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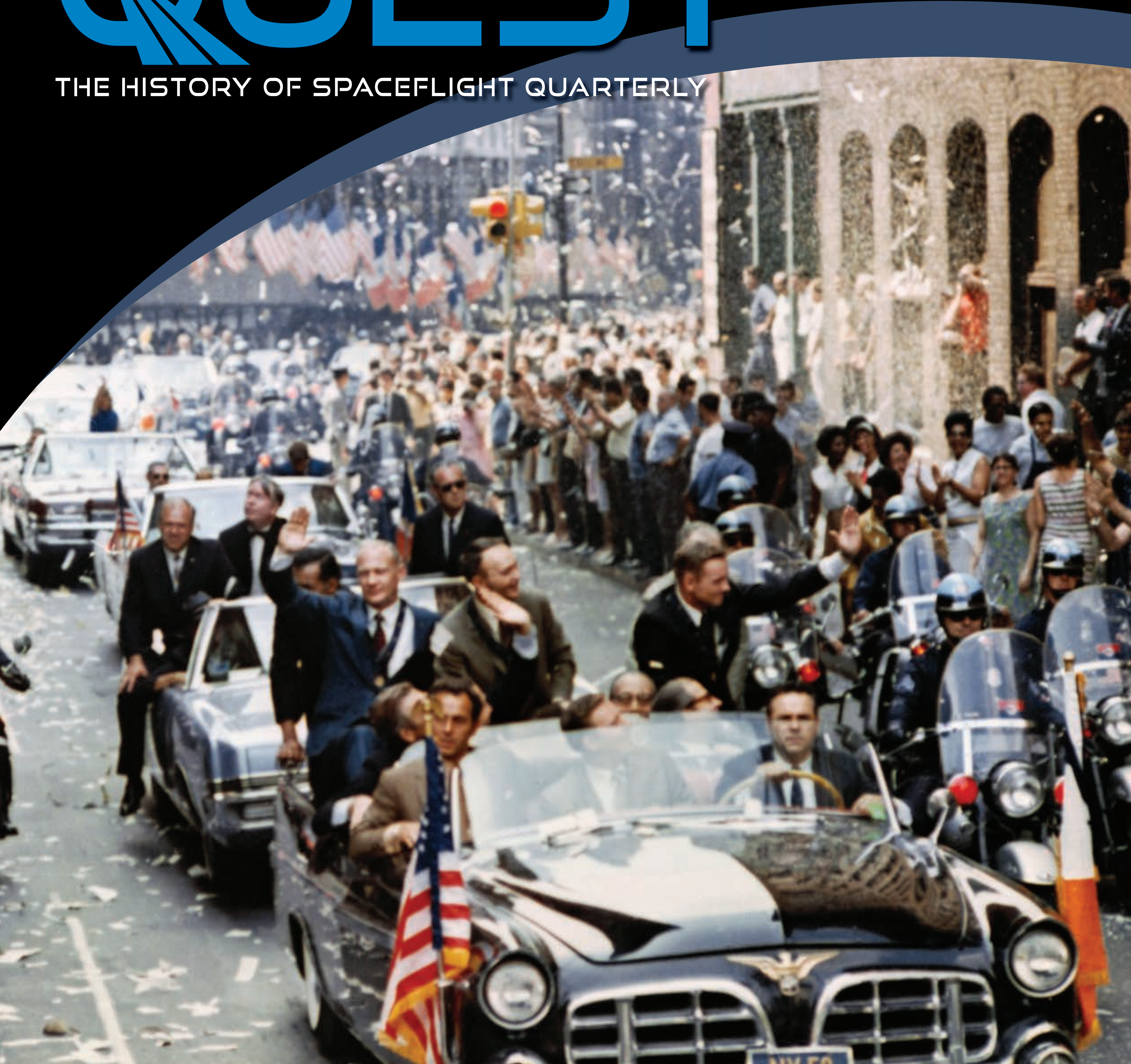

The *Apollo 11* Goodwill World Tour

German Contributions to Soviet Rocketry

High-Risk Management in the US Space Program

Apollo, Minuteman II, and the Birth of the Integrated Circuit Age

The US Space Command in Colorado Springs

Poppy Northcutt: Mission Control Pioneer

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The *Apollo 11* crew are showered in a ticker tape parade down Broadway and Park Avenue in New York City. Pictured in the lead car, from the right are astronauts Neil Armstrong, Michael Collins, and Edwin "Buzz" Aldrin Jr. 13 August 1969

Credit: NASA

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German Contributions to Soviet Rocketry: New Light on a Disputed Topic

BY ALFRED SCHMIDT

This research provides an exhaustive analysis of contributions by the German collective on Gorodomlya Island to Soviet rocketry in the years following World War II. Beyond widely known sources, this article examines in particular CIA interrogations of German specialists repatriated from the USSR and original German publications, which have been out of print for a long time or ignored due to language barriers, including memoirs by contemporary witnesses. These documents help shed new light on a part of space history where original sources are unreliable or missing due to the secrecy and political taboos in the late Stalin era. It aims to enhance our understanding of how and to what extent German concepts fostered Soviet rocketry during its learning phase up into the early 1950s, before it was enabled to develop the first medium-range R-5 missile and the then innovative R-7 intercontinental ballistic missile used to launch the Sputnik *satellites.*


ИЗВЕСТИЯ

У СОВЕТСКИХ РАКЕТНЫХ ТРИУМФОВ БЫЛО НЕМЕЦКОЕ НАЧАЛО

2. Подземное хозяйство Тюрингии

сти до готовности к летным испытаниям.

Институт наш рос буквально не по дням, а по часам. Уже через месяц он приобрел вид вполне солидного научного учреждения. Откуда-то появилась

ИЗВЕСТИЯ

У АМЕРИКАНСКИХ РАКЕТНЫХ ТРИУМФОВ ТАКЖЕ БЫЛО НЕМЕЦКОЕ НАЧАЛО

К такому выводу приходит в конце своих воспоминаний Б. Е. ЧЕРТОК

КАКОВА же в целом роль немецких работ в становлении всей современной ракетно-космической техники?

лать баллистические ракеты твердотопливными, потому что не верил, что жидкостные двигатели могут дать необходимую

Figure 1. *Izvestia* publication of March 1992 with the headline "The Soviet Missile Triumphs Had a German Origin" (left), and "American Missile Triumphs Also Had a German Origin" for the sixth episode (right). Credit: Yeltsin archive

Disputes in Assessing Early Soviet Rocketry

There is a consensus among space historians that German engineers and scientists, from 1945 to 1947, helped the USSR understand and adopt the most advanced technology for the German A4 rocket, also known as the V-2, [1] launching captured rockets and copying them as the Soviet R-1, using Soviet materials. These German scientists also provided some assistance in designing the R-2, a lengthened model of the R-1. However, there is an ongoing dispute concerning how much Soviet rocketry profited from the later German conceptual design studies G-1 (R-10), G-2 (R-12), and G-4 (R-14), all of which were presented to leading Soviet scientists from 1947 to 1949 but never implemented.

After the first two successful *Sputnik* launches in 1957, some Western publications suggested that the Soviet achievement was mainly based on German expertise.[2] On the other hand, Boris Chertok, a leading Soviet engineer, claimed in his memoirs that the "R-7 [was] free of the 'birthmarks' of German rocket technology."[3] From this, historian Asif Siddiqi concluded that: "the available evidence suggests that Korolev and his team made very little use of German expertise at least after 1947. Their influence over the direction of the Soviet ballistic missile program was marginal at best."[4] Michael J. Neufeld stated that "after 1948 [the Germans] were increasingly frozen out and set to work on theoretical designs that were never used."[5] In part, the space historians relied on a 1960 Central Intelligence Agency summary that provided an incomplete picture of the Soviet achievements.[6] Only in 1967, when the R-7 was first exhibited at the Paris Air Show, did CIA and Western rocket scientists finally understand that the Soviet technology was fairly different from the US approach.[7]

Figure 2. Main building of Branch No. 1 of NII-88 on Gorodomlya Island (left); residential building for German families (right).
Credits: Irina Suslina, Kurt Magnus

USAF Historian Ernest G. Schwiebert drew a different conclusion: “The work of the captive German scientists and technicians served as a yardstick against which Soviet accomplishments could be measured, and the Soviets were capable of extracting those developments useful to their program and of discarding others which they had already surpassed.”[8] Historians Frederic I. Ordway and Mitchell Sharpe acknowledged that “the R-14 finally proposed by the Germans was certainly no ‘uprated’ V-2. It was a new departure in rocket design. Indeed, at the time, it was considerably in advance of anything proposed or thought of by [Wernher] von Braun and his team in the United States.”[9] Russian space expert Anatoly Zak stated that “the truth might lie in between: Germans did not designed [*sic*] Sputnik or its rocket, however the concepts developed by Gröttrup’s team on Gorodomlya *did* influence Soviet designers and thus accelerated their efforts,” but still “Russian sources to collaborate this claim” were missing.[10]

This dispute is fueled by the lack of original documents due to the secrecy and the paranoid hostility against non-Soviet achievements in the late Stalin era. It was official state doctrine that all development was Soviet-based, implying that the German influence was minimal.[11] In March 1992, the Russian newspaper *Izvestia* published an abridged version of Chertok’s memoirs as five episodes under the headline “The Soviet Missile Triumphs Had a German Origin,” the first—and only—public admission of German involvement in early Soviet rocketry (Figure 1).[12] After Chertok intervened with the editor-in-chief, a sixth episode with an interview was added as “American Missile Triumphs Also Had a German Origin.”[13] Later, Russian historians discussed noteworthy German contributions and deplored that they had not been officially appreciated.[14] Even comprehensive investigations in Russia after the Cold War did not reveal technical documents or substantial admission that German design principles had actually been used; only organizational memos and design sketches in Russian language were retrieved on Gorodomlya Island and in other Russian archives.[15]

To fill this historical gap, the author has investigated primary sources rarely considered in the past and combined them with other (often Russian) sources for persuasive evidence. This research is based on more than 200 *CIA Information Reports* from 1952 to 1955, with more than 1,000 pages containing detailed German concepts for Soviet missile technology.[16] The information for these reports was gathered with significant support from the British MI6.[17] Many of these (top) secret or confidential CIA documents were not released until 2010 or even 2014, which is why they were never considered by space historians. Moreover, contemporary evidence in German publications (mostly out of print for decades) was overlooked for a more accurate appreciation of the German role. Helmut Gröttrup’s textbook *About Rockets*[18] and his scientific publications,[19] reports by Dr. Werner Albring[20] and Dr. Kurt Magnus,[21] and the memoirs of Irmgard Gröttrup[22] shed new light on exhaustive discussions of technical challenges, conflicts with the Soviet management and the conditions of daily life in Podlipki[23] from 1946 to 1948, and on Gorodomlya Island from 1946 to 1953.

Phases of German Involvement

Technology Transfer of the A4 (1945–1947)

At the end of World War II, about 450 German rocket specialists from Peenemünde evaded approaching Soviet forces and, as part of Operation Overcast, the US Army offered contracts to 125 of them. The US Army also seized a number of complete A4 rockets and preassembled components and other parts sufficient to assemble more than 100 rockets. The Army also seized 15 tons of technical documents, thus preventing instantaneous Soviet access to the unknown German technology. When the state of Thuringia, including its A4 manufacturing sites, was handed over to the Red Army in July 1945, only secondary personnel and damaged material were left for the Soviets.

