THE SOVIET MARKET FOR INVENTIONS:
The case of jet propulsion, 1932 to 1944

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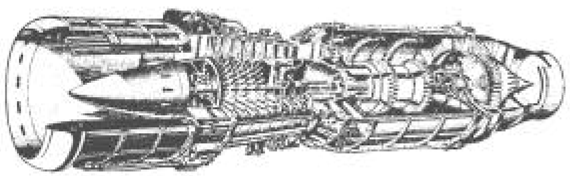
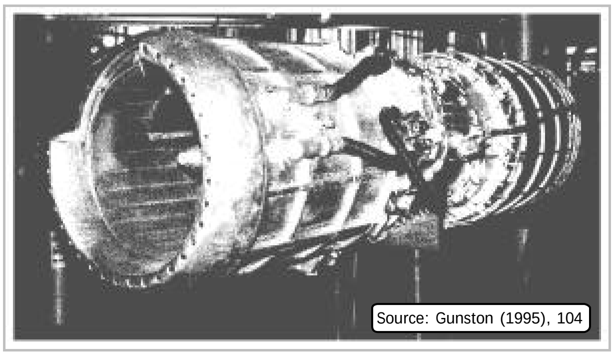
Abstract

The paper outlines the problem of aviation jet propulsion in the interwar period and World War II and analyses Soviet progress towards a solution using newly available archival documentation. Soviet R&D commitments were influenced by long–term security motivations and the need to invest in local tacit knowledge. The scale and diversity of the Soviet R&D effort is described. The allocation of resources resulted from R&D agents' horizontally organised market–like interactions within a vertically organised command system. Financing decisions were made in a context of asymmetric information, adverse selection, and opportunism. Overall funding was rationed; budget constraints on individual projects were soft, but were periodically hardened. In addition to decisions to finance and refinance or terminate projects, takeovers and mergers took place in a secondary asset market. There is evidence of rent–seeking activity, but where rent–seeking was detected it was punished.

A.M. Liul'ka's TR–1, the first Soviet–designed turbojet



Source: Liul'ka and Kuvshinnikov (1981), 93



Source: Gunston (1995), 104

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Introduction

This paper is about the allocation of resources to military research and development (R&D) in a command system. In whose interests were Soviet military resources allocated? Four approaches to this question may be considered. First, a longstanding and authoritative literature suggests that the allocation of resources responded primarily to high–level commands, and that the latter reflected national missions driven by perceptions of external threats. For example, the classic works of Joseph Berliner and David Holloway emphasised the role of national security considerations in driving mission–oriented research in the defence sector.[1]

Other approaches may also be considered. A second approach is derived from "proprietorial" theories of dictatorship, exemplified by the work of Mancur Olson. These imply that an all–powerful dictator would have allocated military technological resources in such a way as to maximise the security of his tax revenues.[2] A third approach is inspired by the literature on rent–seeking in bureaucratic systems; it suggests that we should look more closely for opportunistic behaviour on the part of domestic low–level R&D agents who may have exploited asymmetries in the distribution of information in order to extract rents.[3] Finally, in the spirit of Ronald Wintrobe's analysis of the trading of rents for loyalty in a political market place, we should ask whether there really was a national R&D mission that was first designed in relation to external threats, followed by rent–seeking that fed itself upon the national mission; or whether it was rent–seeking that came first and the national mission was designed to distribute domestic rents in return for domestic loyalty.[4] From these various standpoints military R&D may be analysed as both a public and a private good.

Defence R&D under Dictatorship and Democracy

What do these four approaches predict about the allocation of resources? Consider defence outlays in general. The outcome of the pure national–mission model is straightforward. Defence is a public good. A social–welfare maximising government facing a given threat should allocate resources to military outlays of all kinds until the expected social return equals the cost to society at the margin. However, it is not clear that governments actually do this anywhere in the world.[5]

Consider defence outlays in a dictatorship and a democracy. Michelle Garfinkel has argued that incumbent policy–makers in competitive political systems have an incentive to underinvest in national security in the face of a given threat, because the likelihood of being replaced in the short–term by another policy–maker with different goals prevents the incumbent from fully internalising the long–term benefits.[6] Given that threats are not actually given but are determined by interaction between states,

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[1] Berliner (1976); Holloway (1982a); Hanson and Pavitt (1987).

[2] Olson (1993).

[3] On secrecy and scientific fraud in military R&D see Park (2000), 189; on opportunism in Soviet military R&D see Harrison (2001).

[4] Wintrobe (1998).

[5] For new research on the determinants of European defence expenditures in the interwar period see Eloranta (2000) and (2001).

[6] Garfinkel (1994).

the outcome can be a good equilibrium of low military spending in regions where democracies predominate. Garfinkel also shows empirically that democratic states have tended to spend less on defence than nondemocratic ones.

A proprietorial dictator will make a calculation that differs in several respects from that made by an elected governor. He, not society, bears the whole cost of military outlays because they are a deduction from his rent. He shares in the public–good return, that is the protection of society including his income from it, against external threats. He expects to internalise his return over a longer period than an electoral cycle. In addition to the public–good return that protects both society and the dictator, military outlays provide the dictator with a purely private return: the army will protect him against society. For these reasons the dictator will allocate resources to military outlays until the long–run marginal social benefit, plus the dictator's marginal private benefit, equals the marginal cost. Finally, by engaging in military competition the dictator may stimulate external threats; this can shift the regional context towards a bad equilibrium of heightened insecurity, a higher public–good return, and higher spending.

Now consider investments specifically in military R&D. The explicit motivation of Soviet military R&D was to enhance national security in the future rather than the present.[7] That being the case we might expect investments in military R&D to respond to approximately the same logic as defence consumption, but with two differences. First, time matters more, and this promoted the incentive to invest in military R&D. Time mattered to Stalin, who planned for the long term, and in fact spent most of his life preparing for a future war; it is true that his planning horizon shortened in the late 1930s, but this was because of the growing likelihood of war in the present, not because of an electoral deadline.

The second difference was a disincentive, especially for a poor country. National security is a public good but with a local domain: the sphere of its nonexcludable benefits can be limited to the nation. In contrast R&D output spills over national frontiers unless controlled by official secrecy. Secrets are hard to keep, and strategic competitors can send spies to steal them. Such calculations suggest that a poor country with strategic aspirations like the Soviet Union should have abstained from domestic military R&D altogether and instead relied on exploiting spillovers from richer countries by means of industrial espionage.[8]

However, the disincentive may be less than is often thought. R&D produces knowledge that is only partly explicit; the rest is tacit.[9] Only the explicit element of knowledge is a pure public good with a global domain, with benefits that are excludable through secrecy alone. The evidence suggests that tacit knowledge is

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[7] Standard western accounting definitions (e.g. Pryor, 1968) restrict defence outlays to the pay and subsistence of military personnel, the procurement of weapons, the cost of military operations (e.g. fuel and transport), and defence construction (e.g. barracks, airfields, fortifications). All defence outlays are counted as government consumption, even when they involve defence construction or additions to military stockpiles. Other investments, including in military R&D, add to the productive capacity of society and are counted as firms' gross investment, not under defence. As will become apparent below this differs somewhat from Soviet practice, under which military R&D was paid partly by the army and partly by industry. On defence outlays in Soviet and western national accounts see Harrison (1996), xxviii–xxix.

[8] Some have argued that this is all we need to know about Soviet technology, e.g. Keller (1960) and Sutton (1971).

[9] On tacit knowledge see MacKenzie (1996), 215–16. Tacit knowledge is recognised in economics as the result of "learning by doing" (e.g. Arrow, 1962). The classic example of tacit knowledge is the understanding required to ride a bicycle.

produced jointly with explicit knowledge and is complementary to it in use. Thus explicit knowledge, although easily borrowed or stolen, is hard to exploit without local tacit knowledge. To gain tacit knowledge requires investments in R&D so that agents may “learn by doing”. Thus tacit knowledge enhances the excludability of returns to investments in military R&D so long as the R&D agents themselves are kept personally secure by restrictions on their travel and migration. While the Soviet authorities made every possible use of R&D spillovers from the west, tacit knowledge and its uses were at the core of their motives for investing in R&D at home.

Military R&D and the Distribution of Rents

Under any constitution the military budget may become a focus for rent–seekers, and military R&D is well suited to this.[10] The following factors make it so: military secrecy; relatively soft budget constraints; intrinsic uncertainty about the timescale and expected value of returns to investment that impede selection, including the rational expectation that many projects will fail; and large information biases that impede monitoring. Under these circumstances self–interested R&D agents can be expected to invest resources in lobbying for initial funding or refinancing of their own projects, and some of the resources they invest will be diverted from nominal allocations to military R&D. In addition, their lobbying is designed to attract more funding than an uncorrupted principal would have allocated to them. Thus rent–seeking is a negative–sum game. The result is that military R&D will claim more resources than would be allocated on a comparison of marginal revenues and costs whether to society or to a dictator.

Finally, under any constitution the government may intentionally design its military R&D or procurement system to dissipate rents in return for loyalty. Under democratic arrangements the resulting outlays will exceed the efficient level for a public good. The excess is the signal that loyalty is expected in return; if some waste did not result, those receiving the funding would have no reason to offer thanks to the government in exchange since any politician would rationally promise to undertake at least those expenditures that were efficient.[11] A dictator and his subjects will make a similar calculation, only their criteria for efficiency will be private and are likely to be less restrictive than in a democracy.

One way of differentiating between these four approaches is to consider the significance of R&D failures. From the point of view of the national mission, or the dictator’s interests, an R&D failure was simply part of the cost of success: some experiments fail, and failed experiments are part of the necessary background against which success is achieved. In contrast, from the point of view of rent–seeking R&D agents, failure may well provide more (and more certain) revenue than success, provided the costs of the agents’ failure are either shared with society or borne by the dictator. Thus R&D failures may be a private good although a social bad. Finally, the resources invested in R&D failures may be an unintended consequence of the experimentation process, or they may be intended to compensate agents directly for their loyalty.

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[10] Analysis on these lines is often traced back to US President Dwight D. Eisenhower’s parting warning (17 January 1961) to the American people against “the acquisition of unwarranted influence, whether sought or unsought, by the military–industrial complex”. According to Holloway (1982a), 293, “A major assumption in the argment that a powerful military–industrial complex dominates American policy is that the United States has spent more than is necessary on defence”.

[11] Wintrobe (1998), 31. Consider for example US President George W. Bush’s commitment to implement the National Missile Defense programme alongside the lobbying outlays and political contributions of Boeing, Lockheed Martin, and Raytheon, all big contractors for NMD (Hartung and Ciarrocca, 2000).

Is the allocation of Soviet R&D resources best described as taking place within a hierarchy or a market? This may seem a strange question. A market is a network that is organised horizontally and a hierarchy is a vertical network. In a standard work on Soviet military innovation David Holloway wrote: "It is a characteristic feature of the Soviet economy that vertical relationships predominate over horizontal ones; and this is true of the defence sector too".[12] Even in rich market economies the market for defence goods and services always involves significant vertical relationships of unequal power because the government is a monopsonist. In market economies defence contractors also enjoy non–market advantages over civilian suppliers and competitors in nondefence markets because they can exploit relationships with government that can be made exclusive and defended on grounds of national security and secrecy. In the Soviet economy the government's monopoly of capital funding, credit, and material supply made hierarchy even more important.

In this paper, however, I deliberately emphasise "the market for inventions" in order to lean against a literature that has tended to analyse the Soviet allocation of R&D resources within a framework of exclusively vertical relationships of command and monitoring. In a spirit similar to that of Eugène Zaleski's idea of a sphere of "regulated market economy" within Soviet planning, I will show that horizontal relationships were surprisingly important to the allocation process.[13] However, if the reader is minded to protest that hierarchy was still at the core of the command system and cannot possibly be omitted from the analysis I will be the first to agree.

This paper is in eight parts. Part 1 outlines the problem of jet propulsion facing aviation inventors and designers in all countries in the interwar period. Part 2 describes the scale and diversity of the Soviet R&D effort in this field up to 1944. Parts 3 and 4 identify the funding principals and the design agents, describe some of the networks that bound them together, and find that designers had the advantage of the first move. Parts 5 and 6 describe the transactions that arose from the long term character of projects: decisions to refinance or not to refinance, and secondary asset market transactions such as takeovers and mergers. Part 7 analyses the problem faced by the funding principals in distinguishing between good and bad projects. Part 8 concludes.

1. The Problem of Jet Propulsion

The case through which I explore these issues is the Soviet effort in the field of aviation jet propulsion. "Jet propulsion" or "jet reaction" covers the principle underlying both rocket motors and jet engines: action and reaction are equal and opposite. A rocket is just a jet that does not need to breathe air. For consistency one might refer to the "air–jet" engine to distinguish it from the rocket type of jet, as the Russians did in the 1930s: *vozdushno–reaktivnaia dvigatel'*. But I will call them just jets and rockets. I begin in the dawn of the process in 1932, and I conclude in 1944 when it was apparent that the jet propulsion of aircraft was already an established fact. I explore my topic through the documentary records of the defence industry held by the Russian State Economics Archive (RGAE), supplemented by those of the Red Army held by the Russian State Military Archive (RGVA), with a few records also held by the State Archive of the Russian Federation (GARF), all in Moscow.

In the interwar period, the airscrew propeller driven by a reciprocating piston engine reached its limits in terms of speed and altitude of aircraft performance.[14] This prompted intensive efforts in several countries to develop completely new types of aeroengine based on a continuous thermal cycle giving rise to a jet reaction. Two

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[12] Holloway (1982a), 330.

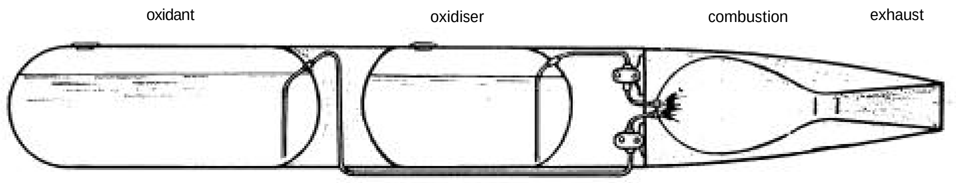
[13] Zaleski (1980), 490–2.

[14] Grigor'ev (1994), 189.

concepts competed, each of classic simplicity, but in each case their practical realisation proved to be extraordinary difficult and complex. One was the rocket motor and the other was the jet engine.

Small solid–fuelled rockets had been used for hundreds of years in many countries for display and signals. A survey prepared in the ammunition commissariat in 1939 reminds us that rockets were used for the first time in European warfare in the Napoleonic wars, initially as an incendiary siege weapon, then as ammunition against troops, and by the middle of the nineteenth century most armies carried substantial stocks of rocket artillery.[15] Towards the twentieth century rifled artillery acquired a significant advantage in accuracy and concentration of fire and rockets were little used in World War I, but in the interwar period rocketry experienced a renaissance in connection with new fuels and artillery uses. Aviation was exceptionally important as a complementary development, since rockets could be used for both air–to–ground and ground–to–air artillery.

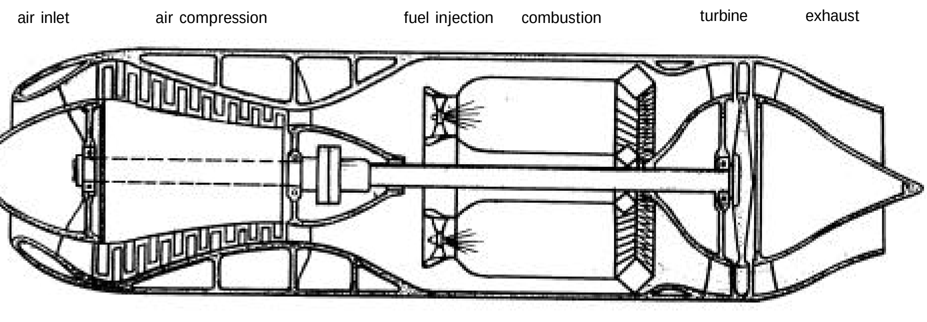
Figure 1. The liquid–fuelled rocket motor



Source: RGAE, 8044/1/1182, 95. Labels are added. This and the drawings reproduced in figures 2 to 4 were evidently prepared in the commissariat of the aircraft industry in 1944 to accompany a briefing for Stalin by commissar A.I. Shakhurin and set of proposals on the development of jet and rocket aircraft and aeroengines. The originals are coloured by hand.

