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Chapter 8

The R-3 Rocket Project Developed in the U.S.S.R. in 1947-1959 as a Basis for the First Soviet Space Launchers*

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By the end of World War II, all the necessary conditions for developing rocketry and space technology had been established in the Soviet Union. They included, first of all, a developed defense industry that supplied all the material needed for the country, contemporary aviation and artillery included, and the Katiusha salvo rocket system. It goes without saying that such an industry could provide an unprecedented acceleration of scientific and technological progress by conversion to civilian production.

Also important was the high standard achieved by our country in natural sciences and engineering, theoretical and experimental sciences and engineering, theoretical and experimental advancements in astronautics fundamentals, as well as extensive experimental results accumulated by the Jet Propulsion Study Group (GIRD in Russian), the Gas Dynamic Laboratory (GDL), and the Rocket Research Institute (RNII in Russian) on principal rocketry trends. Thirdly, the Soviet people aspired to control new spheres, to transform nature and to bring far-reaching plans into reality.

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At that time, the idea of space exploration was accepted as a continuation of prewar expeditions into the Arctic and of stratospheric flights. In the natural course of events, the idea could have yielded rapid and straightforward successful results. But the reality was quite the opposite one. The Cold War was unleashed, and space flights came into reality through the creation of powerful rocket weaponry. That measure was thought to balance the potential threat by both sides.

One can argue whether the production of missile materiel retarded access to space because of wasting vast resources or, on the contrary, accelerated the breakthrough by concentrating a huge creative community on the effort. In practice the history of astronautics is known to have commenced with the creation of the powerful R-7 Intercontinental Ballistic Missile (ICBM). Since the first artificial Earth satellite was launched by the R-7 based booster-rocket, creation of the ICBM represented the chain of events towards the start of the Space Age. The R-7 program resulted from the R-7 Long Range Ballistic Missile (LRBM) project, developed under the management of S. P. Korolev in 1947-1950. The project was not ever completed, and nobody but its first-hand designers know details of the program. The report being delivered is intended to unwrap the mystery.

In 1944, Korolev raised the issue of proceeding to develop rockets of various types, including those for manned flights into the high atmosphere. Having been acquainted with captured German materiel, he became ever more convinced that it was the right time to pass from experimenting with small rocket vehicles to the development of powerful, long-range, high-payload-capacity missiles. When he was in Germany in 1946, he worked out some project statements for developing a LRBM with the range of 600 km, which would have twice the range of the German A-4 (V-2) rocket constructed by Wernher von Braun's team. Korolev estimated that such a rocket would be built within three to five years, when required production resources were allocated for the project at one of the major aircraft plants.

But that idea was not adopted. Aircraft industry was assigned a mission of developing new jet planes. Rocketry was to be advanced at artillery plants, which were freed from ordnance production. For such a conversion to proceed in a sufficiently urgent manner, it was decided as a first step to restore and copy the A-4 rocket production in every detail in order to assimilate and run LRBM fabrication, test, and operation processes and techniques.

The mission was successfully accomplished by Soviet industry. The leading enterprise in that effort was the first Soviet rocketry center in Kaliningrad, Moscow, region. The center was established on the base at Kalinin, named Plant 88. It was known as Research Institute Number 88 (NII-88 in Russian) of the

U.S.S.R. Armament Ministry. The inauguration took place in May 1946. It consisted of the Korolev-headed Special Design Bureau with Project Office Number 3, an experimental plant, a scientific department with aerogasdynamics, strength test and material science experimental assets, and a test station with firing stands.

On 10 October 1948, the R-1 missile, which was a Soviet-developed version of the V-2 rocket, was successfully launched for the first time. It was built by NII-88, 12 research institutes and design bureaus, and 35 plants in a cooperative effort. The program helped to establish a sound team of engineers, scientists, manufacturers, and operators that proved their ability to create complex contemporary technology. The leading part belonged to the Chief Designers Council (CDC) with Korolev as its head. The CDC included the Engine Chief Designer (CD) V. P. Glushko, the Control System CD N. A. Peliugin, the Gyroscopic Devices CD V. I. Kuznetsov, the Radio System CD M. S. Riazansky, and the Ground Support Equipment CD V. P. Barmin. In 1947, the CDC put forward a rocketry development plan. It stated that within two or three years the Soviet rocket scientific-industrial branch would create the R-2 and R-3 missiles, with ranges respectively twice and ten times as much as that of the R-1 rocket—600 and 3,000 km. The R-1 missile's successful test allowed the plan to proceed. The test results indicated that to create the R-3 project it would be necessary to conduct research and development efforts for a much longer period of five years.

