Soviet and Russian Lunar Exploration

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Brian Harvey
Dublin, Ireland, 2007

Prologue

Siberia, summer of 1976. Near the lowland town of Surgut on the River Ob in western Siberia, Russia's space recovery forces had gathered to await the return of Russia's latest moon probe. Already, the short, warm and fly-ridden Siberian summer was passing. Although it was only the 21st August, the birch trees were already turning colour and there was a cool breeze in the evening air. Gathered on the ground were amphibious army vehicles, designed to carry troops across marshy or rough terrain. In the air were half a dozen Mil helicopters, ready to spot a parachute opening in the sky. Getting to the moon probe quickly was important. They had missed Luna 20 four years earlier: it had come down, unseen, on an island in the middle of a snow-covered river, but thankfully they found it before the battery of its beeping beacon had given out. The diesel engines of the army ground crews were already running. The army crews stood around, waiting, waiting.

Bang! There was the sharp echo of a small sonic boom as the spherical spacecraft came through the sound barrier 20 km high. By this stage, it had barrelled through the high atmosphere at a speed of 7 km/sec, hitting the spot on the tiny 10-km by 20-km entry corridor necessary to ensure a safe return to Earth. The heatshield glowed red, then orange, then white hot as the cabin shed speed for heat. On board, in a sealed container, were precious rock and soil granules drilled up from the distant Sea of Crises on the moon's northeastern face. The probe had left the moon three days earlier. Now, through the most perilous phase of the return, the cabin dropped, unaided, through the ever-denser layers of Earth's atmosphere.

Fifteen kilometres high above the marshes, a meter sensed the growing density of Earth's air. The lid of the cabin was explosively blown off. A small drogue parachute fluttered out. At 11 km, it had pulled out a much larger red-and-white canopy, ballooning out above the still-steaming sphere. Two beacons popped out of the top of the cabin. Abruptly halted in its downward spiral, the cabin twisted and was now caught in the wind and began to drift sideways and downward. The helicopter crews spotted the cabin in the air and picked up the beacon on their radios.

Over their radiophones they called up the amphibians who headed straight in the direction of the returning spacecraft. The helicopters saw the cabin reach the ground. The small parachute at once emptied and deflated to lie alongside. In minutes the amphibians had drawn up alongside. The army crews cut the parachute free. Gingerly – it was still warm from the hot fires of reentry – they lifted the blackened cabin into the back of their vehicle, driving back into Surgut. Within hours, it was on its way by air to the Moscow Vernadsky Institute. This was the third set of samples the Soviet Union had brought back from the moon. The first had come from the Sea of Fertility in 1970, with Luna 16. Two years later, Luna 20 had brought back a small sample from the Apollonius Highland. Luna 24 had gone a stage further and drilled deep into the lunar surface and this cabin had the deepest, biggest sample of moon soil of them all.

Nobody realized at the time that this was the last lunar mission of the Soviet Union. Fifty years later, lunar exploration is remembered for who won, the United States and who lost, the Soviet Union. In the popular mind, the view is that the Russians just did not have the technological capacity to send people to the moon. In reality, political rather than technical reasons prevented the Soviet Union from landing cosmonauts on the moon. It is often forgotten that the story of Soviet lunar exploration is, although it had its fair share of disappointments, also one of achievement. The Soviet Union:

- Sent the first spacecraft past the moon (the First Cosmic Ship).
- Launched the first spacecraft to impact on the lunar surface (the Second Cosmic Ship).
- Sent the first spacecraft around the farside of the moon to take photographs (the Automatic Interplanetary Station).
- Made the first soft-landing on the moon (Luna 9).
- Put the first orbiter into lunar orbit (Luna 10).
- Pioneered sophisticated, precise high-speed reentries into the Earth's atmosphere from the moon, becoming the first country to send a spaceship around the moon and recover it on Earth (Zond 5).
- Landed advanced roving laboratories that explored the moon for months on end (the Lunokhods).
- Retrieved two sets of rock samples from the surface of the moon by automatic spacecraft (Luna 16, 20) and drilled into the surface for a core sample (Luna 24).
- Returned a substantial volume of science from its lunar exploration programme.

Not only that, but the Soviet Union:

- Came close to sending a cosmonaut around the moon first.
- Built and successfully tested, in orbit, a lunar lander, the LK.
- Built a manned lunar orbiter, the LOK.
- Assembled and trained a team of cosmonauts to explore the moon's surface, even selecting sites where they would land.
- Came close to perfecting a giant moon rocket, the N-1.
- Designed long-term lunar bases.

