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Mr. John Greenewald, Jr.
[redacted]

Dear Mr. Greenewald:

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Sincerely,

Kelly D. Akers

KELLY D. AKERS
FOIA Program Manager

2 Enclosures

ADA140629

The Process of Soviet Weapons Design

RAND CORP SANTA MONICA CA

MAR 1978

UNCLASSIFIED

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THE PROCESS OF SOVIET WEAPONS DESIGN

Arthur J. Alexander

March 1978

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THE PROCESS OF SOVIET WEAPONS DESIGN

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The Rand Corporation
Santa Monica, California

March 1978

Prepared for a Technology Trends Colloquim
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29 March - 1 April 1978

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Introduction

Explanation and prediction of military R&D in the USSR requires consideration of the system as a whole. Only in context can one make sense of the array of specific strengths and weaknesses found in any undertaking as complex as the way a country acquires its weapons. Although it may approach being a cliche to note the existence of national assymetries and the problems they introduce into analysis, nevertheless they are only infrequently taken into account. In this paper ~~I shall be~~ the author is concerned explicitly with how Soviet institutions, constraints, incentives, and values influence the process of Soviet weapons design. The central theme is that these processes strongly affect outcomes over the medium term future.

Decomposing the Military R&D Matrix

The military R&D system is usefully split, not into the customary categories of basic research, applied research, etc., but into an interacting sequence of inputs, processes, and outputs (see Fig. 1). Military R&D begins with inputs; these are acted upon by processes to produce weapons possessing certain performance specifications; a weapon's performance gives it mission capabilities having military value. Isolated measurements or comparisons of single elements of this matrix are not only incomplete fragments of the total, but can lead to erroneous conclusions on which to base policy advice for one's own country or intelligence evaluations of a potential adversary.

MILITARY R&D MATRIX

INPUTS ➡	PROCESSES ➡	OUTPUTS
• BUDGETS	• INCENTIVES	• PERFORMANCE
• SCIENTISTS	• CONSTRAINTS	• MISSIONS
• ENGINEERS	• R&D STRATEGY	• MILITARY VALUE
• TECHNOLOGY	• PLANNING	

Figure 1

Comparative evaluations of U.S. and Soviet military R&D often begin (and end) with inputs, but so much intervenes between the inputs and ultimate outputs that fine comparisons are frequently not warranted. Given a gross comparability of inputs in the two countries, differences in their military capabilities do not arise primarily from resources, but from the processes and choices that determine how those resources are employed. And it is in process and choice that sharp differences emerge between U.S. and Soviet practice.

Since the military R&D system is a complex matrix of inputs, processes, and outputs conditioned by national characteristics, it is an incorrect procedure to assign the value of one element of this matrix willy-nilly to the matrix as a whole. Narrowly focused analyses yield limited insights about overall R&D effectiveness or about future trends and prospects. The counting of scientists and engineers, the enumeration of advanced or lagging technologies, the emphasis on specific weapons performance figures, are by themselves poor guides to military capabilities--now or in the future. There is at best only a loose connection between inputs and outputs, technology and value, especially in military R&D where so many other forces intervene.

Patterns in Soviet Weapons Design

Soviet weapons exhibit similarities in their designs across very different types of systems. Aircraft, for example, share many of the same attributes as armor, ships, submarines, and missiles. This pattern can be summarized by its most outstanding features: simplicity in equipment; common use of subsystems, components, and parts; incremental growth; and limited performance and mission capabilities. Despite the strong evidence for this pattern, however, not all Soviet weapons include each of the features just mentioned. Rather, the evidence is better viewed as a distribution of possibilities; American systems (in comparison) are characterized by a larger proportion of new and advanced features. Illustrative distributions are shown in Figure 2 where, although the peaks of the two curves are distinctly separate, there is still considerable overlap between them. [1]

The widespread presence of the Soviet pattern suggests that a common set of forces operates across military services and technologies. These forces are identified here as arising, for the most part, from Soviet doctrine on the mass use of force, from the pressures of the economy, and from a bureaucratic inertia supported by a general satisfaction with the process.

