JBIS

Journal of the British Interplanetary Society

VOL. 53 No. 9/10 SEPTEMBER/OCTOBER 2000

LIST OF CONTENTS

EXTRATERRESTRIAL CIVILISATIONS

SPACE HISTORY
(i) UK Rocket Technology (ii) Soviet Luna Probes

MARTIAN LIFE SCIENCE STUDY

* * *

PRICE: £40.00 (US$64); BIS MEMBERS £10.00 (US$18)
OBTAINABLE FROM: THE BRITISH INTERPLANETARY SOCIETY, 27/29 SOUTH LAMBETH ROAD, LONDON SW8 1SZ, ENGLAND

JBIS, Vol. 53, pp.319-356, 2000

The Tough Road Travelled: A New Look at the Second Generation Luna Probes

ASIF SIDDIQI[1], BART HENDRICKX[2] and TIMOTHY VARFOLOMEYEV[3]
1. Pittsburgh, USA.*
2. Antwerpen, Belgium.*
3. St. Petersburg, Russia.*
* c/o The British Interplanetary Society, 27/29 South Lambeth Road, London, SW8 1SZ, England.

Between January 1963 and April 1968 the Soviet Union launched 20 robotic probes as part of its "second generation" lunar exploration programme. The main purpose of this programme was to perform the first ever soft landing on the lunar surface and to place the first probes into lunar orbit. Both goals were accomplished after numerous failures. This article is an attempt to chronicle an amazing story of perseverance that gave the Soviet space programme some of its most notable successes during the 1960s.

Keywords: Space history, Soviet technology, lunar exploration, space policy, robotics.

1. Introduction

The second generation series came on the heels of the nine "first generation" probes, launched between September 1958 and April 1960, which were characterised by some of the most spectacular Soviet successes in the early years of the space race, most notably the first lunar impact (retroactively named Luna-2) and the first photographs of the far side of the Moon (retroactively named Luna-3) [1]. The second generation also had its own successes, most principally the first soft landing of a probe on the Moon with Luna-9 in February 1966. But this singular success was achieved at a high cost, after an unprecedented series of 11 failed attempts to accomplish a survivable landing.

2. Background

Like most space projects dating from the 1960s, proposals for lunar soft-landers arose in the mid-1950s. The most vocal advocate of such missions was the famous Sergey P. Korolev, the Chief Designer of the Experimental Design Bureau No. 1 (OKB-1) based in Kaliningrad (now renamed Korolev) near Moscow. In the late 1950s, the OKB-1 was the leading organisation for the development of Soviet long-range ballistic missiles and spacecraft.

In a long paper presented at a session to celebrate the 125th anniversary of the Moscow Higher Technical School Named After N. E. Bauman (MVTU) on 25 September 1955, Korolev spoke at length about current and future space-related projects including the possibility of landing robotic probes on the surface of the Moon [2]. Korolev, along with Academician Mstislav V. Keldysh, first proposed concrete ideas for lunar exploration in a letter to the Soviet government on 28 January 1958 [3]. Neither soft-landers nor orbiters were considered as part of the first generation project, which initially comprised four different probes named the Objects Ye-1, Ye-2, Ye-3, and Ye-4 [4]. It would be six further months before Korolev (together with OKB-1 Department Chief Mikhail K. Tikhonravov) took the first steps to conceptualise a second generation of lunar probes which would have the primary missions of soft-landing and orbital photography. In an important letter to the government dated 5 July 1958, the two men enumerated a long list of short and long-range civilian goals for the Soviet space programme. With regard to lunar exploration, they proposed using the basic R-7 (SS-6) ICBM, uprated with third and fourth stages, for the three following projects:

(1) The creation of 'research stations' on the surface of the Moon with a mass of 10-20 kg which would be powered by solar panels and equipped with radio systems; the last stage of the launch vehicle would be equipped with special guidance and control systems to control the landing; the work would be carried out in 1958-61;

(2) The creation of a lunar satellite for photographing the surface of the Moon; the work to be carried out in 1959-61;

(3) The accomplishment of lunar flybys with a subsequent return to Earth for recovery of film and other data; all three goals to be completed in the period 1960-64 with the use of a special fourth stage customised for each mission [5].

The two main goals of the second generation series were clearly lunar soft-landing and lunar orbiting, but through 1958 the focus at OKB-1 was on the first generation of probes. In 1959, however, Korolev appears to be have been briefly diverted by concurrent U.S. plans for the Moon. By the end of 1958, the United States had already tried three times unsuccessfully to *orbit* a Pioneer probe around the Moon using the Air Force's Thor Able I booster (in August, October, and November of 1958). Additionally, in the spring of 1959, Space Technology Laboratories (STL) proposed launching four lunar orbiters by the Atlas Able, two of which had actually been originally scheduled as Venus orbiters. The visible Soviet interest in the Moon had evidently prompted the STL to revamp their original schedule. As it happened, all three launch attempts (in November 1959, September 1960, and December 1960) ended in failure [6]. These public displays of interest in a lunar orbiter no doubt were factors in Korolev's decision-making. Unwilling to take second place in the lunar orbit sweepstakes, Korolev and Keldysh, in February 1959, proposed a new interim probe, the Ye-5, to orbit the Moon at the earliest date, possibly by the end of the year. In a document to the government in February 1959, they proposed that a single mission be launched to impact the third stage of the 8K72 launch vehicle on the surface of the Moon. At the same time, "a separate container" would spin off and enter orbit around the Moon. Scientific experiments would be limited to those that were used on the earlier Ye-1 class impact probes, i.e. five modest instruments for investigating interplanetary space. In the same document, the two men proposed a second mission, the Ye-6, for landing a small probe on the surface of the Moon with the goal of transmitting scientific and photographic data (from TV cameras) from the lunar surface back to the Earth. The idea was to reserve two launch vehicles for launching the Ye-6 in the first half of 1960 [7].

The Ye-5 proposal was extremely short-lived and was dropped from further consideration by the end of 1959 probably because of the unavailability of an extra launch vehicle, especially given the repeated and expensive failures in the first generation of probes. Korolev had expected to use the old 8K72 boosters for both the Ye-5 and Ye-6 probes, but as a backup had also considered using a "new" R-7-based launcher named the 8K73 for the Ye-6 landers. The 8K73 was to have used a third stage with Chief Designer Valentin P. Glushko's RD-109 engine with a vacuum thrust of 10 tons. In the event, Glushko was unable to deliver the engine on time, and the 8K73 launcher programme was eventually scrapped. Quite likely, the unavailability of the 8K72 and the demise of the 8K73 were contributing factors to terminating work on the Ye-5 and Ye-6 lunar probes in their original conceptions for launches by 1960 [8].

In late 1959, after some rethinking of lunar goals, Korolev restructured the OKB-1's goals to include two probes, the new (and heavier) Ye-6 lunar lander and the Ye-7 lunar orbiter. They apparently shared a common bus design. Both would be launched by a four-stage version of the R-7 ICBM named the 8K78 (many years later retroactively named the Molniya booster). The four-stage rocket offered increased capabilities and a heavier payload, i.e. it was capable of sending up to 1.5 tons on a trans-lunar trajectory [9]. The actual chain of events leading to official approval of the proposal remains somewhat confusing. Korolev's Deputy Chief Designer Boris Ye. Chertok recalls that on Korolev's initiation the Ye-6 (but not the Ye-7) proposal was evidently approved by the Central Committee and the Council of Ministers as part of a larger decree on the Soviet space programme issued on 10 December 1959 [10]. In the official history of the OKB-1, the authors note that in January 1960 "a decision was taken on the development of research into cosmic space, in which the creation of automatic stations on the Moon and its regions was envisaged..." [11]. The first launch of the Ye-6 lander was scheduled for 1961. Clearly there was some delay in the implementation of the programme.

On 26 March 1960, the OKB-1 completed preliminary research confirming the technical feasibility of achieving a lunar soft-landing [12]. Yet interestingly enough, the very same day, Korolev sent a formal letter directly to Dmitriy F. Ustinov, the then-Chairman of the Military Industrial Commission, and Valeriy D. Kalmykov, the Chairman of the State Committee for Radio-Electronics, asking them to reexamine the level of commitment to the Ye-6 and Ye-7 programmes. Korolev noted that the primary bottleneck in both programmes was the development of reliable control, guidance, and communications systems for the spacecraft. He added that "at the present time, the situation with regard to the creation of the objects [Ye-6] and [Ye-7] is not at all clear, in connection with which we ask you to examine the question of the course of work on these objects and adopt the necessary decisions" [13]. As a supplement to the original letter, Korolev sent a second document to a larger group of important government officials on 7 April 1960 detailing a wide variety of important space projects for implementation in 1960-62. Here he listed both the Ye-6 and Ye-7 as important components of the Soviet space programme; he apparently still believed that both could be launched as early as 1961 [14]. Although Korolev included both projects in a massive draft of the famous "Big Space Plan" of 1960, it seems unlikely that these two lunar projects were included in the actual decree (which still remains classified) when it was formally issued by the Central Committee and the Council of Ministers on 23 June 1960. Korolev was aiming to achieve the Ye-6 landing in 1960-61 and the Ye-7 orbiting by 1961 [15].

Korolev had tasked their development to Department No. 9 Chief (and later Deputy Chief Designer) Tikhonravov who in turn assigned the work to the sector headed by Gleb Yu. Maksimov, the same team who had developed the original first generation of lunar probes. Nikolay P. Beresnev's team was the main group of engineers responsible for the design of the Ye-6 probe. A team under Chertok was assigned to supervise development of the critical guidance and control systems for the spacecraft; Chertok eventually exercised operational control over the programme from 1963 on behalf of Korolev. Work at the OKB-1 on Ye-6 was, however, not a big priority, at least in 1960-61. The concurrent work on Vostok, Zenit, Mars, Venera, and the R-9 ICBM left few resources or time to devote to the lunar probe programme [16]. Part of this was probably due to the lack of a firm commitment from the government on the project. After the initial December 1959 decree, Korolev's several letters and documents on the issue had gone unanswered. It was only on 13 May 1961, over a year after Korolev's important letter in early 1960, that the Soviet government issued a decree committing further funds to the development of the Ye-6 lander and its associated 8K78 launch vehicle [17]. For reasons that are unclear, the Ye-7 orbiter proposal was not included in the decision although the OKB-1 appears to have continued low level work on the orbiter without official sanction. The lack of approval for Ye-7 is somewhat surprising given U.S. efforts at the time. In 1960, NASA had begun work on the Surveyor programme, which at the time included a soft-lander *and* an orbiter, both to be launched by the Atlas Centaur. It was only in mid-1962, for a variety of reasons including problems with the Centaur, failures in the Ranger programme, and changing requirements for an orbiter programme, that NASA decided to cancel the Surveyor orbiter [18]. From a political perspective, a lunar satellite was perhaps not considered of primary importance given the fact that the Soviets had already returned the first photos of the far side of the Moon during the Luna-3 mission in 1959.

Korolev clearly visualised the Ye-6 programme as part of larger goal of lunar exploration. In a document signed on 23 September 1963 which formed the basis for future piloted and robotic exploration of the Moon in the period 1963-68, Korolev prominently mentioned the Ye-6 lander project as an essential step which would lead to future human landing missions to the Moon using the giant N-1 rocket [19].

3. The 8K78 Launch Vehicle

The 8K78 was a four-stage iteration of the original R-7 ICBM. It was originally conceived in early 1959 to launch the first generation of interplanetary probes to Mars and Venus. The basic idea was to use the first three stages to launch the fourth stage and payload into low Earth orbit. At the appropriate time, the fourth stage would then fire to send the payload on an interplanetary trajectory. In terms of configuration, the 8K78 comprised an uprated R-7A ICBM with improved engines, known as the 8K74/III. These improvements were focused on increasing tank pressure in the strap-on boosters and the central core, as well as strengthening the missile's airframe and open truss structure above the core. Most important, Glushko's engineers uprated the RD-107 (one each on the four strap-ons) and RD-108 (a single one on the core) engines for better performance. The third stage, the Blok I, was equipped with OKB-154 Chief Designer Semen A. Kosberg's 8D715K engine, itself derived from the second stage engine of the R-9 (SS-8) ICBM.

Perhaps the most critical element of the 8K78 launch vehicle was the fourth stage, known as the Blok L. Its first version was equipped with the single chamber S1.5400 engine, one of the first rocket engines developed in-house at Korolev's OKB-1. The 6.5 ton thrust engine was not only designed for firing in vacuum conditions, but was also the first operational Soviet rocket engine operating in a closed cycle. The engine could be gimballed for pitch and yaw (up to 3° deviation). Two 10 kg thrust vernier engines were also included for roll control; these fed off the same propellants as the main engine, liquid oxygen (LOX) and kerosene T-1 (later replaced by the newer RG-1 type of kerosene). The engine's propellant tanks were covered by thermal insulation to protect them from the heat of solar radiation during the stay in Earth orbit. The Blok L stage also had a system named the Ignition Ensurance Block (Russian abbreviation BOZ) which, at the end of the unpowered coast in the temporary

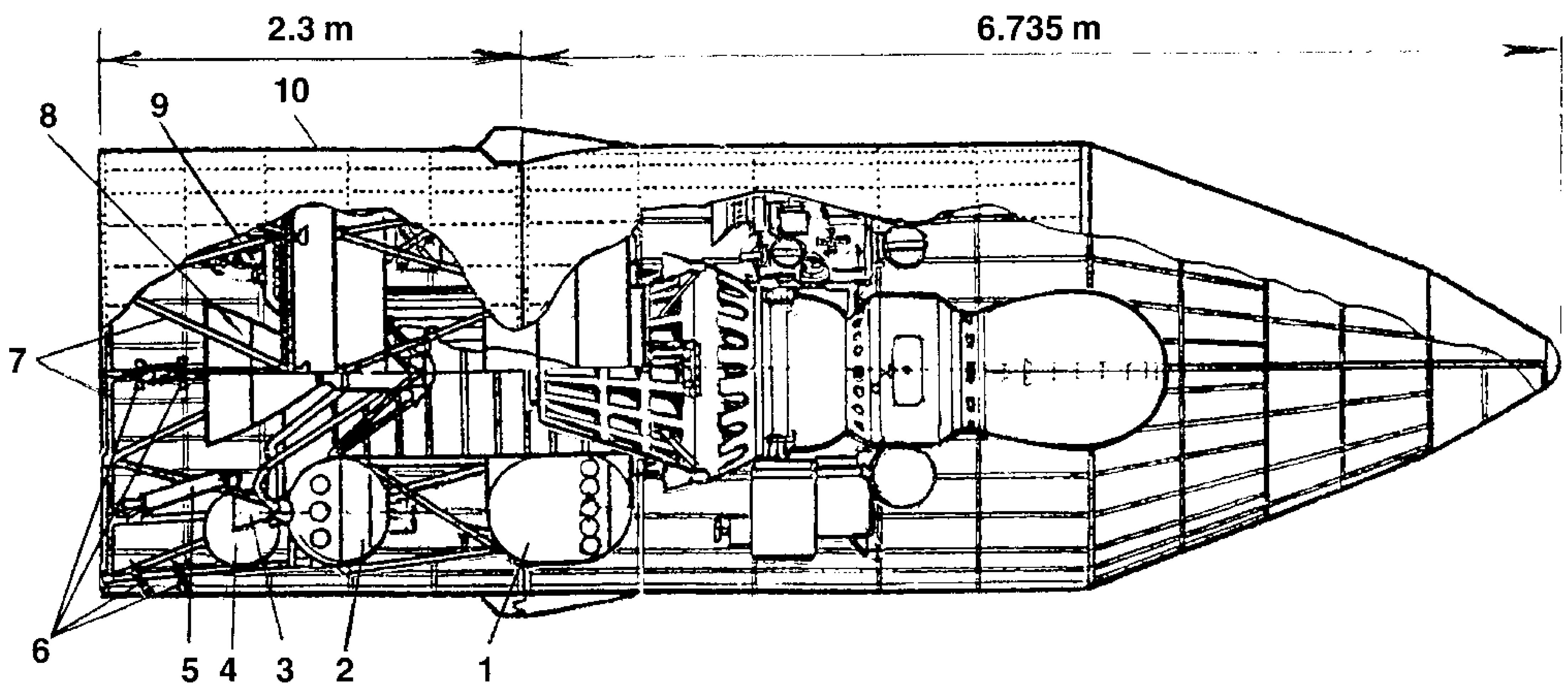

Fig. 1 Cut-away drawing of Blok L and the Ye-6 spacecraft. Key: 1. Blok L oxidizer tank, 2. Blok L fuel tank, 3. Vernier chamber of the S1.5400A1, 4. One of four compressed nitrogen storage bottles, 5. One of four solid rocket motors, 6. Gas thrusters of attitude control system, 7. Open truss structure of BOZ, 8. Main chamber of S1.5400A1 engine, 9. One of two small gas storage bottles, 10. Cylindrical adapter. (source: A. Shlyadinskiy and T. Varfolomeyev)

Earth orbit lasting about 1.5 hours, would make sure that the Blok L was ready for trans-lunar injection firing, i.e. that the internal propellants would flow correctly to the main combustion chamber in microgravity and that the thrust vector of the main engine would be oriented in the correct direction. The first task was performed by four solid propellant rocket motors mounted on the BOZ's open structure which would provide initial acceleration for the Blok L immediately prior to main engine ignition. The second task was carried out by a set of gas thrusters fed by compressed nitrogen (individually known as the Orientation and Stabilisation System (Russian abbreviation SOIS)) which would carry out attitude control and stabilisation for the stage during unpowered flight, just prior to and during the firing of the solid rocket engines, and during the early phase of firing of the main engine. All these systems, as well as operation of the booster third stage (Blok I), were controlled by the I-100 system, installed aboard the Ye-6 probe and developed under Chief Designer Nikolay A. Pilyugin at NII-885. For the Ye-6 version, the total length of the 8K78 booster was 44.018 metres. Total mass was 305.5 tons [20].

Korolev signed a plan for developing the four-stage 8K78 launch vehicle on 15 January 1960 and less than five months later, on 10 May, he signed the actual draft plan for the rocket. The original draft plan was specifically for a configuration suitable for launching probes to Mars, but engineers had also accounted for future versions for other payloads. Because of time restrictions, the OKB-1 did not experimentally verify the Blok I third stage or the Blok L fourth stage in flight conditions prior to actual operational missions beginning October 1960. There was, however, extensive testing of the S1.5400 engine on the ground. Between May and December 1960, the OKB-1 manufactured 54 new engines at the design bureau's Experimental Machine Building Plant and fired them on the ground. Full-scale Blok L stages were fired for the first time on the ground only in early October 1960, days before the first launch of the booster; these tests were successful [21].

By the time of the first attempted Ye-6 probe launch in January 1963, the record of the 8K78 did not instill much confidence. Of the 10 launches, there had been 4 failures of the Blok L, three of the Blok I and one of the basic core/strap-on combination. Of the remaining two spacecraft that had been sent on an interplanetary trajectory, both had failed during the outbound flight [22].

In 1963-64, engineers at OKB-1's Branch No. 3 at Kuybyshev modified the basic 8K78 and introduced a "new" variant used for various robotic deep space and Molniya flights. This model, the 8K78M, used further uprated RD-107 and RD-108 engines on the core and strap-ons. These engines had higher chamber pressure and could use a new form of kerosene, RG-1 (although that does not seem to have happened in the 1960s and 1970s). Kosberg also introduced a new engine for the third stage. Finally, the Blok L used an uprated version of the S1.5400 named the S1.5400A1 (which was redesignated the 11D33) that had a slightly higher vacuum thrust (6.8 tons) than its predecessor. The first 8K78M launch, which was a failure, was in February 1964. The 8K78M completely replaced the 8K78 in the Soviet inventory by December 1965. A further improvement of the 8K78M was carried out by OKB-1's Kuybyshev Branch in 1966-67, resulting in a more efficient vehicle which was introduced during the launch of a Ye-6-class lunar orbiter in February 1968. By this time, design oversight of the first three stages of the booster had been transferred to the Kuybyshev Branch, while Blok L manufacture and design was transferred to the Lavochkin Design Bureau based in Khimki [23].

A second modification of both the basic 8K78 and uprated 8K78M has been called the 8K78/Ye-6 or 8K78M/Ye-6. These boosters were specifically designed to launch the Ye-6 class of lunar probes. The key difference with their predecessors was the transfer of the Blok L control system (which controlled operation of the third and fourth stages) from the Blok L to the payload itself. For the 8K78(M)/Ye-6 launches, the control system was actually installed on the Ye-6 spacecraft. Thus, nominal operation of the third and fourth stages as well as the probe itself now depended on the smooth functioning of the combined control system on the Ye-6. The first 8K78/Ye-6 launch was also the first launch of a Ye-6 probe in January 1963. After a series of catastrophic failures of the control system in 1963-65, engineers eventually opted to separate the functions of the control system as in the previous 8K78 booster [24].

4. The Communications Network

A directive from the Deputy Minister of Defence I. S. Konev on 8 May 1957 had created the foundation of the Soviet ground communications network by establishing 13 stations spread all across the Soviet landmass [25]. Later collectively called the Command-Measurement Network (KIK), these individual stations were manned mostly by Strategic Missile Forces officers. Initially in the early 1960s, all Soviet lunar and interplanetary space missions were *officially* controlled by the Chief Operations and Control Group (GOGU), a team of controllers based at the Ministry of Defence's NII-4 institute. In actuality, however, control over lunar and interplanetary missions was maintained at three other locations which were part of the KIK. The first of these was a temporary station near Simeiz in Crimea where the State Commission controlled the famous Luna-3 mission in 1959. The second was the Scientific-Measurement Point No. 16 (NIP-16) located at Yevpatoriya, also in Crimea. All interplanetary missions and all piloted missions (in 1966-75) were controlled from this location by mission specific GOGU teams. The third location, for control of the Ye-6 series of probes, was at yet another Crimean site, the NIP-10 at Simferepol [26]. The original installations at NIP-10 and NIP-16 together formed the first-generation deep space communications system, known as *Pluton*.

The NIP-10 at Simferopol was outfitted with the TNA-200 single-mirror system, installed in 1961-62. With its 25 m diameter parabolic dish, it was one of the largest communications antennae in the Soviet Union at the time. The NII-885 institute under Chief Designer Mikhail S. Ryazanskiy was responsible for the creation of this system. The same institute developed the deep space communications system for NIP-16 at Yevpatoriya, which consisted of eight ADU-1000 mirrors each with a diameter of eight metres, allowing communications up to 100 million km range. Similar ADU-1000 mirror systems were later installed at NIP-3 (Sary Shagan), NIP-4 (Yeniseyesk), NIP-14 (Shchelkovo near Moscow), and NIP-15 (Galenkiy near Ussuriysk). The Ye-6 programme also appears to have been the reason for introducing modern range measurement and radio-technical communications equipment to the KIK through the early 1960s. At least two new stations, the IP-41Ye at Simeiz and the IP-42Ye in Moscow were added to the KIK specifically for Ye-6 [27].

NIP-10 Chief Nikolay I. Bugayev, a Strategic Missile Forces officer, officially led the GOGU for the Ye-6 missions. Effectively, however, it was Yevgeniy Ya. Boguslavskiy, a Deputy Chief Designer at NII-885 who worked for Ryazanskiy, who directed all mission operations on a day-to-day basis. Unlike piloted missions, interplanetary flights were unique because controllers often had to conduct communications sessions as long as 12 hours. Additionally, control was vastly complicated by the amount of time it took signals to travel back and forth over the long distances. In the case of interplanetary spacecraft to Mars and/or Venus, it might take as long as long as 20 minutes for a single command to reach the spacecraft.

The nearly two dozen ground stations of the KIK were supplemented by a small array of naval ships stationed at various points around the world. In 1959, the NII-4 institute began work on a group of three ships which were to be part of the first generation sea-based communications and tracking network. Because the time for developing a completely new set of vessels would have taken far too long, the institute decided to use already built dry-loading ships of the trading fleet and re-equip them with communications apparatus. These were the *Krasnodar*, the *Ilichevsk*, and the *Dolinsk*, all of which first put out to sea in their new incarnations in August 1960. The first commander of the communications group on these ships was V. G. Bezborodov. In 1965-66, the *Krasnodar* and *Ilichevsk* were replaced by the *Bezhitsa* and *Ristna*, which joined the *Dolinsk*. The three ships served the Soviet space programme up to the mid-1970s [28].

5. The Landers

5.1 The Ye-6 Lander

By late 1961 the OKB-1 had completed the detailed design of the Ye-6 lunar lander. The four-stage 8K78 booster would be able to launch a Ye-6 probe with a mass of no more than 1,500 kg. During the nearly five year modernisation process, engineers were able to increase the mass of a standard flight model from 1,420 kg (Luna-4) up to 1,620 kg (Luna-13), i.e. by 200 kg. It is difficult to say how much of this mass increase represented additional fuel supplies or extra hardware.

The primary goal of the Ye-6 spacecraft was to carry out a survivable soft-landing on the surface of the Moon. After landing, the probe would operate an automatic television camera which would transmit images of the lunar landscape and micro-reliefs of the surface of the Moon back to the Earth, and also send information from instruments such as radiometers, seismographs, and magnetometers. The spacecraft was designed to operate over the course of four Earth days during which time controllers would have the opportunity to perform at least five full communications sessions lasting an hour each. The primary target area was designated as the Ocean of Storms [29].

The 2.7 m tall spacecraft itself was composed of three main elements:

(1) The S5.5 (also known as the KTDU-5) correction-braking engine upon which was mounted the control system block for the spacecraft;

(2) Two detachable compartments loaded with equipment;

(3) The automatic autonomous lunar station for operation on the lunar surface.

The engine unit served as the main supporting frame of the entire Ye-6 spacecraft. The actual engine was developed by the Kaliningrad-based OKB-2 headed by Chief Designer Aleksey M. Isayev. The single chamber engine used AK-27I (a solution of 27% nitrous oxide in concentrated nitric acid – "AK" is the Russian abbreviation for "nitric acid") and TG-02 (an amine derivative) as propellants. The engine had two critical uses, first to accomplish a mid-course correction on the outbound trajectory, and second for the final braking before landing on the lunar surface or entering lunar orbit. The engine assembly comprised a 90 cm diameter spherical oxidizer tank, a toroidal fuel tank and the single combustion chamber. In addition, the system had four arm-mounted thrusters for thrust control in the immediate moments prior to landing; these were fed from the same source of propellants (about 800 kg) as the main engine. Thrusts ranged from 4.1-5.164 tons and 20-35 kg determined by three modes of operation:

(1) Mode 1: mid-course correction, primary chamber thrust of 4,500 kg;

(2) Mode 2: braking for landing, primary chamber thrust of 4,500 kg, with a throttleable range of +/-500 kg;

(3) Mode 3: work of control nozzles after main chamber cutoff, thrust of 25 kg.