Although the United States Apollo programme is one of the great stories of humankind, the story of Soviet and Russian lunar exploration is one worth telling too. First designs for lunar exploration date to the dark, final days of Stalin. The Soviet Union mapped out a plan for a lunar landing and, in pursuit of this, achieved most of the key 'firsts' of lunar exploration. Even when the manned programme faltered, a credible programme of unmanned lunar exploration was carried out, one which Luna 24 brought to an end. The story of Soviet lunar exploration is one of triumph and heartbreak, scientific achievement, engineering creativity, treachery and intrigue. Now, new lunar nations like China and India are following in the paths mapped out in the Soviet Union 60 years ago. And Russia itself is preparing to return to the moon, with the new Luna Glob mission in planning.

Figures

Tables and maps

TABLES

MAPS

Abbreviations and acronyms

AIS	Automatic Interplanetary Station
AKA	Also Known As
BOZ	*Blok Obespecheyna Zapushka* (Ignition Insurance System)
B, V, G, D	Letters in Russian alphabet
ΔV	Velocity change
EOR	Earth Orbit Rendezvous
EVA	Extra Vehicular Activity
GDL	Gas Dynamics Laboratory
GIRD	Group for the study of jet propulsion
GNP	Gross National Product
GSLV	Geo Stationary Launch Vehicle
HF and LF	High Frequency and Low Frequency
HTP	High Test Peroxide
ICBM	InterContinental Ballistic Missile
IKI	Institute for Space Research
IZMIRAN	Institute of Terrestrial Magnetism
KBOM	*Konstruktorskoye Buro Obshchevo Mashinostroeniya* (General Engineering Design Bureau)
KL-1E	'E' for Experimental
KORD	*KOntrol Roboti Dvigvateli* (Engine Control System)
KTDU-5	*Korrektiruiushaya Tormoznaya Dvigatelnaya Ustanovka* (Engine Correction System)
KVD	*Kislorodno Vodorodni Dvigatel* (oxygen hydrogen engine)
L	*Luna, Luniy* (moon)
L-1P	'P' for Preliminary
L-1S	'S' for Simplified
L-3M	'M' for Modified
LEK	Lunar expeditionary craft; Lunar Exploration Council

LK	*Luna Korabl*; *Luniy Korabl* (lunar spacecraft)
LM	Lunar Module (Apollo)
LOI	Lunar Orbit Insertion
LOK	*Luniy Orbitalny Korabl* (moon orbital craft)
LOR	Lunar Orbit Rendezvous
LOX	Liquid OXygen
LZhM	Lunar habitation module
LZM	Laboratory production module
N-1	*Nositel* (carrier) 1
NK	Nikolai Kuznetsov, engine
NKVD	Soviet internal security police
NPO	*Nauchno Proizvodstvennoe Obedinenie* (Research Production Association)
NSSDC	National Space Science Center
OB	Cocooned habitation block
OK	*Orbitalny Korabl* (orbital craft)
OKB-1	*Opytno Konstruktorskoye Buro* (Experimental Design Bureau)
os	Old Style, calendar used before the October Revolution, running 12 days behind the rest of Europe
PDI	Powered Descent Initiation
PrOP	*Pribori Ochenki Prokhodimosti* (Terrain Evaluation Instrument), penetrometer
RIFMA	Roentgen Isotopic Fluorescent Method of Analysis
RLA	Rocket Launch Apparatus
SKB 2	*Spetsealnoye Konstruktorskoye Buro 2* (Special Design Bureau 2)
SLV	Satellite Launch Vehicle
TEI	Trans-Earth Injection
TMK	Heavy interplanetary ship
TsDUC	Centre for Long Range Space Communications
TsKBEM	Central Design Bureau of Experimental Machine Building
TsKBM	Central Design Bureau of Machine Building
TsPK	Centre for Cosmonaut Training
UDMH	Unsymmetrical dimethyl methyl hydrazine

1

Origins of the Soviet lunar programme

The Soviet moon programme began in an unlikely place – in a children's magazine, on 2nd October 1951. Mikhail Tikhonravov was a veteran rocket engineer from the 1920s and was now convinced that a flight to the moon might soon become a practical possibility. In the paranoia of Stalin's Russia, talking about unapproved projects like moon flights was a potentially dangerous enterprise, so he chose a relatively safe outlet, one unlikely to raise the blood pressure of the censors: the pages of *Pionerskaya Pravda*, the newspaper devoted to communist youth. There, on 2nd October 1951, he outlined how two men could fly out to the moon and back in a 1,000 tonne rocketship. The article concluded:

We do not have long to wait. We can assume that the bold dream of Tsiolkovsky will be realized within the next 10 to 15 years. All of you will become witness to this and some of you may even be participants in unprecedented journeys.