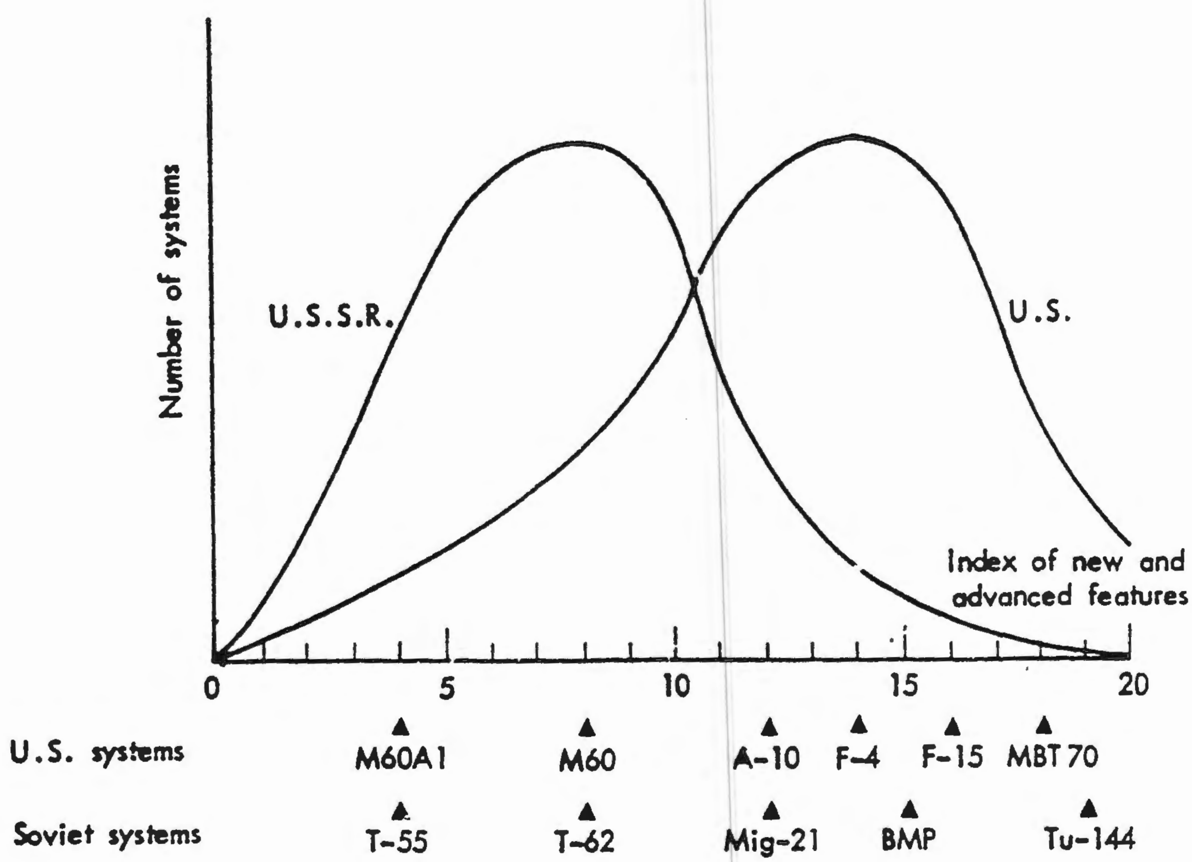

Figure 2

Hypothesized Distributions of U.S. and Soviet Weapons by Index of New and Advanced Features

Despite the pervasiveness of the above pattern, exceptions to it have occurred that, although rare, have importantly affected military capabilities. These exceptions have included nuclear weapons and long-range ballistic missiles in the past, and perhaps directed energy beams today. Since "the development and creation of fundamentally new weapon systems" have come to have special significance to the Soviet military and science communities, [2] this subject must also be considered for a more complete understanding of Soviet weapons development practices.

Simplicity. [3] In general, Soviet weapons are relatively uncomplicated compared with similar Western equipment. Soviet warships, for example, require 25 to 40 percent less propulsion and auxiliary machinery per horsepower than U.S. ships, and proportionately less space in which to house it, largely because of a smaller requirement for electrical power, fresh water distillation, and shipwide air conditioning. This pattern is duplicated in Soviet shipborne electronic equipment which operates to lower performance standards than U.S. equipment. Soviet warships can therefore be smaller and yet carry greater armament. [4]

In a quite different field, the SA-6 surface-to-air missile was described by U.S. defense analysts as "unbelievably simple but effective." [5] Its solid-fuel integral rocket/ram-jet engine (considered inferior in some applications to U.S. liquid-fuel designs under development) permits such simplifications as the elimination of a fuel control system. The SA-6 contains virtually no moving parts; this type of propulsive system has been estimated to cost 40 percent less than the alternative liquid-fuel design. [6]

The T-62 tank is less complex in almost every subsystem than its American counterpart, the M60A1. The T-62 has a manual transmission and a manual, lever-type steering system. (The M60A1 has an automatic transmission and power steering.) The engine of the T-62 is a 40-year-old design. The tank lacks a rangefinder and possesses only a fraction of the vision devices found in the American tank. The T-62 also costs perhaps one-third to one-half less than the M60A1, which is not an example of goldplated U.S. equipment. [7]

One of the best examples of design simplicity comes from a detailed comparison between a Russian engine and an American engine of about the same vintage and having roughly comparable performance. Although the Soviet engine was acknowledged to be an outstanding design, atypical of Soviet engines in general, the design philosophy and approach were quite similar to that found in other engine examples of Soviet origin. [8]

The Russian engine had only about 10 percent of the total number of parts of the American engine, and 18 percent of the parts requiring detailed drawings. It was designed, according to the analysts, for utmost simplicity and concern for costs. [9] Engine idle, for example, was a simple throttle stop; idling RPM therefore varied with ambient conditions, whereas the U.S. engine had a fixed RPM requirement necessitating sensors, servomechanisms, increased complexity, and greater cost. [10] Standard gage materials throughout increased weight but reduced materials cost. Lower turbine inlet temperatures allowed use of conventional materials. As a result of these and other practices, raw materials cost per pound for the U.S. engine was 2 1/2 times greater than for the Soviet.

Relatively open clearances reduced manufacturing cost and resulted in some test-stand performance degradation, but these levels did not degrade further in operations, as was the case for the more precisely manufactured U.S. engine. The Soviet engine, while highly innovative in concept, was rather conservative in execution. Parts were stressed to about half the level of the U.S. example. The Soviet engine was demonstrated to be unusually reliable and required only one-twelfth the maintenance hours per flight hour of the comparable U.S. engine. Furthermore, estimated production cost was one-third that of the American, and crude estimates of life-cycle costs indicated a Russian advantage of about 50 percent.

Commonality. Multiple use of subsystems, components, and parts across equipment of the same vintage, together with repeated use of the same subsystems in succeeding generations, is another typical feature of Soviet weapons development.

In aircraft, the same turboprop engine (NK-12M) was used on the long-range Bear bomber (Tu-95) in 1955, and on the large cargo aircraft An-22 10 years later. [11] Another engine (the Lyulka AL-7) appeared in some 8 different aircraft, from fighters to bombers to seaplanes.

The chassis of the PT-76 reconnaissance tank, which appeared in the early 1950s, was modified for use 15 years later as the transporter for both an anti-aircraft gun (ZSU-23/4) and the SA-6 anti-aircraft missile.

