg capacity in geostationary transfer orbit, already seemingly undersized for the double launches of new satellites ordered by the industry, which exceeded 3–3.5 tons apiece. The situation was even more embarrassing for the European operator given that this brand new launcher was still very expensive and that there were only fifteen Ariane 4 launchers left available to ensure the launches on the books while Ariane 5 was slowly ramping up.

To deal with this, in May 1999 in Brussels, the ministers of the member nations of ESA decided to urgently launch a performance improvement program for Ariane 5 by optimizing the motorization of its lower composite (a 10-ton increase in the propellant load for the solid boosters and the introduction of a Vulcain 2 engine on the central cryogenic stage) and by providing it with a cryogenic upper stage (a project postponed by Germany in 1995). An initial – temporary – version of this stage would be propelled by the HM-7B engine from Ariane 4's third stage before the arrival of a definitive, reignitable version with a Vinci engine. The first version, called 5ECA, began operations in 2002 and wielded a 10-ton capacity. The second, Ariane 5ECB, would follow in 2006 with a 12-ton capacity. To stay at the head of the commercial launch market, Arianespace had no room for error. But fate would not be kind to it.

Figure 10.2. *The Delta-3 from 1997 (source: McDonnell-Douglas)*

In the United States, Boeing, which had bought out McDonnell-Douglas in 1996, inherited the Delta-3 launcher. Derived from the Delta-2 with GEM-46 enlarged solid boosters and a new cryogenic upper stage propelled by an RL10B-2 engine, it proved not only too small for the market, with a capacity limited to 3,810 kg in geostationary transfer orbit, but had also racked up multiple failures. On August 27, 1997, its inaugural flight with the Galaxy 10 satellite from PanAmSat only lasted 72 s. The control loop between the thrust vectoring nozzles of the boosters and the inertial guidance system in the avionics bay entered into resonance. Overburdened, the hydraulic system steering the nozzles ran out of hydraulic fluid and the launcher, devoid of piloting, toppled and was destroyed by the aerodynamic constraints. On May 5, 1998, the second flight put the Orion-3 satellite into orbit for Loral Orion, but a rupture in the second stage's thrust chamber caused its extinction after 3.4 s of propulsion and the satellite was injected into an orbit that never exceeded 1,284 km. The cost of this disaster was calculated at 287 million dollars. On August 23, 2000, at the request of operators and insurers, Boeing performed a third flight with an instrumented mockup as payload. This was a semisuccess, because a slight underperformance of the second stage did not allow the desired orbit to be reached (it peaked at only 20,694 km; the target was 23,404), but it came too late. Boeing threw in the towel on the Delta-3 and focused on the Delta-4 (which would recycle the cryogenic upper stage of its misfortunate predecessor). Following in the Atlas-5's footsteps, Delta-4 was selected in 1997 to become the reference launcher for the US Air Force in the scope of the Evolved Expendable Launch Vehicle (EELV) program and would also be offered on the commercial market to benefit from the scale effect and launch rates that would allow unitary costs to be reduced for each launch. This is how manufacturers and the Pentagon saw it at the time.

Figure 10.3. *Sea Launch liftoff (source: Sea Launch)*

Boeing also pursued its commercialization of the Russian-Ukrainian Zenit-3SL through the Sea Launch consortium. The Odyssey launch platform, refurbished in Stavenger, Norway, and equipped for launches at Vyborg, Russia, had made its way to California, survived a storm in the Bay of Biscay, crossed the Suez Canal, had a layover in Singapore for repairs and arrived in Long Beach on October 4, 1998. The "Sea Launch Commander" ship, built in Glasgow, Scotland, had preceded it after a detour through Saint Petersburg to be equipped with Russian control systems. After the success of its first demonstration flight on March 28, 1999, with an instrumented payload, Sea Launch performed its first commercial flight on October 10 with the direct TV satellite, DirecTV-1R, but suffered a failure during its following flight on March 12, 2000, when the cell phone satellite ICO-F1 from ICO Global Communications was destroyed after the second stage of the launcher stopped 80 s too early[1]. Flights restarted after a 4-month hiatus and Sea Launch seemed to have become an important actor, with multiple orders from Hughes (bought out by Boeing in January 2000) and Loral, the two satellite manufacturers, each with a variety of launch slots to guarantee the best flexibility possible in their delivery calendars.

Long feared for their ability to crush market prices, the Chinese launchers commercialized through the China Great Wall Industry Corporation (CGWIC) were

1 This failure was due to an error in a valve's control software during the final countdown before liftoff. Maladjusted, the valve experienced a glitch that caused the loss of control of the RD-8 vernier engines ensuring the steering of the launcher's second stage and consequently the automatic failure of the propulsion.

taken off the market. Like the Russian and Ukrainian launchers, Chinese launchers were subjected to a quota regime by the United States. An initial agreement in 1988 limited their market access to nine geostationary satellites manufactured in the West until December 31, 1994. A new agreement signed on January 27, 1995 authorized China to launch 15 geostationary satellites by 2001, with the stipulation of not charging with a discount higher than 15% below the tariffs of its Western competitors. In reality, only five launches took place in the scope of the first agreement and six under the second, with a total of four failures, including the very spectacular failure of the new CZ-3B launcher's first flight with the Intelsat-708 satellite on February 14, 1996[2]. Concerned about maintaining a high level of competition in launch services in order to reduce the global cost, the satellite manufacturers Hughes and Loral then participated in the commissions investigating these failures to support the Chinese launchers' return to flight and to restore a position of trust. This contribution by Western experts had attracted the attention of legislators in the United States. On July 8, 1997, the Republican Senator Fred Thompson from Tennessee gave a series of conferences that led to the creation of a special committee of the House of Representatives in June 1998 under the direction of Republican Representative Christopher Cox from California. Made public on May 25, 1999, the committee's report pointed its finger at significant unmonitored transfers of technology from the United States to China, notably concerning the design and conception of the launchers guidance systems, which could easily be transferred to Chinese ballistic missiles. The reliability rate of Chinese launchers greatly benefitted from this, increasing from 78% for the period from 1990 to 1996 to 100% for the decade 1997–2006. As a result of the Cox report, Hughes Electronics Corp. and Loral Space & Communication Corp. were sued by the federal government for violating the legislation on monitoring exports. Loral had to pay a 14 million dollars fine in 2002; Hughes paid 32 million dollars in 2003[3]. Most importantly, on March 15, 1999, a reform to the ITAR (International Traffic in Arms Regulations) transferred satellites, launch services and their essential components to the jurisdiction of the USML (US Munitions List), which restrained their export in the same way as that of arms. Export licenses were no longer distributed by the

---

2 Due to a defect in the inertial control two seconds after liftoff, the launcher veered off course before even clearing its service tower and crashed into a village on the side of a neighboring hill, spreading several hundred tons of toxic propellants upon exploding. Six were officially declared dead in Chinese reports. Unofficial counts estimate the number of victims to be more than 100, even 200.

3 Lockheed Martin was also sued and fined 13 million dollars for transferring an evaluation of the GF-46 solid propellant motor from the EPKM upper stage of the CZ-2E launcher to the Chinese operator Asia Satellite Telecommunications (Asiasat) from Hong Kong in 1994. This report identified some errors in the definition of the qualification tests.

Department of Commerce, but instead by the Department of State. In practice, since all Western satellites contained American components, no satellite on the international market would be authorized for export to a Chinese launch site. Starting in November 1999, Chinese commercial launches were limited to satellites manufactured in China and – from 2005 to 2012 – to seven satellites manufactured in Cannes by Alcatel Espace (later Alcatel Alenia Space and Thales Alenia Space) on the base of an "Itar-Free" platform containing no American components on the USML.

10.1. Transition

It was this more limited competition that the Proton would henceforth face. In early 2001, ILS had 23 launches from Baikonur since 1996 and boasted fifteen consecutive Proton successes since late 1997. The launcher, nevertheless, suffered a much lower reliability rate than government missions from the same period, with two failures in 15 flights.

Figure 10.4. *Mark Albrecht (source: all rights reserved)*

In 1999, Wilbur C. Trafton, who was in charge of ILS, would remain in this position for less than 6 months. He quickly left the company to take over as head of its competitor Sea Launch starting in October. To replace him, ILS called on Mark J. Albrecht. This former legal counselor for national security issues to California Governor Pete Wilson, back when he was only senator, blazed his way through the space industry after having been named executive secretary of the National Space Council by President George H. W. Bush from 1989 to 1992, when he was responsible for managing the industrial consequences of the transition phase between the fall of the Berlin Wall and the collapse of the Soviet Union and preparing the restructuring of the Freedom space station into an international space station with Russia's participation. Later, he would head the office of SAIC (Science Applications International Corporation) in Washington before being named vice-president of Lockheed Martin Space Systems in charge of commercial development.

For his first year as the head of ILS, Mark Albrecht could be proud of his performance. At the Pacific Telecommunications Conference (PTC) in Hawaii on January 26, 2001, he announced that ILS had signed 13 firm launches in 2000 for a value of more than a billion dollars, not to mention seventeen options. The order list would increase to 3 billion dollars. He did not, however, list the clients and satellites associated with these contracts, nor the division of these between the Proton and Atlas launchers, some contracts mentioning "mutual back-up" between Atlas and Proton.

The volatility of this order list after the explosion of the "Internet bubble" would take no time to show up, for among these new contracts were several broadband satellites that would never see the light of day: four Astrolinks from Lockheed Martin (two on Proton and two on Atlas-5), four GE Americom satellites (three on Proton, one on Atlas-2AS) and six satellite clusters for Teledesic (three on Proton and three on Atlas-5). ILS's order list also included eight launches – six on Proton and two on Atlas – for the satellite mobile telephone operator ICO Global Communications, which had just got closer from Teledesic after having spent nine months under the protection of chapter 11 of the US legislation on bankruptcy. Only one Atlas launch eventually took place in 2001; the others were canceled after the ICO/Teledesic program was abandoned in October 2002[4]. In the meantime, Astrolink had been abandoned in late 2001 and GE Americom absorbed by the Luxemburgish operator SES in November 2001[5], so new satellite orders did not proceed.

In fact, far from exploding, as analysts had predicted, the commercial launch market instead seemed to be on the point of collapse. At Khrunichev, a plan to reduce the workforce by 25% was already circulating in late 2000. As for Lockheed Martin in Denver, where the production line for Titan launchers was preparing to be transformed to produce Atlas-5 launchers, a 12% workforce reduction (over 5,000 employees) was announced in March of that year.

---

4 The 2008 launch of ICO-G1 – with a new mission – would be the object of a new contract signed in 2006.

5 SES Americom merged with SES in 2009.

For ILS, two activities had to be made a priority on its Russian offer. On the one hand, it was a matter of consolidating the Proton subsidiary by ensuring the transition of the launcher to the modernized Proton-M version as fast as possible; on the other hand, a significant share of the market had to be grabbed by multiplying the number of contracts, even if it meant cutting prices, particularly Proton's.

Regularly postponed for a year, the Proton-M's maiden flight finally took place on April 7, 2001, and it was a success. A respectable Ekran-M television satellite, a vestige of the Soviet era, was placed directly into geostationary orbit by Khrunichev's maneuverable Breeze-M upper stage, which was used to replace Energiya's DM-2M stage. This first upgrade of the Proton in 34 years largely optimized the system's performances, with lighter structures, a 7% increase in the thrust of the first stage's RD-253 engines, digital avionics integrated into the Breeze stage and a more efficient propellant management system that reduced the quantity of toxic propellants remaining in its reserves after propulsion and thus the residual pollution to impact points in the landing areas negotiated with the Kazakh authorities.

Figure 10.5. *Atlas-5 (source: Lockheed Martin)*

Originally planned with the Intelsat-903 satellite, which the international operator preferred to fly on a traditional Proton-K/DM-2M on March 30, 2002, the first commercial flight of the Proton-M/Breeze-M had to wait until December 29, 2002 with the Canadian direct TV satellite Nimiq-2. This satellite was previously scheduled to fly on the first Atlas-5, which finally lifted off 4 months earlier with a European television satellite, Hot Bird 6 from Eutelsat, then on the second, which was actually preempted for the Greek Hellas-Sat-2 satellite in order to win the launch contract. These changing launch assignments then illustrated ILS's ability to go from one launcher to another according to its availabilities for the most flexible management of its manifest.

The prospect of seeing its DM-2M stage replaced by Khrunichev's Breeze-M did not particularly please RKK Energiya, which led to tensions, sometimes capable of turning into confrontations. In March 2002, Energiya's management therefore forbade operations to fill its stage with propellants for 2 days during the Intelsat-903 launch campaign, repeatedly arguing that Khrunichev had delayed payment on multiple occasions. An agreement was quickly reached, but it reinforced Khrunichev and Lockheed Martin's conviction that it would soon become necessary to find a way to circumvent this troublesome partnership, as its interests would henceforth become more strongly oriented towards Sea Launch, of which it had 25% ownership. In 1999, five DM-2M stages flew on commercial missions for ILS and two DM-SL versions on Sea Launch. In 2000, this number rose to six for ILS and three for Sea Launch. In 2001, it fell to two and two.

The operators' faint-heartedness regarding the new version of a launcher that had proven itself for three decades and a new stage that had not shown demonstrated its long-term reliability – it had only flown twice on Proton and three times on Rockot in a simplified version – would be wiped out by the failure of the Astra-1K launch.

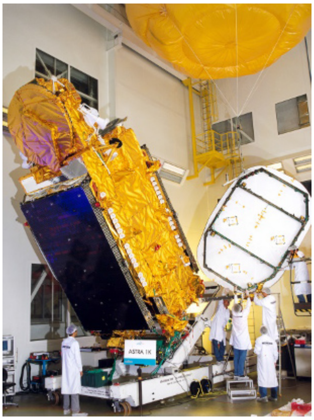


Figure 10.6. *Astra-1K (source: Alcatel Space)*

Built by Alcatel Space, Astra-1K had been ordered by SES to replace three of its satellites and to serve as a backup for four others at its most strategic position 19.2º east from where the operator was broadcasting all over Europe. It was a giant for its time: 5,250 kg at launch, 13 kW of power, 52 Ku-band repeaters and 2 in Ka band, 10 antenna reflectors. For Alcatel Space, it also represented an important transition, because it heralded its new generation of Spacebus-4000 satellite bus – even if its avionics remained that of the 3,000 generation – and integrated plasma propulsion for the first time, with four Russian SPT-100 thrusters and a 230 kg xenon reserve for north-south station keeping.

On November 26, 2002, the three-stage Proton-K filled its role and the DM-2M stage performed a first ignition to place it into parking orbit at an altitude of 175.5 km, awaiting its transition to geostationary transfer orbit. Yet it did not reignite and Europe's technological pearl was separated in low orbit.

Alcatel Space's crew desperately tried to see what could be saved from the mission, but due to the satellite's low altitude, communication windows were limited and separated by long intervals, while the orbit was degrading very quickly. On the 28th, they announced that they had raised the spacecraft's orbit altitude – which had fallen to 152 × 171 km – to 217 × 362 km to avoid an imminent reentry. According to their calculations, the onboard propellant and xenon reserves – calculated to be excessive – should allow geostationary orbit to be achieved, at the cost of 10 of its predicted 13 years of life. For the manufacturer, this would at least allow the numerous technological innovations onboard the satellite to be tested. Recovery by the US Space Shuttle was also suggested but immediately discarded. The Luxemburgish operator, reputed for its technical intransigence in the protection of its investments, preferred to declare the satellite "completely lost" and bring its 292 million euro insurance policy into play[6]. Astra-1K reentered the atmosphere on December 10.

SES brought its own team of experts together in a Failure Review Oversight Board (FROB) to analyze the conclusions of the Russian inquiry committee. Despite the success of one flight by the DM-2 stage starting December 25, 2002, the operator decided in February 2003 to no longer use Energiya's stage and asked to have it replaced with the Breeze-M for the next flight, which was to launch the AMC-9 satellite for its subsidiary SES Americom. Scheduled for February 10, 2003, the launch was pushed back to June 6 and crowned with success. From that day on, ILS's missions would no longer make use of Energiya's stage.

RKK Energiya would remain an official partner in the ILS consortium through its contribution to LKEI, but with no decision-making power.

6 In the end, the insurers paid 275 million dollars of this sum, which also covered launch into orbit and initial operations.

10.2. Price war

In 1996, when ILS debuted its launches, the price for a launch on Proton was negotiated between 50 and 60 million dollars. With the growth of satellite mass, these prices regularly increased, in the order of 2.5% per year on average. In the early 2000s, when the market reached its limit of approximately 20 commercial geostationary satellites to be launched per year and contracts made for large broadband satellites were canceled, ILS had to defend a significant share of the market against its competitors to ensure a sufficient rate for not just one, but two families of launchers.