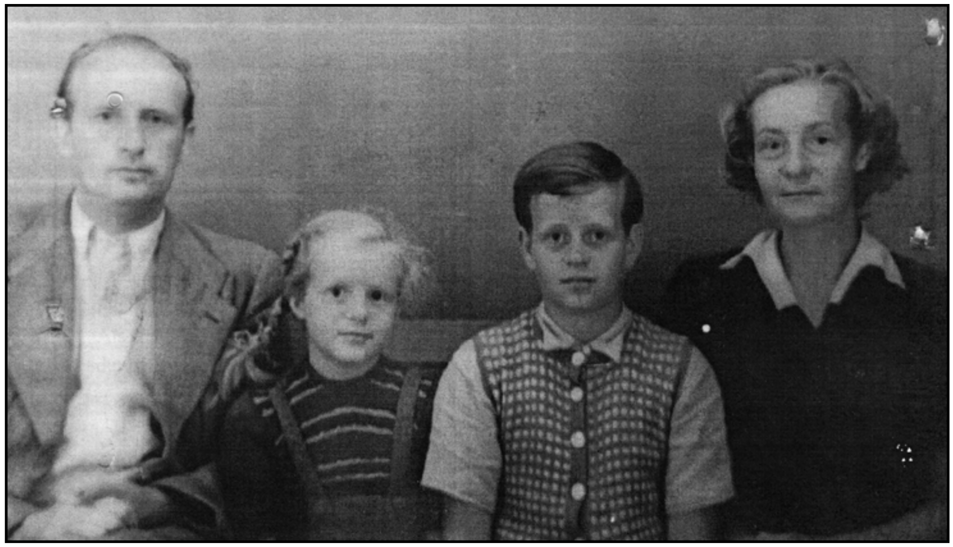

Figure 3. Helmut Gröttrup (1916–1981) with his wife Irmgard (1920–1991) and children Ursula (born 1944) and Peter (1941–2008), circa 1951 on Gorodomlya Island. Courtesy: Ursula Gröttrup

Surprisingly, Boris Chertok managed to voluntarily contract 29-year-old Helmut Gröttrup, a "clever and talented" A4 system engineer.[24]

Until mid-1946, the Soviets hired about 20 engineers with a background in Peenemünde,[25] together with dozens of high-level German scientists, for the new development centers Institut Nordhausen in Bleicherode and Institut Berlin. The primary objectives were to reconstruct the secret A4 technology, to become familiar with its intricate launching procedures, and to reconstruct the V-1 flying bomb and the Wasserfall anti-aircraft missile. In addition, the Mittelwerk plant near Nordhausen and the plants of its suppliers were put back into operation as Zentralwerke for manufacturing and assembling rocket components. All of this work was carried out in friendly German and Soviet cooperation, accompanied by numerous private contacts.[26]

On 22 October 1946, the Soviet Operation Osoaviakhim deported a carefully selected "collective" of 303 German rocketry specialists to Podlipki (99 people, Scientific-Research Institute NII-88), Gorodomlya Island (76 people, Branch No. 1 of NII-88), Chimki (23 engine specialists, OKB-456), and other research institutions (e.g., for communications and guidance systems in NII-885). The surprising action was justified as "five years of reparations work in the USSR," with promises that the German experts would be treated as "guests."[27] All of this served to secure the transfer of advanced German technology. It was far superior to the achievements by the Soviet Group for the Study of Reactive Motion (GIRD) with Valentin Glushko and Sergei Korolev before 1938—when they were sentenced to 10 years of forced labor in the infamous Gulag camps under Stalin's Great Purge.[28] For NII-88, this knowledge transfer was substantially completed in October 1947, when recovered A4s were successfully launched in Kapustin Yar. During this time, the German scientists filled gaps in A4 design calculations, and supported design work on the R-1 based on locally available materials, as prioritized by Dmitry Ustinov, the Minister of Armaments.[29] Private contacts for the Germans with Soviet citizens were now strictly prohibited, and any traveling had to be approved and accompanied by omnipresent MVD (internal troops of the Ministry for Internal Affairs) guards.

From June 1947, the 175-strong German group[30] worked on improvements of the A4, more than doubling its range to 600 km without changing the outer dimensions. They called the project Gerät 1 (G-1), named R-10 by the Soviets,[31] and reported preliminary results to the Scientific-Technical Council (NTS) in September 1947. While acknowledging "a number of interesting, fundamentally new designs for the rocket's individual structural assemblies," the NTS decided to send them back to the drawing board, demanding further details and optimizations. Ustinov wanted to keep them "as tutors and as a viable backup and alternative to Korolev to provide competition" and for a "second opinion on the complex matters of rocket design."[32]

Technology Improvements (1948–1950)

After the Soviet A4 launches, the situation of the German collective changed. Both Ustinov and Korolev, now the

Figure 4. Sergei Korolev (1908–1966) with his wife Nina (1920–1999) on Gorodomlya Island in October 1949 together with branch director Fedor Sukhomlinov. Credit: Alexander A. Korolev

NII-88 Chief Designer, were under extreme pressure to deliver more powerful missiles for Stalin, who was frightened by the US supremacy in nuclear weaponry and air power.[33] After suffering in the Gulag until 1944, Korolev was dependent on success as a personal life assurance policy against Beria's omnipresent secret police MVD/MGB, who would not forgive any mistakes, technical failures, or delays.[34] In parallel, the German rocket scientists were committed to work, hoping that pioneering innovations and achieving targets would earn them a quick return ticket to Germany.[35] Moreover, their ambition to overcome technical challenges outweighed their disappointment about often unfavorable Soviet working and living conditions. They worked on scientific issues even when they met for private reasons, because the isolated collective was condemned to success, and in order to forget their uncertain fate.[36]

The G-1 development effort was accompanied by a clash of culture.[37] The Germans were used to conducting experiments in order to verify new concepts, while the Soviet approach called for specialists to present and "defend" a new project in front of a vigilant 50-strong scientific committee.[38] Only after approval would the project be continued under Gosplan, the Soviet central economic planning authority. The Germans had to carefully elaborate on their concepts, because "the very rigid and formal development and planning system seriously curbed the development work." The "lack of experimental facilities did not permit the perfection of the missile," especially for welding and structural testing.[39]

As a result of the Zhdanov Doctrine[40] and increased Soviet secrecy, all German scientists were eventually relocated from Podlipki to Gorodomlya Island where they lived "like prisoners behind barbed wire."[41] In order to make their isolated stay more pleasant, the Germans started leisure activities typical for a German village of 450 inhabitants with more than 100 families: gardening, making music, theatre, playing tennis on a court they built themselves, discussing philosophy, etc.[42] However, they increasingly worried that their home country would become a potential battleground for nuclear weapons.[43]

The German specialists continued the G-1 design "through most of a technical project stage"[44] and answered numerous questions of experienced and, a rapidly increasing number of, young Soviet scientists. During this time Korolev developed the R-1 and eventually launched it after a painful learning curve—without German support—in September 1948. Simultaneously, he started developing the R-2, an elongated A4 with a target range of 600 km. During a one-week NTS conference in December 1948 for nearly 70 Soviet specialists including Korolev, the Germans presented some 700 pages of documentation and 200 drawings and posters with 150 improvements that would allow for an increased range of 810 km and higher targeting accuracy. With this, the Germans considerably exceeded the Soviet requirements, netting them a financial premium of two monthly salaries.[45] Gröttrup highlighted the "streamlined and inexpensive manufacturing process, simplicity of maintenance and reliability in operation…and other innovations vital for the future development of a long-range ballistic missile." Although the project was approved and Gröttrup warned that "the majority of the design elements could be considered suitable only after thorough check-out and testing," experimental work on Gorodomlya was delayed because the Soviet Gosplan was focused on the R-1 and R-2.[46] In 1948, Ustinov commanded to design a missile for a range of 2,500 km with a warhead of 1,000 kg, which was promptly presented as the two-stage G-2 (Figure 5).

In Peenemünde, the German rocket scientists had to urgently solve the setbacks of the "flying laboratory" A4, supervised by the SS and the Gestapo. In Podlipki and Kapustin Yar, the Soviet engineers were forced to work under extreme time pressure. The constant monitoring by the MVD caused them to minimize the risk of failure by taking a conservative approach. Later on Gorodomlya, the German team could focus, like in scientific research, on more innovative features. Unsurprisingly, Ordway and Sharpe rated the G-4 proposal as "a new departure in rocket design and [at the time] considerably in advance of anything proposed or thought of by von Braun and his team in the United States."[47]

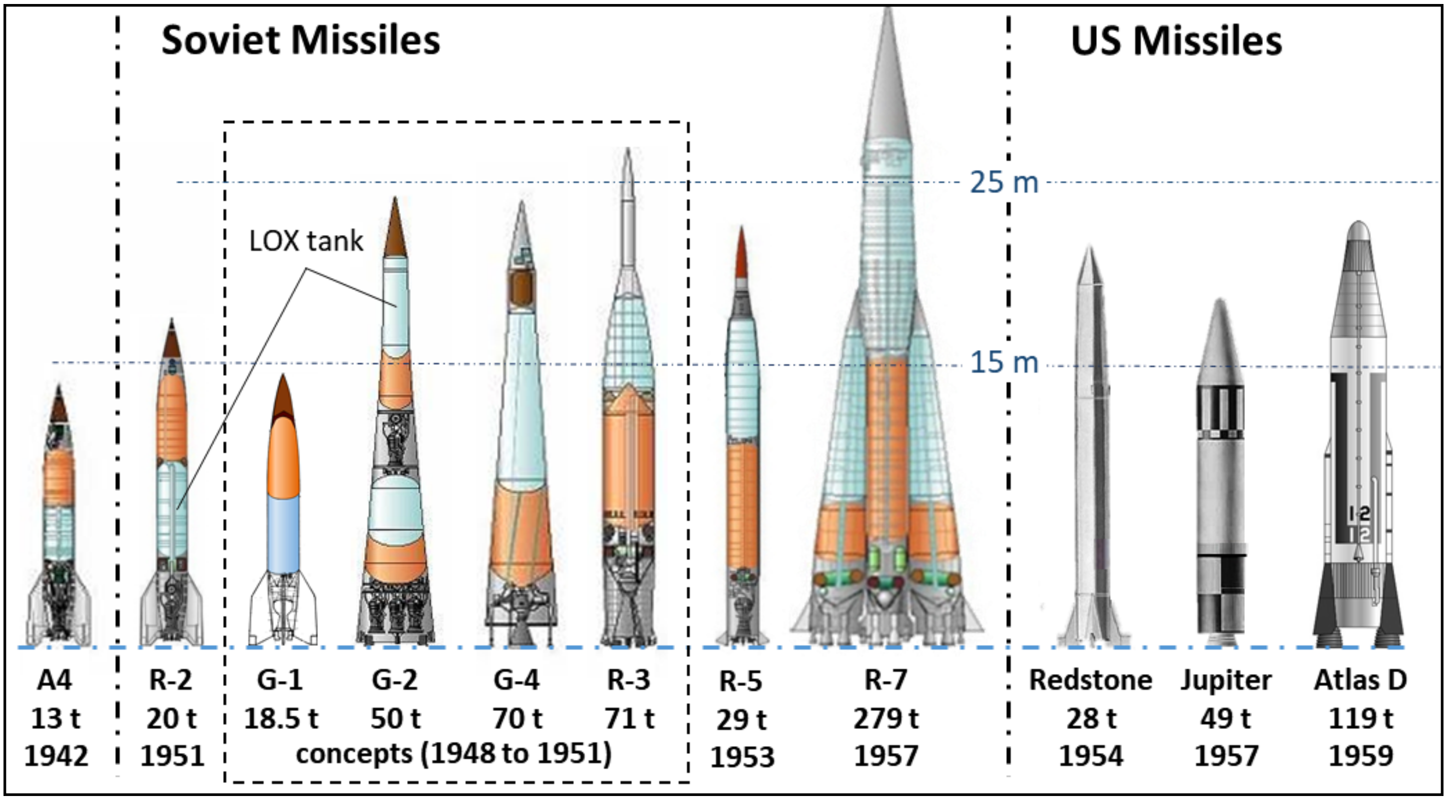

Figure 5. Comparison of Soviet and US missiles until 1959, including the gross weight and the year of first launch. Credits: Mark Wade, "Astronautix"; Wikipedia

In May 1949, Ustinov demanded a missile with a range of 3,000 km carrying a warhead of 3,000 kg as a "second opinion on Korolev's R-3 project," which prompted the German collective to the single-stage G-4 solution. In October 1949, high-ranking Soviet specialists including Korolev reviewed the G-4 proposal. By December, the German collective completed details on 1,600 pages of documentation, together with 150 drawings and 80 posters, as a technical project stage.[48] The Soviets collected all results without any official feedback. However, they continued to ask detailed questions, a clear sign that they were carefully assessing the potentials of future rocket technology.