According to the preliminary research results, the A-4 rocket's structural configuration completely prevented the R-3 construction engineers from using it as a base, and this significantly impeded the R-2 creation. Korolev was a rather skilled aircraft designer and a top manager of an exploratory research rocket program in the GIRD and RNII. That program had embraced a wide range of various objectives, that could be achieved by developing rockets of different types and classes. That is why, together with other specialists, Korolev was delighted with the V-2, which was called a "German technology miracle." But while appreciating its merits, he also perceived the V-2's imitations on the basis of analytical review, and he decided to follow his own path in designing a rocket of a particular layout, free of the shortcomings of von Braun's project. The ultimate statement of his design's advantages, Korolev introduced in his lecture series entitled "The Long Range Ballistic Missile Design Foundations." He delivered it at Bauman Moscow Higher Technical College (MVTU in Russian), in its Higher Engineer Courses in the first half of 1948. In his lectures he used the R-3 project design data for illustration for the first time.

On 7 December 1949, Korolev delivered his project thesis at the NII-88 scientific-technological council session, that could be considered a historical one since, practically, it approved the reported rocketry development course. The project firing range was dramatically increased to five times the range of the R-2X missile, which had been tested by that time. The Korolev-designed layout was introduced in the new missile arrangement only in part. It featured an integral fuel tank and a separating warhead. But the effect was significant. Firing range was doubled, with a launching mass 1.6 times as much and a payload 1.5 times as much as those of the V-2 rocket. The gain was estimated to be achieved mainly through the new lay-out, since engine specific impulse increased only by 7 percent.

To steeply increase the firing range, the R-3 designers had to solve complex problems never before tackled. Similar questions had been analyzed in general only by theoretical astronautics pioneers. Besides, the A-9/A-10 and the Antipode intercontinental rocket projects were developed by Wernher von Braun and Eugen Sänger. But those projects only described a general feasibility of intercontinental range flights for craft of definite estimated parameters. The methods of achieving them were not worked out by the designers. The same is true for such new problems as a heat-protection system design for reentry flight. E.g., the R-3 warhead reentry speed was about 4,500 meters/second (m/s) with fairing heating temperatures above 1,500 degrees C.

The firing accuracy was assigned to be an order of magnitude better than that of the R-1 rocket. The most difficult item was the main rocket problem of boosting assigned payload mass to a prescribed velocity. The point was that the R-3 payload kinetic energy was to be 30 times that of the R-1.

The designers did their best to improve engine performance, but there was almost no hope of improving the new rocket thrust-to-weight ratio. Liquid oxygen-kerosene propellant was more effective, but it gave specific impulse and flight velocity increases of more than 20 percent. Besides, it was necessary to solve new and serious engine development problems. To assure the success of the development, two designer groups were assigned to create a 120 ton thrust engine. They were Glushko's design bureau, which was to develop the RD-110 engine, and the A. I. Poliyarny-headed Department of NII-1 (the former NII-88) institute, chosen to develop the D-2 engine.

It was obvious for Korolev and his colleagues, V. P. Mishin, K. D. Bushuev, S. S. Kriukov, S. S. Lavrov, and S. O. Okhapkin, that they had to discover new layout and structure design features to extend the firing range. The rocket pioneers had discovered, theoretically, the simplest way to solve the problem. It was a multistage rocket. But preliminary studies showed that for a 3,000 km-range, the Korolev-proposed layout of a single stage rocket was significantly more advantageous than a multistage one in launch mass and some other parameters. Besides, it was not bound to additional research, such as staging methods and so on.

Korolev's project for the R-3 missile featured a separated warhead, integral pressurized propellant tanks, a finless rear section, and an aluminum-magnesium alloy as the main structural material. The tanks were pressurized with liquid gas vapor instead of compressed air.

The advantage of a single-stage rocket for achieving extended ranges of fire were validated in the R-3 missile preliminary design for the first time, that being a significant advancement in the theory of LRBM construction.

The missile weight efficiency was improved by compacting its configuration to the greatest possible degree, in addition to the new layout. It was decided to get rid of the inter-tank structure and an instrument section, and to place control and service devices in the previously free space of the rear section. Bolted joints were substituted for welded ones. The engine's proportional length was diminished by increasing the combustion chamber pressure and adopting a contoured nozzle.

