New postwar branches of defence industry (1): rocketry*

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Before World War II the Soviet Union was a regional military power but certainly not a world player. Within a few years after the war, as a result of the rapid development and deployment of new weapons, the USSR had become one of the two global superpowers. Its defence industry, and especially the creation of new production branches for atomic weapons and missiles, jet aviation, and radar, played a fundamental part in this process.

The development of these branches was therefore a success story in Soviet terms. Sometimes it is claimed that this was the *only* success story. Hence the stereotype of the Soviet Union as 'Upper Volta with rockets'. But quite apart from demeaning both the USSR and Upper Volta (a country no doubt rich in history, if poor in GNP), this cliché begs the question of how the Soviet Union, itself a relatively poor, newly industrialising country, had the capacity to become a strategic missile superpower.

In this chapter I explore the effort which was required of the Soviet Union for such rapid progress in the case of rocketry. This progress depended partly on the Soviet Union's own scientific and technological (S&T) resources, and partly on advances made in other countries; it was Germany where many of the most important wartime advances had been made. At the end of World War II the Red Army was in occupation of a sizeable fraction of the German scientific and industrial potential for new weapons, and both the occupation authorities and the Kremlin leadership made determined efforts to exploit this fact. Thus it is of very great interest to establish what were the respective contributions of Soviet and German prewar and wartime rocketry to creating the new postwar strategic missile industry in the Soviet Union.

Much of this investigation can be carried out on the basis of sources available in the west for many years, especially the official accounts of the development of Soviet missile technology, US government evaluations, the memoirs of German scientists, and so on. Other

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sources have become available only comparatively recently: a few documents in Moscow, secondary accounts written by Russian historians with access to ministerial archives, and the memoirs of Soviet participants. These throw further light on the facts previously established.

Soviet rocketry: some issues

A short history

Soviet rocketry was already militarised in the 1920s. There were two main agencies for such research, the Gas Dynamics Laboratory (GDL) of NKVM (the commissariat for the armed forces), and the Jet Propulsion Research Group (GIRD) of Osoaviakhim (the civil defence society). In 1933, largely on the initative of the Red Army's chief of armament Army Commander (later Marshal) M.N. Tukhachevskii, rocketry was centralised in a new Jet Propulsion Research Institute (RNII) under Narkomtiazhprom (the heavy industry commissariat, responsible for defence industry). Its main lines of development were rocket artillery and aviation.[1]

Rocket artillery involved small solid-fuelled rockets, launched from tubes mounted on trucks or aircraft, which could be fired in salvoes at the ground forces of the enemy. The aviation uses of rocketry included booster rockets, which could be either solid- or liquid-fuelled, to assist piston-engined aircraft in take-off and combat manoeuvres. Rocket aircraft, for which the rocket was the main motor, were usually powered by larger liquid-fuelled rockets.

By the beginning of World War II the Soviet Union possessed a commanding lead in solid-fuelled rocket artillery. The first military use of rockets was against the Japanese in 1938 at Khalkin-Gol as an air-launched weapon. In the years before 1941, rocket mortar shells launched from truck and tank platforms were also successfully developed. Most famous of these weapons was the BM-13 *Katiusha* designed by G.E. Langemak, a solid-fuelled barrage missile which delivered a 22kg warhead over a 5km range; its terrifying salvoes gave the Red Army a decisive edge in rocket artillery in World War II.

If we speak of a German lead in rocketry, therefore, we must immediately qualify it by adding that it was not in artillery, but in rocket aviation and long-range rocketry based on larger, more complex liquid-fuelled rocket motors. This lead is illustrated in table 6.1. By the end of World War II the piston-engined aircraft had reached its limits of speed and altitude. Liquid-fuelled rockets were tested first in Germany in 1931; Tikhonravov's GIRD-09 was tested two years later in 1933. The first German rocket aircraft, the Heinkel He-176, was flight-tested in 1937; the Soviet Union's RP-218 designed by S.P. Korolev, was ready for flight testing in 1938, but for reasons to be explained the programme was cancelled. A modified aircraft, the RP-318, slower and less powerful than the He-176, was test-flown in 1940. In wartime the

[1] GARF, 8418/6/243, 35-7.

Soviet lag persisted. The BI-1, tested in the Soviet Union in 1942, was technically the world's first rocket fighter; the German Messerschmitt Me-163a, which preceded it, lacked armament. But the BI-1 never got beyond the experimental stage; the Me-163b of 1943 was, in contrast, an operational aircraft and was used in action. The BI-1 was jerry-built, and suffered from a fundamental design flaw - its straight leading-edge wing, which caused it to lose aerodynamic stability at transsonic speeds. The Me-163 was not only more powerful, but also had a revolutionary delta wing.

None of these bore comparison with the German V-2. The first long-range missile, with a range of 240km and a rocket motor developing 25 *tons* of thrust, the V-2 was in a class of its own. Conceived in 1936, the V-2 would have been ready for testing in 1940 but for Hitler's premature judgement (in 1939) that the war would be over before it was ready for use. Tested in 1942, by the end of 1944 it was being mass-produced; immune to air defence, it was used to bomb London as well as cities in liberated northwestern Europe. It was the single most important technological prize for the invading Allied armies in 1945.

The Soviet rocket specialist G.A. Tokaty, who defected to Britain in 1948, later cited from his own introduction to a Soviet official report prepared in postwar Germany:

> Point by point comparisons disprove the somewhat rooted opinion that we are, scientifically and technologically, inferior to the Germans, French, British and Americans ... M.K. Tikhonravov's rocket No. 09 was launched long before V-2 appeared on paper; ... L.S. Dushkin's engine ORM-65 was designed, built and test-fired before anybody knew about the German HWK-109-509; ... our B-1 was designed, constructed, and flight-tested before the German Me-163B ... But the historic fact is that they, the Germans, produced thousands of V-2s and many Me-163Bs, while we failed to have operational rockets of the V-2 calibre and rocket fighters.[2]

But even these words understated the German achievement, which was not just a production success. The German Messerschmitt Me-163a (though not the Me-163b) flew *before* the Soviet BI-1, and the Soviet ORM-65 (designed by V.P. Glushko, not Dushkin, for the abortive RP-218) never flew at all, although Dushkin's derivative RDA-1-150 powered the first rocket flight of the RP-318 in 1940. And Tikhonravov's GIRD-09 was not remotely comparable with von Braun's far larger and more powerful German V-2.

After World War II, the Soviet Union quickly caught up with German wartime standards and surpassed them. By 1947 Soviet rocket designers had built a rocket plane, the I-270, more powerful than the Me-163b.[3] The I-270 probably took German designs as a starting point, but it was soon recognised that these held little of importance for the

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[2] Tokaty (1968), 343.

[3] Egorov (1994), 419-20.

future.[4] More significant was the fact that by 1948 they had built an improved version of the V-2 which they called the R-1 (its NATO designation became SS-1 *Scud*), and by 1949 a longer-range missile based on a different concept, the R-2 (SS-2 *Sibling*). Within a few more years they would have intercontinental ballistic missiles, space rockets, and the *sputnik*.[5]

Leads and lags

Traditional accounts of Soviet rocketry are mainly concerned with establishing technological leadership, that is, with answering the question 'who was first?' in relation to invention (the creation of a working concept), and then innovation (its application to production).

To begin with there are two extremes. In Soviet accounts the postwar development of Soviet rocketry was represented in such a way as not to acknowledge German technological leadership, or at least any German priority of invention. Instead, Soviet writers (including Tokaty, who, having defected, was entirely free from official restraints) emphasised the home-grown antecedents of postwar Soviet technological developments. The memoirs of even the frankest participants limited the German contribution to priority in establishing a missile industry based on mass production.[6] At the other extreme were western historians such as Antony Sutton, who wrote a multivolume work on the history of Soviet technology in the 1960s and 1970s.[7] Sutton's essential message was that western capitalism exercised technological leadership almost exclusively; the great majority of Soviet machinery products had western origins. It was the Soviet capacity to import and copy western products, and the willingness of western countries to make their technologies available, that gave the Soviet Union the technology of a superpower.

In between the two extremes are those who found that, like the Soviet dogmas against which it reacted, Sutton's approach failed to provide a satisfying account of the Soviet technological development process. By concentrating on identifying western antecedents for Soviet machinery products, it neglected those less numerous fields where technological leadership belonged to the Soviet Union, and exaggerated the relative contribution of western inventiveness. In the 1970s and 1980s specialists associated with the Centre for Russian and East European Studies at the University of Birmingham developed an

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[4] Albrecht (1993), 41-2.