The Su-7 (Fitter) attack aircraft and Su-9 (Fishpot) interceptor originally had common fuselage, tail, and engine, whereas the wings, armament, and equipment were chosen for their different roles. The Su-7 was later fit with variable-sweep wings (the first Soviet use of this technology), a new engine, and other changes to increase its range and payload, thus extending its design life from the early 1950s to the present.

The same 12-cylinder diesel engine or 6-cylinder derivative has been used on almost all Soviet tanks since 1939, and it continues to power the T-62, which will form the bulk of the tank force well into the 1980s.

For decades all Soviet tank guns had seen earlier service as towed artillery or on ships until the adoption of the innovative smooth-bore, high-velocity gun on the T-62. This gun is an interesting counter-example to the general Soviet tendency to avoid technological risk. The use of smooth-bore techniques at least 20 years before any other country is one fruit of the Soviet Union's large military R&D effort. Interestingly, the gun's very high muzzle velocity permitted a considerable simplification of the fire control system. The Soviet tank designer thus accepted technological risk in one subsystem to gain a reduction in complexity and cost elsewhere. And this was the only subsystem changed between the T-62 and its predecessor, the T-55.

Incremental Change. Technological change and improved weapons result primarily from the process of cumulative product improvement and evolutionary growth. The all-new system, with newly developed subsystems, is rare. This is in sharp contrast to American behavior where the "weapon system" concept dominated development practices for at least two decades.

The MiG-21 fighter aircraft, first developed in the mid-1950s, has undergone continuous change in its engine, aerodynamics, armament, avionics, and structure. It has been improved from a simple, clear-weather interceptor to an all-weather fighter with ground-attack capabilities. Range and payload have doubled, and flying qualities have been considerably enhanced over a 20-year period.

In ships, similar patterns of evolutionary change have been noted. The Kildin missile ship was a conversion of the last four Kotlin destroyers, and the Krupnyj class missile ships were based on the hull and propulsion unit of a cancelled class of destroyers. [12]

The first large Soviet rocket booster, used as both an intercontinental ballistic missile (SS-6) and space launcher, can be traced back through several generations of modifications and growth in size to the period after World War II when German and Soviet scientists worked on extending the capability of the German V2 rocket. The propulsion unit of the Soviet rocket consisted of a central core surrounded by four strap-on units, each of which consisted of four rocket motors apiece--or twenty altogether. Rather than develop a new, large engine, the designer chose to make multiple use of proven components. A reason given for this design choice was the unavailability of both materials to withstand the higher temperatures generated in a larger engine, and cooling systems to reduce the temperature to tolerable levels. [13]

Designs with no known antecedents are rare. However, even in these systems, many of the subsystems are based on proven components. This is the case, for example, of the

ZSU-23/4 anti-aircraft gun that was first seen in the mid-1960s. The vehicle's chassis is derived from the PT-76 light tank of the early 1950s. The engine is the 6-cylinder version of the tank diesel produced in the late 1930s. The electronics are vacuum tube components of 1950s vintage. The guns are slightly modified World War II models. There is little new in this weapon--except its design as a system.

One could continue in this vein and describe, for example, the evolution of the T-62 tank, subsystem by subsystem from a 1930 American design by J. Walter Christie; [14] or the development of the solid-fuel mobile ICBM SS-16 and IRBM SS-2 from the SS-13 ballistic missile; or the evolution of the rocket-assisted projectile gun system on the BMP from an early 1940s German design. But the validity and usefulness of a theory, especially one that makes predictions about the future, is not tested by the degree to which it is consistent with known events. Rather it is necessary to test it with new evidence. An opportunity to do this arose when the MiG-25 Foxbat aircraft became available for analysis when a Soviet pilot landed in Japan in September 1976.

MiG-25 Foxbat.[15] The MiG-25 was intended originally to perform a single mission--interception of high-altitude, high-speed targets--although it has since been adapted to a short-range reconnaissance mission. This focus on a narrow task considerably eased the job of the designer and lessened the demands on the required technology. Long range, high turning rate, ground target acquisition, look-down radar, and large ordnance payload and delivery capacity could be ignored. Advanced electronics, exotic materials, precise manufacturing techniques, and complex structures were not required. Stainless steel and aluminum were the primary airframe materials instead of the more expensive and difficult-to-handle titanium or synthetic materials. Rivets were left unground (except in aerodynamically critical areas), and welding was crude, but adequate. The resulting heavy structure and drag penalties were dealt with by powerful fuel-hungry engines and by large fuel tankage. Most importantly, the Soviets accepted the aircraft's limited range and payload. At other than the high-altitude, high-speed design point, performance was significantly degraded. Its ANAB air-to-air missile was used earlier on the Tu-28 (Fiddler), and the ejection seat, Cockpit instruments and engine were off-the-shelf hardware that had been used in the MiG-21 and earlier aircraft. The avionics, for the most part, made use of vacuum tubes. The radar, though based on a technology that is out-of-date by American standards, is one of the most powerful ever seen in an aircraft and therefore less vulnerable to jamming. The number of cockpit instruments were about half those used on the same vintage American F4 and the cockpit layout and instruments were adapted from the MiG-21. Extensive use of ground control for interception considerably reduced the need for on-board aircraft systems.

Through the use of proven technology, the designers achieved a high degree of reliability. American aerospace analysts describe the MiG-25 as "unsurpassed in the ease of maintenance and servicing" and a "masterpiece of standardization." [16]

Reasons for Common Design Patterns

The pervasiveness over time and technologies of the design pattern described above motivates one to seek out causes that are less circumscribed than particular missions, requirements, or threats. Indeed, the principle reasons identified here--doctrine and economic pressures--are deeply rooted in Soviet history and institutions.