The R-3 missile's technical project was begun before the preliminary design review. Soon it became clear that many design solutions needed flight testing. With that end in view, the R-3X missile was developed based on the R-2 rocket. The R-3X had an integral oxygen tank and a finless rear section.

The R-3 missile preliminary project was reviewed by skilled experts, A. A. Kosmodemiansky, A. I. Makarevsky, J. A. Pobedonostsev, H. A. Rakhmatoolin, M. K. Tikhonravov among them. They greatly appreciated the scientific-technical standards of the project, confirmed the missile development feasibility, and recommended starting its fabrication. Preliminary design reviews of the R-3 missile, its control system (under CD B. M. Khonoplev), and the two engines were successful. Nobody had any doubts as to the reality of the missile construction. By 1951 the R-3X missile workshop drawings were ready. The rocket's estimated range was 900 km at a launching mass equal to that of the R-2 missile.

But serious stumbling blocks prevented the engines from being developed in time—when it became clear that those problems would lead to enormously delaying the production of the R-3 missile, Korolev was blamed for an unrealistic objective statement. Critics said that a range of 1,000 km ought to have been assigned, and the rocket model should have been successively evolved as it had been with the R-2 rocket, which had been advanced to a preset standard through a certain number of modifications.

Korolev estimated that the setback had been due to an unrealistic engine design. V. P. Glushko had tried to achieve a qualitatively novel engine through a more intensive operation regime of an old layout. The RD-110 engine, which used a scaled-up version of the A-4 engine combustion chamber, was found unworkable. The German engine layout should not have been used. Besides, in 1946 a Soviet designer, A. M. Isaev, invented an entirely new layout with coupled shells. Under Isaev's arrangement, an internal hot shell was loaded with a compressing pressure difference in a combustion chamber and in cooling passages. The shell was coupled by numerous welding spots with an external cold shell, which was loaded with stretching internal pressure.

The idea of the rapid development of a 120-ton-thrust engine on the basis of the new layout was also problematical. The D-2 engine development was also unsuccessful, due to excessive innovations introduced into the project by Poliarny.

Then Korolev proposed termination of the R-3 rocket development, beginning an intercontinental missile project as a way out of the situation. The statement seemed rather optimistic, but it could ensure a qualitative leap in rocketry and space technology. By that time NII-88 had researched various options of the ICBM. The results showed that with a two-stage rocket layout, each rocket pod engine's thrust was estimated to be up to 50-60 tons. The use of a four-chamber engine could simplify the course of development and enable the R-7 missile to be constructed within a short span of time. Korolev's proposal was thoroughly scrutinized and then approved. In 1951, the R-3 project was terminated and the R-5 and R-7 rocket development started.

The first strategic missile was built based on the R-3X experimental missile, the R-3 layout, and the arrangement of engines for maximum augmentation. The missile was designated R-5M. Its firing range was above 1,000 km. Later on, the R-12 strategic missile was constructed. It used high temperature propellant as more convenient for field operation.

The R-7 project was the foundation for the first ICBM and the Sputnik space vehicle. On that base a successive chain of Vostok, Molnya, and Soyuz space launchers were built, the latter were used as a main payload carrier for more than 30 years.

All successive Soviet powerful rockets developed after the R-3 missile were constructed on Korolev's layout, which became classical. Later, Wernher von Braun and other foreign designers naturally progressed to the same basic arrangements.

Thus, the R-3 project's significance consists of inventing and implementing Korolev's configurational and structural layout, which was more advantageous than that of the V-2. In the course of the R-3 efforts, a feasibility study was conducted to use the rocket as a base for multistage cluster booster arrangements. It is worth mentioning that a cluster of three parallel R-3 rockets could attain orbital velocity. Based on that fact, Korolev became firmly convinced in his proposal to terminate the R-3 and to pass on to the R-7 development, that being the optimal way to spaceflight.

In conclusion, it is worth noting that an integral tank layout proposed for the R-3 missile did not become dogma for Korolev's design bureau experts. In every new project development they analyzed other relevant arrangements, including external and hybrid tanks. Finally, in accordance with the negation of negation law, detachable spherical tanks were employed, instead of integral ones, in the most advanced N-1 heavy lift space launcher design developed under Korolev's management. The arrangement was of a higher weight efficiency at that time. Unfortunately, the N-1 development was terminated at the flight-test phase for numerous reasons. But that unrealized project was used to create the Energia multipurpose space transportation system, as was true for the R-3 and R-7 projects. But the Energia development story is beyond the theme of this report.