[5] The R-1/SS-1 *Scud* was fired in anger 43 years later by Iraq in the war for Kuwait (Albrecht (1993), 90).

[6] In addition to Tokaty, cited above, see also the interview with V.P. Mishin conducted by Konovalov (1991). Similar statements, one by Glushko, another attributed to Korolev, are cited by Albrecht (1993), 80.

[7] Sutton (1968, 1971, 1973).

intermediate approach. They criticised both Soviet orthodoxy and the dogmas of western Cold Warriors. While accepting that in an aggregate sense the Soviet Union was a technological laggard, they identified a more differentiated pattern of sectoral leads and lags which varied across branches of industry and shifted through time.[8] This more realistic approach was an advance, although it was still within the limits of an inquiry into technological leads and lags.

One such limitation is that the traditional leads-and-lags approach, no matter how objectively pursued, tacitly assumes all countries to be converging on the same predetermined path of technological development unless prevented by unsuitable institutions. If this was the case, then certainly the only interesting research task is to establish who first identified the path to be followed, and the delay after which others followed. But what if the path wasn't given in advance, but was worked out as part of a conditional, path-dependent process?

Whether and how laggards catch up with leaders is a major concern for modern growth economics. Empirical investigation usually shows that catching up is a conditional, not automatic process. Catching up appears to require societies to display a 'social capability' for taking up technological opportunities.[9] The overcoming of a lag is as remarkable as the establishment of leadership. Success in imitation needs to be explained just as much as invention. According to David Landes,

> Th[e] readiness and even eagerness to learn from others, including other Europeans - industrial espionage is a theme running through all modern European history - was testimony to an already thriving indigenous technology; good innovators make good imitators.[10]

Echoing Landes, Joel Mokyr has called the gain from imitation an 'exposure effect' arising from 'openness to new information', and points out that 'not all societies were capable of taking full advantage of exposure effects'.[11] Imitation was not necessarily an easy option. According to Ulrich Albrecht, the 'Russification' of imported technologies usually involved a major R&D effort for adaptation to local conditions; copying without adaptation usually resulted in failure. Albrecht therefore proposes 'add-on' engineering as more accurate than

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[8] See Amann, Cooper, and Davies (1977) (see especially chapters by Holloway (1977), Kocourek (1977); Amann and Cooper (1982, 1986) (especially chapter by Holloway (1982)). For a more recent work in this worthy tradition, by a German historian in English translation, see Albrecht (1993).

[9] Abramovitz (1986)

[10] Landes (1969), 28.

[11] Mokyr (1990), 188.

the more usual term ‘reverse engineering’ to describe what really happened.[12]

The technological frontier

Talk of catching up presupposes that we can identify the technological frontier. The idea of a frontier always presents us with three problems: (a) where is it? (b) in which directions is it expanding? (c) where is the optimum? In rocketry in the 1940s these questions were made particularly difficult to answer by increasing returns and technological interdependence. To answer them fully required readiness to finance an expensive, pluralistic, open-ended process of technological exploration. On the part of inventors it also demanded an obsessional drive hard to distinguish from selfishness and wrong-headedness.

Increasing returns

Increasing returns were present in the trilateral trade-off between three attributes of missile technology together making up its military value: *mass* (the number of rockets to be built from given resources), the *destructive power* of each rocket (let us say, the product of range and payload), and *control in flight* (the capacity to manoeuvre, select a target, and return for reuse). Each of these attributes was embodied to an extreme in one or another of the outstanding products of the time. The Soviet *Katiusha* rocket represented the principle of mass - a barrage weapon, solid-fuelled for one-time use, small and expendable, more terrifying than accurate or destructive, fired in salvoes. The German Be-163 and Soviet BI-1 were built for control in flight by a pilot; their rocket motors used more powerful liquid propellants, requiring greater technological sophistication, capable of throttling in flight and of refuelling on the ground for repeated use. For its time the German V-2 represented the ultimate in destructive power.

In between these three extremes there was very little of interest to the military user. As small solid-fuelled rockets were made larger or of longer range, the destructiveness of their shotgun effect on the enemy’s front line diminished rapidly. Only a very large, very long-range missile could be matched with a target of commensurate value and a guaranteed destructive effect - a city, say. Similarly, there was little point in making small liquid-fuelled rockets either for aviation (not powerful enough to propel a piloted aircraft) or for bombardment (too expensive to justify single use against tactical targets). Only large ones made sense for piloted flight, or very large ones for strategic use.

Figure 6.1 illustrates the technological frontier under increasing returns. Increasing returns made it easy for designers to become locked into one specialised aspect or another or rocketry, and to ‘miss’ developments which were technologically available but required leaps of imagination. Varying the mix of attributes in the direction of the average brought few or even negative returns. Wherever the optimum was, it did not lie in compromise.

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[12] Albrecht (1993), 97-100.

Technological interdependence

The uses of rocketry depended to a high degree on the parallel development of complementary technologies, especially the turbojet and the atomic bomb.

The paths of rocket and jet technology were interwoven as scientists addressed the possible application of rocketry to aviation. How was jet propulsion to be applied most effectively to solving the problem of high-speed, high-altitude flight? In the 1930s, most saw it in rocketry. Only a visionary few saw it in the air-breathing jet engine, which obtained its supply of oxidiser from the atmosphere and did not have to carry its own oxidiser supply. The concept of the turbojet was developed simultaneously in Britain, Germany, and the Soviet Union at the end of the 1920s.[13] In the 1930s, practical work proceeded in parallel in Germany and Britain, but the first jet aircraft did not fly there until 1939 and 1941 respectively. By the end of World War II jet aircraft operated under combat conditions in small numbers on both sides, but the real shift out of piston engine technology would come after 1945.

In the meantime the stress and temperature requirements of an operating turbojet required great advances in metallurgy and fuel science; these were beyond the reach of many countries such as the Soviet Union where the first indigenous turbojet design was built only in 1945, and then only for experimental use in ground testing.[14] Even in western Europe and the United States the future preeminence of turbojet aviation continued to be widely contested. Many experts regarded Frank Whittle as an obsessed crank, and for much of the 1930s it would have been hard to find the evidence to prove them wrong. This is why rocket aviation remained on the R&D agenda for so long, not only in wartime Germany but also for a few postwar years in the Soviet Union and the United States. There was not yet any guarantee that other means would be found in the foreseeable future to make aircraft fly higher and faster than before.

Thus, because air jet technology did not develop in a predetermined way, the path of rocketry was also unpredictable, and was dominated by uncertainty. The application of rocketry to aviation was conditioned by the difficulty of solving the problems of the turbojet, which in turn depended on advances in fuel science and metallurgy. In much the same way, the evolution of the ballistic missile depended on finding something worthwhile to put in the warhead, and this turned out to rest upon advances in nuclear science and technology of which few rocket scientists could have had even a glimmering of suspicion before 1945.

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[13] B.S. Stechkin's article outlining the concept of the turbojet appeared in Russian in 1929; the priority of invention is usually accorded to Frank Whittle, whose first UK patents were registered in 1930; and it was in Germany that the first turbojet-powered aircraft, the Heinkel He-178 (based on a design independent of Whittle's) flew in August 1939. See Egorov (1994), 424; Gibbs-Smith (1970), 196.

[14] Egorov (1994), 435.

The development of large, reliable, liquid-fuelled rockets was hugely expensive; justifying the expense required correspondingly valuable targets which could be attacked with sufficient accuracy and a weapon of sufficient destructive power (accuracy and destructive power could be traded off against each other, of course) to damage or destroy them.

Would the atomic bomb prove practicable? If so, then could it be delivered against targets of intercontinental range, and how large a rocket would be required? The first atomic weapons were too bulky to go in anything but relatively slow, vulnerable aircraft.[15] In the subsequent search for an efficient combination of bombs and missiles, the evolution of national technologies diverged; the Soviets took the quicker road of building very powerful rockets to carry very bulky bombs, whereas the Americans took the slower road to miniaturisation of weapons which could be carried by smaller, cheaper rockets.[16] In this it could be said that each country initially followed its comparative advantage, but the result was optimal for each only in a very short term sense. In the long run, each country found itself locked into a disadvantageous path with heavy switching costs; the Americans struggled to lift heavy payloads into space, while the Russians lost the race in nuclear weapon technology.