Doctrine. Military doctrine has much to do with the way the Soviet Union develops its weapons. An historical Russian doctrine of mass armies has influenced the organization of the development effort, the procedures by which it is accomplished, and the values by which it is judged. This doctrine precedes the Soviet era, but it became more or less codified in the late 1920s and refined--one might even say, sanctified--in World War II. [17] A modern doctrine that entertains the possibility of fighting and the necessity of winning a war in the nuclear era also requires masses of men and equipment to survive nuclear exchanges and to fight globally on continent-wide fronts.

This doctrine firmly constrains weapons design. Simple designs are easier to produce and are usually cheaper than complex designs. These weapons should not only be simple in design, but also easy to operate by large conscript armies, they should be reliable, and yet not be markedly inferior to enemy weapons. Standardization of parts, multiple use of components in different models of the same generation, limited change between models of succeeding generations, and a disciplined selection of functions and performance levels have been the means for achieving the Soviet design goals.

Economic Pressures. The pattern of weapons design and development is, also, in part a response to economic system incentives and constraints. The Soviet economy is relatively efficient in the development of mass-produced systems, and relatively inefficient in the production of more complex, high-technology weapons, thereby validating the economic rationality of the doctrine. The weakness of innovation in the Soviet Union flows mainly from the structure of the economy.[18] In the centrally planned Soviet economy, supplies are allocated far in advance of actual need. Optimistic planning targets generate a general shortage of materials--a sellers market in which demand exceeds supply, where a buyer may be required to accept an inferior product or go without. Because supplies are allocated in detail, resources are not fungible; a simple money budget is not adequate to guarantee the availability of resources that have not been planned and allocated in advance. New products and production techniques must be deliberately planned and introduced by bureaucratized administrative bodies. Attempts to reform the system have only increased the regulatory constraints, made the managerial job more complex, and further bureaucratized the planning and management of innovation. While many of these economic problems were more severe in the past than they are today, such shifts as have taken place are only partial. The basic system of the past 45 years continues.

Unreliability of supply imposes a reluctance on designers to ask for new components, or to go to suppliers with whom they have not dealt in the past. Supply problems create incentives to use previously developed components that may not be optimal from an overall systems standpoint, but that can be counted on to perform to known specifications. The rigidities of the planning process allow little flexibility in substituting one material or device for another, or in making reallocations within a given budget level. All of these conditions encourage a conservative, evolutionary approach that minimizes the necessity for flexibility and reallocation. The employment stability of R&D organizations, the detailed plans and regulations, the great difficulty for new organizations to break into established fields, the penalties of failure, and the practices and procedures by which R&D is managed are forces leading to military technological conservatism. [19]

Military industry has been insulated from the worst vicissitudes of the civilian economy by a variety of methods including priorities over materials, equipment, and personnel, and coordination by the Military-Industrial Commission. While more favored than the civilian sector, the Soviet military cannot entirely escape from the perversities and inefficiencies of the rest of the economy. The military sector can be isolated, buffered, and given priorities over civilian demands, but such strategies are neither costless nor completely successful. Furthermore, with the increasing complexity of modern weapon systems that incorporate a broader range of technologies and inputs than in the past, the military is likely to become increasingly dependent on the rest of the economy and will find it more difficult in the future to avoid the effects of the civilian sector's patterns of behavior.

"New in Principle" Weapons

Because of the forces of conservatism, major non-incremental change must often come from high-level political intervention in the R&D process. In aviation, for example, the Party leadership has been the key force behind the development of the first generation of jet fighters, heavy helicopters, and VTOL aircraft. [20] For major systems that are new in principle with neither technical nor institutional precedents, the need for leadership intervention is even more necessary. Despite the fact that generalizations of such interventions are hindered by the very uniqueness that defines them, nevertheless some tentative conclusions seem warranted on the basis of case studies of nuclear weapons and ICBM development. These conclusions can then be tentatively applied to the case of directed energy beams.

Nuclear Weapons. In the development of nuclear weapons, research was initiated and carried out by physicists in the 1930s who paid no attention to weapons applications. However, when the 1940 publication of a highly significant Soviet discovery of spontaneous fission resulted in a complete lack of an American response, the Russians became convinced that there must be a big secret project underway in the United States. In late 1941, a small group of physicists wrote to the State Defence Committee "urging that no time be lost in making a uranium bomb." [21]

After seeking advice from key scientists, the Party and government formed an ad hoc scientific-technical committee to oversee developments. Work proceeded on a relatively small scale, however, until American explosion of a nuclear weapon, whereupon Stalin called for a massive acceleration of Soviet efforts directed by a super-ministerial agency. Russian work on the hydrogen bomb, however, proceeded independently of American efforts, relying mainly on domestic research and findings. The Ministry of Medium Machine Building was established in 1954 to take over most nuclear responsibilities.

ICBMs and Sputniks. Rocket research in the Soviet Union in the 1930s, like nuclear physics, was mainly the work of enthusiasts, with some financing by the Red Army. In World War II, their efforts were devoted to projects with short-term payoffs, but towards the end of the war the Soviet rocket specialists recognized the potential for long-range rocketry of the German activities and alerted the government, which subsequently organized the collection of German equipment and technicians in the wake of the Red Army. The crucial stimulus to the development of long-range rockets, though, came from Stalin in late 1946 and early 1947 through his insistence on the strategic importance of long-range weapons. Ad-hoc groups of experts were formed to advise the political leaders and supervise development. In 1955, the Ministry of General Machine Building was formed to consolidate ballistic missile development and production activities. Upon development of the SS-6 in 1957, rocket designer Korolev approached the Central Committee apparatus with plans (approved after a few months of testing) to launch a sputnik. Space activities from the time of the first sputnik have been supervised by a high-level coordinating committee rather than by a unified authority.

