



RHODUS INTELLIGENCE REPORT

HOW DOES RUSSIA MAKE MISSILES?

CONTRIBUTORS

Kamil Galeev

Olena Smolina

Oleksandr Makhonin

Kateryna Mikhalevska

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ABOUT US

Rhodus Intelligence is an OSINT company focused on the fundamental. We investigate how this world works. To understand its fundamental patterns, we ask simple questions. As we may not necessarily find the answers in a ready form, we produce them ourselves. We identify and examine sources scattered around the unobvious places. We integrate the knowledge scattered around the unobvious disciplines. We document the tacit and translate it to the layman tongue.

Our first investigation gives an understanding of what the Rhodus is all about. It started with a simple question. How can Russia produce missiles after having lost the Soviet machinery and Soviet craftsmanship? The question sounded treacherously basic. Yet, it was impossible to answer based on the literature available. As far as we could see, the quality description of Russian missiles production and the logic behind it did not exist. Therefore, we were to construct it ourselves, bit by a bit.

And that is how the Rhodus Intelligence was born.

Rhodus Intelligence. Study what matters

Founder: Kamil Galeev

CEO: Olena Smolina

Senior Analyst: Oleksandr Makhonin

For inquiries, please email contact@rhodus.com

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INTRODUCTION

The Russian military doctrine is missile centric. Missiles serve as the principal element of the nuclear/non-nuclear deterrence system as well as a means of conventional warfare. In particular, the Russian ability to deliver the weapons of mass destruction and, therefore, to execute the nuclear blackmail relies upon the long range ballistic and cruise missiles. Their manufacture and maintenance continuing despite the unprecedentedly wide sanctions, suggests that both the targeting and implementation of sanctions is inefficient in undermining the Russian war production. With this report we propose a new look into the Russian missile industry's chokepoints, specifically in its manufacturing equipment and production processes.

There's less continuity between the Soviet and the Russian military production than most presume. By the moment of its dissolution in 1991, the Soviet Union was going through an early stage of transition from manual to computer control. Its military industry was still primarily equipped with the manually controlled conventional machines. With the fall of the USSR, the Russian military production collapsed, many of the supply chains and knowledge ecosystems that supported it being effectively wiped out. By the end of decade, Russia had neither the Soviet machine tool industry, nor the Soviet labor capable of producing precise components manually.

In the 2000-2010s, Putin brought the military production back from the dead by replacing the machinist labor with the computerized equipment from Western Europe and to a lesser degree from the developed East Asia. As these supplies formed the manufacturing base of the Russian missiles industry, its capacity to execute the Soviet designs of weaponry, now relies upon the continuous import of spare parts and expendables from the U.S. allies. Contrary to the popular view, many of these supplies are difficult or impossible to substitute with the Chinese manufacture. Limitations of Chinese capabilities explain the otherwise strange invisibility of Chinese machines at the Russian missile producing plants until 2022.

Resurrected from the ashes of the 1990s, the Russian missiles industry developed over reliance on the integrated manufacturing solutions. As the post-Soviet collapse interrupted the continuity of Russian manufacturing tradition, modern Russia ended up with the military industrial workforce of highly uneven (generally low) quality. As every decision taken in the production process presented a potential point of failure, the most sophisticated military producers in Russia were forced to minimize the human decision making to improve consistency. Consequently, they ended up excessively reliant upon the one single company in the world that could provide the foolproof, all-in-one hardware and software solutions largely excluding the human factor from the factory floor.

Based on the Russian official self-estimates, we can describe the pre-war state of the Russian machine tool market with the 90/90 formula. Over 90% of machine tools were being imported, and over 90% were being purchased by the military producers. At this point we can assume that every metalworking machine, part and expendable shipped to Russia can and will be used for the military production purposes as there are no sizable non-military producers left. Therefore, there is no need to prove a connection between a specific Russian machine tool importer and a specific military producer. For the same reason, we can presume that all the foreign-provided technical and software support is currently supporting the military production processes.