In summary, in the interwar period, Soviet rocketry specialised in solid-fuelled rocket artillery and liquid-fuelled rocket aviation. Soviet designers did not see the opportunity seized by von Braun and the Germans in long-range strategic bombardment; instead they built the *Katiusha*. They invested few resources in turbojet development, and concentrated significantly on rocket aviation, but here too they lagged both in propulsion technology and airframe design. Rocket artillery was the only area in which they established world leadership. But this acquires greater significance when we reflect that the Soviets were therefore laggards in everything *except that which actually counted* on the battlefield in World War II. None of the areas in which others led were sufficiently developed by 1945 to make a difference to the war. The V-2 was too inaccurate, too unstable, too limited in range, and too expensive to be really worth firing off in large numbers at Allied cities with a merely conventional warhead. Turbojet aviation was still in its infancy, and German turbojets were tricky and unstable.

Still, Soviet designers did not explore the whole surface of jet propulsion technology before 1945. The special German achievement was to show where a significant section of the frontier actually lay; they showed that the concept of a big, long-range ballistic missile was realisable. If it had been realised once in Germany, it could be realised again by others.

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[15] Holloway (1982), 393.

[16] Von Braun and Ordway (1975), 140.

Explaining the Soviet lag

There were several possible factors in the Soviet pattern of leads and lags. I classify them below under overall resources, institutions (the military R&D system), and the influence of a conservative technology policy.

The shortage of overall resources

A shortage of overall national resources certainly limited the Soviet innovation process relative to Germany's. Soviet prewar real GDP was of a magnitude similar to Germany's, but the ratio of GDP per head was only about two fifths. The two countries had industrial workforces of similar size, but in the Soviet Union industrial productivity was much lower. Thus the USSR certainly had fewer and lower-grade resources available to spend on military R&D. This must be regarded as an important conditioning factor, given the very high cost of the kind of open-ended exploration of all aspects of the technological frontier in rocketry which was required if the chances of missing a technological opportunity were to be minimised.

Overall resources, however, were not the decisive factor. The UK, with an economy the same size as Germany's and richer in per capita terms, was behind Germany in rocketry if not also in jet technology; the USA, with its far larger and wealthier economy, was well behind Britain and Germany in both respects.

The military R&D system

Institutional factors peculiar to the Soviet economy might be construed as inimical to a pluralistic, experimental approach to military technology. The general principles underlying Soviet economic organisation included a hostility to the duplication of facilities involved in competition. The economy of resources associated with centralisation of effort was commonly regarded as more important than the danger of missing out on successful applications. Uniquely, however, these constraints were not applied to military R&D.

The record of Soviet military-technical innovation before, during, and after World War II was outstanding in many fields. Without doubt this reflected effective military R&D institutions. The Soviet R&D system in the aircraft, tank, and armament industries was characterised by pluralism and competition among rival design bureaux. There was only one real client, the defence ministry, but there were several arenas in which to plead for threatened causes. The Army, as the final consumer of new weapons and equipment, encouraged innovation and enforced high standards. This setup provided a quasi-market test for Soviet weapon designers and defence suppliers at least as effective as the quasi-markets for military goods in Germany, France, Britain, or the United States. Soviet designers were able to produce at least some first-class guns, tanks, and aircraft in the course of preparation for World War II. In rocketry itself, lack of resources did not stop the pioneering development of the *Katiusha*.

But it was probably significant that the rocket mortar had an obvious and immediate military application. On the other hand, the advocates of large liquid-fuelled rockets for use in aviation were widely suspected of being dreamers with a hidden agenda of space exploration decades in the future - 'space fanatics' - and in this there was more than a grain of truth.[17]

Soviet military R&D institutions were effective under most but not all circumstances. They appeared to fail under two conditions, (a) if the project was too big for rivalry to be financially feasible, or (b) if rivalry was resolved by political coercion. In the case of liquid-fuelled rocketry both were undoubtedly present and interacted with each other. Liquid-fuelled rocketry was very expensive, so that scientists' demands continually outran the resources available. The security organs were suspicious of scientists who wanted to spend so much government money on projects of doubtful immediate utility.

Technological conservatism

A tradition of conservatism in Soviet policy for military R&D was noted by the Soviet atomic scientist P.L. Kapitsa in the following terms:

> ... suspicion of scientists and engineers was a major reason for the Soviet Union's poor record in developing technologies that were new in principle ... Soviet ideas did not receive full support until and unless they had been proved by Western experience.[18]

Rocket aviation was often regarded as a diversion from the real task of developing weapons for the coming war.[19] When rocketry was centralised in 1933 in the RNII, rocket aviation was omitted from its terms of reference. Korolev's work was only adopted by the RNII in 1935, after a campaign fought within the Red Army and Academy of Sciences.[20] Even this victory was short-lived. Soon the country was swept by the Ezhov purges. In 1937 Tukhachevskii, the Red Army's leading proponent of rocketry in all its applications, was arrested and executed as a traitor. The purge of RNII began in October with the arrest of the institute's director I.T. Kleimenov and the *Katiusha*'s designer Langemak.[21] In June 1938 work on Korolev's rocket plane was suspended, the apparent grounds being the need to concentrate resources for rearmament on projects of more immediate military

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[17] See for example Albrecht (1993), 87.

[18] Cited by Holloway (1994), 147.

[19] Kerimov (1994).

[20] Egorov (1994), 398-9.

[21] Albrecht (1993), 76.

application.[22] A few days later Korelev was arrested, accused of being a Trotskyist saboteur, and sentenced to ten years' forced labour.[23]

Official hostility to Korolev's work on rocket aviation was clearly a factor (according to one source he was accused of 'criminal lack of results').[24] It is true that the NKVD showed little bias towards *individuals* engaged in different lines of work. Korolev and his chief collaborator, the liquid-fuel propulsion expert Glushko, were both imprisoned, but Langemak perished, credit for his work being redirected to his assistant A.G. Kostikov, who survived.[25] But impartiality towards individuals did not mean indifference to alternative projects. The rocket artillery and air jet programmes were continued, while the testing of liquid-fuelled rocket aircraft was cast temporarily into limbo.

Thus several of the Soviet Union's rocket specialists were executed or dispersed to forced labour camps, and began the war in prison. The lucky ones were eventually reemployed in the NKVD's special design bureau (*sharashka*) no. 29 under the aircraft designer A.N. Tupolev, where they designed jet and rocket boosters for piston-engined aircraft and other auxiliary projects of immediate application, but they were no longer in a position to follow the path dictated by their own inventiveness. The RNII itself was disbanded, and rocketry was reorganised under NII-3 of the commissariat for ammunition; under wartime pressures the latter was renamed the State Institute for jet propulsion technology (GIRT) in 1942.

It hardly needs stressing that imprisonment and execution were not appropriate arguments in the incentive structure facing Soviet defence designers. On the other hand there may have been a grain of truth in the accusation levelled against the rocketeers that they were diverting state funds for defence into private projects for space exploration. The ultimate goal of stepping off the earth into the cosmos was clearly a powerful motive among the Soviet rocketeers. In the postwar years this motive would be openly acknowledged, but only after space exploration had been legitimated by virtue of its military applications and contribution to Soviet prestige. Ironically, exactly the same accusation was levelled against von Braun and his German colleagues by Himmler in 1944, and again there was some semblance of truth to it.[26]

The evidence of these developments is therefore that in respect of liquid-fuelled rocketry before World War II the Soviet model of pluralism and rivalry in military R&D failed. Many obstacles were placed before Soviet designers, and they were prevented from

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[22] Romanov (1990), 133.

[23] Romanov (1990), 136-8.

[24] Kerimov (1994).

[25] Medvedev (1978), 36-7.

[26] Ordway and Sharpe (1979), 46-8.

undertaking the open-ended experimentation which the technological environment called for. Without these obstacles the Soviet lag behind Germany in rocket aviation would have been significantly shortened. Whether Soviet designers would, could, or should also have moved in the same direction as the Germans towards long-range ballistic missiles seems much less likely, even improbable.

We cannot identify unambiguously the reasons for official conservatism. There were both good and bad reasons why Soviet government policy might have emphasised the virtues of conservatism. One explanation, is that centralised control over technological exploration was fostered by vested interests resistant to change and distrustful of any kind of heterodox thinking. It is consistent with the latter argument that the normal model of pluralism and rivalry in military R&D was prevented from working by the coercive intervention of the NKVD.