Pattern for Fundamentally New Weapons. The pattern I would tentatively abstract from these two cases includes the following steps. Initial research is promoted by scientists who notice, on their own or through foreign example, potential military applications. These perceptions are then transmitted to a high-level authority--State Defense Committee, Stalin, Central Committee Secretariat--which then provides the political stimulus required to gather and coordinate resources from dispersed organizations. Ad hoc scientific advisory groups and scientific-managerial supervisory committees provide expert advice, analysis, and project direction. When the new activity achieves a sufficient level of continuity and maturity, a conventional ministry has been established to carry on the work.

Energy Beams. My speculative scenario for the project history of the Soviet Union's energy beam development is based on the above pattern plus certain other considerations.

Particle beam research seems to have reached a sizeable scale around 1967 when three sets of influences coalesced: (1) concern surfaced over the ability of the Soviet Union to harness the potential of science; (2) research in high-energy physics may have led certain scientists to see potential military applications of their work; and (3) the ABM weapons of the Air Defense Forces (PVO) anti-missile branch were judged to be ineffective.

In the 1960s, Soviet analysts of science and technology, together with the Soviet leaders, became concerned about their ability to initiate and develop capabilities that were new in principle. The existing process appeared to be effective in supporting priorities already decided upon, but identifying and selecting new programs to be given the highest state priorities was a complex and hazardous affair. One particular anxiety was that scientific opportunities and military requirements would not coalesce quickly enough to ensure the development of the most advanced weapons. Believing that such opportunities flowed directly from science, the Soviet leadership believed it to be necessary to bring science and application closer together through various organizational and management techniques. The General Staff increased its capabilities for technical analyses and weapons selection with much of its effort centered around formal systems-analysis techniques. Of greater importance were the promotions to leading positions of men with experience in developing weapons that were new in kind. These appointments included Generals Ogarkov and Alekseev to head the General Staff and its Scientific-Technical

Committee, and D. F. Ustinov to be Minister of Defence. But perhaps of most long-term significance has been the increased sensitivity of the political, industrial, and military leadership to the general problem of bringing science and application closer together. [22]

In few areas do science and application come closer than they do in high-energy power generation research. For several decades the Soviet Union has led the world in key areas of high-energy research. Some intelligence analysts have suspected that much of this research may also have potential military capability and that, in fact, a significant proportion of the Soviet effort has been redirected toward the military mission--conjectured to be the use of focused, high-energy particle beams to intercept and render harmless enemy missiles, warheads, and aircraft. [23] Suggestive of a military connection is the absence of organizational affiliation information for many authors of scientific papers in this field, including one of the major participants L. I. Rudakov. [24] More than suggestive is the claim that some of the work is under the direct control of the PVO. [25]

The major part of this research has been conducted by a half dozen Academy of Sciences institutes supported by a large number of other organizations in the Academy, universities, and industrial ministries. [26] Despite the large number of institutes, their administrative and geographical dispersion, and the wide range of activities in which they are engaged, close coordination seems to tie them together. Coordination is evidenced, for example, in the complementarity of research topics and the participation of a few leading scientists in the guidance, review, and consultation furnished to the scattered researchers. [27]

The connection between energy beam research and the PVO (mentioned above) is particularly intriguing, especially when one considers the inability of the PVO to field an effective anti-missile defense in the 1960s. Although Khrushchev boasted in 1962 that the USSR "had missiles which could hit a fly in outer space," a statement that echoed defense chief Malinovsky's claim that "the problem of destroying missiles in outer space had been successfully solved," neither the Griffon, the SA-5, nor the Galosh systems were fully effective in the anti-missile role. By 1967, the Soviet Union's ABM problems, especially against MIRVed missiles, had become evident even to PVO generals, one of whom declared the time not ripe for continuing deployment, adding that "one is required to carry on a lot more research, developmental work, and experiments." [28] The repeated difficulties with ABM developments, loss of support for existing systems from military and political leaders, and finally the 1972 ABM treaty that prohibited further deployment presumably would have created a severe crisis within the anti-missile forces of the PVO. The incentives to investigate completely different technological alternatives were clearly present, and bureaucratic lags would probably have left the PVO with the budgets to commit to high risk research with breakthrough potential.

Scientists, on their part, who might have seen military application of their high-energy research, would have approached the Central Committee Secretariat and Party apparatus with proposals and requests for support. PVO support for these proposals could be expected. Following Politburo approval of these ideas, a lead institute would be made responsible for overall conduct of the effort and a scientist-management committee formed to provide coordination, resolve conflicts, and police priorities.

The leadership was sensitized to the need for close cooperation between the military and science by the ideas circulating at the time. The new regime of Brezhnev and Kosygin also emphasized its commitment to scientific decisionmaking and its reliance on the views of experts. Energy beams for ballistic missile defense were the very epitome of the kind of application contemplated by the analysts and promoted by the leadership. Representative of the best of Soviet science, at the frontier on a world-wide comparison, the potential payoffs of a coalescence of science and defense were so revolutionary that it could have been difficult, in fact, not to have gone ahead with the project.

Once the project won approval and began to grow, bureaucratic momentum and incrementalism would generate the forces to keep it going. Explaining why such a project continues after ten or fifteen years is therefore quite different from speculating on how it began in the first place.