The base of the engine assembly also included a 5 m long probe which ran from the mid-section of the spacecraft and extended "below", past the S5.5 engine. This probe would make contact with the surface prior to the main body of the vehicle, at which point a circuit would command the thrusters to terminate firing and eject the lander from the top of the bus. Although the S5.5 was used for the initial seven Ye-6 probes, beginning with Luna-5 in May 1965, the spacecraft used the S5.5A (or KTDU-5A) engine. The differences between the two engines appear to have been minimal at best and may have had to do with production processes.

The spacecraft's main control system, developed by the Monino-based NII-885 under Chief Designer Pilyugin, was mounted on the upper portion of the engine assembly. Interestingly enough, this was Pilyugin's first job in designing a guidance system for a spacecraft. Previously his department at NII-885 (Complex No. 1) had only developed guidance systems for ballistic missiles such as the R-5M (SS-3) and R-7 (SS-6) or space launch vehicles such as the 8K72 (Luna) and 8K82K (Vostok) boosters [30]. The goal before Pilyugin's engineers was to design a reliable inertial control system using gyroscopes to direct the spacecraft during critical portions of the mission, a task made difficult by the limited mass available for the complex – 80 kg. Initially, the guidance system had to control the work of the third (Blok I) and fourth (Blok L) stages of the 8K78 booster during ascent to Earth orbit. In Earth orbit, the system, known as the I-100, would stabilise the stack during passive flight, following which it would place the payload in a correct attitude for directing the Blok L trans-lunar injection stage in the appropriate direction. Attitude control nozzles of the SOIS would carry out these orientation and stabilisation maneuvers on command from the I-100. The unit would continue attitude control duties after separation of the escape stage and would control one mid-course correction. Then, during the probe's approach the Moon, the system had to configure the

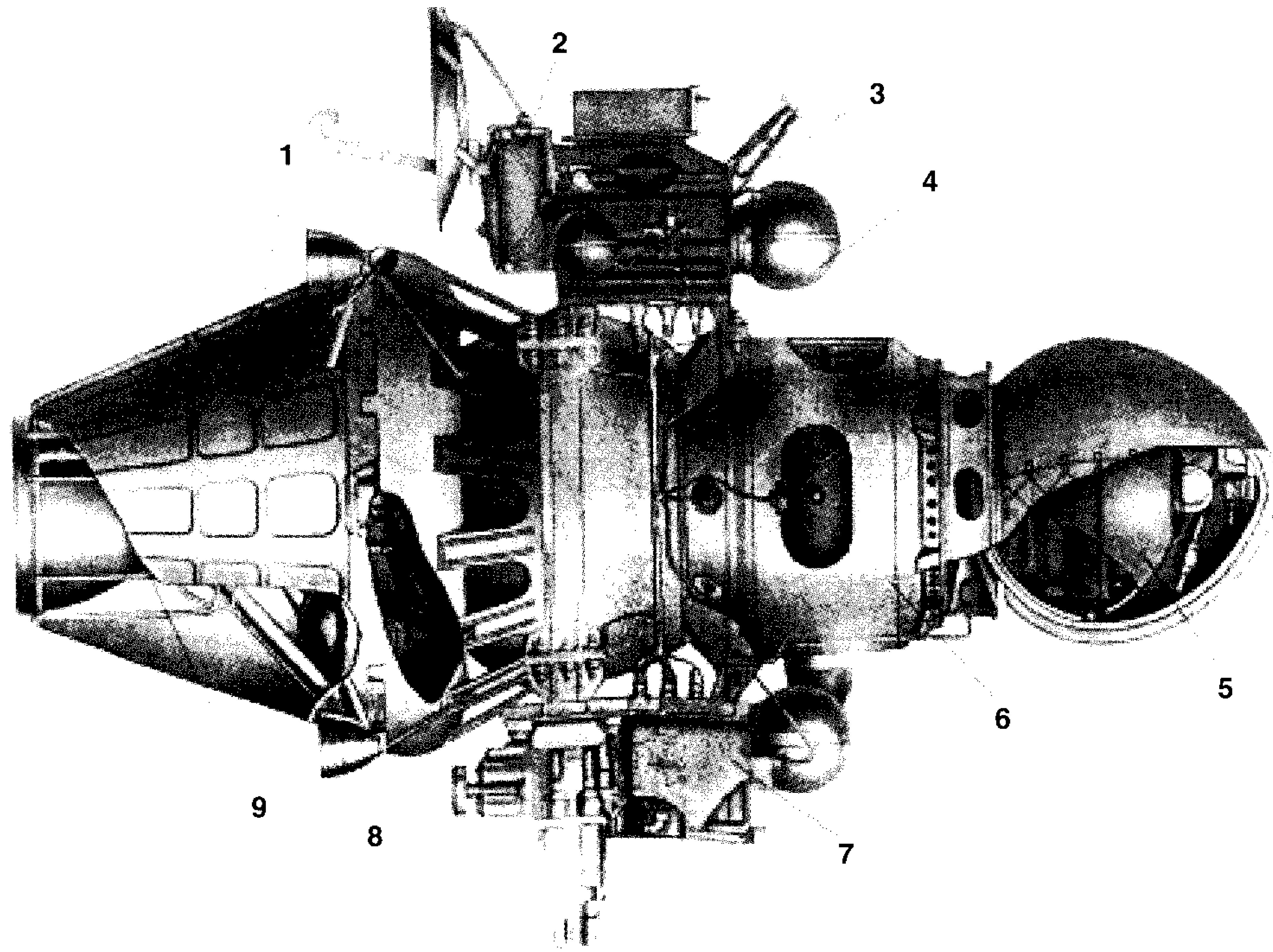

Fig. 2 The Ye-6 spacecraft. Key: 1. Protective screen of S5.5/KTDU-5 correction/braking engine, 2. Radio-altimeter, 3. Detachable compartment nr. 2 with radio equipment, 4. One of four gas-storage bottles of attitude control system, 5. Automatic Lunar Station (ALS), 6. I-100 control system, 7. Detachable compartment nr. 1 with astro-navigation system and air bottle for shock absorbing system, 8. Vernier chamber, 9. S5.5/KTDU-5 correction/braking engine. (source: Nauka Publishers, Moscow)

spacecraft in the correct attitude (using optical sensors) prior to initiation of retro-fire, i.e. position the vehicle's firing axis perpendicular to and in the direction of the lunar surface. The system would have to determine (via a signal from the radio-altimeter) the exact moment to begin firing the main engine. The control system compartment, as ultimately developed, was internally pressurised to 1.2 Earth atmospheres. The power source for the I-100 included a battery, the PT-500 inverter with a nominal power rating of 500 watts, and commutating devices. This particular unit would be a source of much controversy in the initial series of Ye-6 flights to the Moon.

On each side of the central cylindrical body of the Ye-6, the probe had two detachable compartments. They had a total mass of 312 kg and each was internally pressurised at 0.13 atmospheres. Compartment No. 1 housed a power source, a pneumatic system for filling shock absorbing airbags on the lander with gas from a bottle, and an astro-navigation system comprising an "optical correction block" and orientation and electrical blocks. The astro-navigation system was used for orienting the spacecraft during the mid-course correction and final retro-fire; it would also be used for verifying the correct trajectory of the spacecraft by measuring angles between the Moon, Sun and Earth. The system, developed by a branch of the NII-1 under Chief Designer Valentin P. Morachevskiy, used a set of five optical sensors: two terrestrial, two lunar and one solar sensor. The sensors on the system would feed data to the I-100 which itself would issue commands to the spacecraft as a whole [31].

Compartment No. 2 housed part of the radio-technical system, programmed timers, radio-link command systems, a 9.3 GHz radio-altimeter, «controlling organs» (probably attitude control thrusters), and a chemical power source block. Engineers did not incorporate solar panels on the spacecraft since the missions were expected to be relatively short. The attitude control thrusters (20 g thrust) used compressed nitrogen stored in four (two large and two small) spherical bottles installed externally on Compartment No. 2. The OKB-1 subcontracted development of the radio-telemetry systems, like the probe's guidance systems, to NII-885, although it was Chief Designer Ryazanskiy and not Pilyugin who oversaw their development. Competitive proposals from another department at NII-885 and one from SKB-567 were rejected due to concerns over precision and unreliability respectively.

The most important element of the Ye-6 spacecraft was the Automatic Lunar Station (ALS), an egg-shaped capsule with a diameter of 58 cm which was built from an aluminium alloy. The mass was gradually increased from 82 kg on the original landers to 112 kg on Luna-13 (actually, a Ye-6M model) [32]. Engineers designed the lander based around an internal shock-absorbing framework. During flight to the Moon, the ALS was covered in a thermal blanket. Within the thermal blanket, there was a second covering, this one comprising an expandable rubber chamber with a protective kapron (a type of nylon) shell. Compressed gases from one spherical bottle mounted on the separable Compartment No. 1 would inflate this second covering into two independent cushioning airbags which would protect the actual lander cocoon moments before impact. These shock-absorbing airbags would disperse the main component of the kinetic energy upon the hard landing and thus cushion all the lander's instruments from damage. The top portion of the ALS carried a television camera and associated equipment as well as a 6 mm diameter, 10 mm long gas-discharge radiation counter. The lower portion of the «egg» contained chemical batteries to power the lander, a thermal control system to regulate temperatures during the lunar stay, a programmed timer, and communications equipment. Evaporated water automatically cooled circulating gas within the capsule whenever the temperature within the lander rose above a preset level. The ALS also had an outer thermal coating to ensure "normal" temperature regimes (about 19-30°C) for instruments within the probe. There were four spring-loaded petal-like "leaves" which covered the top of the lander during landing and which opened up following a successful landing; these petals were equipped with antenna for transmitting data from the TV camera. Deployment of the petals would release a second set of four 75 cm long antennae for transmitting telemetry to the Earth. Total diameter across the opened petals was approximately 160 cm. The height of the lander on the surface was about 112 cm.

In the plans outlined by Korolev in late 1964 the landers were to carry a modest suite of scientific instrumentation. These were designed for the following three experiments:

1. Research on lunar seismic activity using the "LS" instrument;
2. Research on lunar magnetic fields using the "SG-572" instrument;
3. Recording intensity of cosmic rays during flight to the Moon and on the lunar surface using the "KS-17" instrument.

The LS instrument comprised a suspended seismograph and a measuring counter; it would carry out measurements between the communications sessions. The SG-57 device was a tri-component instrument for studying the lunar magnetic poles during radio communications sessions. The KS-17 was a simple radio-meter for recording cosmic ray levels. All the scientific instruments together would have had a mass of 5 kg. In practice, due to mass constraints, engineers had to limit scientific experiments to those involving measuring background radiation levels. On the first successful Ye-6 lander (actually a variant known as Ye-6M), Luna-9, the only scientific instrument was the SBM-10 radiation detector. A later Ye-6M, Luna-13 carried a more extensive suite of scientific devices.

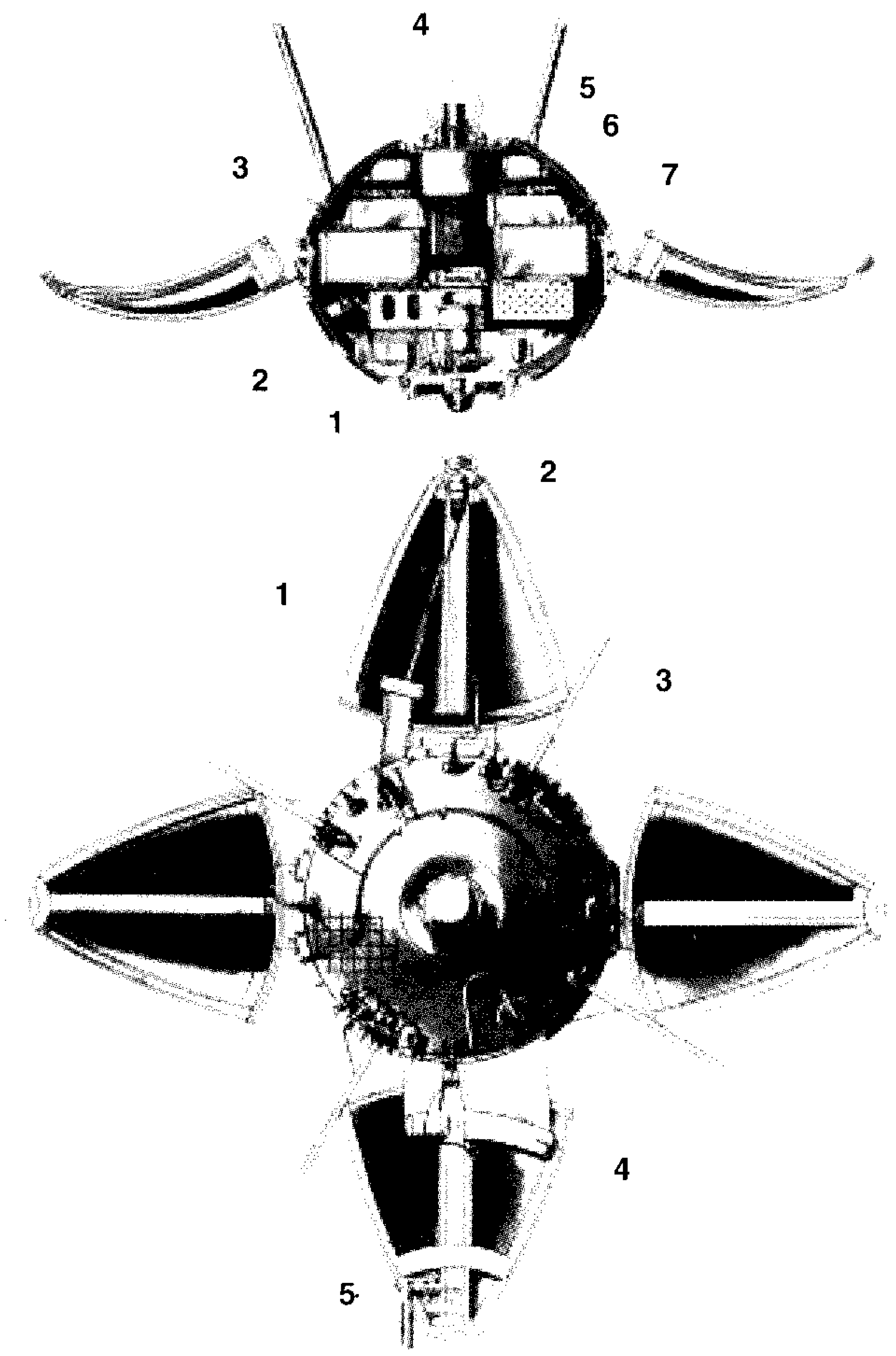

Fig. 3 The Ye-6 Automatic Lunar Station.
Cut-away View: 1. Thermal control system, 2. Power sources, 3. Radio equipment, 4. Porthole, 5. Television camera, 6. Scientific equipment, 7. Container.
Top View: 1. Hinged panels, 2. Locking mechanism, 3. Rod antennae, 4. Filter, 5. Magnetometer pin.
(source: Nauka Publishers, Moscow)

From a publicity perspective, clearly the most important device on the Ye-6 lander was the 3.6 kg TV camera complex. The first 11 Ye-6 probes carried a system known as the *Volga*, designed and built by the Leningrad-based NII-380 under Chief Designer Igor A. Rosselevich. The system used an optical mechanical principle with the combined use of a scanner and a mirror allowing it to scan horizontally and vertically via the moving mirror. The camera could scan a complete 360° within an hour to construct a complete panorama. The device, which had a resolution of up to 5.5 mm at a distance of 1.5 m (20 mm from 2 m), was placed in a pressurised glass cylinder. Power requirements for the

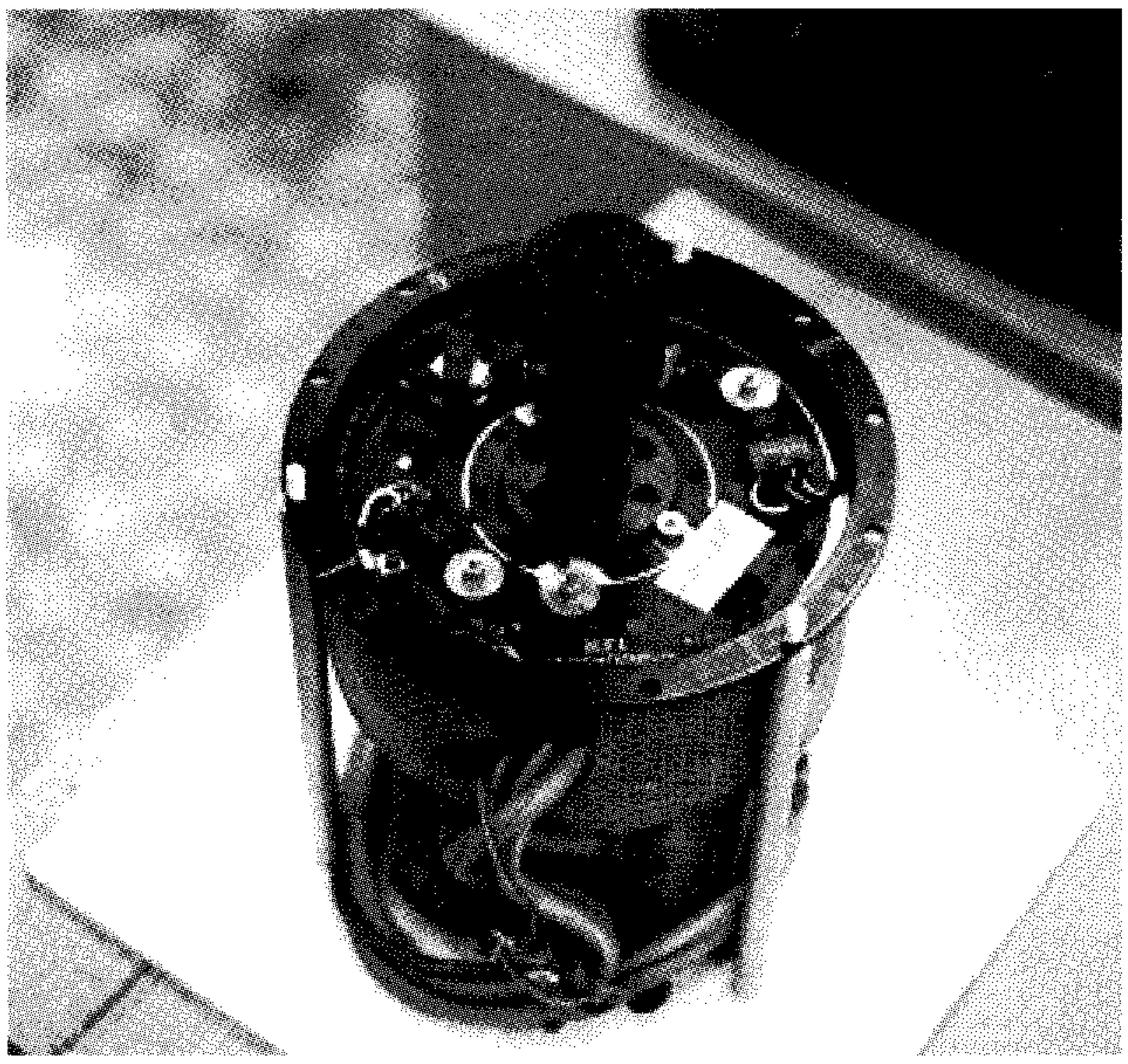

Fig. 4 The *Volga* camera on display at the VNIIT museum, St. Petersburg. (source: T. Varfolomeyev)

tiny system were only 15 watts. In late 1965, Rosselevich apparently decided to withdraw his system from the Ye-6 lander due to an overload of other commitments and a lack of faith in Babakin's abilities, forcing the engineers to look elsewhere. A team at NII-885 under Arnold Selivanov quickly offered an alternative system with a mass of 1.3 kg which appears to have similar but not identical features to the *Volga*; notably, it was designed to operate in vacuum unlike its predecessor. This system was first carried on the 12th lander, Luna-9, which was also the first fully successful mission in the programme [33] (See entry under Ye-6M for details of this camera).

5.2 The Ye-6M Lander

Luna-9 and Luna-13 are referred to by Russian sources as being of the Ye-6M type. On what basis this new designator was introduced still remains somewhat of a mystery. The most plausible inference is that the design changes made to the Ye-6 spacecraft after the series of failures culminating in the Luna-8 accident in December 1965 prompted OKB-1 engineers to use a modified (thus the M) model on Luna-9. The available evidence suggests otherwise, i.e. that plans for the Ye-6M predated the failures in the programme in late 1965. The modified Ye-6M spacecraft was in fact mentioned in the famous Party and government decree of 3 August 1964 which sanctioned (among other things) the N-1/L-3 lunar landing programme. By May 1965, OKB-1's plan was to launch the last Ye-6 models in July and September and the first Ye-6M lander in October. What kind of modifications were originally foreseen for the Ye-6M variant is not clear.

After the debacle of Luna-8, *additional* changes were introduced, but these were not performed by Korolev's engineers at OKB-1, but rather at a different organisation. In June 1965, Korolev had met with Chief Designer Georgiy N. Babakin of the Lavochkin Design Bureau and decided to transfer responsibility for the lander programme to the latter Design Bureau in order to allow Korolev to devote more resources to piloted space projects. The actual transfer of materials and production models was implemented sometime in late 1965 [34].

The Lavochkin Design Bureau had only recently turned its attentions to the space programme. The enterprise was originally established as Plant No. 301 in July 1937 in the Moscow suburb of Khimki; in 1939, a young aviation designer, Semen A. Lavockhin arrived at the plant to head a design team working on fighter aircraft. The plant was relocated and split up several times between November 1940 and October 1945; at the latter time, it returned to its original Khimki location. Through the war, Lavochkin led work on several excellent fighter aircraft, efforts which were continued into the postwar era on such famous planes as the La-152 (the first aircraft with a laminar flow wing) and the La-160 (the first Soviet fighter to have a sweptback wing and achieve near supersonic speeds). In the 1950s, Lavochkin's design bureau, OKB-301, diversified into producing surface-to-air missiles and also the creation of the 350 Burya intercontinental cruise missile. Lavochkin passed away in July 1960 and the plant was renamed the State Union Machine Building Plant Named After S. A. Lavochkin (GSMZ Lavochkin). With the loss of the enterprise's patriarch, the organisation lost much of its influence. In November 1962, the design bureau became Branch No. 3 of Vladimir N. Chelomey's OKB-52 and for the first time engaged in some work on space projects, specifically in aiding Chelomey's main centre in "IS" (ASAT) and "US" (RORSAT/EORSAT) satellite development. A new phase in its existence began in March 1965 when the organisation once again became independent, this time at the helm of newly appointed Chief Designer Babakin, a long time veteran at the Lavochkin design bureau, who was now tasked with turning his team's goals completely towards the development of spacecraft and upper stages. Babakin was 50 years old at the time [35].

After the Luna-8 accident in December 1965, Babakin's engineers introduced changes primarily related to the sequence of operations prior to landing. In the Ye-6, inflation of the shock-absorbers was carried out prior to main engine ignition. But as two senior engineers from the Lavochkin Design

Bureau later noted, the sequence was changed for the "Babakin variant": "it was established that the filling of the shock-absorbers [with air] was essential to carry out after ignition of the braking engine, in order to give the possibility to counteract harmful rotating moments that arose when the shock-absorbers were inflated before braking engine ignition" [36]. This reasoning seems to be supported by at least two contemporary accounts of the Luna-9 mission from 1966 in which the authors note that the airbags were "prepared for landing while the engine was working" [37]. Because the bottle containing compressed air for the shock absorbers was in a container attached to the separable Compartment No. 1 which was jettisoned before pressurisation, Babakin's engineers moved this bottle from the detachable module and attached it to the side of the I-100 control system compartment on the main bus [38]. One source has noted that another difference on Luna-9 was that the attitude control gas thrusters were used in a continuous mode rather than intermittently to stabilise the spacecraft following airbag inflation [39]. When comparing drawings of Ye-6 and Ye-6M, it is also clear that the thermal blanket surrounding the lander was more elongated on the latter, but the reason for this is not clear.

Both Luna-9 and Luna-13 had original OKB-1 serial numbers of 13 and 14 respectively. After their transfer to the Lavochkin Design Bureau, Babakin changed the numbers to 202 to 205 respectively. A test model with the 201 serial number was also produced by Lavochkin.