In the 1930s rockets also began to be used in an entirely new way, as aviation boosters. However, to create a primary aviation power plant would require a rocket motor of unprecedented size and complexity, using more powerful liquid fuels (see figure 1) with pressurised or pumped fuel delivery, and requiring substantial advances in material and fuel sciences and control systems. In the interwar years the practical gain from such an achievement remained speculative; because rocket fuel contained its own combustion ingredients, rockets were understood to be capable of performing at limitless altitudes but only for limited duration.

Figure 2. The turbojet



Source: RGAE, 8044/1/1182, 97. Labels are added.

The concept of the air–breathing jet engine was of much more recent origin. At its simplest there was a hollow tube; provided the tube was already moving at high

[15] RGAE, *fond* 7516, *opis'* 1, *delo* 324, folios 6–11 (hereafter 7516/1/324, 6–11) (no date but 1939). USSR ministries were called "People's Commissariats" (here commissariats for short) until March 1946.

speed air would enter the tube at one end and be compressed (hence "ramjet"), after which it was mixed with fuel and burnt; the exhaust gases left the other end of the tube in a jet stream, driving the tube forward. The defect of the ramjet was that it could not serve as a primary power plant because the aircraft had to be accelerated to high speed before the ramjet could ignite. A primary power plant had to be able to suck in and compress air when stationary. In Frank Whittle's patent of 1930 this function was to be met by a single moving part, a rotating spindle driving a compressor at the front and driven by a turbine at the rear; combustion would take place between the compressor and turbine, and the exhaust gases would drive the turbine: hence, "turbojet". Figure 2 shows an engine with an axial compressor of the type developed in Germany during the war as distinct from the radial compressor favoured by the early British turbojets.

As with interwar rocketry the practical gains from such a device lacked experimental confirmation. Jets were understood in theory to be capable of higher speeds at higher altitudes than airscrew engines, though not of space flight, and for much longer duration than rockets. The concept of a gas turbine arose naturally from existing applications of steam turbines, principally in electricity generation and marine engineering.[16] But to combine a jet engine with a gas turbocompressor required developments in material and fuel sciences and control systems far beyond the level of the time.

Expectations, both positive and negative, were very important. In each country faith in the future of the turbojet, reinforced by the belief that rivals in other countries were making equal or greater efforts, drove the R&D effort along a path of trial and error. Final success made the turbojet a self–fulfilling prophecy.[17] But there were many failures *en route*, and these were double–edged. With hindsight the failures were a part of learning and a necessary cost of success. At the time, however, they often fuelled scepticism and conservatism, as those involved sometimes recognised. As an investigation into the faulty manufacture of parts for a Soviet prototype gas turbine reported in 1938: "to start the engine in the form produced by the factory — if it were possible — could only end in an accident *and destroy the idea of building a gas turbine at its very inception*".[18]

Scepticism was an obstacle everywhere. In Britain Whittle feared that each mishap would destroy his funders' faith in both himself and his engine.[19] In the United States the National Academy of Sciences reported negatively on the technical feasibility of the turbojet in June 1940; this was a year *after* the first successful though secret test flight of a Heinkel turbojet aircraft in Germany.[20] According to the Soviet turbojet pioneer A.M. Liul'ka scepticism persisted in the Soviet Union until the end of 1943.[21] Even in Germany the scepticism evaporated only after the principle

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[16] Voronkov (1984), 115.

[17] On the "technological trajectory" as a self–fulfilling prophecy see MacKenzie (1996), 57.

[18] RGAE, 8328/1/995, 111 (9 December 1938): emphasis added. The investigator was the steam turbine designer A. Kozhevnikov, the prototype was an Uvarov design (see table 1), and the manufacturer was the Kolomna engineering works.

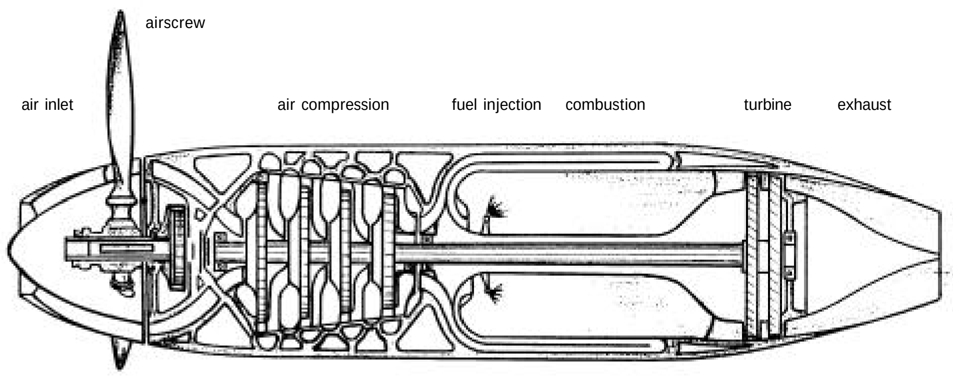
[19] E.g. Whittle (1953), 78.

[20] A passage from the report reproduced by Golley (1987), facing page 114, bears Whittle's handwritten comment: "Good thing I was too stupid to know this".

[21] Liul'ka and Kuvshinnikov (1981), 89.

had been demonstrated in flight.[22] But as we shall see it was also characteristic of inventors to ascribe their difficulties to resistance by unbelievers.

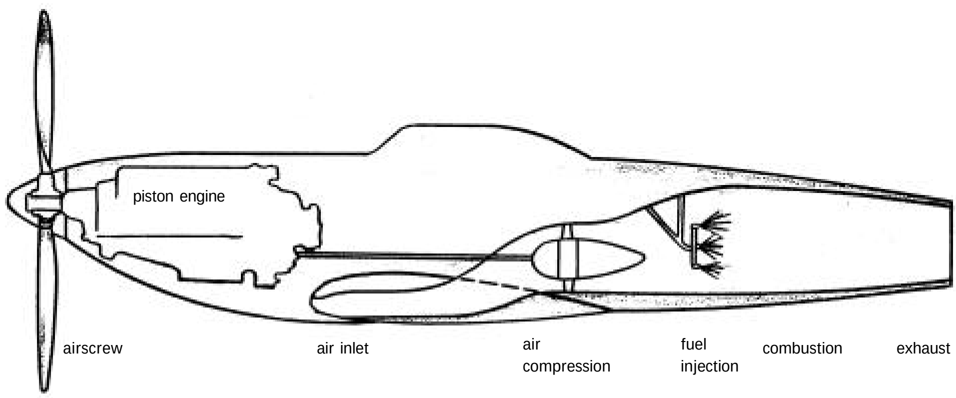
Figure 3. The propjet



Source: RGAE, 8044/1/1182, 96. Labels are added.

Theory ran far ahead of what was technically practicable. For example, the thermodynamic efficiency of the turbojet was already understood to be poor at low speeds and altitudes, so a further development on the turbojet conceived well before it could be implemented was the "propjet" (figure 3): the turbine drives not only the compressor but also an airscrew propeller subject to reduction gearing, which improves thermodynamic efficiency provided high speeds and altitudes are not required. And between the turbojet and propjet lay the fanjet, or turbojet with a bypass chamber, universally applied in modern jet airliners; a bypass engine was patented by Liul'ka in April 1941.[23]

Figure 4. The hybrid jet engine with compressor



Source: RGAE, 8044/1/1182, 94. Labels are added.

A natural response to the great gap between theory and practice was to compromise. To get around the fundamental difficulty of the turbocompressor, clever and inventive people all over Europe were exploring a variety of intermediate steps and hybrid solutions; the Soviet Union was only unusual in both pursuing a relatively wide range of alternatives and finding little practical success in any.[24] The simplest stopgap was to place auxiliary ramjet boosters on an otherwise conventional aircraft,

[22] Ermenc (1990), 8 (interview: Hans von Ohain) and 89 (Peter Kappus).

[23] Liul'ka and Kuvshinnikov (1981), 91.

[24] Surveys of Soviet interwar progress in this direction include Egorov (1994), 424–36; Serov (1997); and Gordon and Dexter (1999).

but this was also least satisfactory because the boosters added little extra speed and resulted in considerable aerodynamic losses.

A more complex alternative, but still less demanding than the turbojet, was to build a hybrid engine: a supercharged jet for which the compressor was driven by an auxiliary piston engine rather than a gas turbine, enabling the jet engine to act as the primary power plant. A hybrid engine of Soviet design is shown in figure 4: the piston engine drives both a conventional airscrew and a compressor for a jet engine. The aircraft shown looks like the experimental I–107/Su–5 tested in 1945.

There was also widespread interest in the refinement of existing steam turbine technology as an alternative means of driving a conventional airscrew. If oil–fired steam turbines had replaced the reciprocating engine at sea, then why not in the air as well? Finally, there remained rocketry: if the turbojet remained impractical, then rocket motors must be developed far beyond their existing limits. I include all these in the scope of this paper.

From a mission standpoint, what were the appropriate responses to the extent of technological uncertainty? The chances of progress could be enhanced mainly by an open–ended commitment to advance on many fronts at the same time. Many problems demanded simultaneous technological solutions. Many applications would not be detected without free–ranging exploration of new technologies. The state had to fund many projects, accepting a high probability of failure in any one project, in order to ensure that at least some successful projects would be included. Failed inventions were part of the costs of success.[25]

As far as the scale of effort is concerned, no government would accept a completely open financial commitment, but there were different degrees of open–handedness across countries. For each country the feasibility of a given commitment varied with the economy's size, development level, and mobilisation capacity. The interwar British, German, and Soviet economies were of approximately similar size. Britain and Germany were more developed in science and industry than the USSR, but the Soviet economy was not without an advantage in its superior mobilisation capacity.[26]

2. Scale and Diversity

Table 1 provides an overview of Soviet R&D projects in jet propulsion and aviation turbines from 1932 to 1944. It is compiled mainly from the plans, reports, and memoranda of the commissariats of defence, internal affairs, heavy industry, the defence industry, ammunition, and the aircraft industry, as shown in appendix A. The table is organised by R&D establishment, and is somewhat more complete than the narrative accounts supplied by previous authorities which have tended to focus on famous designers such as Liul'ka and V.V. Uvarov; this led to a neglect of those projects not associated with famous designers, or which ended in failure so that their sponsors have preferred to forget about them.

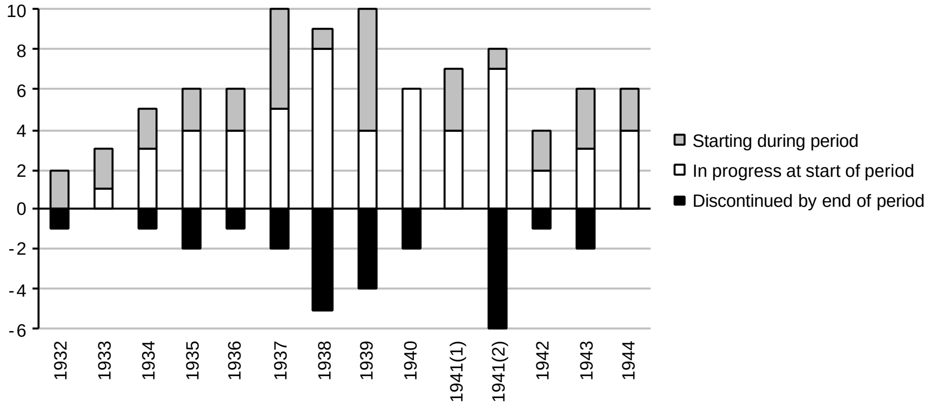
The table shows that in the prewar years a dozen research establishments were involved; these are detailed with their affiliations in appendix B. First among them, the only one with a continuous commitment throughout the period under review, was the body formed in January 1934 as RNII: the Jet Propulsion Research Institute. RNII's history is complex and turbulent.[27] It underwent half a dozen changes of name and/or affiliation in a dozen years; these are summarised in figure B–1. Many establishments had no connection with the aircraft industry; for example, until the war RNII was regarded principally as an artillery establishment, and some others

[25] Mokyr (1990), 176–7.

[26] Harrison (1998).

[27] Harrison (2000), 127–30; Siddiqi (2000a), 1–14.

Figure 5. Major Soviet R&D projects in jet propulsion and turbines for aviation, 1932–1944



Source: calculated from table 2.

were affiliated to the energy sector. Table 1 also indicates that some long–standing projects were nomadic; for example, in the interwar years Aksiutin's and Uvarov's projects moved from one institute or bureau to another. There were also cases of forced relocation by the NKVD (commissariat for internal affairs) such as those involving the future chief designers of the Soviet Union S.P. Korolev and V.P. Glushko. Finally, some establishments shared projects and designers. These mean that the number of R&D establishments involved over a period of time tended to exceed the number of designers and projects.

The time profile of the number of projects is illustrated in figure 5. It shows significant growth, turnover, and fluctuations. There was a cycle in the number of major projects in progress which peaked at eight at the beginning of 1938. In the years 1932 to 1937 fifteen projects were initiated and seven terminated, leaving eight continuing into 1938. In the latter year there was a sudden retrenchment: one new project began while five were terminated. In the period from 1939 to the outbreak of war in mid–1941 there was high turnover and some renewed expansion: a further six projects were terminated but nine new ones took their place. As a result, at the outbreak of war there was a new peak with seven projects in progress. In the first critical six months of the war only one new project was initiated and six were cancelled, so that at the beginning of 1942 the field of effort was at its most restricted in more than ten years: only two projects continued. But in 1942 a new diffusion of effort began with seven new projects beginning and only three further terminations through 1944, leaving six major projects in progress at the closing date of the period under review. Most important of the latter was Liul'ka's TR–1, illustrated on the cover page.

The spread of this cycle across establishments is also clear. The continuous core of jet propulsion R&D was located in RNII–NII–3. Nearly all the expansion of research up to 1938 involved a diffusion of effort to other establishments, mainly those belonging to heavy industry and the Red Army. These projects were eliminated in the two retrenchments of 1938 and 1941, leaving RNII–NII–3 alone in the field at the beginning of 1942.

Table 2 compares the pattern of efforts in jet and turbine engineering with that in aviation rocketry. It shows that jet and turbine projects accounted for most of the activity and nearly all the volatility shown in figure 5. For example, they were seven out of the eight projects continuing at the beginning of 1938 and also in mid–1941. All of the terminations of 1938 and the second half of 1941 were jet and turbine projects. In fact at the end of 1941 there were no jet or turbine projects in progress at all, and there was a complete if temporary break until progress resumed in 1942.

Did this effort represent a significant commitment of national resources? On the information available at present, the answer appears to be no: the entire business amounted to little more than a cottage industry. A reasonable guess at the scale of a typical project in the late 1930s would be half a million rubles a year, involving the direct employment of five scientific workers and an additional handful of ancillary staff. On the basis of an annual average wage for that period of 3000 rubles, half a million rubles would also represent the direct–plus–indirect employment of 150 to 200 public–sector workers. If so, then the seven projects in progress at the peak of interwar activity represented a maximum annual outlay of three to four million rubles per year, the direct employment of 30 to 40 scientific workers, and the direct–plus–indirect employment of perhaps 1000 public–sector employees.

In more detail, table 3 shows that RNII–NII–3, the most important organisation in this field, employed roughly 400 staff in the mid–1930s and that this total had doubled by the outbreak of war. Of course there was a very high proportion of scientifically and technically qualified staff, including a couple of hundred "engineering and technical employees", perhaps roughly equivalent to the science faculty of a small or medium university of that time. Table 4 presents the two main rocketry establishments, RNII and its offshoot KB–7, in comparison with the other research outfits of the ammunition industry in 1938. It shows that RNII remained substantially larger than KB–7 in staffing, budget, and R&D profile. But even in combination they represented little more than loose change. In 1938 the two largest establishments in the industry, NII–24 (together with its Leningrad filial) and KB–47, deployed 170 scientific workers, 355 research topics, and nearly 32 million rubles. By another measure, the 57 scientific workers at RNII and KB–7 represented little more than 0.5 per thousand of the scientific workers employed in the Soviet economy two years later.[28]

The value of work done by RNII–NII–3 grew rapidly in the interwar period. Between 1936 and 1939 it more than trebled, before coming to a sudden halt in 1940; figures are as follows: [29]

1936	3 377 thousand rubles
1937 plan	4 482 thousand rubles
1938	6 111 thousand rubles
1939	11 434 thousand rubles
1940	11 233 thousand rubles

Nominal stagnation in 1940 probably meant a substantial cut in real terms.[30] Still, considering general trends over the second half of the 1930s, these figures were rising

[28] There were 98 300 "scientific workers" in the Soviet Union in 1940 according to Goskomstat (1987), 64.