Luckily, its two primary competitors – Arianespace and Sea Launch – lacked one major advantage: a regular captive government market. Each year, the Russian federal government launched four to five missions on Proton, whereas the Pentagon and NASA ensured three to four missions on the Atlas' annual manifest.

Satellite	Amount of the contract M$	Manufacturing cost	Launch cost (space forces)	Management (3.5 %)	Income taxes (35 %)	Total expenses
Astra-1F	49.05	19.46	23.82	1.33	1.91	58.48
Inmarsat	35.50					
Telstar-5	47.25	29.11	15.83	1.77	0.96	52.05
Iridium-1	55.15					
PanAmSat-5	47.25	24.30	16.42	1.82	0.92	47.27
Iridium-2	55.73					
Astra-1G	50.37	26.50	17.24	2.04	0.83	48.92
Asiasat-3	51.38	30.50	15.44	1.90	0.67	50.38
Iridium-3	55.66					
Echostar-4	56.02	31.64	15.70	1.78	0.46	51.88
Astra-2A	57.72	32.47	16.83	1.73	0.30	51.78

Table 10.1. *Financial review of the first 11 commercial Proton launches (according to the Khrunichev Center)*

Figure 10.7. *Ariane-517 liftoff on December 11, 2002 (source: Arianespace)*

Arianespace, on the other hand, was limited to not only keeping a significant order list, but a varied one to support the dual launches on Ariane-5. This situation was aggravated by the failure on December 11, 2002 of Ariane-5ECA's maiden fight, which would force the Europeans to push its introduction back to 2005 and, in the meantime, to add the "generic" standard Ariane-5G to the Ariane-5ECA launchers in production, whose capacity would nevertheless increase to 7 tons in transfer orbit, which still was not enough to bring together the largest satellites on the market, which constituted the very core of Proton's goal. Moreover, the significant investments necessary for the Ariane-5ECA to fly again led to the adjournment *sine die* of the definitive Ariane-ECB version with a 12-ton capacity. Yet Arianespace was counting on this very vehicle to launch its First In, First Out (FIFO) offer, because of which it could have launched every satellite in the order they arrived in Kourou. When the Ariane-4 was withdrawn from the line in early 2003, Arianespace found itself in an extremely vulnerable position for several years with an overly expensive, ill-adapted launcher and results in the red that had to be cleared by European states that were less and less inclined to sign blank checks for it[7].

7 Profitable since its creation, Arianespace went into the red in 2000, suffering 242 million euros in losses, then another 193 million in 2001 and 105 million in 2002 before bouncing back with profits in 2003, because of the fact that the ESA's EGAS (European Guaranteed Access to Space) financial support program came into effect.

Sea Launch, whose system showed enough ingenuity to ensure strong media coverage, was the first truly private launch operator, yet this was its very weakness. With no access to Russian or US government launches, it also did not have their support during dry spells. Boeing had invested more than 400 million dollars in the issue and was counting on long-term returns on this investment, which implied maintaining a large profit margin on each launch. Furthermore, the use of the Zenit on the Odyssey platform suffered numerous operation deficiencies. For example, the transfer of the launcher and its satellite could not take place by sea, as originally planned – which limited the number of launches per campaign to only one instead of two. The transfer taking place at Long Beach before liftoff, the satellite was no longer accessible for the 16-day trip necessary to reach the Equator and any problem therefore required its return to California[8].

However, Sea Launch appeared to be a very credible competitor, to the extent that some Arianespace advisors foresaw an alliance with ILS to counter it in 2001.

To force at least one of its two competitors out of the ring, ILS started a spectacularly low-price policy on Proton launches in 2001. Some contracts were signed at around 45 million dollars, whereas the prices billed by Sea Launch or Arianespace for equivalent satellites were in the neighborhood of 70–90 million dollars. In September 2003, the Malaysian operator Measat thus signed a 48.7 million dollars contract for Measat-3, weighing in at 4,765 kg, which amounted to more than 10,000 $/kg. The following April, Télésat Canada signed a 45.5 million dollars contract to launch its Anik-F3 satellite, which weighed 4,640 kg. This was a record – for the contracts with published values – of 9,800 $/kg, in a market whose baseline was rather of the order of 13,000–15,000 $/kg. According to rumors at the time, offers might have even been made at 38 or even 35 million dollars, though this could not be confirmed. These extremely low tariffs also allowed the Proton to become competitive on the mid-sized satellite market and to win the contract to launch Thor-5 (2,450 kg), signed in November 2005. Yet, these satellites were essential to Arianespace to succeed in pairing with satellites weighing more than 4 tons for dual launches.

However, Arianespace succeeded in escaping this situation because of the support of the European states[9] and the trust of some clients who kept its order list at a level sufficient to support a regular launch rate. Ariane-5's launch rate thus went

8 During Sea Launch's entire period of activity, this actually never happened.

9 The EGAS (European Guaranteed Access to Space) support program, initially designed to only last six years, was extended far beyond 2010, but with regularly decreasing amounts. In 2011, ILS threatened to condemn this "subsidy" to the World Trade Organization.

from three launches in 2003 and 2004 to five in 2005 and 2006, with Ariane-5ECA's return to flight, then seven in 2007 and six in 2008.

Figure 10.8. *Thor-5 launch (source: ILS)*

Sea Launch was not so lucky and barely reached the rate that would at least ensure breaking even. After having performed two launches in 2001 and two in 2002, the Zenit increased to three launches in 2003 and 2004, then four in 2005 and five in 2006, with an order book that struggled to take off. According to some industrial sources in the United States, since late 2001, Sea Launch had attempted to preempt ILS with offers below 60 million dollars, particularly to Intelsat, but this was unsuccessful.

Launches were also commercialized from Baikonur by Land Launch starting in 2005. This was a company formed by Sea Launch and Russian-Ukrainian partners brought together in the Space International Services (KB Yuzhnoye, RKK Energiya, TsENKI, MZ Yuzhmash and the Ural Mining Metallurgy Company) to attack the market on satellites weighing less than 4,000 kg. The launcher was nearly identical, but by lifting off from Kazakhstan instead of the Pacific, it lost nearly 40% of its capacity in geostationary transfer orbit. As it did not call on Sea Launch's US personnel or resources, its price was also greatly impacted, dropping from 75–85 million dollars to approximately 45 million.

The fact remains that lacking a rhythm of six flights per year, Sea Launch was losing money. Over time, Sea Launch would announce that economic measures would allow it to drop its break-even point to four, then three flights per year.

In fact, starting in 2001, to save money, Boeing merged the commercialization of Sea Launch with that of Delta launchers into a single entity, Boeing Launch Services. Following the model set forth by the Proton and Atlas, the Zenit found itself associated with the new Boeing launcher, the Delta-4. This new launcher performed its maiden flight on November 20, 2002, carrying the W5 satellite on behalf of Eutelsat. Yet, the two launchers were also competing on the commercial market, the US launcher having the advantage that it also benefitted from the captive market of the Pentagon, which it shared with the Atlas.

Figure 10.9. *Failure of the NSS-8 launch on January 30, 2007 (source: Sea Launch)*

On January 30, 2007, Sea Launch's destiny was decided with the launch of NSS-8, the first satellite ever allocated by SES, parent company of New Skies Satellites, to the Zenit. Built by Boeing, this 5,840 kg giant was the second largest satellite ever launched by Sea Launch and it was already a year behind the original schedule. The images, directly transmitted around the world via Internet, were terrible. The first stage had barely been lit when a plume of smoke shrouded the launcher, which, instead of rising, seemed to sink through the platform, which was immediately engulfed in a ball of flames 100 m across. Pollution in the RD-171 engine's liquid oxygen turbo pump had led to a loss of pressure and an immediate cessation of propulsion. It was determined that the launcher had not risen more than 10 or maximum 15 cm before falling back into the flame trench and exploding. The Odyssey platform had suffered significant damage to its superstructures, but none at the structural level and would undergo repair lasting a few months before flying again.

Launcher	2001	2002	2003	2004	2005	2006
Proton incl. ILS	6 2	8 (+ 1 failure) 4 (+ 1 failure)	5 1	8 4	7 4	5 (+ 1 failure) 4
Atlas 2/3 incl. ILS	4 1	4 2	3 1	5 4	1 0	0 0
Atlas 5 incl. ILS	0 0	1 1	2 2	1 1	2 1	2 1

Table 10.2. *Proton and Atlas launches (2001–2006)*

However, the most significant damage was to Sea Launch's credibility. This accident would cost the space insurance sector 450 million dollars. SES, one of the two largest satellite operators in the world, definitively stripped Sea Launch and Land Launch of its launch providers and transferred its SES-3 satellite on Proton; XM Radio would do the same with its XM-5 satellite, while Hughes Network Systems (HNS) and Intelsat would cancel their own contracts to fall back on Ariane-5.

Sea Launch would resume flights a year later and take on seven missions before placing itself under the protection of chapter 11 of US bankruptcy law on June 22, 2009 and leaving the market for 2 years, the time to restructure under the control of Energiya Overseas Ltd., subsidiary of RKK Energiya.

The goal to eliminate a competitor was thus achieved, but in the meantime, ILS had stopped existing in its initial form.

10.3. Divorce

The price war on the Proton had been a hard pill to swallow for the Russian partners, because the launchers had practically been sold at cost, while 15% of each contract had to return to the joint account. At the same time, they had had the impression that Lockheed Martin would spare efforts on its own Atlas-5 launcher to facilitate its introduction onto the commercial market. In practice, for Khrunichev's management, this would mean that the Proton had subsidized the Atlas, without any real profit for the former, which culminated in four commercial flights per year in 2005–2006, behind Sea Launch (11 satellites launched in the same period) and far behind Arianespace (18).

Despite this, the Atlas-5 did not manage to make itself known on the market and when its military missions debuted in the framework of the EELV program, it seemed clear that the target price was incompatible with the level of service demanded by the US Air Force.

In Spring 2006, Khrunichev made Lockheed Martin aware of its intention to increase the consortium's price for launches on Proton by 15% – from 35–40 million dollars to 45–50 million per unit.

At Lockheed Martin, Robert J. Stevens' arrival to the helm in August 2004 as the CEO and Vance Coffman's successor had also changed the situation. With his financial director, Chris E. Kubasik, he reviewed the group's comprehensive strategy to increase margins and improve the predictability of the results. The space sector was characterized by a significant flow of capital with low margins and particularly strong variability. "All launch service operators are facing chaotic revenue cycles, which the people at Wall Street do not like", emphasized Ted McFarland, head of marketing at ILS.

Yet, the "price war" had pulled the market down to a level that the EELV program's launchers could not follow. Boeing was the first to give up, withdrawing the Delta-4 from the commercial market in 2003. Lockheed Martin discretely followed suit in 2005 with its Atlas-5. The two manufacturers would call on public financing to compensate for the shortage to be made up. It was the failure of a policy started 10 years prior to sponsor government launches with the help of the competing market. There would no longer be US launchers on the commercial market until the advent of SpaceX in the early 2010s.

On May 2, 2005, Lockheed Martin and Boeing announced their merger to form United Launch Alliance (ULA) to produce and commercialize their Atlas-5, Delta-2 and Delta-4 launchers together for the US government. After having received the Pentagon's approval in January and again in September, the company, equally owned by Lockheed Martin and Boeing, would officially be created on December 1, 2006.

Figure 10.10. *Frank McKenna and Mario Lemme (source: all rights reserved)*

In the meantime, Lockheed Martin had been negotiating its withdrawal from ILS with Khrunichev since May. This was announced on September 7, 2006 and became effective at the end of the year. Lockheed Martin's shares were initially transferred to Space Transport Inc., an entity created for the occasion in the British Virgin Islands. STI had been created by Mario Lemme, president of Weissker Inc., a Moscow counseling company partnered with ILS for administrative processes linked to the export of satellites to Baikonur. This German citizen joined ILS's board of directors in 2003 and was presented as the primary intermediary for this "divorce" between Lockheed Martin and its Russian partners. The transaction was evaluated at 150 million dollars. On May 29, 2008, the shares held by STI would be bought back by Khrunichev.

When Lockheed Martin withdrew, ILS had performed 37 launches on Proton, which had insured it for 2.5 billion dollars in revenue. Its order book included 11 contracts, with a total value of 500 million dollars.

Khrunichev would greatly benefit from this divorce. If the ILS headquarters remained in Delaware, with additional headquarters in McLean, Virginia, in the Washington suburbs, and a US chairmanship was given to a former vice president of ILS, Frank McKenna, it was Khrunichev that would receive all the dividends from these contracts. The revenue, which had maxed out between 100 and 200 million dollars, would start to climb, more than tripling in 5 years: 210 million in 2006, 390 in 2007, 506 in 2008, 584 in 2009, 601 in 2010, 648 in 2011. With competition primarily limited to Arianespace, the rhythm of missions would also increase: four commercial flights in 2007 (including one failed one), six in 2008 (also including one failure), seven in 2009 and eight in 2010.

Figure 10.11. *SES-3 and Kazsat-2 on July 15, 2011 (source: ILS)*

The various improvements to the Proton-M allowed its carrying capacity in geostationary transfer orbit to increase: 6,000 kg with the phase 2 in 2007, 6,150 kg with the phase 3 in 2010 and soon 6,300 kg with the phase 4 planned for 2014, but which would not actually fly until June 9, 2016. To access the market for smaller satellites, a new offer was proposed to unite a Western satellite with a Russian satellite whose structure would serve as an adapter. Thus, on July 15, 2011, SES-3 (3,170 kg) was launched atop KazSat-2, a satellite built by Khrunichev for Kazakhstan. The beauty of the system was that it did not require the use of additional structures detrimental to performances, like the Speltra used by Arianespace on Ariane-5. However, it did require one of the satellites to be specifically designed for this type of mission, yet only Russian manufacturers had compatible platforms at that time. As such, work was started with Orbital Sciences Corp. (OSC) in the United States for a "Proton Duo" offer in order to commercialize double launches on the base of a Star-2H platform in the lower position and a Star-2 in the upper position, but this would not turn out due to a lack of sufficient orders with the American manufacturer.

10.4. Challenges for the future

In the early 2010s, ILS had perfectly integrated itself onto the market, but it would have to face three major challenges: maintaining the reliability and availability of the Proton, the arrival of a new, very aggressive competitor and the long-term succession of the Proton.

Reliability was a major problem. On March 14, 2008, the failure in a Breeze-M stage during its second ignition had caused the AMC-14 satellite to enter an improper transfer orbit following its mission[10]. In the 7 years that followed, ILS put 41 commercial payloads into orbit for operators around the world: the Americas (DirecTV, Echostar, SatMex, Sirius XM Radio, Sky Terra, Telesat, Viasat), Asia and the Pacific (Asiasat), Europe (Eutelsat, SES), the Middle East (Arabsat, Türksat, Yahsat) and international organizations (Inmarsat, Intelsat). However, success was hard to achieve for several government missions.

On December 5, 2010, a new DM-03 upper stage from Energiya was overloaded with propellants, which caused a trio of Uragan-M navigation satellites from the Glonass system to be lost. The upper composite was several tons too heavy, so the

10 An attempt to save the mission through the intermediary of a lunar orbit as was done for Asiasat-3 in 1998 had been studied by SES and Lockheed Martin, then abandoned when it was discovered that Boeing (formerly Hughes) had patented the procedure. Given over to the Pentagon, AMC-14 could finally reach geosynchronous orbit with a 13° incline.

three-stage Proton could not place it into parking orbit and the stage, as well as its payload, fell back into the Pacific 1,500 km northwest of Hawaii.

On August 17, 2011, Express AM-4, the most powerful satellite ever ordered by the national operator Russian Satellite Communications Corp. (RSCC), was sent into an improper transfer orbit following a glitch in the Breeze-M stage. Contact was lost after the fourth of five planned ignitions and could only be reestablished with the satellite, in a lower transfer (995 × 20,294 km, 51.23º incline). With a mass of 5,700 kg for 14 kW and equipped with 10 antenna reflectors, this was the largest telecommunications satellite that had ever been built in Europe, specifically in Toulouse by Astrium Satellites. The insurance claimed amounted to 7.523 billion rubles (245 million dollars). The inquiry commission blamed the flight software, which had not given the inertial guidance system enough time to ensure the stabilization of the Breeze-M stage. The stage's control had begun to veer starting with its third ignition until it totally lost its orientation and performed its fifth ignition in the wrong direction.

Less than a year later, on August 6, 2012, a similar mishap affected the pair made up of the Russian Express MD-2 satellite – from RSCC – and the Telkom-3, a Russian-made Indonesian satellite. Once again, a failure in the Breeze-M upper stage was the cause, with its premature extinction 7 s after its third ignition. The two satellites found themselves in an orbit maxing out at 5,000 km. The combined claim was evaluated at 237 million dollars.