Our investigation is based on a broad range of documental and visual sources along the supply chain, ranging from the official TV propaganda to the HR job postings. Integrating and cross-examining the

data, we have constructed a representative picture of the Russian missiles industry's manufacturing base, its bottlenecks and chokepoints, allowing for an efficient targeting and implementation of sanctions. Furthermore, we have developed the instruments and methodology for tracking the supply and maintenance chains for independent researchers to use. Based on the database of military industry's procurements we have compiled, researchers, journalists and public bodies will be able to track and analyze the economic activities of the Russian missiles industry. This will serve to obstruct the missile industry's supply lines and undermine Russian war production.

The Rhodus Intelligence report "How does Russia make missiles?" is based on our investigation of the 28 ballistic, cruise, anti-ship and air defense missile-producing facilities belonging to or associated with the four corporations of Roscosmos, Tactical Missiles Corporation, Almaz-Antey and Rostec. While far from exhaustive, this sample allows us to construct a comprehensive picture of the manufacturing base supporting the Russian nuclear/nonnuclear deterrence system as well as its strategic chokepoints. Whereas this report is focusing on the missiles production, our methodology is applicable to investigating the entire Russian military industrial complex, including the missiles, the nuclear weaponry, the aircraft, the navy, and the land army weaponry production.

Part 1. HOW MISSILES ARE MADE

Military production is the cornerstone of Russian military power. **The Russian ability to overcome its enemies on the battlefield relies upon its capacity to outproduce them on the factory floor.** It is the sheer quantity of weaponry that gives Russia an upper hand in its war with Ukraine¹. Most importantly of all, it is the sheer quantity of missiles². Missiles deter external actors from intervening into the Russian war in Ukraine and give Russia its key advantage in the hostilities.

Serving as the principal means of the WMD delivery, **long range cruise and ballistic missiles allow Russia to plausibly execute the nuclear blackmail.** Countering the enemy air force and projectiles, air defense missiles cover the Russian ground forces from every possible aerial threat. Used as a means of conventional strikes, missiles compensate for the shortcomings of the Russian land army and serve as an instrument of terror against the civilian infrastructure.

Despite the unprecedentedly wide sanctions, Russia has only increased its output of missiles³. This implies that the targeting and the implementation of sanctions has been highly inefficient in undermining the Russian war production. Missile production is primarily constrained by the metalworking capacity, rather than by the microchips supply⁴. **It is the very high capacity for precision metalworking, especially, precision machining, that the Russian military superiority and, ultimately, the great power status is based upon.**

Execution of a missile's mechanical design primarily relies on machining. Allowing for the greater precision compared with other metalworking processes, machining is indispensable for producing weaponry. Most parts of tight control and convoluted geometry must necessarily be machined, making machining the central production process in the missiles industry. This includes the engine(s), fuel tanks, rocket body, etc. **Machining is most of what a missile plant is doing⁵.**

Starting from 2003, Putin has radically expanded the Russian machining capacity, replacing manually controlled Soviet tools with the CNC machines imported from Western Europe and developed East Asia. As these imports formed the Russian missile manufacturing base, the military production was put on a permanent needle of spare parts, consumables and software support from the U.S. allies. As a result, **precision machining became the key chokepoint of the Russian war industry.**

¹ Vershinin, Alex. "The Return of Industrial Warfare." The Royal United Services Institute (RUSI) (2022).

² On the missile-centrism of Russian military doctrine, see Golts, Aleksandr. Military reform and militarism in Russia. Lynne Rienner Publishers, 2018. P. 71

³ Julian E. Barnes, Eric Schmitt and Thomas Gibbons-Neff. 2023. "Russia Overcomes Sanctions to Expand Missile Production, Officials Say". New York Times, September 13.

⁴ Most microelectronic components are easy to acquire, hard to track and easy to overstock with. This makes the microelectronics-focused approach counterproductive for practical purposes of sanctions policy.

⁵ See the distribution of Krasnoyarsk Machine-Building Plant production processes in Красмаш. «Буклет к 80-летию ОАО "Красмаш". Written 2012. Published 2016. Accessed December 11, 2022. P. 37.

SLBM Sineva...