[29] For 1936 and 1937 plan see appendix C. For 1938–9 see RGAE, 8162/1/240, 32 (13 January 1940), and for 1940 RGAE, 8162/1/449, 3 (14 January 1941). The figure for 1940 that had been planned and approved by KO was slightly higher at 11 725 thousand rubles. However, towards the end of that year an investigation uncovered that the responsible fourth chief administration of the commissariat of aircraft production had illegally planned a much higher figure of 13 162 thousand rubles; see RGAE, 7516/1/692, 3 (21 November 1940). No doubt this was followed by hasty and perhaps severe cutbacks during December.

faster than the Red Army's overall procurement of military equipment. The latter, however, was greater by several orders of magnitude.[31]

It is important to bear in mind, moreover, the greater part of the work done at RNII–NII–3 was concerned with rocket artillery and had nothing to do with aviation. Jet engineering and aviation rocketry accounted for just two fifths of the direct costs of research and experimentation planned by RNII in 1937 (925 thousand rubles out of 2.3 millions).[32] Subsequently, this proportion declined. For example, in the preliminary allocations to the projects listed by NII–3 in its thematic plan for research and experimentation in 1940, the proportion of aviation–related projects fell to less than 6 per cent (700 out of 11 725 thousand rubles).[33]

Figures for outlays and personnel in wartime R&D for jet propulsion are lacking. It is clear that the outbreak of war saw a sharp cutback followed by a degree of recovery. By 1944 work on jet propulsion had assumed new urgency. The reason was that jet and rocket aircraft with German markings had appeared in combat roles in the skies over Europe. British jet aircraft were also entering service. The problems of principle had been solved and the sceptics had been answered. The Soviet aircraft industry was lagging behind, and it was now a practical matter of catching up with all speed. However, it seems unlikely that the resources committed to jet propulsion R&D in the war period up to May 1944 represented a significant advance on the peacetime effort in the same direction.

The Soviet outlays appear trivial in comparison with the resources that Germany devoted to the development of V–weapons. A postwar American estimate put the total development costs of the jet–powered V–1 cruise missile at approximately $200 million in wartime US prices, and those of the V–2 rocket at ten times that amount, or roughly the same as the $2 billion costs of developing the atomic bomb in the United States.[34] It seems unlikely that the total of Soviet resources invested in aviation jet propulsion up to the end of 1944 exceeded $20 million on the same standard of valuation.[35]

What limited Soviet outlays on jet propulsion R&D? For reasons that are considered in more detail below, financial constraints on Soviet R&D projects were soft. On a few occasions this was made explicit. At a meeting of the technical council of the chief administration for the aircraft industry held in August 1936 to review the development of a number of steam turbine projects, one of the designers present reported: "they told me, to carry out the testing of the turbine in our factory funds of the order of a million rubles are needed". The presiding deputy commissar for heavy industry M.M. Kaganovich interrupted: "I can provide it". Kaganovich told another

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[30] Between 1937 and 1940 average industrial product prices and railway freight charges rose at rates varying from 6 to 56 per cent (Bergson, 1961, 367–8), and annual earnings by 30 per cent (ibid., 422).

[31] Equipment orders for the army and navy in 1937 were 5.7 *billion* rubles (Davies and Harrison, 2000, 82), and 14.5 billion rubles for the army alone in 1940 (Harrison, 1996, 281).

[32] RGAE, 8159/1/6, 74 (December 1936).

[33] RGAE, 8162/1/300, 65–66, 80–81 (17 November 1940).

[34] Ordway and Sharpe (1979), 242, 253. I am not familiar with similar estimates of the overall development costs of the jet engine in Britain or Germany.

[35] Table 3 suggests a total of 87 project years from 1932 to 1944; take 100 in case of omitted projects. Take the late 1930s as the standard, so each project year cost half a million rubles, making 50 million rubles as the cumulative total. One prewar ruble was worth anything from 10 and 35 US wartime cents (Harrison, 1996, 275); again, take the upper figure, which gives $17.5 millions. Add some more for luck.

designer to proceed if he could to a flight test: "Whatever it costs I'll pay". He summed up: "I am not so poor, we have money in the sums that are needed, the boss is not hoarding it, comrade Ordzhonikidze [G.K. Ordzhonikidze, Kaganovich's superior] says to take what you need."[36]

At first sight, ignoring the cost to society, soft budget constraints might seem like a good thing because the chances of successful invention would appear to increase with the number of generously funded projects. However, soft budget constraints probably also encouraged adverse behavioural responses. Hanson and Pavitt note a tendency of government–funded R&D to generate "too few technical alternatives"; this is because, when budget constraints are soft, R&D agents display too little care in coming to conclusions. They "do not apply the normal, prudent practice of commercial firms in carefully exploring technical alternatives in order to reduce technical and commercial alternatives. Instead, they tend to follow a high risk strategy of premature commitment to the full scale commercial development of a particular technical configuration, before the reduction of key technical and commercial uncertainties".[37] In other words, uncertain outcomes are not a good reason to throw money at a problem.

Moreover, soft budget constraints for existing projects did not mean unlimited funding for the field as a whole. Rather, funding was limited otherwise, by administrative denial of funding to new proposals and interventions to terminate projects in progress. In the interwar years progress in jet propulsion was accompanied by an institutional cycle. In the first phase new technological possibilities were defined and exploration began in a dispersed, fragmentary way. Proposals acquired funding and financial constraints were relatively soft, so projects proliferated. Resource commitments grew and became dispersed. At a certain point the authorities lost patience with rising expenses and lack of results. The need was felt to concentrate resources and focus efforts more narrowly, so the second phase of the cycle took the form of terminating those projects judged less successful and concentrating funding on a limited range of priorities in a limited range of organisations. Then the cycle was repeated because beyond a point concentration resulted in mistakes: scientific exploration and experimentation were curtailed in some direction or other that would subsequently prove useful. Therefore, concentration was usually temporary because challenges to central priorities and organisational monopolies would emerge from below and the first phase would begin again.

There were two complete cycles in the interwar years. The first cycle began in the 1920s and culminated at the beginning of our period. It was marked by the establishment of RNII as the centre for jet propulsion R&D; at the same time aircraft design had been deliberately concentrated in TsAGI (the Central Aero–Hydrodynamic Institute), and conventional aeroengineering in TsIAM (the Central Institute for Aviation Engineering). The second cycle is illustrated in figure 5; it culminated in the purge of RNII and its conversion to NII–3, an establishment specialised in rocket ammunition. A third cycle began in 1940 but was interrupted by the war.

3. The Funding Principals

David Holloway has suggested that the diffusion of major innovations through the Soviet defence sector may be analysed in terms of the balance between supply–side or "discovery–push" factors and "demand–pull" factors.[38] In the case of jet propulsion projects, which predominated?

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[36] RGAE, 8328/1/824, 40, 51, 52ob (22 August 1936).

[37] Hanson and Pavitt (1987), 46.

[38] Holloway (1982a), 288.

I will refer to the actors on the demand side as the *funding principals*. At times we may need to distinguish among them between the fundholder and the funding department. The *fundholder* was the legal owner of the R&D assets, usually a production commissariat, but the Red Army also maintained its own R&D establishments. The *funding department* paid for R&D services. Centralised orders were paid out of the USSR state budget. In addition, budgetary institutions such as the defence commissariat were entitled to enter into decentralised contracts with industrial institutes and design bureaux for R&D services. Finally, the fundholder could also commission R&D services on an in–house basis from its own establishments. For example, we find that the 11 725 thousand rubles of total expenditure on research planned by NII–3 in 1940 were to be financed partly from the state budget, partly from decentralised contracts made with outside funding departments, and partly by the fundholder, the ammunition commissariat, represented by the chief administration; the breakdown was as follows:[39]

Source of funding	*Number of projects*	*Thousand rubles*
State budget	18	5 790
Contracts	15	3 440
Chief administration	12	2 495

Both fundholders and funding departments compiled operational plans for research and experimentation within a framework of strategic directives that were issued from time to time by high–level government committees: the Council for Labour and Defence, the executive subcommittee of the Council of People's Commissars responsible for defence matters, and the war cabinet. In practice, regardless of the formal issuing authority, effective decision–making power was secretly exercised by Stalin personally in consultation with a varying circle of members of the Politburo or, in wartime, his war cabinet, usually after receiving representations or representatives of the funding departments and fundholders.[40] Among the most important directives affecting R&D for jet propulsion during the period under review were the following:[41]

Date	*Issuing authority*	*Decision*
July 1932	KO SNK (defence committee of the Council of People's Commissars)	To intensify research on jet propulsion
Sept. 1933	STO (Council of Labour and Defence)	To establish RNII
July 1940	KO SNK	To proceed with design of Liul'ka turbojet
Aug. 1941	GKO (State Defence Committee, or war cabinet)	To proceed with design of Bolkhovitinov ("BI") rocket fighter
Nov. 1942	GKO	To produce Kostikov ("302") rocket fighter
Feb. 1944	GKO	To establish NII–1
May 1944	GKO	To proceed with design of a number of rocket and jet aircraft and engines

Within this framework both funding departments and fundholders formulated operational plans. The most important planning horizon was annual. The Red Army

[39] RGAE, 8162/1/449, 3 (14 January 1941).

[40] Khlevniuk et al. (1995); Khlevniuk (1996).

[41] Danilov (1981), 71.

had an annual plan for the development of military inventions some of which it funded directly through its own R&D establishments and some of which it contracted out to other organisations. Industrial ministries, including the branches of the defence industry, had their own R&D plans, including an annual plan for aeroengine research and experimentation to be carried out by its own institutes and bureaux, part of which was made up by contracts accepted from the Red Army.

How did projects win a place in the plan? There was a variety of routes, but their common feature was that the initiative lay with the designer. This was not a process whereby all–seeing and all–knowing planners identified needs from above, sought out designers, and put them together with resources to meet the needs identified. Rather, proposals came first from below. This was recognised by commissar for the aircraft industry A.I. Shakhurin when he explained to deputy prime minister N.A. Voznesenskii in February 1941: "Work on the creation of jet propulsion engines at home in the USSR […] began on the initiative of a few engineers taking the form of inventors' proposals".[42]

Successful proposals required investments in lobbying. Such investments could bring not only success for individual proposals but also long–term privileged relationships with government officials responsible for funding. This could make it difficult to establish where the initiative lay and blur the whole distinction between discovery–push and demand–pull as a result. To win support for their projects and adoption of their designs, designers had to be "heterogeneous engineers" capable of reshaping organisational as well as technological constraints.[43] To create a demand for new designs they had to build coalitions with soldiers or industrialists to overcome interests vested in markets for products that already existed.[44] In particular, they had to overcome the preference of industry for the undisturbed mass production of weapons in long serial runs, which was often at odds with radical product innovation and the risks and requirements of continual upheaval in production.[45]

For example, the aircraft designer P.O. Sukhoi is said to have won success in having his designs adopted only after he took on a partner, E.A. Ivanov, who had the political and bureaucratic skills to push his product through the military and party–state apparatus.[46] This provides an exception to the rule that Soviet producers did not need to hire marketing agents, only supply facilitators or *tolkachi.* Other examples are the alliances formed in Germany by the turbojet pioneer Hans von Ohain with the aircraft manufacturer Otto Heinkel, and in the Soviet Union by the rocket pioneers with the military leader M.N. Tukhachevskii.[47]

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[42] RGAE, 8044/1/460, 59 (5 February, 1941). This was the case not only with jet propulsion, as the history of the Soviet "uranium project" suggests: even in this most secret and unified project in the history of the Soviet Union, the first movers were the atomic physicists (Holloway, 1994, especially chapter 4, 72–95).

[43] MacKenzie (1996), 13.

[44] Holloway (1982a), 292. On the political "connectedness" of successful postwar Soviet designers see Almquist (1990). 70–3.

[45] Berliner (1976), 534–8; on the defence industry specifically see Albrecht (1989), 195–7 and 207–8.

[46] Ozerov (1973), 53.

[47] Siddiqi (2000a), 7. According to Peter Kappus of BMW, interviewed in 1974 by Ermenc (1990), 91, the support of Heinkel was critical to Ohain's success with the turbojet in Germany and explained why Whittle took twice as long in the UK.

Tukhachevskii, Red Army chief of armament from 1931 to 1936, was the single most important patron of jet propulsion in the Soviet Union between the wars.[48] Under his aegis at the outset was the Leningrad Gas Dynamics Laboratory (GDL), founded in 1929 by the Red Army's administration for military inventions for the development of solid–fuelled rocket ammunition. In Moscow in 1931 a voluntary society of rocket scientists, the Group for Study of Jet–Propelled Motion (GIRD), began to promote the cause of space exploration based on liquid–fuelled rocketry.[49] The group was led by Korolev and sponsored by the civil defence organisation Osoaviakhim. In September 1933 Tukhachevskii sponsored a merger of GDL and GIRD in a new establishment subordinated directly to him, the Jet Propulsion Research Institute (RNII).[50] He hoped perhaps to acquire a monopoly as both fundholder and funding authority for all forms of jet propulsion development. But to his frustration, by a decree of the Council for Labour and Defence the new establishment was almost immediately transferred to the commissariat of heavy industry under Ordzhonikidze.[51] This followed the precedent of existing parallel arrangements for TsAGI and TsIAM.

Although no longer the fundholder, the Red Army and Tukhachevskii personally retained close involvement with RNII as the funding department contracting for much of its R&D output. RNII was an unhappy marriage, and divisions soon emerged between the weapons specialists of GDL and the space enthusiasts of GIRD. The new director I.T. Kleimenov, formerly head of GDL, curtailed work on liquid–fuelled rockets on the grounds of its low expected military utility, sidelining Korolev and the other *GIRDovtsy*. The result was a huge row that embroiled RNII and the local party organisation, and pitched Korolev and Tukhachevskii against Kleimenov and Ordzhonikidze.[52] In 1935 Tukhachevskii exploited these divisions to recruit Korneev, an engineer dismissed by Kleimenov, and some other former *GIRDovtsy* to KB–7, a new design bureau devoted to liquid–fuelled rocketry and established under the Red Army administration for military inventions.[53] Thus he became a fundholder in jet propulsion development once more, although without a monopoly.

For reasons that are largely unrelated to this topic Tukhachevskii was arrested in May 1937 and, along with many other officers, subsequently executed as a traitor.[54] After this, the cause of aviation jet propulsion lacked a high–level sponsor until

[48] In November 1929 the post of chief of armament of the Red Army was created to help carry through its equipment modernisation. The first chief of armament was Army Commander I.P. Uborevich, followed in 1931 by Army Commander, later Marshal M.N. Tukhachevskii. Among the departments reporting to the chief of armament was an administration for military inventions. In 1936 the post of chief of armament was abolished, its place taken by a chief administration for supply of weapons and equipment, and under the latter a department for inventions (see Holloway, 1982a, 321). On Tukhachevskii and Red Army rearmament more generally see Samuelson (1996 and 2000) and Stoecker (1998).

[49] GARF, 8418/6/243, 35–37 (14 May 1933).

[50] RGVA, 4/14/1171, 33 (23 January 1934); see also Siddiqi (2000a), 4–7.

[51] RGVA, 34272/1/146, 134 (31 October 1933).

[52] RGVA, 34272/1/177, 5–10 (27 May 1934), 17–19 (29 May 1934), 20–21 (June 1934), 1–2 (26 July 1934), and 33 (13 September 1934). See also Siddiqi (2000a), 7–9; Siddiqi (2000b).