On December 8, 2012, the other Russian telecommunications satellite operator, AO Gascom, subsidiary of Gazprom, lost a Western-made satellite. Yamal-402 (4,463 kg, 10.5 kW) was sent into geostationary transfer orbit with a perigee 4,400 km too low and a 26º incline instead of 9º. This time, however, the mission could be saved by teams from the manufacturer Thales Alenia Space, which would manage to bring the satellite into its definitive orbit.

Figure 10.12. *Intelsat-23 launched on October 14, 2012 (source: ILS)*

A different cause was identified for each of these failures, which raised the question of quality control management at Khrunichev. Some Western observers did not hesitate to take stabs at a supposed "loss of competence" in the Russian space industry, which had, incidentally, just experienced some astounding failures, like the loss of the Progress-M-12M cargo on August 24, 2011 or that of the Phobos-Grunt Mars probe after its November 8 launch.

Even if these were not its doing, ILS suffered from these failures, which regularly grounded its launcher and ruined its credibility with its clients. The number of commercial payloads it launched thus fell to five in 2011, before once again rising to seven in 2012.

Figure 10.13. *Phil Slack, Karen Monaghan, Janice Starzyk (source: ILS)*

In June 2013, at the Paris Air Show, Alexander Seliverstov, general manager of Khrounitchev, alongside Phil Slack, who had replaced Frank McKenna at the head of ILS, gave details of a quality control improvement plan for the Proton's production line, to be spread across several years.

Unfortunately, on July 2, for its second flight with the new DM-03 stage, the Proton experienced its most resounding failure. It had barely lifted off from complex no. 81/24 in Baikonur when the launcher started to rock, as if it were trying to regain its balance, then began to curve, reaching 800 m before breaking apart and exploding. Several hundred tons of toxic propellants were vaporized into the atmosphere and the few observers fled in a panic. The remains of the launcher and its three Uragan satellites collapsed into a ball of fire near neighboring launch pad no. 81/23.

The inquiry commission would demonstrate that angular accelerators had been installed upside down in the launcher's inertia center, yet since this equipment had been designed with "failsafes" to avoid just such an error, the responsible technician must have put them into place with a mallet. Two supervisors had then countersigned his work.

This was the straw that broke the camel's back. The Kremlin, represented by Deputy Prime Minister Dmitry Rogozin, decided to get involved and heads rolled. In August, Khrunichev's deputy general manager in charge of quality control, Alexander Kobzar, was fired, as was the head of the Proton's final assembly, Valery Grekov, and the head of the technical control department, Mikhail Lebedev. In the meantime, on August 2, Vladimir Popovkin, head of Roskosmos, had the questionable privilege of being publicly reprimanded for "his incompetence" by Prime Minister Dmitry Medvedev. Appointed to this position in April 2011 after the dismissal of his predecessor Anatoly Perminov following the failure of the December 2010 Glonass launch, he would be replaced by Oleg Ostapenko on October 10, 2013.

Great revisions to the Russian space sector, studied for more than a year and ratified by the Kremlin in June, were implemented starting September 4. This would lead to the creation of a new entity, ORKK (Obedinennaya Raketno-Komicheskaya Korporatsiya)[11], responsible for chaperoning all of the primary production centers, including GKNPTs Khrunichev and Roskosmos.

Figure 10.14. *Express-AM4R launch on May 15, 2014 (source: all rights reserved)*

On May 15, 2014, the Express-AM-4R satellite, twin to the Express-AM-4 ordered from Astrium (which had since become Airbus Defence & Space) by RSCC in March 2012 to replace it, suffered the same fate as its predecessor, this time due to a structural defect in one of the vernier engines in the Proton's third stage. The satellite, the Breeze stage, and the third stage were destroyed as they fell into the atmosphere near the Chinese border.

11 Presented in the West with its English abbreviation URSC (United Rocket & Space Corp.).

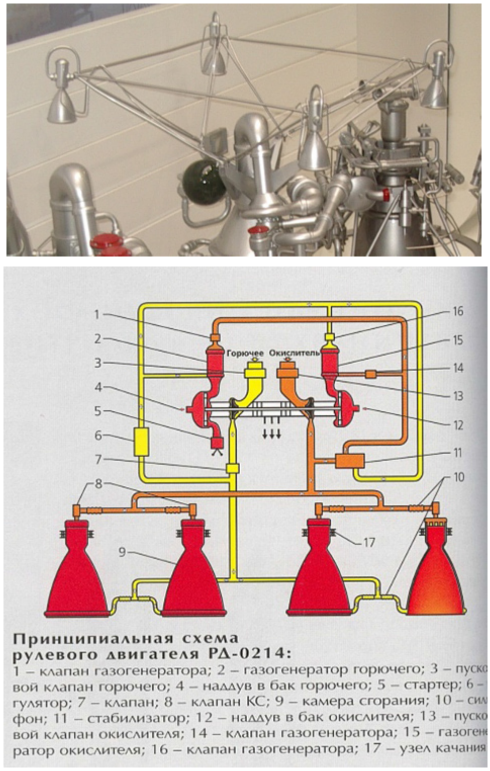


Figure 10.15. *The RD-0214's Vernier engines (source: All rights reserved)*

A year and one day later, on May 16, 2015, it was an ILS launch that failed. The anomaly showed up after 497 s of flight, at an altitude of 161 km. Once again, the Proton's third stage, the Breeze-M, and the payload fell back into the atmosphere over the oblast of Chita, in the far east of Russia. The passenger of this flight was MexSat-1 "Centenario", a 5,325 kg satellite built by Boeing at the request of the Mexican Ministry of Telecommunications and Transport. This was the first "geomobile" satellite produced by the Californian manufacturer on the base of its 702HP bus. It was supposed to establish an infrastructure valued at 1.6 billion dollars for 3G+ mobile telecommunications for government applications: defense, civil security, humanitarian purposes, telemedicine, distance learning, etc. This launch was insured for 390 million dollars.

The inquiry commission would once again focus on the third stage's vernier engines and reveal a connection between this failure, the previous, and a third that took place on January 18, 1988. At the origin of these accidents lay an abnormal vibration in the vernier engine's turbo pump, caused by heat-induced wear and tear on the rotor inside the casing. During the 2014 flight, this vibration had led to the dislocation of the interface between the vernier and the stage. In 2015, it was the vernier itself that was destroyed. Initially, a manufacturing flaw at the Voronezh factory (VMZ) had been suspected, but the inquiry would prove that it was a design flaw. After analysis, the investigators discovered that this was the cause of the three failures in 2015, 2014 and 1988, but that it had nearly caused many others since the Proton had started flying in a three-stage version.

10.5. A surprising rival

These disappointments came at the worst possible time for ILS because they coincided with an unexpected competitor's burst onto the market: the US company Space Exploration Technologies Inc. (SpaceX). Founded in 2002 by the South African-born American millionaire Elon Musk – also the CEO of Tesla Motors electric cars – SpaceX succeeded where all private investors had previously failed: developing an operational orbital launcher. Elon Musk nearly lost his shirt doing this, because he would need four launches by his small Falcon-1, from March 2006 to September 2008, to successfully put a 165 kg technological capsule into orbit. This triumph left him penniless, but crowned with a certain credibility. After landing one of NASA's COTS (Commercial Orbital Transportation System) contracts in August 2006 to study and develop a supply system for the International Space Station (278 million dollars), he was chosen in December 2008 for 12 supply missions with the CRS (Commercial Resupply Service) market valued at 1.6 billion dollars. Benefitting from access to NASA's expertise and patents, SpaceX then developed a low-cost launcher concept, optimized for low-cost mass production rather than performance. According to one European manufacturer who visited the SpaceX factory in Hawthorne, a suburb of Los Angeles, "It's almost as if a Soviet launcher were being produced with the methods and means of the Japanese auto industry".

Figure 10.16. *The failure on July 2, 2013 (source: all rights reserved)*

Figure 10.17. *Space X's Falcon-9 (source: Space X)*

This Falcon-9 had two stages equipped with a single type of engine running on kerosene and liquid oxygen, the Merlin. Nine Merlin units propelled the first stage and only one the second. SpaceX also designed these motors based on technologies developed by NASA in the 1990s for its Fastrac and Bantam programs, and more than 75% of the launcher and its equipment was made in the Hawthorne factory to make the best possible use of economies of scale.

SpaceX's commercial policy was very aggressive. Starting in 2007, the Falcon-9 was offered at 35 million dollars to operators for an estimated capacity of 4,000 kg in transfer orbit. The first contract was signed in September 2007 with the British operator Avanti for its Hylas-1 satellite, but the contract was transferred to Arianespace in July 2009 for a launch on Ariane-5 in November 2010. As the first flight approached, SpaceX revised its launch price, which climbed to 50 million dollars, and the first clients benefitted from this bargain, like the Israeli operator Spacecom for its Amos-4 satellite[12].

12 Amos-4 would finally be launched in 2013 on Zenit-3 by Land Launch and the contract with SpaceX would be reallocated to Amos-6, which would be destroyed on September 1, 2016 during a static firing test of the Falcon-9 launcher, 2 days before the scheduled date of its effective launch.

The Falcon-9's qualification flight in its initial version (v1.0) took place on June 4, 2010 and was successful. Immediately after this, a 494 million dollars contract was signed with Iridium to deploy 72 Iridum Next satellites intended to renew its constellation on eight Falcon-9[13].

Six months later, the second Falcon-9 flight placed the prototype of the Dragon capsule into orbit. It was because of this capsule that SpaceX could transfer cargo to the Station but also bring it back to Earth. Two years later, on May 25, 2012, the second Dragon capsule docked at the ISS and rotations began the following October. In late 2012, SpaceX was able to announce a backlog of more than 40 launches worth 4 billion dollars[14], even though the first commercial launch had not yet taken place. The operational version of the Falcon-9 (v1.1) flew on September 29, 2013 and the first commercial launch, with the SES-8 satellite, followed on December 3.

Raking in success after success, SpaceX overturned the order of commercial space transport, forcing the Europeans to urgently rethink their plans for the next steps after Ariane-5, encouraging, along with Boeing, the emergence of a new segment of the market: "all electrical" satellites. Carrying xenon tanks 10 times lighter than chemical propellant tanks, these satellites were thus smaller, which made the Proton less competitive to carry them, except as part of a dual launch.

The price of the Falcon-9 soared to 56.6 million dollars in late 2013, then 60 million in 2014 and 62 million in 2015 for a demonstrated capacity that could henceforth reach 5.3 tons in geostationary transfer orbit. ILS felt the effects of this, with a low number of announced contracts: two in 2012, then four in 2013, but only one in 2014… with a Russian client[15], for the very first time. In 2015, only one contract was signed, with Hispasat, while one contract signed in 2013 with Eutelsat was turned into a multilaunch agreement to allow the European operator to reserve a time slot on Proton on short notice. The backlog would gradually shrink as launches went on.

13 The deployment scenario would later be modified with seven clusters of 10 satellites instead of eight clusters of nine.

14 This total included the Dragon missions to service the ISS.

15 The oil company Gazprom for its Yamal-601 satellite, ordered from Thales Alenia Space. Project management would later be modified, with the satellite bus allocated to ISS Reshetnev, while Thales Alenia Space would only retain the payload. The responsibility for launching it could have been transferred to Khrunichev.

Figure 10.18. *Kirk Pysher (source: all rights reserved)*

On August 4, 2014, Phil Slack announced a planned cut to the number of commercial flights in the coming years, from 7 or 8 to 3 or 4. Phil Slack would soon step aside for Kirk Pysher, his former vicepresident in charge of mission quality and product development, on September 11, 2015.

In an attempt to expand its market, ILS pursued an offer diversification policy through its dual launch agreements with ISS Reshetnev in March 2014 and with the Russian manufacturer Dauria Aerospace, which specialized in small satellites. However, this was to no avail.

10.6. From Proton to Angara

What will the Proton's future be in these conditions? Its disappearance from the commercial market should be unimaginable in the short or medium term, particularly since, as it seems, Sea Launch's return can no longer be considered feasible. Satellite operators regularly confirmed that they were no more willing to lock themselves into a duopoly than to be confined to a monopoly in terms of space access. As long as China remains off the market and India has only one credible offer, facing Arianespace and SpaceX, there should always be room for ILS.

The fact remains that the Proton launcher is doomed to disappear. Its toxic propellants are a source of endless arguments with Kazakhstan's government, to which Russia rents the Baikonur cosmodrome for an annual fee of 115 million dollars as part of a lease agreement planned to last until 2020, then extended to 2050 in 2005. It is also necessary to negotiate stage reentry areas with Astana, and each launch failure results in temporary flight bans from the Kazakh authorities. In 2013, the July 2 failure ended in a demand from the Kazakh authorities for 13,690,757,305 tenges (nearly 70 million dollars) in compensation to depollute a 13,100 m^2 area around the site where nearly 500 tons of toxic propellants had been spilled.

Russia has been preparing for the transition from the Proton to a new launcher, both more modern and more "ecological", for more than 20 years and profited from this in an attempt to repatriate all of its launch activities to its own territory and take back full sovereignty.

The key to this transition is the Angara family of modular launchers, which Khrunichev has begun developing (see Chapter 4) and which first had to be used at the Plesetsk base. In its original design, the Angara family needed to be able to perform all government missions from the northern cosmodrome, including geostationary missions.

For commercial flights, this option was not possible, so Khrunichev also studied different sites to build a launch complex for Angara to efficiently place satellites in geostationary orbit. In 1999, discussions revolved around Christmas Island in the Indian Ocean. In 2001, the idea was the former US military base at Cam Ranh, Vietnam. None of these projects were followed up on.

In 2004, an agreement was signed between Russia and Kazakhstan to develop a launch site for Angara at Baikonur. After planning to modify site 200/40 meant for the Proton, in 2008, the project was moved to site 250, where the first model of the Energiya launcher lifted off on May 15, 1987. Due to a lack of financing, no work could be performed and the project was abandoned at the start of the 2010s, having becoming null and void because of the plan to develop a pad for Angara launches at the new cosmodrome in Vostochniy.

The commercial use of Angara, to follow the Proton, also imposed itself in the idea to withdraw the latter. ILS announced its intention to commercialize Angara starting in late 2002. At that time, the first flight of the Angara-5 was expected for 2005, with an eye to replace the Proton at the end of the decade. Delays in the development of Angara led to silence on this topic for years.

Figure 10.19. *The Angara-A5 on December 23, 2014 (source: all rights reserved)*

Angara's first test flight, in the "light" Angara 1.2PP version, was successful conducted on July 9, 2014, as was the "heavy" Angara-A5 version on December 23. The next flights were postponed to 2016, then 2017, giving Khrunichev time to finish the production of launcher elements in the Polyot factory in Omsk.

On July 16, 2015, ILS again officially added the Angara-1.2 to its commercial range, alongside the Proton. Angara-5 will complete this offer once it is available from the Vostochniy cosmodrome in 2021. On August 1, ILS announced its first client on Angara: the KARI (Korea Aerospace Research Institute), for the South Korean radar satellite, Kompsat-6, around 2020.

According to the information published in 2014, the Proton's annual production should decrease over a 10-year period, dropping from 11 to eight launchers in 2018, then only five in 2025. Inversely, the production of Angara-A5 launchers should start at two launchers per year in 2015, then rise to four in 2021, six in 2023 and seven per year starting in 2024.

Before being retired from service after 60 years of activity, the Proton launchers still had numerous missions to accomplish. One of the most spectacular was continuing the exploration of Mars, interrupted in Russia since the loss of the Phobos missions and the failures of the Mars-96 and Phobos-Grunt. The partnership with the European Space Agency and Roskosmos on the ExoMars program had given it another chance. The first mission was launched on March 14, 2016 with an orbiter and a landing craft made in Europe. These would reach the red planet on October 19. The second mission, pushed back from 2018 to 2020, will hopefully break the curse that has weighed on Russian Martian missions until now, with the launch of a Russian-made lander meant to place a European rover on the surface of the planet, equipped with a drill to search for traces of life, present or fossil, up to 2 m below the surface.

This would be a great way for Proton to take its leave, before the Angara goes into commercial service. The hope is that Angara will attract great attention by becoming the launcher for manned Russian missions starting in 2023. Who knows? Maybe a launch from the Angara family could even some day perform the mission that the Proton was refused: sending men to the Moon.