Luna-9 and Luna-13 carried a different camera system than the earlier Ye-6 models. Like the earlier *Volga*, the new system comprised a fixed lens placed below a nodding mirror – the latter being capable of rotating in two planes. The mirror would rotate in the vertical plane for a single line on the image and then move a little in the horizontal plane for the next line of the photo. Overall, the camera had a mass of 1.5 kg and used 2.5 watts of power, i.e. lighter and more efficient than the *Volga*. It was in the form of a rotating cylindrical turret 8 cm in diameter and 25 cm long. Only a small part of the camera, the lens window and a solar screen, actually protruded from the top of the ALS. In a deployed position, the lens window was about 60 cm above the ground, making the horizon about 1.5 km distant. In practice, the view was limited to 11° above and 18° below (a total of 29°) the normal horizontal. A complete 360° panorama contained a total of 6,000 lines with 500 elements per line and took 100 minutes to film. Resolution capability was 2 mm from a distance of 1.5 m, an improvement over the *Volga*. Engineers installed small targets which hung down off the four rod antennae in order to calibrate brightness for the camera; there were also three thin vertical dihedral mirrors around the turret on top of the lander for stereo imaging of the surface. Commands to turn on the camera could be issued either

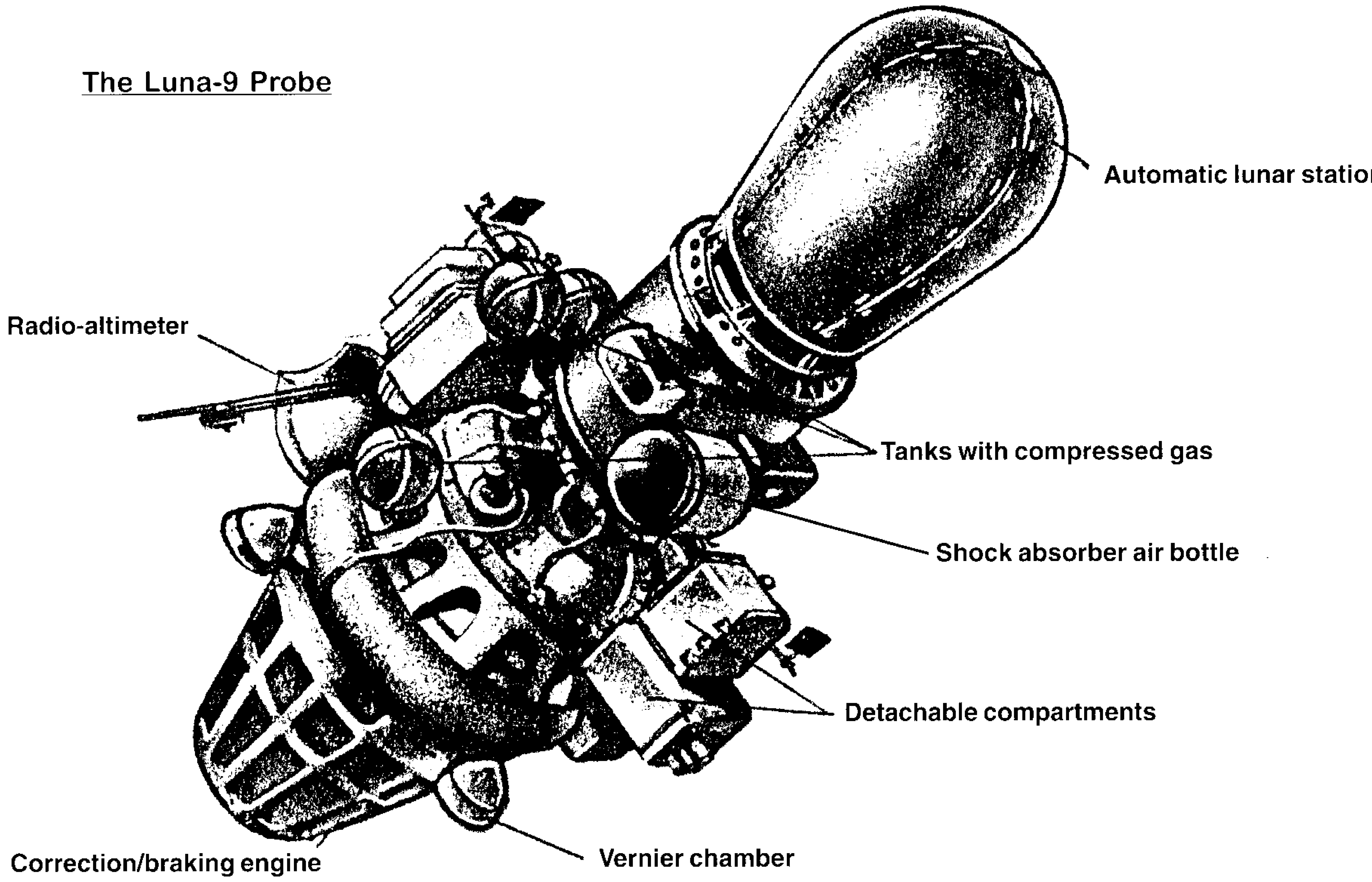

Fig. 5 Soviet drawing of Luna-9. Air bottle for shock absorbers is now on the I-100 compartment.
(source: V. Dobrovolskiy, *Tekhnika – molodezhi* magazine)

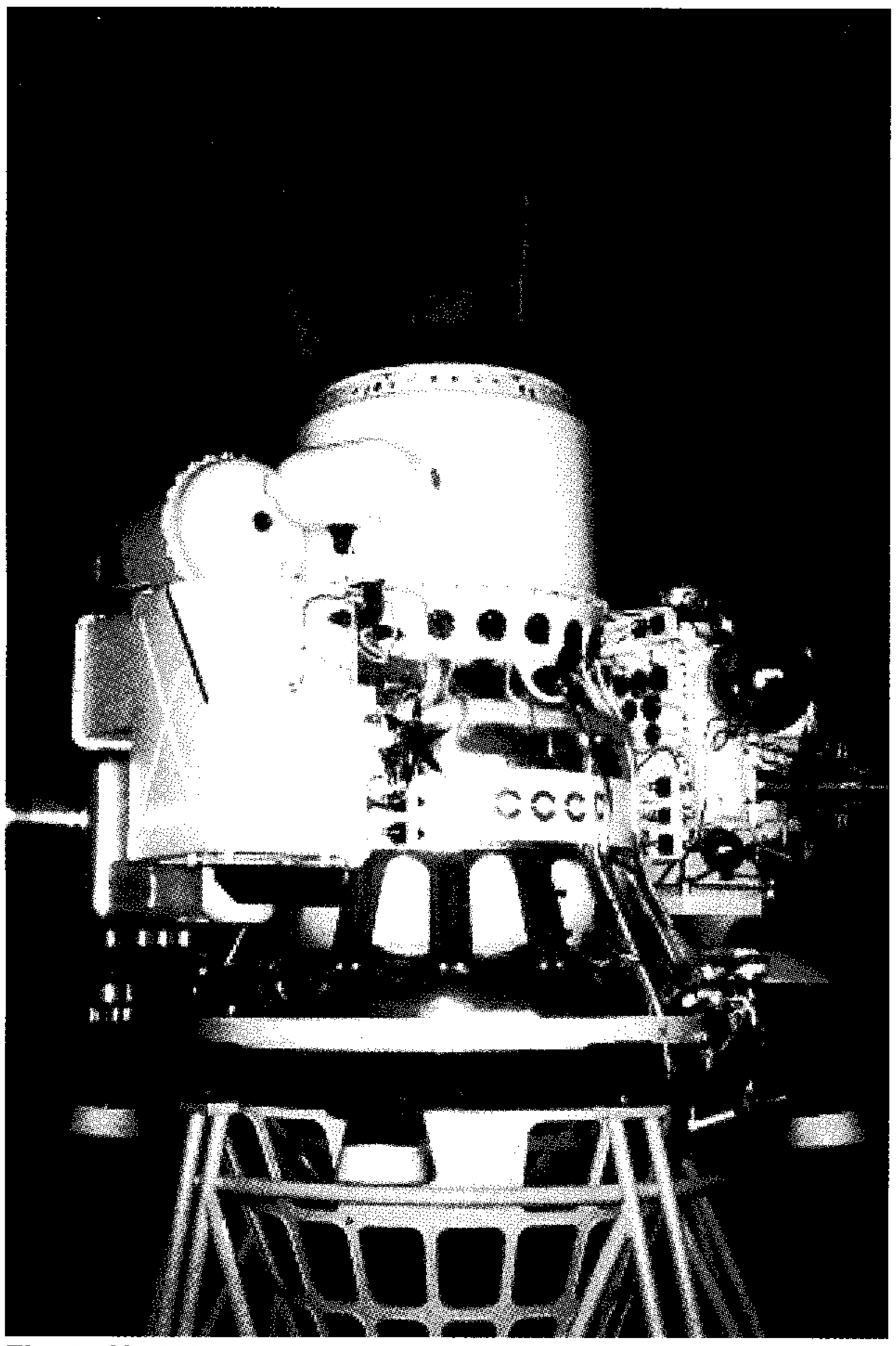

Fig. 6. Ye-6M model on display at the Tsiolkovskiy Museum, Kaluga. (source: B. Hendrickx)

from the ground or by the programmed timer. By using the mirrors, controllers had the capability to point the camera in different directions. Actually, Luna-13 carried *two* of these cameras to provide stereoscopic images.

The final Ye-6M lander, Luna-13, carried a much more extensive suite of scientific experiments than its predecessor, Luna-9, and was equipped with a new improved thermal control system. The main improvements were the addition of two folded booms which were capable of extending 1.5 m away from the lander. Each boom carried a special instrument at the end of each arm. One was a radiation densitometer to determine the composition of the lunar surface; the other was a mechanical soil penetrator. The former used gamma rays emitted by a cesium-137 sample which was either absorbed or scattered by lunar soil. The amount of scattering was measured by three independent series of SBM-10M radiation counters to estimate the density of the lunar soil. The penetrator had an explosive charge (lasting 0.6-1.0 seconds with a force of 5-7 kg) which would force a 3.5 cm diameter 5 cm long titanium-tipped rod into the lunar surface. Scientists would be able to extract information on the nature of lunar soil by studying how fast and how far into the soil the instrument penetrated. The device was built by VNII-100 (now VNIItransmash), the same institute that developed the wheels of the Lunokhod rovers, and was to provide important information for their design. Other scientific instruments on Luna-13 included a piezoelectric dynamograph which consisted of three mutually perpendicular accelerometers to establish the mechanical properties of the lunar surface down to a depth of 20-30 cm by measuring the impulse during landing of the spacecraft. The probe also had four radiometer pickups to measure thermal radiation from the lunar surface. Finally, there was a gas-discharge instrument to measure direct and reflected cosmic particles [40].

5.3 The Ye-6A Lander

Little is known about this unflown variant. In a document dated 23 September 1963 dealing primarily with the piloted lunar programme, Korolev mentions a version of the basic Ye-6 known as the Ye-6A which would have an increased lander mass of 150 kg (up from the original Ye-6 mass of about 82 kg). The increased mass would be taken up by a larger number of scientific instruments [41]. It is possible that the Ye-6A eventually proved to be too ambitious and was downgraded to Ye-6M.

5.4 The Ye-6 Lander Flight Profile

The mission profile for the Ye-6 missions was dictated to a great degree by the necessity to accomplish the first survivable landing on the Moon before the Americans. This meant that the landing on the Moon had to be as simple and foolproof as possible. For example, during the landing on the Moon, if the motion of the vehicle was nearly perpendicular to the lunar surface (so that lateral velocity was close to zero) and if the direction of thrust of the braking engine was directly vertical to the lunar surface, then engineers would need only to precisely determine the ignition and cutoff times for the main engine. Consequently, for engine ignition only one instrument was required: a radio-altimeter. These stipulations also introduced some limitations to what the Ye-6 landers could accomplish. Because of the relationship of the Moon's orbit to the Earth, Ye-6 spacecraft with this mission profile could only land in the western hemisphere close to the edge of the visible side of the moon, only near the lunar equator, and at a time when the Sun was rising over the lunar horizon at the place of landing. In sum, this meant that, unlike the American Surveyor landers, the Ye-6 could only land in the Ocean of Storms and nowhere else. This was part of the reason that there

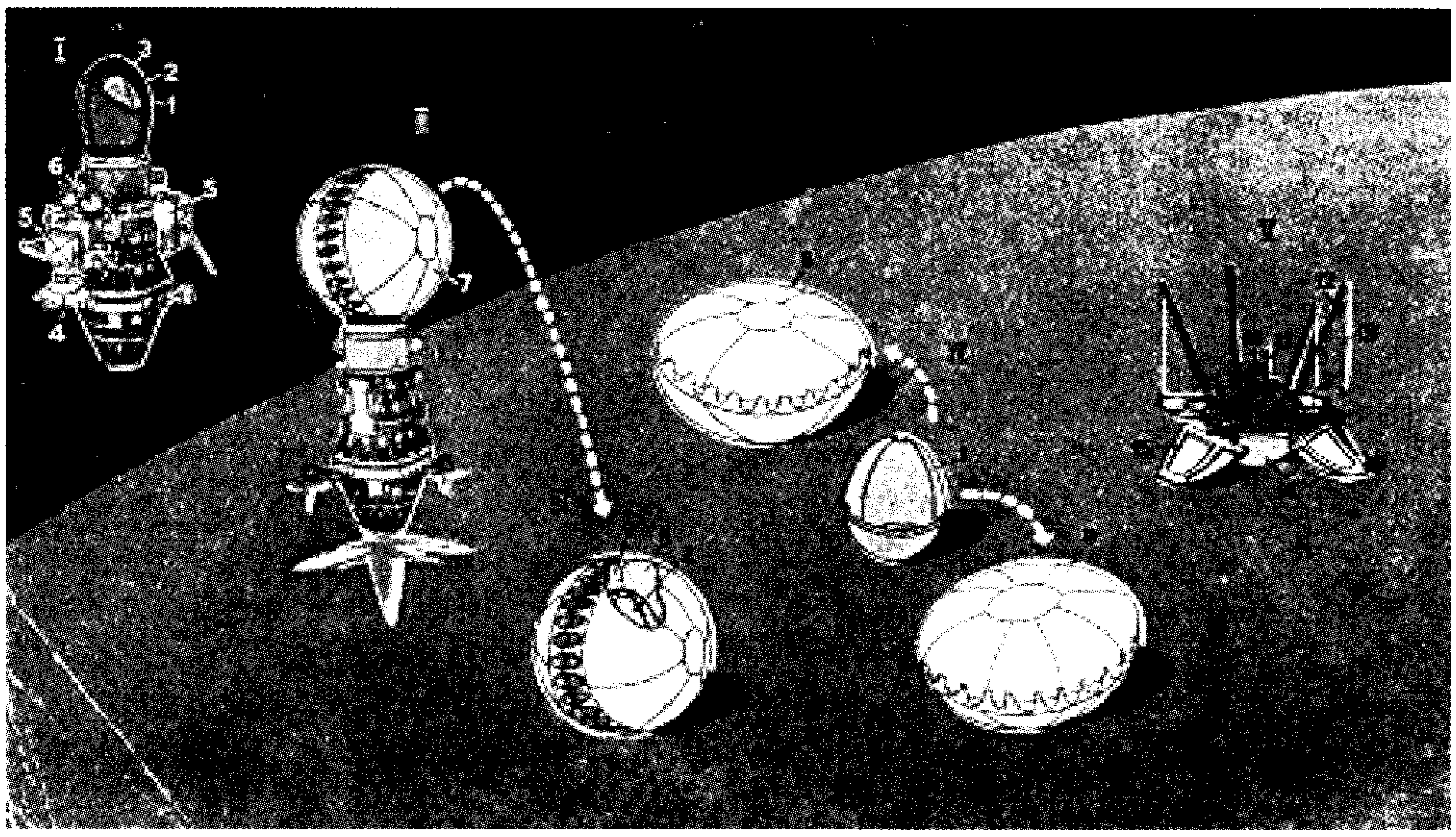

Fig. 7 The Ye-6M landing sequence. I. Ye-6M lander approach to the Moon, II. Retro-rocket firing and inflation of shock absorbers, III. ALS package impact on the lunar surface, IV. Shock absorber bag separation and lander release, V. Lander deployment on the surface.
(source: *Nauka i zhizn* magazine)

were only two successful landings because there was evidently little reason to send more spacecraft to the same region of the Moon.

The basic trajectory modelling for the Ye-6 series was carried out at the Department of Applied Mathematics of the V. A. Steklov Mathematics Institute of the USSR Academy of Sciences, a department headed by the ubiquitous Keldysh. Dmitriy Ye. Okhotsimskiy, one of the prodigy scientists behind the design of the first R-7 ICBM, was the leader of the trajectory modelling team.

The flight profile given below is largely based on one described by Korolev in late 1964. Deviations, both deliberate and accidental, from the parameters described were not uncommon in the actual flight series lasting through 1965-66.

A nominal Ye-6 mission began with the launch of the probe on top of a four-stage 8K78 booster. The first three stages would insert the Blok L fourth stage and the Ye-6 spacecraft into an intermediate Earth orbit. At the appropriate time, the Blok L stage would fire to insert the payload on a trans-lunar trajectory. The probe would separate from the upper stage soon after engine cutoff. A nominal trajectory to the Moon would last 3.5 days. Velocity relative to the Moon prior to initiation of braking near the Moon would be 2,630 m/s. Actual landing was targeted to the morning terminator in the Ocean of Storms, west of the Reiner and Marius craters. Errors in the control system in targeting could be corrected only up to a certain point. For example, the maximum acceptable error of 20,000-22,000 km from the target landing site had to be corrected at a distance no more than 250,000 km from the Earth.

During the coast to the Moon, ground controllers would conduct as many as nine communications sessions with the spacecraft for recording trajectory or transmitting telemetric information on its onboard systems. All onboard operations were automatically performed although the commands for them had to be issued from the ground. The first four communications sessions were for ground control to determine the exact magnitude and direction of the mid-course correction based on data from the astro-navigation system. The fifth session was for issuing the command for the correction after having ensured that the spacecraft was in the correct attitude with the aid of the solar and lunar optical sensors. The maximum possible delta-V for the correction was 130 m/s. The spacecraft was automatically programmed so that the engine would not be able to fire if the attitude control sensors lost sight of the Moon or the Sun. There would then be a repeat attempt to fire the engine correctly, compensating for the aborted impulse. If all went well, the spacecraft would then be aimed not more than 150 km away from the target landing area. If for some reason the spacecraft trajectory deviated significantly from the nominal flight plan, then the probe would automatically initiate an "emergency" communications session with the Earth, with the possibility of firing the engine to enter lunar orbit.

Approximately two hours prior to the scheduled landing, controllers would once again orient the spacecraft using the Sun, the Moon, and the Earth. At a distance of between 8,300 and 8,700 km from the lunar surface, the Ye-6 probe would be aligned such that the main engine was configured directly vertical and pointing in the direction of the Moon. At an altitude of 75 km, a command from the radio-altimeter would automatically issue a command to switch on the main engine after a certain interval. After this the astro-navigation system would be switched off and stabilisation would be maintained only with the gyroscopes of the I-100 control system. Shortly before or after the ignition of the main

S5.5 engine, the two detachable compartments would be jettisoned. On the Ye-6M missions the spacecraft would then discard the thermal covering over the ALS and inflate the two shock-absorbing airbags covering the lander to a pressure of 1 atmospheres (on the Ye-6 missions this occurred before the engine start sequence was initiated). Sometime between 250 to 265 m altitude the primary engine chamber would shut off (after about 42 seconds of firing time), leaving the probe to reduce velocity during its descent with the four smaller control nozzles with thrusts on the order of 25 kg. At 3-4 m from the surface, the long boom sensor would make contact with the lunar surface, thus issuing a command to eject the small ALS away from the main spacecraft bus and in a direction away from the surface. The ejection would be accomplished by a small amount of compressed gas released from the shock absorbing "package" around the ALS. A possible range of impact velocities for the lander was between 4 to 24 m/s (the latter being in the case of a major failure during descent) with 15 m/s being the highest survivable value. According to the Ye-6 draft plan, the lander's shock-absorbers were equipped to survive loads as high as 200 g's.

Approximately four minutes after landing, a programmed timer would issue a command to split apart the shock absorbing airbags, finally releasing the actual lander; a further minute later, springs on the ALS would open up its four petals, which would unfold and collectively make sure the probe was upright on the lunar surface.

Following landing, there would be at least five communications sessions with the Earth, each lasting one hour daily. Either ground control or automatic time sequencers on board the lander could initiate these sessions, which were for transmitting images of the lunar surface or telemetry from the scientific instruments on board [42].

5.5 Development

OKB-1 engineers determined the basic design and flight profile of the Ye-6 spacecraft by late 1961. It, however, took much longer than expected to declare the entire system ready for flight. One of the major bottlenecks appears to have been the redesigned I-100 control system for the Ye-6 which unlike previous 8K78 missions would now control the third and fourth stages as well as the payload itself. This meant that the hard experience of the several failed 8K78 launches in 1960-63 came to naught. It was as if engineers had to begin from ground zero again. The limited mass of the Ye-6 spacecraft also meant that few if any systems had much of a redundancy. Thus, engineers had to implement long and lengthy tests to declare systems reliable enough for flight, knowing that the failure of a single system could put the entire mission in doubt. An official Central Committee and Council of Ministers decree on 23 March 1962 was evidently issued to account for all the delays, stipulating that the first launch of the probes be in 1963 [43]. The USSR Academy of Sciences also finally threw in its support for the Ye-6 programme. In a document dated 22 December 1962 and sent to "directive organs", Academy President Keldysh listed four major goals for lunar exploration in the period 1963-1964: soft-landing on the Moon, lunar orbiting, landing of a self-propelled surface vehicle on the Moon, and piloted circumlunar flights. Perhaps a little too ambitious given the exigencies of the Soviet space programme at the time, Keldysh's document does, however, indicate that support from the Ye-6 programme was building by 1962 after several years of ambivalence on the part of the Soviet leadership [44].

Throughout 1962, OKB-1 engineers implemented an intensive test regime for the new lunar probes. This included tests of the boom sensor at the base of the spacecraft using a special simulator unit, tests inflating the shock absorbing bags in a special vacuum pressure chamber using a full-scale model of the vehicle, a number of tests to simulate the correct separation of the cushioning airbags around the lander after touchdown, and simulations jettisoning the separable compartments of the spacecraft at temperatures of -50°C in which the pyrocartridges were frozen with liquid nitrogen and then commanded to release. One important set of ground tests was to simulate the actual landing sequence of the Ye-6: models of the spacecraft were dropped from heights of 20 m and all of the critical events of landing were fully verified. Engineers at the NII-229 at Zagorsk were responsible for checking the operation of the TV and radio-equipment during these simulations in which special conditions such as the absence of sunlight were properly reproduced. Other tests included those involving the thermal system in the lander, ascertaining the benchmarks for the astro-navigation system sensors, testing the small attitude control thrusters, testing the main S5.5 engine, and testing the entire system in a thermal chamber to account for temperature variations. One of the more interesting ground tests involved the possibility of spurious explosions during impact of probe segments on the surface of the Moon due to the existence of residual propellants [45]. It was in December 1962, after all these tests, that the

OKB-1 manufactured its first Ye-6 flight model, about three years after initial conceptualisation of the Ye-6 series [46].

5.6 Ye-6 Missions: Rough Road to a Soft Landing [47]

5.6.1 The 1963 Missions

Even though the government resolution giving the final go-ahead for the Ye-6 soft landers was issued on 13 May 1961, it was not until the first months of 1962 that actual metal-cutting got underway at the workshops of OKB-1 in Kaliningrad. Another government resolution released on 23 March 1962 formalised the division of labour among the various subcontractors and called for the first flights to be launched in 1963. Construction got underway of an initial four landers, one mock-up (Ye-6 No. 1) and three flightworthy vehicles (Ye-6 No. 2, 3, 4).

As 1962 turned into 1963 the Ye-6 No. 2 probe, safely ensconced in the nosecone of an 8K78 booster, sat poised for launch at its Baykonur launch pad. The launch was to take place almost exactly four years to the day after the first successful Soviet lunar launch (retroactively called Luna-1) and was to be the first Soviet lunar launch attempt since April 1960, when the final two first-generation Lunas had failed to reach orbit. A successful mission would be a major propaganda triumph for the Soviet Union, the more so because the American Ranger programme had been temporarily suspended two months earlier after five unsuccessful missions. The final three of those Rangers ("Block II") had also been designed to deliver small landing capsules to the lunar surface.

The odds of Ye-6 safely making it to the Moon on the very first attempt, however, were estimated no higher than 10 %. Not only had the first probe been built in less than a year's time on the basis of "rough" blueprints, the 8K78 booster that was supposed to send it en route to the Moon had failed on 8 out of 10 launch attempts in the Venera and Mars programmes between October 1960 and November 1962. Five of those failures had been due to teething problems with the new Blok L upper stage, which was to fire the probes out of their parking orbits around the Earth. Moreover, this particular launch marked the introduction of the untried I-100 unified control system that was to take charge of *both* the spacecraft and the two upper stages of the rocket. While saving a considerable amount of mass, it required a complete redesign of the control systems flown on earlier missions. Further complicating the situation was the fact that the organisation responsible for the I-100 system (headed by Pilyugin) only had experience in developing control systems for missiles and rockets, not spacecraft. In short, all indications were that it was going to take several tries to achieve success.

The first Ye-6 probe lifted off from Baykonur on 4 January 1963. The first three stages of the 8K78 flawlessly delivered the Blok L and spacecraft to the intended parking orbit inclined 64.9° to the equator. About one hour later, as the stack flew over the Atlantic Ocean just south of the equator, controllers waited anxiously for information about the escape burn. Telemetry from the Blok L was to be received by the tracking ship *Dolinsk*, dispatched from the Black Sea port of Odessa to the Gulf of Guinea. For reasons of secrecy, information about the Blok L burn was telegraphed in highly coded form to the communications centre of the Black Sea Fleet in Odessa to give controllers in Moscow and Baykonur a rough idea of the stage's performance or some initial clues as to why it had malfunctioned. The actual telemetry tapes were sent to the Soviet Union by diplomatic post and sometimes took one to two months to reach their final destination.

As had been the case on five earlier 8K78 missions, the news from the Gulf of Guinea was not good. Blok L had once again failed to ignite and reentered the atmosphere along with the Ye-6 probe one day later. The Soviets did not issue an official announcement about the launch, although in 1962 they had in fact agreed to report *anything* that reached Earth orbit to the U.N. It was not until several months later, in a letter dated 6 June 1963, that Adlai E. Stevenson, the chief U.S. delegate to the U.N., identified six recent Soviet parking orbit failures, including an attempt in January 1963 [48]. A few weeks later, on 25 June 1963, NASA reported on four such failures and gave the launch date for the Luna attempt as 4 January, adding that the payload had broken up into three pieces in Earth orbit [49]. The star-crossed Luna was retroactively listed with the new international designation 1963-1A, which replaced the designation with Greek letters used for satellite launches until the end of 1962.