In the December NTS meeting—then without German participation—Korolev justified the targets of his R-3 project: "It is meaningful and necessary to develop in the near future a single-stage ballistic rocket of long range which exhausts completely the possibilities of non-staged rockets. That is important, since if one possesses a rocket with simple design with large range, then this rocket could be used as part of a more complex staged rocket." Moreover, Korolev favored the "parallel arrangement of all stages…as the most realistic layout for achieving very long ranges."[49] This is exactly what he later did with the R-7—without having developed the R-3.

Phase-Out (1950–1953)

The Germans' hope, that the accomplished missile design would accelerate their homecoming was to no avail, although the initially projected "five years of reparations work" were coming to an end. They had to stay on the island, sometimes short of food and supplies, and unaware that Korolev struggled with the R-2 launch until July 1951.[50]

Based on the questions of Soviet engineers, the German specialists conjectured what challenges impeded the development of the R-3, a single-stage design with similar objectives to the G-4.[51] When Korolev got stuck he switched the priority of his work to the less challenging R-5.[52] Eventually, the German collective realized that their innovative concepts had increased their value as a viable knowledge base for the Soviet rocketry, delaying their anticipated return to Germany.[53] As a result, they collectively refused to investigate hypergolic propellants as commanded by Ustinov, due to health hazards.

In October 1950, German work shifted to less important tasks, as Ustinov decreed that top secret

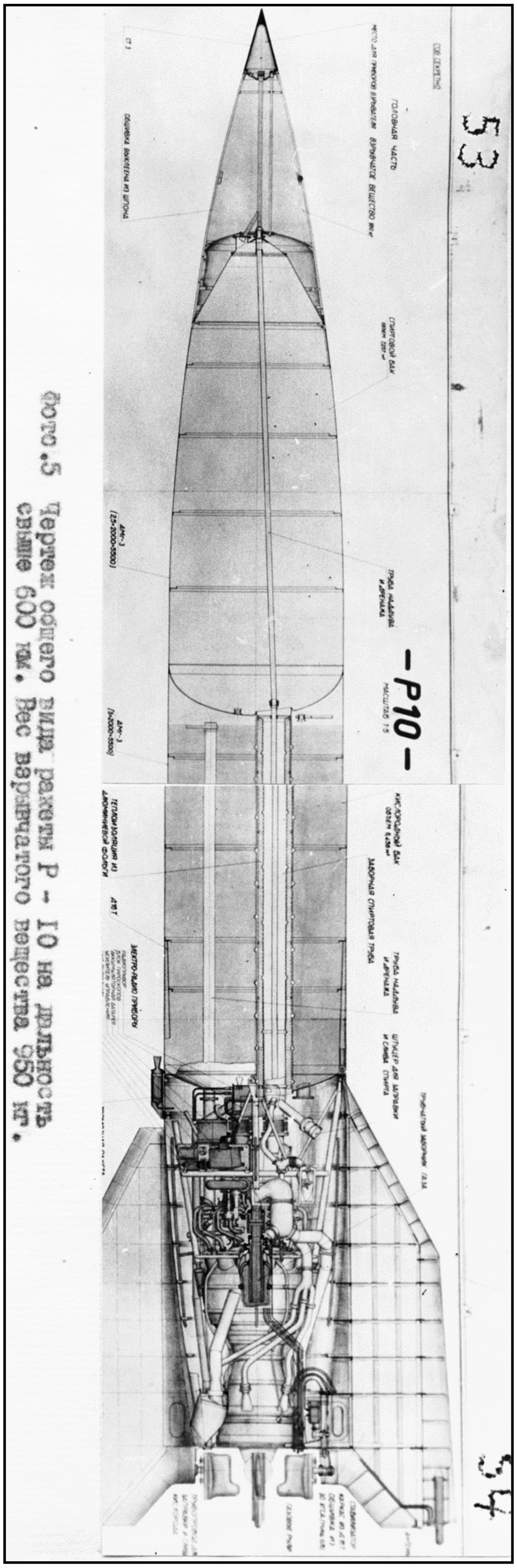

Figure 6. Design sketch of the G-1 (Soviet R-10) retrieved from Zvezda Enterprise archives.[62]
Credit: Irina Suslina, Elena Borisova

research be discontinued.[54] However, in July 1951, the Ministry of State Security (MGB) extended the Germans' captivity since they had been involved in "processing of particularly important problems."[55]

In January 1952, an initial group of 50 Germans, mostly second-tier technicians, widows, and orphans, was repatriated to Germany, followed in June by a large group of 113 specialists (about 350 people, including families).

For the remaining group of 24 specialists (among them Gröttrup, Magnus, and Umpfenbach; approximately 60 people, including their families) no explanation was given for their sustained detention—be it for political reasons because they had irked the Soviet administration, or because they were still required as indispensable advisors in case of technical issues.[56] Later in November 1953, they returned home, eight months after Stalin's death.

Before leaving, all Gorodomlya specialists had to sign a nondisclosure obligation with the MGB.[57] Most of them obeyed this commitment, with the exception of about 20 "dragon returnees," who shared their knowledge with the MI6 and the CIA.[58] They confirmed that there was a "native Soviet guided missile program under Korolev." Gröttrup pointed out that the "interest of the Soviet intelligentsia is far greater and much more intimate than was the case in Germany." He cited the early Russian space pioneer Konstantin Tsiolkovsky, and warned that the "Soviets would have been the first to utilize long-distance rockets if the general level of technics had been high enough."[59] However, many US experts believed as late as 1954 that the USSR would not be able to successfully create the complex technology required for intercontinental ballistic missiles within the 1950s—until *Sputnik*'s launch in 1957 proved them wrong.[60]

Only Helmut Gröttrup, who was developing early commercial computer applications, dared to publish a summary of the G-4 principles ("status by the end of 1950") in early 1958, and his comprehensive textbook *About Rockets.* He claimed "that it is possible to launch ballistic missiles with a mass ratio of 0.1 and a payload share of 40% of the empty weight" by ultra-lightweight design and two-stage rockets, in which only the engines of the first stage are jettisoned."[61] Without knowing details, he identified the essential R-7 characteristics.

German Influence on Soviet Rocketry

To what extent did German innovations on Gorodomlya Island catalyze Soviet rocketry? Certainly, there were ideas from Peenemünde and simultaneous inventions by Soviet engineers. However, it is rather unlikely that all similarities, found in later Soviet rocket designs, are coincidences, given that Korolev and his engineers carefully analyzed the German development. It cannot even be ruled out that some concepts retrieved from the CIA interrogations resonated in early US missile development.

Basic Improvements

The A4 suffered from several obvious weaknesses that required many vital improvements. The German collective collaborated as an interdisciplinary team, and focused on reducing empty weight, increasing efficiency and proposing more accurate guidance systems in the G-1 project. They tweaked the A4, without changing its size and aerodynamic shape, as optimized in the Peenemünde supersonic wind tunnel (see Figure 6).

Konrad Toebe, an excellent aircraft engineer formerly employed by Arado Flugzeugwerke, noted that "many things of the V-2 [airframe] were designed incorrectly…and pointed to a very inferior stage of development in the structure" where the impact of thermal stress due to very low LOX temperatures and high surface temperatures during supersonic flight "had not been systematically considered." Instead, he proposed "a single-shell structure [where] the tanks must be permanently subjected to a certain pressure"—pressurized balloon tanks for a self-containing (monocoque) structure to reduce weight and increase propellant capacities. Internal pressure imposed tensile stress on the skin, protected it against buckling and provided integral stability, like a tin can with extremely thin walls. They also proposed using turbine exhaust gases to pressurize the alcohol tank.[63]

The instrument section and antennas were moved to the aft compartment and mounted on special brackets to mitigate vibration. This way, access to the electronic control system and the gyroscopic devices (inertial platform) was significantly improved for the final checks. Access doors in the equipment section, which had caused severe mechanical stability issues in the A4, were no longer required.[64]

The A4 had used the kinetic energy of the rocket frame for additional destructive power. However, the excessive heat and aerodynamic forces during reentry required a heavy design of the shell without completely avoiding in-flight breakup (Luftzerleger). Reduced empty weight *and* ignition of nuclear warheads above ground would significantly curtail the kinetic effect. So the German specialists' designs focused on detaching the warhead "at a predetermined point after propellant cut-off" and shaping it as a conical "nose section," for aerodynamic stability during reentry. Impregnated plywood would provide an ablative heat shield, with low heat conduction by charring effect. However, they could not verify whether a thickness of 20 mm would be enough.[65] The Soviets optimized the ablative material for the R-5, with "specific coatings based on sublimated (evaporating) high enthalpy materials."[66] In human spaceflight, similar protection technology was required for the reentry of Vostok and Mercury spacecraft.

With these modifications, the G-1 nearly tripled the range of the A4 to 810 km and halved the empty-to-full weight ratio to 0.15 (see Table 1). The G-4 project refined the design of the pressurized balloon tanks, including material selection, the design of junctions between the sections, and the manufacturing process. Calculations indicated that a thickness of 0.6 mm with a newly developed Soviet alloy steel or with a lightweight metal of 2 mm would be sufficient for the shell.[67] Even thermal insulation of the LOX tank was considered to be dispensable, as the liquid oxygen evaporated less than anticipated. Ice on the outside of the LOX tank could be reduced by appropriate surface treatment; thin layers of ice would be shaken off by vibrations during takeoff, with little impact on range. During the flight, heat transfer would assist in pressurizing the LOX tank.[68]

For the first time, Korolev's R-2 implemented a balloon tank based on an aluminum alloy for the fuel and moved the control compartment to the aft. He achieved a range of 600 km and an empty-to-full weight ratio of 0.18, within the limits of technical feasibility of the late 1940s (see Table 1). From 1953, Korolev used monocoque design for both tanks (welded from aluminum and magnesium alloys, respectively), thus achieving an empty-to-full weight ratio of 0.14 for the R-5 and 0.08 for the R-7.[69]

Another significant enhancement was more efficient and precise attitude and velocity control. Balanced thrust of multiple engines, as foreseen for the G-2, could determine the missile's elevation and azimuth, but air rudders were still indispensable for roll stabilization. For the G-4, the Germans proposed two "nozzles [fed by the exhaust gas of the turbines] adjustable [by control motors] in direction to provide additional thrust and prevent rotation of the missile about its longitudinal axis." [71] Later, it became known as Vernier thruster.

In addition, the Germans proposed to tilt the nozzle on a "gimbal motor mount," for a variable thrust vector of a single main engine. They designed "a close-fitting ball and socket" at the bottom of the conical fuel tank. This way, the engine could be swiveled by up to ±4°, driven by "two hydraulic motors which were operated with high-pressure alcohol" from the second stage of the fuel pump.[72] They also developed and tested a prototype of a swivel-mounted control engine.[73]

The R-7 used 12 Vernier thrusters, fueled by LOX and kerosene, each with a thrust of up to 24.5 kN. Two of them were located at the periphery of each booster to counteract rolling.