Figure 10.20. *ExoMars launch on March 14, 2016 (source: ESA)*

Appendix

List of Launches

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
07/16/65	Proton-1	2	1	Success	81R	207		N-4 no. 1
11/02/65	Proton-2	2	2	Success	81R	209		N-4 no. 2
03/24/66	Proton	2	3	Failure (second stage)	81R	211		N-4 no. 3
07/06/66	Proton-3	2	4	Success	81R	212		N-4 no. 4
03/10/67	Cosmos-146	4	5	Failure (fourth stage)	81L	227-01	11S824 no. 10	11F91 no. 2P
04/08/67	Cosmos-154	4	6	Failure (fourth stage)	81L	228-01	11S824 no. 11	11F91 no. 3P
09/28/67	Zond	4	7	Failure (first stage)	81L	229-01	11S824 no. 12	11F91 no. 4L
11/22/67	Zond	4	8	Failure (second stage)	81R	230-01	11S824 no. 13	11F91 no. 5L
03/02/68	Zond-4	4	9	Success	81L	231-01	11S824 no. 14	11F91 no. 6L
04/23/68	Zond	4	10	Failure (second stage)	81L	232-01	11S824 no. 15	11F91 no. 7L
09/15/68	Zond-5	4	11	Success	81L	234-01	11S824 no. 17	11F91 no. 9L
11/10/68	Zond-6	4	12	Success	81L	235-01	11S824 no. 19	11F91 no. 12L
11/16/68	Proton-4	3	13	Success	81L	236-01		N-6 no. 1
01/20/69	Zond	4	14	Failure (second stage)	81L	237-01	11S824 no. 20	11F91 no. 13L
02/19/69	Luna	4	15	Failure (first stage)	81L	239-01	11S824 no. 201	E-8 no. 201

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
03/27/69	Mars-69	4	16	Failure (third stage)	81L	240-01	11S824 no. 521	M-69 no. 521
04/02/69	Mars-69	4	17	Failure (first stage)	81L	233-01	11S824 no. 522	M-69 no. 522
06/05/69	Luna	4	18	Failure (fourth stage)	81L	238-01	11S824 no. 401	E-8-5 no. 401
07/13/69	Luna-15	4	19	Success	81L	241-01	11S824 no. 402	E-8-5 no. 402
08/07/69	Zond-7	4	20	Success	81L	243-01	11S824 no. 18	11F91 no. 11L
09/23/69	Cosmos-300	4	21	Failure (fourth stage)	81L	244-01	11S824 no. 403	E-8-5 no. 403
10/22/69	Cosmos-305	4	22	Failure (fourth stage)	81L	241-01	11S824 no. 404	E-8-5 no. 404
11/28/69	Block-D test	4	23	Failure (third stage)	81L	245-01	11S824 no. 25	7K-L1E no. 1
02/06/70	Luna	4	24	Failure (first stage)	81L	247-01	11S824 no. 405	E-8-5 no. 405
08/17/70	Maquette	3	25	Suborbital	81L	246-01		GBM 82EV
09/12/70	Luna-16	4	26	Success	81L	248-01	11S824 no. 406	E-8-5 no. 406
10/20/70	Zond-8	4	27	Success	81L	250-01	11S824 no. 21	11F91 no. 14L
11/10/70	Luna-17	4	28	Success	81L	251-01	11S824 no. 203	E-8 no. 203
12/02/70	Cosmos-382	4	29	Success	81L	252-01	11S824 no. 26	7K-L1E no. 2
04/19/71	Salyut-1	3	30	Success	81L	254-01		17K no. 121
05/10/71	Cosmos-419	4	31	Failure (fourth stage)	81L	253-01	11S824 no. 1101	M-71 no. 170
05/19/71	Mars-2	4	32	Success	81L	255-01	11S824 no. 1201	M-71 no. 171
05/28/71	Mars-3	4	33	Success	81L	249-01	11S824 no. 1301	M-71 no. 172
09/02/71	Luna-18	4	34	Success	81L	256-01	11S824 no. 0601	E-8-5 no. 407
09/28/71	Luna-19	4	35	Success	81L	257-01	11S824 no. 400	E-8LS no. 202

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
02/14/72	Luna-20	4	36	Success	81L	258-01	11S824 no. 0801	E-8-5 no. 408
07/29/72	Salyut	3	37	Failure (second stage)	81L	260-01		17K no. 122
01/08/73	Luna-21	4	38	Success	81L	259-01	11S824 no. 205	E-8 no. 204
04/03/73	Almaz-1	3	39	Success	81L	283-01		11F71 no. 101-1
05/11/73	Cosmos-557	3	40	Success	81L	284-01		17K no. 123
07/21/73	Mars-4	4	41	Success	81L	261-01	11S824 no. 1701	M-73 no. 52S
07/25/73	Mars-5	4	42	Success	81L	262-01	11S824 no. 1801	M-73 no. 53S
08/05/73	Mars-6	4	43	Success	81L	281-01	11S824 no. 1901	M-73 no. 50P
08/09/73	Mars-7	4	44	Success	81L	281-02	11S824 no. 2001	M-73 no. 51P
03/26/74	Cosmos-637	4	45	Success	81L	282-01	11S86 no. 1L	GBM 11F638
05/29/74	Luna-22	4	46	Success	81L	282-02	11S824 no. 0701	E-8LS no. 220
06/24/74	Almaz-2	3	47	Success	81L	283-02		11F71 no. 101-2
07/29/74	Molnya-1S	4	48	Success	81L	287-01	11S86 no. 2L	11F658 no. 38
10/28/74	Luna-23	4	49	Success	81L	285-01	11S824 no. 0901	E-8-5M no. 410
12/26/74	Salyut-4	3	50	Success	81L	284-02		17K no. 124
06/08/75	Venera-9	4	51	Success	81L	286-01	11S824M no. 1L	4V-1 no. 660
06/14/75	Venera-10	4	52	Success	81L	81L 285-02	11S824M no. 2L	4V-1 no. 661
10/08/75	Cosmos-775	4	53	Success	81L	286-02	11S86 no. 4L	5V95
10/16/75	Luna	4	54	Failure (fourth stage)	81L	287-02	11S824 no. 1401	E-8-5M no. 411
12/22/75	Raduga-1	4	55	Success	81L	288-01	11S86 no. 3L	11F638 no. 11L
06/22/76	Almaz-3	3	56	Success	81L	290-02	11F71 no. 103	
08/09/76	Luna-24	4	57	Success	81L	288-02	11S824 no. 1501	E-8-5M no. 412
09/11/76	Raduga-2	4	58	Success	81L	289-01	11S86 no. 5L	11F638 no. 12L

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
10/26/76	Ecran-1	4	59	Success	81L	290-01	11S86 no. 6L	11F647 no. 11L
12/15/76	Cosmos-881	3	60	Success	81L	289-02		11F74 no. 009/1
	Cosmos-882							11F74 no. 009A/1
07/17/77	Cosmos-929	3	61	Success	81L	293-02		11F72 no. 16101
07/23/77	Raduga-3	4	62	Success	200R	291-01	11S86 no. 7L	11F368 no. 13L
08/04/77	Cosmos	3	63	Failure (first stage)	81L	293-01		11F74 no. 009A/P
	Cosmos							11F74 no. 009P
09/20/77	Ecran-2	4	64	Success	200R	291-02	11S86 no. 9L	11F647 no. 12L
09/29/77	Salyut-6	3	65	Success	81L	295-01		17K no. 125
03/30/78	Cosmos-997	3	66	Success	81L	292-01		11F74 no. 009A/P2
	Cosmos-998							11F74 no. 009P/2
05/27/78	Ecran	4	67	Failure (first stage)	200R	294-02	11S86 no. 11L	11F647 no. 13L
07/08/78	Raduga-4	4	68	Success	200R	292-02	11S86 no. 10L	11F368 no. 14L
08/17/78	Ecran	4	69	Failure (second stage)	200R	297-02	11S86 no. 14L	11F647 no. 15L
09/09/78	Venera-11	4	70	Success	81L	296-01	11S824M no. 3L	4V-1 no. 360
09/14/78	Venera-12	4	71	Success	81L	296-02	11S824M no. 4L	4V-1 no. 361
10/17/78	Ecran	4	72	Failure (second stage)	200R	298-01	11S86 no. 12L	11F647 no. 14L
12/19/78	Gorizont-1	4	73	Failure (fourth stage)	200R	295-02	11S86 no. 17L	11F662 no. 11L
02/21/79	Ecran-3	4	74	Success	200R	294-01	11S86 no. 13L	11F647 no. 16L
04/26/79	Raduga-5	4	75	Success	200R	298-02	11S86 no. 15L	11F638 no. 15L
05/22/79	Cosmos-1100	4	76	Success	81L	300-02		11F74 no. 0102
	Cosmos-1101							11F74 no. 0102A
07/05/79	Gorizont-2	4	77	Success	200R	299-01	11S86 no. 21L	11F662 no. 12L
10/03/79	Ecran-4	4	78	Success	200R	302-02	11S86 no. 23L	11F647 no. 17L
12/28/79	Gorizont-3	4	79	Success	200R	303-01	11S86 no. 24L	11F662 no. 13L
02/20/80	Raduga-6	4	80	Success	200L	297-01	11S86 no. 16L	11F638 no. 16L

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
06/14/80	Gorizont-4	4	81	Success	200L	303-02	11S86 no. 27L	11F662 no. 15L
07/14/80	Ecran-5	4	82	Success	200R	301-01	11S86 no. 25L	11F647 no. 19L
10/05/80	Raduga-7	4	83	Success	200L	300-01	11S86 no. 19L	11F638 no. 17L
12/26/80	Ecran-6	4	84	Success	200R	304-01	11S86 no. 32L	11F647 no. 20L
03/18/81	Raduga-8	4	85	Success	200R	306-01	11S86 no. 18L	11F638 no. 18L
04/25/81	Cosmos-1267	3	86	Success	200L	299-02		11F72 no. 16301
06/26/81	Ecran-7	4	87	Success	200R	305-01	11S86 no. 20L	11F647 no. 21L
07/30/81	Raduga-9	4	88	Success	200L	301-02	11S86 no. 22L	11F638 no. 19L
10/09/81	Raduga-10	4	89	Success	200L	310-01	11S86 no. 36L	11F638 no. 20L
10/30/81	Venera-13	4	90	Success	200R	311-01	11S824M no. 5L	4V-1M no. 760
11/04/81	Venera-14	4	91	Success	200L	311-02	11S824M no. 6L	4V-1M no. 761
02/05/82	Ecran-8	4	92	Success	200R	308-01	11S86 no. 26L	11F647 no. 22L
03/15/82	Gorizont-5	4	93	Success	200L	305-02	11S86 no. 35L	11F662 no. 14L
04/19/82	Salyut-7	3	94	Success	200R	306-02		17K no. 125-2
05/19/82	Cosmos-1366	4	95	Success	200L	310-02	11S86 no. 28L	11F663 no. 11L
07/23/82	Ecran	4	96	Failure (first stage)	200R	307-02	11S86 no. 30L	11F647 no. 23L
09/16/82	Ecran-9	4	97	Success	200R	309-01	11S86 no. 31L	11F647 no. 24L
10/12/82	Cosmos-1413	4	98	Success	200L	315-01	11S861 no. 1L	11F654 no. 11L
	Cosmos-1414							11F654 GBM
	Cosmos-1415							11F654 GBM
10/20/82	Gorizont-6	4	99	Success	200R	312-01	11S86 no. 37L	11F662 no. 16L
01/26/82	Raduga-11	4	100	Success	200L	313-01	11S86 no. 29L	11F638 no. 21L
12/24/82	Raduga	4	101	Failure (second stage)	200R	314-01	11S86 no. 33L	11F638 no. 22L
03/02/83	Cosmos-1443	3	102	Success	200L	309-02		11F72 no. 16401
03/12/83	Ecran-10	4	103	Success	200R	304-02	11S86 no. 34L	11F647 no. 18L
03/23/83	Astron	4	104	Success	200L	307-01	11S824M no. 7L	1A
04/08/83	Raduga-12	4	105	Success	200R	315-02	11S86 no. 38L	11F638 no. 23L

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
06/02/83	Venera-15	4	106	Success	200L	321-01	11S824M no. 8L	4V-2 no. 860
06/07/83	Venera-16	4	107	Success	200R	321-02	11S824M no. 9L	4V-2 no. 861
07/01/83	Gorizont-7	4	108	Success	200L	314-02	11S86 no. 39L	11F662 no. 17L
08/11/83	Cosmos-1490	4	109	Success	200L	317-01	11S861 no. 2L	11F654 no. 12L
	Cosmos-1491							11F654 no. 13L
	Cosmos-1492							11F654 GBM
08/26/83	Raduga-13	4	110	Success	200R	316-02	11S86 no. 40L	11F638 no. 24L
09/29/83	Ecran-11	4	111	Success	200R	318-01	11S86 no. 50L	11F647 no. 25L
11/20/83	Gorizont-8	4	112	Success	200L	308-02	11S86 no. 41L	11F662 no. 18L
12/29/83	Cosmos-1519	4	113	Success	200R	320-02	11S861 no. 4L	11F654 no. 14L
	Cosmos-1520							11F654 no. 15L
	Cosmos-1521							11F654 GBM
02/16/84	Raduga-14	4	114	Success	200L	318-02	11S86 no. 42L	11F638 no. 25L
03/02/84	Cosmos-1540	4	115	Success	200R	316-01	11S86 no. 43L	11F663 no. 12L
03/16/84	Ecran-12	4	116	Success	200L	322-01	11S86 no. 44L	11F647 no. 26L
03/29/84	Cosmos-1546	4	117	Success	200R	319-02	11S86 no. 45L	74X6 (Oko)
04/22/84	Gorizont-9	4	118	Success	200L	312-02	11S86 no. 46L	11F662 no. 19L
05/19/84	Cosmos-1554	4	119	Success	200R	323-02	11S861 no. 3L	11F654 no. 16L
	Cosmos-1555							11F654 no. 17L
	Cosmos-1556							11F654 GBM
06/22/84	Raduga-15	4	120	Success	200L	319-01	11S86 no. 47L	11F638 no. 27L
08/02/84	Gorizont-10	4	121	Success	200R	324-01	11S86 no. 48L	11F662 no. 20L
08/24/84	Ecran-13	4	122	Success	200L	324-02	11S86 no. 51L	11F647 no. 27L
09/05/84	Cosmos-1593	4	123	Success	200R	320-01	11S861 no. 5L	11F654 no. 18L
	Cosmos-1594							11F654 no. 19L
	Cosmos-1595							11F654 GBM
09/29/84	Cosmos-1603	4	124	Success	200L	327-02	11S861 no. 6L	11F664 (Tselina-2)
12/15/84	Vega-1	4	125	Success	200L	329-01	11S824M no. 11L	5VK no. 901

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
12/21/84	Vega-2	4	126	Success	200R	325-02	11S824M no. 12L	5VK no. 902
01/18/85	Gorizont-11	4	127	Success	200L	326-02	11S86 no. 52L	11F662 no. 21L
02/21/85	Cosmos-1629	4	128	Success	200L	327-01	11S86 no. 49L	74X6 (Oko)
03/22/85	Ecran-14	4	129	Success	200R	328-01	11S86 no. 53L	11F647 no. 28L
05/18/85	Cosmos-1650	4	130	Success	200L	330-02	11S861 no. 7L	11F654 no. 20L
	Cosmos-1651							11F654 no. 21L
	Cosmos-1652							11F654 GBM
05/30/85	Cosmos-1656	4	131	Success	200R	313-02	11S861 no. 8L	11F664 (Tselina-2)
08/09/85	Raduga-16	4	132	Success	200L	317-02	11S86 no. 55L	11F638 no. 26L
09/27/85	Cosmos-1686	3	133	Success	200L	331-01		11F72 no. 16501
10/25/85	Cosmos-1700	4	134	Success	200R	332-02	11S861 no. 9L	11F669 no. 11L
11/15/85	Raduga-17	4	135	Success	200L	326-01	11S86 no. 56L	11F638 no. 28L
12/25/85	Cosmos-1710	4	136	Success	200L	334-02	11S861 no. 11L	11F654 no. 22L
	Cosmos-1711							11F654 no. 23L
	Cosmos-1712							11F654 GBM
01/17/86	Raduga-18	4	137	Success	200R	331-02	11S861 no. 57L	11F638 no. 29L
02/20/86	Mir	3	138	Success	200L	337-01		17K no. 12701
04/04/86	Cosmos-1738	4	139	Success	200R	302-01	11S86 no. 59L	11F663 no. 13L
05/24/86	Ecran-15	4	140	Success	200L	333-01	11S86 no. 64L	11F647 no. 30L
06/10/86	Gorizont-12	4	141	Success	200R	322-02	11S86 no. 60L	11F662 no. 24L
09/16/86	Cosmos-1778	4	142	Success	200R	336-01	11S861 no. 10L	11F654 no. 24L
	Cosmos-1779							11F654 no. 25L
	Cosmos-1780							11F654 no. 26L
10/25/86	Raduga-19	4	143	Success	200R	335-02	11S86 no. 62L	11F638 no. 30L
11/18/86	Gorizont-13	4	144	Success	200L	334-01	11S86 no. 58L	11F662 no. 22L
11/29/86	Almaz	3	145	Failure (second stage)	200R	338-01		11F668 no. 303
01/30/87	Cosmos-1817	4	146	Failure (fourth stage)	200R	341-01	11S861 no. 17L	11F647M no. 11L