The telemetry gathered by the *Dolinsk* indicated that there had been no electrical command from the I-100 control unit to ignite the Blok L engine; it did not, however, make it possible to unequivocally pinpoint the cause of the failure. It did help dispel the idea that some of the earlier Blok L malfunctions had been caused by oxygen fumes accumulating in the oxidizer tank during the coast in low orbit and

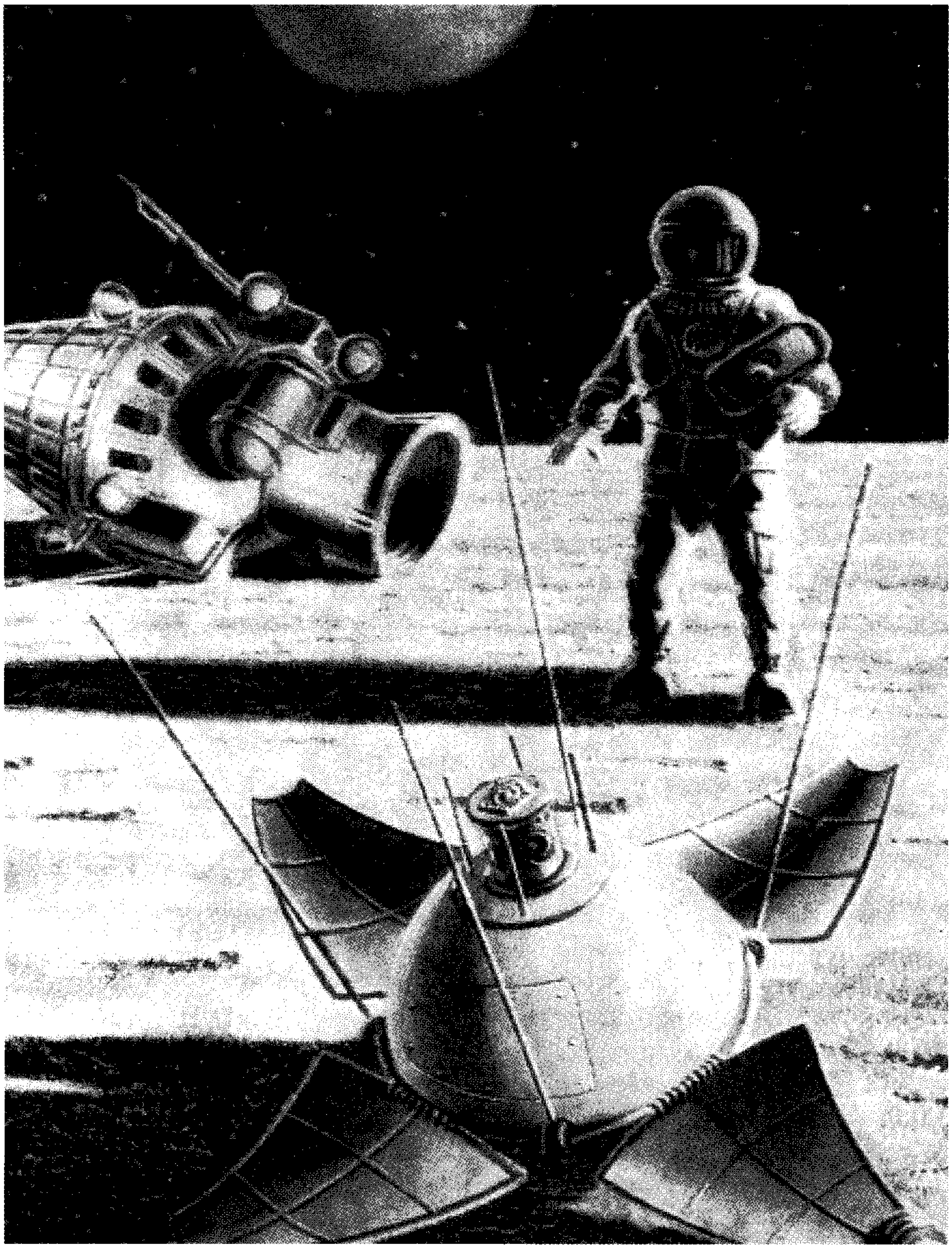

Fig. 8 Painting by A. Leonov and A. Sokolov shows a cosmonaut visiting a Ye-6 lander. Spacecraft bus is in the background. (source: T. Varfolomeyev)

causing an explosion when mixed with the kerosene fuel in the combustion chamber. The State Commission concluded that the accident was most likely caused by the failure of a DC inverter in the power system of the I-100 control unit, which was to convert a direct current of 30 volts into a three-phase alternating current of 40 volts for certain systems. Prior to launch the I-100 was filled with dry nitrogen and laboratory tests showed that this could affect the brushes of the inverter's commutator, ultimately resulting in a short-circuit of the whole power system. The inverter, called PT-500 (because of the nominal power rating of 500 W), was built by the NII-627 research institute of Andronik G. Iosifyan. Subsequent tests of the inverter carried out at NII-627 raised doubts about this scenario, but in the absence of other clues it was officially blamed for the failure. A recommendation was made to slightly moisten the nitrogen gas and add a small amount of oxygen to the atmosphere in the container housing the PT-500.

The next Luna (Ye-6 No. 3) lifted off barely one month later, on 3 February 1963, but did not even make it into Earth orbit. After 2nd stage separation the rocket lost attitude control and the third and fourth stages plummeted back to the Pacific near Midway island. Like all Soviet launch failures at the time, no official announcement was made about this attempt, but several highly placed officials in the Soviet space programme had misgivings about this Kremlin policy. At the meeting of the State Commission following this mishap, Academician Keldysh, the President of the USSR Academy of Sciences, voiced his indignation at the cover-up, but the message from Moscow was clear: officially, there were no launch failures in the Soviet Union.

The investigation showed that the booster had gone off course because of erroneous data received by its Trajectory Control System (SKT). The task of the SKT was to hand over control from the core stage to the I-100. Mounted on the Blok L upper stage, the SKT consisted of a set of integrators that collected data about the rocket's trajectory (pitch, yaw, roll, lateral deviation, speed, range) during the operation of stages 1 and 2. Those data were needed by the I-100 to take over control of the 3rd stage after 2nd stage separation. They were provided to the SKT by torque sensors and accelerometers mounted on the two gyroscopes in the I-100 (one azimuth gyro for pitch and one vertical gyro for yaw and roll), which spun during 1st/2nd stage operation although other elements of the I-100 were inactive at that point. For the I-100 to take control of the third stage, the trajectory data received by the SKT had to correspond to those provided to the integrators of the 1st and 2nd stage control system by the gyros in the lower stages. However, during this particular launch the pitch data received by the SKT from the I-100 azimuth gyro began deviating from the actual values at T+1m45s and by the time the 2nd stage separated at T+4m55s the deviation was so big that the I-100 could not cope with it.

There were two possible reasons why the azimuth gyro (a flotation type gyro) had provided wrong data to the SKT. The initial pre-launch setting of its orientation axis could have deviated from that of the gyros in the core stage, meaning the third stage was essentially targeted for the Pacific even before the rocket lifted off. Alternatively, its torque sensor could have sent false information because of instabilities in its circuit or because of a problem with the electrical coils that were to heat the fluid in which the gyro was suspended. Regardless of the exact reason, it was obvious that it was the second failure in as many attempts caused by Pilyugin's I-100 control unit.

After two months of round-the-clock work Pilyugin assured the State Commission that everything possible had been done to correct the problems with the I-100 system. As the next available lunar launch window slid open on 2 April, Ye-6 No. 4 blasted skyward in a third attempt to make a soft landing on the Moon and safely reached Earth orbit several minutes later. When word arrived from the *Dolinsk* that the Blok L had successfully fired, the news came almost as a surprise to the members of the State Commission following events at Baykonur. For the first time a Ye-6 probe was actually on its way to the Moon. It was also the first time that a Soviet lunar probe was successfully launched from an Earth parking orbit, the 1st generation probes having followed direct lunar insertion trajectories

Assured that Ye-6 No. 4 was Moon-bound, the TASS news agency announced the mission as Luna-4. Officially, it was only the fourth Soviet mission to the Moon, although in actual fact it marked the 12th Luna mission overall, taking into account six launch failures in the Ye-1 and Ye-3 programmes between 1958 and 1960 and the two earlier failures in the Ye-6 programme. TASS reported a spacecraft mass of 1,422 kg, but revealed little about the purpose of the mission, saying only the probe would reach "the vicinity of the Moon" in three and a half days time. Apparently, confidence in the successful outcome of the flight was not very high. As recounted by Boris Ye. Chertok in his memoirs, many members of the State Commission scoffed at such vague announcements, which belittled the efforts invested in these missions and did little to boost public interest in the space programme. Georgiy A. Tyulin, the Chairman of the Ye-6 State Commission, tried to convince Korolev to raise this matter during a meeting with Nikita S. Khrushchev, but the Chief Designer refused, probably realising this would be to no avail. Although there was no official word on the exact purpose of the mission, several statements from Soviet officials did indicate that a landing was imminent, one report saying that "scientists have to clarify the conditions cosmonauts will meet, how they are to overcome landing difficulties and how they should prepare for a prolonged stay on the Moon" [50].

Soon after receiving confirmation of the Blok L burn, the members of the State Commission flew from Baykonur to the NIP-10 control station in Simferopol in the Crimea. The location of this station was considered no less secret than that of the cosmodrome where Luna-4 had been launched, with TASS referring to it only as a "special measurement complex located on the territory of the Soviet Union". Although Jodrell Bank in England was not officially asked to support in tracking (as had been the case during the first-generation Luna missions), TASS did reveal that communications with Luna-4 were being maintained at a frequency of 183.6 Mhz and also provided updates on the probe's exact location in space, which was clearly an invitation to monitor signals in order to obtain independent confirmation of the Soviet tracking data. Jodrell Bank did not acquire Luna-4 until 4 April, when it monitored the probe for six hours. The signals were said to be much more complicated than those of Luna-3. Although not revealed at the time, Luna-4 was also being tracked by the 45m dish of the Naval Research Lab in Maryland at the request of the US National Security Agency [51].

Now that the 8K78 booster had done its job, it was possible to put the Ye-6 through its paces for the first time. The first day of Luna-4's flight apparently went trouble-free, TASS reporting that the pressure and temperature inside the spacecraft were being maintained within the prescribed limits. Trajectory measurements were being backed up by optical tracking of the spacecraft by a team at the Crimea Astrophysical Observatory (headed by Andrey Severnyy), which according to TASS was able to photograph Luna-4 as a 14.5 magnitude star against the starry background on the night from 2 to 3 April.

On 4 April TASS issued a surprising statement, saying that Luna-4 was approaching the Moon and would pass "close to its surface". Although radio communication with the probe was said to be good, it was clear something had gone wrong with the critical mid-course correction burn, causing Luna-4 to miss the Moon. Further indication of trouble came when Radio Moscow cancelled a programme scheduled for the evening of 5 April called "Hitting the Moon", playing piano music and poetry instead [52].

Eventually, Luna-4 zipped by the Moon at a distance of 8,500 km on 6 April at 1.24 a.m. UT. In its final communique on the mission, TASS said radio communications with the craft would continue "for several more days". The news agency added that the probe had ended up in a highly elliptical 90,000 x 700,000 km Earth orbit (actually a barycentric orbit around the combined centre of gravity of the Earth and the Moon), but that due to perturbations from the Sun and the Moon it would eventually enter a heliocentric orbit. After the failure the Russians characteristically claimed that the intention had been all along to fly past the Moon. A similar false claim had been made for the Luna-1 hard landing attempt in 1959.

The culprit for the latest Luna setback was the Yupiter astro-navigation system mounted in Compartment No. 1, which had failed shortly before the mid-course correction burn, preventing it from taking place. It was developed by a team led by Valentin Morachevskiy, which had been formed on the initiative of Keldysh, who was therefore named by the State Commission to head a special commission to investigate the problem. By assigning this task to the President of the USSR Academy of Sciences himself, it was also hoped that the various contractors would be made aware of the need to place higher emphasis on quality control. Despite his preoccupation with many other things, Keldysh devoted a considerable amount of time to the analysis of the problem and at times made the designers of the system blush with shame. While exhaustive laboratory tests could not pinpoint the exact cause of the failure, they did turn up dozens of basic flaws in the astro-navigation system that could easily have been detected prior to the beginning of the Ye-6 missions. The only excuse was the rush to get the first missions off the ground as soon as possible.

With hindsight, the first batch of Ye-6 probes had simply not been ready to fly in 1963, a fact initially masked by the launch failures of the two first probes, which probably would have suffered the same fate as Luna-4. The commission made about a dozen recommendations to improve the astro-navigation system, many of them relating to thermal control. It was also decided to back up the angular trajectory measurements by installing a radio transmitter called *Mayak* – even though that would add more mass to the probe. Signals from *Mayak* were to be received in Yevpatoriya (NIP-16), Ussuriysk (NIP-15) and Moscow (NIP-14/Shchelkovo) and the data were to be processed by Keldysh's Department of Applied Mechanics, NII-4, and NII-88. It took almost a year to complete the modifications and prepare a new batch of Ye-6 stations for launch.

5.6.2 The 1964 Missions

The first months of 1964 promised to be very busy at Baykonur, with no fewer than five 8K78 boosters to be launched between mid-February and mid-April. Three were to launch 3MV-1 Venera probes while two others were readied for Luna launches. The first of the Lunas was to go up on 21 March and if it failed a second probe would be launched during the next window on 20 April. Sometimes the hectic preparations and sleepless nights led to serious accidents during testing. Boris Chertok describes how one unidentified Luna inadvertently fired the explosive bolts separating its instrument packages from the KTDU engine unit and how another vehicle was "destroyed" after an airtightness test in a pressure chamber when engineers forgot to equalise the probe's internal pressure with that of the chamber. However, it seems unlikely that these incidents involved the probes being prepared for the spring 1964 launches.

On 19 February the first of the 3MV-1 Venera probes (actually a test version which would have been named Zond) was lost due to a breakdown in the third stage of the 8K78. An identical 3MV-1 test vehicle had become stranded in Earth orbit due to a Blok L failure the past November. At the upper echelons of power the patience with the numerous lunar and deep space failures was wearing thin. On 11 March the members of the State Commission, busy overseeing preparations for the next Luna at the cosmodrome, were summoned to appear at the Kremlin two days later to report to Leonid V. Smirnov, the head of the Military-Industrial Commission (VPK), the top government body under the Council of Ministers which managed the entire defence industry. Korolev and Keldysh, who had stayed behind in Moscow, were also present. Korolev reported that the latest 8K78 failure was an isolated incident that would not affect subsequent missions. To everyone's relief no sanctions followed, the VPK simply acknowledging assurances that everything had been done to prevent similar catastrophes on future 3MV and Ye-6 flights. Barely had the meeting turned to another subject, when Chertok was called away to receive the news that just two hours earlier the next Luna (Ye-6 No. 6) had been damaged by a fire after someone had connected the wrong cables. The same night the State Commission members returned to Baykonur, carrying with them spare parts hurriedly collected from various subcontractors and "cannibalised" from another Ye-6 undergoing assembly at OKB-1. Once they arrived, it turned out the damage was less serious than expected and repairs had already been effected with spare parts available at the launch site. Everything was ready for launch on 21 March, almost one full year after the ill-fated Luna-4 mission.

The 8K78 groomed for this launch was the 100th R-7 type rocket flown since May 1957, but that did not stop this particular version of the rocket from acting up once again. The third stage shut down prematurely and sent another Ye-6 probe hurtling back to Earth. Analysis showed that the stage's main LOX valve had failed to open because a valve rod had broken off. Kosberg's OKB-154 in Voronezh which built the third stage engine was ordered to carefully check all third stage valves for the upcoming missions.

Following two 3MV-1 launches on 27 March and 2 April (one unsuccessful, the other successful) another 8K78 was rolled out to the pad for the launch of Ye-6 No. 5 on 20 April. Almost unbelievably, the third stage once again shut down earlier than planned, but this time the problem lay not with the engine itself, but with the power supply to the third stage. The available information indicates that power for the third stage was provided by a battery in the Ignition Ensurance Block (BOZ) of the fourth stage and was routed to it via the PT-500 DC inverter in the I-100 control unit aboard the Ye-6 probe. At T+5m40s a fault occurred in the circuit between the BOZ battery and the I-100, resulting in the shutdown of the third stage engine. U.S. Air Force radars in Turkey detected the failure [53].

The problem was therefore again related to the I-100, which had now been responsible for three of the five failures. The fact that two of its five major subsystems had needed replacement in the final days before this launch was an additional indicator that Pilyugin's control system required further changes. At a meeting in Moscow following the failure Chertok even proposed that a team under Boris V. Raushenbakh at OKB-1 develop an entirely new control and astro-navigation system, but since this would ground Ye-6 for an estimated two years, the idea was not even put forward to Korolev. A suggestion to unify the radio system with that of the Mars/Venera probes was also turned down, mainly because it would necessitate the transfer of operations from Simferopol to Yevpatoriya [54].

When the telemetry tapes from the *Dolinsk* arrived two weeks after the launch failure, it once again proved impossible to establish the exact cause of the failure. By this time Pilyugin (responsible for the I-100 as a whole) and Iosifyan (responsible for the inverter) were mutually blaming each other for the unreliability of the I-100 and were barely on speaking terms, forcing Chertok to act as mediator between the two. Irrespective of the exact cause, tests did show that certain sections of the I-100 unit were prone to overheating. It was therefore deemed necessary to cool the I-100 prior to launch, which required some modifications to the launch pad. This and other redesign work on the I-100 once again stopped the Ye-6 flight programme dead in its tracks.

5.6.3 The 1965 Missions

5.6.3.1 More Launch Problems

Another year went by before the programme was resumed. Not only did the modifications to the I-100 system require time, OKB-1 was very busy with the interim Voskhod project and early work on the N-1/L-3 piloted lunar landing programme. The latter had finally been approved in August 1964, making a piloted lunar landing an official national goal more than three years after President John F. Kennedy had initiated project Apollo. Some within the Soviet space community wondered what chances of success a complex project like N-1/L-3 had given the numerous setbacks suffered by the comparatively simple Luna probes. A consolation might have been that the Americans were experiencing similar problems with their Ranger spacecraft, although their long string of failures came to an end on 31 July 1964 with the successful kamikaze mission of Ranger-7, which beamed back over 4,000 close-up pictures of the lunar surface before crashing into the Sea of Clouds. Ranger-8 provided an encore in February 1965 [55]. It was high time for a Soviet response.

Preparations for the next Luna mission coincided with those for the high-priority Voskhod-2 mission, which was to feature the world's first spacewalk by cosmonaut Aleksey A. Leonov. Problems with an automated precursor flight (Kosmos-57) on 22 February slightly pushed back the piloted mission, allowing managers to decide on 27 February to launch Ye-6 No. 9 as planned during a tight launch window on 12 March [56]. Nevertheless, Korolev found the timing very inconvenient. With Voskhod-2 requiring all his attention, Luna was clearly the last thing on his mind. In a letter to his wife on 27 February he wrote:

> Now we'll also have to squeeze in work on [Luna]. This is our old theme, as you know, it's been delayed a long time and now in March (exactly now !) is the most convenient time [to launch]. I don't think anything good will come out of this, but the leadership and all my comrades insist on pressing ahead with this work as well [57].

Korolev's pessimism about the outcome of the mission proved prophetic. Following a 1 minute 41 second launch delay caused by a problem with one of the launch pad gantries, the first three stages of the 8K78 rocket safely delivered the payload to low Earth orbit, but only about an hour later Ye-6 No. 9 became the second probe to see its lunar ambitions thwarted by a Blok L failure. Writing in his diaries, Lt.-General Nikolay P. Kamanin noted Korolev's disappointment:

> Korolev was very distressed by the failure and looked as if he had all of a sudden aged ten years [58].

By now Soviet policy was to cover up failures by announcing them as successful flights in the all-embracing Kosmos programme. Ye-6 No. 9 was accordingly christened Kosmos-60 even though the telltale parameters of its parking orbit soon gave away its true mission to Western observers. The marooned Luna made a fiery re-entry through the Earth's atmosphere five days after launch.

Analysis showed that the problem was once again related to the I-100 control unit. Obviously, the one-year interval between Luna flights had not been enough to iron out the problems with the system, nor had it eased the tensions between Pilyugin and Iosifyan, with Pilyugin once again pointing the finger at Iosifyan's PT-500 inverter. Subsequent tests of the PT-500's rotor at the Pilyugin bureau showed that a washer could get caught on a screw used to fasten the cover of the PT-500 container. This in turn could lead to a short-circuit in the PT-500 and the complete breakdown of the power supply system. Similar tests done at Iosifyan's organisation produced ambiguous results, but in the absence of other evidence the State Commission established this as the official cause of the Blok L failure.

By now it was evident that some basic changes had to be made to the control system, which had been responsible for four of the six Ye-6 failures. The available descriptions of the failures indicate that the exact causes could never be pinpointed, probably because the telemetry downlinked by the spacecraft did not contain sufficient information. This made it difficult to take the required corrective action. Realising that it might take several more missions to completely debug the I-100 system, the State Commission took a decision that was probably long overdue, namely to separate the control systems of the booster's upper stages and those of the Ye-6 probe itself. The control system for the third and fourth stages was now to be installed on the fourth stage, just as it had always been on the Mars/Venera missions. The single PT-500 inverter aboard the Ye-6 probe was replaced by two PT-200 inverters on Ye-6 and the fourth stage. Mechanically this was not difficult, but the whole electric circuitry and method of testing had to be changed and new thermal tests were required. In order to minimise delays in the flight programme, the Blok L upper stages and Ye-6 probes already at Baykonur were not shipped back to OKB-1 in Kaliningrad but modified at the cosmodrome itself.

Modifications were made in time to perform another launch attempt the next month. Korolev, in poor health and very busy with man-related projects at OKB-1 in Moscow, was in no mood to return to the barren steppes of Kazakhstan, but during a discussion of the Ye-6 programme the USSR Council of Ministers had strongly urged all Chief Designers to be present at the cosmodrome for the Luna launches [59]. Ye-6 No. 8 lifted off on 10 April, but just minutes later ground contollers saw in disbelief how another third stage failure sent a Luna plummeting back to the Pacific. The only positive news was that the failure was not caused by the new control system, but by a random problem in the third stage LOX supply, as had been the case in the March 1964 attempt. This time the third stage had not ignited at all because the nitrogen pipeline of the LOX tank pressurisation system had become depressurised. The first real test of the new control system would have to wait until the next mission.

5.6.3.2 Luna-5/6: A Hit and a Miss

The next attempt was scheduled for 9 May which coincided with the 20th anniversary of the Soviet Union's victory over Nazi Germany (Victory Holiday). As if to join in the celebrations, Ye-6 No. 10 smoothly rode into orbit and after coasting for one hour was safely propelled to the Moon by the Blok L. The new control system had passed its first critical test. For the first time in over two years a Ye-6 probe had escaped the grip of Earth's gravity. TASS announced the launch as Luna-5 and reported a mass of 1,476 kg. It said nothing about the purpose of the flight except that it was aimed at the Moon.

After confirmation of the Blok L burn was received, members of the State Commission, including Korolev and Keldysh, flew to Simferopol to monitor the flight from the NIP-10 control station. During some of the early communications sessions, radio signals from Luna-5 came through poorly, apparently due to interference from radars of the Black Sea fleet. While Korolev made telephone calls to the Black Sea Fleet Commander in an attempt to have the radars shut down, it turned out that the cause of the interference was in the 25m parabolic antenna of NIP-10 itself. There had been a delay in filling the cooling system of the antenna's maser with liquid nitrogen, which caused one of the oscillators to self-activate.

Tension rose as the time came to perform the critical mid-course correction, the point where Luna-4's mission had gone wrong. Flight controllers were in for another disappointment. Soon after the engine fired, Luna-5 began spinning around its axis and was brought back under control only with great difficulty. A quick analysis of the situation showed that the flotation gyroscope of the I-100 unit had not been given enough time to heat up prior to the burn and had not properly stabilised the probe by the time the engine was ignited. A second attempt was made to alter Luna's course, but this time the engine did not fire at all due to a faulty command sent up from the ground, enough for Korolev to fly into one of his feared rages. By now it was too late to aim Luna-5 for its scheduled landing site. All that could be hoped for was to land the probe anywhere at all. As it was being positioned for the retroburn the spacecraft once again lost stabilisation due to the cold flotation gyroscope and eventually crashed into the Sea of Clouds on 12 May at 19.10 UT, some 700 km from its intended landing site. An unconfirmed report at the time said that the Rodewisch observatory in the south of the German Democratic Republic had observed the dust cloud kicked up by Luna-5. It was said to have been visible for 11 minutes and was reported to be 225 km long by 80 km wide [60]. The same report suggested that the cloud had been caused by Luna's retrocket, but there was no confirmation from the Soviet side that the engine had actually fired. In fact, tracking data from Jodrell Bank and also declassified data from the U.S. STONEHOUSE tracking station in Asmara, Ethopia (first used on this mission) indicate that no retroburn took place [61]. It is possible though that some of the pre-landing operations were carried out simply to test the systems involved. Chertok notes for instance that the thermal blankets covering the airbags were jettisoned.

Despite this new setback, the flight of Luna-5 had been the most successful Ye-6 mission to date and provided ground controllers with valuable new information. It had come down 700 km off target and was shattered to bits on impact, but at least it ended up where it was supposed to, namely on the surface of the Moon. In doing so it became only the second Soviet spacecraft to reach the lunar surface, almost six years after the (intended) crash landing of Luna-2. The TASS news agency made the best of it, saying that "a lot of information had been gathered to further perfect a system for making a soft landing on the Moon". In another TASS report Keldysh was quoted as saying that the purpose of the mission had been "to obtain preliminary experimental data on the operation of all systems of the probe needed to ensure a soft lunar landing under natural flight conditions". While cleverly leaving open the question if Luna-5 itself was a soft-landing attempt, these statements were the first official confirmation that a soft landing was the ultimate goal of the programme. Behind the scenes Keldysh had finally convinced the Soviet leadership to at least partially lift the veil of secrecy surrounding the Luna missions, arguing one could not go on announcing launches of 1.5 ton lunar probes without informing the world's scientific community about their flight objectives.

Following the Luna-5 mission measures were taken to ensure that the flotation gyroscope was properly heated prior to the correction and deceleration burns. It had also been noticed that the thermal cover of the airbags imparted an unwanted torque to the spacecraft when they were thrown off. Corrective action was taken in time to prepare Ye-6 No. 7 in time for a launch on 8 June. Once again the launch went off without a hitch, boosting confidence that the separation of the spacecraft and upper stage control systems had finally done the trick. Barely hours after the translunar injection burn the members of the Ye-6 State Commission were back at NIP-10 to track the flight of the probe, announced by TASS as Luna-6. Communications with the spacecraft, reported by TASS to weigh 1,442 kg, went very smoothly this time and everything seemed in perfect shape when the time arrived to carry out the mid-course correction manoeuvre on the evening of 9 June. Unfortunately, Luna had more nasty surprises in store. As acknowledged by TASS at the time, the KTDU engine ignited as planned, but then continued to fire beyond its planned shutdown point and eventually exhausted its fuel supply. Calculations showed that Luna-6 would miss the Moon by about 160,000 km late on 11 June.

To make things worse, early analysis of telemetry sent to the spacecraft traced the problem to human error. When sending up data for the manoeuvre, controllers had made a mistake in the critical command that told a built-in timer when to shut down the engine. It was an easily avoidable mistake and one that made this failure a very bitter pill to swallow. The people of Ryazanskiy's NII-885, who were responsible for tracking, command and control, braced themselves for another dressing-down from Korolev, but to everyone's surprise the Chief Designer maintained his calm. While all hopes of reaching the lunar surface were dashed, a plan was quickly drawn up to salvage as much as possible from this mission. With all the fuel depleted, it was impossible to reignite the KTDU, but commands were uplinked to inflate the lander's airbags and to separate the lander from the spacecraft bus, both of which were successfully executed. Contact was maintained to a distance of 600,000 km, after which Luna-6 silently slipped into heliocentric orbit, becoming another small artificial planet of the Sun.

5.6.3.3 Luna-7/8: Trying the Kremlin's Patience

After returning from the Crimea, Korolev convened a meeting to discuss the future of the Ye-6 programme. Among those invited was Georgiy Babakin, the newly appointed Chief Designer of the Lavochkin Design Bureau, which had begun taking over lunar and planetary programmes from OKB-1 in March. Korolev declared that it was time for OKB-1 to fully concentrate on efforts to put Soviet cosmonauts on the Moon in three years time, jokingly adding that during this time "Babakin was to land so many probes on the Moon that there wouldn't be any room left for the Americans". Already having taken over work on lunar orbiters and the Ye-8 Moon rovers, Babakin was reluctant to get involved in the Ye-6 landers, but Korolev wanted to do everything possible to achieve a soft landing on the Moon to pave the way for his piloted lunar expeditions. In the end it was decided that OKB-1's factory would manufacture two or three more Ye-6 landers and that Lavochkin would build at least one of its own based on OKB-1 blueprints. This was probably seen as a safeguard against further failures in the OKB-1 missions and would allow Lavochkin to gain experience in building the Ye-6 spacecraft bus, which was essentially the same for the landers and orbiters.