Criticism and Self-Criticism

Some observers suggest that the distribution of Soviet weapons is tending to become more like the American (see Figure 2), and less like the pattern described earlier where simplicity, commonality, evolutionary growth, and constrained performance characterize the process. In addition to energy beams, they point to the BMP infantry combat vehicle with its all-new (but one) subsystems, [29] or to the increased performance of new tactical aircraft and the latest generation of ballistic missiles. Critics correctly argue that the direct hardware evidence on which the above analysis is based represents mid-1960s technology and processes, at the latest.

I do not believe, however, that the case for major changes in Soviet military R&D styles has been established. It must first be noted that, while the case for change is possibly correct, one cannot be definite in such conclusions without a close look at the hardware. And in this, the Russians are uncooperative. One must also note that Soviet weapons have generally looked better externally than under detailed technical analysis. Time after time, western analysts have been surprised by the apparent lack of congruity between earlier perceptions of the weapon's value and the technology subsequently revealed by close inspection. These surprises arise when the value of one element of the weapons acquisition matrix (e.g., speed or military value) is injudiciously assigned to the other elements or to the matrix as a whole.

Furthermore, there is little evidence that the processes, organizations, incentives, and constraints have changed to any great degree over the past decade. Since the forces behind Soviet behavioral patterns have not changed, I would not expect the design pattern itself to change.

Finally, the performance levels demonstrated in recent Soviet equipment are not inconsistent with a long-term sequence of conservative advances that, cumulatively, could result in substantial qualitative improvements. We have seen such improvements in the past: from the V2 of 1944 to the SS-6 of 1957, from the MiG-21 Fishbed A in 1955 to the Fishbed L in the mid-1970s. Since the first examination of the World War II T-34 tank to the most recent information on the MiG-25 Foxbat, the same pattern emerges. [30] It is unlikely that the structure of the past 25 years and more has been overturned. On the other hand, altered perceptions of the role of science and new emphases on quality throughout the economy may signal future change. Trajectories can shift; even in the USSR. However, so deeply do the forces flow, that I would predict little more than marginal change over a five to ten year period, short of major disruption, crisis, or failure.

Conjectures and Conclusions

Soviet weapons technology, on the whole, is less advanced than comparable U.S. weapons technology. [31] Nevertheless, there is considerable evidence that these technological shortcomings often do not result in lesser military value. A dilemma for analysts is thus raised: how does the Soviet Union manage to field presumably capable and effective military weapons though it suffers a general technological inferiority with respect to the United States? Answers to this question, based on hints and fragments, remain conjectural at this point.

The simplest answer is that the Soviet Union compensates for its technological inferiority by fielding masses of men and equipment, and by spending more on its military might than potential adversaries. This answer, though, is only partial, for in many cases, Soviet weapons on a face-to-face comparison are comparable in military value to their western rivals'.

Additional reasons for Soviet weapons effectiveness lie in design continuity, operational testing, and the criteria used to evaluate the weapons.

A feature of Soviet weapons development, often disregarded in the U.S., is the function of design, where design is used here in the sense of creatively bringing together and adapting existing elements into a unified construction. The art of design is promoted in the Soviet Union by the continuity of design teams and the continuous construction and test of prototypes. Budgets and manpower levels of defense industry research institutes and design bureaus are stable and relatively independent of short-run production trends. Soviet institutions exhibit much less of the cyclical ups and downs of American weapons development teams as they follow the award, completion, or cancellation of contracts. [32] This stability results in a regular progression of designs and prototypes yielding a level and quality of experience that only comes from the actual creation and test of new ideas in working hardware.[33] The availability of improved weapons in prototype form may also make the follow-on production decision more likely than does the American military-political process of promoting a plan instead of a product.

Not only is the designer educated by the development of new models, but so too is the user. Fragmentary evidence suggests that extensive field testing of new equipment is an essential part of the Soviet weapons acquisition process whereby feedback is generated for the next design iteration. Requirements generation, design, and development is thus abetted by troop testing in large-scale exercises and in more routine training activities. Western analysts first saw evidence of a preliminary version of the T-72 tank, for example, in the 1970 Dvina exercises, and over the next few years several other versions were apparently produced and issued for troop testing.[34] Twenty-five examples each of early versions of the MiG-21--one version with swept wings and the other with delta wings--were built for evaluation by the Soviet Air Force. After selection of the delta-winged fighter, a hundred pre-series models were delivered to regiments for further operational testing. [35] Similarly, test examples of the VTOL Yak-36 (Forger) were operated aboard the helicopter cruiser Moskva in early 1974 prior to later deployment of about a half dozen pre-production versions in service test aboard the Kiev two years later. [36] Operational testing is especially important in the Soviet context where the constraints on technology and performance demand careful consideration of design tradeoffs.

The Soviet military evaluates equipment as an integrated and complementary part of the total fighting force and not as, in the American context, a collection of specifications or, in the extreme, a single index number. Thus, Soviet evaluation of tanks and anti-tank weapons centers on how they affect the rate of advance of military units, whereas the American measure of effectiveness is the probability of destroying an enemy tank. [37] The Soviet measure requires consideration of the weapon in its full tactical environment. This is a difficult and complex task, but its accomplishment may be aided by an experimental approach to exercises and training where alternatives are examined in a realistic operational framework.[38]

This analysis implies that, if the Soviet Union desires to play a global role as a militarily competitive super-power, it is forced by necessity to choose--to choose missions, weapons, capabilities, and the technologies to achieve them. Necessity and choice are inseparable correlates to Soviet power. For the U.S., since necessity has been somewhat less binding, individual choices in the past were less critical. Predictions of future weapons and technologies, however, must consider the future constraints likely to influence future choices, in both the Soviet Union and the United States.