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
03/19/87	Raduga-20	4	147	Success	200R	323-01	11S86 no. 63L	11F638 no. 31L
03/31/87	Kvant-1	3	148	Success	200L	336-02		37KE+77KE
04/24/87	Cosmos-1838	4	149	Failure (fourth stage)	200R	335-01	11S861 no. 18L	11F654 no. 30L
	Cosmos-1839							11F654 no. 31L
	Cosmos-1840							11F654 no. 32L
05/11/87	Gorizont-14	4	150	Success	200L	338-02	11S86 no. 61L	11F662 no. 23L
07/25/87	Cosmos-1870	3	151	Success	200R	347-01		11F668 no. 304
09/03/87	Ecran-16	4	152	Success	200L	337-02	11S86 no. 65L	11F647 no. 29L
09/16/87	Cosmos-1883	4	153	Success	200R	339-02	11S861 no. 26L	11F654 no. 33L
	Cosmos-1884							11F654 no. 34L
	Cosmos-1885							11F654 no. 35L
10/01/87	Cosmos-1888	4	154	Success	200L	328-02	11S861 no. 14L	11F663 no. 15L
10/28/87	Cosmos-1894	4	155	Success	200R	325-01	11S861 no. 28L	74X6 (US-K)
11/26/87	Cosmos-1897	4	156	Success	200L	330-01	11S861 no. 29L	11F669 no. 12L
12/10/87	Raduga-21	4	157	Success	200R	343-01	11S861 no. 30L	11F638 no. 32L
12/27/87	Ecran-17	4	158	Success	200L	345-01	11S861 no. 31L	11F647M no. 13L
01/18/88	Gorizont	4	159	Failure (third stage)	200R	341-02	11S861 no. 21L	11F662 no. 25L
2/17/88	Cosmos-1917	4	160	Failure (fourth stage)	200L	346-02	11S861 no. 32L	11F654 no. 38L
	Cosmos-1918							11F654 no. 37L
	Cosmos-1919							11F654 no. 36L
03/31/88	Gorizont-15	4	161	Success	200R	343-02	11S86 no. 54L	11F662 no. 26L
04/26/88	Cosmos-1940	4	162	Success	200L	332-01	11S861 no. 12L	74X6 (US-K)
05/06/88	Ecran-18	4	163	Success	200R	349-01	11S86 no. 66L	11F647 no. 31L

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
05/21/88	Cosmos-1946	4	164	Success	200L	348-01	11S861 no. 13L	11F654 no. 39L
	Cosmos-1947							11F654 no. 40L
	Cosmos-1948							11F654 no. 41L
07/07/88	Phobos-1	4	165	Success	200L	356-02	11S824F no. 2L	1F no. 101
07/12/88	Phobos-2	4	166	Success	200R	356-01	11S824F no. 1L	1F no. 102
08/02/88	Cosmos-1961	4	167	Success	200L	351-01	11S861 no. 33L	11F663 no. 16L
08/18/88	Gorizont-16	4	168	Success	200R	333-02	11S861 no. 15L	11F662 no. 28L
09/16/88	Cosmos-1970	4	169	Success	200L	349-02	11S861 no. 43L	11F654 no. 42L
	Cosmos-1971							11F654 no. 43L
	Cosmos-1972							11F654 no. 44L
10/20/88	Raduga-22	4	170	Success	200L	339-01	11S861 no. 40L	11F638 no. 34L
12/10/88	Ecran-19	4	171	Success	200R	329-02	11F861 no. 19L	11F647M no. 12L
01/10/89	Cosmos-1987	4	172	Success	200L	350-02	11F861 no. 42L	11F654 no. 27L
	Cosmos-1988							11F654 no. 45L
	Cosmos-1989							Etalon no. 1L
01/26/89	Gorizont-17	4	173	Success	200R	351-02	11S861 no. 20L	11F662 no. 29L
04/14/89	Raduga-23	4	174	Success	200L	359-02	11S861 no. 22L	11F638 no. 33L
05/31/89	Cosmos-2022	4	175	Success	200R	352-02	11S861 no. 39L	11F654 no. 28L
	Cosmos-2023							11F654 no. 29L
	Cosmos-2024							Etalon no. 2L
06/22/89	Raduga-1/1	4	176	Success	200L	355-02	11S861 no. 16L	17F15 no. 11L
07/06/89	Gorizont-18	4	177	Success	200R	340-02	11S861 no. 25L	11F662 no. 27L
09/28/89	Gorizont-19	4	178	Success	200R	346-01	11S861 no. 27L	11F662 no. 31L

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
11/26/89	Kvant-2	3	179	Success	200L	354-01		77KSD no. 17101
12/01/89	Granat	4	180	Success	200R	352-01	11S824M no. 10L	1AS
12/15/89	Raduga-24	4	181	Success	81L	344-01	11S861 no. 23L	11F638 no. 36L
12/27/89	Cosmos-2054	4	182	Success	200L	347-02	11S861 no. 34L	11F669 no. 14L
02/15/90	Raduga-25	4	183	Success	81L	363-02	11S861 no. 41L	11F638 no. 35L
05/19/90	Cosmos-2079	4	184	Success	200R	350-01	11S861 no. 37L	11F654 no. 46L
	Cosmos-2080							11F654 no. 51L
	Cosmos-2081							11F654 no. 52L
05/31/90	Cristal	3	185	Success	200L	360-01		77KST no. 17201
06/21/90	Gorizont-20	4	186	Success	200R	342-02	11S86 no. 67L	11F662 no. 30L
07/19/90	Cosmos-2085	4	187	Success	200L	340-01	11S861 no. 24L	11F663 no. 17L
08/09/90	Ecran	4	188	Failure (third stage)	200L	345-02	11S861 no. 44L	11F647M no. 14L
11/03/90	Gorizont-21	4	189	Success	81L	370-01	11S861 no. 35L	11F662 no. 32L
11/23/90	Gorizont-22	4	190	Success	200L	348-02	11S861 no. 46L	11F662 no. 33L
12/08/90	Cosmos-2109	4	191	Success	200R	366-02	11S861 no. 47L	11F654 no. 47L
	Cosmos-2110							11F654 no. 48L
	Cosmos-2111							11F654 no. 49L
12/20/90	Raduga-26	4	192	Success	81L	361-01	11S861 no. 48L	11F638 no. 37L
12/27/90	Raduga-1/2	4	193	Success	200L	342-01	11S861 no. 46L	17F15 no. 12L
02/14/91	Cosmos-2133	4	194	Success	200L	344-02	11S861 no. 38L	71X6 (US-KMO)
02/28/91	Raduga-27	4	195	Success	81L	360-02	11S861 no. 49L	11F638 no. 38L
03/31/91	Almaz-1	3	196	Success	200R	365-01		11F668 no. 305

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
04/04/91	Cosmos-2139	4	197	Success	200L	354-02	11S861 no. 53L	11F654 no. 50L
	Cosmos-2140							11F654 no. 53L
	Cosmos-2141							11F654 no. 54L
07/02/91	Gorizont-23	4	198	Success	200L	373-01	11S861 no. 50L	11F662 no. 34L
09/13/91	Cosmos-2155	4	199	Success	81L	353-01	11S861 no. 54L	74X6 (US-K)
10/23/91	Gorizont-24	4	200	Success	200L	362-02	11S861 no. 55L	11F662 no. 35L
11/22/91	Cosmos-2172	4	201	Success	81L	353-02	11S861 no. 51L	11F663 no. 18L
12/19/91	Raduga-28	4	202	Success	81L	355-01	11S861 no. 52L	11F638 no. 39L
01/29/92	Cosmos-2177	4	203	Success	81L	372-02	11S861 no. 59L	11F654 no. 68L
	Cosmos-2178							11F654 no. 69L
	Cosmos-2179							11F654 no. 71L
04/02/92	Gorizont-25	4	204	Success	81L	369-01	11S861 no. 57L	11F622 no. 36L
07/14/92	Gorizont-26	4	205	Success	81L	371-02	11S861 no. 60L	11F662 no. 37L
07/30/92	Cosmos-2204	4	206	Success	81L	376-01	11S861 no. 63L	11F654 no. 56L
	Cosmos-2205							11F654 no. 72L
	Cosmos-2206							11F654 no. 74L
09/10/92	Cosmos-2209	4	207	Success	81L	363-01	11S861 no. 61L	74X6 (US-K)
10/30/92	Ecran-20	4	208	Success	81L	372-01	11S861 no. 58L	11F647M no. 15L
11/27/92	Gorizont-27	4	209	Success	81L	364-01	11S861 no. 65L	11F662 no. 38L
12/17/92	Cosmos-2224	4	210	Success	200L	357-02	11S861 no. 64L	71X6 (US-KMO)
02/17/93	Cosmos-2234	4	211	Success	81L	362-01	11S861 no. 66L	11F654 no. 73L
	Cosmos-2235							11F654 no. 59L
	Cosmos-2236							11F654 no. 57L

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
03/25/93	Raduga-29	4	212	Success	81L	358-01	11S861 no. 67L	11F638 no. 42L
05/27/93	Gorizont	4	213	Failure (second stage)	81L	364-02	11S861 no. 69L	11F662 no. 39L
10/01/93	Raduga-30	4	214	Success	81L	359-01	11S861 no. 36L	11F638 no. 41L
10/28/93	Gorizont-28	4	215	Success	81L	368-01	11S861 no. 72L	11F662 no. 40L
11/18/93	Gorizont-29	4	216	Success	81L	367-01	11S861 no. 85L	11F662 no. 41L
01/20/94	Gals-1	4	217	Success	81L	358-02	11S861-01 no. 03L	17F71 no. 11L
02/05/94	Raduga-1/3	4	218	Success	81L	375-02	11S861 no. 83L	17F15 no. 13L
02/18/94	Raduga-31	4	219	Success	81L	376-02	11S861 no. 73L	11F638 no. 40L
04/11/94	Cosmos-2275	4	220	Success	81L	377-01	11S861 no. 70L	11F654 no. 58L
	Cosmos-2276							11F654 no. 60L
	Cosmos-2277							11F654 no. 61L
05/20/94	Gorizont-30	4	221	Success	81L	357-01	11S861 no. 71L	11F662 no. 42L
07/07/94	Cosmos-2282	4	222	Success	81L	365-02	11S861 no. 68L	71X6 (US-KMO)
08/11/94	Cosmos-2287	4	223	Success	81L	367-02	11S861 no. 74L	11F654 no. 67L
	Cosmos-2288							11F654 no. 70L
	Cosmos-2289							11F654 no. 75L
09/22/94	Cosmos-2291	4	224	Success	200L	381-02	11S861 no. 86L	11F663 no. 19L
10/13/94	Express-1	4	225	Success	200L	377-02	11S861-01 no. 01L	11F639 no. 11L
10/31/94	Elektro-1	4	226	Success	81L	361-02	11S861 no. 56L	11F652 no. 1L
11/20/94	Cosmos-2294	4	227	Success	200L	371-01	11S861 no. 97L	11F654 no. 62L
	Cosmos-2295							11F654 no. 63L
	Cosmos-2296							11F654 no. 64L

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
12/16/94	Luch-1	4	228	Success	81L	373-02	11S861 no. 75L	11F669 no. 13L
12/28/94	Raduga-32	4	229	Success	81L	366-01	11S861 no. 62L	11F638 no. 43L
03/07/95	Cosmos-2307	4	230	Success	200L	370-02	11S861 no. 76L	11F654 no. 65L
	Cosmos-2308							11F654 no. 66L
	Cosmos-2309							11F654 no. 77L
05/20/95	Spectre	3	231	Success	81L	378-02		77KSO no. 17301
07/24/95	Cosmos-2316	4	232	Success	81L	374-01	11S861 no. 77L	11F654 no. 80L
	Cosmos-2317							11F654 no. 81L
	Cosmos-2318							11F654 no. 85L
08/30/95	Cosmos-2319	4	233	Success	81L	369-02	11S861 no. 78L	11F663 no. 20L
10/11/95	Luch-2	4	234	Success	81L	386-01	11S861 no. 79L	14F30 (Helios)
11/17/95	Gals-2	4	235	Success	200L	384-01	11S861 no. 94L	17F71 no. 12L
12/14/95	Cosmos-2323	4	236	Success	200L	378-01	11S861 no. 80L	11F654 no. 82L
	Cosmos-2324							11F654 no. 78L
	Cosmos-2325							11F654 no. 76L
01/25/96	Gorizont-31	4	237	Success	200L	374-02	11S861 no. 81L	11F662 no. 43L
02/19/96	Raduga-33	4	238	Failure (fourth stage)	200L	383-02	11S861 no. 82L	11F638 no. 44L
04/09/96	Astra-1F	4	239	Success	81L	390-01	DM-3 no. 1L	First launch ILS
04/23/96	Priroda	3	240	Success	81L	385-01		77KSI no. 17401
05/25/96	Gorizont-32	4	241	Success	200L	379-01	11S861 no. 100L	11F662 no. 44L
09/06/96	Inmarsat-3F2	4	242	Success	81L	375-01	DM-1 no. 1L	Commercial
09/26/96	Express-2	4	243	Success	200L	379-02	11S861-01 no. 2L	11F639 no. 12L

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
11/16/96	Mars-96	4	244	Failure (fourth stage)	200L	392-02	11S824F no. 3L	M1 no. 520
05/24/97	Telstar-5	4	245	Success	81L	380-02	DM-4 no. 1L	Second launch ILS
06/06/97	Cosmos-2344	4	246	Success	200L	380-01	DM-5 no. 1L	11F664 no. 1L
06/18/97	Iridium	4	247	Success	81L	390-02	DM-2 no. 1L	Commercial
08/14/97	Cosmos-2345	4	248	Success	200L	381-01	11S861 no. 88L	74X6 (US-K)
08/28/97	PanAmSat-5	4	249	Success	81L	387-02	DM-3 no. 3L	Third launch ILS
09/13/97	Iridium	4	250	Success	81L	391-01	DM-2 no. 2L	Commercial
11/12/97	Coupon-1	4	251	Success	200L	384-02	11S861-01 no. 8L	K95K
12/03/97	Astra-1G	4	252	Success	81L	382-02	DM-3 no. 2L	Fourth launch ILS
12/25/97	Asiasat-3	4	253	Failure (fourth stage)	81L	394-01	DM-3 no. 5L	Fifth launch ILS
04/07/98	Iridium	4	254	Success	81L	391-02	DM-2 no. 4L	Commercial
04/29/98	Cosmos-2350	4	255	Success	200L	384-02	11S861 no. 98L	71X6 (US-KMO)
05/08/98	Echostar-4	4	256	Success	81L	395-02	DM-3 no. 7L	Sixth launch ILS
08/29/98	Astra-2A	4	257	Success	81L	383-01	DM-3 no. 9L	Seventh launch ILS
11/04/98	PanAmSat-8	4	258	Success	81L	396-01	DM-3 no. 10L	Eighth launch ILS
11/20/98	FGB Zarya	3	259	Success	81L	395-01		77KM
12/30/98	Cosmos-2362	4	260	Success	200L	385-02	11S861 no. 92L	11F654 no. 79L
	Cosmos-2363							11F654 no. 84L
	Cosmos-2364							11F654 no. 86L
02/15/99	Telstar-6	4	261	Success	81L	396-01	DM-3 no. 4L	Ninth launch ILS
02/28/99	Raduga-1/4	4	262	Success	81L	387-01	11S861 no. 84L	17F15 no. 14L
03/21/99	Asiasat-3S	4	263	Success	81L	388-01	DM-3 no. 12L	10th launch ILS
05/20/99	Nimiq-1	4	264	Success	81L	396-02	DM-3 no. 11L	11th launch ILS
06/18/99	Astra-1H	4	265	Success	81L	397-02	DM-3 no. 8L	12th launch ILS