His article was noticed immediately by Western intelligence, which apparently scanned children's magazines as well the main national political press. In what may have been the first occasion that Soviet space plans were noticed in the West, the *New York Times* noted 'Dr Tikhonravov's article', commenting that Soviet advances in rockets were developing rapidly and might equal, if not exceed, Western achievements. Indeed, at official level within the Soviet Union, his article was noticed too, for when the next edition of the *Great Soviet Encyclopaedia* came to be written, Mikhail Tikhonravov was invited to write a section called *Interplanetary communications* (1954) [1].

The next step took place in April 1954, a year after the death of Stalin. Although there was no direct connexion between scientific research institute NII-4 (NII stands for Scientific Research Institute, or in Russian *Nauchno Issledovatelsky Institut*), where Mikhail Tikhonravov was posted and the OKB-1 experimental design bureau (in Russian, *Opytno Konstrucktorskoye Buro*), where the chief designer of spaceflight

Mikhail Tikhonravov

Sergei Korolev worked, there was clearly a degree of informal collaboration between them. In 1946, Stalin had appointed a council of spaceflight designers and it was headed by a 'chief designer' (in Russian *Glavnykonstruktor*). The chief designer was Sergei Korolev, the legend who led the Soviet space programme from its inception. The chief designer was not just a crucial engineering post, but the political leader of the space programme, making it the most coveted position in the industry. His support was now critical.

May 1954 was the deadline for proposals for projects for countries interested in participating in the forthcoming International Geophysical Year. Encouraged, indeed prompted by Sergei Korolev, the Russian proposal was written by Mikhail Tikhonravov, in consultation with leading Soviet mathematician Mstislav Keldysh and Russia's top rocket engine designer, Valentin Glushko. Called *Report on an artificial satellite of the Earth*, it was, according to historian Siddiqi, one of the great researchers of the period, a *tour de force* of foresight for the 1950s and remarkable even in the present day [2]. Even though the Soviet Union had yet to commit itself to a small Earth satellite, the writers tried to engage their country in a project for manned spaceflight from the very start. The third section of the report dealt with the problems of reaching the moon and outlined how the rocket that they were then building could send a probe to the moon and bring it back to Earth through means of atmospheric braking. *Report on an artificial satellite of the Earth* did not emerge from the archives until the 1990s, but it was the first mention, in an official document of plans for a Soviet flight to the moon. Although the report appeared at first sight to sink in a sea of red bureaucratic ink, in fact it became the basis of the Soviet space programme. Siddiqi says that the combination of Korolev's managerial genius and Tikhonravov's technical acumen became the basis of humankind's departure from the Earth.

Sergei Korolev, Mstislav Keldysh

With the Soviet Union at last thawing out from the time of terror, it was now possible to discuss lunar missions more openly. The 25th September 1955 marked the 125th anniversary of the NE Baumann Moscow Higher Technical School. Here, chief designer Sergei Korolev gave a lengthy paper called *On the question of the application of rockets for research into the upper layers of the atmosphere*. Here, he outlined the possibility of landing robotic probes on the surface of the moon. As the chief designer, Korolev had developed a series of rockets, derived from the German V-2, firing some with animals into the upper atmosphere. Now under Soviet Premier Nikita Khrushchev he was tasked with developing the Soviet Union's first intercontinental ballistic missile (ICBM), capable of hitting the United States. The postwar Soviet rocket effort was driven by two complementary imperatives. The political leadership wanted missiles, while the engineers wanted rockets to explore space. Engineers had to justify their rocket building in terms of their military capability and potential. Only later did the political leadership appreciate that missiles designed for military purposes could also be powerful servants of non-military political objectives. While the intercontinental ballistic missile would indeed, Korolev knew, meet Khrushchev's military needs, Korolev always designed the rocket with a second purpose in mind: to open the door to space travel.

THE 1956 LENINGRAD CONFERENCE

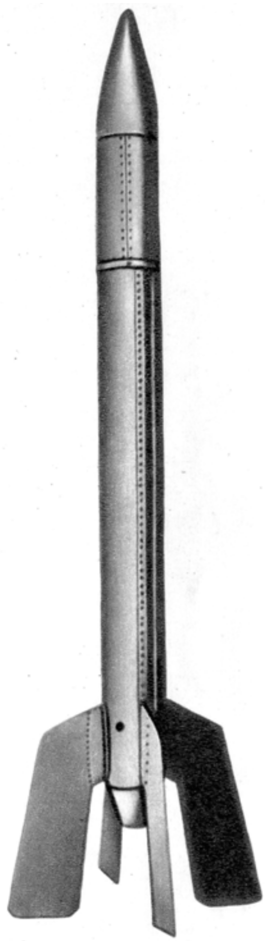
The following year, the State University of Leningrad convened a conference of physicists to examine the nature of the moon and the planets. It was held in Leningrad in February 1956. Most of those attending were scientists, astronomers and what would now be called planetologists. Also there was Mikhail Tikhonravov, not representing *Pionerskaya Pravda*, but this time the Artillery Institute, where NII-4 was located. The conference in Leningrad State University, which reviewed the state of knowledge of our moon at the time, was well publicized and news of its deliberations were again picked up in the West [3].