Another, equally plausible explanation, however, is that the Soviet Union, a relatively poor country, could aim to avoid the costs of exploring uncharted technological territory by leaving the task to more industrially developed countries; Soviet technology could rely on the spillover benefits arising from others' R&D spending. The expense and long time horizon required for effective development of liquid-fuelled rocketry may simply have been too great for normal arrangements to work in a poor country faced with a growing war emergency. Even for Germany the missile programme was appallingly expensive and produced only limited returns. The V-2 had many drawbacks; in some ways it would make more sense to describe it as the ultimate achievement of *prewar* rocketry - the end of that road, not the beginning of a new one. Among its defects were a high failure rate, of which the most important cause was instability in flight arising from a badly designed tail assembly. Its range suffered from the limitations inherent in an integral, one-piece design (the rocket casing had to accompany the warhead to the target). Its unit cost, inclusive of R&D overheads, was high both in terms of badly needed submarines and night fighters foregone, and relative to the value of the target.[27] The whole V-2 programme may have cost the German economy half as much again as the atomic bomb project cost the the much larger US economy.[28] Later Speer would come to see his support for the V-2 programme as 'probably one of my most serious mistakes'.[29]

When we attempt to explain the Soviet wartime lag in long-range rocketry, we may thus consider the factors of resources, system, and policy. In each case we find influences at work, but we cannot easily assign weights to them. These were unique events, with a big role for chance variation in initial conditions, resulting in prolonged divergence of the German and Soviet technological development paths.

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[27] Milward (1977), 106.

[28] Ordway and Sharpe (1979), 242.

[29] Cited by Ordway and Sharpe (1979), 249.

The impact of German rocketry, 1944-5

Soviet liquid-fuelled rocketry lagged behind German benchmarks before 1945. Behind this lay a defective exploration of the technological space. The problem was not that Soviet resources had been used up in the search, but that the Soviet search was insufficiently thorough. It was limited by several factors including the overall shortage of resources, a coercive political regime, and wartime emergencies. This failure might be designated rational (the Soviet Union being a poor country with limited resources and other priorities), or the result of institutional conservatism and myopia. Whichever is the case, Soviet rocket scientists certainly felt it as a failure.

It is not clear when Moscow first became aware of the scale of German wartime rocketry developments. The western Allies knew enough about Peenemünde to bomb it in 1943. According to Chertok it was Churchill's letter to Stalin of 13 July 1944 which renewed Soviet interest in rocketry.[30] However, already on 18 February 1944 Stalin's war cabinet, the GKO, had resolved to reestablish a jet propulsion research unit as NII-1 of Narkomaviaprom. This gave new priority to jet propulsion technology, and 1944 saw the accelerated flight-testing of several rocket- and ramjet-assisted aircraft.[31] Also in the summer of 1944, the rocket specialists were released from captivity; Korolev's release was dated 13 July, too soon to be in reponse to Churchill's letter.[32]

Hitler finally launched the V-2 campaign in September. In the same month, Soviet forces overran the V-2 proving ground near Debica in southeastern Poland. The objects which they found - fuel tanks, combustion chambers, elements of the guidance system - were crated up and sent back to Moscow for investigation in NII-1. There they were examined with slack-jawed incredulity.[33] The V-2 was 15 or 20 times more powerful than the largest liquid-fuelled rocket yet constructed in the Soviet Union. The very measurements of the V-2, incidentally, reflect the empirical, path-dependent character of its development. Its performance had been specified in 1936 by Gen. Walter Dornberger in multiples of the famous Paris Gun of World War I - twice the range, and ten times the payload - and its dimensions in terms of the maximum limits imposed by German railway transport.[34] Soviet rocketry specialists began immediately to think about developing long-range missiles along lines which were inevitably defined in relation to the new baseline established by the V-2; this transpired without any

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[30] Chertok (1992a).

[31] Egorov (1995), 413-24, 431-6.

[32] Romanov (1990), 174.

[33] A graphic account is given by one of the participants, Chertok (1992a).

[34] Ordway and Sharpe (1979), 28.

stimulus arising from foreknowledge of atomic weaponry and the advantages of a missile delivery system.

The occupation of Germany set the stage for inter-Ally competition over German technological assets. The Americans quickly secured the services of the main group of leading German specialists from Peenemünde, who brought with them a large number of V-2s and tons of technical documentation; they were thereby protected against denazification and flown to America to work for the US government on short-term contracts, leaving their families in Germany. Helmut Gröttrup, a guidance systems expert, alone of the top personnel from Peenemünde chose not to leave Germany. The German specialists of the second rank also stayed behind.

Initially, Soviet use of German specialists in rocketry followed a form of collaboration. In the autumn of 1946, however, it was switched to a predatory model.

The Russians in Germany: collaboration

Soviet rocket specialists began to arrive in Germany in April 1945; they formed the first echelon of what became known as the 'inter-departmental' commission sent from the USSR to inspect and evaluate German rocketry. Represented on the commission were the Red Army's chief artillery administration in addition to the ministries of armament and mortar armament, the aircraft, chemical, and electrical industries, and shipbuilding.[35] It was 'inter-departmental' also in the sense that at this time no one in Moscow was in overall charge of Soviet rocketry; responsibility was slipping out of the hands of Narkomaviaprom (the ministry for the aircraft industry) and would soon fall into the lap of Narkomvooruzheniia (the ministry for armament under D.M. Ustinov). Other members of the 'inter-departmental' commission arrived in the summer and late autumn; by the end of the year 30 or more of the top names in Soviet rocket science would be at work in Germany. Listed with their specialised experience and affiliations (where known) in table 6.2, these were experts who knew fairly precisely what they were looking for. According to G.A. Tokaty, they arrived prepared with detailed lists of all the main German aerospace research and production establishments, considerable information about the leading German personnel, and knowledge of the history and development of German rocketry and aviation.[36]

The Soviet acquisition programme had to overcome numerous obstacles. Peenemünde itself had been bombed by the Allies in March 1943; the bombing itself had not been especially effective, but had initiated a policy of dispersal of auxiliary establishments into the German interior.[37] In February 1945, the bulk of its remaining facilities

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[35] Ivkin (1997), 34 (report of Beriia and others to Stalin, 17 April 1946).

[36] Tokaty (1968), 342.

[37] Ordway and Sharpe (1979), 111-29.

and personnel had been transferred to the neighbourhood of the V-2 underground production facility at Nordhausen in Thuringia (ironically, Nordhausen would turn out to be no more than a dozen kilometres to the east of the demarcation between the Soviet and western occupation zones). Before surrender, the Germans had destroyed or concealed the majority of ‘objects, test beds, models and materials’; in going over to the British and Americans, the principal German scientists had taken with them virtually all the main technical documents.[38] Before handing over the Mittelwerk factory at Nordhausen to the Red Army on 1 June 1945, the Americans shipped out roughly 100 V-2 missiles; they also took possession of 14 tons of technical documentation which von Braun and his colleagues had concealed in a tunnel in the Harz mountains.[39]

The Soviet group found 10 complete V-2s, of which 5 were shipped back to the Soviet Union.[40] The loss of the all-important V-2 documentation was made partially good from a consignment of German government papers stranded in Prague at the end of the war in the course of transshipment to Austria; a Soviet mission led by V.P. Mishin spirited them back to the Soviet Union under the noses of the Czechoslovak authorities.[41] Another mission to Vienna secured the documentation of the V-2 guidance system.[42] The booty was not limited to the V-2, as table 6.3 indicates. Soviet acquisitions included not only strategic weapons but also anti-aircraft and anti-tank missiles, and air-to-air, air-to-sea, and air-to-surface missiles. The summary statistics reported in table 6.4 number Soviet acquisitions in literally dozens of different kinds of missiles, rocket motors, guidance systems, and fuels.[43] These tables illustrate well the thoroughness which which German rocket science had mapped out the accessible technological territory. But there is no doubt that the V-2 was understood by everyone to be the most important prize.

The utilisation process followed two phases, of which the first proceeded in the Soviet occupation zone of Germany. It began with location of available materials and personnel (mostly of the middle rank), and recruitment of the latter to their former employment under new masters. The German specialists were driven to collaborate by a variety of motives, including the promise of food rations, the protection offered from denazification, and the professional desire to continue in their chosen field of work; the top German specialists could get these

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[38] RTsKhIDNI, 17/127/1296, 5.

[39] Von Braun and Ordway (1975), 118.

[40] RTsKhIDNI, 17/127/1296, 15-16

[41] Budnik (1991); Konovalov (1991).

[42] Kerimov (1994).

[43] RTsKhIDNI, 17/127/1296, 18.

things from the Americans, but only the Russians were offering them to the lower rank personnel. What none of them could get, not even Wernher von Braun, even from the Americans, was the promise of being able to carry on without leaving Germany - a decisive factor behind Gröttrup's decision to work for the Russians.