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
07/05/99	Raduga-34	4	266	Failure (second stage)	81L	389-01	14S43 no. 88501	11F638 no. 45L
09/06/99	Yamal-101	4	267	Success	81L	388-02	11S861-01 no. 4L	Governmental
	Yamal-102							Governmental
09/26/99	LMI-1	4	268	Success	81L	398-02	DM-3 no. 18L	13th launch ILS
10/27/99	Express-A1	4	269	Failure (second stage)	200L	386-02	11S861 no. 102L	Governmental
02/12/00	ACeS/Garuda	4	270	Success	81L	399-02	DM-3 no. 15L	14th launch ILS
03/12/00	Express-A2	4	271	Success	200L	399-01	11S861-01 no. 10L	Governmental
04/17/00	Sesat-1	4	272	Success	200L	397-01	11S861-01 no. 9L	Commercial
06/06/00	Gorizont-33	4	273	Success	81L	392-01	14S43 no. 88502	11F662 no. 45L
06/22/00	Express-A3	4	274	Success	200L	394-02	11S861 no. 89L	Governmental
06/30/00	Sirius-1	4	275	Success	81L	400-01	DM-3 no. 29L	15th launch ILS
07/05/00	Cosmos-2371	4	276	Success	200L	389-02	11S861 no. 90L	11F663 no. 21L
07/12/00	Zvezda	3	277	Success	81L	398-01		17KSM
08/28/00	Raduga-1/5	4	278	Success	81L	401-02	11S861 no. 87L	17F15 no. 15L
09/05/00	Sirius-2	4	279	Success	81L	400-02	DM-3 no. 22L	16th launch ILS
10/01/00	GE-1A	4	280	Success	81L	401-01	DM-3 no. 13L	17th launch ILS
10/13/00	Cosmos-2374	4	281	Success	81L	393-01	11S861 no. 91L	11F654
	Cosmos-2375							11F654
	Cosmos-2376							11F654
10/22/00	GE-6	4	282	Success	81L	402-01	DM-3 no. 19L	18th launch ILS
11/30/00	Sirius-3	4	283	Success	81L	402-02	DM-3 no. 17L	19th launch ILS
04/07/01	Ecran-M16	4	284	Success	81L	535-01/M	14S43 no. 88503	11F647M
05/15/01	PAS-10	4	285	Success	81L	403-01	DM-3 no. 6L	20th launch ILS
06/16/01	Astra-2C	4	286	Success	81L	403-02	DM-3 no. 27L	21st launch ILS

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
08/24/01	Cosmos-2379	4	287	Success	81L	404-01	11S861 no. 99L	71X6 (US-KMO)
10/05/01	Raduga-1/6	4	288	Success	81L	405-01	11S861 no. 93L	17F15 no. 16L
12/01/01	Cosmos-2380	4	289	Success	81L	405-02	11S861 no. 101L	11F654
	Cosmos-2381							11F654
	Cosmos-2382							11F654M
03/30/02	Intelsat-903	4	290	Success	81L	406-01	DM-3 no. 28L	22nd launch ILS
05/07/02	DirecTV-5	4	291	Success	81L	404-02	DM-3 no. 21L	23rd launch ILS
06/10/02	Express-A1R	4	292	Success	200L	407-01	11S861-01 no. 11L	Governmental
07/25/02	Cosmos-2392	4	293	Success	81L	408-01	DM-5 no. 2L	11F664 no. 2L
08/22/02	Echostar-8	4	294	Success	81L	406-02	DM-3 no. 20L	24th launch ILS
10/17/02	Integral	4	295	Success	200L	409-01	DM-2 no. 5L	ESA satellite
11/26/02	Astra-1K	4	296	Failure (fourth stage)	81L	408-02	DM-3 no. 24L	25th launch ILS
12/25/02	Cosmos-2394	4	297	Success	81L	409-02	11S861 no. 95L	11F654
	Cosmos-2395							11F654
	Cosmos-2396							11F654M
12/30/02	Nimiq-2	4	298	Success	81L	535-02/M	14S43 no. 88504	26th launch ILS
04/24/03	Cosmos-2397	4	299	Success	81L	410-02	11S861 no. 96L	71X6 (US-KMO)
06/10/03	GE-12/AMC-9	4	300	Success	200L	410-01	14S43 no. 88505	27th launch ILS
11/24/03	Yamal-201	4	301	Success	81L	407-02	11S861-01 no. 12L	Governmental
	Yamal-202							Governmental
12/10/03	Cosmos-2402	4	302	Success	81L	410-03	14S43 no. 88506	11F654
	Cosmos-2403							11F654
	Cosmos-2404							11F654M

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
12/28/03	Express-AM22	4	303	Success	200L	410-04	11S861-01 no. 13L	Governmental
03/17/04	W-3A	4	304	Success	81L	535-03	14S43 no. 88507	28th launch ILS
03/27/04	Raduga-1/7	4	305	Success	81L	410-05	11S861 no. 105L	17F15 no. 17L
04/27/04	Express-AM11	4	306	Success	200L	410-06	11S861-01 no. 14L	Governmental
06/15/04	Intelsat-10	4	307	Success	200L	535-06	14S43 no. 88509	29th launch ILS
08/04/04	Amazonas-1	4	308	Success	200L	535-07	14S43 no. 88508	30th launch ILS
10/15/04	AMC-15	4	309	Success	200L	535-08	14S43 no. 88510	31st launch ILS
10/30/04	Express-AM1	4	310	Success	200L	410-08	11S861-01 no. 15L	Governmental
12/25/04	Cosmos-2411	4	311	Success	81L	410-09	11S861 no. 104L	11F654
	Cosmos-2412							11F654
	Cosmos-2413							11F654M
02/03/05	AMC-12	4	312	Success	81L	535-09	14S43 no. 88511	32nd launch ILS
03/30/05	Express-AM2	4	313	Success	200L	410-10	11S861-01 no. 16L	Governmental
05/22/05	DirecTV-8	4	314	Success	200L	535-10	14S43 no. 88512	33rd launch ILS
06/23/05	Express-AM3	4	315	Success	200L	410-07	11S861 no. 103L	Governmental
09/08/05	Anik-F1R	4	316	Success	200L	535-12	14S43 no. 88513	34th launch ILS
12/25/05	Cosmos-2417	4	317	Success	81L	410-11	11S861 no. 106L	11F654M
	Cosmos-2418							11F654M
	Cosmos-2419							11F654M
12/28/05	AMC-23	4	318	Success	200L	535-13	14S43 no. 88514	35th launch ILS
02/28/06	Arabsat-4A	4	319	Failure (fourth stage)	200L	535-11	14S43 no. 88515	36th launch ILS

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
08/04/06	Hot Bird-8	4	321	Success	200L	535-14	14S43 no. 88516	37th launch ILS
11/08/06	Arabsat-4B	4	322	Success	200L	535-15	14S43 no. 88517	38th launch ILS
12/12/06	Measat-3	4	323	Success	200L	535-21	14S43 no. 88518	39th launch ILS
12/25/06	Cosmos-2424	4	324	Success	81L	410-15	11S861 no. 108L	11F654M
	Cosmos-2425							11F654M
	Cosmos-2426							11F654M
04/10/07	Anik-F3	4	325	Success	200L	535-16	14S43 no. 88521	40th launch ILS
07/07/07	DirecTV-10	4	326	Success	200L	535-20	14S43 no. 88520	41st launch ILS
09/05/07	JCSat-11	4	327	Failure (second stage)	200L	535-22	14S43 no. 88522	42nd launch ILS
10/25/07	Cosmos-2431	4	328	Success	81L	410-17	11S861 no. 110L	11F654M
	Cosmos-2432							11F654M
	Cosmos-2433							11F654M
11/17/07	Sirius-4 (NSAB)	4	329	Success	200L	535-23	14S43 no. 88523	43rd launch ILS
12/09/07	Raduga-1M-1	4	330	Success	81L	535-26	14S43 no. 88526	17F15M no. 11L
12/25/07	Cosmos-2434	4	331	Success	81L	535-28	11S861 no. 109L	11F654M
	Cosmos-2435							11F654M
	Cosmos-2436							11F654M
01/28/08	Express-AM33	4	332	Success	200L	535-27	14S43 no. 88527	Governmental
02/11/08	Thor-5	4	333	Success	200L	535-24	14S43 no. 88524	44th launch ILS
03/15/08	AMC-14	4	334	Failure (fourth stage)	200L	535-25	14S43 no. 88525	45th launch ILS
06/27/08	Cosmos-2440	4	335	Success	81L	410-14	11S861 no. 111L	71X6 (US-KMO)
08/19/08	Inmarsat-4F3	4	336	Success	200L	935-02	14S43 no. 99502	46th launch ILS

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
09/19/08	Nimiq-4	4	337	Success	200L	535-29	14S43 no. 88528	47th launch ILS
09/25/08	Cosmos-2442	4	338	Success	81L	535-31	11S861 no. 112L	11F654M
	Cosmos-2443							11F654M
	Cosmos-2444							11F654M
11/05/08	Astra-1M	4	339	Success	200L	535-33	14S43 no. 88531	48th launch ILS
12/10/08	Ciel-2	4	340	Success	200L	935-03	14S43 no. 99503	49th launch ILS
12/25/08	Cosmos-2447	4	341	Success	81L	535-34	11S861 no. 114L	11F654M
	Cosmos-2448							11F654M
	Cosmos-2449							11F654M
02/11/09	Express-AM44	4	342	Success	200L	935-01	14S43 no. 99501	Governmental
	Express-MD-1	4						Governmental
02/20/09	Raduga-1/8	4	343	Success	81L	410-16	11S861 no. 107L	17F15 no. 18L
04/04/09	W2A	4	344	Success	200L	935-04	14S43 no. 99504	50th launch ILS
05/16/09	Protostar-2	4	345	Success	200L	935-05	14S43 no. 99505	51st launch ILS
06/30/09	Sirius-FM5	4	346	Success	200L	935-06	14S43 no. 99506	52nd launch ILS
08/11/09	Asiasat-5	4	347	Success	200L	935-07	14S43 no. 99507	53rd launch ILS
09/17/09	Nimiq-5	4	348	Success	200L	935-08	14S43 no. 99508	54th launch ILS
11/23/09	W-7	4	349	Success	200L	935-09	14S43 no. 99509	55th launch ILS
12/14/09	Cosmos-2456	4	350	Success	81L	535-38	11S861 no. 115L	11F654M
	Cosmos-2457							11F654M
	Cosmos-2458							11F654M
12/29/09	DirecTV-12	4	351	Success	200L	935-10	14S43 no. 99510	56th launch ILS

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
01/28/10	Raduga-1M-2	4	352	Success	81L	535-35	14S43 no. 88527	17F15M no. 12L
02/12/10	Intelsat-16	4	353	Success	200L	535-32	14S43 no. 99511	57th launch ILS
03/02/10	Cosmos-2459	4	354	Success	81L	535-40	11S861 no. 116L	11F654M
	Cosmos-2460							11F654M
	Cosmos-2461							11F654M
03/20/10	Echostar-14	4	355	Success	200L	935-14	14S43 no. 99514	58th launch ILS
04/24/10	AMC-4R/SES-1	4	356	Success	200L	935-11	14S43 no. 99512	59th launch ILS
06/04/10	Arabsat-5B	4	357	Success	200L	935-12	14S43 no. 99513	60th launch ILS
07/10/10	Echostar-15	4	358	Success	200L	935-15	14S43 no. 99515	61th launch ILS
09/02/10	Cosmos-2464	4	359	Success	81L	535-30	11S861 no. 118L	11F654M
	Cosmos-2465							11F654M
	Cosmos-2466							11F654M
10/15/10	XM-5	4	360	Success	81L	935-16	14S43 no. 99517	62nd launch ILS
11/14/10	Skyterra-1	4	361	Success	200L	935-13	14S43 no. 99516	63rd launch ILS
12/05/10	Cosmos	4	362	Failure (fourth stage)	81L	535-37	11S861-03 no. 1L	11F654M
	Cosmos							11F654M
	Cosmos							11F654M
12/27/10	KaSat-1	4	363	Success	200L	935-17	14S43 no. 99518	64th launch ILS
05/20/11	Telstar-14R	4	364	Success	200L	935-19	14S43 no. 99520	65th launch ILS
07/16/11	SES-3	4	365	Success	200L	935-18	14S43 no. 99519	66th launch ILS
	Kazsat-2							Commercial

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
08/18/11	Express-AM4	4	366	Failure (fourth stage)	200L	935-21	14S43 no. 99524	Governmental
09/21/11	Garpun-1	4	367	Success	81L	535-42	14S43 no. 88529	14F136 no. 11L
09/29/11	Quetzsat-1	4	368	Success	200L	935-22	14S43 no. 99524	67th launch ILS
10/18/11	Viasat-1	4	369	Success	200L	935-20	14S43 no. 99521	68th launch ILS
11/04/11	Cosmos-2475	4	370	Success	81L	535-39	14S43 no. 99523	11F654M
	Cosmos-2476							11F654M
	Cosmos-2477							11F654M
11/25/11	Asiatsat-7	4	371	Success	200L	935-25	14S43 no. 99527	69th launch ILS
12/11/11	Luch-5A	4	372	Success	81L	935-23	14S43 no. 99525	Governmental
	Amos-5							Commercial
02/15/12	SES-4	4	373	Success	200L	935-24	14S43 no. 99526	70th ILS
03/25/12	Intelsat-22	4	374	Success	200L	935-28	14S43 no. 99537	71th ILS
03/30/12	Oko-2	4	375	Success	81L	410-18	11S861 no. 117L	71X6 no. 7128
04/24/12	Yahsat-1B	4	376	Success	200L	935-27	14S43 no. 99329	72nd ILS
05/17/12	Nimiq-6	4	377	Success	81L	935-29	14S43 no. 99530	73rd ILS
07/09/12	Astra-4B/SES-5	4	378	Success	81L	935-30	14S43 no. 99531	74th ILS
08/06/12	Telkom-3	4	379	Failure (fourth stage)	81L	935-31	14S43 no. 99532	Commercial
	Express-MD-2							Governmental
10/14/12	Intelsat-23	4	380	Success	81L	935-26	14S43 no. 99534	75th ILS
11/02/12	Luch-5B	4	381	Success	81L	935-32	14S43 no. 99533	Governmental
	Yamal-300K							Governmental

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
11/20/12	Echostar-16	4	382	Success	200L	935-33	14S43 no. 99528	76th ILS
12/08/12	Yamal-402	4	383	Failure (fourth stage)	200L	935-34	14S43 no. 99535	77th ILS
03/26/13	Satmex-8	4	384	Success	200L	935-36	14S43 no. 99536	78th ILS
04/15/13	Anik-G1	4	385	Success	200L	935-37	14S43 no. 99538	79th ILS
05/14/13	Eutelsat-3D	4	386	Success	200L	935-38	14S43 no. 99539	80th ILS
06/03/13	SES-6	4	387	Success	200L	935-40	14S43 no. 99541	81st ILS
07/02/13	Glonass-M	4	388	Failure (first stage)	81L	535-43	11S861-03 no. 2L	11F654M
	Glonass-M							11F654M
	Glonass-M							11F654M
09/30/13	Astra-second	4	389	Success	200L	935-39	14S43 no. 99540	82nd ILS
10/25/13	Sirius-FM6	4	390	Success	200L	935-35	14S43 no. 99542	83rd ILS
11/12/13	Raduga-1M-3	4	391	Success	81L	535-41	14S43 no. 88532	17F15M no. 13L
12/08/13	Inmarsat-5F1	4	392	Success	200L	935-44	14S43 no. 99546	84th ILS
12/26/13	Express-AM5	4	393	Success	81L	935-41	14S43 no. 99543	Governmental
02/15/14	Turksat-4A	4	394	Success	81L	935-43	14S43 no. 99544	85th ILS
03/16/14	Express-AT1	4	395	Success	81L	935-42	14S43 no. 99545	Governmental
	Express-AT2							Governmental
04/28/14	Luch-5V	4	396	Success	81L	935-46	14S43 no. 99548	Governmental
	Kazsat-3							Commercial
05/16/14	Express-AM4R	4	397	Failure (third stage)	200L	935-45	14S43 no. 99547	Governmental