Before the Ye-6 missions resumed, the Soviet Union was able to restore some of its lost lunar pride with the successful mission of Zond-3, which flew past the Moon on 20 July 1965 and photographed uncharted territory of the Moon's far side. It was the first Soviet lunar success since October 1959, when Luna-3 (a Ye-2A probe) had returned the first ever pictures of the far side of the Moon. What the Soviets did not say was that Zond-3 was a quickly improvised mission that did not fit in the mainstream lunar exploration programme. It actually was a 3MV-4A Mars photographic flyby probe that had missed its late 1964 launch window and was relegated to a lunar flyby instead to test some of its on-board systems [62]. Regardless of its original purpose, it finally gave the Soviet lunar programme something to show off in the wake of the U.S. Ranger successes. OKB-1 engineers noted not without pride that Zond-3's control and navigation systems had been built entirely in-house, gently hinting at the Ye-6 failures caused by systems of Pilyugin and Morachevskiy, whose organisations were supposed to be specialised in these matters.

By August 1965 another Ye-6 probe (serial No. 11) and 8K78 booster were delivered to the Baykonur cosmodrome for a launch attempt on 4 September at 07.05.36 UT. This time the rocket did not make it off the ground at all due to a faulty sensor in the so-called Apparent Speed Control System of stages 1 and 2. Fixing the problem required the rocket to be drained and returned to the assembly building, meaning another launch attempt could not take place until early October at the earliest. By now rumours were circulating in the space community that the Kremlin's patience with the Luna failures was running out and that heads were about to roll, or worse, that the whole programme might be cancelled. One reason why this issue hadn't been raised earlier may be that the earlier Ye-6 failures had been largely overshadowed by the successful missions in the Vostok and Voskhod programmes. Now that the piloted flight programme had virtually ground to a halt after Voskhod-2, the spotlight turned on the next most prestigious space project, namely Ye-6. Bearing overall responsibility as Korolev's deputy for the Luna programme, Boris Ye. Chertok was seen as the most likely victim of the expected sanctions. Meanwhile, Korolev, Keldysh and Tyulin used their influence to convince members of the VPK and the Central Committee of the need to continue the Ye-6 flights, arguing among other things that a response was needed to U.S. successes in lunar exploration. To their relief, a planned September meeting of the VPK to discuss the status of the project was delayed because of more pressing concerns. Ye-6 and its engineers were given a reprieve.

The pressure was now higher than ever to achieve success as soon as possible. Ye-6 No. 11 and its trouble-plagued 8K78 booster were turned around for another launch attempt on 4 October, the 8th anniversary of Sputnik. For the third time in a row the launch and translunar injection burn went flawlessly, after which TASS announced the mission as Luna-7. Spacecraft mass was reported as 1,506 kg. Babakin and some of his engineers were present at Baykonur to watch the launch and subsequently flew to Simferopol to observe flight operations at NIP-10 [63]. An innovation on this mission was the use of a 2.6 m telescope by the Crimea Astrophysical Observatory to obtain multiple exposure photographs to check the probe's trajectory [64].

Luna-7 passed a major milestone in the evening of 5 October with the successful completion of its trajectory correction manoeuvre, conducted during the sixth communications session with the probe. For the first time there was real hope a Ye-6 was about to reach the Moon intact. This was reflected by a TASS statement on 6 October, which for the first time ever gave the expected landing time in advance, saying Luna-7 would reach the Moon's surface around 22.00 UT on 7 October. On the morning of 7 October a more concrete landing time of 22.08 UT was announced.

Operations continued to go smoothly as Luna-7 approached the Moon, although Pilyugin's infamous I-100 unit had to be regularly switched off to cool down. Flight controllers in the NIP-10 control room were glued to their monitors as the moment arrived to align the probe for the deceleration burn. This was an automatic procedure in which two hours before the planned landing time, the optical sensors of the astro-navigation system were to lock onto the Sun, Moon and Earth respectively to create a set of reference coordinates which the I-100 needed to command the subsequent roll and pitch manoeuvres that would point the engine's thrust vector exactly vertically to the lunar surface. Unfortunately, as Luna-7 closed in on the Moon, data coming back from the probe indicated that one of the terrestrial sensors had lost its lock on the Earth. Expectation turned into despair. With the terrestrial sensor having lost its target, the probe had lost the "lunar vertical" and the automatic systems were programmed to block the firing of the KTDU. All controllers could do was watch helplessly how Luna-7 headed for a crash landing in the Ocean of Storms. TASS announced an impact time of 22.08.24 UT on 7 October west of the crater Kepler (not far from the intended landing point) and laconically stated: "During the approach to the Moon the majority of operations required for a soft landing on the Moon were carried out. Some operations were not carried out in accordance with the programme and require additional testing".

Analysis carried out overnight showed that the terrestrial optical sensor of the astro-navigation system was preset at the wrong angle. In about thirty minutes following lock-on, the Earth had gradually moved to the edge of the sensor's field of view. At that point an otherwise benign deviation was enough for the sensor to lose track of the Earth altogether. Other faults were discovered in the lunar vertical alignment procedure as well, giving Morachevskiy's team several things to account for. It was the second Ye-6 failure caused by the astro-navigation system (following Luna-4). Interestingly, traditional Western accounts of the Luna-7 failure have given a different scenario, saying that due to a timer failure the KTDU engine was switched on too early and therefore shut down at too great an altitude for the probe to survive the resulting impact [65]. The new Russian information would indicate that the KTDU was not fired at all [66]. This is also confirmed by declassified data from the American STONEHOUSE tracking station in Ethiopia [67].

After this 10th consecutive failure, the fate of the Ye-6 programme hung in the balance. Having gone one failure too far, Luna was put on the agenda of one of the weekly VPK meetings at the insistence of

Dmitriy Ustinov, the Secretary of the Communist Party's Central Committee responsible for space and defence affairs and the *de facto* head of the Soviet space programme between 1965 and 1976 [68]. Overseeing the activities of eight ministries involved in the space and defence industry, the VPK was a very powerful body, comprising not only ministers, but also the Commanders-in-Chief of some of the armed services and the President of the USSR Academy of Sciences. It was headed by Leonid Smirnov, who at the same time was a Deputy Chairman of the USSR Council of Ministers. While the VPK was not authorised to initiate or cancel projects, its recommendations could have a direct impact on the space policy decisions made by the Party's Central Committee and signed into law by General Secretary Leonid Brezhnev.

A small delegation from Korolev's Design Bureau was summoned to appear at the VPK meeting, which took place as usual in the Oval Hall of the Kremlin and was attended by Ustinov himself. Ye-6 project manager Boris Chertok was allotted 15-20 minutes in the agenda to explain the programme's failures and justify its continuation. Korolev was worried. He knew Chertok was not a skilled orator and had not been impressed by a dress rehearsal of the presentation held at the Design Bureau. Realizing the Ye-6 programme faced possible cancellation and having plenty of experience with these kinds of situations, Korolev decided to take the floor himself when the time came for Chertok to speak. Rather than go through the individual causes of all the mishaps, Korolev stressed that failures were part of the learning process and that this had not been taken into account while drawing up the budget and timelines for the Ye-6 project. He added, however, that every flight had brought them closer to success and assured the VPK members that the next flight would meet its objective. When asked for permission to proceed with the next launch, none of the members objected. Korolev's presentation had taken no longer than ten minutes. Many years later Chertok would acknowledge that Korolev's eloquence had probably saved the day:

> If I had appeared myself, the Ye-6 project might well have been closed down [69].

At Baykonur another four Molniya boosters were being readied for launches in the final two months of the year. Three were to launch Venera probes in November and the fourth was to lift off in early December with Ye-6 No.12, the final lunar lander built at OKB-1. Shortly before departing for the cosmodrome in late October, Chertok convened a meeting of the Chief Designers responsible for the control, tracking, and orientation systems of the Ye-6 and Mars/Venera probes. He strongly criticised the poor quality of some of the systems delivered to the OKB-1 factory, singling out the fact that on the three last Ye-6 probes alone Pilyugin's I-100 system had to be removed for repair work five times. Moreover, some of the subsystems were delivered so late that they could undergo integrated tests only after arriving at the launch site. Pilyugin admitted shortcomings in the I-100 testing process, pointing out that three years after the beginning of the Ye-6 project he still did not have a test stand equipped with Morachevskiy's optical sensors, Isayev's automatic devices, and Ryazanskiy's radio systems. Whether he put the blame for that on himself or the respective designers of those systems is not clear. At any rate, Pilyugin promised to take the necessary measures, but added that such a test stand might no longer be required if the next Luna was successful.

After the three Venera launches (two successful, one a failure), attention turned to the next Luna. Although a launch was possible as early as 30 November, the State Commission decided on 28 November to rest the launch teams and set the mission for 3 December. Liftoff came right on time and about one hour later Blok L successfully put Ye-6 No.12 en route to the Moon. Weighing 1,552 kg, Luna-8 was the heaviest Ye-6 to date, 46 kg heavier than Luna-7. The mass gain was probably related to the fact that it was the first Luna to be inserted into a 51.8° parking orbit rather than the 64.8° orbit used by all its predecessors. The lower inclination (also used by the Mars/Venera probes) made it possible to make more effective use of the Earth's rotational speed to help push the probe into orbit. There are also indications that this was the first Luna launch to use a Molniya booster with a more efficient core stage and strap-ons (borrowed from the 11A511 Soyuz launcher).

For the first time TASS mentioned a mission objective in its launch announcement, saying Luna-8 was to "further perfect elements of a lunar soft landing system". Actually acknowledging that Luna-8 was supposed to perform a soft landing itself was apparently still considered too risky. Two Soviet scientists quoted by *Pravda* following the launch mentioned "the colossal research opportunities" that would be opened up by a soft lander, but cautioned that Luna-8 was only to perfect the landing technique and that this was "an extremely complicated task".

The morning after launch Korolev and the members of the State Commission went to Baykonur's aerodrome for the traditional four-hour flight to the Crimea. Unknown to everyone at the time, the legendary Chief Designer would never return to the cosmodrome again. At NIP-10 everything turned out to be going smoothly with Luna-8. Having acted as observers on the previous flight, the engineers of the Lavochkin Design Bureau now took active part in controlling the flight [70]. According to TASS the mid-course correction burn took place at 19.00 UT on 4 December [71].

It was getting close to midnight local time on 6 December as flight controllers once again gathered at the NIP-10 control room to monitor the final stages of a Luna mission. This time Morachevskiy's optical sensors worked as promised, following which the I-100 system pointed Luna's radio altimeter and KTDU engine in the right direction for the 42-second deceleration burn, which was to take place at an altitude of 74.8 km. Shortly before the burn a command was sent to inflate the two airbags that would cushion the impact of the lander. However, telemetry soon showed that the pressure in the airbags began dropping and seconds later altitude data was lost, indicating Luna had been knocked off course. With the radio altimeter not pointing at the lunar surface, the KTDU ignition sequence could not be triggered, but it appears that during the probe's rotation the altimeter momentarily found the lunar surface again and sent an ignition command to the KTDU. However, the engine cut off after only 9 seconds, possibly because the propellants had become unsettled as a result of the probe's uncontrolled motion. Consequently, Luna-8 was still moving at a significant speed by the time it reached the lunar surface. There was still a glimmer of hope that the capsule might have separated from the spacecraft bus and survived impact. Its transmitter was programmed to shut down at the moment of separation and be switched back on only five minutes after landing to prevent a short circuit during touchdown [72]. Controllers duly waited for the signal to appear, but nothing happened. Luna-8 was dead. It had struck the lunar surface at 21.51.30 UT west of the crater Kepler (9°8' N, 63°18' W). TASS reported that "the station's systems functioned normally at all stages of the landing except the final one".

The first analysis of data showed that the radio altimeter had lost its lock on the lunar surface 13 seconds after the command had been sent to inflate the airbags. Calculations showed that Luna-8 was spinning at a rate of 12 degrees per second at the time of KTDU ignition, more than three times what the probe's stabilisation system could handle. It was clear that the airbags had somehow become deflated and that the escaping gas had acted as a thruster and sent Luna-8 into a spin. It took another five days to find the exact cause of the accident. The airbags had been pierced by a plastic mounting bracket of the petal-shaped stabilisation panels that were supposed to be opened after landing. The bracket had partly broken off and the sharp edges had punctured one of the rubber airbags. The entire sequence of events could be perfectly reproduced in the laboratory. In the end, the problem was traced back to one single worker who had made a mistake during the manufacturing process of the bracket. It was a good demonstration of how small mistakes could have major consequences.

Korolev was devastated by the failure. As Boris Chertok later recalled:

> When I looked at [Korolev], I wasn't sure for whom I was to feel sorry most: the lunar probe, the pieces of which were now lying about the lunar dust more than four hundred thousand kilometres away from us, or this big, strong man, who was saddened beyond all measure [73].

At the behest of Ustinov another VPK meeting was in the making to scrutinise the root causes of the Ye-6 failures. This time Korolev himself was to be called to account. However, subsequent events decided otherwise. Barely a month after Luna-8 crashed into the Sea of Storms, Korolev was hospitalised for surgery and died on the operating table several days later. His dream to see a Soviet probe make a soft landing on the Moon did not come true during his lifetime. It was now up to Babakin's team to prove that it could be done.

5.7 Ye-6M Missions: Success at Last [74]

5.7.1 The Triumph of Luna-9

By mid-January 1966 the launch of Luna-9 was set for 31 January. Following the successful launch, TASS did not mention a soft-landing objective in its launch announcement. The spacecraft was reported to weigh 1,583 kg. A 48-second mid-course correction was carried out on 1 February at 19.29 UT with Luna-9 some 233,000 km from the Moon. It resulted in a velocity change of 71.2 m/s and set the probe on course for a landing in the Ocean of Storms two days later. By 13.00 UT on 3 February all data for the descent sequence had been transmitted to the spacecraft. About one hour before touchdown and with 8,300 km to go to the lunar surface Luna-9 was placed in the proper attitude for the deceleration burn with its retro-engine facing forward. At an altitude of 74.885 km Luna's KTDU main engine burst into life with just 48 seconds to go to touchdown. By the time the engine cut off some 250 m above the lunar surface, it had slowed the probe from 2,600 m/s to just several metres per second. Seconds later the 99.8 kg lander separated from the spacecraft bus and hit the lunar surface at 18.45.30 UT west of the craters Reiner and Marius in the Ocean of Storms (7° 8' N, 64° 22' W) [75]. Safely ensconced in its two hemispheric airbags, the capsule then bounced over the lunar surface and came to rest halfway up the inner slope of a 25 metre diameter crater. Having shed the airbags, it deployed its four petal-shaped panels in order to assume an upright position.

At Mission Control in Simferopol tension was now running higher than ever. It would be another four minutes or so before the lander's transmitter, shut down before impact to prevent a short circuit, would be reactivated. All eyes were focused on a number of oscillographs that were to detect a change in the signal-to-noise ratio. The minutes seemed to last ages. Then one of the controllers saw how the recording pen on his oscillograph began to move slowly and triumphantly called out "Signal received" [76]. Scenes of jubilation followed. After three frustrating years of setbacks it was a sweet moment indeed. Luna-9 had scored another major Soviet space first, performing the first soft-landing on the Moon four months before America's Surveyor and becoming the first spacecraft to send back signals from the surface of another world.

Luna-9 had landed shortly after local sunrise and would now wait about seven hours for the Sun to climb from 3° to about 7° elevation to send back the first panoramic picture of the lunar surface. This happened during a communications session lasting from 1.50 to 3.37 UT early on 4 February. Although historic in nature, the first images showed little contrast and were rather disappointing to the flight controllers in Simferopol, who set to work to change the camera settings for the next communications session later in the day [77]. There was not much time to get things right, because the lander's batteries were supposed to last only a couple of days. The Soviets, however, were not the only ones listening in to Luna-9. Jodrell Bank in England had been monitoring the flight from the beginning and also intercepted the first picture data, which were converted into images with a newspaper facsimile machine hastily dispatched by car from the *Daily Express* offices in Manchester. To the Soviets' dismay, the Jodrell Bank pictures were released to the world several days before the official Soviet ones. Because the true scale of the lunar view was not known, the British versions were slightly distorted,

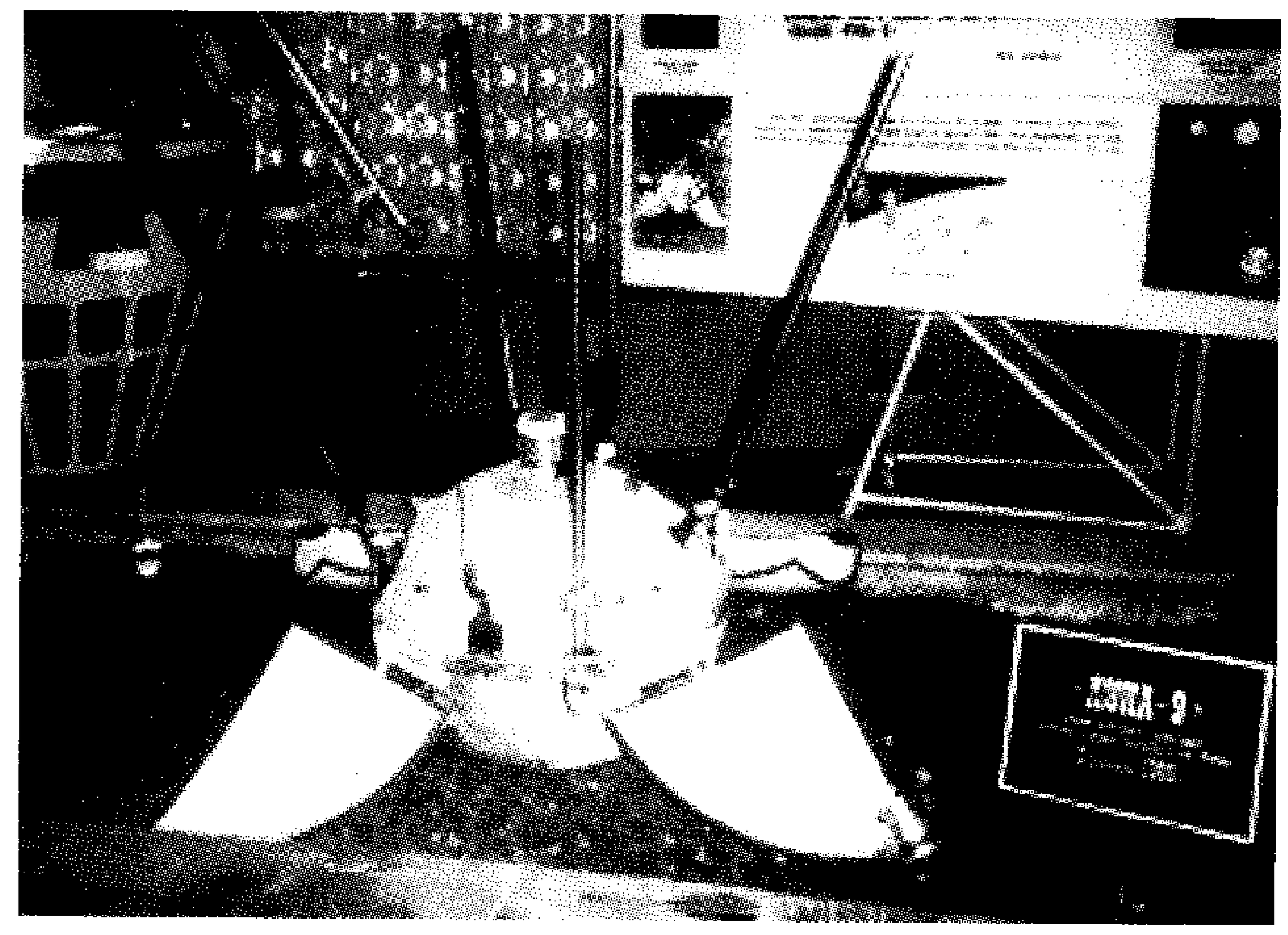

Fig. 9 Luna-9 ALS on display at the Lavochkin Museum, Moscow. (source: B. Hendrickx)

making the lunar features appear taller and more jagged than they really were. Jodrell Bank officials justified the scoop by underlining the international importance of the pictures and saying that no scientific analysis of the images had been made. The pictures were also picked up and decoded by U.S. sensors, but it was decided not to release them, possibly not to reveal too much about American tracking capabilities.

A Russian article later revealed that the Soviets' own pictures had become entangled in bureaucracy because their release required the personal approval of Leonid Brezhnev. They were first sent from Simferopol to an unidentified space organisation, then to a defence branch of the Central Committee and next to the Politburo. By the time they wound up on Brezhnev's desk it was night and no one had the nerve to wake up the General Secretary, contributing to the delay [78]. Whether this is legend or fact is, of course, hard to tell.

A second panorama was relayed on 4 February (15.30-16.55 UT) and a third one followed on 5 February (16.00-17.41 UT), by which time the Sun's elevation angles had increased to respectively 14° and 27°, causing the shadow relief to change. It was noticed that Luna-9 had slightly shifted its position, possibly because the diminishing water supply in its thermal control system had changed its weight distribution. As a result the camera's perspective was moved about 100 mm, giving an unexpected opportunity to make stereoscopic studies of nearby areas and more accurately determine the distance of objects. The 5 February session was expected to be the last one, but enough battery power turned out to be available for an additional session on 6 February (20.37-22.55 UT) during which images of smaller areas were sent to Earth. TASS reported that at the end of its mission the lander had con-

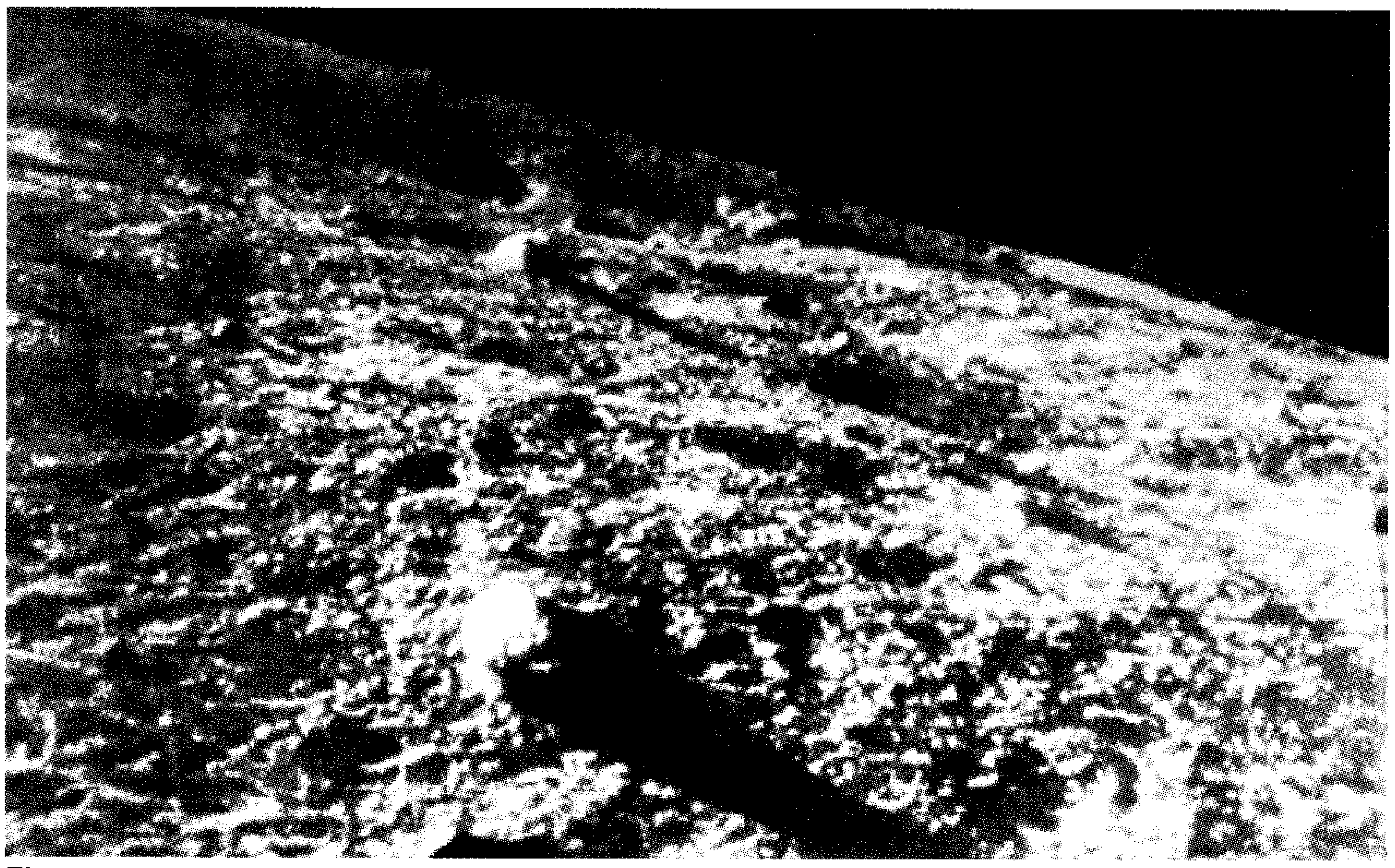

Fig. 10 Part of a lunar panorama taken by Luna-9. (source: Novosti news agency)

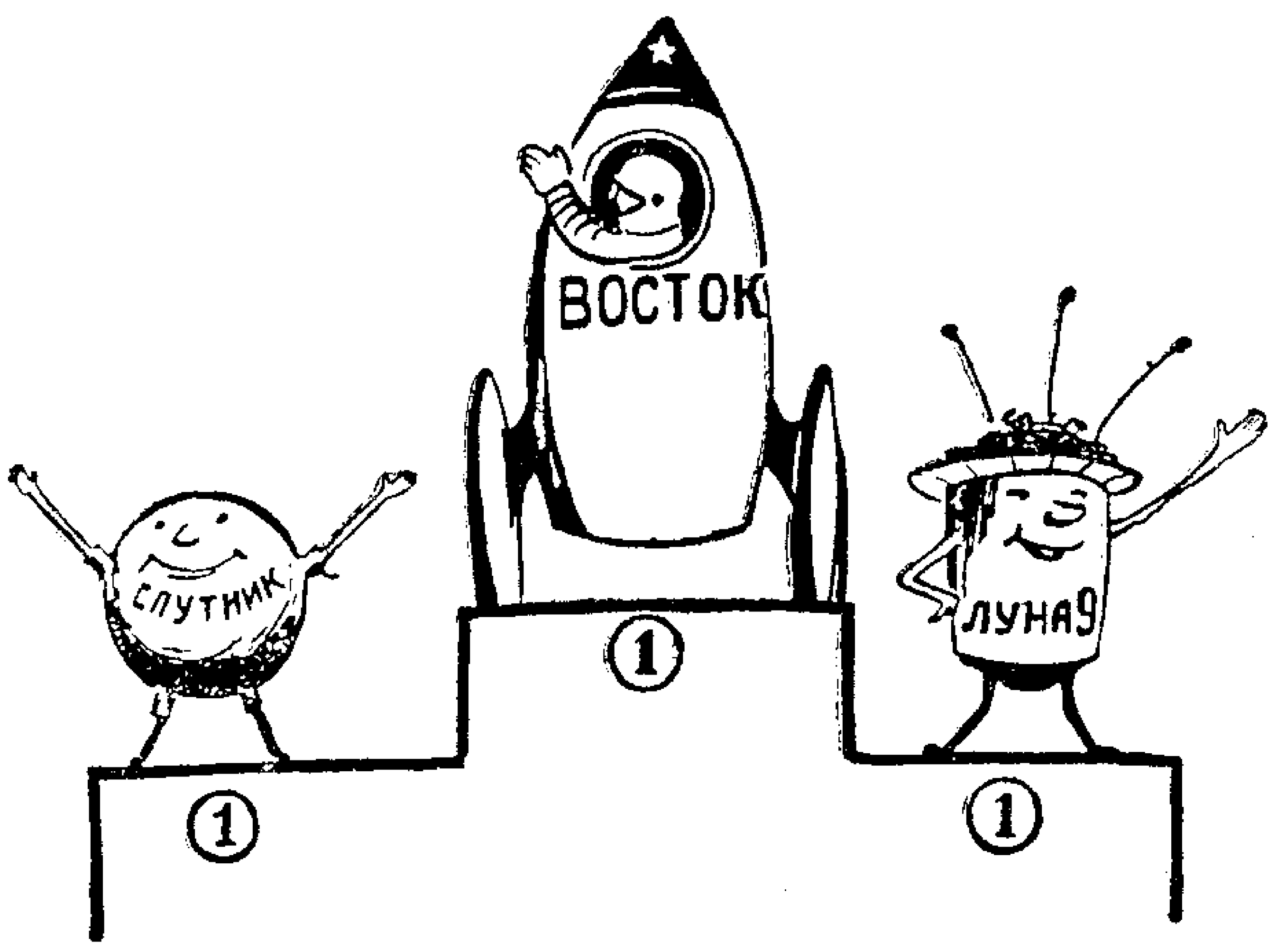

Fig. 11 Soviet cartoon puts Luna-9 on an equal footing with Sputnik and Vostok.

ducted seven communications sessions lasting 8 hours 5 minutes in all.