Following the deliberations in Leningrad State University, Korolev paid a visit to Tikhonravov's Artillery Institute. There, he asked its designers, engineers and experts to explain their work to him. As was his wont, Korolev said little, preferring to listen and taking a particular interest in their work on trajectories. Being a man more of action than of words, the institute soon found out that it had made its mark. Wielding his authority as chief designer, Korolev transferred the institute to his own, the first experimental design bureau, OKB-1. There, the NII-4 personnel could be under his direct control and enlisted fully in his cause. They now became department #9 of OKB-1, founded 8th March 1957 [4]. We do not know what Mikhail Tikhonravov thought of this. He was a quiet man who preferred to work in the background and who rarely sought the limelight. His unassuming nature concealed great imagination, a steely sense of purpose and, as the situation in the early 1950s required some considerable courage.

This was typical of Korolev. Long before his intercontinental ballistic missile had flown, some time before the first Sputnik had even been approved, he was already thinking ahead to a flight to the moon. Working on several projects at once daunted many lesser men, but it was his *forte*. Korolev's drive, imagination, timing and ability to knock heads (and institutes) together do much to explain the early successes of the Soviet space programme [5]. The relationship between Tikhonravov and Korolev has attracted little attention, but it was a key element in the early Soviet lunar programme. One person who has commented is Sergei Khrushchev, son of the Soviet leader Nikita Khrushchev. Sergei Khrushchev says that Korolev was not an originator of technical ideas, but someone able to gather the best engineers and technicians around him. He was able, though, to spot talent, to organize, to manage, to drive ideas and concepts through the political system. Although many of the ideas of his design bureau were attributed externally to him, he made sure that, within the bureau, individual designers were recognized, promoted, praised and rewarded. Khrushchev: 'Mikhail Tikhonravov was a man of brilliant intellect and imaginative scope [but] totally devoid of organizational talents' [6]. The combination of Korolev the organizer and Tikhonravov the designer worked well and between them they built the moon programme.

INTRODUCING THE FATHER OF THE SOVIET MOON PROGRAMME: MIKHAIL TIKHONRAVOV

Tikhonravov's background in the space programme went as far back as Korolev's, even though he was much less publicly prominent. But what do we know about Mikhail Tikhonravov? Mikhail Tikhonravov was the architect of the Soviet moon



GIRD-09

programme. He was born 16th July 1900 (OS)[1] and began his early aeronautical career by studying the flight characteristics of birds and insects. In 1922, his study called *Some statistical and aerodynamical data on birds* was published in *Aircraft* magazine. He graduated from the Zhukovsky air force academy in 1925 and worked in aviation. In 1932 he joined Korolev's group of amateur rocketeers, the GIRD (Group for the study of jet propulsion), moving in and out of rocketry and jet propulsion in the 1930s and 1940s. He wrote *Density of air and its change with altitude* for a military magazine in 1924. Seven more articles on aeronautics appeared by 1939. In the course of his work he met the ageing theoretician Konstantin Tsiolkovsky and joined the Moscow GIRD. He was closely involved with Korolev in the construction of amateur rockets

[1] OS is Old Style, the calendar in use before the Bolshevik revolution, which ran twelve days behind the rest of Europe. New style dates are given for those born after the revolution.

launched over 1933–5. The Moscow group had fired the first liquid-fuel Russian rocket from a forest near Moscow. The rocket was called the GIRD-09, a needle-like contraption just able to fly higher than the tall trees. Launching on 17th August 1933, it reached the mighty height of 400 m in its 18 sec mission. The GIRD rocket was designed by Mikhail Tikhonravov. The work of these young rocketeers and theoreticians was later to become extremely significant for the later moon missions. GIRD was supervised by a technical council with four teams, led respectively by Friedrich Tsander, Sergei Korolev, Yuri Pobedonostsev and Mikhail Tikhonravov, with Tikhonravov having responsibility for liquid propellants [7]. The group was really driven by Sergei Korolev (born 30th December 1906 (OS)), a graduate of Moscow Higher Technical School who designed, built and flew his own gliders and for which he developed rockets as a means to get them airborne.