Table 1. Essential Data of Missiles[70]

	A4	G-1 (draft)	G-4 (draft)	R-2	R-5	R-7	Redstone	Jupiter IRBM	Atlas D
First successful launch	1942	-	-	1951	1953	1957	1954	1957	1959
Warhead [t]	1.0	1.0	3.4	1.0	1.42	5.37	2.68	1.00	1.4
Range [km]	270	810	3,000	600	1,200	8,000	323	2,700	8,000
Launching weight [t]	12.8	18.4	70	20.1	30	268	27.8	49.8	119
Launching thrust [kN]	245	313	990	365	430	3,905	367	667	1,629
Ratio thrust-to-weight	1,95	1.73	1.46	1.85	1.46	1.48	1.35	1.36	1.40
Fuel *	A 75%	(A)	A 75%	A 92%	A 92%	K	A 75%	RP-1	RP-1
Empty weight [t] **	4.00	2.73	3.4	3.59	4.2	21.5	3.1	6.2	?
Ratio empty-to-full weight	31%	14.8%	4.9%	17.9%	14.0%	8.0%	11.2%	12.4%	?
Balloon tanks		✓	✓	(p)	✓	✓	(p)	(p)	(p)
Reversed tanks			✓		✓	✓			
Instrument compartment	ahead	aft	aft	aft	aft	aft	ahead	ahead	ahead
Simultaneous emptying		✓	✓			✓			
Jettisoned boosters						✓			✓
Conical shape			✓			✓			
Graphite thrust vanes	✓	✓		✓	✓		✓		
Gimbaled main engines			✓					✓	✓
Vernier thrusters			✓			✓		✓	✓

Notes: * A % = alcoholic content of fuel; K = kerosene or refined petroleum (RP-1); ** not including the warhead; (p) only partially implemented

Four thrusters on the central stage (i) controlled azimuth and elevation after releasing the boosters, and (ii) adjusted the velocity for enhanced target accuracy. The steering units of the Vernier thrusters on gimbals of ±45° were hydraulically powered by kerosene from the main fuel pump.[74]

With the R-9, a two-stage ICBM developed in the early 1960s, the first stage engine RD-111 with four chambers was gimbaled. The thrust of the second stage was controlled via Vernier thrusters using spent turbine gas of the RD-0106.[75] In the US, the Jupiter IRBM (PGM-19) and Atlas missiles used gimbaled engines and Vernier thrusters for the first time.

Reversed Arrangement of the Tanks

For the G-2 and G-4, the Germans proposed reversing the arrangement of the tanks and installing the LOX tank in front. For one thing, the denser and heavier liquid shifted the center of gravity forward for enhanced flight stability. In addition, the head position increased the LOX pressure for the oxygen pump and reduced the risk of cavitation. Also, the fuel tank was always filled first, and stabilized the bottom balloon tank before the LOX tank was filled.[76]

With the R-5 and R-7, Korolev implemented the reversed arrangement of the tanks and kept it for future missiles.[77] The US Saturn V for Apollo also positioned the LOX tank ahead in its first stage.

Simultaneous Emptying of Tanks and Thrust Control

The reduced weight of the empty rocket encouraged further optimizations. The fuel and LOX consumption of the engine never achieved the ideal stoichiometric ratio, no matter how engine adjustments were perfected by calibrated diaphragms. Therefore, residual propellant at cut-off was empty weight for range calculations. Because minor alterations of the ratio had little impact on thrust, they developed a method by emptying the tanks simultaneously. Pairs of level switches measured the propellant consumption in each tank, and activated a regulator for the turbine governors of the turbopumps for equaled emptying.[78]

Reduced empty weight increased acceleration at the end of the flight path, but would also cause greater mechanical stress on the supporting structure. In order to avoid heavy-weight construction, they proposed to limit acceleration. Moreover, Gröttrup argued that thrust at lift-off should be reduced to a factor times 1.4 the weight or even less (instead of 1.9, with the A4) because (i) lower speed in denser atmospheres would reduce thermal stress, and (ii) smaller engines would further improve the weight efficiency.[79]

The Soviets applied simultaneous emptying and thrust limitation, for both the R-5 and the R-7. For the four boosters of the R-7, synchronizing propellant consumption (named SOBIS) was vitally important, because asymmetrical tank load would inevitably offset the center of gravity, causing major target deviations or even structural overstraining.[80]

Conical Shape

The ogival shape of the A4 had been optimized in the Peenemünde wind tunnel for minimized air resistance. Aerodynamic (arrow) stability was achieved by large tail fins, which shifted the center of pressure to the rear. Without a supersonic wind tunnel in Gorodomlya, the Germans could not determine the optimum shapes for larger missiles. Hence, for the G-2 and G-4, they completely redesigned the tail section of the A4, doing away with the controlled air rudders on the fins and heavy graphite vanes in the jet stream. They preferred a conical shape (see Figure 5), as proposed by Werner Albring. It enabled the simplest design for (i) mechanical stability, (ii) ease of manufacturing, (iii) extra space for larger engines, (iv) advantages in supersonic flight, and (v) theoretical calculations in aerodynamics and stress analysis.[81] Although the center of gravity moved behind the center of pressure during some flight phases (even with the LOX tank in front), enhanced gyroscopic control by Vernier thrusters would stabilize the rocket.[82] Gröttrup saw the G-4's "revolutionary concepts" as "breaking with old tradition" and considered "the conical shape of the rocket the best, and, fundamentally, the only possible solution," with "every detail…checked and counter-checked to assess its possible influence on other aspects of the rocket's design, on its trajectory, its maneuverability, on its

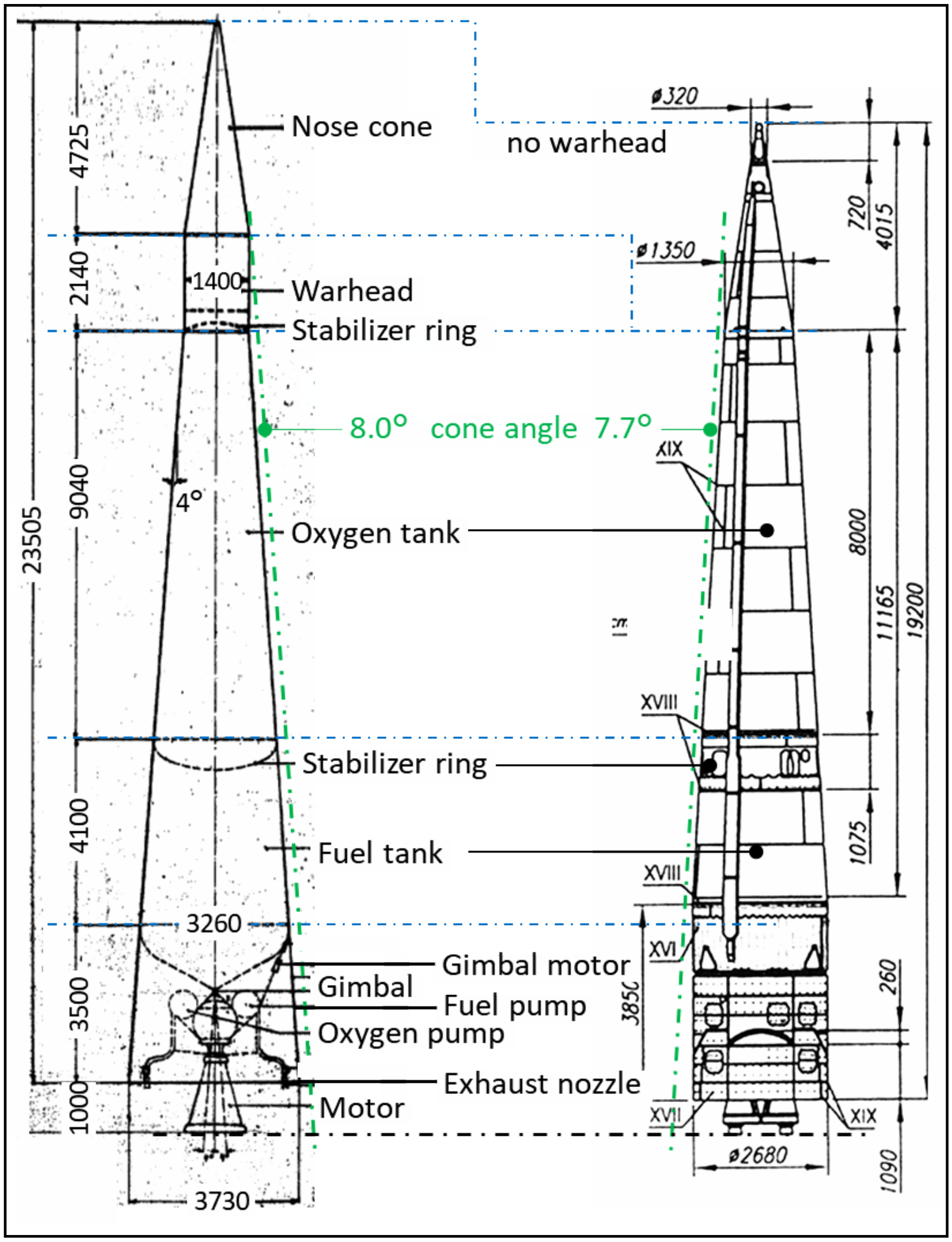

Figure 7. Design sketch of G-4 (left, 1949) and R-7 booster (right, 1955).
Credit: Toebe, author[86]

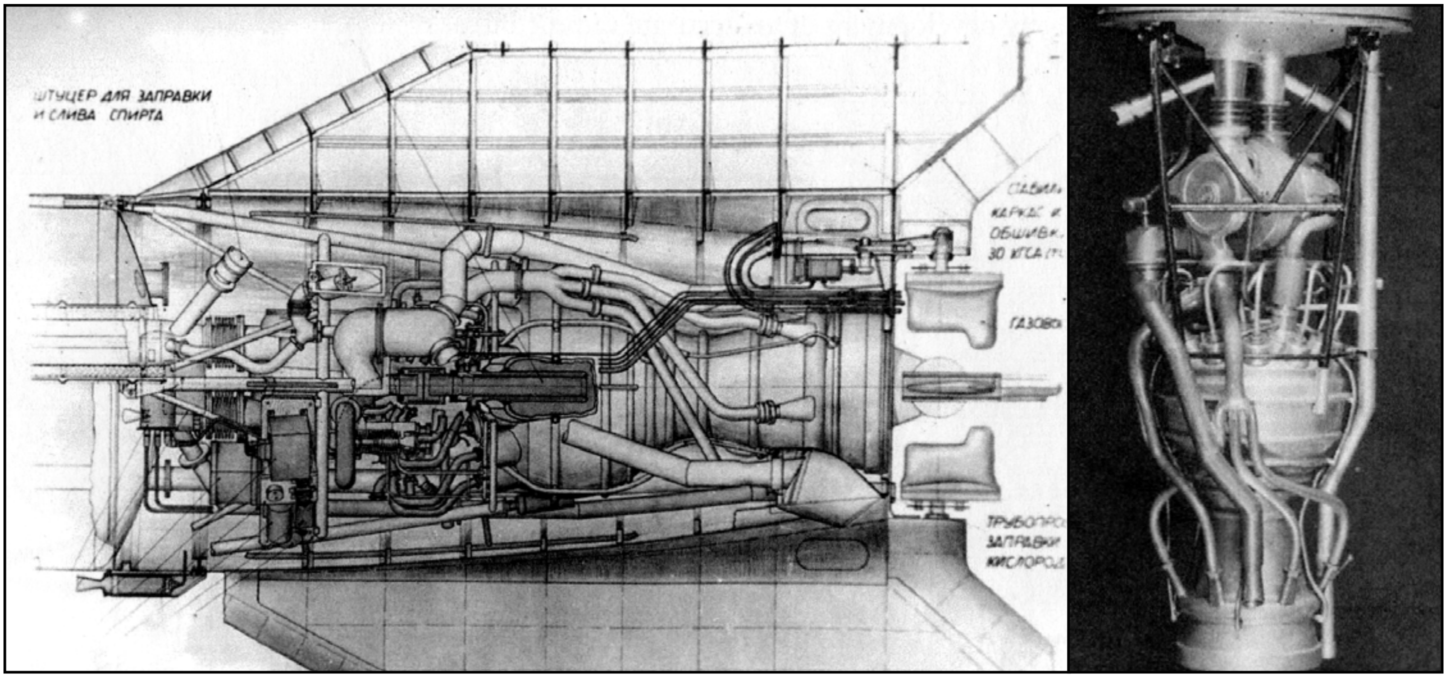

Figure 8. Detailed sketch of the G-1 tail section and model of the propulsion unit with gas bleeding. Credit: Irina Suslina

operation and transport, and last, but not least, on the total cost of production."[83]

For the R-5, the Soviet designers dispensed with the large stabilizing fins but kept four rudders at the tail and added four thrust vanes (as in the A4) for attitude control.[84] The R-7 relied on four conical strap-on boosters, each with a controlled rudder at the outer edge of the tail. They were attached to the central stage as a "packet configuration," producing an overall conical shape. Without thrust vanes, precise flight control was achieved by means of additional Vernier thrusters. As depicted in Figure 7, the shape (cone angles of 8.0° and 7.7°) and diameter of the nose cone reveal striking resemblance of the G-4 missile and the R-7 boosters. The rear diameter was reduced to 2.68 m to allow railway transportation. For this, the tank section was shortened from 13.14 to 11.16 m and the top diameter from 1.40 to 1.35 m.[85] Even the N1 rocket used this approach, with a cone angle of 8.0° for its first two stages.