At Nordhausen the Russians secured the services of some 200 specialists who had remained in the neighbourhood, and set up work in an informal research institute, which Chertok christened 'Rabe' (in English 'Raven', shortened from *Raketenbau*) in nearby Bleicherode. Reinforced by subsequent arrivals from Moscow, Institute 'Rabe' was soon engaged in a variety of tasks, including reverse engineering and copying of German rocketry products, filling gaps in their technical documentation, and completing and testing unfinished German design work.[44] At the same time, all over the Soviet occupation zone, similar joint Soviet-German enterprises, institutes, and other establishments were being created wherever rocketry and aviation technology had been formerly practised. By the spring of 1946 the total number of German rocket specialists involved had risen to 1200.[45]

Such joint endeavours did not proceed without difficulty. Nordhausen and Bleicherode were right on the western edge of the eastern occupation zone; the German employees lived on both sides of the border, and were as vulnerable to western as to Soviet pressure. Various agencies competed for their loyalty. Elsewhere, amid general suffering and deprivation the local population was jealous of the privileged life accorded to the German specialists, regardless of their wartime responsibilities. Moreover, the German specialists themselves tended to adopt a proprietary attitude to their own knowledge, which they became reluctant to share with their Soviet colleagues, and tried to monopolise it, since it was the only source of their bargaining power *vis à vis* their new employers and of their privilege relative to their compatriots.[46]

The transition to a predatory model

The transition to the second, predatory phase of the utilisation process began with Ustinov's bid for control over the development of long-range rocketry, and finished with the wholesale transfer of German assets and specialists to Soviet territory.

To begin with, rocketry lacked a patron. The 'inter-departmental' commission had no parent ministry in Moscow. According to Iaroslav Golovanov, Korolev's biographer, Gaidukov had offered his children to more than one potential foster-carer. At Narkomaviaprom, Shakhurin lacked interest. As far as he was concerned, rocketry was an artillery

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[44] Budnik (1991), Konovalov (1991), Chertok (1992b, 1992c).

[45] Ivkin (1997), 34 (report of Beriia and others to Stalin, 17 April 1946).

[46] Sokolov (1955), 20-6, gives an account of the working of joint Soviet-German aviation design bureaux .

matter. Reporting to Malenkov on the installations remaining at Peenemünde in June 1945, he had recommended their transfer to the commissariat for ammunition.[47] Subsequently he tried to recall his aviation specialists from Nordhausen, an order which Gaidukov had politely ignored.[48] But Vannikov of the ammunition commissariat (later Minselmash) was absorbed in the atomic bomb project. Ustinov, people's commissar for armament, held his counsel, and sent his deputy V.M. Riabikov to Germany to review the situation. Armed with Riabikov's report, and supported by a powerful coalition (Beriia, Malenkov, Bulganin, Vannikov, and Iakovlev), Ustinov went to Stalin. The result was that Stalin gave rocketry to Ustinov.[49]

By a Council of Ministers decree of 13 May 1946, signed by Stalin and Ia.E. Chadaev, a 'special committee for jet propulsion technology' was formed under the leadership of G.M. Malenkov, with Ustinov as one of his two deputies.[50] The committee was given inclusive powers and exclusive responsibilities for oversight of developments in its field. The decree fixed core priorities (the copying of the German V-2 and *Wasserfall* missiles), lead organisations (Ustinov's Minvooruzhenie for liquid-fuelled missiles, Minselmash for powder rockets, and Minaviaprom for aviation), a further list of supply ministries for subcontract work, and new and revised organisational structures for ministries, enterprises, and research outfits including the conversion to missile production of armament factory no. 88, the attachment to it of a new research institute NII-88, and establishment of a new central firing range for missiles tests. It ordered Minaviaprom to transfer 20 rocket specialists to Minvooruzhenie, and prohibited any agency from seeking to recall its personnel from work on jet propulsion (as Shakhurin had previously tried to recall his aviation specialists from Nordhausen).

As for the work in Germany, the decree confirmed what had become the official model of knowledge transfer. The German research installations and personnel concerned with the V-2, *Wasserfall*, *Rheintochter*, *Schmetterling*, and other missiles, were to be

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[47] Dated 8 June 1945, this document was published by Ivkin (1997), 32.

[48] Golovanov (1994), 358-9.

[49] For the joint recommendation of this group, dated 17 April 1946, see Ivkin (1997), 33-4. The decisive meeting with Stalin followed on 29 April, with Riabikov also in attendance (ibid., 41n). For other detail see Golovanov (1994), 362-4.

[50] The text of this decree was published in Nezavisimaia gazeta (Moscow), 24 February 1995. Malenkov's other deputy was I.G. Zubovich, detached from the Ministry of the Electrical Industry for this purpose. Other members of the committee were the artillery commander N.D. Iakovlev, P.I. Kirpichnikov, A.I. Berg, P.N. Goremykin, I.A. Serov, and N.E. Nosovskii.

reassembled and put back to work. Alongside each German were to work Soviet specialists sent by Moscow to acquire German skills and knowledge. Privileged rations and other conditions were assigned to German and Soviet personnel alike; MGB General Serov was commissioned to ensure the supply of consumer goods, accommodation, and vehicles adequate for the conditions of 'normal work', and the defence ministry in Moscow and occupation headquarters in Germany were ordered to help him as required. The procurement of supplies in Germany and equipment from the United States were to be financed partly under reparations, partly from 70m German marks and $2m from Soviet currency reserves. Ustinov, Iakovlev, and Kabanov were ordered to Germany for a fortnight with a team of specialists to set this work up on a proper footing; Nosovskii, assisted by Kuznetsov and Gaidukov, was sent to head up the work in Germany for as long as it continued.

But the decree also foreshadowed the end of the German phase. It required the Malenkov committee 'to resolve the question of the transfer of design bureaux and German specialists from Germany to the USSR by the end of 1946', and ordered the lead ministries in Moscow and designated subcontract organisations to prepare the ground for their relocation, including the provision of accommodation for several hundred Germans 'by 15 October 1946'.

Arriving in Nordhausen in the second half of May 1946, Ustinov saw that the scale of work required was clearly greater than could be done under Chertok's Institute 'Rabe'.[51] He put the Nordhausen operation on a new, more regular and elaborate footing. An Institute 'Nordhausen' was formed, with Korolev as deputy director and chief engineer. The Nordhausen Institute became the lead organisation for a complex of more specialised joint establishments in the district, working on V-2 technical documentation, the rocket motor, the guidance system (the former Institute 'Rabe'), the launch system, test-firing, and telemetry. In August, Ustinov set up (and headed) a state commission for study and generalisation of the experience of rocket building in Germany.[52] His visit to Germany was also the occasion for Ustinov to name Korolev chief designer of long-range missiles.[53] The collaborative work in Germany moved to a climax.

The exact motivation of the decision to relocate the entire German operation to Soviet territory is not known. It was probably prompted by the difficulties of operating in Germany already outlined above, especially the difficulty of maintaining secrecy. Other factors may have included the increasing permanence of the German partition, and the rising importance attached in Moscow to securing a demilitarisation of

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51 Chertok (1992b).

52 Konovalov (1991), Chertok (1992c). Other details of the Nordhausen Institute, based on Tokaty's and Gröttrup's memoirs, can be found in Ordway and Sharpe (1979), 320-2.

53 Konovalov (1991); Rebrov (1995).

Germany's western zone, which made the maintenance of joint military R&D establishments in the eastern zone an embarrassment. The timing of the decision's execution, at the end of October 1946, may also have been influenced by the simultaneous breakdown of the Paris peace talks. [54] However, greater foresight is suggested by the fact that the mid-October deadline for availability of the deportees' living accommodation had already been fixed in mid-May.

The deportation, codenamed 'Osoaviakhim', was carried out suddenly and without warning, between 3000 and 3500 German specialists being shipped off to the Soviet Union at the end of October, accompanied by their family members, personal property and household effects, and office and research facilities. Among them the 2800 rocketry and aviation specialists were the largest single contingent; most of these were probably from the aircraft industry, since von Braun later put the number of rocket specialists alone at no more than 200. There were also nuclear, electronic, optical, radio, and chemical specialists.[55] The first rank of German rocket science was largely missing, represented only by Gröttrup.

'Osoaviakhim' was in fact the second wave of such deportations, the first wave, mainly of atomic scientists, having been spread over the months from May to September 1945. By 1948 some 200 000 German scientific workers (including family members) were living and working on Soviet territory.[56] In quantity if not in quality, this was 'probably one of the largest mass movements of 'brains' in the recent history of the civilized world'.[57]

Back in the USSR

In Moscow, meanwhile, a framework had been established for absorption of the German resources. Overall responsibility for strategic rocketry was assumed by Ustinov, with Minvooruzheniia as the coordinating centre of a broad network of collaborating and subcontract organisations. As laid down in the May decree, a new research institute for long-range rocketry was attached to the former artillery factory no. 88 (so the institute became NII-88; an auxiliary institute for guidance systems became NII-885). These institutes brought together the main members of the Soviet team in Germany with the German specialists.[58]

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[54] Thanks to Naomi Azraeli for these suggestions. See also Kuvshinov, Sobolev (1995), 105.