Tikhonravov wrote a book on space travel in 1935 and then disappears from the records until the end period of the war. He was one of the few to escape the purges. Tikhonravov was a talented man who painted oils in his spare time and studied insects and beetles. Tikhonravov re-emerged in 1944 designing high-altitude rockets for the Lebedev Institute of the Academy of Sciences and two years later was transferred to Scientific Research Institute NII-4, staffed mainly by artillery officers, to design and build missiles. In the later 1940s, his name reappears on an edited book on the writings of Konstantin Tsiolkovsky and Friedrich Tsander. Tikhonravov designed the first plans for sending humans into space – the VR-190 suborbital rocket, able to send two stratonauts on an up-and-down mission 200 km high, a flight eventually emulated by Alan Shepard and Virgil Grissom in 1961. From 1948 onward, Tikhonravov worked for the Artillery Academy of Sciences and put forward the idea of grouping rockets together in a cluster of packets to achieve new velocities and lifting power. It was at such a presentation attended by Korolev in 1948 that the two men resumed their collaboration that had been broken by the purges [8]. On 15th March 1950, Tikhonravov put forward one of the formative papers of the Soviet space programme, with a convoluted but self-explanatory title: *On the possibility of achieving first cosmic velocity and creating an Earth satellite with the aid of a multi-stage missile using the current level of technology*.

This paper caused a stir and indeed led to Tikhonravov's banishment. In the final, paranoid days of Stalin, he fell under suspicion for giving unwarranted attention to non-military affairs and for not concentrating sufficiently on the defence of the motherland. He was demoted, rather than imprisoned or worse, but ironically this gave him all the more time to consider long-term objectives. During this period of reflection, the article for *Pionerskaya Pravda* was conceived. Following the death of Stalin, he was restored to his old work in the Directorate of the Deputy Commander of Artillery. There, he organized the 'satellite team' that paved the way for the Soviet Union to launch the first Sputnik. His memorandum *A report on an artificial satellite of the Earth* (25th May 1954) included a final section called *Problems of reaching the moon* which outlined a 1,500 kg spacecraft to land on the moon and return using atmospheric braking. His ideas had now moved from a children's newspaper to an official Soviet document in the period of three years.

April 1956 saw the Soviet Academy of Sciences organize the all-Union conference

On rocket research into the upper layers of the atmosphere. Here, Sergei Korolev made a lengthy presentation. He told the conference:

It is also a real task to prepare the flight of a rocket to the moon and back to the Earth. The simplest way to solve this problem is to launch a probe from an Earth satellite orbit. At the same time, it is possible to perform such a flight directly from the Earth. These are prospects of the not too distant future.

Department #9 was later reorganized and subtitled the 'Planning department for the development of space apparatus'. In April 1957, the planning department produced a detailed technical document, *A project research plan for the creation of piloted satellites and automatic spacecraft for lunar exploration*. The key question, iterated by Tikhonravov, was the need to construct an upper stage for the planned intercontinental ballistic missile. Meantime, the Academy of Sciences appointed the Commission on Interplanetary Communications to oversee the planning or 'the conquest of cosmic space': vice-chairman was Mikhail Tikhonravov.

There the matter rested for the moment, as OKB-1 focused on the great challenge of launching an artificial Earth satellite that autumn.

Chronology of the idea of a Soviet moon rocket

1951	*Flight to the moon* by Mikhail Tikhonravov in *Pionerskaya Pravda*.
1954	*Report on an artificial satellite of the Earth* by Tikhonravov, Glushko and Keldysh.
1955	*On the question of the application of rockets for research into the upper layers of the atmosphere* by Sergei Korolev.
1956	Conference on moon in Leningrad State University (February). Korolev formally announces goal of moon mission (April) at conference *On rocket research into the upper layers of the atmosphere*. Artillery institute's research institute NII-4 transferred to OKB-1 as Department #9 under Tikhonravov.
1957	Department #9's *Project research plan for the creation of piloted satellites and automatic spacecraft for lunar exploration* (April). Academy of Sciences establishes the Commission on Interplanetary Communications, led by Tikhonravov.

SOVIET SPACE PROGRAMME BEFORE SPUTNIK

The Soviet space programme before Sputnik was the coming together of a number of diverse bodies, people, institutes and traditions. Going to the moon, Earth's nearest celestial neighbour, had always been a part of this idea.

The Soviet space programme actually stretched back into Tsarist times. Its chief visionary was a deaf schoolteacher, Konstantin Tsiolkovsky (1857–1935). He was a remarkable man who carried out space experiments in his home, drew designs for interstellar spacecraft, calculated rocket trajectories (Tsiolkovsky's formula is still taught in mathematics) and wrote science fiction about the exploration of the solar system. Rocketry was little encouraged under the tsars – indeed, another early designer, Nikolai Kibalchich, was executed in 1881 for turning his knowledge of explosives to use in an assassination plot.