[53] Siddiqi (2000a), 8.

[54] Stoecker (1998), 000–000; Samuelson (2000), 186–7.

Stalin's deputy and central committee secretary G.M. Malenkov began to take an interest in 1943.[55]

4. The First–Movers

Who held the initiative in the Soviet market for jet propulsion projects? The stereotype of a command system might lead one to suppose that the initiative lay above with the funding authority. The existence of connections of patronage and networking between funding principals and R&D agents makes this a more complicated issue.

One way of weighing the question up is to ask what was the most important difficulty for the funding principals: was it to *promote*, or to *limit* the number of projects involving jet propulsion? The clearcut answer to this question is that the funding principals struggled continually to limit and constrain initiatives and proposals from below. Rather than the funding principals having to stimulate activity at lower levels, it was initiatives from below that were critical in stimulating higher–level interest and finding patrons. These initiatives were diverse and flowed from many sources, and were much more numerous than initiatives from above. One result is that R&D projects had a tendency to proliferate that the funding principals found difficult to control. This is reflected in the character of high–level decisions: reports and resolutions prescribing the consolidation or cancellation of existing rival projects greatly outweighed the number of decisions authorising new ones.

In the present section I describe briefly the sources of proposals from lower levels, which were of three kinds: from established designers, from backyard inventors, and from foreigners. I note separately the uses that these proposals made of information from the foreign press and foreign commercial information.

Initiatives of Established Designers

Established designers constantly brought proposals for radical innovations to the attention of funding principals; it was their job to do so. As an example of the former, here is deputy commissar M.M. Kaganovich who was responsible for the aircraft industry in 1936:[56]

> Three years ago comrade Tsvetkov came to me and proposed making such a turbine, I went to the boss, the people's commissar signed a decree to the effect that, in urgent order, under personal responsibility, [inaudible] to make a turbine […]

Designers worked to secure ministerial approval and the funding that followed. If refused at one level, they appealed to the next. If necessary they initiated projects unofficially, without waiting for authorisation, based on the resources of the organisations within which they worked, then used preliminary results in lobbying to gain official backing.[57]

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[55] See for example RGAE, 8044/1/984, 264–275 (22 October 1943) for a report on the history and perspectives of jet propulsion prepared for Malenkov by aircraft industry commissar Shakhurin.

[56] RGAE, 8328/1/824 (22 August 1936), 35.

[57] The principle is illustrated by an anecdote (Perakh, 1998, §9.1): in the 1930s A.F. Ioffe, director of the Physical–Technical Institute in Leningrad, was approached by a group of young scientists who wanted to embark on research in atomic physics. Ioffe recognised the potential of their proposal but was under continuous pressure to give more resources to applied research. He realised it might be difficult to justify it to the party authorities, and resolved to go ahead by means of a ruse. He allocated laboratory space to the atomic physics project unofficially, and posted a sign on the door: "Stockroom". As he expected, at the next inspection the party officials walked

Such behaviour and its consequences are revealed in a statement by NII–3 director A.G. Kostikov to a meeting of his scientific–technical council in May 1942 at a moment when resources could not have been more under strain:[58]

> As an example of how we are forced to diffuse the attention of our cadres I will take the first research department. There are 26 [research] topics for 10 engineers. Some of these topics are incidental to our institute and do not match its profile or specialisation. These topics arose because there were people to put them forward and instead of passing them on to those organisations for whom such topics were more appropriate we engaged in them ourselves. […] It's characteristic of such topics that working on them involves unnecessary investigations since [we have] no matching experience. Often what is done is done many times, and all because we took on what was not our business, because we have neither experience nor cadres to work on items that do not match the profile of our institute.

Initiatives of Backyard Inventors

Ordinary citizens with and without technical qualifications also wrote to the Red Army with ideas and proposals for work on high–speed, high–altitude aviation, a few of which were taken up.

The files of the Red Army administration for military inventions show, for example, that in April 1932 and again in March 1936 one E.A. Blau submitted proposals for different aeroengines based on jet propulsion. These proposals were reviewed and rejected. In the judgement of one reviewer, "despite the fact that the author is an engineer [his designs] are distinguished by their naivety and demonstrate a complete absence of elementary information concerning jet propulsion".[59] Another file collects 51 proposals for jet, rocket, or turbine engines and airframes that were submitted in 1937, some professionally executed, some handwritten and childishly illustrated. Each proposal was either met with formal requests for further information or else rejected out of hand. One author proposed to lighten his superheavy airframe by filling the wings with hydrogen, neglecting the fact that a cubic metre of hydrogen generates only one kilogramme of buoyancy; another proposed a winged or cruise missile but omitted to allow for a guidance system or automatic stabilisation.[60]

A somewhat special case is presented by GIRD, a voluntary society until it was merged with GDL to form RNII in 1933. The *GIRDovtsy* were not exactly backyard inventors but they were not conscripts either. They were civilian enthusiasts who worked with minimal funding or other official sponsorship, fired by their own enthusiasm. Their great achievement was the successful launch of the Soviet Union's first liquid–fuelled rocket in August 1933.[61]

Initiatives by Foreign Designers

In the late 1920s and early 1930s sympathetic foreigners with a technical interest wrote to the Red Army drawing its attention to the military significance of work on rocketry going on abroad and offering to promote such work in the Soviet Union. For example, in 1932 a German specialist in rocketry and communist party member or sympathiser, Rolf Engel, was referred to Tukhachevskii. According to his biography he had worked in German astronomy and as a member of the Verein für Raumschiffart (Association for Space Travel) at its test firing range outside Berlin.

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straight past without curiosity. The project was safe until the time was right for Stalin to recognise the importance of atomic physics.

[58] RGAE, 8162/1/574, 101 (7 May 1942).

[59] RGVA, 29/56/349 (1932–1936).

[60] RGVA, 29/56/354 (1937).

[61] GARF, 8418/6/243, 42 (22 August 1933).

Engel volunteered a report on developments in rocketry in Germany and abroad, emphasising the breadth and depth of German developments; finally, he proposed to bring a group to the Soviet Union to collaborate with Soviet rocketeers.[62]

Designers' Initiatives Based on the Foreign Press

Established designers were able to monitor the foreign press and work the information they obtained in order to push experimental aerospace projects up the agenda and support claims for funding.

The Red Army chief of armament's files for 1931 testify to the pressure from below to note progress abroad and emulate it at home. This pressure was given a clear relevance to funding decisions. For example, in May 1931 GDL director Petropavloskii reported to the Red Army on work on rocketry abroad, mainly in Germany and the United States.[63] In Germany a number of research groups and firms (including Junkers and Opel) were described as competing for both patents and funding under the umbrella of a voluntary society for space travel including armed forces representatives. The American scene was said to be characterised by a similar mix of commercial and military motivations. Petropavlovskii noted the applications of rocketry to aviation as well as artillery, including the possibility of an aircraft with a primary rocket power plant capable of speeds of 1000 kilometres per hour and higher. In a similar survey submitted at the same time the GDL rocket engineer Glushko emphasised both the intensity of activity in the West and the solubility of the basic issues in building rocket aircraft; he concluded that "in the West both industrial and particularly military circles are keenly interested in the question of creating rocket shells and apparatuses".[64]

In the mid–1930s the absence of foreign press information was used to promote claims for funding of foreign commercial expeditions. For example RNII director Kleimenov used this reasoning on three occasions in 1936 to request permission to send his engineers abroad generally, then on a tour of Germany, France, Britain, and America, then to the Paris air show.[65]

In general the lack of foreign press information was taken to mean that foreign powers were pressing ahead with developments in secret. At the same time the limited information that was obtained from foreign publications was analysed exhaustively and exploited in funding claims. In 1939 an article on developments in rocketry that had appeared three years earlier in the Italian journal *Revista Maritima* was eventually passed through to NII–3 director Slonimer.[66] The latter cited the article as providing evidence of Germany's intensive development of rocket munitions, in support of requests to make good the institute's needs with regard to finance, material supplies, and engineering workers. He also requested additional information to be gathered abroad by the "corresponding organisations" and put in for permission to send a delegation from the institute to New York to an armaments exhibition.[67] The following year he made a similar request to send two specialists to

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[62] RGVA, 34272/1/146, 28–39 (no date but 1932).

[63] RGVA, 34272/1/105, 91–94ob (20 May 1931).

[64] RGVA, 34272/1/105, 118–120 (May 1931).

[65] RGAE, 8159/1/149, 220 (26 July 1936), 219 (29 September 1936) and 218 (13 October 1936).

[66] The reference was to *Revista Maritima*, 1936, no. 6, 421–439; see RGAE, 7516/1/324, 12–42, for the translation. The article was mainly devoted to rocket artillery, but possible applications to aviation were discussed on the final page.

[67] RGAE, 7516/1/324, 1–4 (9 April 1939).

Germany to find out more about work on rocketry there, again citing the *Revista Maritima* article in support.[68]

A survey of the historical applications of rocketry written in the ammunition commissariat in 1939 noted that, despite the veil of secrecy that had descended over most military aspects of rocketry abroad, the little that was being published testified to the urgency of rivalry in rocket technology. The examples the author cited were from a French work translated into Russian in the defence commissariat.[69] A translation of an American article from 1939 listed the potential uses of rockets as ranging from field artillery to intercontinental bombardment and space exploration, and emphasised their ease of construction and use.[70]

Press information was not cut off with the outbreak of war. Following the April 1941 maiden flight of the Whittle jet–powered Gloster E.28/39, *Flight* magazine published a series of articles about jet propulsion in London. These articles were subsequently collected in a booklet and republished by the magazine editor.[71] It appears to be in this version that they reached the Soviet Union. Their impact was significant. The booklet circulated among designers; the description of the Italian Caproni–Campini N.1 of 1940 is reported to have encouraged staff at TsAGI in a similar design.[72] In July 1944 commissar for the aircraft industry Shakhurin copied many original *Flight* drawings to illustrate both existing and futuristic jet and turbine projects in a long briefing report for Malenkov.[73]

There is no indication that Soviet aeroengine designers had access to any information about the progress of jet engines or rocketry in any other country from unconventional means such as espionage.

Designers' Initiatives Based on Foreign Commercial Information

Trade links provided information to designers, but its value to those lobbying for resources for jet propulsion projects was limited by trade restrictions arising from military secrecy. In 1935 the aircraft designer A.N. Tupolev visited the United States (this was his second visit, the first have taken place in 1929/30) and toured a number of aircraft factories. He saw nothing of American progress in military rocketry and his report was silent on the whole issue of jet propulsion.[74] But even without secrecy considerations this would be unsurprising because the Americans had invested so little. Surveys of the German aircraft industry were also carried out in the context of the August 1939 nonaggression pact and reported to the secretariat of the commissariat for the aircraft industry in September 1940. It is more significant that these were innocent of information concerning the immense German investment and active progress towards new jet and rocket aircraft and artillery.[75]

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[68] RGAE, 8162/1/305, 30 (16 April 1940).

[69] RGAE, 7516/1/324 (no date but 1939), 10.

[70] RGAE, 7516/1/323, 1–18 (no date but 1939), translates "What can we expect of rockets?" by Major James Randolph of the US Army artillery reserve, published in *Army Ordnance*, 19(112), Jan.–Feb. 1939, 225 ff.

[71] Smith (no date).

[72] Gordon and Dexter (1999), 150. The Italian aircraft was based on a principle similar to that illustrated in figure 4, but it had no airscrew and relied entirely on a jet for forward motion. Its piston engine drove the compressor, nothing else.

[73] RGAE, 8044/1/1182, 123–147 (28 July 1944).

[74] RGVA, 29/38/96, 1–479 (10 June 1936).

[75] RGAE, 8044/1/359, 1–187 (27 September 1940); 8044/1/358, 1–9 (29 September 1940).

5. Refinancing

When projects are long term, projects in progress require periodic refinancing. Alternatively, they must be discontinued. By examining refinancing decisions affecting projects in progress we can learn more about the incentives facing designers and funding principals and the calculations they made. There was also a mechanism for the resolution of disputes over refinancing: designers could and did appeal the outcomes of adverse decisions to higher authority, ultimately to Stalin.

Decisions to Refinance

Under the system that I have described, projects arose out of initiatives at lower levels. The role of funding principals and planning decisions was reactive and tended to validate these initiatives. Consequently the refinancing of projects in progress was normal and explicit decisions to this effect are not normally observed. An exceptional insight is provided by a ministerial review of continuing projects in steam turbine development held in 1936. As table 1 shows, the first projects to build an aviation steam turbine began in 1933. During the 1930s no less than ten such projects found funding sponsorship. Six can be associated with named designers: Aksiutin, Kozhevnikov, Przheslavskii, Sinev, Tsvetkov, and the partnership of Dybskii and Udod. All had been closed down by the end of 1939.

The attraction of the steam turbine lay in the fact that it was a proven technology that could be operated with existing materials. Its weakness as a source of aviation power lay in its low power–to–weight and power–to–volume ratios, in particular the requirement for large boilers and condensers which could not be accommodated within an airframe light enough to be driven by the turbine.[76] In August 1936 M.M. Kaganovich chaired a meeting of his technical council in the chief administration for the aircraft industry on the development of a number of steam turbine projects. Kaganovich's mood was one of intense frustration, and he repeatedly interrupted the designers with heavy sarcasm:[77]

> With existing dimensions is it sensible or feasible to place such a plant in an aircraft? One turbine engineer suggested placing 5 turbines in an aircraft, but for this the aircraft must weigh 125 tons without additional payload. You could put a F[eliks] D[zerzhinskii] locomotive in an aircraft, but then the aircraft would weigh 2000 tons. This is comrade B[inaudible]'s fantasy, he's got 245–metre wings and a 45–metre fuselage.
>
> […] We're not talking about a boiler on a Tsvetkov *locomotive*. Whoever's first to give us a turbine, we'll take it and work with it and the result will be that the airscrew will turn on the ground, if we put an airscrew on a locomotive it'll also turn, but we need to put it in *an aircraft at altitude* [emphasis added].
>
> […] Three years ago comrade Tsvetkov came to me and proposed making such a turbine, I went to the boss, the people's commissar signed a decree to the effect that, in urgent order, under personal responsibility, [inaudible] to make a turbine, [they] began to make it, and now he comes and says: "There's a turbine but no boiler". That's how they move technology forward. It's as if we got pig–iron but no metal.
>
> […] I said to comrade Aksiutin […] I'll give you a TB–7 airplane, smash it to pieces if you want, but taxi it along, lift it up to 100 metres, and then it will be a deed of proof that a turbine lifts up. Whatever it costs I'll pay. But […]
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> […] I can't sit for three years and see no results.

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[76] Liul'ka and Kuvshinnikov (1981), 88.

[77] RGAE, 8328/1/824 (22 August 1936), 12, 15, 35, 51, and 52 respectively.

The designers' response was to plead for time to allow the technology to evolve. They promised to build smaller, more efficient boilers and condensers. The aircraft designers Petliakov and Lavochkin were present. It was obvious that the engines being designed would not fit an existing airframe, so Petliakov asked that there should be more consideration of aircraft design and Kaganovich promptly put him in charge of liaison. Money and time had been spent, and while there was the smallest possibility of a positive outcome he was not going to give up. The outcome was that the steam turbine projects drifted on for three more years before the last was closed down. Regrettably, the decisions to close them down have not been found. The projects simply vanished one by one from plans and reports.

Decisions Not To Refinance

A straightforward decision not to refinance a project in progress is illustrated from a file of the Red Army department of inventions.[78] In October 1937 engineer R.G. Sergeev of the design department of aircraft factory no. 22 at Fili submitted a proposal to design a 500– to 1000–kilogramme thrust rocket motor for an auxiliary flight booster, aircraft launcher, or rocket fighter. He based his proposal on a suggestion by the German specialist Eugen Sänger that had been published in an unnamed Swiss journal in 1936. He signed an agreement with the department of inventions on 15 August 1938 for the sum of 5000 rubles. He failed to complete the work promised, so his expenses were paid off in the sum of 1000 rubles only on 26 September 1940. From this we learn that small sums were easily written off. Bigger decisions were usually more complicated.