[55] Kuvshinov and Sobolev (1995), 105; von Braun and Ordway (1975), 118.

[56] Semiriaga (1995), 142-3.

[57] Schroder (1955), 27.

[58] Chertok (1992d, 1992e); Ivkin (1994), 74.

Their initial brief was to test-fly the German V-2, then copy it from components of Soviet manufacture. These terms of reference were significantly extended in March 1947 when a meeting at the Kremlin took a decision, if only in principle, to find an intercontinental means of delivering an atomic weapon. Two alternatives were under consideration, both of them speculative -either to develop ballistic rocketry significantly beyond the V-2 concept, or the so-called Sänger project for a skip-glide orbital rocket-plane (the ‘antipodal bomber’).[59] The Sänger project had already been under investigation by a group at NII-1 under M.V. Keldysh.[60] The Kremlin meeting set up a special subcommittee, including Vasilii Stalin, Serov, Tokaty, and Keldysh. The Russian specialists were divided; Keldysh thought the project was feasible, whereas Tokaty had reservations. Stalin then referred the matter to the German specialists (against Tokaty’s more self-reliant inclination), who tended also to scepticism.[61] At this point the Sänger project was abandoned in favour of ballistic rocketry, which meant that the future fell into the hands of the new chief designer of long-range missiles Korolev.

Here can be seen starting to reemerge the prewar tensions between officials and scientists. It was the officials - Stalin himself, his son Vasilii Stalin (now an air force general, and a fierce critic of Soviet aviation technology), and Ustinov - who insisted on starting from German technological foundations, where the specialists, whose professional pride was at stake, usually wanted to diverge sooner and more radically from German starting points.[62]

The results of the combined efforts of the German and Soviet specialists over the following years can be stated briefly. One year after the return to Soviet territory, in October-November 1947, 11 German V-2s were launched from the new testing site at Kapustin Iar near Astrakhan; five reached the target, roughly equalling the Germans’ own wartime success rate. A year later, the Soviet version of the V-2, but with an improved tail section and guidance system, was ready for testing; 12 were launched in October-November 1948, of which 7 reached the target.

At the same time both the Soviet and German teams had been working on new, longer-range missiles which departed from the V-2 concept in a detachable warhead. Korolev had unveiled his concept,

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[59] The meetings were described by Tokaty (1964), 280-1, (1968), 345-6.

[60] Holloway (1994), 247.

[61] Tokaty (1968), 346; Ordway and Sharpe (1979), 329.

[62] For the scientists’ viewpoint see Tokaty (1968), 343, 345-6; Chertok (1992d).

which would eventually become the R-2, in March 1947.[63] When the R-2 was tested successfully, in May-June 1949, the Soviet specialists could be said to have significantly exceeded the German 1945 benchmark.[64]

The Germans in Russia

What part was played by the Germans? There were 150 of them, headed by Gröttrup, attached to NII-88. Probably the initial model for their utilisation was the traditional one of independent Soviet and German design bureaux independently pursing projects on competitive lines. But it did not work out this way, for reasons of security, motivation, the difficulty of teamwork, scientific nationalism, and finance.

Security

Basically the Soviet officials did not know what to do with them. To use them effectively would have meant placing them at the heart of the Soviet missile programme. Instead they were systematically isolated and kept in the dark. At first they were located in a Moscow suburb, but over a few months they were reassembled in a more remote location - Gorodomlia, an island in the upper Volga, the site of a former medical research institute.[65] The reasons for this were doubtless related to security, although not necessarily in a straightforward way. Security in the obvious sense had already been guaranteed by relocating the German specialists on Soviet territory, restricting their movement and controlling their correspondence. Keeping them away from the Soviet missile programme must have reflected more complex motivations. If the Germans might eventually return home, for example, the less they knew the better. One could imagine the Russians in the position of the interrogator who knows less than the witness; under such circumstances a question may give the witness more information than the answer gives to the interrogator. Another factor may have been the secretiveness encouraged for its own sake throughout the Soviet system in defence of official privilege.

Motivation

Under the circumstances German motivation and morale were always fragile. These men and women thought at first that they would be called on as key players in the Soviet space programme; what they wanted was to get into space and they didn’t much care who they had to working for to do it - Hitler one year, Stalin the next. ‘War has to serve science!’,

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[63] Ishlinskii (1986), 298-300 (G.S. Vetrov). For an account of the contemporaneous German work see Ordway and Sharpe (1979), 329-30.

[64] Budnik (1991), Chertok (1992d), Ivkin (1994), 74.

[65] For accounts of the Germans’ work and life in Gorodomlia, see Gröttrup (1959), Ordway and Sharpe (1979), 325-6, 335-43.

Gröttrup declared in 1947 just as he had in 1944.[66] At first Ustinov encouraged the Germans' self-important attitudes; 'You're to give the orders! *You* are C-in-C of rocket construction!', he told Gröttrup.[67] The truth of the predatory model, when it dawned on them, had to be a devastating blow - they were there only to transmit their knowledge and experience to others, and would not be given any independent role. On top of this the Germans were given no assurances or hints as to when or whether they would ever go home. At the same time, although materially privileged by comparison with Soviet employees, and not held under penal conditions, they were subjected to intense surveillance and control over movement.

The difficulty of teamwork

The V-2 had been built by teamwork - a systems engineering approach. In Russia Gröttrup struggled vainly to maintain the collective spirit developed in Peenemünde and Nordhausen, first against the demands of competing ministries for personnel and equipment, then against the internal tensions in the group. The collective spirit depended upon leadership and trust. The possibilities of leadership were undermined by erosion of the Germans' goals and motivation, and their arbitrary reallocation to tasks, while the suspiciousness of the watchers and the divisive allocation of privileges destroyed trust. 'How different it was at Peenemünde!', wrote Irmgard Gröttrup in a fit of nostalgia: 'There, we were like one big family'.[68] Under these conditions teamwork soon became impossible.[69]

Scientific nationalism

To make matters worse, the Russians themselves were divided over the potential role of the Germans. The officials were more committed to making use of them than the specialists. Once the V-2 had been successfully tested, the Germans were commissioned to design rockets of longer and longer range, the key to which was detaching the warhead in flight, for example the R-10 which was the Gorodomlia analogue to the R-2 being developed simultaneously by Korolev. Not knowing anything about Korolev's activities, the Germans thought that with this concept they had stolen a march on the Soviet specialists; at the same time, they worried that Korolev would try to steal their ideas and key personnel.[70] The fact was that Korolev was indeed developing a similar missile, but had no intention of either acknowledging a German contribution, or of letting any of the Germans anywhere near it. The

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[66] Gröttrup (1959), 56.

[67] Gröttrup (1959), 30.

[68] Gröttrup (1959), 52.

[69] Ordway and Sharpe (1979), 342.

[70] Gröttrup (1959), 107.

proprietary, defensive attitudes of the Soviet specialists (as distinct from the officials) were by now well established; having lost six years of work on liquid-fuelled rocketry in prison, emerging to find the Germans already realising ideas of which he had only dreamed, Korolev had no intention of spending the rest of his career working under German instruction to German designs.[71] In the same spirit Glushko ignored the Germans allocated to him to work on propulsion and soon allowed them to go to Gröttrup.[72] Probably the campaign of scientific and cultural nationalism initiated in 1946 by A.A. Zhdanov also played into the Russian specialists' hands.

Finance

All this made an inescapable dilemma for Ustinov. Long-range missiles cost far more to build than guns, tanks, or aircraft. The German aircraft specialists held under similar conditions worked on many designs, several of which reached the stage of experimental prototypes and were test-flown.[73] In rocketry real pluralism and rivalry were too expensive; Ustinov could not afford to carry through competing projects beyond the design stage. He could not realise the German and Soviet designs simultaneously. Nor could he merge them; for national reasons he could not place Korolev under Gröttrup, but nor could he place the Germans under Korolev since Korolev would refuse their unwanted assistance. The Germans were left without a role. At first Ustinov strung them along with promises of approval and funding; eventually he had no alternative but to switch the Germans to low grade tasks, and eventually out of secret work altogether.[74] He began to send them home; by the end of 1953 they had all gone back to Germany.

Conclusions

In 1945-7 the Soviet Union gained from Germany three things relevant to the tasks of reaching the technological frontier mapped out locally by Germany, and then going beyond. These were (a) the practical concept of what was already possible in long-range rocketry, (b) the physical assets represented by the German trophy materiel - working models and parts, documents, and research and production facilities, and (c) the human assets and embodied technological knowledge of the German specialists themselves.