The 1920s became the golden age of theoretical Soviet cosmonautics. Popular societies blossomed, exhibitions were held, science fiction was published, an encyclopaedia of space travel issued. It was rich in theoretical, practical and popular work. Friedrich Tsander and Alexander Shargei (AKA Yuri Kondratyuk) outlined how spacecraft could fly to the moon and Mars. Popular societies were set up to popularize space travel and exhibitions were held. In St Petersburg, the Gas Dynamics Laboratory (GDL) was set up in the old St Peter and Paul Fortress. It attracted the brightest Russian chemical engineer of the century, Valentin Glushko and here the first static Russian rocket engines were developed. Glushko, born 20th August 1908 (OS), was a precocious young engineer who had built a toy rocket at age 13, corresponded with Tsiolkovsky in 1923 and wrote his own first contributions on spaceflight in 1924. He joined the original rocket engine design bureau in Russia, the Gas Dynamics Laboratory, in 1925 and was given his own subdivision in 1929, when he was just over 20 years old. The following year, Glushko began his first experiments with nitric acid fuels and developed new ways of insulating rocket engines through exotic materials like zirconium. 1931 found him working on self-igniting fuels, swivelling (gimballing) engines and high-speed turbine pumps.

Alexander Shargei addressed some of the key questions of lunar missions in *The conquest of interplanetary space* (1929). He put forward the notion that, in landing on the moon or planets, the landing stage should be left behind and used as a launching

Valentin Glushko, chief designer

pad for the returning spacecraft. He suggested that it would be more economical to land on a moon or planet from an orbit, rather than by a direct descent. He outlined how explorers from the moon and planets could return by using the Earth's atmosphere to break their speed through reentry. In 1930, the elderly Konstantin Tsiolkovsky was advisor to a film called *Kosmicheskoye putechestviye* (Space journey), a Mosfilm spectacular in which spacesuited Soviet cosmonauts travelled weightless to the moon (the actors were suspended on wires to simulate zero gravity) and then walked its surface.

This flourishing of theory, practice and literature came to an abrupt and grotesque end in 1936 with the start of the great purges. The head of the army's rocket programme, Marshal Tukhachevsky, was seized, charged with treason and shot, all within a matter of hours. Sergei Korolev was sent off to the gulag and Glushko was put under arrest for six years. The leaders of GDL, Langemaak and Kleimenov, were shot. Most other engineers were put under house arrest and very few escaped the wrath of Stalin in some shape or form (lucky Tikhonravov was one of them). The amateur societies were closed down. Fortunate was Tsiolkovsky not to see all this, for he died in old age in 1935.

The survivors of the Gulags were let out – or kept under a relaxed form of arrest – to contribute to the war effort. Rocketeers now put their talents to work in aircraft design to win the war against Germany. Their real shock came in 1944 when they learned of the progress made by Germany in rocket design. Mikhail Tikhonravov was one of a team of Russian scientists to visit Poland in August 1944 behind then rapidly retreating German lines. They went there on foot of intelligence reports sent to Britain which indicated that Germany was developing a rocket weapon. Following the RAF attack on the main German launch site at Peenemünde, Germany had moved testing to an experimental station in Debica, Poland, near the city of Krakow. Polish agents had found the launch and impact sites there and had managed to salvage the remains of the rocket, including, crucially, the engine. British prime minister Winston Churchill asked Stalin to facilitate access by British experts to the site, though this meant of course that Stalin's experts would benefit equally from what they found. They found that Germany had stolen a march on them all and under the guidance of their chief designer, Wernher von Braun, had launched the world's first real ballistic rocket, the A-4, on 3rd October 1942. A month after Tikhonravov's visit to Poland, the first A-4s were fired as a military weapon. Over 1944–5, the A-4, renamed the V-2, was used to bombard London and Antwerp. The Germans had also moved ahead with sophisticated guided missiles (like the *Schmetterling*) and anti-aircraft missiles (like the *Wasserfall*) and were far advanced in a range of related technologies. In early 1945, the Red Army swept into the development centre of the A-4, the Baltic launch site of Peenemünde.