We know more about decisions not to refinance projects from the turbulent history of RNII. Frustration with the results of military R&D boiled over in the purges of 1937–8.[79] In May 1937 Tukhachevskii was arrested. The purge of RNII began in October with the arrest of director Kleimenov, Glushko, and others including the rocket mortar designer G.E. Langemak. In June 1938 work on the Korolev–Glushko rocket glider was suspended, the reasons given being the need to concentrate resources for rearmament on projects of more immediate military utility. A few days later Korelev was arrested, accused of being a Trotskyist saboteur, and sentenced to ten years' forced labour. Impatience with the lack of results of Korolev's work on rocket aviation was clearly a factor. The testing of liquid–fuelled rocket aircraft was suspended while the rocket artillery programme was stepped up.

The end of KB–7 was decided by a combination of factors. An immediate threat was the context created by the fate of its sponsor Tukhachevskii. In 1937 KB–7 director Korneev staved off immediate repression by joining in the destruction of the leading figures of RNII; he sent slanderous allegations to Stalin about Kleimenov.[80] In January 1938, with Tukhachevskii gone, KB–7 was taken away from the Red Army and handed over to the commissariat of the defence industry where, like RNII (now NII–3), it was attached to the thirteenth chief administration for ammunition. But Tukhachevskii had devised KB–7 for the far–off development of liquid–fuelled rocketry, not the quick results now sought for immediate armament. Over three years KB–7 produced nothing to show for its outlays. Take for example the report of work

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[78] RGVA, 29/56/361 (1937 to 1940).

[79] Harrison (2000), 128–30; Siddiqi (2000a), 10–11. For earlier accounts of the purge at RNII see Medvedev (1978), 34–7, 42–3; Holloway (1982b), 387–8.

[80] RGVA, 4/14/1628, 123–128 (15 June 1937). Kleimenov might have been protected from association with Tukhachevskii by a history of personal conflict with Tukhachevskii's subordinates; see for examples RGVA, 34272/1/177, 1–2 (26 July 1934) and 33 (13 September 1934). However, he had been weakened by the suicide of his patron Ordzhonikidze and the repression of the latter's subordinates.

of the thirteenth chief administration for 1938, which lists the projects completed under each institute or bureau and the weapons officially adopted by the Red Army for armament as a result. Under KB–7 the report says only: "for armament in 1938 nothing supplied, in view of the long–term [*perspektivnyi*] character of work".[81]

In the atmosphere of the time KB–7 became an easy target. In early 1939 the Red Army evidently made a decision to close down a wide range of projects in ammunition R&D, not just those concerned with aviation jet propulsion, but including the work it was funding in KB–7. According to reports made to ammunition commissar I.P. Sergeev, and forwarded by him to deputy defence commissar G.I. Kulik, navy commissar M.P. Frinovskii, and prime minister V.M. Molotov, the aggregate plan for ammunition research and experimentation for 1939 had been agreed among these commissariats and with the General Staff the previous year.[82] However, in the course of disaggregating the plan and agreeing individual contracts with R&D establishments, the Red Army had unilaterally reneged on commitments worth 40 million rubles (out of 52.5 millions) and the Navy on 7.5 millions (out of 25 millions). Even after immediate cutbacks, 25 million rubles worth of research and experimentation remained without a sponsor, including two institutes that were entirely without funding, one of which was KB–7; among those projects without funding at NII–3 were the Korolev–Glushko rocket glider and a ramjet project.

The effect of these decisions to withhold refinancing was not straightforward. It is not known whether Sergeev's protests received a hearing either in the defence commissariat or in Molotov's Council of People's Commissars. By the end of the year KB–7 had been closed down; according to Asif Siddiqi the staff, starved of funding, turned on each other and eventually on Korneev too who was arrested and imprisoned.[83] On the other hand the rocket glider and ramjet projects at NII–3 were evidently reinstated, and the Korolev–Glusko RP–318 made its maiden test flight in its inventors' absence in 1940. To judge from the annual employment return shown in table 4, NII–3 continued to expand during 1939 at a high rate, possibly by absorbing the staff of KB–7. But, as already noted, the funding of NII–3 was squeezed again in 1940 and its expansion was brought to a sudden halt.

In short, in 1939 the funding principal lost patience with its R&D investments and tried suddenly to impose a harsh constraint on the budget for research and experimentation. In the short term the attempt was only partly successful because the constraint was relaxed again to some extent, either as a result of the fundholder's lobbying to reverse the curtailment of funding, or by drawing on the fundholder's budget, or by some combination of the two. It is possible that the efforts to curtail R&D funding continued in 1940.

The aircraft industry yields a variety of examples of projects being closed in response to a lack of results. Ulrich Albrecht lists the Kalinin, Shcherbakov, Berezniak–Bolkhovitinov, and Gudkov OKBs (experimental design bureaux) as cases where the entire establishment was closed as a result of failure to create successful designs.[84] In some cases the chief designer was imprisoned (Gudkov) or executed (Kalinin). These and similar episodes including the purge of RNII made subsequent threats of extreme penalties for R&D failures highly credible. For example, the key staff responsible for designing the Soviet Union's first atomic bomb all expected to

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[81] RGAE, 8162/1/89, 125 (no date but 1939).

[82] RGAE, 8162/1/299, 36–54 (March to April 1939). Commissar Sergeev was unconnected with the engineer Sergeev previously mentioned.

[83] Siddiqi (2000b), 31.

[84] Albrecht (1989), 136, 215.

be arrested if it failed to detonate.[85] The need for credible penalisation of individuals for R&D failures could be seen as a consequence of the difficulty of making credible commitments to financial penalties for project failure.

Appeals Against Adverse Decisions

Some designers were quick to appeal against decisions to discontinue project financing to higher authority. Disputes within RNII were a plentiful source of petitions. For example, in May 1934 both Korneev and Korolev complained to higher party and military authorities over the suppression of liquid–fuelled rocketry projects by RNII director Kleimenov.[86] After the RNII purge, like many loyal victims of repression Korolev wrote to both Beriia and Stalin personally from prison to protest his innocence and plead for his return to work, as well as appealing directly to the prosecutor.[87]

Those who appealed to higher authority against adverse decisions were taking a decision to place greater trust in vertical relationships than in horizontal ones. For some this was a risky strategy. For an appeal to succeed, it was necessary for the appellant to have a previously accumulated reputation with higher authority. This was usually either a reputation for achievement, won by making an outstanding contribution to society, or a reputation for loyalty gained by betraying real or alleged wrong doing by potential rivals in the horizontal network. Reputation for loyalty was intrinsically fragile; it could be easily discredited by others choosing the same strategy. For less talented agents, therefore, winning a reputation for loyalty to superiors was a good way of making enemies, and to risk one's credit at higher levels without substantial achievement to back it up simply ensured self–destruction as the fate of Korneev in 1939 suggests.

Liul'ka too is said to have had the reputation of a "complainer" (*zhalobshchik*).[88] His petition to Stalin of May 1942 to allow him to resume work on the turbojet is a rare case in that it led to the result that the petitioner envisaged.[89] But Liul'ka's petition was based on a degree of achievement, at least, rather than on the revelation of his rivals' wrong doing; it may have suited his rivals to go along with his petition in order to raise the profile of the issue in their own interest.[90]

Like most such petitions, Korolev's own appeals from prison were probably ignored; his subsequent transfer from the Kolyma to the NKVD *sharaga* at factory no. 16 in Kazan' was entirely the result of Tupolev's intervention on his behalf.[91]

6. The secondary market

When projects are long term their need for refinancing has the necessary effect of creating a secondary asset market. Of course in principle this was a centralised system in which each project was owned by a ministerial fundholder and ownership was not freely transferable. In reality there were substantial incentives for officials to mount takeover or merger bids for projects of other fundholding authorities. The attraction

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[85] Holloway (1994), 215; Simonov (2000), 154. See further Mylde (2000).

[86] RGVA, 34272/1/177, 5–10 (Korneev to the Okt'iabrskii party raikom, 27 May 1934), and 17–19 (Korolev to Tukhachevskii, 29 May 1934).

[87] Korolev's letters to Beriia and Stalin are given by Golovanov (1994), 286–9, and his appeal by Raushenbakh (1998), 61–4.

[88] Serov (1997), 4.

[89] RGAE, 8044/1/817, 19–25 (Liul'ka to Stalin, 18 May 1942).

[90] Serov (1997), 3.

[91] Raushenbakh (1998), 66.

of a project in progress lay in the sunk costs that had already been incurred at the expense of others to whom the new fundholder did not have to pay compensation. Even if the transfer was of people rather than physical assets, the project personnel brought with them a significant intangible capital: accumulated tacit knowledge. The cost of takeover was not financial but political. First, a bid required the payment of direct lobbying costs. Second, it required the expenditure of reputation; a successful bidder made promises for which he might later be held to account. Third, it contributed indirectly to weakening the ownership rights over economic assets on which all fundholders ultimately relied. However, circumstances could easily arise in which it was more dangerous to abstain from the secondary market than to enter it.

These can easily be translated into the costs and benefits of roving banditry, to use Mancur Olson's felicitous metaphor.[92] Stalin's regime was one of a stationary bandit intent on maximising the long–term rents accruing to a dictator. But in the secondary market beneath his purview, lesser bandits roved. To a certain point this was beneficial to the regime; it reallocated resources to those who would put them to the best use. But the standard of valuation of "best use" was private not social. Moreover, it tended to dissipate the rents accruing to the dictator, and weakened the dictator's drive to maximise his long–run revenues.

In the secondary market for R&D assets the transactions that we can observe were of three kinds. First, projects were sometimes the object of takeover bids and bidding wars. Second, theft of intellectual property in particular projects might have been an issue; there is no evidence of such theft, but there is evidence that measures were taken to prevent it. Third, some projects were taken over by the NKVD on the basis of its powers of arrest and confinement.

Takeovers and Mergers

Which was better: to be large or small? In the command system to be small was only advantageous if it meant being overlooked. For example, to work in KB–7 in 1937 meant an additional life expectancy of two years compared with work in RNII. However, under more normal circumstances the command system favoured large projects because of their economies of scope: larger units required fewer lines of outside communication and were less reliant on outsiders for essential goods and services. The preference for scale was reflected in the frequent calls to eliminate duplication of effort and "parallelism". Calls for rationalisation and centralisation were rarely if ever questioned; they were regarded as progressive almost beyond debate, especially when comparisons were made with the scale of R&D establishments in aeroengineering abroad.[93] As a result, smaller units were always in danger of being swept up by rivals, while larger units were continually on the lookout for opportunities for rationalisations favourable to themselves.

The logic of the takeover bid could be seen as a call to restructure liabilities. Consider a failing project, i.e. one that had incurred significant sunk costs without giving results on schedule. Was the project intrinsically bad, or just badly funded or led? If the lack of results compared with the sunk costs could be ascribed to poor resources or organisation, then it was efficient to write off the sunk costs and refinance the project under new management. Such a logic was strengthened when the scope of activity and the number of projects was on the increase because this also brought a rising number of potentially weak projects. Thus proposals for takeovers and mergers were particular evident in the years 1937 and 1938, during and after the RNII purge.

[92] Olson (1993).

[93] RGAE, 8044/1/460, 49–51 (31 December 1940): an explanatory memorandum by People's Commissar for the Aircraft Industry A.I. Shakhurin on the 1941 plan for aeroengineering research and experimentation.

For example in December 1937 acting director Sinev of SKB (the special–purpose design bureau) of the commissariat of the defence industry submitted a memorandum listing six steam turbine projects in progress in four different institutes and three different cities. Welcoming the piecemeal advances already made, he criticised their "cottage–industry" scope (*kustarshchina*). Claiming the support of his own team and the Khar'kov project leaders, he called for all the groups to be brought together in a single "unified production–experimentation base" in Moscow, with close links to the aircraft industry.[94]

Another channel for proposals for concentration at this time was the system of peer review. Thus late in 1937 Uvarov from VTI (the All–Union Thermal–Technical Institute) was commissioned to report to the commissariat of the defence industry on the progress of a rival "gas–steam turbine" being developed at factory no. 18 by designers Dybskii and Udod. After commenting on the weaknesses that he had observed, Uvarov commented: "the continuation of work on the lines under investigation should be curtailed, the more so since work on steam and gas turbocompressors is already going on [elsewhere]. *These two lines [of work] completely cover the authors' design, and for this reason duplication will yield nothing new*".[95]

A bid to restructure research on jet aeroengines was directly sparked by the purge of RNII. Staff of the Academy of Sciences Institute of Theoretical Geophysics wrote to prime minister Molotov at the end of December 1937; Molotov's secretary forwarded it to both defence commissar K.E. Voroshilov and deputy commissar for defence industry M.M. Kaganovich for comment.[96] The writers pointed to the unmet needs of Soviet aviation in contrast to the resources being devoted to jet aeroengine development by the "capitalist countries", the designs being pursued by the Breguet and Junkers companies in France and Germany, and the veil of military secrecy which concealed real progress abroad. They ascribed resistance to jet designs in the Soviet Union to "presently exposed enemies of the people", an alliance of soldiers and designers including Langemak of RNII and Efimov, chief of the Red Army artillery administration, both recently executed. As for the engineers working in the field such as I.A. Merkulov, they charged them with "creating 'conditions' of work bordering on mockery" (the phrase "bordering on" was probably significant: not *actually* mockery, just bordering on it). They called for a policy of concentration of personnel and projects in one or more enlarged collectives based on KB–7. The writers concluded with a proposal for pure and applied research encompassing ramjets, pulse–jets, and hybrid engines.

This was therefore an example either of an altruistic takeover bid or a takeover bid by proxy, since the Institute of Theoretical Geophysics had no clear interest in the fortunes of KB–7. The bid was unsuccessful. Kaganovich called on the new NII–3 director Kostikov for comment. The latter presented a strongly argued case for his own institute to be the new centre for jet engine R&D, based on a short scientific review of jet concepts and experimental results. He concluded that it was essential to draw into this line of work people "closely involved with aviation technology" as opposed to those "incidentally showing an interest" (this was a slighting reference to KB–7); Kaganovich in turn supported the NII–3 position.[97] So did the Army: the new air force chief Loktionov wrote to Voroshilov supporting the writers of the Institute of Theoretical Geophysics in principle but rejecting the case for KB–7 on grounds

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[94] RGAE, 8328/1/992, 14–18 (19 December 1937).

[95] RGAE, 8328/1/996, 22–24 (1 January 1938): emphasis added.

[96] RGVA, 4/14/1925, 16–18 and RGAE, 7515/1/378, 304–306 (both (31 December 1937).

[97] RGAE, 7515/1/378, 298–303 (no date).

that the latter lacked the necessary research and production equipment. He recommended NII–3 as the new centre for jet engine development, and deputy defence commissar Fed'ko repeated these arguments to Molotov adding a proposal that NII–3 absorb relevant personnel of KB–7.[98] This was the eventual outcome, although KB–7 survived until the end of 1939.

Shortly afterwards a new struggle arose for control over the development of aviation steam turbines: yes, this was still "work in progress", and the lack of results was being attributed not to intrinsic badness of the project but to dispersion of resources and duplication of effort. In mid–1938 the commissariat of the defence industry submitted to Molotov its long–delayed draft plan for aeroengine experimentation for that year. It proposed that all work on aviation steam turbines should be centralised in TsKTI (the Central Boiler and Turbine Institute) in Leningrad and that a grant of 2.5 million rubles should be made to TsKTI to expand its plant and equipment for this purpose.[99] On the defensive this time, SKB director Sinev wrote to Molotov, the Kaganovich brothers (one commissar for the defence industry, the other the responsible central committee secretary), and defence commissar Voroshilov to protest this recommendation.[100] Sinev made three charges against TsKTI: it lacked an "aviation culture"; it was ineffective even at its primary task, the design of steam turbines for power stations; and it was already "overlarge" (*gromozdkaia*). Again he proposed the formation of a new bureau in Moscow based on one of a range of existing aviation establishments.