An acquisition strategy of incremental change has become a hallmark of Soviet behavior. This strategy has advantages that are particularly valuable in the Soviet context. It minimizes risk by continuing in the same direction as in the past, limiting consideration of alternatives "to those policies that differ in relatively small degree from policies presently in effect." [39] However, in order for an incremental approach to be an adequate method of achieving change, three conditions are necessary:

(1) the results of present policies must be in the main satisfactory; (2) there must be a high degree of continuity in the nature of the problems; (3) there must be a high degree of continuity in the available means for dealing with the problem. [40] Since all of these conditions seem to be present in Soviet weapons acquisition policy, one could predict little more than marginal change in the future, short of major crisis or failure.

FOOTNOTES

[1] This figure was suggested by James Sterling, Foreign Science and Technology Center, U.S. Army. The index of new and advanced features could be calculated by assigning numbers on a scale from one to ten to each subsystem: one number representing the modernity of the subsystem; and the other reflecting the level of performance or technology demonstrated by the subsystem. Addition of the two sub-indices, or the logarithm of their product could yield curves of the type shown. For the use of a similar index number in a different context, see Robert L. Perry,et al. System Acquisition Strategies, The Rand Corporation, R-733-PR/ARPA, June 1971, p. 13.

[2] Marshal I. I. Yakubovsky, quoted by Michael J. Deane and Mark E. Miller, "Science and Technology in Soviet Military Planning," Strategic Review, Summer 1977, p. 80.

[3] "Simplicity" is best defined here as the absence of complexity, wherein the dictionary definition of complexity is sufficient for present purposes: "characterized by a very complicated, involved, or intricate arrangement of parts." The concept is best applied comparatively rather than absolutely: e.g., the Soviet T-62 tank today is more complex than the T-34 of World War II, but simpler than the U.S. M60A1. It should also apply to the mechanisms of equipment rather than to performance capabilities. That is, a distinction should be made between inputs and outputs, between the internal arrangements by which performance is achieved and the performance itself.

[4] J. W. Kehoe, Jr., "Warship Design: Ours and Theirs," U.S. Naval Institute Proceedings, August 1975, pp. 56-65.

[5] "U.S. finds SA-6 to be Simple, Effective," Aviation Week and Space Technology, December 3, 1973, p. 22.

[6] The solid-fuel integral rocket/ramjet, unlike liquid fuel designs, cannot be modulated for optimum performance as a function of speed and altitude. The solid design therefore suffers performance degradation off its design point and at high altitude when it loses oxidative efficiency. The U.S. has emphasized liquid-fuel designs in a number of mission areas despite many advantages of solid fuel technology. J. Phillip Geddes, "Advanced Propulsion Systems for Missiles," Interavia, March 1977, p. 252.

[7] Arthur J. Alexander, Armor Development in the Soviet Union and the United States, R-1860-NA, The Rand Corporation, June 1976, pp. 120-122.

[8] The Russian engine, for example, had a somewhat

better thrust-to-weight ratio than the U.S. engine.

[9] CIA testimony, Allocation of Resources in the Soviet Union and China - 1976, U.S. Congress, Joint Economic Committee, 94th Congress, 2nd Session, 1976, p. 66.

[10] The American analysts could find no good reasons for a fixed RPM requirement.

[11] This same engine was also used on the Tu-114 transport and on the derivative Tu-126 (Moss) early warning aircraft.

[12] Michael MccGwire, "Soviet Naval Procurement," The Soviet Union and Near East Seminar, Royal United Services Institute, London, March 1970, p. 79.

[13] The SS-6 was not entirely successful as an ICBM, although it did spark the "missile gap" of the late 1950s. As a space launcher, it continues to be used in modified form to the present time.

[14] Although both the Russians and British bought licenses for the Christie designs and went on to improve them and produce successful models, the American Ordnance Department rejected Christie's tanks (despite Congressional appropriations and directions to purchase them) in part because they did not meet precisely Ordnance requirements. Alexander, op cit., pp. 71-73.

[15] This description is taken from the following sources: Aviation Week and Space Technology, October 11, 1976, pp.18-19; October 25, 1976, pp. 16-17; November 1, 1976, p. 9; March 28, 1977, pp. 17-18.

[16] David Binder, "U.S. Experts Say MIG-25 Shows Some Advanced Technology," New York Times, January 26, 1977, p. 11.

[17] The importance of history in the formation of Soviet doctrine is emphasized by Leites, who quotes a 1931 statement of Stalin, the echoes of which are still heard in current Party declarations, "Those who fall behind, get beaten! But we do not want to be beaten. No, we refuse to be beaten! One feature of the history of old Russia was the continual beatings she suffered for falling behind, for her backwardness. She was beaten by the Mongol Khans. She was beaten by the Turkish beys. She was beaten by the Polish and Lithuanian gentry. She was beaten by the British and French capitalists. She was beaten by the Japanese barons. All beat her--for her backwardness; for military backwardness, for cultural backwardness, for political backwardness, for industrial backwardness.... Such is the jungle law of capitalism. You are backward, you are

weak--therefore you are wrong; hence you can be beaten and enslaved. You are mighty--therefore you are right; hence, we must be wary of you. That is why we must no longer lag behind." Nathan Leites, The Operational Code of the Politburo, McGraw Hill, 1951, p. 79.

[18] Under the term "structure," Berliner includes prices, decision rules, incentives, and organizational arrangements. Joseph Berliner, The Innovation Decision in Soviet Industry, MIT Press, Cambridge, Mass. 1976, pp. 8-19.

[19] It must be emphasized that this conservatism refers to technology and not to design. Over the years, the Soviet Union has been a producer of innovative weapons designs--from the T-34 tank, to the BMP infantry combat vehicle, to the Kiev aircraft carrier.