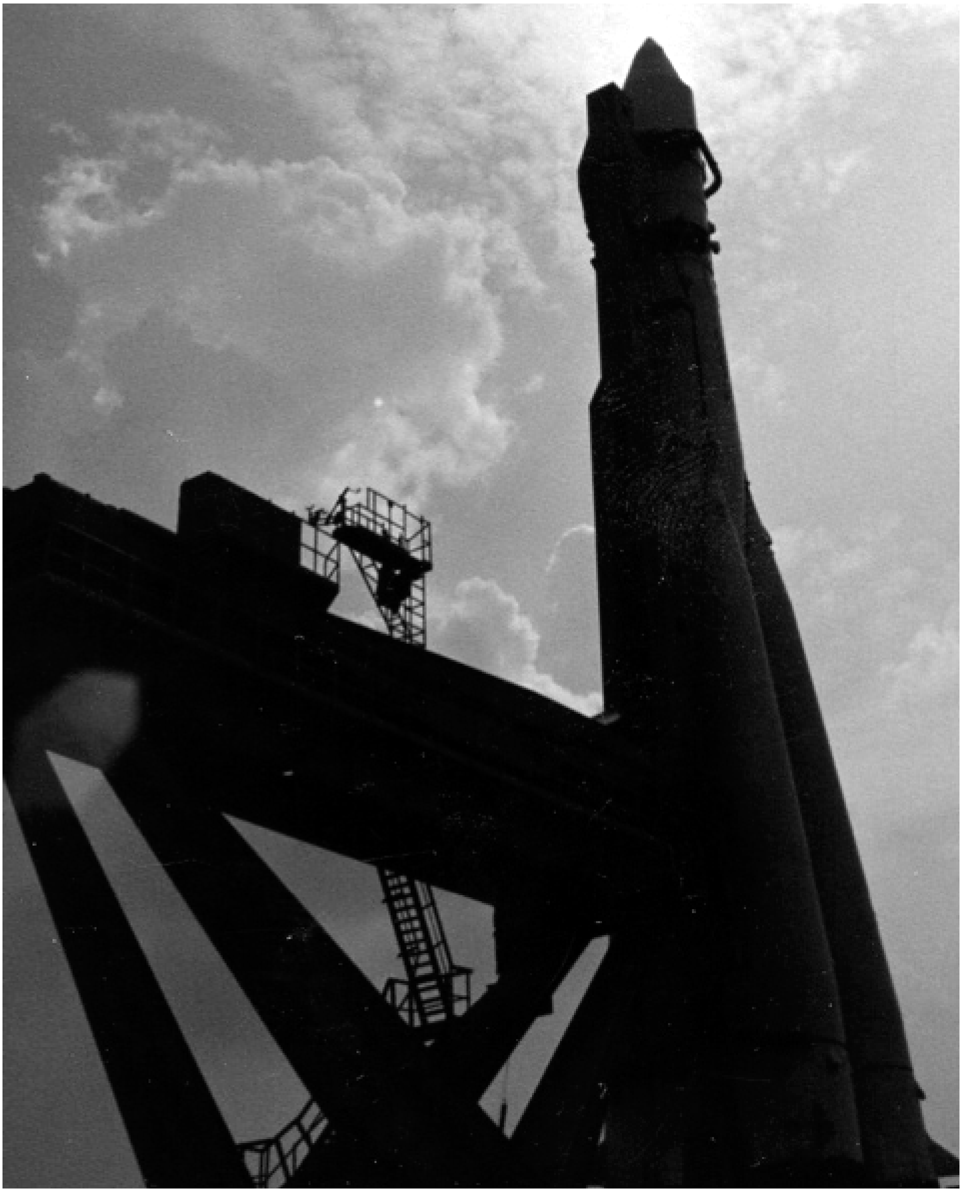
THE POSTWAR MOBILIZATION

Neither the Russians, Americans, British nor French were under any misapprehensions about the achievement of von Braun and his colleagues. Each side dispatched its top rocket experts to Germany to pick over the remains of the A-4. For one brief moment in time, all the world's great rocket designers were within a few kilometres of each another. Von Braun was there, though busily trying to exfiltrate himself to America. For the Soviet Union, Valentin Glushko, Sergei Korolev, Vasili Mishin, Georgi Tyulin and Boris Chertok. For the United States, Theodor von Karman, William Pickering and Tsien Hsue Shen (who eventually became the founder of the Chinese space programme). Later in 1945, Britain was to fire three V-2s over the North Sea. Britain's wartime allies were invited to watch. The British admitted one 'Colonel Glushko' but they refused admittance to another 'Captain Korolev' because his paperwork was not in order and he had to watch the launching from the perimeter fence. The British were not fooled by these civilians in military uniforms, for they could give remarkably little account of their frontline experience (or wounds) in the course of four years' warfare.

Korolev and Glushko returned to Russia where Stalin put them quickly to work to build up a Soviet rocket programme. The primary aim was to develop missiles and if the engineers entertained ambitions for using them for space travel, they may not have kept Stalin so fully informed. The rocket effort was reorganized, a series of design bureaux being created from then onwards, the lead one being Korolev's own, OKB-1. Glushko was, naturally, put in charge of engines (OKB-456). In 1946, the Council of Designers was created, Korolev as chief designer. This was a significant development, for it included all the key specialisms necessary for the later lunar programme: engines (Valentin Glushko), radio systems (Mikhail Ryazansky), guidance (Nikolai Pilyugin), construction (Vladimir Barmin) and gyros (Viktor Kuznetsov). In 1947, the Russians managed to fire the first of a number of German A-4s from a missile base, Kapustin Yar, near Stalingrad on the River Volga. The Russian reverse-engineered version was called the R-1 (R for rocket, *Raket* in Russian) and its successors became the basis for the postwar Soviet missile forces. Animals were later launched on up-and-down missions on later derivatives, like the R-5.