I rank these in diminishing order of importance. Most important was just for the Soviet authorities to know that the frontier of rocketry already lay further out that anyone in the Soviet Union had previously imagined. Next most important was to have access to the German

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[71] Chertok (1923d).

[72] Ordway and Sharpe (1979), 327.

[73] Kuvshinov and Sobolev (1995).

[74] Chertok (1992d).

weapons, design documents and facilities; these told them most about the range of the frontier which Germany had explored, and how to get there. Of least value were the German personnel.[75]

One might expect it to be the other way around. Modern ideas about the factor of human capital in economic growth and catch-up processes lead us to place greatest emphasis on human development and embodied knowledge, then on physical capital, and least on disembodied conceptual knowledge. Why do such ideas mislead us here? The assets which the Soviet Union gained from Germany must been assessed in relation to those Soviet assets already accumulated. Thus the Soviets already had their own rocket specialists to match the specialists found in Germany. They had their own working models of rocketry and design and production facilities, but across a much narrower range of the spectrum than in Germany. They lacked altogether, until the Germans gave it to them, the concept of a V-2. Thus the concept was more critical than the trophy assets, and both were more important than the German specialists themselves.

There is another reason for arguing that the German specialists were less important than may appear at first sight. The Russians *also* failed to make the most of them because they applied a predatory model of embodied knowledge transfer which proved unworkable. Its acquisition was handled in a very wasteful way. Embodied knowledge was the most difficult aspect of technology to transfer, as the experience of the Gorodomlia Germans confirmed, because it existed primarily in the collective mentality. The predatory model destroyed the Germans' teamwork approach. This also implies that Soviet science and industry successfully absorbed German missile technology largely on the basis of its own human resources. Moreover, the destruction of the Germans' teamwork did not prevent the Russians from evolving their own teamwork under Korolev.

Thus Soviet postwar successes were built partly on German foundations, but it was easy to do this given that there was already a previous accumulation of Soviet experience and expertise. Some of this experience was not directly useful, but was useful experience in searching the technological frontier and in learning by trial and error, so was not just technological failure or economic waste. The problem was not that resources had been used up in the search, but that the Soviet search had been incomplete; it was limited by several factors including overall shortage of resources, a coercive political regime, and wartime emergencies. As a result the prewar development process had slowed down, and some of the accumulated resources had been dispersed, but they were reassembled once a sufficiently high priority had been attached to their further development in 1944. Thus Soviet science and technology were able to build on German achievements and soon surpass them.

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[75] German personnel were probably more important to the Americans, and von Braun and others played a leading role in the United States missile and space exploration programme for a quarter of a century after the war. See Ordway and Sharpe (1979).

Table 6.1. Innovation in liquid-fuelled rocketry, Germany and USSR, 1931-49

	Germany		USSR	
First liquid-fuelled rocket	1931	Various experimental rockets of the amateur Verein für Raumschiffart.	1933	The experimental GIRD-09, designed by M.K. Tikhonravov, reached a height of 6000m.
First rocket aircraft	1937	The experimental Heinkel He-176, powered by a Walter motor developing 600kgf of thrust.	1940	The RP-318-1, designed by S.P. Korolev, powered by a 140kgf motor, could fly for 110 seconds at 140kph. The motor was based on an original design by V.P. Glushko, but both Korolev and Glushko were in prison at the time.
First rocket fighter	1943	The delta-wing Messerschmidt Me-163b, powered by a 1600kgf Walter motor, could fly for 7-8 minutes at 880kph, and saw action in aerial combat in 1944.	1942	The BI-1 (BI stood for the designers, A.Ia. Berezniak and A.M. Isaev), powered by a 1100kgf motor designed by L.M. Dushkin, could fly for 7 minutes at 800kph. The BI-1 was intended to be an operational combat aircraft, but the test programme was halted after a fatal crash in 1943.
First long-range missile	1942	The A-4 (V-2), with a 25 000kgf motor and a 1000kg warhead, had a range of 240km; in 1944-5 some 6000 were produced, of which just over half were successfully launched at Allied targets.	1949	Although the Soviets successfully tested the R-1 (a somewhat improved copy of the V-2) in 1948, the first such Soviet-designed missile was Korolev's 600km-range R-2, eventually deployed in Germany in 1951.

Sources:
Ordway and Sharpe (1979), 15 (the VfR rockets), GARF, 8418/6/23, 42 (GIRD-09), von Braun and Ordway (1975), 108 (the He-176), and 109 (the Me-163b); Shavrov (1988), 130-3, and Egorov (1994), 402-4 (the RP-318-1); Shavrov (1988), 285-90, and Egorov (1994), 405-9 (the BI-1); von Braun and Ordway (1975), 106, and RTsKhIDNI, 17/127/1296, 10-11 (the V-2); Ivkin (1994), 74 (the R-2).

Table 6.2. Soviet rocket specialists and officials sent to Germany, 1945-6

Specialists	
Barmin, V.P. (Minselmash)	rocket artillery specialist; sent to Germany, August 1945; chief engineer, Institute 'Berlin' (SAM missiles); Institute 'Nordhausen', responsible for documentation of the V-2 launch system; afterwards, NII-88 (Minvooruzheniia) responsible for launch assemblies
Berezniak, A.I., NII-1 (Minaviaprom	liquid-fuelled rocket motor specialist; co-designer with Isaev of the wartime experimental BI-1 rocket fighter; worked on first V-2 fragments received in Moscow, 1944; sent to Germany, 1945; worked in Institutes 'Rabe' and 'Nordhausen'
Boguslavskii, E.Ia.	guidance systems specialist; worked under Riazanskii in Institute 'Nordhausen'
Budnik, V.S., NII-1 (Minaviaprom)	sent to Germany, 24 May 1945; first chief, joint OKB at Sommerd (Erfurt), Institute 'Nordhausen' (V-2 documentation); after Germany, Korolev's deputy, NII-88 (Minvooruzheniia), responsible for design work
Chertok, B.E., NII-1 (Minaviaprom)	guidance systems specialist, liquid-fuelled rockets; worked on first V-2 fragments received in Moscow, 1944; sent to Germany on 23 April 1945; organised Institute 'Rabe' (Nordhausen); chief of sector for guidance systems, Institute 'Nordhausen'; after Germany, liaison with the Germans in Gorodomlia for Minvooruzheniia
Chizhikov, S.G. (Minaviaprom)	worked in Institute 'Rabe' (Nordhausen)
Gaidukov, L.M., Gen.	rocket artillery specialist; chief of party central committtee department; head of 'inter-departmental' commission sent to Germany, 24 April 1945; chief of Institute 'Nordhausen'; after Germany, chief of NII-88 (Minvooruzheniia); assistant to Nosovskii, chief representative of the special committee for jet propulsion technology in Germany, 1946
Glushko, V.P., NII-1 (Minaviaprom)	liquid-fuelled rocket motor specialist; imprisoned 1938-44; sent to Germany, August 1945; Institute 'Nordhausen', responsible for documentation of the V-2 rocket motor, and in charge of production

	of rocket motors; after Germany, chief designer of rocket motors, NII-88 (Minvooruzheniia), and chief of NII-456 (Minaviaprom)
Isaev, A.M., NII-1 (Minaviaprom)	liquid-fuelled rocket motor specialist; co-designer with Berezniak of the wartime experimental BI-1 rocket fighter; on first V-2 fragments received in Moscow, 1944; sent to Germany, 1945; organised Institute 'Rabe' (Nordhausen) under Chertok; Institute 'Nordhausen', responsible for test firing at Leesten
Kerimov, K.A.	rocket artillery specialist; sent to Germany, 1945; head of joint Soviet-German OKB for telemetry, responsible for redeveloping the V-2 'Messina' guidance system
Korolev, S.P.	liquid-fuelled rocket designer; prominent in GIRD, then RNII; imprisoned 1938-44, employed in TsKB-29 (NKVD); sent to Germany, August or late October 1945; technical leader of 'Vystrel' group, responsible for test-firing V-2s; deputy chief and chief engineer, Institute 'Nordhausen'; designated chief rocket designer, 1946; after Germany, chief designer of long-range ballistic missiles, NII-88 (Minvooruzheniia)
Kuznetsov, N.N., Gen.	artillery commander; assistant to Nosovskii, chief representative of the special committee for jet propulsion technology in Germany, 1946
Kuznetsov, V.I.	sent to Germany, 9 August 1945; Institute 'Nordhausen', responsible for V-2 guidance system; after Germany, chief of NII-10 (Ministry of the Shipbuilding Industry), responsible for gyroscopic guidance mechanisms
Mishin, V.P., NII-1 (Minaviaprom)	ballistics specialist; worked on first V-2 fragments received in Moscow, 1944; sent to Germany, 9 August 1945; chief of successful mission to Prague in pursuit of V-2 documentation archive; Institute 'Nordhausen', in charge of ballistics bureau; recruited by Korolev, took over from Budnik as chief, joint Soviet-German OKB at Sommerd (Erfurt), Institute 'Nordhausen' (V-2 documentation); after Germany, Korolev's first deputy as chief designer, NII-88 (Minvooruzheniia), responsible for ballistics and V-2