Packet Configuration

As part of the G-2 project, the German team proposed combining three G-1 engines for enhanced range and/or payload.[87] Since the engines were arranged at an angle of 120°, the individual thrust control was able to determine the thrust vector. This way, the Germans dispensed with the thrust vanes, for higher performance. The number of engines could be even increased to four or six and "expended motors dropped from the missile from different heights."[88] Alternatively, they proposed "a number of rockets…to surround a missile carrying the warhead…and to release the warhead-carrying missile on its second stage of the powered flight."[89]

Mikhail Tikhonravov—who was involved in GIRD and the early A4 technology transfer—picked up this approach and became the most committed supporter of Korolev's ICBM configurations. In particular, in the early 1950s, he worked on clustering (or packeting) several rockets, with a fully interconnected control system, for launching Earth satellites.[90] To avoid firing in a vacuum, the R-7 boosters and the core stage—one-and-a-half stage—were ignited on the ground. The four boosters were jettisoned when fully burnt out after 120 seconds of flight. As Chertok later summarized: "By all parameters, [the R-7] remained the most reliable rocket in the world for manned flights." Comprehensive redundancy measures and permanent struggling for reliability "enabled the Soviet Union to take the lead in cosmonautics," continued into the *Soyuz 2* era, the workhorse of space traveling.[91]

Gas Bleeding for the Turbine

In order to improve range even more, Dr. Karl-Joachim Umpfenbach (1902–1954), a senior physicist for fluid mechanics, proposed powering the turbopumps by the combustion pressure of the engine (gas bleeding). This would discard the steam generator with its hydrogen peroxide and sodium permanganate containers, about 200 kg for an A4 engine. Before launch, the turbopumps were started by external pressurized air. As a challenge, the exhaust gas temperature of 2500°C had to be reduced to approximately 600°C or 800°C. He achieved this by adding fuel before it entered the turbine. Then it was discharged to the Vernier thrusters, dissipating some fuel energy. On a test stand on Gorodomlya Island, Umpfenbach demonstrated the feasibility of this approach by driving an A4 turbopump, and exceeded expectations by December 1951. The team also developed measurement and control devices for automated test runs with varying combustion pressures, fuel mixture ratios, and gas temperatures.[92]

In 1950, the highly interested Soviets built a similar test stand in Kapustin Yar (Branch No. 2 of NII-88), where they successfully verified gas bleeding without German involvement.[93] In 1959–1960, they significantly improved the principle for the S1.5400 engine. Instead of using hot exhaust gas from the engine, they mixed the entire volume of liquid oxygen and some kerosene discharged from regenerative nozzle cooling. This oxidizer-rich composition fed the pre-burner driving the turbine. For afterburning, the partially combusted turbine exhaust was supplied to the main engine for a staged (closed) combustion cycle recovering the entire propellant energy. In February 1961, Molniya, an enhanced R-7, with the S1.5400 engine in its fourth stage, successfully accelerated the *Venera 1* probe for its interplanetary voyage. This NII-88 success motivated Glushko's OKB-456 to perfect this principle with the RD-253 (first launched with Proton in 1965). Later, the RD-170 (first launched with Energia in 1985) became the world's most powerful liquid-fuel rocket engine, with a thrust of 800 tons. The down-sized RD-180 was supplied to the US for the Atlas III rocket. The initial test flight took place in May 2000; it is still in use with Atlas V.[94]

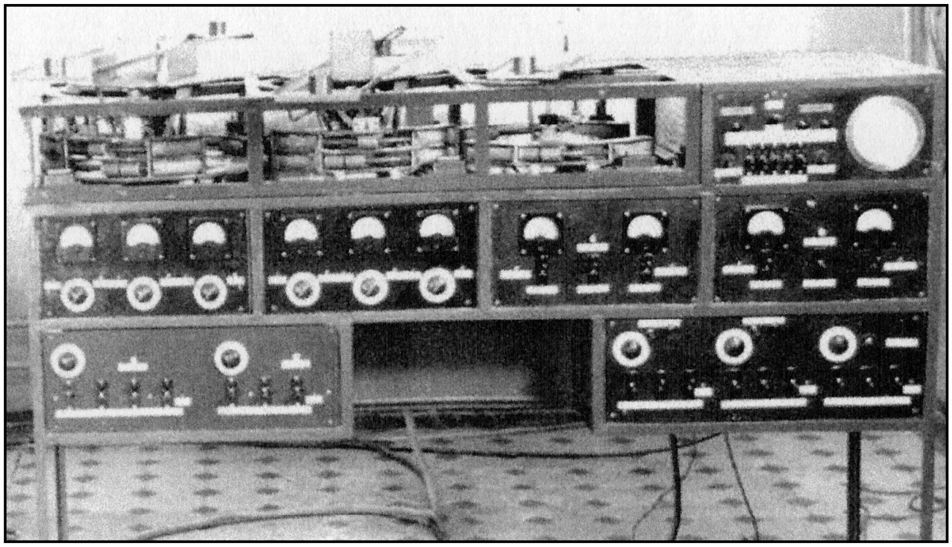

Figure 9. Simulation of trajectory (Bahnmodell). Credit: Irina Suslina

Guidance and Control System

As a ground-breaking A4 achievement, the Horizont and Vertikant gyroscopes provided stable pitch, yaw, and roll control. For higher G-1 accuracy, Kurt Magnus proposed using the Steuergerät SG-70 as an inertial platform, including an accelerometer and integrating gyro. It had been developed by the German company Kreiselgeräte GmbH during WW II.[95] This technology was further developed for the R-2 by Nikolay Pilyugin in NII-885, to improve target accuracy.[96]

Moreover, Dr. Johannes Hoch designed the control loop as part of the Bahnmodell (trajectory computer). In 1950, Hoch and half a dozen Gorodomlya team members were transferred to KB-1.[97] They continued to improve the Wasserfall missile (project R-113)[98] and to develop Soviet surface-to-air missiles (SAM). The project culminated in development of the Soviet *S-25* Berkut and its successors.[99]

Non-Material Influence

Beyond innovative concepts, the German specialists taught the Soviet engineers accuracy, strict focus on quality, and proof of qualification in all steps of development and manufacturing required to successfully launch rockets. After initial R-1 and R-2 failures, Korolev's team learned a culture of thorough systems engineering with comprehensive evaluation of potential failure situations. Under extreme time pressure, the Soviet rocket industry eventually achieved a quantum leap in reliability, contrary to most other industries in the USSR.[100]

"The exploitation of the German's skills and experience was very carefully organized to minimize contact with Soviet peers," Korolev's biographer James Harford concluded.[101]

Magnus stated that "Korolev took a lot of time to discuss things with us indi-

радиолокационному управлению. Профессиональный уровень весьма широк: 5 профессоров, 25 докторов наук, 15 дипломированных инженеров, 65 инженеров-практиков, мастера производства, техники, механики, токари и слесари.

На первоначальном этапе от них требовалась передача методик исследования отдельных проблем и моделирования процессов, выпуск русского комплекта документации баллистических и зенитных ракет.

После строительства секретного испытательного полигона Капустин Яр, в октябре-ноябре 1947 года группа из более 20 немецких ученых и специалистов Филиала № 1 принимала участие в серии первых пусков, реконструированных ФАУ-2, оказывая необходимые консультации, и решая возникающие проблемы.

Одновременно Филиалу № 1 поручается сконструировать более мощную и совершенную ракету, чем ФАУ-2. Руководителем проекта и главным конструктором новой ракеты Г-1 (Р-10) назначается Гельмут Греттруп. Созданный для этого отдел «Г» НИИ-88 формально получает все права научно-исследовательского отдела.

В течение 1947-1948 гг. эскизный проект ракеты Г-1 (Р-10) был разработан. Господин Греттруп был уверен в его высоких достоинствах. Проект содержал ряд интересных идей и предложений. Дальность полета ракеты составляла уже не 600, а 800 км, точность стрельбы обеспечивалась новой радиосистемой управления. Научно-техническому совету НИИ-88 были представлены графики и диаграммы, чертежи ракеты: по баллистике, аэродинамике, прочности и устойчивости, двигателю и управлению.

Торжественное собрание. Немецкие специалисты.

Немецкие специалисты на летных испытаниях ракет А-4 на полигоне Капустин Яр. 1947 г.

Ракета Р-10

Прибор, моделирующий полет ракеты-банмодель доктора Хоха

Блок суммирующих гироскопов.

6

В качестве экспериментальных образцов Филиалом № 1 были разработаны и изготовлены новые приборы управления ракеты: суммирующий гироскоп, усилитель управления, программный механизм, пневматическая рулевая машинка; из наземного оборудования стартовый пульт и пульт испытания управления перед стартом.

Г. Греттруп, 1948 г.

«Можно признать, что решение поставленной задачи найдено … Даже если бы ракета не вызывала никакого интереса как оружие, она была бы необходима в качестве объекта для испытаний, названных выше нововведений (отделяющаяся головка, несущие баки, усовершенствованная турбина ЖРД, новое управление), которые имеют очень большое значение для дальнейшего развития баллистических ракет дальнего действия…», - из доклада Греттрупа.

Научно-технический совет одобрил проект и счел необходимым форсировать экспериментальные работы, связанные с отработкой принципиально новых вопросов, имеющихся в проекте и всесторонней «стендовой» проверке конструктивных решений. Участники совета прекрасно понимали, что на острове Городомля, посреди озера Селигер нет возможности и достаточной экспериментальной базы, чтобы проверить новые идеи на практике. Советская промышленность была не в силах помогать Филиалу № 1. Поступавшие в Филиал материалы и оборудование доставлялись не регулярно и часто с большим опозданием. По характеру проводимых работ Филиалу требовались различные материалы в небольшом количестве, но очень разнообразного ассортимента. Своих фондов Филиал не имел и снабжался из текущих запасов лабораторий НИИ-88 и завода № 88.

В новом проекте Г-2 (Р-12) группа Греттрупа нашла оптимальное техническое решение для создания ракеты, способной доставлять боеголовку весом не менее одной тонны на расстояние свыше 2500 км. В технологически упрощенную конструкцию одноступенчатой конической формы ракеты вновь были заложены нововведения: впервые предусматривался отказ от газоструйных рулей, продольное и поперечное деление ракеты на ступени, двигательная установка в виде блока из трех двигателей, сброс части двигателей в процессе разгона.