This was therefore a defensive move against a hostile takeover. But the defence failed; it was referred to air force chief Loktionov, who rejected it and upheld the recommendation in favour of TsKTI.[101] And as table 1 shows 1938 saw the end of aviation steam turbines at SKB. On the other hand the victory of TsKTI was hollow, because steam aviation was going nowhere and all such projects had been closed down by the end of 1939. In the end, after spending tens of millions of rubles, everyone had to recognise that these were just *bad projects*.[102]

As has been seen, the years 1938 and 1939 brought a dramatic curtailment in the number of projects in aviation rocket and jet R&D. In 1940 a new expansion phase began. Therefore it is no surprise to find that, in his memorandum of February 1941 to deputy prime minister Voznesenskii, commissar of the aircraft industry Shakhurin listed the various ongoing projects and proposed "to concentrate all the work in progress in [NII–3] of NKBP [the ammunition commissiat] … and transfer the institute to NKAP [the commissariat of the aircraft industry]", enclosing a draft decree to that effect.[103] This particular bid failed for the moment, or was overtaken by events; after the outbreak of war NII–3 was first subordinated directly to the Council of People's Commissars, and handed over to NKAP only in 1944.

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[98] RGVA, 4/14/1925, 21–21ob (4 February 1938) and 4/14/1925, 22–22ob (15 February 1938).

[99] RGVA, 4/14/1925, 232–248 (26 June 1938).

[100] RGVA, 4/14/1925, 150–152 (17 May 1938).

[101] RGVA, 4/14/1925, 155 (19 May 1938).

[102] Acting SKB director Sinev put the total of sunk costs of the various steam turbine projects up to the end of 1937 at 20 million rubles over five and a half years; see RGAE, 8328/1/992, 15 (19 December 1937). (And he was arguing for 10 million rubles *more*.)

[103] RGAE, 8044/1/460, 60–57 (5 February 1941).

Raids on Intellectual Property

One way in which R&D agents might have captured projects already in progress was by taking over their new explicit knowledge. The explicit knowledge could then have been used to underpin new proposals for development funding. The new proposals would have looked "good" because they would have been in a position to expropriate rents that should have accrued to the originators of the explicit knowledge without having to account for the sunk costs of experimentation already incurred by them.

There is no direct evidence of such activity. However, there is evidence that both designers and ministries regarded plagiarism as a threat to their future rents. For example, at the August 1936 review of steam turbine projects in the commissariat of heavy industry it became apparent to Kaganovich that many of the barriers against the collaboration among designers that he desired were created by the designers themselves, each intent on protecting his own intellectual monopoly, and by their departmental superiors. Development work for the Aksiutin turbine was proceeding at LKZ (the Leningrad Kirov factory), but without results. Why had engineer Vinblad failed to make himself useful to Aksiutin on the LKZ site? Because no one would issue him with a pass. Why not? A participating engineer commented: "[..] because there was rivalry, the special proprietary interest [*opeka*] of each in this business. Each was trying to turn this business into a business [associated with] his own name".[104] In response, Kaganovich was simultaneously reassuring and threatening:[105]

> I will take all measures to protect the authorship of one or another comrade at work. If it's Aksiutin's turbine so let it be, but if he's up to some fabrication, and not up to realising a technical solution to the problem, and for this reason has kept Vinblad away from the installation for a full year, then that is an obvious criminal act and an obvious detriment to the value of the turbine for our work.
>
> In our country there are no secrets and the designer who holds on to big secrets and does not carry them out into life — in the capitalist world he would simply perish and in the socialist [world] he is simply good for nothing. That's why we will set in train all measures and powers to help you realise the ideas and creativity that you have performed, while you are guaranteed full protection of authorship.

But secrets remained, and the readiness to defend them continued to reflect departmental interest. Eighteen months later an official of the Leningrad research institute for naval shipbuilding wrote to the head of the eighteenth chief administration of the commissariat of the defence industry asking for assistance in gaining access to the work of Uvarov on gas turbines at VTI in Moscow:[106]

> Our attempts to gain access to the work of Prof. Uvarov have not succeeded. From personal conversations of our colleague military engineer (first grade) Zotikov with Prof. Uvarov it became apparent that serving as motives for refusal were hostility to LMZ *im. Stalina* [the Leningrad Metallurgical Factory] (more precisely, of chief of the steam turbine bureau Prof. Grinberg) and in addition ostensibly special instructions about the secrecy of the work.

The reply of the eighteenth chief administration was a curt refusal to intervene.[107]

Hostile Takeovers Using Powers of Arrest and Confinement

As is well known the NKVD arrested a number of aircraft and aeroengine designers in the purges of 1936–8 and used them to formulate proposals for implementing new

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[104] RGAE, 8328/1/824 (22 August 1936), 38.

[105] RGAE, 8328/1/824 (22 August 1936), 35, 52.

[106] RGAE, 8328/1/995 (3 May 1938), 6.

[107] RGAE, 8328/1/995 (15 May 1938), 5.

designs.[108] Most were from TsAGI, TsIAM, and the Tupolev design bureau (including Tupolev himself) at factory no. 156. Tupolev's *sharaga* was subsequently organised as TsKB–29. Of the RNII personnel arrested in 1937, some were shot and the rest sent to labour camps. Some survivors were subsequently recalled from the Kolyma and put to work in the NKVD aeroengine *sharaga* in Kazan'.

7. Good and Bad Projects

There were good reasons for governments to ration the funding of military aviation R&D. Most important was the fact that the availability of funding attracted both bad and good projects which those allocating research funding could not tell apart beforehand. This created strong incentives to ration available funding across projects and through time. Through time alternative projects could be compared in the hope of identifying the bad projects that should not be refinanced. Effectively, they were used to provide information about each other. For example, competitive rivalry eventually became commonplace in Soviet aviation R&D: rival design bureaux were assigned specifications by the government, and competed for their designs to be adopted by the consumer, the defence ministry.[109]

This mechanism could not be used in the case of unique projects such as the building of the first Soviet atomic bomb. In that case, the difficulty was mitigated by using the results of the Manhattan project, gained through espionage, both to guide and to monitor Soviet progress.[110]

A deeper problem persisted even when projects were not unique, if they were long term; this meant that projects could attract refinancing even when they were known to be bad. Rationing funding through time enabled the monitoring of progress so that refinancing decisions could be taken in the light of more information than was available originally. However, suppose a project was taking longer to complete than had been promised at the outset. Because some costs were already sunk, it could still be efficient for both the funding principal and the R&D agent to continue a project that the principal would have preferred not to finance in the first place.[111] The result was an element of adverse selection: it gave R&D agents an incentive to understate needs and overstate expected returns so as to obtain the first instalment of funding. Once the first instalment was paid and had become a sunk cost, the payment of the next instalment became more likely. Moreover, if results fell short at the stage where refinancing was necessary, the designer could always shift blame to the funder since the first instalment of funding was always less than the full sum originally proposed.

What factors determined whether a project was "good" or "bad" from the point of view of the national mission? This depended on four factors: the unknown state of nature, the level of funding, the organisation of resources and teamwork, and the motivation of the design team. First, the state of nature determined whether or not the project was intrinsically bad. Second, even for an intrinsically good project the level of funding needed to be appropriate to the task. Third, the physical and human resources employed on the project required effective organisation, including teamwork and leadership; a design team that lacked the right equipment or was poorly led would give poor results. Finally, success depended on motivation: what was good or bad depended on whether the state saw it the same way as the designer.

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[108] On the history of the *sharaga* or *sharashka* institution see Albrecht (1989), 133–5, and Starkov (2000), 255–60. On the Tupolev *sharaga* see Ozerov (1973), and on the Kazan' *sharaga* Golovanov (1994), 318–28.

[109] Holloway (1982a), 317–19.

[110] Mylde (2000).

[111] Dewatripont and Maskin (1995).

Thus some inventors involved in jet propulsion R&D may have been motivated otherwise: to realise a dream, to build an empire, to live in style, or to live in peace. In 1937–8, official suspicions of "other" motivation were hardened into the designation "enemy of the people". It is not necessary to go to this extreme to accept that R&D agents' motivations were not necessarily aligned at all times with the preferences of the state.

When a project failed, did it matter whether it was intrinsically bad, or potentially good but poorly funded or organised? Under well–functioning market arrangements with unconstrained credit, free entry, and competition among many projects, it should not have mattered: good projects would have driven out bad ones and efficient leaders would have driven out the rest, and the reasons why some projects failed would have been of interest only to economic historians. But under Soviet arrangements it was of great practical significance to the funding principals. This is because, with funding rationed and entry controlled, there was a danger that bad projects might drive out good ones. Therefore it was necessary for the funding authorities to diagnose the causes of project failure to see if they could be rectified. However, it was also extremely difficult, and perhaps impossible, to do so without hindsight. Even with hindsight it is still very difficult, and for this reason I avoid comment on the intrinsic goodness or causes of failure of individual projects. Only classes of project can be evaluated in this way; for example, all the aviation steam turbine projects were intrinsically bad, but I do not know which ones were also poorly funded or poorly led.

The various research establishments reported regularly to higher authority on each project in progress.[112] From time to time the same authorities launched special reviews which ranged from round–table exchanges of specialist opinion concerning common difficulties shared by several projects, and specific investigations of specific projects thought to be at risk of failing. But the difficulty of establishing the causes of project failure made it easy for designers to place the blame for their own lack of success elsewhere. They tended to blame either the scepticism of the funder or the incompetence of the producer.[113] In the last years before the war they sometimes also blamed the bad faith of "enemies of the people".

As has already been shown, designers sometimes implicitly faulted the funder for providing resources on too small a scale and also for dispersing them too widely, that is, sharing them with rival projects: they argued that more time and more focused funding would turn things round. Designers also blamed producers for failure to share the motivation of the design, leading to incompetent or neglectful preparation of components and assemblies. For example, the steam turbine designer Aksiutin complained to Tukhachevskii in 1935 that LKZ was incapable of playing a constructive role because it was gripped by "a certain conservatism utterly alien to the aviation culture" and commented that LKZ had declined a contract to build an Uvarov turbine for VTI giving as its official reason that the turbine required "too many parts to be completed to 'aviation standards' that would be an embarrassment

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[112] For example see RGAE, 8159/1/137, 2–28 (no date but 1937), 8162/1/240, 9–63 (9 January 1940), and 8162/1/449, 2–61 (14 January 1941) for the annual reports of RNII–NII–3 in 1936, 1939, and 1940 respectively. In 1967 the annual reports for 1937 and 1938 were transferred from RGAE to the archive of the USSR Academy of Sciences where they can no longer be traced.

[113] Whittle (1953), 206–7, ascribes some of the resistance he encountered to an alliance between the Rover Company and British "officials, who had spent the greater part of their lives in the familiar field of piston engines, [who] subconsciously resented the advent of a type of engine which rendered useless much of their specialised knowledge slowly acquired over many years".

for the factory [*chto dlia zavoda zatrudnitel'no*]". [114] Again, when Kozhevnikov investigated the failure to complete construction of the Uvarov gas turbine at the Kolomna engineering factory during 1938 in a case already cited above, he laid blame entirely on the incompetent work of the factory, making this a case of a good project that was badly supported. [115]

According to the recollection of the aircraft designer A.S. Iakovlev, Stalin himself reflected on this problem:

> A designer is a creative worker. Like the painter of a picture or the writer of a literary work, the product of a designer's or scholar's creativity can be successful or unsuccessful. The only difference is that from a picture or verse you can tell the author's talent right away. […] With a designer it's more complicated: his design can look very attractive on paper, but final success or failure is determined much later as a result of the work of a numerous collective and after the expenditure of substantial material means … Most designers get carried away with themselves and are convinced of their own and no one else's righteousness; on the basis of an overdeveloped self–regard and the mistrust that is characteristic of every author they tend to attribute their own failures to prejudice against themselves and their creations.[116]

Were the different intrinsic motivations of R&D agents a factor in project success and failure? Again, these need not have mattered under well–functioning market arrangements because those projects hijacked to serve someone's hidden agenda would have been driven from the market. But Soviet funding institutions offered a degree of protection for self–serving interests; this made it necessary for the state mount periodic inquisitions into the motivation of its agents, through which Stalin and his security chiefs N.I. Ezhov, then L.P. Beriia, sought to peer into the souls of their scientists and engineers.

A particularly complicated situation arose if the state's preferences only became well defined in the course of exploring the technological frontier, and then some of the R&D agents who had thought themselves to be working to the state's agenda found the state to be the party that was unexpectedly otherwise motivated. For example Korolev became a traitor in 1937 because the state's agenda had changed, and he became a hero again in 1957 for the same reason. Finally, this could give rise to a situation in which R&D agents fought each other for a say in determining government priorities, and some prevailed at others' expense. This is roughly what happened at RNII in the years between its establishment and the purge of 1937–8.

Asif Siddiqi has proposed a framework for understanding motivational conflicts among the rocket specialists at RNII.[117] They clashed over solid versus liquid propellants, nitric acid versus liquid oxygen, and winged versus ballistic missiles. Siddiqi suggests that each dispute was organised around differences in agents' orientation towards long–term goals. Some were more responsive to military imperatives and saw rocketry primarily as a means of artillery bombardment. A military orientation led them to favour more stable and storable solid fuels despite their lower energy content and lower potential for control in flight. They favoured nitric acid over liquid oxygen because the former was more available and more storable. Finally they favoured winged over ballistic missiles because winged missiles could cover longer ranges given weaker engines. Others were ultimately more interested in the perspectives for exploring the cosmos for which powerful engines using fuels of exceptionally high energy content were the first essential. The dividing

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[114] RGVA, 33989/2/235, 192 (15 December 1935).

[115] RGAE, 8328/1/995, 106–16 (9 December 1938).

[116] Iakovlev (2000), 501.

[117] Siddiqi (2000b).

line between these two groups was also to a large extent former Red Army GDL versus formerly civilian GIRD, and ex–Leningrad versus Moscow.

Within RNII the former *GIRDovtsy* were clearly closer to an aviation problematic than the artillerymen of former GDL. But in the wider world of Soviet aviation the men of GIRD were completely atypical. They saw an aircraft as no more than a convenient temporary platform for a rocket technology ultimately destined for space. Korolev, for example, promoted the development of the Soviet Union's first winged rocket aircraft only as a pragmatic response to the fact that he did not yet have a rocket motor powerful enough to travel far without wings. In principle he was completely committed to the development of ballistic rocketry.

The clash between artillerymen and space enthusiasts at RNII simmered through the mid–1930s before boiling over in the purge of 1937–8 in which the *GIRDovtsy* were swept away, taking several of their opponents with them. Why did these conflicts flare with such intensity? Siddiqi suggests that the technological uncertainties were simply too large to be settled scientifically on the basis of the limited funding provided by principals. This heightened the risks of R&D activity, and high stakes plus limited resources fed back into bitter infighting.[118] But secondary markets in R&D assets became more active at the same time, which suggests that agents pursued market–type strategies to insure themselves as well as political strategies.

Were bad projects deliberately tolerated or fostered at any level in order to distribute rents and promote vertical relationships of trust and loyalty? Some allegations concern the rocket designer Kostikov. The background is important, for Kostikov remains a controversial figure to this day. His critics resent the fact that he took the public credit for developing the highly successful *Katiusha* rocket mortar from its true originator Langemak who was executed.[119] They argue that he was not an accidental beneficiary of the purge at RNII but a willing tool of Ezhov and Stalin, a renegade *GIRDovets* who turned against his former comrades. They hold him at least partly responsible for the repression of Korolev and others.[120] Korolev is said to have carried a lifelong grudge against him for this reason.[121]

Gennadii Serov has suggested that Kostikov was unduly favoured by Stalin in the wartime allocation of project funding. In November 1942 Stalin authorised the development of Kostikov's unproven design for the 302 rocket fighter, at a time when the development of new weapons in other fields was being ruthlessly suppressed in favour of mass production of existing ones. Serov notes the "practically unlimited financial possibilities" at Kostikov's disposal: 25 million rubles for NII–3–GIRT in 1943, compared with a similar sum for the Iakovlev and Mikoian aircraft OKBs put together.[122] It is true that subsequently Kostikov was punished for the 302's failure: in the spring of 1944 he was sacked, then arrested. On the other hand his punishment was mild: he was released after a year in prison, and retained his military rank and decorations. In Iaroslav Golovanov's words, "Stalin had need of Kostikov, since [the latter] was one of the bearers of the Stalinist world order".[123]

There is more evidence of the dissipation of rents at lower levels. For example, the collegium of the ammunition commissariat investigated the work of NII–3

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[118] Siddiqi (2000b).