	redevelopment
Mrykin, A.G.	Gaidukov's deputy as head of 'inter-departmental' commission, sent to Germany, 24 April 1945
Pallo, A.V.	liquid-fuelled rocket motor designer; sent to Germany, December 1945; Institute 'Nordhausen', in charge of test firing under Isaev at Leesten
Pashkov, G.N. (Gosplan)	chief, Gosplan defence sector; sent to Germany, 1945, after Germany, chief of Gosplan missile department
Piliugin, N.A., NII-1 (Minaviaprom)	worked on first V-2 fragments received in Moscow, 1944; sent to Germany, 9 August 1945; worked on V-2 documentation, Institute 'Nordhausen', responsible for guidance system; after Germany, Riazanskii's deputy responsible for guidance systems, NII-885 (Minvooruzheniia)
Pobedonostsev, Iu.A., NII-1 (Minaviaprom)	specialist on pulsejets; worked on first V-2 fragments received in Moscow, 1944; sent to Germany, 24 August 1945; Institutes 'Berlin' and 'Nordhausen'; after Germany, chief engineer of NII-88 (Minvooruzheniia)
Raikov, I.O. (Minaviaprom)	sent to Germany, 1945; worked in Institutes 'Rabe' and 'Nordhausen'
Riazanskii, M.S. (Minprom sredstv sviazi)	sent to Germany, 9 August 1945; worked on V-2 documentation, Institute 'Nordhausen', responsible for guidance system; after Germany, responsible for guidance systems, NII-885 (Minvooruzheniia)
Rudnitskii, V.A. (Minselmash)	rocket artillery specialist; sent to Germany on 9 August 1945; Institute 'Nordhausen', responsible for redeveloping V-2 ground equipment
Semenov, A.I.	deputy chief of 'inter-departmental' commission sent to Germany, 24 April 1945
Smirnov, S.S. (Minaviaprom)	sent to Germany, 1945; worked in Institutes 'Rabe' and 'Nordhausen'
Sokolov, V.L. (Minaviaprom)	sent to Germany, May 1945; defected to the United States, October 1946
Tiulin, G.A.	sent to Germany, 1945; Institute 'Nordhausen', following Mishin as chief of ballistics bureau
Tokaty (Tokaev), G.A., Col., TsAGI (Minaviaprom),	rocketry specialist; sent to Germany, June 1945; chief rocket scientist of the Soviet air force; member, special commission on the Sänger project, 1947; defected to the

	United Kingdom, 1948
Voskresenskii, L.A., NII-1 (Minaviaprom)	worked on first V-2 fragments to be received in Moscow, 1944; sent to Germany, 1945; worked in Institutes 'Rabe' and 'Nordhausen'; headed the 'Vystrel' group after Korolev
Officials:	
Iakovlev, N.D., Gen.	artillery commander; member, Council of Ministers special committee for jet propulsion technology, 1946; visited Germany with Ustinov, 1946
Malenkov, G.M.	Central Committee secretary since 1939; member, GKO, 1941-5, responsible for aircraft production; deputy chairman, Council of Ministers, since 1946, responsible for industry; Politburo member since 1946; chairman, Council of Ministers special committee for jet propulsion technology, 1946
Nosovskii, N.E.	member, Council of Ministers special committee for jet propulsion technology, 1946; chief representative of the special committee in Germany
Riabikov, V.M., deputy minister of armament (Minvooruzheniia)	naval artillery specialist; Ustinov's deputy; sent by Ustinov to Germany in 1945-6 to evaluate German-Soviet missile development
Serov, I.A., Gen. (MGB)	member, Council of Ministers special committee for jet propulsion technology, 1946; organised deportation of German scientists to USSR ('Osoaviakhim'), 1946; head of State Commission for long-range missiles, 1947; member, special commission on the Sänger project, 1947; attended first V-2 launching, 1947
Stalin, V.I., Gen.	air force commander; instigated arrest of Shakhurin (minister, Minaviaprom) and Novikov (chief of air force), 1946; member, special commission on the Sänger project, 1947
Ustinov, D.F., minister of armament (Minvooruzheniia)	took over main responsibility for missile development from Minaviaprom in 1946; deputy chairman, Council of Ministers special committee for jet propulsion technology, 1946; visited Germany, 1946; head of state commission for study and generalisation of the experience of rocket building in Germany, 1946

Sources for table 6.2: compiled from Budnik (1991), Chertok (1992a-1992e), Danilov, (1981), Egorov (1994), Golovanov (1994), Ivkin (1994), Kerimov (1994); Konovalov (1991), Pashkov (1989), Rebrov (1995).

Table 6.3. Main items of German rocketry captured by Soviet forces, 1945

Surface-to-surface missiles	
V-2 (A-4)	guided liquid-fuelled rocket (height 14m, weight 12 500kg, propellant turbopump-fed liquid oxygen and ethyl spirit, thrust 25 000kg, warhead 1000kg, range 300 km)
Rheinbote[a]	solid-fuelled multi-stage rocket (height 11m, weight 1540kg, first-stage thrust 38 000kgf, warhead 32kg, range 150km)

Rocket and anti-tank artillery	
320mm	incendiary shell (range 4km)
210mm	demolition shell (range 5km), 5-tube launcher
200mm	demolition shell (range 6km), 6-tube launcher
158mm	fragmentation, smoke, and chemical shells (range 5.5km)
150mm	artillery rocket shell
105mm, 75mm	recoilless cannon
88mm Panzerschreck	anti-tank shell and launcher
80mm	fragmentation shell (range 5.8km), 48-tube launcher
Panzerfaust	anti-tank shell (range 60-100m)

Surface-to-air missiles	
Enzian[a]	radio-controlled liquid-fuelled rocket (weight 2000kg, range 15km)[b]
Hs-117 Schmetterling[a]	liquid-fuelled rocket (weight 450kg, range 10km)[b]
Rheintochter[a]	liquid or solid-fuelled rocket (self-guided or radio guided, two solid-fuel launch boosters, weight 1500kg, range 15km)[b]
Taifun[a]	liquid or solid-fuelled barrage missile (weight 30kg, range 12km)
Wasserfall[a]	liquid-fuelled rocket (height 8m, weight 4000kg, thrust 8000kg, warhead 100-150kg, range 15km)[b]

Air-to-surface missiles	
RS-1000	solid-fuelled armour-piercing rocket (weight 1000kg)
RS-1800	solid-fuelled armour-piercing rocket (weight 1800kg)

Air-to-ship missiles	
Henschel	guided cruise missile (length 3-4m, wingspan 3m, weight 1000kg, warhead 250kg)
Hs-293	radio-guided liquid-fuelled torpedo (weight 1000kg, range 16km)
Hs-294[a]	liquid-fuelled torpedo (weight 2200kg, range 14km)
SB-800a	solid-fuelled rocket

Air-to-air missiles	
Drache	heat-seeking rocket
R-100[a]	solid-fuelled rocket
SS-500[a]	solid-fuelled rocket
X-4[a]	wire-guided rocket shell (weight 50kg, range 3-5km)

Piloted aircraft and rocket motors	
DFS-346[a]	supersonic rocket aircraft
Messerschmidt Me-163B Komet	rocket fighter
Walter HWK-109-509	liquid-fuelled rocket motor (thrust 600kgf)

Source: compiled from RTsKhIDNI, 17/127/1296.
Notes:

[a] Prototype or experimental.

[b] Von Braun and Ordway (1975), 111-12, give alternative figures for range as follows: Enzian - 30km, Schmetterling - 16km, Rheintochter 1 and 2 - 12km and 35km respectively, Wasserfall - 27km.

Table 6.4. Summary of German jet propulsion technology captured by Soviet forces, 1945 (number of types in each category)

Category	Number of types
Liquid-fuelled rockets	8
Solid-fuelled rockets	41
[Rocket and jet] engines	32
Guidance systems	186
Liquid fuels	32
Solid fuels	80

Source: RTsKhIDNI, 17/127/1296, 15.