Проекты ракеты Г-2

Из книги В. Альбринга «Городомля».
«Министр Устинов посетил немецкий коллектив только дважды. Генерал Гайдуков приезжал не чаще… Господин Королев посещал коллектив чаще. Но никогда не сообщал о своих собственных результатах и опыте и никогда не сравнивал наши проработки с собственными».

7

Figure 10. Pages 6 and 7 from the Zvezda Enterprise *Star Pages* publication of 2016. Credit: Elena Borisova

vidually or in groups" in Bleicherode and Podlipki.[102] Later, "a swarm of his mostly young, intelligent and ambitious [Soviet] colleagues were pestering us with ever-new questions…thirsty for knowledge and eager to learn." They reported back to Korolev and his experts in NII-88, but soon returned with more elaborate questions. "Our anticipations turned into certainty: there was a group of experts parallel to ours, but anonymous to us! Its members were first-class specialists, they followed and controlled our work, but remained invisible to us."[103]

Conclusion

Detained for more than five years on Russia's Gorodomlya Island, the 170-strong German collective improved the A4 technology and initiated innovative concepts. During this time, Korolev rigidly coordinated the missile development dispersed among seven ministries with dozens of design departments, and inspired thousands of motivated engineers to successfully grapple with the challenges at the forefront of technology during the pre-digital era. Within a decade of launching the R-2 missile, they shot the first satellites into orbit, hit the Moon with *Luna 2*, and took photos from its back with *Luna 3* in 1959. In 1961, they safely launched Yuri Gagarin, the first man to orbit the Earth. Space exploration, both Tsiolkovsky's legacy and Korolev's and Tikhonravov's hidden dream, became a reality.[104]

In his first public statement after the *Sputnik* launches, Gröttrup appraised the German involvement: "The share of our work in these [Soviet] successes is difficult to estimate, because even during our stay in the Soviet Union we were unable to access the developments of our Russian colleagues with their much greater possibilities. But it certainly contributed only a fraction to the development work that enabled the *Sputnik* launch."[105] Albring described a meeting with Yuri Pobedonostsev—the founder of GIRD and NII-88 deputy director until 1949— soon after the *Sputnik* launch in 1957: "He asked me what was going through my mind when I heard the reports on the flight of the *Sputnik* He added, word for word, *'What then has become of our joint work at Bleicherode and in the Soviet Union.'"*[106]

However, the Zhdanov Doctrine prohibited official Soviet admission, with still instilled impact on historiography. Only in August 2016, the Zvezda Enterprise as today's successor of the NII-88 branch[107] recapped the German contributions in its commemorative publication, *Star Pages,* for the 70th anniversary of rocket technology on Gorodomlya Island. It was the first time that the important role of the German rocket specialists was officially recognized (Figure 10):

> In the G-2 project, Gröttrup's team found the optimal technical solution for…a single-stage rocket with a conical shape. Many inno-

> vations were applied: for the first time there were no thrust vanes, and the rocket was divided into longitudinal and transverse stages, with a bundle of three engines as a propulsion block and thrust control during acceleration.
>
> When realizing the G-4 project… the German collective used its accrued expertise…The German experience in terms of basic research and practical engineering application became a good school for the Soviet scientists. Many valuable concepts were adopted from the German collective, which spared the Soviet rocket industry many years of development and failures.[108]

In the same vein, Chertok admitted that "the Germans' technical experience saved us many years of creative work."[109] Without diminishing Korolev's outstanding accomplishments for space travel, numerous details provide persuasive evidence that advanced German concepts inspired and catalyzed essential features of Soviet rocketry.

About the Author

Alfred Schmidt lives in Germany, and has a master's degree in Electrical and Control Engineering from the Technical University of Munich. After his retirement, he edited the biographic review *Helmut Gröttrup: Raketen, Banknoten, Chipkarten* [*Helmut Gröttrup: Rockets, Banknotes, Smart Cards*] on the achievements of a major German rocket scientist from Peenemünde and the head of the German rocket collective in the Soviet Union. Based on this research and his access to Gröttrup's legacy, the author investigated the German contributions to Soviet rocketry.

Notes

1 In this research, the Peenemünde term "A4" (Aggregat 4) is preferred over the Nazi propaganda name "V-2" ("Vergeltungswaffe 2", "retaliation weapon 2").

2 As the USSR lagged behind in many economic areas, nobody could imagine how the Soviets achieved a noteworthy advantage in rocketry over the US.

3 Boris Y. Chertok, *Rockets and People. Volume II* (NASA SP-2005-2012, translation of the Russian original from 1995), 73.

4 Asif A. Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (NASA SP-2000-4408, 2000), 84, hereafter, Siddiqi, *Challenge.*

5 Michael J. Neufeld, "The Nazi aerospace exodus: towards a global, transnational history" (*History and Technology: An International Journal*, 28:1 (2012), 49-67), 58.

6 CIA, *Scientific Intelligence Research Aid No. 74: Scientific Research Institute and Experimental Factory 88 for Guided Missile Development, Moskva/Kaliningrad* (OSI-C-RA/60-2, 4 March 1960), hereafter, CIA, *SIRA*.

7 M. C. Wonus, *The Case of the SS-6 [R-7]* (*CIA Studies in Intelligence*, Volume 13, 1969), 25-31, https://www.cia.gov/readingroom/docs/case_of_the_ss-6.pdf, hereafter, CIA, *SS-6*. He concluded: "Guided by the 'divine righteousness of domestic design concepts,' [US experts] overruled their [CIA's] superior technical judgements."

8 Ernest G. Schwiebert, *USAF's Ballistic Missiles—1954-1964. A Concise History* (*Air Force and Space Digest*, May 1964), 61.

9 Frederic I. Ordway III and Mitchell R. Sharpe, *V-2s on the Steppes* (Ty Crowell Co. 1979), 337; CIA, *The R-14 Project, a Design of a Long-Range Missile at Gorodomlya Island* (RDP80-00810A001800090003-0, 26 August 1953), hereafter, CIA, *R-14 Project*. Ordway's and Sharpe's findings were based on this then unreleased CIA document and letters with Helmut Gröttrup as mentioned on p. 442.

10 Anatoly Zak, "RussianSpaceWeb: News and history of astronautics in the former USSR," August 2012, https://russianspaceweb.com/gorodomlya.html, thereafter, Zak, "Gorodomlya." Zak concluded "that the G-4 was still generating interest at NII-88 as late as 1951, however he [Gröttrup] was told nothing about any progress on the project."

11 Chertok, 23. In 1948, Chertok published a book with his lectures about the A4 control system, but was ordered to scratch the printing job and to destroy all printed copies. Chertok, 46-47, quoted Yuri Pobedonostsev, the earlier GIRD and Katyusha expert: "No matter what [the Germans] come up with, it won't be in step with our current trend in ideology, which dictates that everything created recently or previously in science and technology be done without any foreign influence."

12 Boris Konovalov, *У советских ракетных триумфов было немецкое начало* [*The Soviet Missile Triumphs Had a German Origin*] (*Izvestia*, No. 54-58, 5-10 March 1992).

13 Chertok, 70. This episode is a remarkable example how 40 years of Soviet propaganda and internalized fear of falling into disgrace may have distorted Chertok's remembrance.

14 Alexander V. Korolev, "Ружаны стратегические: Немецкий след в советском ракетостроении: Городомля [Ruzhany Strategic: The German Trace in Soviet Rocket Engineering: Gorodomlya]," 2019, https://rvsn.ruzhany.info/0_2018/gorodomlja_01_00.html#my01_05. The Russian military historian (not related to Sergei K.) claims that "some of the ideas proposed by the Germans were

used in subsequent Soviet developments."

15 Matthias Uhl, *Stalins V-2: Der Technologietransfer der deutschen Fernlenkwaffentechnik in die UdSSR und der Aufbau der sowjetischen Raketenindustrie 1945 bis 1959* [*Technology transfer of German long-range guided missile technology and the establishment of the Soviet rocket industry 1945 to 1959*] (Bernard & Graefe, 1997), 16-20, 186-212; Asif A. Siddiqi, *Germans in Russia: Cold War, Technology Transfer, and National Identity* (OSIRIS 2009, 24:), 120-143, hereafter, Siddiqi, *Germans in Russia*; Jürgen Michels and Olaf Przybilski, *Peenemünde und seine Erben in Ost und West: Entwicklung und Weg deutscher Geheimwaffen* [*Peenemünde and Its Heirs in the East and West: Development and Path of German Secret Weapons*] (Bernard & Graefe, 1997), 222-253.

16 More than 300 CIA documents related to German/Soviet rocketry activities were retrieved from the CIA Reading Room (https://www.cia.gov/readingroom/home) when searching for "Gorodomlya," "Groettrup," "R-14," and the like. A comprehensive list "CIA Documents and Sources" is provided here https://owncloud.birkenwald.de/owncloud/index.php/s/GRjpnP2W22YarkA. The tab "Interrogated Returnees" names German returnees who provided information to the CIA. For US secrecy reasons, a larger number of documents still contain numerous denied pages or blanked out information.

17 Paul Maddrell, *Spying On Science: Western Intelligence in Divided Germany 1945–1961* (Oxford University Press, 2006), 186-188. The MI6 escorted about 20 "Dragon Returnees" of Gorodomlya Island from East to West Berlin for interrogation on Soviet activities.

18 Helmut Gröttrup, *Über Raketen: Allgemeinverständliche Einführung in Physik und Technik der Rakete* [*About rockets: A generally understandable introduction to the physics and technology of rockets*] (Ullstein-Verlag, 1959), hereafter, Gröttrup, *About Rockets*.

19 Helmut Gröttrup, *Aus den Arbeiten des deutschen Raketenkollektivs in der Sowjet-Union* [*From the work of the German Rocket Collective in the Soviet Union*] (*Raketentechnik und Raumfahrtforschung*, volume 2, April 1958), 58-62, hereafter, Gröttrup, *German Collective*.

20 Werner Albring, *Gorodomlia—Deutsche Raketenforscher in Rußland* (Luchterhand, 1991), published in English as *Gorodomlya Island: German Rocket Scientists in Russia* (Books on Demand, 2016), hereafter, Albring, *Gorodomlya*. From 1952 to 1979, Albring (1914–2007) taught Applied Fluid Mechanics at the TU Dresden.

21 Kurt Magnus, *Raketensklaven* [*Rocket slaves*], Deutsche Verlagsanstalt, 1993. From 1958 to 1980, Magnus (1912–2003) taught Applied Mechanics at the University of Stuttgart and Mechatronics at the TU Munich.

22 Irmgard Gröttrup, *Die Besessenen und die Mächtigen: Im Schatten der roten Rakete* [*The Obsessed and the Mighty: In the Shadow of the Red Rocket], Steingrüben*, 1958, published in English as *Rocket Wife* (André Deutsch, 1959), hereafter, Gröttrup, *Rocket Wife*. This memoir includes technical details contributed by her husband Helmut. For the fear of the KGB, Irmgard Gröttrup encrypted the Soviet names.

23 In 1996, the city of Podlipki (20 km in the north-east of Moscow) was renamed "Королёв" [Korolev] in honor of Sergei Korolev.

24 Gröttrup was an experienced rocket scientist who reported directly to Wernher von Braun and Ernst Steinhoff in Peenemünde, especially engaged in the transmission and evaluation of telemetric data. For personal reasons, he declined to join *Operation Paperclip*. In June 1946, von Braun characterized him as "an extremely clever and talented leader of a development group," capable of "gradually building up a capable group from former Peenemünde specialists who can successfully pursue all new developments for the Russians" (quoted after Rainer Eisfeld, *Mondsüchtig – Wernher von Braun und die Geburt der Raumfahrt aus dem Geist der Barbarei* [*Moonstruck – Wernher von Braun and the Birth of Space Travel Out of the Spirit of Barbarism*], Rowohlt, 1996, 178).