[119] Medvedev, 1978, 36–7

[120] Siddiqi (2000b), 25.

[121] Golovanov (1994), 512. But these accusations are considered "unfounded" by Raushenbakh (1998), 66.

[122] Serov (1997), 4.

[123] Golvanov (1994), 511.

towards the end of 1940. The session was chaired by the minister, commissar Sergeev. The investigation found that NII–3 director Slonimer had pursued "deception, sleight of hand, and false representation of the work of the institute" in relation to rocket armament towards various levels of higher authority up to and including Malenkov and Voroshilov.[124] He had done so in order to request bonuses and medals for himself and others, and he had also used these to buy the collusion of his immediate superior.[125]

Slonimer had committed other crimes as well. He had ignored orders "to cleanse the apparatus of NII–3 of politically ill–intentioned elements […] the contamination of NII–3 by such persons persists to the present day". He had reported plan fulfilment in terms of ruble outlays, not in terms of real project completion. He had engaged in opportunistic plan corrections to make the plan easier to fulfil. He had overbid for scarce aviation fuel and had diverted it to unauthorised uses for personal transport; detailed figures were provided. Interestingly Kostikov was also reprimanded for lack of progress in his work and because, having complained to higher authority about restrictions imposed on his work by Slonimer, he had failed to alert the authorities to the (alleged) true state of affairs in the institute. Slonimer was subsequently dismissed and arrested.

Within a few months it was Sergeev's turn on the rack. A commission comprising Marshals Kulik, Novikov, and Kuznetsov reported to Stalin and Molotov that in the ammunition commissariat under Sergeev bureaucracy, favouritism, and nepotism were flourishing.[126] Subsequently, Sergeev was dismissed.

But what these episodes show is that, when rent–seeking was identified, it was punished. If there was safety, it lay in underfunding. Thus, in 1950 Stalin suddenly accused his favourite aircraft designer Iakovlev of diverting state funds into excessive salary and bonus payments ("Do you know what they say about you behind your back? They tell me you are a looter [*rvach*])". What saved him was the solidarity of his immediate superior, minister of the aircraft industry M.V. Khrunichev, who could assure Stalin that Iakovlev's design team and production workers were fewer in number, lower paid, and less well equipped than those of the other designers.[127]

8. Conclusions

This investigation, while limited to a study of research and experimentation in the field of aviation jet propulsion, suggests a number of findings of more general significance.

1. Jet propulsion R&D was carried out in the context of a vertically organised command system. Within this context there was a great deal of market–like activity on the supply side including horizontal rivalry, competitive rent–seeking, and attempts to bar entry and create monopolies. There was also a secondary market in R&D projects involving takeover and merger activity.
2. The first–mover's advantage was held by the designer. The evidence is that there were more initiatives for radical innovation proposals than the authorities were willing to fund. There was no shortage of inventiveness. The main problem for the authorities was to control, not to promote inventive activity.

[124] RGAE, 7516/1/692, 1–7 (21 November 1940).

[125] For such a request see RGAE, 8162/1/306, 186–7 (22 July 1940).

[126] RGAE, 7516/1/823, 84–91 (20 March 1941). How surprising, to find that in this low–trust culture a senior official preferred to work with relatives and cronies.

[127] Iakovlev (2000), 395.

3. In the Soviet Union jet propulsion R&D was an artisan industry. The resources made available for new research in jet propulsion were extremely limited and funding was rationed. However, budget constraints on individual projects in progress tended to become soft. Once a project had been selected for funding it had a good chance of its funding being continued until aggregate limits on the funding principals' resources and patience were breached.
4. There was a cyclical aspect to the diffusion of jet propulsion R&D projects. At first projects proliferated, so resource commitments grew and became dispersed. At a certain point funding principals lost patience, terminated those projects judged to be failing, and redirected funding to more limited priorities. Then, the limitation of activity gave rise to unexploited opportunities, so new challenges to central priorities and organisational monopolies emerged and designers' lobbying activity resumed.
5. It was difficult or impossible for the authorities to tell good ideas from bad ones. It was difficult in advance because of technological uncertainty and discrepant motivations. It was not much less difficult when projects were in progress because projects could fail for reasons unrelated to the goodness of the original idea. In the presence of sunk costs, refinancing a project in progress was usually easier than terminating it. It is possible that adverse selection was the result.
6. Designers who were successful in getting their proposals selected for initial funding and subsequent refinancing were "heterogeneous engineers". They invested resources in lobbying and political reputation to ensure that their projects were selected for funding and, once selected, to protect them against termination from above or takeover by rivals in the name of rationalisation.
7. When faced with adverse funding or career decisions or takeover threats designers retained the option of appealing to higher instances in the vertical hierarchy. The success of such appeals rested in part of reputation, but the political element in reputations was fragile and it seems that appeals were rarely successful.
8. The evidence suggests that the costs of Soviet R&D were inflated by rent–seeking activity. Like other economic agents, design personnel overbid for resources, concealed reserves, diverted surplus stocks to private use, and exaggerated achievements for the sake of reward. The evidence that Stalin distributed rents through the R&D system to reward loyalty is anecdotal; the evidence also shows that rent–seeking was punished when detected.
9. The Soviet willingness to invest resources in military R&D in general reflected the long–term character of Stalin's motivation, plus the importance of tacit knowledge produced at home to complement the explicit knowledge obtained from abroad in limited quantities by various means though not, in the case of jet propulsion, espionage.

Table 1. Major Soviet R&D projects for aeroengines based on jet propulsion and turbines, by establishment, 1932 to 1944

	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941(1)	1941(2)	1942	1943	1944
GDL, GIRD, RNII, NII–3, GIRT, NIIRA, NII–1	Glushko rocket motor and aviation boosters————?													
					Rocket glider————?			Rocket glider (also at OSK zavoda no. 1) ——?						
						Ramjet ————?								
								Hybrid jet engine with compressor————?						
										Dushkin–Isaev rocket motor ————?				
											Aviation rocket booster			
														Liul'ka turbojet (from TsIAM)
VTI	Gas turbine				Uvarov gas turbines ————?									
				Steam turbine		Przhe–slavskii binary–cycle steam turbine		Steam turbine						
MAI			Gas turbine											
VVA		Aksiutin steam turbine (continuing at Energet. inst. and SKB) ————?												
Energet. institut						Aksiutin steam turbine (from VVA) ————?								
SKB									Liul'ka turbojet ————?					
						Sinev steam turbine —?								
KB–2		Kozhevnikov gas–steam turbine ————?												
KhAI			Tsvetkov steam turbine ————?											
NII GVF				Steam turbine										

Continued.

Table 1 (continued).

	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941(1)	1941(2)	1942	1943	1944
Z–d no. 18						Dybskii–Udod gas–steam turbine ————?								
TsKTI						Steam turbines —————?								
								Merkulov ramjet (also at OSK zavoda no. 1)						
								Liul'ka turbojet						
KB–7							Ramjet	Rocket motor						
OSK z–da no. 1								Rocket glider (also at NII–3) ————?						
								Merkulov ramjet (also at TsKTI) —————?						
Z–d no. 28										Bas–Dubov–Zaslavskii ramjet ————?				
TsIAM										Uvarov gas turbine —?			Uvarov propjet ——?	
													Liul'ka turbojet (also at OKB–293, continuing at NII–1)	Fadeev–Kholshch–evnikov hybrid jet engine with compressor
														Tolstov hybrid jet engine with compressor
OKB–293												Dushkin–Isaev rocket motor (also at GIRT) –?		
												Liul'ka turbojet (also at OKB–293, continuing at NII–1) ————?		

Continued.

Table 1 (continued).

	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941(1)	1941(2)	1942	1943	1944
KB z–da no. 16												Glushko rocket motor ——?		
Z–d no. 84													Merkulov ramjet	
TsAGI													Abram–ovich hybrid jet engine with compressor	

Source: Appendix A, supplemented by Egorov (1994), 424–36. The documentation supporting appendix A comprises plans, reports, and memoranda of the People's Commissariats of Defence, Internal Affairs, Heavy Industry, the Defence Industry, Ammunition, and the Aircraft Industry.

Table 2. The number of major Soviet projects for aeroengines based on jet propulsion and turbines, 1932 to 1944

	Rocket motors					Jet and turbine engines				
	In progress at start of year	Starting during year	Continuing during year	Discontinued by end of year	In progress at end of year	In progress at start of year	Starting during year	Continuing during year	Discontinued by end of year	In progress at end of year
	[1]	[2]	[3]	[4]	[5]	[1]	[2]	[3]	[4]	[5]
1932	0	1	1	0	1	0	1	1	–1	0
1933	1	0	1	0	1	0	2	2	0	2
1934	1	0	1	0	1	2	2	4	–1	3
1935	1	0	1	0	1	3	2	5	–2	3
1936	1	1	2	0	2	3	1	4	–1	3
1937	2	0	2	–1	1	3	5	8	–1	7
1938	1	0	1	0	1	7	1	8	–5	3
1939	1	2	3	–1	2	3	4	7	–3	4
1940	2	0	2	–2	0	4	0	4	0	4
1941(1)	0	1	1	0	1	4	2	6	0	6
1941(2)	1	1	2	0	2	6	0	6	–6	0
1942	2	0	2	–1	1	0	2	2	0	2
1943	1	1	2	0	2	2	2	4	–2	2
1944	2	0	2	..	..	2	2	4	..	..

Source: calculated from table 1. Column [1] = [5] in the previous year; [5] = [4] + [3]; [3] = [2] + [1].

Table 3. Personnel of RNII–NII–3, by employment status: 1935 to 1941 (number of persons, annual average)

	1935	1936	1937 plan	1938	1939	1940	1941 plan
Engineering & technical employees	..	102	118	..	..	..	215
Manual employees	..	196	295	..	..	..	385
Nonmanual employees	76	84	88	..	..	..	..
— accounting & clerical	..	..	..	..	..	..	125
— production & planning	..	..	..	..	..	..	79
Junior service personnel	37	64	63	..	..	..	32
Total	403	446	476	514	799	..	836

Source: 1935 from RGAE, 8162/1/16, 16, and 1936–7 from ibid., 4 (no date but about February 1937); 1938–9 from RGAE, 8162/1/240, 32 (13 January 1940); 1941 from RGAE, 8162/1/449, 144 (18 November 1941).

Table 4. The research institutes and design bureaux of the thirteenth chief administration of the People's Commissariat of Ammunition, 1938

	Budget, thou. rubles	Planned research topics	Scientific workers
NII–24	12 764	178	60
—Leningrad filial	11 052	81	55
KB–47	8 006	94	55
NII–3	5 667	39	44
KB–7	1 200	9	13
KB–31	700	6	19
Total	39 389	407	246

Source: RGAE, 8162/1/299, 9 (no date but 1938).

Appendix A. Soviet R&D Projects for Aeroengines Based on Jet Propulsion and Turbines Listed in Ministerial Plans and Reports, 1932 to 1944

Year	Date	Design organisation	Designer	Design object
1932	4 July	GDL	Glushko	Rocket motor
1932	4 July	VTI	..	Gas turbine
1933	27 Jan.	VVA	Aksiutin	Steam turbine
1933	5 Dec.	KB–2	Kozhevnikov	Gas–steam turbine
1934	23 Jan.	RNII (former GDL)	..	Aviation boosters
1934	23 Jan.	RNII (former GIRD)	..	Rocket motors
1934	29 Jan.	KhAI	..	Steam turbine
1934	10 May	MAI	..	GT–1 gas turbine
1934	4 July	KB–2	Kozhevnikov	Gas–steam turbine
1935	16 April	KhAI	..	Air–naval steam turbine PT–6
1935	16 April	NII GVF	..	Air–naval steam turbine PT–3
1935	16 April	VTI	..	Air–naval steam turbine
1936	Dec.	VTI	..	GT–1 gas turbine
1936	8 Jan.	VTI	..	GT–1 gas turbine
1936	19 Jan.	KB–2	Kozhevnikov	Gas–steam turbine
1936	28 April	RNII	..	Rocket glider
1936	22 Aug.	VVA	Aksiutin	Steam turbine
1936	Dec.	RNII	..	Ramjet
1936	Dec.	RNII	..	Liquid–fuelled aviation rocket motor
1936	Dec.	RNII	..	Rocket glider
1937	..	RNII	..	Rocket glider
1937	28 Feb.	Energet. institut SKB	Aksiutin	Steam turbine PT–1

Year	Date	Design organisation	Designer	Design object
1937	28 Feb.	KhAI	Tsvetkov	Steam turbine PT–6
1937	28 Feb.	MAI VTI	Przheslavskii	Binary–cycle turbine
1937	28 Feb.	TsKTI	..	Turbine “S”
1937	28 Feb.	VTI	Uvarov	Gas turbines GTU–3, GTU–5
1937	11 June	Energet. institut SKB	Aksiutin	Steam turbine PT–1
1937	11 June	KhAI	Tsvetkov	Steam turbine PT–6
1937	11 June	MAI VTI	..	Binary–cycle turbine
1937	11 June	TsKTI	..	Turbine “S”
1937	1 Dec.	KhAI	Tsvetkov	Steam turbine PT–6
1937	1 Dec.	MAI VTI	Przheslavskii	Binary–cycle turbine
1937	1 Dec.	SKB	Sinev	Steam turbine
1937	1 Dec.	TsKTI	Laditskii Fimin	..
1937	27 Dec.	KhAI	Gindez Lozino–Lozinskii	..
1937	27 Dec.	MAI	Kvasnikov	..
1937	27 Dec.	Z–d no. 18	Dybskii–Udod	Steam turbine
1938	1 Jan.	Z–d no. 18	Dybskii–Udod	Steam turbine
1938	Feb.	KhAI	..	Steam turbine
1938	Feb.	SKB	..	Steam turbine
1938	Feb.	VTI	..	Steam turbine
1938	4 Feb.	KB–7	..	Ramjet
1938	4 Feb.	NII–3	..	Ramjet
1938	3 May	TsKTI	..	Steam turbines VT–1, VTK–100, VTK–3000
1938	9 Dec.	VTI	Uvarov	Gas turbine GTU–3

Year	Date	Design organisation	Designer	Design object
1939	..	KB–7	..	Liquid–fuelled rocket motor
1939	..	NII–3	..	Rocket glider RP–318
1939	9 April	NII–3	..	Ramjet
1939	4 June	KB–7	..	Liquid–fuelled rocket motor
1939	4 June	NII–3	..	Liquid–fuelled rocket motor Hybrid jet engine with compressor
1939	4 June	TsKTI	..	Steam turbines PT–1M, VTK–300
1939	4 June	VTI	..	Gas turbine
1939	20 Oct.	NII–3		Rocket glider
1939	10 Dec.	..	Uvarov	Gas turbine
1939	10 Dec.	..	..	Steam turbines
1939	10 Dec.	TsKTI	Liul'ka Merkulov	Air jets
1940	13 Jan.	NII–3	..	Rocket glider Ramjet Hybrid jet engine with compressor
1940	17 Sept.	NII–3		Rocket glider Ramjet Hybrid jet engine with compressor
1941	14 Jan.	NII–3	..	Ramjet Hybrid jet engine with compressor
1941	20 Mar.	TsIAM	Uvarov	Gas turbine GTU–3
1941	5 Feb.; 5 Apr.	z–d no. 1	Merkulov	..
1941	5 Feb.; 5 Apr.	z–d no. 28	Bas–Dubov Zaslavskii	..
1941	5 Feb.; 5 Apr.	NII–3	..	Hybrid jet engine with compressor