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
09/28/14	Olymp-K	4	398	Success	81L	935-47	14S43 no. 99549	ELINT GEO
10/21/14	Express-AM6	4	399	Success (problem fourth stage)	81L	935-48	14S43 no. 99550	Governmental
12/16/14	Yamal-401	4	400	Success	81L	935-50	14S43 no. 99551	86th ILS
12/28/14	Astra-2G	4	401	Success	200L	935-49	14S43 no. 99552	87th ILS
02/01/15	Inmarsat-5F2	4	402	Success	200L	935-51	14S43 no. 99554	88th ILS
03/19/15	Express-AM7	4	403	Success	200L	935-52	14S43 no. 99553	Governmental
04/29/15	Mexsat-1	4	404	Failure (third stage)	200L	935-54	14S43 no. 99555	89th ILS
08/28/15	Inmarsat-5F3	4	405	Success	200L	935-55	14S43 no. 99556	90th ILS
09/14/15	Express-AM8	4	406	Success	81L	935-53	11S861-03 no. 5L	Governmental
10/16/15	Turksat-4B	4	407	Success	200L	935-56	14S43 no. 99557	91st ILS
12/13/15	Cosmos-2513	4	408	Success	81L	535-44	14S43 no. 88533	11F136 no. 12L (Garpun-2)
12/25/15	Express-AMU-1	4	409	Success	81L	935-57	14S43 no. 99559	Governmental
01/28/16	Eutelsat-9B/EDRS	4	410	Success	200L	935-58	14S43 no. 99558	92nd ILS
03/14/16	ExoMars-TGO	4	411	Success	200L	935-60	14S43 no. 99560	ESA
06/09/16	Intelsat-31	4	412	Success Phase IV	81L	937-01	14S43 no. 99570	93rd ILS
May 2017	Echostar-21	4	413	? Phase IV	?	?	14S43	94th ILS
June 2017	Cosmos	4	414	?	?	?	14S43	Blagovest no. 1
July	Amazonas-5	4	?	?	?	?	14S43	95th ILS
August	Cosmos	4	?	?	?	?	11S861-03	Military?
October	Asiasat-9	4	?	?	?	?	14S43	96th ILS

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
November	Glonass-M	4	?	?	?	?	11S861-03	11F654M
	Glonass-M							11F654M
	Glonass-M							11F654M
December	Cosmos	4	?	?	?	?	11S861-03	Military?
Planned 7 launches in 2017 including 3 for ILS								
March 2018	Spectre-RG	4	?	?	?	?	11S861-03	Astronomical observation
2018	MLM/Nauka	3	?	?	?	?		ISS module
2018	Glonass-K-18	4	?	?	?		11S861-03	Navigation Block-7
	Glonass-K-19							
	Glonass-K-20							
2018	Eutelsat-5WestB	3	?	?	?	?	14S43	ILS
2018	Yamal-601	4	?	?	?	?	14S43	Governmental
2018	Cosmos	4	?	?	?	?	14S43	Blagovest no. 2
2018	Glonass-K-21	4	?	?	?	?	11S861-03	Navigation Block-8
	Glonass-K-22							
	Glonass-K-23							
2018	Elektro-L3	4	?	?	?		11S861-03	Meteorology
Planned 8 launches in 2018 including 1 for ILS								
2019	Express-80	4	?	?	?	?	14S43	Governmental
	Express-103							Governmental
2019	Express-AMU-3	4	?	?	?	?	14S43	Governmental
	Express-AMU-7							Governmental
2019	Elektro-L4	4	?	?	?	?	11S861-03	Meteorology
2019	HEM-1	3	?	?	?	?		ISS module
2019	Luch-5M-1	4	?	?	?	?	11S861-03	Governmental
2019	Express-AMU-4	4	?	?	?	?	14S43	Governmental

Date	Satellite	No. of stages	No.	Observations	Pad	Launcher	Fourth stage	Satellite model
2019	ILS/Eutelsat	4	?	?	?	?	Proton Medium no. 1	ILS
2019	ILS/Intelsat	4	?	?	?	?	14S43	ILS
2019	Cosmos	4	?	?	?	?	14S43	Blagovest no. 3
2019	?	3	?	?	?	?	Proton Light no. 1	?
Planned 10 launches in 2019 including 2 for ILS								
8/5/20	ExoMars-Rover	4	?	?	?	?	14S43	ESA
2020	ILS/Eutelsat	4	?	?	?	?	14S43	ILS
2020	ILS/Intelsat	4	?	?	?	?	14S43	ILS
Planned 3 launches in 2020 including 2 for ILS								
2021	Spectre-UF	4	?	?	?	?	11S861-03	Scientific
2021	Elektro-L5	4	?	?	?	?	11S861-03	Meteorology
2021	ILS/Intelsat	4	?	?	?	?	14S43	ILS
2021	Express-RV-1	4	?	?	?	?	14S43	Governmental
	Express-RV-2							
Planned 4 launches in 2021 including 1 for ILS								
2022	Express-AMU-5	4	?	?	?	?	14S43	Governmental
2022	Express-AMU-6	4	?	?	?	?	14S43	Governmental
2022	Express-RV-3	4	?	?	?	?	14S43	Governmental
	Express-RV-4							
2022	ILS/Eutelsat	4	?	?	?	?	14S43	ILS
2022	ILS/Intelsat	4	?	?	?	?	14S43	ILS
Planned 5 launches in 2022 including 2 for ILS								
2023	ILS/Intelsat	4	?	?	?	?	14S43	ILS
2024	?							
2025	End of operation							

Bibliography

History of astronautics

[AFA 91] AFANASIEV I., *Neizvestnye Korabli* (*Unknown spacecrafts*), Znanie, St. Petersburg, 1991.

[AFA 97] AFANASIEV I., *"R-12, Sandalovoe Derevo"* (*R-12, Sandal's tree*), Hobby Magazine, Moscow, 1997.

[AFA 06] AFANASIEV I., LAVRENOV A., *Bolshoi Kosmicheskiy Klub* (*The big cosmic club*), RTS Soft, Moscow, 2006.

[BAT 05] BATOURINE Y.M. (ed.), *Mirovaya Pilotiruemaya Kosmonavtika* (*The manned cosmonautic of the world*), RTSoft, Moscow, 2005.

[BAT 08] BATOURINE Y.M., *Sovietskaya Kosmitcheskaya Initsiativa v gosoudarstvennykh dokumentakh 1946-1964*, RTSoft, Moscow, 2008.

[BRU 01] BRUK A.A., OUDALOV K.G., SMIRNOV S.G. *et al.*, *Encyclopédie illustrée des avions de V. M. Miassichtchev,* vol. 2, Avico Press, Moscow, 2001.

[CLA 88] CLARK P., *The Soviet Manned Space Program*, Salamander Books, London, 1988.

[COL 86] COLLECTIF D'AUTEURS, *Encyclopédie Universalis de l'espace*, Universalis, Boulogne-Billancourt, 1986.

[DAV 00] DAVYDOV I.V., *Triumf i Tragediya Sovetskoi Kosmonavtiki* (*Triumph and tragedy of Soviet cosmonautics*), Globus, Moscow, 2000.

[DAV 11] DAVYDOV V.A. (ed.), *Pervyï pilotirouemyï polet*, vols 1–2, Rodina Media, Moscow, 2011.

[FAV 97] FAVORSKI V., MESHERYAKOV I., *Voenno-Kosmicheskie Sily* (*Military Space forces*), vol. 1, Editions typographie de St. Petersburg Nauka, Moscow, 1997.

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

[FAV 98] FAVORSKI V., MESHERYAKOV I., *Voenno-Kosmicheskie Sily* (*Military Space forces*, vol. 2, Editions typographie de St. Petersburg Nauka, Moscow, 1998.

[FAV 01] FAVORSKI V., MESHERYAKOV I., *Voenno-Kosmicheskie Sily* (*Military Space forces*), vol. 3, Vestnik Vozdouchno Flota, 2001.

[FAV 03a] FAVORSKI V., MESHERYAKOV I., *Kosmonavtika i raketno-kosmitcheskaya promychlennosty*, vol. 1 – 1946-1975, Machinostroenie Publishers, Moscow, 2003.

[FAV 03b] FAVORSKI V., MESHERYAKOV I., *Kosmonavtika i raketno-kosmitcheskaya promychlennosty*, vol. 2 – 1976-1992, Machinostroenie Publishers, Moscow, 2003.

[GLU 85] GLUSHKO V.P., *Encyclopediya Kosmonavtika* (*Encyclopedia of Cosmonautics*), Sovetsakya Entsiklopediya, Moscow, 1985.

[HEP 87] HEPPENHEIMER T. A., *Countdown, A History of Space Flight*, John Wiley & Sons, New York, 1987.

[IVA 02] IVANOV S. (ed.), "Space Weapons", in *The XXI Century Encyclopedia vol. 5: Russia's Arms and Technologies*, Oruzhie i tekhnologii, Moscow, 2002.

[KAM 95] KAMANINE N.P., *Skrytyï Kosmos*, vol. 1 – 1960–1963, Infortext IF, 1995.

[KAM 97] KAMANINE N.P., *Skrytyï Kosmos*, vol. 2 – 1964–1966, Infortext IF, 1997.

[KAM 99] KAMANINE N.P., *Skrytyï Kosmos*, vol. 3 – 1967–1968, Infortext IF, 1999.

[KAM 01] KAMANINE N.P., *Skrytyï Kosmos*, vol. 4 – 1969–1978, Infortext IF, 2001.

[LAR 92] LARDIER C., *L'astronautique soviétique*, Armand Colin, Malakoff, 1992.

[LAR 07] LARDIER C., "L'histoire de Spoutnik-1", *Bulletin d'information de l'Institut français d'histoire de l'espace*, no. 2, pp. 3–7, October 2007.

[LAR 10] LARDIER C., BARENSKY S., *Les deux vies de Soyouz*, Edite, Paris, 2010.

[MEC 96] MECHERIAKOV I.V., *V Mire Kosmonavtiki* (*In the cosmonautic world*), Russki Kupets Nizhni, Novgorod, 1996.

[MIC 90] MICHINE V.P., *Pochemy My Ne Sletali na Lunu* (*Why we did not go to the moon*), Znanie, St. Petersburg, 1990.

[MIC 98] MICHINE V.P., *Ot Sozdaniya Ballisticheskikh Raket k Raketno-Kosmicheskomu* (*On the creation of rocketry and space ballistic missiles*), Inform-Znanie, Moscow, 1998.

[MIN 99] MINAIEV A.V., *Sovietskaya Voennaya Moch – ot Stalina do Gorbatcheva* (*Soviet military power, from Stalin to Gorbachev*), Military Parade, Moscow, 1999.

[MOZ 86] MOZJORINE Y.A. (ed.), *Kosmonavtika SSSR*, Mashinostroenie Publishers, Moscow, 1986.

[RAU 01] RAUSHENBAKH B.V. (ed.), *Issledovaniya po Istorii i Teorii Razvitiya Aviatsionnoi i Raketno-Kosmicheskoi Nauki i Tekhniki*, Nauka, Moscow, 2001.

[SAG 94] SAGDEEV R., *The Making of a Soviet Scientist*, John Wiley & Sons, New York, 1994.

[SER 99] SERGEEV I.D. (ed.), *Voenny Entsiklopedicheski Slovar RVSN* (*The encyclopedic dictionary of RVSN)*, BRE, Moscow, 1999.

[SID 00] SIDDIQI A.A., *Challenge to Apollo, the Soviet Union and the Space Race 1945-1974*, NASA, Washington DC, 2000.

[SOV 11] SOVIETSKY KOSMOS, Special Edition to Celebrate the 50th Anniversary of Gagarin's Flight, APRF Editions, Moscow, 2011.

[SPA 97] SPASSKY N. (ed.), "Raketno-kosmitcheskaya tekhnika" (Rocketry and Space technology), *Russia's Arms Catalog*, vol. 6, Military Parade, 1996–1997.

[TAR 92] TARASENKO M., *Voennye Aspekty Sovetskoi Kosmonavtiki* (*Military aspects of Soviet cosmonautics)*, Nikol, Moscow, 1992.

[TCH 95] TCHERTOK B., *Rakety i Ludi* (translated by NASA: *Rockets and People*, NASA, 2005), vol. 1, Machinostroenie Publishers, Moscow, 1995.

[TCH 96] TCHERTOK B., *Rakety i Ludi – Fili, Podlipki, Tyuratam* (translated by NASA: *Rockets and People*, NASA, 2006), vol. 2, Machinostroenie Publishers, Moscow, 1996.

[TCH 97] TCHERTOK B., *Rakety i Ludi – Goryachie Dni Kholodnoi Voiny* (translated by NASA: *Rockets and People*, NASA, 2008), vol. 3, Machinostroenie Publishers, Moscow, 1997.

[TCH 99] TCHERTOK B., *Rakety i Ludi – Lunaya Gonka (The race to the moon)*, vol. 4, Machinostroenie Publishers, Moscow, 1999.

[TCH 11] "Tchelovek, Korabl, Kosmos", Recueil de documents pour les 50 ans du vol de Gagarine, RGANTD, Novyï Khronograf, Moscow, 2011.

Books about Korolev

[AST 73] ASTASHENKOV P.T., *Orbity Glavnogo Konstruktora* (*The main designer's orbits*), DOSAAF, Moscow, 1973.

[GOL 94] GOLOVANOV Y.K., *Korolev: Mify i Fakty* (*Korolev: facts and myths*), Nauka, Moscow, 1994.

[HAR 97] HARFORD J., *Korolev*, John Wiley & Sons, New York, 1997.

[ICH 86] ICHLINSKY A.Y., *Akademik S.P.Korolev – Outchenyi, Ingenier, Tchelovek* (*Academician S.P. Korolev – scientist, engineer, man*), Nauka, Moscow, 1986.

[KEL 80] KELDYSH M.V., *Tvorcheskoe Nasledie S. P. Koroleva* (*The creative legacy of S.P. Korolev*), Nauka, Moscow, 1980.

[KOR 02] KOROLEVA N., *Otets* (*Father*), Nauka, Moscow, 2001–2002.

[KUZ 06] KUZNETSKY M.I., *Korolev i troujeniki Baïkonour* (*Korolev and workers from Baikonur*), Krasnoznamenk, Vladi, 2006.

[VET 98] VETROV G.S., *S. P. Korolev i Ego Delo* (*S P. Korolev and his work*), Nauka, Moscow, 1998.

Books about Chelomey, OKB-23 and Khrunichev's factory

[BAK 11] BAKHVALOV Y.O., ALBREKHT A.V., ARISTOV L.I. *et al.*, *Pod Krylom Miassichtcheva* (*KB Saliout - 60 years*), vol. 1, Restart, Moscow, 2011.

[COL 02] COLLECTIF D'AUTEURS, *Zvezdnaya epokha Miassichtcheva v Filiakh*, Vozdushniy Transport, Moscow, 2002.

[COL 04] COLLECTIF D'AUTEURS, *Kosmodrom Baïkonour, 19 OIITch istorii, vospominania veteranov*, Jubileïny, 2004.

[EFR 12] EFREMOV G.A., GORBATKO V.V., MALIKOV A.I. *et al.*, *Sbornik dokladov outchenykh i spetsialistov NPO Mach na XXXVI Akademitcheskikh Tcheniyakh po Kosmonavtike*, NPO Mach, 2012.

[EVT 97] EVTEEV I., *Echtche podnimalos plamya*, Inter-Vesy, Moscow, 1997.

[EVT 02] EVTEEV I., *Operezhaya Vremya* (*Passing the time*), Bioinformservice, Moscow, 2002.

[KIS 09] KISSELEV A.I., *Jizny, posviachtchennaya sozdaniyou raket, orbitalnykh stantsia, kosmitechskikh apparatov*, Centre biographique international, Moscow, 2009.

[OSO 03] OSOKINE I.A., *Vosvrachtchenie iz kosmos*, Bioinformservice, Moscow, 2003.

[POL 08] POLIATCHENKO V.A., *Na More i v kosmos*, Morsar AV, St. Petersburg, 2008.

[SMI 11] SMIRITCHEVSKY L.D., *Otkrovenno o cokrovennom*, NPO Mach, Moscow, 2011.

[NAO 06] *Naoutchno-tekhnitcheskie pazrabotki OKB-23-KB Saliout*, vol. 1, Vozdushniy Transport, Moscow, 2006.

Books on the history of launchers

[DEM 01] DEMYANKO Y.G., *Yadernye Raketnye Dvigateli (Nuclear rocket engines)*, OOO Norma-Inform, Moscow, 2001.

[DRO 05] DROGOVOZ I., *Raketnye Voiska SSSR* (*The Soviet Union's rocket armies*), AST, Moscow, 2005.

[DYA 01] DYADIN G.V., *Pamyatnye Starty* (*The launch of a memory*), TsIPK, Moscow, 2001.

[EVS 99] EVSTAFIEV M.D., *Dolgii Puti K Bouria* (*The long path towards Bouria*), Vouzovskaya Kniga, Moscow, 1999.

[FIL 01] FILIN V.M., *Put k Energii*, Logos, Moscow, 2001.

[GUB 98] GUBAREV V., *Yuzhnuy Start* (*Yuzhnoye launches*), Editions Nekos, Moscow, 1998.

[KAR 99] KARPENKO A.V., OUTKINE A.F., POPOV A.D., *Otvetchestvennye Strategitcheskye raketnye Kompleksy Spravotchnik* (*The complexes of national strategic rockets, a reference book*), Nevskii Bastion, St. Petersburg, 1999.

[OUM 01] OUMANSKY S.P., *Rakety Nositeli, Kosmodromy* (*Rockets, launchers, cosmodromes*), Restart+, Moscow, 2001.