The significant breakthrough that made possible the development of space travel was an intercontinental ballistic missile (ICBM). In the early 1950s, as the Cold War intensified, the rival countries attempted to develop the means of delivering a nuclear payload across the world. The ICBM was significant for space travel because the lifting power, thrust and performance required of an ICBM was similar to that required for getting a satellite into orbit. In essence, if you could launch an ICBM, you could launch a satellite. And if you could launch a satellite, you could later send a small payload to the moon.

Approval for a Soviet ICBM was given in 1953. An ICBM in the 1950s was a step beyond the A-4, as much as the A-4 of the 1940s was a step beyond the tiny amateur rockets of the 1930s. Korolev was the mastermind of what became known as the R-7 rocket. It was larger than any rocket built before. It used a fuel mixture of liquid oxygen and kerosene, a significant improvement on the alcohol used on the German A-4. Its powerful engines were designed and built by Valentin Glushko, whose own design bureau, OKB-456, was now fully operational. The real breakthrough for the R-7 was that in addition to the core stage with four engines (block A), four stages of similar dimensions were grouped around its side (blocks B, V, G and D). This was



The R-7

called a 'packet' design – an idea of Mikhail Tikhonravov dating to 1947 when he worked for NII-4. No fewer than 20 engines fired at liftoff. Work began on this project over 1950–3.

The new rocket required a new cosmodrome. Kapustin Yar was too close to American listening bases in Turkey. A new site was selected at Tyuratam, north of a bend in the Syr Darya river, deep in Kazakhstan. The launch site was called Baikonour, but this was a deliberate deception. Baikonour was actually a railhead 280 km to the north, but the Russians figured that if they called it Baikonour and if nuclear war broke out, the Americans would mistakenly target their warheads on the small, undefended unfortunate railway station to the north rather than the real rocket base. Construction of the new cosmodrome started in 1955, the labourers living and working in primitive and hostile conditions. Their first task was to construct, out of an old quarry, a launch pad and flame pit. The first pad was built to take the new ICBM, the R-7.

Scientific direction for the space programme was provided by the Academy of Sciences. The Academy dated back to the time of Peter the Great. Following the European tradition, he established a centre of learning for Russia's academic community in St Petersburg. This had survived the revolution, though now it was renamed the Soviet Academy of Sciences. For the political leadership's point of view, the Academy provided a visible and acceptable international face for a space programme that had its roots in military imperatives. The chief expert on the space programme within the Academy of Sciences was Mstislav Keldysh, a quiet, graying, mathematical academician. Mstislav Keldysh was son of Vsevolod M. Keldysh (1878–1965), one of the great engineers of the early Soviet state, the designer of the Moscow Canal, the Moscow Metro and the Dniepr Aluminium Plant. Young Mstislav was professor of aerohydrodynamics in Moscow University, an academician in 1943 at the tender age of 32 and from 1953 director of the Institute of Applied Mathematics. Following Stalin's death, he had introduced computers into Soviet industry. He was on the praesidium of the Academy from 1953, won the Lenin Prize in 1957 and later, from 1961 to 1975, was academy president. He was the most prestigious scientist in the Soviet Union, though he made little of the hundreds of awards with which he was showered in his lifetime. His support and that of the academy for Korolev and Tikhonravov was to become critical.

In the 1950s, the idea of a Russian space programme enjoyed discussion in the popular Soviet media. The golden age of the 1920s had come to an abrupt end in 1936 and talking about space travel remained dangerous as long as Stalin ruled the Kremlin. When the political environment thawed out, ideas around space travel once again flourished in the Soviet media – newspapers, magazines and film. Soviet astronomers resumed studies that had been interrupted by the war. A department of astrobotany was founded by the Kazakh Academy of Sciences and its director, Gavril Tikhov, publicized the possibililities of life on Mars and Venus. His books were wildly popular and he toured the country giving lectures.

By 1957, the key elements of the Russian space programme were in place:

- A strong theoretical base.
- Practical experience of building engines from the 1920s and small rockets from the 1930s.
- A council of designers, led by a chief designer.
- A lead design bureau, OKB-1, with a specialized department, #9.
- Specialized design bureaux for all critical support areas, such as engines.