Year	Date	Design organisation	Designer	Design object
1941	5 Feb.; 5 Apr.	SKB–1	Liul'ka	Axial turbojet
1941	12 Apr.	NII–3	..	Ramjet
				Hybrid jet engine with compressor
				Liquid–fuelled rocket motor for interceptor aircraft
1941	30 July	NII–3	..	Ramjet
				Hybrid jet engine with compressor
				Liquid–fuelled rocket motor for interceptor aircraft
1941	7 Aug.	NII–3	..	Ramjet
				Hybrid jet engine with compressor
				Liquid–fuelled rocket motor for interceptor aircraft
1941	30 Dec.	NII–3	..	Ramjet
				Hybrid jet engine with compressor
				Liquid–fuelled rocket motor for interceptor aircraft
				Rocket booster
1942	5 Jan.	NII–3	..	
1942	4 May	NII–3	..	Ramjet
				Hybrid jet engine with compressor
				Liquid–fuelled rocket motor for interceptor aircraft
				Rocket booster
1942	7 May	NII–3	..	Ramjet
				Hybrid jet engine with compressor
1942	29 May	NII–3	..	Ramjet
				Hybrid jet engine with compressor
				Rocket interceptor aircraft

Year	Date	Design organisation	Designer	Design object
1942	8 June	OKB–293	Bolkhovitinov Dushkin Liul’ka	BI fighter with liquid–fuelled rocket motor
1942	10 Aug.	OKB–293	Liul’ka	Turbojet
1943	20 May	TsIAM	Liul’ka	Turbojet
1943	22 Oct.	z–d no. 84	Merkulov	Ramjet
1943	22 Oct.	GIRT	..	Liquid–fuelled rocket motor for BI
1943	22 Oct.	KB z–da no. 16	Glushko	Liquid–fuelled rocket motor
1943	22 Oct.	OKB–293	Bolkhovitinov	BI fighter with liquid–fuelled rocket motor
1943	22 Oct.	TsAGI	Abramovich	Hybrid jet engine with compressor
1943	22 Oct.	TsIAM	Liul’ka Uvarov	Turbojets
1944	..	KB z–da no. 16	Glushko	Rocket motor
1944	..	NII–3	Dushkin Isaev	Rocket motors
1944	..	NIIRA	Liul’ka	Turbojet
1944	..	TsIAM	Fadeev Kholshchevnikov Tolstov	Hybrid jet engine with compressor
1944	..	TsIAM	Uvarov	Propjet
1944	16 July	KB z–da no. 16	Glushko	Rocket motor RD–1

Sources: GARF, 9401/2/65, 385; RGAE, 7516/1/309, 15; RGAE, 7516/1/318, 42–56; RGAE, 7516/1/319, 1–36; RGAE, 8044/1/460, 59, 104; RGAE, 8044/1/613, 172; RGAE, 8044/1/817, 18; RGAE, 8044/1/829, 235–242, ; RGAE, 8044/1/984, 253–258; RGAE, 8044/1/985, 73–76; RGAE, 8044/1/994, 21–23, ; RGAE, 8044/1/1182, 77–78, 81–84; RGAE, 8159/1/6, 74; RGAE, 8159/1/137, 2–28; RGAE, 8159/1/140, 12–15; RGAE, 8162/1/89, 101; RGAE, 8162/1/240, 55–58; RGAE, 8162/1/300, 65–66, 80–81; RGAE, 8162/1/448, 7, 9; RGAE, 8162/1/449, 16–20, 96–7, 180–1; RGAE, 8162/1/574, 20, 24–26, 38–40, 85, 101; RGAE, 8328/1/696, 25, 133; RGAE, 8328/1/824, 1–50; RGAE, 8328/1/919, 84; RGAE, 8328/1/992, 6–7; RGAE, 8328/1/995, 106; RGAE, 8328/1/996, 16–18, 22–23ob; RGVA, 34272/1/167, 23–24, 47–55, 102–119; RGVA, 4/14/1171, 33, 36; RGVA, 4/14/1925, 21; RGVA, 4/14/2800, 4.

Appendix B. Key to Design Institutions

Energet. institut (Energeticheskii institut AN SSSR): Institute of Energetics of the USSR Academy of Sciences

GDL (Gazo–Dinamicheskaia laboratoriia UVI RKKA): Gas Dynamics Laboratory of the Administration of Military Inventions of the Workers' and Peasants' Red Army

GIRD (Gruppa po Izucheniiu Reaktivnoi Dvizheniia pri TsS Osoaviakhima): Group for the Study of Jet Propelled Motion of the Central Council of the Society for Cooperation in Air and Chemical Defence

GIRT (Gosudarstvennyi Institut Reaktivnoi Tekhniki pri SNK SSSR): State Institute for Jet Propulsion Technology of the USSR Council of People's Commissars

KB zavoda no. 16 (Konstruktorskoe biuro 4–ogo spetsotdela NKVD zavoda no. 16 NKAP): design Bureau of the People's Commissariat of Internal Affairs Fourth Special Department at factory no. 16 of the People's Commissariat of the Aircraft Industry, Kazan' (in other words, an NKVD *sharaga*)

KB–2 (Konstruktorskoe biuro no. 2 UVI RKKA): design bureau no. 2 of the Administration of Military Inventions of the Workers' and Peasants' Red Army

KB–7 (Konstruktorskoe biuro no. 7 UVI RKKA, later NKOP–NKB): design bureau no. 7 of the Administration of Military Inventions of the Workers' and Peasants' Red Army, later of the People's Commissariat of the Defence Industry (later Ammunition)

KhAI (Khar'kovskii Aviatsionnyi institut NKTP–NKOP–NKAP): Kharkov Aviation Institute of the People's Commissiat of Heavy Industry (later Defence Industry, later Aircraft Industry)

MAI (Moskovskii Aviatsionnyi institut NKTP–NKOP–NKAP): Moscow Aviation Institute of the People's Commissiat of Heavy Industry (later Defence Industry, later Aircraft Industry)

NII GVF (Nauchno–Issledovatel'skii institut Grazhdansko–Vozdushnogo Flota GUGVF SNK): Research Institute of the Civil Air Fleet of the Chief Administration of the Civil Air Fleet of the Council of People's Commissars

NII–1 (Nauchno–Issledovatel'skii institut no. 1 NKAP): research institute no. 3 of the People's Commissiat of the Aircraft Industry

NII–3 (Nauchno–Issledovatel'skii institut no. 3 NKOP–NKB): research institute no. 3 of the People's Commissiat of the Defence Industry (later Ammunition)

NIIRA (Nauchno–Issledovatel'skii institut Reaktivnoi Aviatsii NKAP): Research Institute for Jet–Propelled Aviation of the People's Commissariat of the Aircraft Industry

OKB–293 (Opytno–konstruktorskoe biuro zavoda no. 293 NKAP): experimental design bureau no. 293 of the People's Commissariat of the Aircraft Industry

OSK z–da no. 1 (otdel spetsial’nykh konstruktsii zavoda no. 1 NKAP): department of special–purpose designs of factory no. 1 of the People’s Commissariat of the Aircraft Industry

RNII (Reaktivnyi Nauchno–Issledovatel’skii institut NKTP): Jet Propulsion Research Institute of the People’s Commissariat of Heavy Industry

SKB, later **SKB–1** (Spetsial’noe konstruktorskoe Pervogo glavnogo upravleniia NKOP): Special–purpose Design Bureau of the First Chief Administration of the People’s Commissariat of the Defence Industry

TsAGI (Tsentral’nyi Aero–Gidrodinamicheskii institut NKTP–NKOP–NKAP): Central Aero–Hydrodynamic Institute of the People’s Commissariat of Heavy Industry (later the Defence Industry, later the Aircraft Industry)

TsIAM (Tsentral’nyi Institut Aviationnogo Motorostroeniia NKTP–NKOP–NKAP): Central Institute for Aeroengine Building of the People’s Commissariat of Heavy Industry (later the Defence Industry, later the Aircraft Industry)

TsKTI (Tsentral’nyi Kotlo–turbinnyi institut Energoproma NKTP): Central Boiler and Turbine Institute of the Electricity Supply Industry Administration of the People’s Commissariat of Heavy Industry (Leningrad)

VTI (Vsesoiuznyi Teplotekhnicheskii institut im. Dzerzhinskogo NKTP): Dzerzhinskii All–Union Thermal–Technical Institute of the Electricity Supply Industry Administration of the People’s Commissariat of Heavy Industry

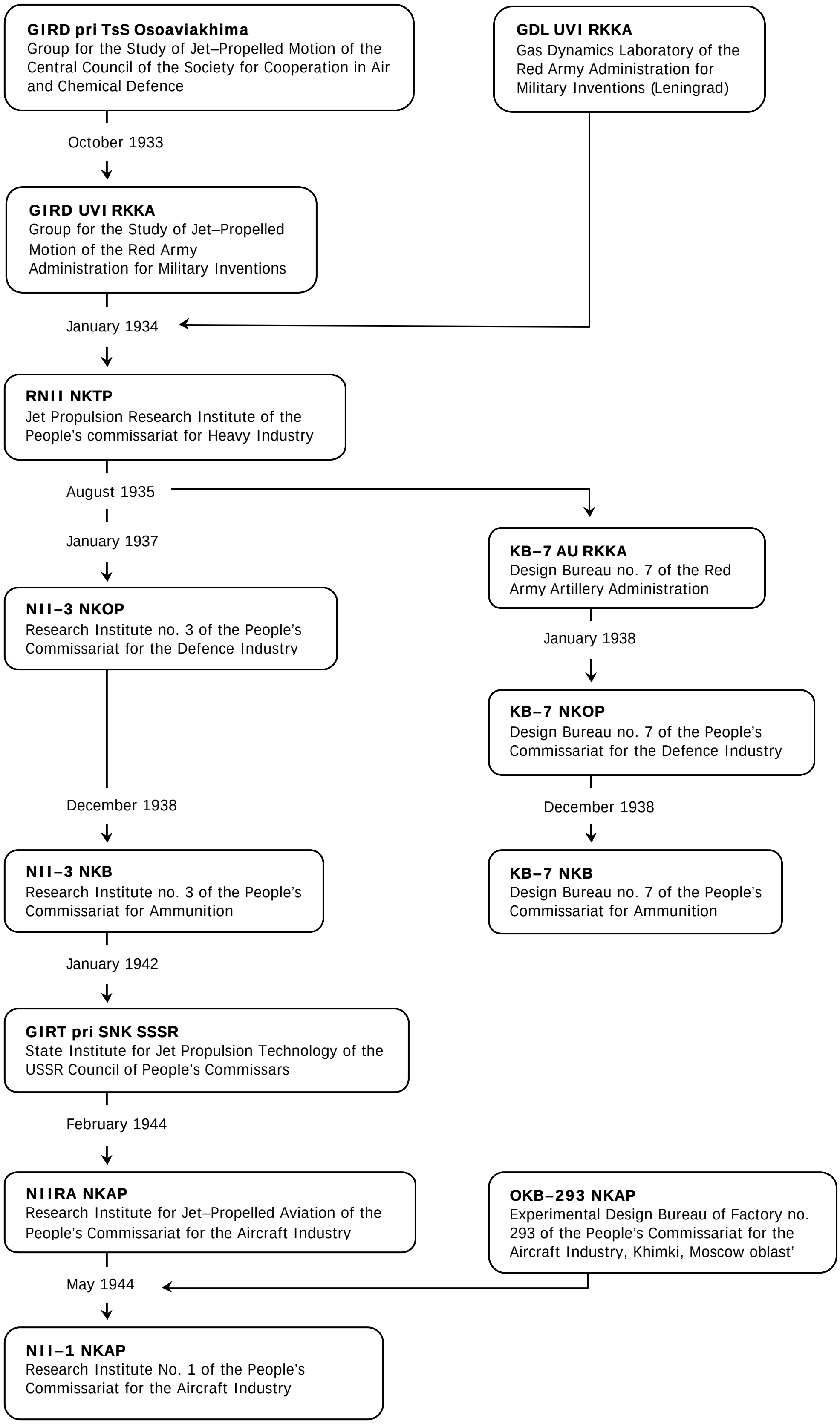
VVA (Voenno–Vozdushnaia Akademiia RKKA): Air Force Academy of the Workers’ and Peasants’ Red Army

z–d no. 18 (zavod no. 28 NKOP): factory no. 18 of the People’s Commissariat of the Defence (later Aircraft) Industry

z–d no. 28 (zavod no. 28 NKAP): factory no. 28 of the People’s Commissariat of the Aircraft Industry

z–d no. 84 (zavod no. 84 NKAP): factory no. 84 of the People’s Commissariat of the Aircraft Industry

Figure B–1. The evolutionary path of RNII, 1932 to 1944



Sources and notes: see next page.

Sources and notes to figure B–1. For most details see Siddiqi (2000), 1–18. Additionally, while GIRD was originally sponsored by Osoaviakhim, a memorandum of 23 January 1934 notes that it was taken over by UVI RKKA in October 1933 before being merged with GDL, renamed RNII, and transferred to NKTP (RGVA 4/14/1171, 33). Siddiqi states that NII–3 was handed over to NKB in November 1937, but this commissariat was only created with the dissolution of NKOP in December 1938. Various documents indicate that NKB also acquired KB–7 from the Red Army's artillery administration at the beginning of 1938. A memorandum from deputy defence commissar Fed'ko to Molotov dated 15 February 1938 refers to "the former KB no. 7 AU RKKA, transferred to NKOP" (RGVA, 4/14/1925, 22), and KB–7 is listed among the establishments of the NKB thirteenth chief administration in its report of work for the year 1938 (RGAE, 8162/1/89, 101). KB–7 was apparently dissolved in 1939. GIRT is described as "pri SNK SSSR" in its deed of transfer to NKAP, not dated but of 1944 (RGAE, 8044/1/1182, 11–16). All establishments were located in Moscow unless otherwise noted.

Appendix C. Income and Expenditure of NII–3: 1936 and 1937 Plan (Thousand Rubles)

	1936 (report)	1937 (plan)
Income		
From the USSR state budget		
—under §53	1 980.0	2 080.0
—for staff training	11.4	57.0
From contracts with other organisations	1 385.0	2 300.0
From sale of surplus stores	15.0	75.0
From liquidation of assets	8.6	0.0
Other income and revenues	20.0	50.0
Total	3 420.0	4 482.0 [a]

Continued.

Appendix C (continued)

	1936 (report)	1937 (plan)
Expenditure		
I. On research in departments and laboratories of the institute		
A. Direct expenditures		
—Wages	633.0	858.0
—Wage supplements	83.0	102.8
—Work done by other organisations	282.0	300.0
—Other direct expenditures	1497.0	1857.4
B. Institutional expenditures		
—Wages	193.0 (Wages, wage supplements, and other institutional expenditures combined)	83.0
—Wage supplements		10.0
—Other institutional expenditures		290.1
C. Administrative expenditures		
—Wages	575.0 (Wages, wage supplements, travel costs, and other administrative expenditures combined)	389.0
—Wage supplements		46.7
—Travel costs (*komandirovki*)		47.0
—Other administrative expenditures		441.0
Subtotal, section I	3268.0 [b]	4425.0
— *less* Internal procurement	–1303.0	–2085.0
II. Auxiliary, experimental, and sideline production		
A. Direct expenditures		
—Wages	556.0	1057.0
—Wage supplements	72.0	126.8
—Other direct expenditures	341.0	337.5
B. Working expenditures		
—Wages	253.0 (Wages, wage supplements, and other working expenditures combined)	210.0
—Wage supplements		25.3
—Other working expenditures		224.2
C. Administrative expenditures		
—Wages	175.0 (Wages, wage supplements, and other administrative expenditures combined)	197.0
—Wage supplements		23.6
—Other administrative expenditures		15.6
Subtotal, section II	1397.0	2217.0
— *less* Internal procurement	–94.0	–132.0
III. Special–purpose expenditures not included in research costs		
—Staff training	15.0	57.0
Total, sections I, II, and III	3377.0 [c]	4482.0

Source: RGAE, 8162/1/16, 2–3 (28 February 1937). All expenditure section subtotals are gross, including expenditures on the institute's own provision of in–sourced materials. The supply of these is covered in section II. Thus gross expenditures under section II equal the total of internal procurements to be subtracted from gross outlays under each of sections I, II, and III in order to calculate the bottom–line expenditure total for the institute as a whole. Some column subtotals are given incorrectly; corrected sums are as follows:

[a] 4562.0 thousand rubles (also handwritten in the original by the typed sum)
[b] 3268.0 thousand rubles.
[c] 3283.0 thousand rubles.

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