[20] The aircraft designer A. S. Yakovlev, for example, was reluctant to take on the design of a vertical take-off aircraft (Freehand) because of its risk and the absence of a clear military requirement. He accepted the job only after being directed to do so by higher authorities. Demonstrating the independence of leading designers, Yakovlev attached a condition to his acceptance of the project that he be allowed to borrow engineers from other design bureaus. D. C. Winston, "Russia Seeks Supersonic VTOL by 1970," Aviation Week and Space Technology, June 24, 1968, p. 211.

[21] Many of the details of nuclear weapons development are taken from I. N. Golovin, I. V. Khurchatov, Atomizdat, Moscow, 1973, and from Herbert York, The Advisors. Oppenheimer, Teller, and the Superbomb, W. H. Freeman and Co., San Francisco, 1976, ch. 3, 4.

[22] It is now believed by many Soviet writers that the Engels' claim that "if industry makes a technical demand it moves science forward more than ten universities" is no longer valid. One military analyst holds that the reverse is now true. With the development of science and the complexity of military R&D, the direction of influence is now "from science to military affairs, since contemporary science is able to find ways of raising the combat capabilities of the army and navy which are new in principle." Colonel V. Bondarenko, Kommunist vooruzhennykh sil, No. 24, 1971. However, most studies on innovation in capitalist countries suggest that Engels continues to be correct; that 60-90 percent of innovations are stimulated by demand (requirements). See, for example, James M. Utterback, "Innovation in Industry and the Diffusion of Technology," Science, February 15, 1974.

[23] It is not our purpose here to argue either the feasibility of beam weapons or whether, indeed, the Soviet research is directed toward military goals. Rather, we shall assume that the main thrust of the research is weapons related, and proceed from that assumption. See, for example, Clarence Robinson, Jr., "Soviets Push for Beam Weapons," Aviation Week and Space Technology, May 2, 1977.

[24] Through his co-authors, Rudakov has been associated with several institutes: the Khurchatov Institute in Moscow and the Institute of Nuclear Physics in Novosibinsk. Simon Kassel and Charles D. Hendricks, High Current Particle Beams, I: The Western USSR Research Groups, R-1552-ARPA, The Rand Corporation, April 1975, p. 11.

[25] Robinson, op cit., p. 16.

[26] "Hundreds of laboratories and thousands of top scientists" have been identified as working on the technology necessary for production of high-energy beams. Robinson, op cit., p. 21.

[27] Kassel and Hendricks, op cit., p. 9.

[28] Quoted in Alexander Ghebhardt, Implications of Organizational and Bureaucratic Policy Models for Soviet ABM Decisionmaking, Ph.D. dissertation in Political Science, Columbia University, 1975, p. 95.

[29] The exception is the rocket-assisted projectile (noted above).

[30] Liddell-Hart's description of the T-34 can still be applied to Soviet weapons today:

> "The machines were rough inside and out. Their design showed little regard for the comfort of the crew. They lacked the refinements and instruments that Western tank experts considered necessary as aids to driving, shooting, and control....
>
> "On the other hand, they had good thickness and shape of armor, a powerful gun, high speed, and reliability--the four essential elements.... Regard for comfort and the desire for more instrumental aids involve added weight and complications of manufacture. Such desires repeatedly delayed the development and spoiled the performance of British and American tanks. So they did with the Germans, whose production suffered from the search for technical perfection."

B. H. Liddell-Hart, The Red Army, Harcourt, Brace, & Co., 1956, p. 181.

[31] In Congressional hearings, for example, the CIA testified that, "Whereas in the United States we had the technological capability to produce almost all types of Soviet equipment, there is some U.S. equipment that the Soviets do not have the technology to produce." Allocation of Resources in the Soviet Union and China - 1977, Part 3, U.S. Congress, Joint Economic Committee, 95th Cong., 1st Session, p. 25. Similarly, in the 1976 hearings (of the same title), responding to a question asking for the identification of Soviet weapons more advanced than their American counterpart, the CIA said that, "although some Soviet weapon systems have capabilities that exceed those of U.S. systems in such things as range, these are the result of design choice and do not reflect a higher state of technology.", p. 67.

[32] Over the longer run, design bureaus are not completely immune to assessments of their worth. Continuous experience of unaccepted designs can lead to the reduction of a Soviet design bureau's strength or even to its demise, although occurrence of this latter possibility is rare.

[33] Organizational stability, especially when combined with high barriers to new competitors, can also lead to rigidity and loss of originality.

[34] Deployment and variants of the new Soviet tank are described in: J. Gratzl, "T-64, Some Thoughts on the New Soviet Battle Tank," International Defense Review, January 1976; "Details of the Soviet T-72 Battle Tank," International Defense Review, December 1977.

[35] Alexander Boyd, The Soviet Air Force Since 1918, Macdonald and Jones, London, 1977, p. 228

[36] Air Enthusiast, March 1974; Air International, November 1976, p. 208.

[37] These points are developed by a Rand colleague, Larry Gershwin, in a forthcoming study on Technology Utilization for Land Combat Forces.

[38] A simple example of the relationship between tactics, requirements, and design is provided by the T-62 tank. Its armor is distributed more toward the front than is the armor on the American M60. However, the Soviet tactic is for a tank platoon as a unit to turn toward the target before firing, thus presenting the most protected part of the vehicle to the enemy. The tankers are aided in this maneuver by a simple gyro-compass in the driver's compartment which allows the

platoon commander or tank commander to direct the units toward a specific compass heading. This tactic allows the tank designer to trade off armor weight on the sides and rear for a lighter, smaller, cheaper vehicle.

[39] Charles E. Lindblom, "The Science of 'Muddling Through,'" Public Administration Review, Spring 1959, p. 84.

[40] Yehezkel Dror, "Muddling Through--Science or Inertia?", Public Administration Review, September 1964, p. 154.

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