25 CIA, *Guided Missiles Development at Office No. 1 of Plant No. 88 Near Ostashkov* (RDP82-00457R014900010010-9, 10 November 1952), item 3, hereafter, CIA, *Guided Missiles*.

26 Uhl, 91-130; Chertok, 254, 267-369; Albring, *Gorodomlya*, 31-55; Neufeld, 51. Sergei Korolev, Valentin Glushko, Yuri Pobedonostsev and Mikhail Tikhonravov played a major role among the Soviet scientists in Germany until October 1946.

27 Chertok, 47-48; Magnus, 28-30, 43-45; Albring, *Gorodomlya*, 18; Gröttrup, *Rocket Wife*, 21.

28 James Harford, *Korolev: How One Man Masterminded the Soviet Drive to Beat America to the Moon* (John Wiley & Sons, 1997), 29-63.

29 Uhl, 126-159; Chertok, 48, 54-55, 119-140; Neufeld, 60; Dmitry Ustinov, *On the employment of the German specialists in the NII-88 of the Ministry of Armaments* (RGAE, 12 October 1951, translated in Albring, *Gorodomlya*, Appendix D). Ustinov stated the "solution of the following tasks of the German collective: (1) Assistance with the generation of technical documentation; (2) Development of projects for new rocket technology products using their experience and knowledge in this field; (3) Development and construction of facilities for the simulation of technical procedures during rocket flights as well as various measuring devices corresponding to the individual activities of the NII-88."

30 Harford, 79, refers to "13 professors, 32 doctor-engineers, and 95 diploma-engineers" among the 175 Germans in NII-88, while "only 17 of these men had actually worked at Peenemünde."

31 Mark Wade, "Astronautix: Russian Designations," 2010, http://www.astronautix.com/r/russiandesignations.html The designations R-10 for G-1, R-12 for G-2, and R-14 for G-4 were used by the Soviets, but the G- designations are preferred in this paper to avoid confusion with the later R-12 ("Dvina") and R-14 ("Chusovaya") missiles installed during the Cuban Missile Crisis in 1962.

32 Zak, "Gorodomlya," Cause for the demise of the German collective in the USSR.

33 Mikhail Pervov, *Зенитное ракетное оружие противовоздушной обороны страны* [*Anti-aircraft Missile Weapons of the Air Defense of the Country*], Moscow, 2001, 32: "After Stalin assigned Ustinov to manage the missile program, Ustinov told one of his aides that upon seeing Beria's cold stare that night, he knew that the responsibility was 'not to be taken lightly,' that this was 'a very, very serious matter,' and that 'there would be no excuses from me.'"

34 Natalya Korolyova, *Vater* [*Father*] (Elbe-Dnjepr-Verlag, 2010), 300-304, 335. Stalin called Korolev together with Ustinov for reporting to the government in April 1947 and July 1949. It was not until 1957 that Khrushchev fully rehabilitated him (and Glushko) from the *Gulag* convictions as a late appraisal of their achievements.

35 Albring, *Gorodomlya*, 55, quoted Ustinov: "Please, gentlemen, build us a good rocket; we will be very grateful to you." Gröttrup, *Rocket Wife*, 131, remembered for 1949: "[Helmut] asked the Minister [Ustinow] how much longer we would have to stay in Russia—'Until you and your entire Collective can fly to Berlin by rocket'." Frequent misperception claims that the German collective denied work for the USSR as a consequence of the forcible deportation.

36 Gröttrup, *Rocket Wife*, 132, commented in October 1949: "Today Helmut was at last given the task of developing the R-14 rocket for which our home life has been sacrificed. The past few weeks have been a physical as well as a nervous strain for him; the insoluble problem of what to do is written all over his face."

37 Christoph Mick, *Forschen für Stalin: Deutsche Fachleute in der Sowjetischen Rüstungsindustrie 1945–1958* [*Research for Stalin: German Specialists in the Soviet Armaments Industry 1945–1958*] (Oldenbourg, 2000), 191-198.

38 Albring, *Gorodomlya*, 71, described the often aggressive Soviet style of discussion, far different from the formal politeness in German academies: "The conference room in Moscow seemed like a naval battleground…One wave of attack after another surged towards us…we were defenseless in the face of this carefully planned attack."

39 CIA, *R-10 Guided Missile Project at Gorodomlya Island* (RDP80-00810A001400010001-4, 19 June 1953), hereafter, CIA, *R-10 Project,* items 139-145. This report is mainly based on Konrad Toebe's interrogation (similar drawings are depicted in Michels and Przybilski, 237-240).

40 Chertok, 47: "As part of this campaign, they organized active searches for the Russian authors of all inventions, discoveries, and the latest scientific theories, without exception." See also Mick, 220-229.

41 Albring, *Gorodomlya*, 134-145, deeply reflected why "gentle and peace-loving people work on perfecting terrible weapons" and the "person involved gains total satisfaction in mastering his topic," the dilemma of developing rockets which can be applied for peaceful purposes (satellites, space exploration) and as "arsenals of the most terrible destruction," irreversible for mankind on Earth.

42 Albring, *Gorodomlya*, 86-105; Magnus, 226-250; Gröttrup, *Rocket Wife*, 70, 138. Chertok's misconception explained these activities from the lack of challenging development tasks. The German collective worked 48 weekly hours behind secret office doors.

43 Uhl, 236-241. From June 1958, the US Army secretly deployed von Braun's *Redstone* to West Germany, and the USSR countered Korolev's *R-5M* in East Germany. A4 successors with nuclear warheads fueled the next Berlin Crisis.

44 CIA, *SIRA*, 6-7: "The technical project…presented the new design with all calculations completed and all parts drawn with sufficient detail to permit a non-specialized drawing office to proceed with the completion of a full set of production drawings."

45 CIA, *Development of Guided Missiles at Bleicherode and Institute 88* (RDP80-00810A003300530005-2, 22 January 1954), items 9-16, hereafter, CIA, *Gröttrup*. This report was based on Gröttrup's MI6 and CIA interrogation in January 1954. See also Albring, *Gorodomlya*, 72-74.

46 CIA, *Development of the R-10, R-14, and R-15 Missiles* (RDP80-00810A003500220003-6, 12 April 1954), items 1-9, hereafter, CIA, *R-10/R-14/R-15*; Anatoly Zak, "RussianSpaceWeb: G-1 project—the first review at NII-88's Scientific and Technical Council," https://russianspaceweb.com/a4_team_moscow.html#g1; Chertok, 47-48, 50-56, 60-65; Siddiqi, *Challenge*, 58-59; Siddiqi, *Germans in Russia*, 138-139; Albring, *Gorodomlya*, 70-73, supplement 7-9; Magnus, 164-179; Anatoly Zak, "RussianSpaceWeb: The R-2 ballistic missile," https://russianspaceweb.com/r2.html, hereafter, Zak, "R-2"; CIA, *R-10 Project*, items

143-147. As a Gosplan effect, test stands were delayed because all resources had to be planned and ordered on a yearly basis.

47 Ordway and Sharpe, 337, 442. Their assessment was based on CIA, *R-14 Project*.

48 CIA, *R-10/R-14/R-15*, item 12. Ustinov summarized for 1949: "Comprehensive theoretical calculations were carried out, and new proposals for the solution to individual questions of the control of the rockets were made … However, as a result of the bulky design (large overall dimensions) and, among other things, a series of unsolvable problems of aerodynamics and stabilization as well as with the fuel feed, the continuation of these tasks proved to be inappropriate." This statement is rather similar to the NTS evaluation of December 1949 for the "tremendous complexity" of Korolev's R-3 (cf. Chertok, 67-68) which eventually turned out as "far too ambitious."

49 Boris Rauschenbach, *С. П. Королёв и его дело* [*S.P. Korolev and His Lifework*], Nauca, 1998, 134. See also Siddiqi, *Challenge*, 74-77.

50 Korolyova, 324; Siddiqi, *Challenge*, 70, 72; Uhl, 178-179. In autumn 1950, none of the twelve R-2 launches met the primary objective.

51 CIA, *R-10/R-14/R-15*, item 11. Albring, *Gorodomlya*, 103, refers to a contact with Korolev in early 1951: "Sometime later, Hr. Gröttrup told me that Mr. Korolev had come to see him in his office on the island once more to discuss our final project [G-4]. According to Hr. Gröttrup, Korolev seemed depressed and when he was leaving he acted as if they were seeing each other for the last time. Gröttrup presumed that Korolev was having great personal problems." There is no other mentioning of this meeting which exactly fits to the severe R-2 and R-3 issues. For the same time, Gröttrup, *Rocket Wife,* 150-151, noted: "Moscow sends almost daily requests for further particulars about the R-14. The new Russian arrivals are keenly interested in Helmut's previous reports, and it often happens that he has to explain to the engineers the use of a formula or a calculation."

52 Anatoly Zak, "RussianSpaceWeb: Rockets: R3 family," https://russianspaceweb.com/r3.html, hereafter, Zak, "R-3". The R-3 project was cancelled in 1952 because the OKB-456's engine *RD-110* for a thrust of 120 tons (based on kerosene) failed and "Korolev was able to convince the government that R-3 was too bulky and ineffective." See also Siddiqi, *Challenge*, 99.

53 Mick, 203-209.

54 Gröttrup, *Rocket Wife,* 141-146; Magnus, 219-223.

55 Yevgeny Pitovranov (RGAE Register 397, 15 July 1951) quoted by Uhl, 205, 261: "Nevertheless, due to the special situation in Branch No. 1 of NII-88, especially in connection with the work on particularly important problems, we consider it appropriate to keep these personas in the USSR and transfer them to tasks with non-secret relevance for 1½ years."

56 Magnus, 254-256, 296-345; Gröttrup, *Rocket Wife*, 163-165, 175-183: "Were political reasons the only ones, or was there some technical reason for their choice? We never hear anything now about the Russian rocket programme, although Helmut and Jochen [Umpfenbach] guess what they can from what they are ordered to do. This is not just idle curiosity: their brain-child is very close to their hearts and they are keenly interested to know whether the practical tests and the firing tests confirm their theoretical work."

57 Magnus, 344. This obligation demanded absolute concealment about places, institutions, the nature of work, and involved Soviet citizens.

58 Maddrell, 222-225, 280-281: "The best-informed of them was Gröttrup; a British intelligence analyst [Young] commented [in January 1954] that he had provided 'useful pointers regarding parallel Russian developments'." See also Neufeld, 55-56.

59 CIA, *Gröttrup*, items 29-31. The identical arguments are found within Gröttrup's legacy documents NL 281 (Deutsches Museum, 2017) for his MI6/CIA interrogations (December 1953 to February 1954). See also Gröttrup, *Rocket Wife*, 161, quoting Helmut: "The Russian physicists would treat us quite differently. The intelligentsia here has a real liking for physics and they won't remain blind to its findings."

60 The CIA's *National Intelligence Estimate (NIE)* of 11 June 1954 predicted Soviet ICBM series production for 1963. See also CIA, *SS-6*, 27-31.

61 Gröttrup, *About Rockets*, 25, 122-159; Gröttrup, *German Collective*, 62. Gröttrup made his way in West Germany, invented the smart card in 1967, and developed banknote processing systems at Giesecke+Devrient, Munich, laying ground for the *ISS/BPS 3000* which has been used by the US Federal Reserve System since 1992.

62 Irina Suslina, Немецкие специалисты и ракеты России—Остров Городомля [*German Specialists and Russian Rockets—Gorodomlya Island*] (St. Petersburg Polytechnic University, 2009), 154-229, hereafter, Suslina, *Russian Rockets*. A summary of her archival research findings is included in Albring, *Gorodomlya*, supplement 37-48. The drawing is rather similar to Toebe's design sketches in CIA, *R-10 Project,* 31, 42. It clearly demonstrates how German documents were completely Russified.

63 CIA, *R-10 Project*, items 24-44, 74-85, 109-118; Gröttrup, *About Rockets,* 125-130; Albring, *Gorodomlya*, 18; Chertok, 51, 60.