[PAN 01] PANATOV G.S., *Samaliot TANTK G. M. Beriev 1945-1968* (*G. M. Beriev's TANTK planes, 1945-1968*), Restart+, Moscow, 2001.

[PER 98] PERVOV M., *Mezhkontinetalnye Ballisticheskie Rakety SSSR i Rossi* (*USSR and Russian ballistic intercontinental rockets*), Krasny Proletary, Moscow, 1998.

[PER 99] PERVOV M., *Raketnye Kompleksy RVSN*, OAO Tipographie Novosti, Moscow, 1999.

[PER 01] PERVOV M., *Zenitnoe Raketnoe Oruzhie Protivovozdushnoi Oborony Strany (Zenithal rockets of the country's anti-aircraft defense)*, Aviarus-XXI, Moscow, 2001.

[PER 03] PERMINOV A.N. (ed.), *Kosmitcheskie Voïska* (*Space army*), Moscow, 2003.

[SAM 05] Samara Space Center, "Spaceports Worldwide, Baikonur, Plesetsk, Kourou", Brochure, 2005.

[YAK 99] YAKOVLEV V.N., *Raketniy Sh'it Otechestva* (*Protecting the nation using rockets)*, TsIPK RVSN, Moscow, 1999.

Baikonur

[BAI 84] *Baïkonour-Otcherki, Poemy, Stikhi, Khronika* (*Baikonor – essays, poems, verses, chronicals*), vol. 1, Jazouchy, Alma-Ata, 1984.

[BAI 00] *Baïkonour 45 ans*, PK Rekslide, Karaganda, 2000.

[BAI 05] *Baïkonour, the advent of a new century*, Military Parade, Moscow, 2005.

[BAR 05] BARANOV L.T. (ed.), *Kosmodrom Baïkonour – 50 Kosmitcheskikh Liot* (*Baikonur's cosmodrome – 50 years in space*), Forces Spatiales, 2005.

[BOL 06] BOLTENKO A.S., LAPIDUS B.G., PROUSS O.P. (eds), *Rokot Kosmodrom – Vospominania veteranov Baïkonour* (*The growls of Baikonur*), OOO Izdatelskii Dom Michanka, Kiev, 2006.

[CHE 88] CHESTOPALOV N.F. (eds.), *Sovietskie Voennye Stroiteli* (*Soviet military builders*), Voennoe Izdatelstvo, Moscow, 1988.

[COL 92] COLLECTIF D'AUTEURS, *Kosmodrom Baïkonour. V Natchal Puti* (*Baikonor's cosmodrome. At the beginning of the journey*), Le conseil des vétérans du cosmodrome, Moscow, 1992.

[COL 04] COLLECTIF D'AUTEURS, *Glavni stroitel Baïkonour* (*Baikonur's main builder*), Moscovskie utchbniki CD Presse, Moscow, 2004.

[COL 05] COLLECTIF D'AUTEURS, *Baîkonour – 50 istoria kosmodroma v vospominaniakh veteranov* (*Baikonur – 50 cosmodrome stories in the memories' of veterans)*, Novosti, Moscow, 2005.

[GER 94] GERTCHIK K.V. (ed.), *Proryv v kosmos – Otcherki ob ispytateliakh, spetsialistakh i stroïteliakh kosmodroma Baïkonour* (*The breakthrough in the cosmos – essay on the experimenters, speclialists and cosmodrome builders of Baikonur)*, TOO Veles, Moscow, 1994.

[GER 98] GERTCHIK K.V. (ed.), *Nezabyvaemyï Baïkonour* (*The unforgettable Baikonur*), Moscow, 1998.

[GER 01] GERTCHIK K.V., *Baïkonur, Pamyat Serdtsa* (*Baikonur, the memory of the heart*), Terra, Moscow, 2001.

[GER 01] GERTCHIK K.V., *Vzgliad Skvoz Gody* (*Looking through the years*), IPO Profizdat, Moscow, 2001.

[IVA 06] IVANOV V.L., *Povsednevnaya Jizn* (*Daily life*), Molodaya Gvardia, Moscow, 2006.

[KHR 07] KHRENOV V.A. (ed.), *Moï Baïkonour* (*My Baikonur*), Geroï Otetchesv, Moscow, 2007.

[KOU 94] KOUROUCHINE A.A. (ed.), *Glazami Otchevidtsev. Vospominania veteranov Baïkonour (Eyewitness accounts. Recollections of Baikonur veterans)* vol. 2, Le conseil des vétérans du cosmodrome, Moscow, 1994.

[KOU 01] KOUROUCHINE A. A., *C Baïkonour k Lune, Marsu, Venere: vospominaniia veteranov Baïkonour* (*From Baikonur towards the Moon, Mars and Venus*), Graal, Moscow, 2001.

[KUZ 95] KUZNETSKY M.I., STRAJEVA I.V., *Baikonur-Tchoudo XX Veka* (*Baikonur – the miracle of the 20th century*), Sovremennyi Pissatel, Moscow, 1995.

[KUZ 97] KUZNETSKY M.I., *Baikonur. Korolev. Yangel*, IPF Voronezh, 1997.

[KUZ 01] KUZNETSKY M.I., *Gagarin na Kosmodrome Baikonur*, Krasnoznamenk, Vladi, 2001.

[KUZ 04] KUZNETSKY M.I., *Tvortzy raketno-kosmitcheskoï tekhniki na Kosmodrome Baïkonour* (*Creators of the rocketry and science approach to the Baikonur cosmodrome*), Krasnoznamenk, Vladi, 2004.

[MEN 97] MENCHIKOV V.A. (ed.), *Glazami Otchevidtsev. Vospominania veteranov Baïkonour (Eyewitness accounts. Recollections of Baikonur veterans)*, vol. 3, Kosmo, Moscow, 1997.

[MEN 94] MENSHIKOV V.L., *Baikonur, Moya Bol i Lyubov* (*Baikonur, my pain and my love*), Moscow, 1994.

[MEN 03] MENSHIKOV V.L., *Baïkonour-Moskva-Jubilenyï* (*Baikonur-Moscow-Jubilee*), Restart, Moscow, 2003.

[MOL 82] MOLTCHANOV A.F., POUCHKARIOV A.A., *Kosmitcheskaya Gavan* (*The cosmic harbor*), Machinostroenie Publishers, Moscow, 1982.

[OME 00] OMELKO V., *Kosmodrom Baïkonour*, OmV-Loutch, Moscow, 2000.

[PIT 05] PITALEV G., *Vypolnit k srokou, ob ispolnenii dolojit* (*Completed on time, an execution report*), Demiourg-ART, Moscow, 2005.

[POP 86] POPOVITCH P. R. (ed.), *Baïkonour-Otcherki, Poemy, Stikhi; Khronika* (*Baikonur – essays, poems, verses, chronicals*), vol. 2, Jazouchy, Alma-Ata, 1986.

[POR 07] POROCHKOV V.V., *Raketno-kosmitcheskiï podvig Baïkonoura* (*The rocketry and space achievement of Baikonur*), Patriot, Moscow, 2007.

[SHA 95] SHATALOV D., "The history of foundation of the Soviet cosmodrome Baïkonour", *IAA-95-IAA.2.1.04 Presentation at the 46th International Aeronautics Congress*, Oslo, Norway, 2–6 October, 1995.

[TVE 76] TVERDOVSKY V.N., *Kosmodrom*, Machinostroenie Publishers, Moscow, 1976.

[VIL 94] VILLAIN J. (ed.), *Baïkonour, la porte des étoiles*, Armand Colin, Paris, 1994.

[VOL 77] VOLSKY A.P. (ed.), *Kosmodrom*, Voennoe Izdatelstva, Moscow, 1977.

[VOU 87] VOUKOLOV L.I., MALAKHOVSKAYA E.E., POLIVINE N.G. (eds.), *Baïkonour-Otcherki, Poemy, Stikhi, Khronika* (*Baikonour – essays, poems, verses, chronicals*), vol. 3, Jazouchy, Alma-Ata, 1987.

[ZAK 96] ZAKHAROV A.G., *Kak eto bylo. Vospominania hatchalnik kosmodroma Baïkonour* (*It was like that. Memoir of the Head of the Baikonur cosmodrome)*, 1996.

[ZAV 91] ZAVALICHINE A.P. (ed.), *Glazami Otchevidtsev. Vospominania veteranov Baïkonour* (*Eyewitness accounts. Memories of Baikonur veterans)*, vol. 1, DOSAAF, Moscow, 1991.

Books about Companies

[ALB 94] Album photo, *RKK Energiya imeni S.P. Koroleva,* 1994.

[BAR 01] BARMINE I.V., *Na zemle i v kosmos* (*On Earth and in the cosmos*), KBOM, Moscow, 2001.

[COL 11a] COLLECTIF D'AUTEURS, *TsNII Mach Kosmitcheskiï naoutchnyï Tsentr, Tome 1 – Stranitsy Istorii*, RINFO, Riazan, 2011.

[COL 11b] COLLECTIF D'AUTEURS, *TsNII Mach Kosmitcheskiï naoutchnyï Tsentr, Tome 2 – Obespetchenie Pazvitia Institut*, RINFO, Riazan, 2011.

[EFR 04] EFREMOV G.A., MAKAROV L.E., POLIATCHENKO V.A. *et al*., *Sixty let samootverjennovo trouda vo imia mira 1944-2004* (*60 years of selfless labor in the image of the world from 1944-2004*), Oroujie i Tekhnologii, Moscow, 2004.

[EFR 09] EFREMOV G.A., MAKAROV L.E., DEGTIAREV A.O. *et al*., *Tvortsy i sozidateli. Oda kollektivou* (*65 years of NPO Machinostroeniya*), Bedretdinov i Ko, Moscow, 2009.

[GOR 06] GOROKHOV A., *GKNPTs imeni Khrunicheva, 90 let* (*90 years of Khrunichev*) *– Filevskie Krylya*, vol. 1, Polygon Press, Moscow, 2006.

[GOR 06] GOROKHOV A., *GKNPTs imeni Khrunicheva, 90 let* (*90 years of Khrunichev*) *– Filevskie Orbity*, tome 2, Polygon Press, Moscow, 2006.

[GKN 06] *GKNPTs imeni Khrunicheva, 90 let* (*90 years of Krunichev*), Military Parade, Moscow, 2006.

[GKN 11] *GKNPTs imeni Khrunicheva, 95 let* (*95 years of Krunichev)*, Restart, Moscow, 2011.

[KB 11] KB Motor 1961-2011, Brochure, 1961-2011.

[KOB 97] KOBELEV V. N., *TSKBTM 50 ans – Nazemloe Obordourovanie (Terrestrial devices)*, Moscow, 1997.

[KON 04] KONIOUKHOV S.N. (ed.), *Prizvany Vremenem* (*50 years of KB Yuzhnoye*), vol. 1 *– L'opposant à la coopération internationale*, ART-Press, Paris, 2004.

[KON 04] KONIOUKHOV S.N. (ed.), *Prizvany Vremenem* (*50 years of KB Yuzhnoye*), vol. 2 *– Fusées et satellites du KB Yujnoe*, ART-Press, Paris, 2004.

[KOR 99] KORNEYEV N.M., NEOUSTROIEV V.N., *V. P. Barmine: osnovnye etapy jizni i deiatelnosti (V.P. Barmin: the main stages in his life and activity)*, KBOM, Moscow, 1999.

[KHR 98] Khrunichev State Research and Production Center, Brochure, 1998.

[KHR 01] Khrunichev State Research and Production Space Center, Brochure, 2001.

[LOP 11] LOPOTA V.A., *RKK Energiya Imeni S.P. Koroleva, v pervom deciatiletii XXI veka*, RKK Energyia, 2011.

[NPO 01] NPO Mashinostroenia, Brochure, 2001.

[PAL 94] PALLO-KORUSTIN V., *Dnepropetrovskiy Raketno-Kosmicheskiy Tsentr (The rocketry and space centre of Dniepropetrovsk)*, Dnepropetrovsk, 1994.

[SEM 96] SEMENOV Y.P., *RKK Energiya imeni S.P. Koroleva*, RKK Energyia, 1996.

[SEM 01] SEMENOV Y.P., *RKK Energiya imeni S.P. Koroleva, Na Rubezhe Dvukh Vekov*, RKK Energyia, 2001.

[TIT 06] TITOV A.V. (ed.), *KB Motor: 45 let i vsia Jizn* (*KB motor: 45 years and a lifetime*), OOO Oko-Inform, Moscow, 2006.

[VAR 11] VAROTCHKO A.G. (ed.), *KB Motor: 50 let*, IPO "U Nikitskikh Vorot", Moscow, 2011.

[ZHI 96] ZHILTSOV S., *GKNPTs imeni Khrunicheva, 80 let* (*80 years of Khrunichev*), Military Parade, Moscow, 1996.

Journals

[BAJ 03] BAJINOV I.K., "O Rabotakh M.K. Tikhonravova (The works of M.K. Tikhonravov)", *Novosti I Kosmonavtiki,* vol. 8, pp. 68–71, 2003.

[KOS 02a] *Kosmodrom*, no. 8, 2002.

[KOS 02b] *Kosmodrom*, no. 9, Ploshadki Baikonura (The areas of Baikonur), 2002.

[KOS 02c] *Kosmodrom*, no. 12, 2002.

[LAN 05] "Lancement du satellite Monitor-E", Press release about Tsenki, no. 9, 2005.

[MAR 05a] MARININE I., TVERSKOÏ O., "Kosmodrom Baïkonour – Sevodnia i zavtra", *Novosti I Kosmonavtiki,* vol. 2, pp. 58–63, 2005.

[MAR 05b] MARKOV Y., MARININE I., "Pervyï Kosmoport planety Zemlia", *Novosti I Kosmonavtiki,* vol. 5, pp. 1–4, 2005.

[NET 05] NETCHESSA Y.V., "Vitoribus Gloria", Press release on Tsenki and the launch of the Photon-M satellite, vol. 6, no. 26, 2005.

[NET 06] NETCHESSA Y.V., "Baïkonour – Unikalnyï kosmitcheskiï port", *Rossiski Kosmos*, pp. 54–59 (vol. 1), pp. 46–51 (vol. 2), pp. 56–61 (vol. 3), 2006.

[PAT 05] PATROUCHEV V.S., "Vospominania voennogo ispiotatelia (1953-1957)", Tsenki's press release on the launch of the Progress-M52 satellite, vol. 2, no. 22, 2005.

[POR 05] POROCHKOV V.V., SEMENOV N.L., "Khronika pervykh pouskov rakety R-7", Tsenki's press release on the launch of the Express-AM2 satellite, vol. 3, no. 23, 2005.

[VAR 07] VARFOLOMEIEV T., "Pervaya mejkontinentalnaya: rojdenie Semerki", *Novosti I Kosmonavtiki,* vol. 7, pp. 68–70, 2007.

[ZAR 07] ZARETSKY Y., "Kak rojdaioutsia chedevry", Tsenki's press release on the launch of the Radarsat-2 satellite, vol. 13, no. 64, 2007.

Espionage

[CIA 63] CIA/NPIC, Development of the Kapustin Yar/Vladimirovka and Tyuratam Missile Test Center USSR, Photographic intelligence report, 1957–1963.

[NPI 00] NPIC/R-124/621962, Terminal Range Facilities of the Tuira Tam Missile Test Range USSR, Top secret CIA document, declassified 9 May 2000.

[PEE 87] PEEBLES C., *Guardians*, Presidio Press, New York, 1987.

[POC 00] POCOCK C., *The U2 Skyplane Toward the Unknown*, Schiffer, Atglen, 2000.

[STR 61] 1 I-8/I-6 1, Strength and Deployment of Soviet Long Range Ballistic Missile Forces, National Intelligence Estimate, 21 September 1961.

Commercialization

[ALB 11] ALBRECHT M., *Falling Back to Earth, A First Hand Account of the Great Space Race and the End of the Cold War*, New Media Books, Breinigsville, 2011.

[EIS 04] EISENHOWER S., *Partners in Space, US-Russian Cooperation after the Cold War*, The Eisenhower Institute, Washington, 2004.

[MAN 09] MANBER J., *Selling Space, Inside the Soviet Conspiracy that Transformed the U.S. Space Program*, Apogee Books, Burlington, 2009.

[VIL 98] VILLAIN R., DIB I., PICCHIOTTINO S., Launch Services Market Survey, Worldwide Prospect to 2007, Euroconsult Research Report, Paris, 1998.

Index

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

M

O, P

Q, R

S

T, U

V

Index of Names

The Proton Launcher: History and Developments,
First Edition. Christian Lardier and Stefan Barensky.

C

D

E, F

G

I, J

K

L

M

N

O

P

R

S

T

U

V

Y, Z