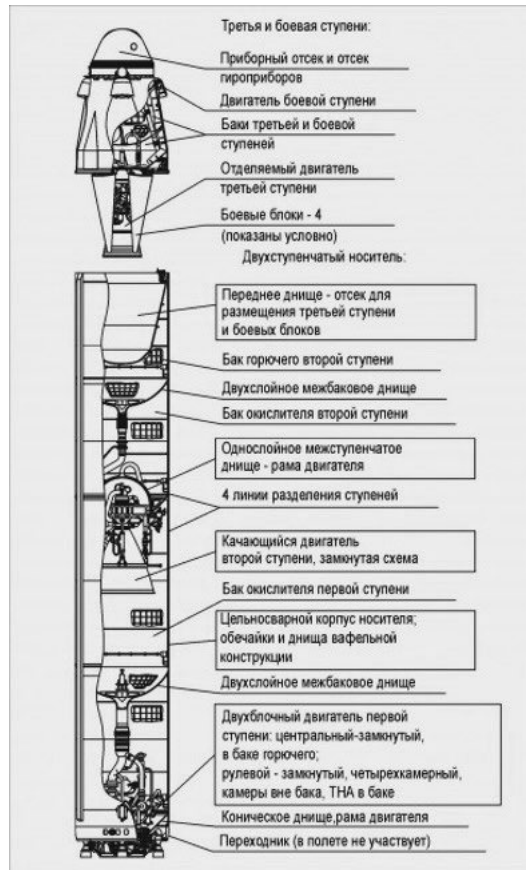


Figure 1: SLBM Sineva

Figure 2: SLBM Sineva design

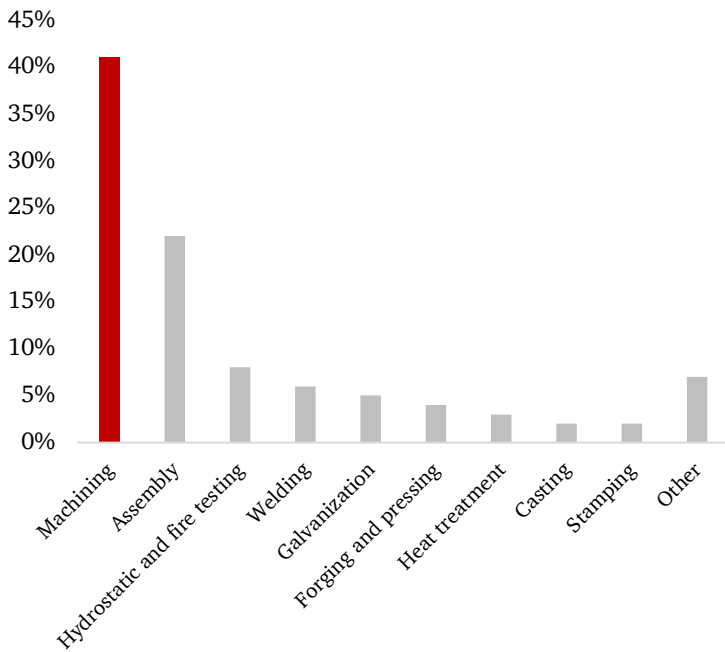
Source: Makeyev Design Bureau website <https://makeyev.ru/activities/missile-systems/Narubegevekov/Sineva/>



Figure 3: SLBM Sineva launch

... and what it takes to make it on the Krasmash Plant

Figure 4: Missile production process: Krasmash



Machining is most of what the missile industry is doing. And almost the entire precision machining capacity relies upon the import from and the software support by the U.S. allies.

Almost the entire machining park has been imported from the US allies between 2003 and 2023.