The only experiment carried by Luna-9 (not counting the TV camera) was a radiation detector (SBM-10), which measured a dosage of 30 millirads per day, probably caused by the interaction of cosmic rays with the lunar surface. The most important scientific discovery of the mission was the very fact that the probe had not sunk into metres of dust, positive proof that the lunar soil was hard enough to support heavy piloted spacecraft. This had been one of the primary objectives of the Ye-6 programme when it was conceived in the late 1950s. Although this was a comforting thought, engineers both in the Soviet Union and the United States probably saw this as a foregone conclusion, because the design of their piloted lunar landers had been pretty much frozen by this time.

The Soviet propaganda machine bathed in the glory of this long-awaited success, which was announced with much fanfare and sparked worldwide reaction. However, little or nothing was said about the numerous attempts it had taken to achieve success, nor was anything revealed about the people behind the scenes who had made this feat possible. Babakin, Chertok, and Keldysh made efforts to have the mission dedicated to the memory of Korolev in the TASS statement about the landing. The request was passed on to VPK chairman Leonid Smirnov by Georgiy Tyulin, the head of the Luna State Commission, but to no avail. Although Korolev's name had been declassified following his death the month before, the Central Committee decided to dedicate the landing to the upcoming 23rd Congress of the Soviet Communist Party [79].

5.7.2 Luna-13 Does an Encore

Although Luna-9 had accomplished all goals of the lander programme, it was decided to launch one more mission before the end of the year. Ye-6M No. 205 lifted off from Baykonur on 21 December 1966 and was announced as Luna-13 after leaving Earth orbit. TASS did not give a launch mass, but another Soviet source gives it as 1,620 kg [80]. After a successful mid-course correction the following day at 18.41 UT, it approached the Moon on 24 December, firing its KTDU engine at an altitude of 70 km, slightly lower than Luna-9. Touchdown came at 18.01 UT in the Ocean of Storms between the craters Krafft and Seleucus (18°52'N, 62°03'W), some 440 km from the silent Luna-9. The first signal from the lunar surface was received at 18.05.30 UT.

Weighing 112 kg, the Luna-13 lander was slightly heavier than its predecessor – it was equipped with improved thermal control systems and was carrying several experiments to study the strength of the soil. The first of those was performed on impact, when the three-axis accelerometer carried inside the lander's pressurised body measured the landing forces to learn more about the soil structure to a depth of 20-30 cm. The results showed that the

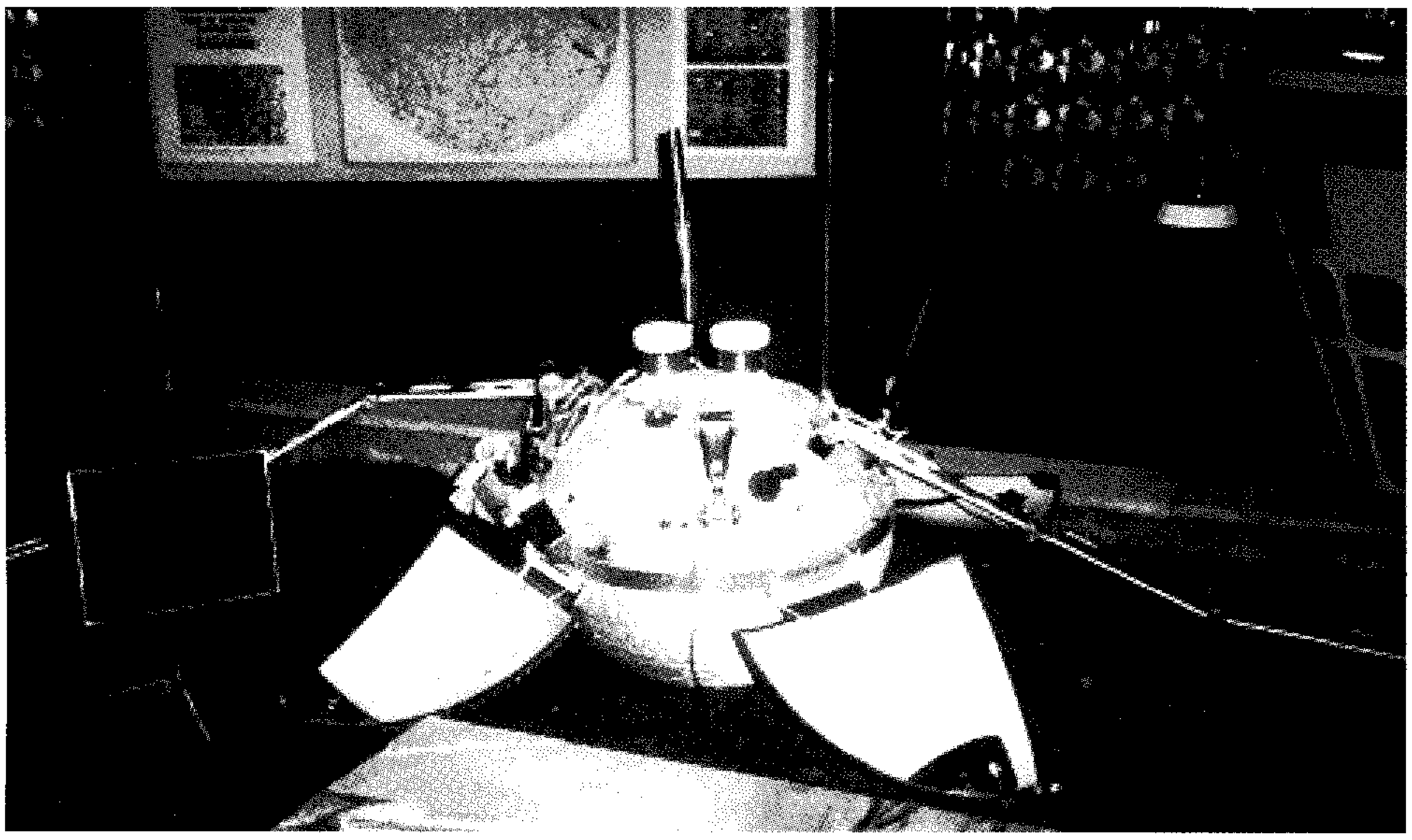

Fig. 12 Luna-13 ALS on display at the Lavochkin Museum, Moscow. Note the stereoscopic camera and the arms with the radiation densitometer (left) and the soil penetrator (right). (source: B. Hendrickx)

lunar soil was solid and relatively free of dust. Just minutes after landing, as the four stabilizing petals opened, the two spring-loaded booms were deployed from opposite sides of the capsule. At 18.06 UT the mechanical soil penetrator carried on one of the two folded booms was activated by an explosive charge. The titanium-tipped rod penetrated to a depth of 4.5 cm, indicating the soil had a granular mixture similar to medium-density terrestrial soil and was slightly cohesive with a density of about 0.8 g/cm^3. The radiation density meter carried on the other boom provided data that almost exactly matched those of the penetrator.

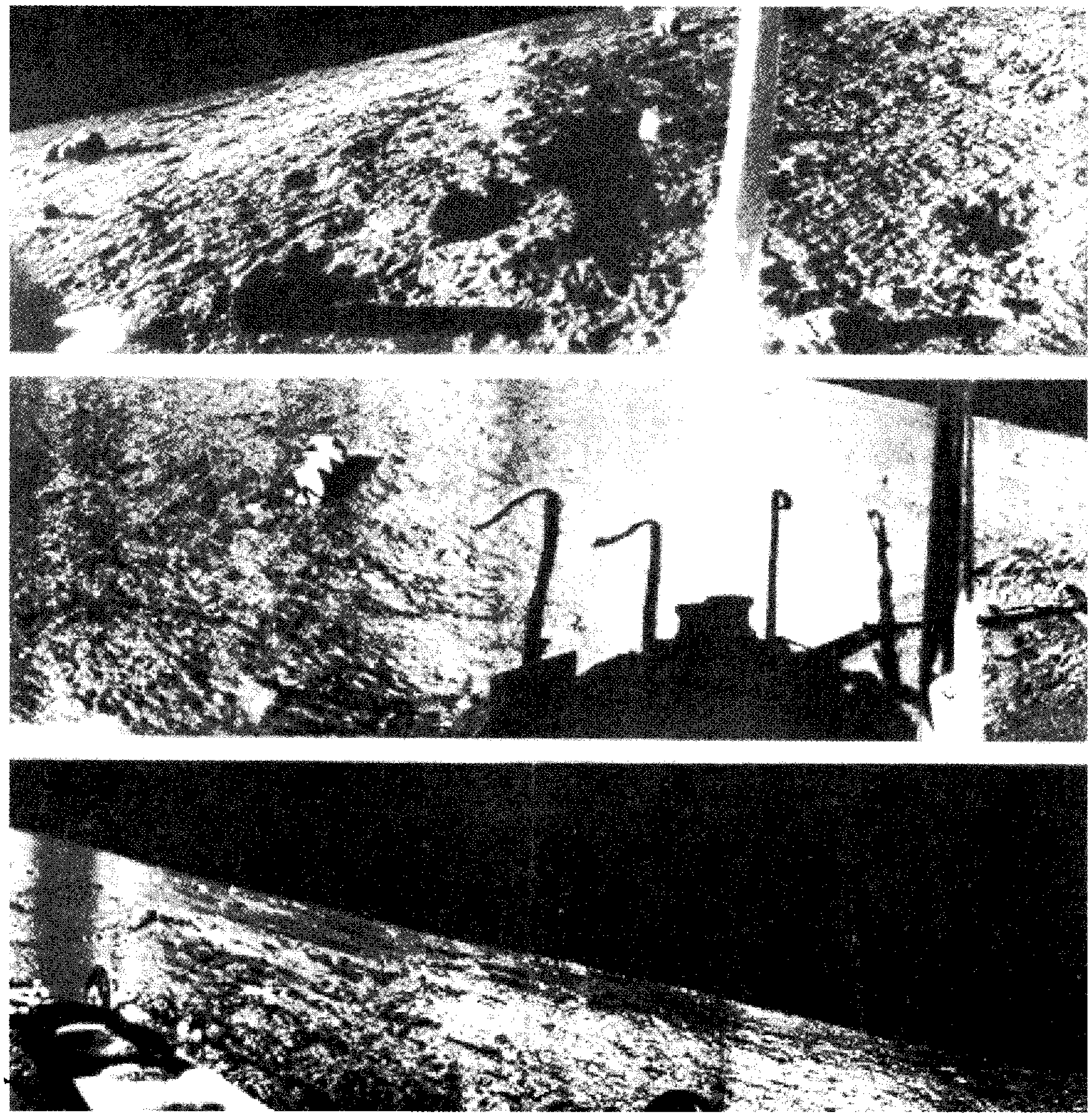

Fig. 13 The lunar surface as seen by Luna-13. (source: *Nauka i zhizn* magazine)

Luna-13 had landed shortly before local sunrise, which occurred at 00.30 UT in the morning of 25 December. The first picture session began at 12.15 UT that day, by which time the Sun had risen to about 6° elevation. The probe carried twin cameras to produce stereoscopic images, but one of them failed after landing [81]. The pictures showed a terrain less hilly than that seen by Luna-9, with the horizon being much farther away. Also visible were stones several centimetres across which had apparently fallen at low speed and were probably ejecta from meteorite impacts. The Luna-13 pictures were also received by Jodrell Bank, but bearing in mind the Soviets' outrage over the publication of the Luna-9 images, it was decided to release them only after official permission from the Soviet side.

The four radiometers around the capsule's circumference recorded a noontime temperature of about 117°C. A radiation detector mounted adjacent to the camera turret showed that radiation levels would not be hazardous to humans visiting the Moon. Another four panoramas were received the following days. The last communications session was held between 4.05 and 6.13 UT on 28 December.

6. The Orbiters

6.1 The Ye-6S and Ye-7 Orbiters

After the aborted attempt with the Surveyor Orbiter, NASA resurrected the idea of a robotic lunar orbiter by 1962-63 and completed plans for a small orbiter by March 1963. Under the Langley Research Centre's direction, a contract was awarded to Boeing in May 1964 to deliver an orbiter equipped with a photography system developed by Eastman Kodak as well as three scientific experiments [82]. The first of five spacecraft was scheduled to take off by 1965-66. At the same time, OKB-1 also had its own lunar orbiter programme, the apparently underfunded Ye-7 project which had been proposed by Korolev as early as 1959. Unlike the Ye-6 lander, the Soviet government did not approve further development of the Ye-7 in various official decrees in 1960-62. OKB-1 did, however, continue work on its development through the early 1960s despite the lack of a firm high-level commitment. When Korolev turned over all work on automated lunar probes to Babakin in 1965, the transferred product included one if not more partially completed models of the Ye-7 orbiter. Little is known about the design of the Ye-7 except that it was to have carried a sophisticated TV camera complex. There are also indications that it was to be used as a communications relay satellite for the L-3 lunar landing missions. It is unclear if the orbiter had a main bus different from that of the Ye-6 lander. Isayev's OKB-2 began development of the S5.5 main engine for Korolev's second generation probes in 1959, and it is likely that the same engine might have been used for both, implying that the bus was also very similar [83].

For reasons that are unclear, the Ye-7 orbiter plan had fallen badly behind schedule by the time Babakin inherited the programme. A confluence of political exigencies and technical limitations forced a major rethink of the lunar orbiter programme. The 23rd Congress of the Communist Party was planned to be held in March 1966 in Moscow. Original plans were to launch the piloted Voskhod-3 spacecraft into orbit around the time to commemorate this highly important political event. As it turned out, there were repeated delays in the Voskhod-3 schedule as a result of insufficient confidence in its launch vehicle and life support systems. In early February, immediately after the Luna-9 landing, Babakin offered an alternative at a meeting with Academician Keldysh. He convinced Keldysh that given appropriate high-level commitment, he could have a functioning spacecraft in lunar orbit by the time of the Congress. His plan was apparently to use an already built Ye-6-type spacecraft bus, add a radiosystem to precisely measure orbital parameters of the satellite, and install a special payload (replacing the lander) for a fairly extensive array of scientific instruments making sure that their functioning was compatible with other onboard equipment. As for the mission profile, Babakin's engineers would alter the plan of work of the astro-navigation system to ensure a lunar orbit insertion burn rather than a lunar landing burn on the spacecraft's approach to the Moon [84]. This "new" spacecraft was called the Ye-6S. Unlike the Ye-7, it did not carry any photography system; in fact, it is quite likely that problems with the photo-system on the Ye-7 may have been responsible for the delays in the Ye-7 programme. Kerim A. Kerimov, a member of the State Commission for the lunar launches who was also a senior official in the Ministry of General Machine Building (MOM), recalled later that the Ye-6S spacecraft was "manufactured from technical documentation from the Korolev design bureau for the [Ye-7] apparatus" [85]. It is possible that the two Ye-6S probes eventually launched in March 1966 were both Ye-6 lander buses (serial numbers 204 and 206) quickly refitted with scientific and service equipment from uncompleted Ye-7 orbiters.

The main bus, i.e. the engine, instrument compartments, and control section of the Ye-6S, was virtually identical to that of the Ye-6 lander. The landing capsule, however, was replaced by a 245 kg stubby roughly cylindrical satellite which would be detached for lunar orbit insertion. This payload was a pressurised capsule (850-860 mm pressure at 21° to 23°C) about 75 cm wide and 1.5 m long. Internal batteries provided power for operation. The overall Ye-6S spacecraft weighed 1,582 kg and was 4 m long [86].

The payload carried seven major scientific instruments:

1. A three-component magnetometer for establishing the boundaries of a possible lunar magnetic field, which was capable of detecting magnetic fields of up to 50γ with a resolution of 1γ; this instrument was mounted at the end of a 1.5 m long deployable

boom so as to isolate it from the fields associated with the satellite itself;

2. A gamma-ray spectrometer (0.3-4 MeV) for comparing the natural cosmic background radiation emitted by the lunar surface. By eliminating the amount of radiation induced by reactions with cosmic rays, scientists would be able to calculate the natural radioactivity, and therefore the amount of uranium, thorium, and calcium-40;

3. Five gas discharge counters for recording solar corpuscular and cosmic radiation and low-energy electrons to determine the lunar ionosphere and investigate charged particles in the "tail" of the circumlunar magnetosphere of the Earth; three of the five counters were primarily designed for measuring the fluorescence of lunar rocks due to solar x-radiation which would allow the determination of the relative content of several elements in lunar rocks;

4. Two four-electrode ion traps and a modulation type charged particle trap for recording the solar wind's ion and electron flux and to search for the lunar ionosphere;

5. A piezoelectric micrometer detector for recording meteoric particles in lunar and interplanetary space. The instrument, which was similar to the one carried on Luna-3 (Ye-2A), had a registering area of 1.2 m^2 and a sensitivity of 7×10^{-8} g;

6. An infrared detector comprising two 15 x 30 mm flat plate receivers to determine integral thermal radiation of the Moon;

7. Low energy X-ray photon counters for measuring X-ray fluorescent radiation of rocks on the lunar surface.

Scientists on the Earth also planned two further experiments with the Ye-6S spacecraft. They intended to examine communications power levels while the vehicle passed behind the Moon and emerged on the other side in order to determine if there was any thin gaseous medium near the lunar surface that refracted the radio waves—a process known as radio occultation. Additionally, there were plans to measure the natural changes in the orbit of the spacecraft to plot the Moon's gravitational field. This was an essential task not only for future robotic missions but also for piloted lunar missions whose orbital trajectories could be adversely affected by mass concentrations below the lunar surface [87].

Up to final braking into lunar orbit, the mission profile of the Ye-6S was quite similar to that of the Ye-6 lander. Instead of effecting a braking burn to initiate descent on to the lunar surface, the Ye-6S fired its engines with a smaller burn (in essentially the same direction) to reduce velocity relative to the Moon by about 850 m/s, allowing the Moon's gravity to pull the vehicle into lunar orbit. Both side compartments were jettisoned prior to this burn. The necessity of a smaller burn meant that less propellant was carried on the orbiter, thus permitting a larger payload. Twenty seconds after the burn, the main spacecraft ejected the small orbiter payload, spinning at about 2 rpm [88].

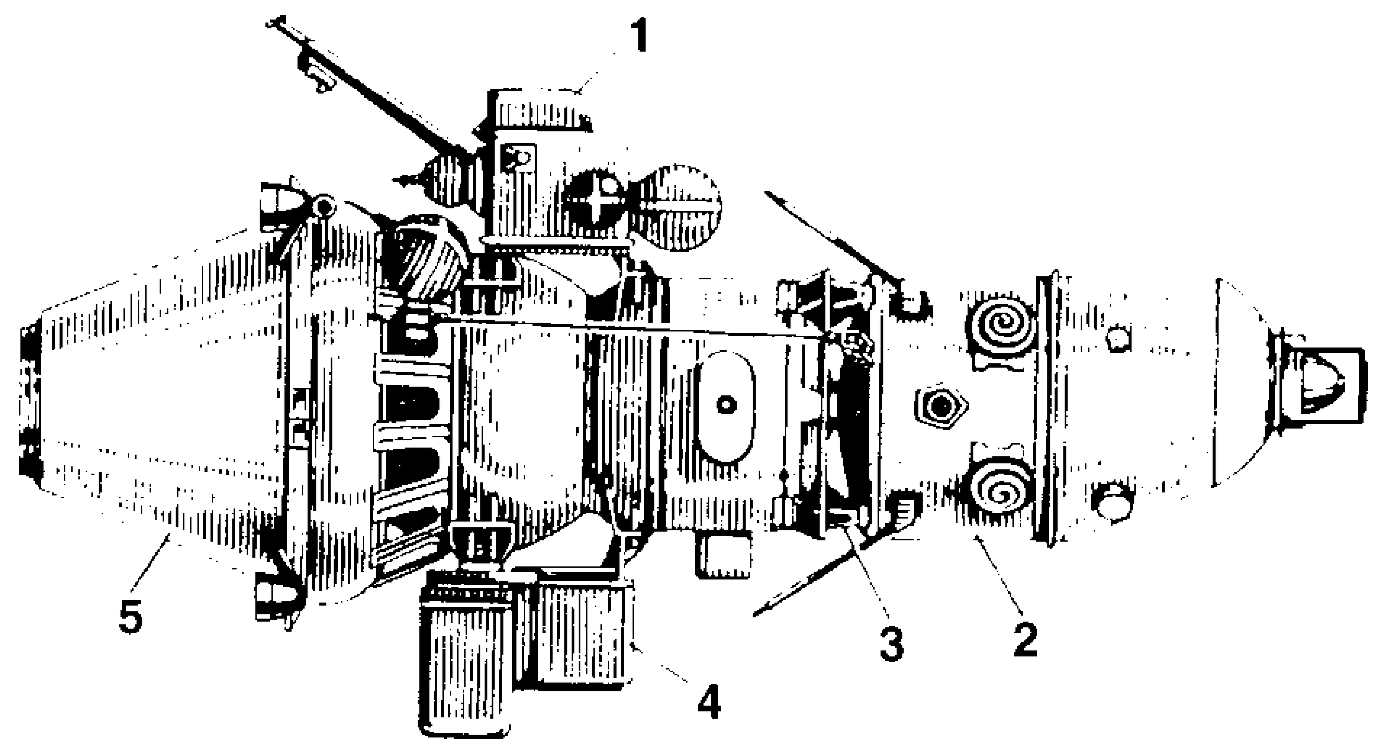

Fig. 14 Drawing of Luna-10. 1. radio equipment and scientific instruments, 2. artificial lunar satellite, 3. satellite separation equipment, 4. astro-navigation system, 5. correction/braking engine. (source: Mir Publishers)

6.2 The Ye-6LF Orbiter

Even after the two launches of the "interim" Ye-6S lunar orbiter (as Kosmos-111 and Luna-10), there appear to have been plans to launch the older but more complex Ye-7 lunar orbiters. Presumably, there were more delays. Perhaps prompted by the impending missions of NASA's Lunar Orbiter (the first of which was scheduled for July-August 1966), Academician Keldysh and Babakin took action to make sure that the first pictures of the lunar surface from lunar orbit were of the Soviet variety. The two men together authored a letter to the government asking permission to build two examples of a manoeuvreable lunar orbiter for a lunar imaging mission to identify possible future landing sites. The first of these would be launched in August 1966; the launch date of the second would be determined based on the results of the first mission [89]. A secondary objective was to obtain preliminary data on mass concentrations on the Moon which might affect lunar orbital trajectories. This particular model was code-named the Ye-6LF. It is possible (although unconfirmed) that these two orbiters were originally the Ye-7 model, but renamed sometime in the spring of 1966 to account for the closer design lineage with the original Ye-6.