64 Zak, “R-2”; CIA, *R-10 Project*, items 81-82.

65 CIA, *R-10 Project*, items 51-73, 89-91; Albring, *Gorodomlya*, 18-19, 99-101; CIA, *R-14 Project*, items 18-25, 82.

66 Chertok, 49-51, 139, 242-243, 397; Zak, “R-2”; RSC Energia, “Energia: Launchers: Rocket R-5,” 2021, https://web.archive.org/web/20211023212134/https://www.energia.ru/english/energia/launchers/rocket-r5.html, hereafter, RSC Energia, “R-5.”

67 Uhl, 171, 177-179; CIA, *R-14 Project*, items 26-43, 81. The new steel became brittle at very low temperatures and was not suitable for the LOX tank.

68 CIA, *R-10 Project*, items 35-37; RSC Energia, “R-5”; Gröttrup, *German Collective*, 58-59.

69 RSC Energia, “R-5”; RSC Energia, “Energia: Launchers: Rocket R-7,” 2021, https://web.archive.org/web/20211021165926/https://www.energia.ru/english/energia/launchers/rocket-r7.html, hereafter, RSC Energia, “R-7”; Anatoly Zak, “RussianSpaceWeb: The R-5 ballistic missile,” https://russianspaceweb.com/r5.html, hereafter, Zak, “R-5.”

70 Mark Wade, “Astronautix,” 2019, http://www.astronautix.com; Uhl, 177-189; RSC Energia, “R-5”; RSC Energia, “R-7.” Weight and thrust values vary between development stages and source.

71 CIA, *R-14 Project*, item 50; CIA, *Gröttrup*, item 23; Zak, “R-3.”

72 CIA, *R-14 Project,* items 36, 71-72, pp. 33-36; CIA, *Gröttrup*, items 22-23; CIA, *Guided Missile Activities at Ostashkov and Kapustin Yar* (RDP80-00810A007400250006-0, 23 September 1955), item 29, hereafter, CIA, *Activities at Ostashkov*; Gröttrup, *About Rockets*, 158; Uhl, 168; Zak, “R-3.”

73 Suslina, *Russian Rockets*, 199.

74 RSC Energia, “R-7”; Chertok, 290-292; NPO Energomash, “ЖРД РД-107 и РД-108 и их модификации [RD-107 and RD-108 Liquid-Propellant Engines and Their Modifications],” http://www.lpre.de/energomash/RD-107/index.htm#-sources.

75 RSC Energia, “Energia: Launchers: Rocket R-9,” https://web.archive.org/web/20211024160135/https://www.energia.ru/english/energia/launchers/rocket-r9.html; Mark Wade, “Astronautix: R-9,” 2019, http://www.astronautix.com/r/r-9.html; Mark Wade, “Astronautix: RD-111,” 2019, http://www.astronautix.com/r/rd-111.html.

76 CIA, *R-14 Project*, items 28-30; CIA, *Gröttrup*, item 21.

77 Zak, “R-5”; RSC Energia, “R-5”; RSC Energia, “R-7.”

78 CIA, *R-10 Project*, items 86-88; CIA, *Gröttrup*, items 20, 23; Gröttrup, *German Collective*, 59; CIA, *USSR Guided Missiles Development* (RDP80-00810A004600480001-1, 18 November 1954, released 28 October 2008 with 68 pages denied), 9, hereafter, CIA, *USSR. Missiles*. Ustinow for 1948 (quoted in Albring, *Gorodomlya*, Appendix D): “The Germans developed a series of measuring devices, such as a probe for measuring the quantity of fuel in the rocket tanks, and also differential manometers with safety valves, a dynamic thrust sensor, a summating [integrating] gyroscope and equipment for its testing and variants of transformers and similar.”

79 CIA, *R-10 Project*, item 142; CIA, *R-14 Project*, item 8; CIA, *Gröttrup*, item 25; Gröttrup, *German Collective*, 59-60; Gröttrup, *About Rockets*, 156-160. The US *Saturn V* was launched with a thrust-to-weight ratio of approx. 1.20, the Soviet N1 with a ratio of 1.3, since four out of 30 engines could be shut down in case of failure.

80 RSC Energia, “R-7”; Chertok, 292-293. SOBIS = Sistema oporozheniya bakov i sinkhronizatsii [Tank Depletion and Synchronization System]. See also: Russian Wikipedia, “Система опорожнения баков [Tank emptying system],” https://ru.wikipedia.org/Система_опорожнения_баков.

81 Albring, *Gorodomlya*, 97-103; CIA, *R-10 Project Missile*, item 72; CIA, *R-14 Project*, items 9-12, 26-29; CIA, *Gröttrup*, items 21-23, 25. Toebe stated: “Although [conical] shape was not advantageous for the initial phase of the flight, the air resistance would not be intolerable. The relatively low speed in the denser atmosphere would keep this resistance small.”

82 Gröttrup, *About Rockets*, 106-110; Michels and Przybilski, 236-240.

83 Gröttrup, *Rocket Wife,* 127-128, 185. Helmut is quoted with the words: “It won’t be easy for Wernher von Braun to explore new avenues. We are unencumbered, and men like Wolff, Albring, Magnus and Umpfenbach are irreplaceable. I am sure we’ll succeed with this new venture. Their [Russians’] ballistics is based on a long-standing tradition, and they know a great deal about it. The Russians are sure to agree to the new project.”

84 Chertok, 188-189.

85 RSC Energia, “R-5”; RSC Energia, “R-7.”

86 Based on CIA, *R-14 Project*, 23-24. The G-4 dimensions (unreadable in the CIA document) are based on Konrad Toebe‘s private documents; R-7 sketch from http://www.ninfinger.org/models/vault2007/R-7/index.html, soyuz-u2-2-SCALE-DATA.jpg.

87 Michels and Przybilski, 237; Chertok, 66.

88 CIA, *R-14 Project*, item 6a. The US *Atlas* jettisoned the booster engines during the ascent, keeping the tanks with remaining propellants.

89 CIA, *R-14 Project*, item 6b; CIA, *R-10 Project*, item 98; Uhl, 171, 211.

90 Siddiqi, *Challenge*, 103-105; Chertok, 168, 470-471.

91 RSC Energia, "R-7"; Chertok, 73, 237, 290, 294-295, 301-305.

92 CIA, *Guided Missiles*, items 8-9; CIA, *R-10 Project*, item 85; CIA, *Gröttrup*, items 14, 17-18; CIA, *R-14 Project*, items 44, 47; CIA, *Rocket Engine Testing at NII 88, Gorodomlya Island* (RDP80-00810A000100380009-3, 19 June 1953), item 8, 44-60; CIA, *USSR Missiles*, 7; Suslina, *Russian Rockets*, 183-188; Gröttrup, *Rocket Wife*, 186; Gröttrup, *German Collective*, 61; Gröttrup, *About Rockets*, 145-147; CIA, *Activities at Ostashkov*, items 20-21, 15-18.

93 CIA, *Gröttrup*, item 18; CIA, *USSR Missiles*; CIA, *Activities at Ostashkov*, items 22-24. Some sources claim that Aleksei Isaev of NII-88 proposed staged combustion in 1949, but this was probably sparked by the earlier German G-1 proposals.

94 Wikipedia, *S.15400*, https://en.wikipedia.org/wiki/S1.5400; Energomash, ***ЖРД РД-253 (11Д43) и РД-275 (14Д14)*** [RD-253 (11D43) and RD-275 (14D14) liquid-propellant engines], http://www.lpre.de/energomash/RD-253/index.htm; Energomash, ***ЖРД РД-170 (11Д521) и РД-171 (11Д520)*** [RD-170 (11D521) and RD-171 (11D520) liquid-propellant engines], http://www.lpre.de/energomash/RD-170/index.htm. In the US, the *RS-25 Space Shuttle Main Engine*, first launched in 1981, also applied a staged combustion cycle, but with a fuel-rich approach.

95 Uhl, 178; Chertok, 52.

96 Chertok 52, 61-64, 67, 125, 177-179, 184, 193.

97 Russian Wikipedia, ***С-25*** [S-25], https://ru.wikipedia.org/wiki/%D0%A1-25: "German rocket specialists taken from Germany after the war and a 'special contingent' of imprisoned Soviet specialists moved from SB-1 to KB-1" for developing surface-to-aircraft missiles, inheriting all work from the NII-88 on the *Wasserfall* missile (see also Chertok, 62-65, 185, 203; Mick, 147-148).

98 CIA, *Project R-113 at Branch No. 1 of NII-88 on Gorodomlya Island* (RDP80-00810A001600390007-5, 24 August 1953), items 2-7, 15-22; CIA, *Comparison of Ballistic Data on the Wasserfall and R-113 Missiles* (RDP81-01030R000100460006-4, 9 April 1954), items 10-14; Uhl, 208-209. On Gorodomlya, work on R-113 continued until April 1951 (cf. Harford, 88).

99 Chertok 62-65, 185, 203, 208-210: "The designs for the *Berkut* system were so grandiose and radical that no one at NII-88 could even dream of them."

100 Uhl, 212; Chertok, 68, 73; Anatoly Zak, *The Rest of the Rocket Scientists* (*Air & Space Magazine,* September 2003), https://www.smithsonianmag.com/air-space-magazine/the-rest-of-the-rocket-scientists-4376617/.

101 Harford, 79-80.

102 Magnus, 107-108. Gröttrup's, Magnus' and Albring's memoirs do not indicate that Korolev avoided close contact "for purely personal reasons" or that he "ignored everything that had to do with the work of the German collective" as insinuated by Chertok, 47-49, who erroneously claimed that Korolev did "not once visit the island nor did [he] associate with Gröttrup or with the other leading German Specialists." Korolyova, 322, and Zak, "Gorodomlya," reported on visits in the summer of 1948 and October 1949.

103 Magnus, 352-358, concluded: "It is therefore safe to assume that some of the procedures and projects worked out in Podlipki or Gorodomlya were incorporated into later Soviet developments. But Korolev's own outstanding contribution to both the launch of the first Soviet satellite and the realization of the first manned space flights is undisputed."

104 Harford, 123-124; Chertok, 239-538; Uhl, 192-247. Harford, 45, referred to their early "passion for space" in 1934 when they participated in a conference for the *Study of the Stratosphere*. Magnus, 29-30, remembered Korolev's confession during a Bleicherode meeting in 1946: "And if we increased the cut-off velocity further by about 40 per cent, then we would visit the Moon. Let's all work together to achieve this."

105 Helmut Gröttrup, *Deutsche Raketenspezialisten in der Sowjetunion* [*German Rocket Specialists in the USSR*] (Mitteilungen der Deutschen Gesellschaft für Raketentechnik und Raumfahrt 11, February 1958), 20-22.

106 Albring, *Gorodomlya*, 103-104. This talk was private. In the German Democratic Republic, any public reasoning of exclusive Soviet achievements was perceived as suspicious doubt about the USSR leadership, cf. Uhl, 17.

107 *Zavod Zvezda* [Russian for "Star Enterprise"], a subcontractor of *RSC Energia*, is specialized in high-precision gyroscopes and sensors for space travel, goes back to Nikolay Pilyugin and NII-885. A video on its history page includes images and video clips from early Soviet rocketry activities, Gröttrup and Korolev (from 1:45 to 2:30), http://www.zavod-zvezda.ru/istoriya.html. See also Chertok, 407-408.

108 Elena Borisova, *Звездные страницы* [Star Pages] (commemorative publication issued by Zavod Zvezda on the 70th anniversary of rocket development on Gorodomlya Island, Solnechny, August 2016), 7-9. The brochure was published with 2,000 copies for the employees.

109 Chertok, 73. However, due to many similarities with German G-4 concepts, his claim that "R-7 was free of the 'birthmarks' of German rocket technology" is not sustainable.

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