Like the Ye-6S, the Ye-6LF also retained the basic Ye-6 lander bus. In this case, the lander was re-

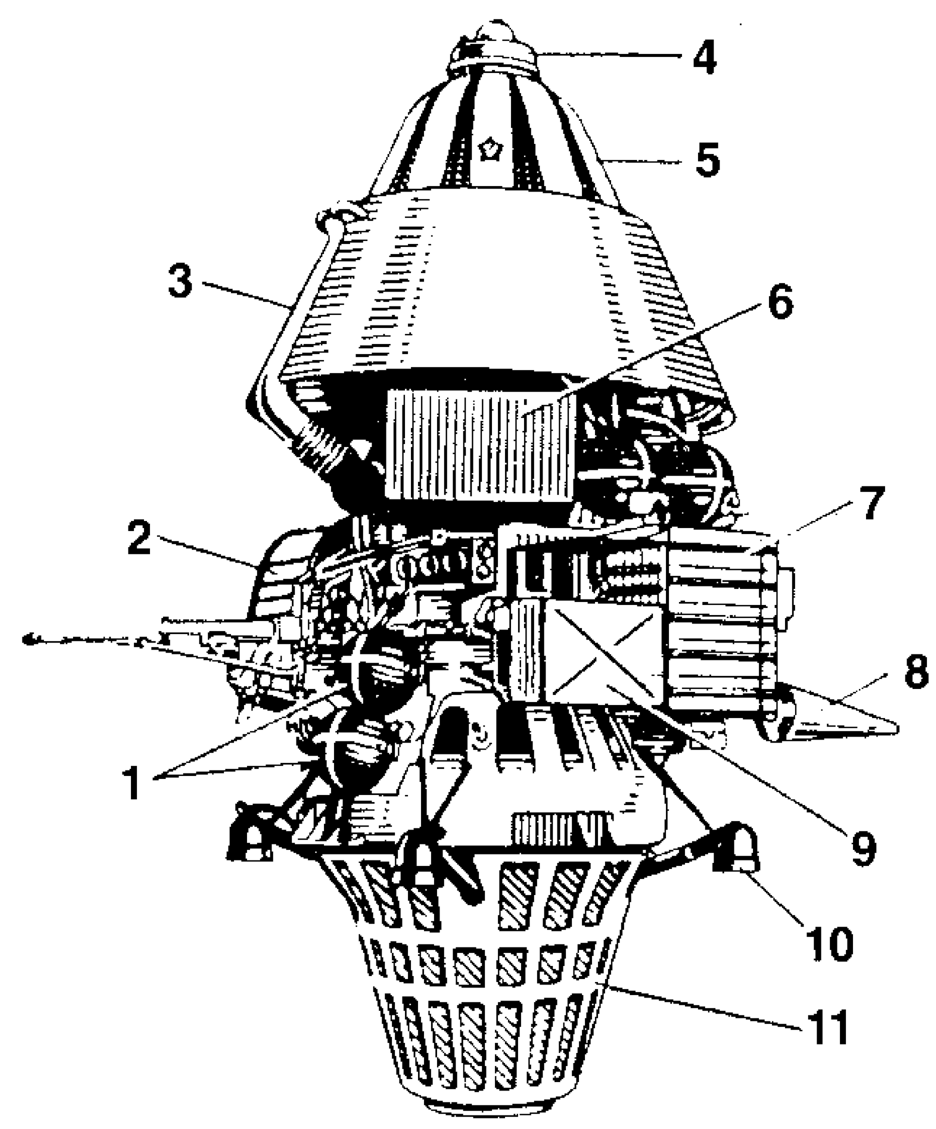

Fig. 15 Drawing of Luna-12. 1. gas bottles for astro-navigation system, 2. TV equipment, 3. temperature control system radiator, 4. radiometer, 5. instrument compartment, 6. chemical battery, 7. optical and mechanical unit of astro-navigation system, 8. antenna, 9. electronic unit of astro-navigation system, 10. vernier chamber, 11. correction/braking engine. (source: Nauka Publishers)

placed by a large cone-shaped instrument compartment which was not detachable. A temperature control system radiator covered the lower part of this cone. A box strapped near the base of the cone carried the battery for the scientific package. The actual camera system was attached on the side of the main bus, taking the position of the old detachable Compartment No. 2 which had housed the radio-altimeter for landing procedures. Interestingly enough, the photo-television system used on the Ye-6LF was similar to the one used on Zond-3 (3MV-4A) launched in July 1965 for a flyby of the Moon. A conventional camera took photographs which were developed, fixed, and dried automatically and then scanned by a TV camera at 67 lines/frame for transmission to Earth (taking 135 seconds to transmit one frame). These "quick-look" images were then followed by full 34 minute long scanning of each picture at 1,100 lines/frame. These photographs covered a lunar surface area of 25 km^2 from an altitude of 100-340 km. According to official Soviet sources, the best resolution was about 15-20 m. Scientific instruments on the spacecraft included a gamma-ray detector, a magnetometer, radiation detectors (for the solar wind, cosmic rays, and X-rays), an infra-red radiometer, and micrometeoroid detectors, i.e. an almost identical package to the one carried on the Ye-6S orbiters [90]. An extra experiment was the R-1 "reduction gear" instrument to verify the possibility of gear transmission in the vacuum of space in preparation for the future Lunokhod (Ye-8) lunar rovers [91]. Two Ye-6LF orbiters were launched, Luna-11 and Luna-12. Their total masses were given as 1,640 and 1,620 kg respectively [92].

6.3 The Ye-6LS Orbiter

The Ye-6LS was a special sub-group of the Ye-6 class of probes whose mission goals were oriented primarily towards future piloted missions in the N-1/L-3 lunar landing programme, i.e. to test deep space communications systems and obtain better data on lunar gravitational anomalies. The design characteristics of the Ye-6LS orbiter still remain shrouded in mystery and no pictures of the model have ever been published. The spacecraft bus was evidently very similar to the Ye-6LF model judging by the same sequence of serial numbers for both vehicles; in place of the TV equipment, however, the Ye-6LS carried communications, tracking, and control gear from the Lunar Orbital Ship (LOK) of the L-3 lunar complex. These were used not only to check the spacecraft's systems, but also to calibrate ground-based systems, especially the TNA-200 antenna system at Simferepol. The only confirmed scientific equipment on board was for measuring charged solar particles and cosmic rays. According to one source, Luna-14, one of the flown Ye-6LS vehicles, carried experimental gear drives made of different materials and using different lubricants to see how they were affected by the vacuum of space. Similar devices were to be used later for the wheels of Lunokhod and drills of the sample return probes [93]. The evidence of the three attempted launches in the Ye-6LS series suggests that missions for this model were planned in both high elliptical Earth orbit and lunar orbit versions. Mass has never been officially announced, but was probably roughly 1,600 kg. Three Ye-6LS orbiters were launched, Kosmos-159, a launch failure in February 1968, and Luna-14 [94].

6.4 Ye-6S Missions [95]

The first lunar orbiter (Ye-6S No. 204) left the launch pad on 1 March 1966, but the Blok L upper stage of the 8K78M rocket lost roll control during its coast in low Earth orbit and failed to fire [96]. It marked the first Blok L failure in a year. The stranded lunar orbiter was designated Kosmos-111 and burnt up in the atmosphere on 3 March.

With the 23rd Congress of the Soviet Communist Party set to open in Moscow on 29 March, pressure was high to mount several space spectaculars. Plans to launch the two-man Voskhod-3 mission during the Congress had been scrapped due to problems with the spacecraft's life support systems. This left a Molniya communications satellite launch and another attempt to place a Ye-6S into lunar orbit. The Molniya launch on 27 March suffered a third stage failure, but despite the fact that Luna used a virtually identical booster, it was decided to press ahead with the launch of Ye-6S No. 206 on 31 March.

After a smooth launch, the probe entered a 200 x 250 km parking orbit with an inclination of 51.9° and was fired to the Moon by the Blok L shortly afterwards. TASS announced the launch as Luna-10 and in a remarkable bout of candour revealed that it would "test a system ensuring the setting up of an artificial Moon satellite with the object of exploring circumlunar space". A KTDU burn on 1 April set the probe on course for lunar orbit insertion on 3 April. With about 8,000 km to go to the Moon, Luna-10 was placed in the proper attitude for the burn, which took place at 18.44 UT. It slowed the craft by 850 m/s (from 2.1 to 1.25 km/s), enough for it to be captured into an initial 350 x 1000 km orbit inclined 71.9° to the lunar equator. Twenty seconds later the 245 kg instrument section was separated from the main spacecraft bus. It was another lunar triumph for the Soviet Union, which had now become the first nation to place a spacecraft into orbit around another celestial body.

Underscoring the propaganda nature of its mission, Luna-10 radioed the first notes of the *Internationale* to the Communist Party Congress in Moscow the following morning. Said to be a live broadcast from lunar orbit, it prompted a standing ovation from the 5,000 or so delegates in attendance. The tune was transmitted by a set of solid state oscillators which had been programmed to reproduce the notes in the right order and with the correct length. In a test the previous night all the notes had come through perfectly, but in a final dress rehearsal on the morning of the broadcast it turned out one of the oscillators had failed and one of the notes was missing. Wary of treating the Congress delegates to a less than perfect rendition, the flight controllers decided to play the version recorded the night before, a fact they kept secret until many years later. As one of them put it, "playing jokes on the Central Committee was very dangerous." The choice of the tune had been a matter of serious debate before the mission. The first idea had been to relay a passage from the Soviet national anthem, but this was rejected because it might be interpreted as a sign that the Soviet Union considered lunar space its own exclusive territory. A Russian song titled *Wide Is My Native Country* was turned down on similar grounds. In the end it was felt that the *Internationale* was the most "neutral" choice [97].

Having fulfilled its ceremonial duty, Luna-10 got down to a series of scientific experiments. Its magnetometer detected a very weak magnetic field with an intensity only 0.05 to 0.1 per cent that of the Earth's. Since the intensity of the field did not change with distance, researchers concluded Luna actually recorded the interplanetary field as it became deformed in the vicinity of the Moon. The magnetometer also found that the Moon has no magnetic poles and detected the Earth's magnetic tail. The ion detectors failed to record radiation belts, showing that the weak magnetic field trapped only about 0.1 per cent of the energetic particles trapped near Earth. The gamma-ray spectrometer showed that the lunar rocks were comparable to basalt rocks on Earth and that there was no major difference between radiation from the mare lowlands and the mountainous highlands. Cosmic radiation was higher than expected (5 particles per cm^2 per second), but this was probably due to the fact that the low solar activity at the time allowed more galactic cosmic rays to penetrate the Solar System. Luna's piezoelectric meteroid detector registered 198 impacts between April 3 and May 12. Although this was 100 times the rate in interplanetary space, this was not considered to be a hazard for piloted spacecraft. Most of the material was believed to have been

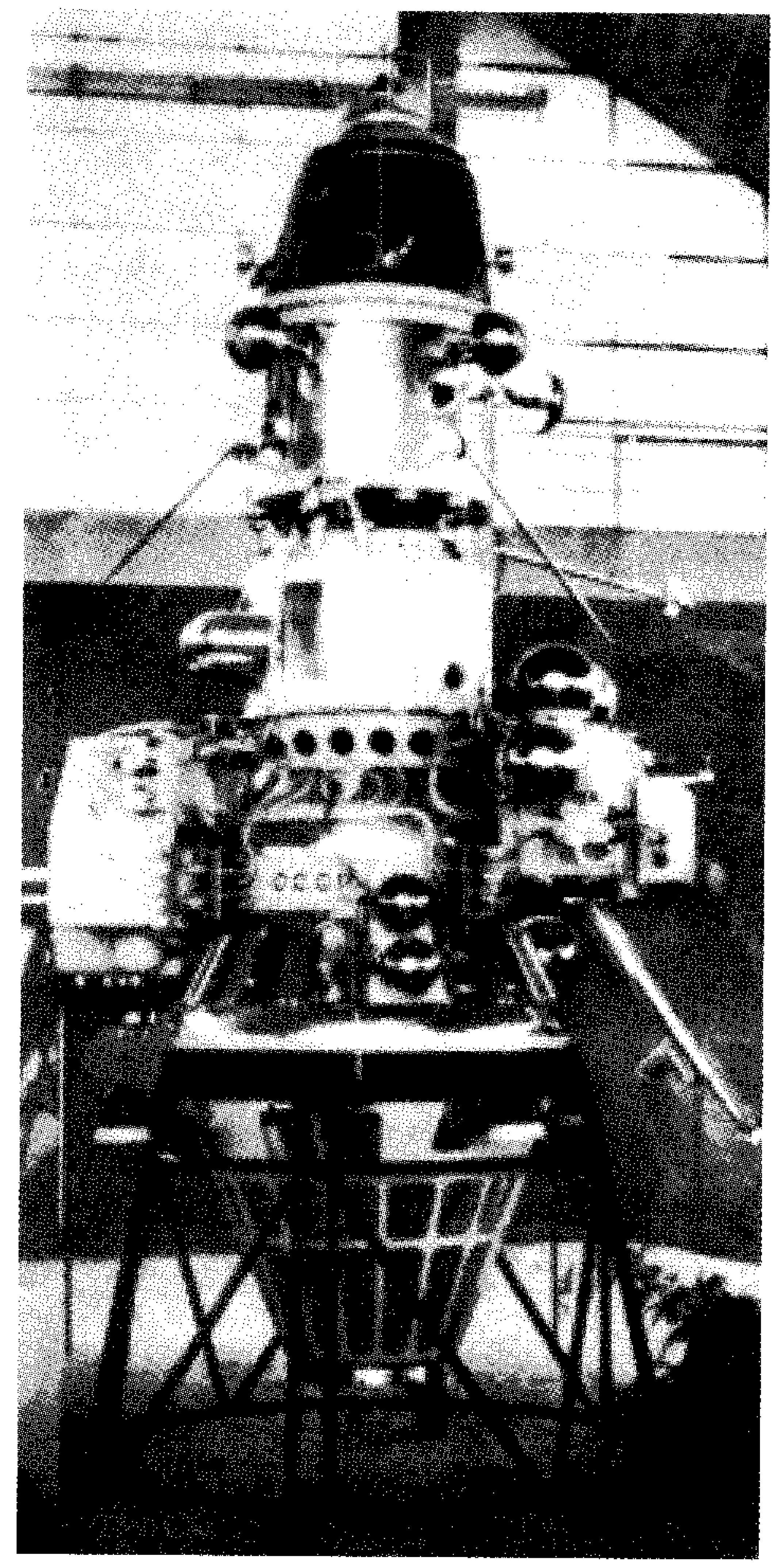

Fig. 16 Luna-10 model. (source: Novosti news agency)

injected into lunar orbit by meteorite impacts on the Moon.

Radio signals sent to Earth by Luna-10 showed no change in strength as the spacecraft passed behind the Moon's limb, indicating the Moon did not have an atmosphere of any significance. Accurate tracking of the spacecraft was carried out in the decimetre waveband using the NIP-16 ground station in Yevpatoriya, which is why many of the ground team members moved there from the nearby NIP-10 station in Simferopol after Luna-10 had reached lunar orbit [98]. The findings refuted earlier theories that the Moon was a sphere with a slight bulge toward the Earth and showed that it was pear-shaped with an elongation facing away from the Earth. Luna-10 provided the first evidence of the so-called *mascons* ("mass concentrations"), zones of anomalous high density under the circular mare basins which distorted lunar orbits and were a major factor in planning lunar orbit operations for future piloted missions [99]. Their discovery has usually been credited to the US Lunar Orbiters.

Luna-10's batteries ran out on 30 May 1966 after the probe had completed 460 orbits around the Moon. It had conducted 219 radio communications sessions with the Earth. After 56 days its orbit had changed to 378 x 985 km. The stage was now set for a pair of more sophisticated imaging orbiters.

6.5 Ye-6LF Missions [100]

The first of the imaging probes (Ye-6LF No. 101) was launched as Luna-11 on 24 August 1966, just two weeks after NASA had launched its first Lunar Orbiter. TASS did not mention the photographic objective, saying merely that it would test spacecraft systems in orbit and make scientific investigations of near-lunar space. A KTDU burn on 27 August at 21.49 UT placed Luna-11 into a 160 x 1193 km orbit with an inclination of 27°. As planned, the instrument section remained attached to the spacecraft bus.

The Soviet Union revealed very little information about Luna-11, fuelling speculation in the West that it had suffered some kind of failure. Jodrell Bank lost contact with Luna-11 four minutes after the retroburn, but picked up signals when the craft came back within its visibility zone the following night, confirming it was in lunar orbit. The British radio observatory received signals similar to Luna-9's television transmissions, but they were scrambled and could not be decoded. Since the Russians released no images, it was believed that its photographic mission had failed or that it had simply been a repeat of Luna-10. TASS only reported that the probe had completed its mission on 1 October after 277 revolutions and 137 communications sessions, the last of which had taken place at 2.03 UT. According to the news agency further radio communication had been stopped because the probe's on-board power sources had completely used up their resources.

It was not until more than thirty years later that the Russians partially lifted the veil of secrecy surrounding this mission [101]. It had indeed carried a television camera and was supposed to send back images in two modes: a "stabilised" mode as the probe reached its closest point to the Moon after the retroburn and also a mode where it rolled around an axis pointing at the Sun. Things had gone wrong during or shortly after the orbit insertion burn, when the probe lost its proper orientation, apparently due to an object that had become dislodged and entered the nozzle of one of the stabilizing thrusters. This would explain Jodrell Bank's loss of contact with Luna-11 only minutes after the retroburn. The probe did send back images, but all they showed were black space. If Jodrell Bank had managed to decode them, there would have been nothing to see. Luna-11 may have been stabilised later on, but information later released about Luna-12 indicates that for some reason all the images were to be made within 24 hours after lunar orbit insertion (possibly because of the camera's high power requirements). The lack of data released would suggest that the non-photographic part of the mission was not very successful either.

On 22 October, three weeks after Luna-11 had gone dead, an identical spacecraft (Ye-6LF No. 102) was launched from Baykonur and announced to the world as Luna-12. Despite the failure of Luna-11's photographic mission, TASS frankly stated that the objectives were "lunar photography and scientific observations from lunar orbit". After the traditional course correction the day after launch, Luna-12 arrived in the vicinity of the Moon on 25 October, placing itself into a 133 x 1200 km orbit with an inclination of 10°. The equatorial orbit suggests that the mission was primarily designed to look for landing sites for the L-3 programme, which (just as those for Apollo) would have been confined to the Moon's equatorial region (because of propellant restrictions). It was not until 29 October that Soviet television showed a few images of the Sea of Rains and the crater Aristarchus. Taken from between 100 and 340 km, they showed features measuring as small as 15 m, but were not as sharp as those returned by the U.S. Lunar Orbiters. No others have ever been released, possibly because of their relatively poor quality or because the Soviets did not want to reveal potential landing sites for their piloted lunar missions.

It was later revealed that special measures were taken to ensure that Jodrell Bank would not be able to repeat its Luna-9 scoop during the Luna-12 mission. One option considered was to gradually send back the pictures during the brief windows that Luna-12 was only within range of the Crimea, which could pick up the spacecraft three hours before it entered Jodrell Bank's radio visibility zone. However, in that mode "it would have taken months" for the pictures to trickle down to Earth. Another solution was found, enabling the Russians to send back the pictures in 24 hours, while still leaving Jodrell Bank empty-handed. As one of the Lavochkin Design Bureau veterans explained:

> "We were able to send back information in two bands, the metre and decimetre bands, and to quickly switch from one band to the other, while Jodrell Bank needed about a day to reconfigure its equipment [for this] ... That is the way we worked: we made full use of the [three hour Soviet window] and then, as the probe came within range of Jodrell Bank, began alternating between the two modes in varying sequences, playing cat and mouse with Jodrell Bank. We successfully completed our nearly round-the-clock work to send back the images and breathed a sigh of relief. It was as if a great weight had been lifted from our shoulders" [102].

Similar measures are likely to have been taken for Luna-11, which would explain the "scrambled transmissions" received by Jodrell Bank during that mission.

With its photographic mission complete, Luna-12 was spin-stabilised with a slow roll every 255 seconds in order to begin its particle and fields mission. Radio signals picked up from the probe were carefully analyzed to find out more about the mascons detected by Luna-10. Instruments carried by Luna-12 reportedly inaugurated X-ray astronomy by detecting X-ray emissions from the Moon's surface as a secondary effect of fluorescence under the influence of the Sun's X-rays (although similar research is known to have been carried out by Luna-10) [103]. According to TASS the research programme was completed on 19 January 1967 after 302 communications sessions and 602 orbits of the Moon and radio communication with the station had been discontinued.

One source claims the passive mission lasted one full year [104]. It says that in accordance with predictions the perilune had sunk to 20 km after half a year, but that from then on the orbit began decaying much more rapidly than expected, which could only be explained by inaccuracies in the available mascon data. There was enough propellant to raise the orbit, but since one of the attitude control thrusters had failed it was impossible to keep the probe properly stabilised if the KTDU main engine were to perform one long burn. It was therefore decided to perform seven short burns of the engine on seven consecutive apolune passes, which would have the same cumulative effect as one long manoeuvre. The plan was put into effect with very little time to spare before Luna-12's predicted impact and reportedly raised its perilune to 70 km, thereby significantly increasing its lifetime.

6.6 YE-6LS Missions

The first stage of the programme got underway with the launch of Ye-6LS No.111 on 16 May 1967. The 8K78M launch vehicle delivered the spacecraft and its Blok L upper stage to a parking orbit of roughly 200 x 420 km with an inclination of 51.77°. Subsequently the Blok L was fired to boost the vehicle to a 260 x 60,710 km orbit with an inclination of 51.70°. TASS labelled the spacecraft Kosmos-159, but revealed nothing about its actual mission. The Soviets never launched another satellite into a similar orbit and the purpose of the flight remained a mystery to Western observers, who in the absence of any other evidence usually classified it as a propulsion test related to the piloted lunar programme.

While Kosmos-159 has now been positively identified as the first vehicle in the Ye-6LS series, even Russian sources differ on the outcome of the mission. One source claims it was a lunar orbiter that got stranded in Earth orbit [105], while another contends it reached the desired orbit [106]. The first idea can be disregarded just by looking at the Greenwich Hour Angle at the moment of launch. The GHA for Soviet launches to the Moon in those days was around 240°, whereas for Kosmos-159 it was 57.6°. In other words, it was launched *away* from the Moon [107]. Moreover, it has been confirmed that a "high-apogee satellite" was developed in 1967 to perfect trajectory measurement techniques that would be needed on later lunar orbit missions to more accurately detect orbital perturbations caused by the Moon's gravitational field [108]. However, the same source also states that the apogee needed to be more than 250,000 km for the tests to be of any significant value. The apogee of Kosmos-159 fell far short of that requirement.

An educated guess therefore would be that Kosmos-159 was to be used to calibrate trajectory measurement equipment and also LOK communications systems in an orbit facing away from the Moon but reaching out to more than half the lunar distance. This would be a precursor to tests of the same systems in lunar orbit on later Ye-6LS missions. A similar approach was followed in the piloted circumlunar programme, where Zond-4 was launched away from the Moon to a distance of over 300,000 km to test communications systems and a high-speed re-entry without being affected by the Moon's sphere of influence. On the Kosmos-159 mission the Blok L upper stage apparently suffered an early engine cut-off, restricting the spacecraft's apogee to roughly 60,000 km. Even though this may not have been the desired distance, it is not at all unlikely that communications and other tests were performed and provided valuable data. Kosmos-159 remained in orbit until 11 November 1977.

The second launch in this programme (Ye-6LS No.112) took place on 7 February 1968, but failed to reach orbit. The third stage engine cut off prematurely due to an excessive fuel consumption rate through the gas generator. It was the first use of the Kosberg bureau's 11D55 engine on the third stage of an 8K78M booster (it had earlier been introduced on the three-stage Soyuz rocket) [109]. The lunar Greenwhich Hour Angle at the time of launch shows that the spacecraft was headed for lunar orbit rather than a high-apogee orbit [110].

The series was concluded by Ye-6LS No.113, launched as Luna-14 on 7 April 1968. A course correction was carried out on 8 April at 19.37 UT. On 10 April at 19.25 UT the probe fired its retrorocket engine, which reduced its speed from 2.190km/s to 1.279 km/s, as a result of which it settled into a lunar orbit of 160 x 870 km inclined 42° to the equator. TASS reported that it was to study the relationships between the masses of the Earth and the Moon and the Moon's gravitational field and also the propagation and stability of radio signals transmitted to and from the spacecraft. Luna-14 was also said to be carrying scientific equipment for studying solar radiation. Very little information was provided about the progress of the flight and no end-of-mission date was announced. Most Western observers placed Luna-14 in the same category as Luna-12 and speculated that its camera had failed. This is now known not to be true. It apparently tested LOK communications systems in lunar orbit and allowed the use of perfected trajectory measurement techniques (possibly tested to some extent by Kosmos-159) to more precisely map orbital perturbations than had been possible in the Ye-6LF programme. These data were of vital importance to plan orbital and landing operations in both the Ye-8 and L-3 programmes.

7. Conclusion

The "second generation" Luna programme was one of the most important robotic exploration efforts by either the United States and the Soviet Union during the so-called "space race". The project achieved two of the most enduring "firsts" in the history of the space era:

(1) The first survivable landing of a manmade object on the surface of another celestial body (Luna-9); and

(2) The first orbiting of a manmade object around another celestial body (Luna-10).

Luna-9 also returned the first pictures taken from the surface of another celestial body. The importance of that mission seems somewhat perfunctory now, especially after six spectacular Apollo lunar landings in 1969-72 when 12 astronauts walked on the Moon, but from the vantage point of early 1966, one can imagine the kind of public response to the unqualified success of Luna-9. As it happened, these Luna missions also proved to be the swansong for the rising Soviet space programme, the last two major firsts before a spate of almost bizarre failures that plagued the Soviets for many many years.

The story of the second generation Lunas was, of course, not a complete success. The first landing was achieved at the cost of 11 consecutive failures. Originally planned for 1960-61, Korolev had to continually push back deadlines for the project, first because of inadequate support from the Soviet government, and then due to in-flight failures. The latter are particularly noteworthy because it illuminates one of the fundamental ideologies of the Soviet space program of the 1960s: the rush to go directly to flight-testing before adequate ground-testing, a factor which crippled the N-1/L-3 lunar landing programme. In the case of the second generation Luna programme, three impediments clearly prevented early accomplishment of the landing:

(1) Inadequate (separate and integrated) ground-testing of various Ye-6 systems which led to successive in-flight failures;

(2) Production of low quality components which repeatedly failed during flight-testing;

(3) Operator error during several missions.

One could argue that the first two and possibly all three reasons were directly due to the intense pressure felt by Korolev and his associates during the period 1960-66 to accomplish the first lunar soft-landing. Indeed, like much about the space race of the 1960s, to achieve something second was the same as not achieving the goal at all. It was the "firsts" that truly mattered. It was in search of this goal that engineers relentlessly pushed themselves in the Luna programme, facing failure after failure in their rush to reach that objective. To their credit, they finally achieved it. Luna-9 safely landed on the surface of the Moon four months before the landing of NASA's Surveyor 1 and claimed yet another impressive first for the Soviet space programme.

8. Acknowledgments

The authors would like to thank Oleg Ivanovskiy, the curator of the NPO Lavochkin museum and Sven Grahn for their assistance in preparing this article.

TABLE 1: *Overview of second-generation Luna missions.*

Name	Launch Date	Launch Time (UT)	Spacecraft	S/C No.	Launcher + Serial No.	Comments
none	Jan 4 1963	0849	Ye-6	2	8K78/Ye-6 T103-09	Blok L inverter failure, TLI failure
none	Feb 3 1963	0929:14	Ye-6	3	8K78/Ye-6 G103-10	Blok L guidance failure, no Earth orbit
Luna-4	Apr 2 1963	0816:37	Ye-6	4	8K78/Ye-6 G103-11	Yupiter astronavigation system failure
none	Mar 21 1964	0815:35	Ye-6	6	8K78M/Ye-6 T15000-20	3rd stage valve failure, no Earth orbit
none	Apr 20 1964	0808:28	Ye-6	5	8K78M/Ye-6 T15000-21	Blok I & Blok L failure, no Earth orbit
Kosmos-60	Mar 12 1965	0930	Ye-6	9	8K78/Ye-6 R103-25	Blok L guidance failure, TLI failure
none	Apr 10 1965	?	Ye-6	8	8K78 R103-26	Blok I failure, no Earth orbit
Luna-5	May 9 1965	0749 :37	Ye-6	10	8K78M U103-30	Spacecraft guidance failure, landing failed
Luna-6	Jun 8 1965	0740	Ye-6	7	8K78M U103-31	Incorrect command to engine, landing failed
Luna-7	Oct 4 1965	0756 :40	Ye-6	11	8K78 U103-27	Loss of s/c orientation, landing failure
Luna-8	Dec 3 1965	1046:14	Ye-6	12	8K78 U103-28	Soft-landing failure
Luna-9	Jan 31 1966	1141:37	Ye-6M	202/13	8K78M U103-32	1st successful landing
Kosmos-111	Mar 1 1966	1103 :49	Ye-6S	204	8K78M N103-41	TLI failure, no lunar orbit
Luna-10	Mar 31 1966	1047	Ye-6S	206	8K78M N103-42	1st successful lunar orbit
Luna-11	Aug 24 1966	0803	Ye-6LF	101	8K78M N103-43	Successful lunar orbit
Luna-12	Oct 22 1966	0842	Ye-6LF	102	8K78M N103-44	Successful lunar orbit
Luna-13	Dec 21 1966	1017	Ye-6M	205/14	8K78M N103-45	Successful lunar soft-landing
Kosmos-159	May 16 1967	2143:57	Ye-6LS	111	8K78M Ya716-56	Probably reached lower than planned orbit
none	Feb 7 1968	1043:54	Ye-6LS	112	8K78M Ya716-57	No Earth orbit, launcher failure
Luna-14	Apr 7 1968	1009:32	Ye-6LS	113	8K78M Ya716-58	successful lunar orbit

Sources

1. B. Ye. Chertok, *Rakety i lyudi: goryachiye dni kholodnoy voyny*, (Moscow: Mashinostroyeniye, 1997).
2. K. Lantratov, "Jubilees: 25 Years for Lunokhod-1" (in Russian), *Novosti kosmonavtiki 23*, (November 5-18, 1995): 79-83.
3. K. Lantratov, "Jubilees: 25 Years for Lunokhod-1" (in Russian), *Novosti kosmonavtiki 24*, (November 19-December 2, 1995): 70-79.
4. Jonathan McDowell, April 26, 1994 and July 31, 1994, personal correspondence to the author.
5. Timothy Varfolomeyev, "Soviet Rocketry that Conquered Space: Part 1: From the First ICBM to Sputnik Launcher", *Spaceflight*, 37, (August 1995): 260-263.
6. Timothy Varfolomeyev, "Soviet Rocketry that Conquered Space: Part 2: Space Rockets for Lunar Probes", *Spaceflight*, **38**, (February 1996): 49-52.
7. Timothy Varfolomeyev, "Soviet Rocketry that Conquered Space: Part 5: The First Planetary Probe Attempts", *Spaceflight*, **40**, (March 1998): 85-88.

References

1. For a historical account of the first generation probes, see A. A. Siddiqi, "First to the Moon", *JBIS*, **51**, pp. 231-238 (1998). For further comments on the article, see T. Varfolomeyev, "Correspondence", *JBIS*, **52**, pp. 157-160 (1999).
2. The paper at Bauman has been reproduced in full as S. P. Korolev, "On the Question of the Application of Rockets for Research of the Upper Layers of the Atmosphere" (in Russian), in *S. P. Korolev i ego delo: svet i teni v istorii kosmonavtiki: izbrannyye trudy i dokumenty*, eds. B. V. Raushenbakh and G. S. Vetrov, Nauka, Moscow, 1998, pp. 190-200.

3. This document has been reproduced in full as M. V. Keldysh and S. P. Korolev, "On Launches of Rockets to the Moon" (in Russian), in *M. V. Keldysh: izbrannyye trudy: raketnaya tekhnika i kosmonavtika*, eds. V. S. Avduyevskiy and T. M. Yeneyev, Nauka, Moscow, 1988, pp. 241-243.
4. The sixth letter of the Russian Cyrillic alphabet looks like the English "E" but is formally transliterated as "Ye" rather than "E" since the former is closer to its pronunciation. It is the 31st letter of the Russian alphabet, which looks like a reverse latin "E", that is transliterated as "E".
5. This document has been reproduced in full as S. P. Korolev and M. K. Tikhonravov, "On Prospective Work on the Exploration of Cosmic Space" (in Russian), in *Tvorcheskoye naslediye Akademika Sergeya Pavlovicha Koroleva: izbrannyye trudy i dokumenty*, ed., M. V. Keldysh, Nauka, Moscow, 1980, pp. 405-408.
6. A. Wilson, *The Eagle Has Wings: The Story of American Space Exploration, **1945-1975***, British Interplanetary Society, London, 1982, pp. 26-27.
7. Korolev and Keldysh sent this document, dated 16 February 1959, to K. N. Rudnev (Chairman of the State Committee for Defence Technology) and G. N. Pashkov (a Deputy Chairman of the Military-Industrial Commission) for consideration as a draft for a decree of the Central Committee and Council of Ministers. The primary thematic focus of the document was on the Object OD programme for photographic reconnaissance. The document is reproduced in full as S. P. Korolev and M. V. Keldysh, "Explanatory Notes for the Plan of Scientific-Research and Experimental-Design Work for the Exploration of Cosmic Space in 1959-1960" (in Russian), in Raushenbakh and Vetrov, *S. P. Korolev i ego delo*, pp. 264-268.
8. One source suggests that the Ye-5 was to have been launched by the 8K73 but delays and then the ultimate cancellation of the 8K73 booster programme eventually prompted Korolev to cancel the Ye-5 orbiter project. See K. Lantratov, "Anniversaries: 25 Years from Lunokhod-1" (in Russian), *Novosti Kosmonavtiki*, 23, pp. 79-83 (November 5-18, 1995).
9. Ibid.
10. B. Ye. Chertok, *Rakety i lyudi: goryachiye dni kholodnoy voyny*, Mashinostroyeniye, Moscow, 1997, p. 276.
11. Yu. P. Semenov (ed), *Raketno-Kosmicheskaya Korporatsiya "Energiya" imeni S. P. Koroleva*, RKK Energiya named after S. P. Korolev, Korolev, 1996, p. 146.
12. Raushenbakh and Vetrov, ***S. P. Korolev i ego delo***, p. 611.
13. This letter is reproduced in full as S. P. Korolev, "On Acceleration of Work on Automatic Lunar Stations" (in Russian), in Keldysh, *Tvorcheskoye naslediye Akademika Sergeya Pavlovicha Koroleva*, pp. 414-415. Note that another source states that the letter was sent on 26 March 1961. See Semenov, *Raketno-Kosmicheskaya Korporatsiya...*, p. 146. This is an error.
14. This document has been reproduced in full as S. P. Korolev, "Draft Letter to CC CPSU" (in Russian), in Raushenbakh and Vetrov, *S. P. Korolev i ego delo*, pp. 287-288.
15. This document has been reproduced in full as S. P. Korolev, "Draft Decree of the CC CPSU and the USSR Council of Ministers" (in Russian), in Raushenbakh and Vetrov, *S. P. Korolev i ego delo*, pp. 295-301.
16. Chertok, *Rakety i lyudi*, p. 276.
17. Raushenbakh and Vetrov, *S. P. Korolev i ego delo*, pp. 611, 683.
18. Linda Neuman Ezell, *NASA Historical Data Book: Volume II: Programs and Projects 1958-1968*,NASA SP-4012, Washington, D.C., 1988, p. 319; J. J. Wentworth, «A Survey of Surveyor: A Look Back at America's Robotic Lunar Landing Program", *Quest*, **2**, 4-16 (Winter 1993).
19. S. P. Korolev, "Proposals on Research and Exploration of the Moon in 1963-1968" (in Russian), in Raushenbakh and Vetrov, *S. P. Korolev i ego delo*, pp. 416-426.
20. T. Varfolomeyev, "Soviet Rocketry that Conquered Space: Part 4: The Development of a Four-Stage Launcher, 1958-1960," *Spaceflight*, **40**, 28-30, (January 1998); Raushenbakh and Vetrov, *S. P. Korolev i ego delo*, pp. 603-605; Semenov, *Raketno-Kosmicheskaya Korporatsiya...*, pp. 138-140.
21. Semenov, *Raketno-Kosmicheskaya Korporatsiya...*, pp. 138-140; Raushenbakh and Vetrov, *S. P. Korolev i ego delo*, pp. 603-605.
22. From table of launches in T. Varfolomeyev, "Soviet Rocketry that Conquered Space: Part 5: The First Planetary Probe Attempts, 1960-1964", *Spaceflight*. **40**, pp. 85-88, (March 1998). In the interim, in 1962, engineers had introduced some improvements to the 8K78. These comprised using a new third stage airframe and fairing, and uprating the first and second stage engines by increasing combustion chamber pressure.
23. T. Varfolomeyev, "Soviet Rocketry that Conquered Space: Part 6: The Improved Four-Stage Launch Vehicle, 1964-1972", *Spaceflight*, **40**, pp. 181-184, (May 1998).
24. Semenov, *Raketno-Kosmicheskaya Korporatsiya...*, p. 148.
25. V. V. Favorskiy and I. V. Meshcheryakov (eds), *Voyenno-kosmicheskiye sily (voyenno-istoricheskiy trud): kniga I: kosmonavtika i vooruzhennyye sily*, Izdatelstvo Sankt-Peterburgskoy tipografii no. 1 VO Nauka, Moscow, 1997, pp. 36-37.
26. Semenov, *Raketno-Kosmicheskaya Korporatsiya...*, p. 352.
27. Favorskiy and Meshcheryakov, *Voyenno-kosmicheskiye sily (voyenno-istoricheskiy trud)*, pp. 100-101; B. A. Pokrovskiy, *Kosmos nachinayetsya na zemlye*, Patriot, Moscow, 1996, p. 255 ; A.S. Vinitskiy (ed.), *Radiosistemy mezhplanetnykh kosmicheskikh apparatov*, Radio i svyaz, Moscow, 1993, pp. 33, 43.
28. Favorskiy and Meshcheryakov, *Voyenno-kosmicheskiye sily (voyenno-istoricheskiy trud)*, pp. 68-69, 175; Pokrovskiy. *Kosmos nachinayetsya na zemlye*, pp. 341-347 ; V.G. Bezborodov, A.M. Zhakov, *Suda kosmicheskoy sluzhby*, Sudostroyeniye, Leningrad, 1980, pp. 225-226.
29. These enumerated goals are listed in the prospectus of the Ye-6 lander (dating from 1964), which has been published in full (albeit with disguised designations) as S. P. Korolev, "Automatic Stations for the First Landing on the Moon" (in Russian) in Keldysh, *Tvorcheskoye naslediye Akademika Sergeya Pavlovicha Koroleva*, pp. 515-519.
30. Pilyugin's Complex Nr. 1 separated from NII-885 in April 1963 to become the independent Scientific-Research Institute of Automation and Instrument Building (NII AP).
31. The NII-1 Branch appears to have later separated to become Department Nr. 1 of NII-993. See Chertok, *Rakety i lyudi*, p. 278. Later Chertok refers to it as a branch of NII-923. See Chertok, *Rakety i lyudi*, p. 320. This branch was probably related to OKB-169 which developed the astro-navigation system for the La-350 Burya intercontinental cruise missile. See A. V. Karpenko, A. F. Utkin, and A. D. Popov, *Otechestvennyye strategicheskiye raketnye kompleksy (spravochnik)*, Nevskiy bastion, St. Petersburg, 1999, p. 109.
32. The 82 kg mass is mentioned by Korolev in a September 1963 document called "Proposals for Research and Exploration of the Moon", published in: Raushenbakh and Vetrov, *S.P. Korolev i ego delo*, p. 418. About a year later Korolev mentioned a mass of 105 kg, see Korolev, "Automatic Station for the First Landing on the Moon"

in: Keldysh, *Tvorcheskoye naslediye S.P. Koroleva*, p. 519.

33. The description of the Ye-6 probe has been summarised from the following sources: Korolev, "Automatic Station for the First Landing on the Moon"; Semenov, *Raketno-Kosmicheskaya Korporatsiya...*, pp. 146-147; V. P. Glushko, *Razvitiye raketostroyeniya i kosmonavtiki v SSSR: izdaniye vtoroye, dopolnennoye*, Mashinostroyeniye, Moscow, 1981, p. 67; V. P. Glushko (ed), *Kosmonavtika entsiklopediya*, Sovetskaya entsiklopediya, Moscow, 1985, p. 209; N. L. Johnson, *Handbook of Soviet Lunar and Planetary Exploration,* **47**, Univelt, San Diego, CA, 1979, pp. 25-29; A. Wilson, *Solar System Log*, Jane's Publishing Company Limited, London, 1987, pp. 33-35; N. Beresnev, "Thirtieth Anniversary of Soft Lunar Landing", *Aerospace Journal*, 70-71 (December 1995); Notes by T. Varfolomeyev at VNIIT Museum, St. Petersburg, July 1998.
34. Raushenbakh and Vetrov, *S. P. Korolev i ego delo*, p. 613; Chertok, *Rakety i lyudi*, p. 305. One source notes that G. N. Babakin familiarised himself with Korolev's lunar landers for the first time on 3 March 1965, the day after Babakin was appointed Chief Designer of GSMZ Lavochkin. See A. N. Banketov and V. S. Panshin, "The Success of the OKB of G. N. Babakin in Launches of Automatic Lunar and Interplanetary Stations (ALS and AMS)" (in Russian), *Trudy XXIV chteniy, posvyashchennykh razrabotke nauchnogo naslediya i razvitiyu idey K. E. Tsiolkovskogo (Kaluga, 17-20 Sentyabrya, 1991 g.): sektsiya "Issledovaniye nauchnogo tvorchestva K. E. Tsiolkovsogo i istorii aviatsii i kosmonavtiki"*, IIET RAN, Moscow, 1992, pp. 85-92. In a telephone interview with one of the authors, Lavochkin Chief Designer Oleg G. Ivanovskiy said that "design documentation" for the Ye-6 and MV probes was turned over to Lavochkin in late March 1965.
35. G. P. Svishchev (ed), *Aviatsiya entsiklopediya*, Bolshaya Rossiyskaya Entsiklopediya, Moscow, 1994, p. 372; S. M. Ganin and V. I. Ivanovskiy, "The Multi-channel 'Dal' Anti-Aircraft Missile System of Great Range" (in Russian), *Nevskiy bastion*, **1**, 7-15 (1998).
36. Banketov and Panshin, "The Success of the OKB of G. N. Babakin in Launches of Automatic Lunar and Interplanetary Stations (ALS and AMS)."
37. "A Great Achievement of Mankind: The First Automatic Station on the Moon" (in Russian), *Pravda*, February 6, 1966; *Pervye panoramy lunnoy poverkhnosti, tom 1*, Nauka, Moscow, 1966, p. 38.
38. Confusingly, one source suggests that the primary change was that the inflation of the shock-absorbing airbags was performed during the firing of the main engine on the Ye-6; on the Ye-6M, this was reportedly changed so that the inflation could occur immediately *before* ignition. Engineers supposedly introduced the new change as a result of failures with the airbag deployment on the last two Ye-6 missions, Luna-7 (October 1965) and Luna-8 (December 1965). This information would now appear to be erroneous. See Lantratov, "Anniversaries: 25 Years from Lunokhod-1."
39. N. G. Babakin, A. N. Banketov and V. N. Smorkalov, *G. N. Babakin: zhizn i deyatelnost*, Adamant, Moscow, 1996, p. 38.
40. Johnson, *Handbook of Soviet Lunar and Planetary Exploration*, pp. 45-47; Wilson, *Solar System Log*, pp. 42-43; *Pervye panoramy lunnoy poverkhnosti, tom 2*, Nauka, Moscow, 1969, pp. 9-22; *VNIItransmash: stranitsy istorii*, St. Petersburg, 1999, p. 228; telephone conversation with Oleg Ivanovskiy, curator of the NPO Lavochkin museum, 22 October 1999.
41. This is from S. P. Korolev, "Proposals for Research and Exploration of the Moon" (in Russian), in Raushenbakh and Vetrov, *S. P. Korolev i ego delo*, p. 418. Actually, the spacecraft is referred to in this source as U6-A, but this is probably an error.
42. The nominal Ye-6 mission profile is from Korolev, "Automatic Stations for the First Landing on the Moon." See also *Pervye panoramy lunnoy poverkhnosti, tom 1,* Nauka, Moscow, 1966, pp. 24-42; Semenov, *Raketno-Kosmicheskaya Korporatsiya...*, pp. 146-147; Wilson, *Solar System Log*, pp. 33-35.
43. Chertok, *Rakety i lyudi*, pp. 276, 279-280.
44. This document is reproduced as M. V. Keldysh, "On a Plan of Scientific Research on Cosmic Space in 1963-1964" (in Russian), in Avduyevskiy and Yeneyev, *M. V. Keldysh: izbrannyye trudy: raketnaya tekhnika i kosmonavtika*, pp. 460-462.
45. Semenov, *Raketno-Kosmicheskaya Korporatsiya...*, pp. 147-148.
46. Chertok, *Rakety i lyudi*, p. 280.
47. This section is largely based on the Ye-6 chapter in Chertok, *Rakety i lyudi*, pp. 274-357. Additional information about launch failures comes from Varfolomeyev, "Soviet Rocketry that Conquered Space: Part 5: The First Planetary Probe Attempts, 1960-1964", and also from unpublished information obtained by T. Varfolomeyev. TASS quotes are largely from G.A. Skuridin (ed.), *Osvoyeniye kosmicheskogo prostranstva v SSSR, 1957-1967*, Nauka, Moscow, 1971 and translations of TASS reports provided by *Space Business News, Russian News Briefs* of Electro-Optical Systems Inc.
48. K. Teltsch, "6 Soviet Space Failures Believed to Have Been Probes of Planets", *The New York Times*, June 16, 1963, p. 2.
49. "4 Soviet Failures in Space Reported", *The New York Times*, June 26, 1963, p. 13.
50. "Old Devil Moon", *Newsweek*, April 8, 1963, p. 62.
51. S. Grahn, *Jodrell Bank's Role in Early Space Tracking Activities (part 2),* article on the website of Sven Grahn at http://www.users.wineasy.se/svengrahn/trackind/jodrell/jodrole2.htm
52. R. Reeves, *The Superpower Space Race: An Explosive Rivalry Through The Solar System*, Plenum Press, New York & London, 1994, p. 63.
53. J.W. Finney, "Space Aides Tell of Soviet Failure", *The New York Times*, April 30, 1964, p. 9.
54. Chertok, ***Rakety i lyudi,*** p. 184.
55. R. Cargill Hall, *Lunar Impact: A History of Project Ranger*, NASA SP-4210, Washington, D.C., 1977, pp. 264-280, 282-296.
56. N.P. Kamanin, *Skrytyy kosmos: kniga vtoraya (1964-1966gg)*, Infortekst, Moscow , 1997, pp. 144, 153.
57. M. Pastukhova, "Brighter Than Any Legend" (in Russian), *Ogonek*, **49**, 23 (December 1987).
58. Kamanin, *Skrytyy kosmos...*, pp. 162-163.
59. Ibid., p. 176.
60. "Luna V Dust Cloud Reported", *Space Business Daily*, **20**, Nr. 5, May 21, 1965 (the report originated from the East German news agency ADN and was published in *Pravda* and subsequently relayed by the Novosti Press Agency).
61. S. Grahn, *Jodrell Bank's Role in Early Space Tracking Activities (part 2)*; S. Grahn, *The US Deep Space Intelligence Collection Programe*, article on the website of Sven Grahn at http://www.users.wineasy.se/svengrahn/trackind/Deepspac/Deepspac.htm
62. K. Lantratov, "To Mars" (in Russian), *Novosti Kosmonavtiki*, **20**, 53-72 (23 September-6 October 1996).
63. Babakin, Banketov and Smorkalov, *G.N. Babakin*, p. 107.
64. K. Gatland, *Robot Explorers*, Blandford Press, London, 1972, p. 134.
65. It appears this is based on observations from Jodrell Bank, which detected a "change in signals" between 20.58-21.04 UT that was interpreted as a KTDU burn

(although the burn could not have lasted that long). Some Western sources mistakenly give the time as 21.58 UT, which would of course have better matched the 22.08 UT impact time.

66. See also Kamanin, *Skrytyy kosmos...*, p. 302.
67. Grahn website, *The US Deep Space Intelligence Collection Program.*
68. Chertok says that the VPK meeting took place after Luna-7 although two other sources claim it was after Luna-8. See Ya. Golovanov, *Korolev: fakty i mify*, Nauka, Moscow, 1994, p. 764 and Pokrovskiy, *Kosmos nachinayetsya na zemlye*, p. 258.
69. Golovanov, *Korolev: fakty i mify*, p. 764.
70. Babakin, Banketov and Smorkalov, *G.N. Babakin*, p. 107.
71. Chertok says that it was decided to perform a dress rehearsal of the pre-burn orientation sequence on 4 December and that the actual burn was performed on 5 December. The velocity change was slightly less than planned.
72. Babakin, Banketov and Smorkalov, *G.N. Babakin*, p. 37.
73. Golovanov, *Korolev: fakty i mify*, p. 763.
74. Flight descriptions have been largely compiled from the following Western sources: Gatland, *Robot Explorers*; Johnson, *Handbook of Soviet Lunar and Planetary Exploration*; Wilson, *Solar System Log*; Reeves, *The Superpower Space Race: An Explosive Rivalry Through The Solar System.* Also used were two digests of Soviet press and news agency reports on Luna-9: V. Novokhatko (ed.), *Luna otkryvayetsya lyudyam*, Izdatelstvo politicheskoy literatury, Moscow, 1966 and N. Shumilov (ed.), *Lunnaya panorama*, Izdatelstvo Izvestiya, Moscow, 1966. Additional information on the Luna-13 mission is from *Pervye panoramy lunnoy poverkhnosti, tom 2*, Nauka, Moscow, 1969.
75. These are the coordinates given by *Pravda* on February 6, 1966. Some other sources (including Soviet ones) give a longitude of 60°22'W.
76. Babakin, Banketov and Smorkalov, *G.N. Babakin*, pp. 39-40.
77. Ibid, p. 40.
78. V. Gubarev, "The Moon Is Hard!" (in Russian), *Pravda*, February 3, 1992.
79. Ibid.; Chertok, *Rakety i lyudi*, p. 275.
80. Glushko, *Kosmonavtika entsiklopediya*, p. 222.
81. Telephone conversation with Oleg Ivanovskiy, curator of the NPO Lavochkin museum, 22 October 1999.
82. Ezell, *NASA Historical Data Book*, pp. 319-321.
83. V. K. Kupriyanov and V. V. Chernyshev, *I vecherniy start...: rasskaz o glavnom konstruktorye raketnykh dvigateley Alekseye Mikhaylovichye Isayevye*, Moskovskiy rabochiy, Moscow, 1988, p. 220. At the same time, it is also possible that the Ye-7 bus was similar to the unified 2MV or 3MV spacecraft designed to photograph Mars and Venus. See S. P. Korolev, "Goals of the Unification of Automatic Space Apparatus" (in Russian), in Raushenbakh and Vetrov, *S. P. Korolev i ego delo*, pp. 323-325 where Korolev writes about a unified spacecraft named "Apparatus A" for photographing Mars, Venus, and the Earth. This document is dated 9 February 1961.
84. Babakin, Banketov and Smorkalov, *G. N. Babakin*, p. 42.
85. K. Kerimov, *Dorogi v kosmos (zapiski predsedatelya Gosudarstvennoy komissii)*, Azerbaydzhan, Baku, 1995, p. 268. Kerimov actually refers to the Ye-7 as "Luna-Zh" which was the "hidden" designation used for Ye-7 before the *glasnost* era. Kerimov's official position at the time was Chief of the 3rd Chief Directorate of the MOM.
86. This mass is from Glushko, *Kosmonavtika entsiklopediya*, p. 222. Note that a Western analysis found that the announced mass was inconsistent with the announced mission trajectories, i.e. the lunar orbital mass of the spacecraft for Ye-6S should have been 910 kg instead of 615 kg (245 kg lunar satellite + 370 kg empty retrofire module). This would indicate that the mass of Luna-10 (a Ye-6S satellite) may have been overstated and be closer to 1,185 kg rather than the announced c. 1,600 kg. See P. Clark, "The Mystery of Luna 10 and Luna 11", *Spaceflight*, 21, pp. 519-520 (December 1979).
87. Johnson, *Handbook of Soviet Lunar and Planetary Exploration*, pp. 37-39.
88. Wilson, *Solar System Log*. pp. 35-36. Note that *Pravda* said that the orbiter payload was ejected 20 *seconds* after the shutdown of the engine, while all Western sources say it was 20 *minutes*.
89. This letter has been reproduced as M. V. Keldysh and G. N. Babakin, "On Photographing the Lunar Surface with an Artificial Satellite of the Moon" (in Russian), in Avduyevskiy and Yeneyev. *M. V. Keldysh: izbrannyye trudy*, pp. 480-481.
90. Wilson, *Solar System Log*. pp. 40-41; Johnson, *Handbook of Soviet Lunar and Planetary Exploration*, pp. 41-43; G. V. Petrovich (ed), *The Soviet Encyclopaedia of Space Flight*, Mir Publishers, Moscow, 1969, pp. 236-237; Babakin, Banketov and Smorkalov, *G. N. Babakin*, p. 54.
91. Babakin, Banketov and Smorkalov, *G.N. Babakin*, p. 46. This source says the R-1 was installed on both Luna-11 and Luna-12. Another source claims it was carried on Luna-10 and Luna-11. See: *VNIItransmash: stranitsy istorii*, St. Petersburg, 1999.
92. Glushko, *Kosmonavtika entsiklopediya*, p. 222.
93. Babakin, Banketov and Smorkalov, *G. N. Babakin*, p. 54.
94. Glushko, *Kosmonavtika entsiklopediya*, p. 222; C. Lardier, *"L'Astronautique Soviétique"*, Armand Colin, Paris, 1992, p. 267.
95. Flight descriptions have been largely compiled from Western sources (see reference 74).
96. Varfolomeyev, "Soviet Rocketry that Conquered Space: Part 5: The First Planetary Probe Attempts, 1960-1964."
97. Babakin, Banketov and Smorkalov, *G. N. Babakin*, pp. 43-44.
98. Ibid, p. 44.
99. Ibid, p. 47.
100. Flight descriptions have been largely compiled from Western sources (see reference 74).
101. Babakin, Banketov and Smorkalov, *G. N. Babakin*, pp. 45-46.
102. Ibid, p. 46.
103. Petrovich, *The Soviet Encyclopedia of Space Flight*, p. 45.
104. Babakin, Banketov and Smorkalov, *G. N. Babakin*, pp. 46-47.
105. "Calendar of Memorable Events" (in Russian), *Novosti Kosmonavtiki*, 10, 52 (5-18 May 1997).
106. Varfolomeyev, "Soviet Rocketry that Conquered Space: Part 5: The First Planetary Probe Attempts, 1960-1964,
107. P. Clark, "Obscure Unmanned Soviet Satellite Missions", *JBIS*, **46**, 372-373 (October 1993).
108. Babakin, Banketov and Smorkalov, *G. N. Babakin*, p. 52.
109. Varfolomeyev, "Soviet Rocketry that Conquered Space: Part 6: The Improved Four-Stage Launch Vehicle, 1964-1972,"
110. Correspondence with P. S. Clark, 13 May 1999.

(Received 15 February 2000)