Figure 5: Kovosvit Mas, Czechia



Figure 6: DMG Mori AG, Germany

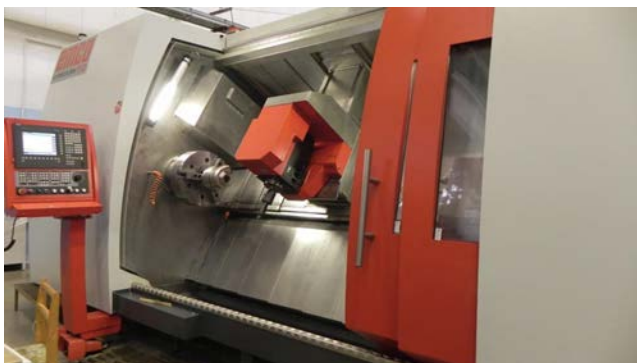


Figure 7: EMCO, Austria

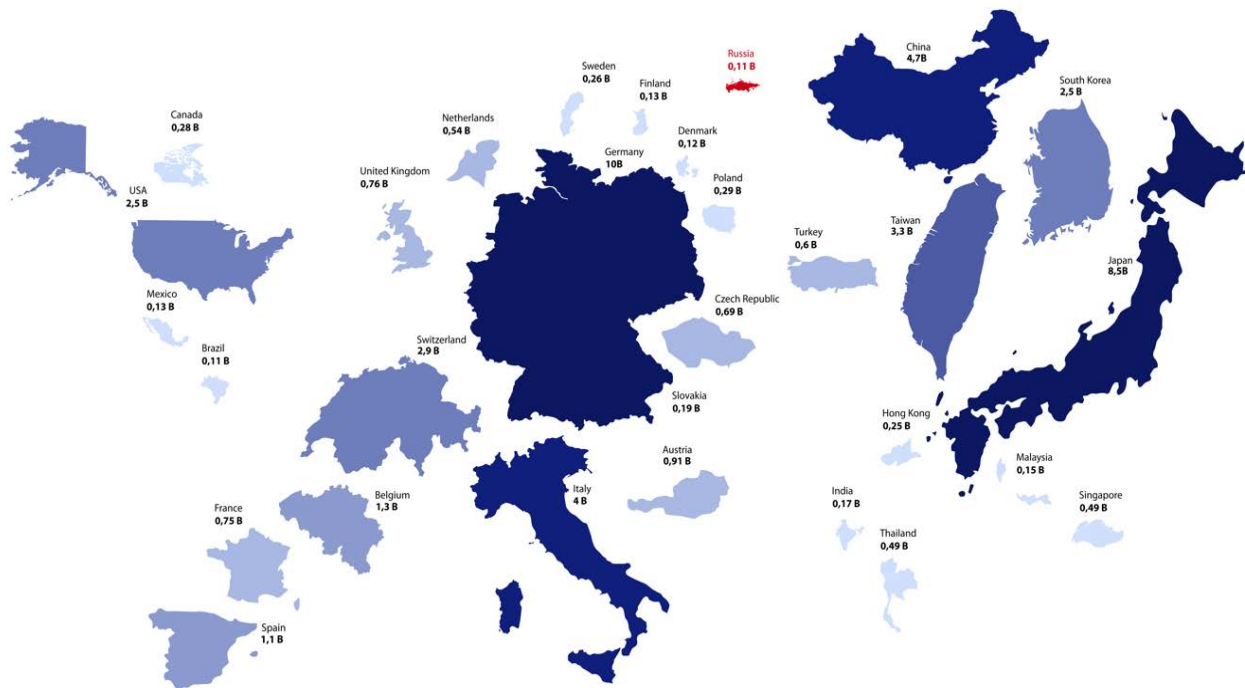


Figure 8: ANCA, Australia

Part 2. WHO PRODUCES MACHINE TOOLS?

The machine tool industry is heavily concentrated geographically. A handful of developed countries located in Western Europe and East Asia count for almost all the global exports⁶, **Germany and Japan being the world's two undisputed leaders**. Considering that the machine tool industry provides the production base for all the other manufacturing industries, including the military, the vast quantitative and qualitative regional disparities in machine tool production have far-reaching strategic consequences.

Figure 9: Global distribution of machine tool exporters, 2019



Source: Gardner Intelligence. The World Machine Tool Survey, 2021

The extreme unevenness in how countries count their machinery output makes these estimates effectively incomparable. Consequently, foreign trade figures serve as a far better comparative indicator of the domestic production capacities than self-reported “domestic production” estimates.

The **machine tool production is a knowledge intensive industry**. It is more demanding in terms of technology and competent labor than most manufacturing industries⁷. As it is based on the innovative digital control technology, mature mechanical engineering, and the continuous tradition of craftsmanship, those of the old industrial powers that managed to adapt to the recent disruptive change in technology play a far disproportionate role on this market. While some catching development producers are closing the quantitative gap, the gap in quality and technology is more difficult to bridge⁸.

⁶ Based on Gardner Intelligence. World Machine Tool Survey Report, 2019, 2021.

⁷ Malmlöf, Tomas. "The Russian Machine Tool Industry: Prospects for a Turnaround." (2019). P. 21.

⁸ See Arnold, Heinrich M., and Heinrich M. Arnold. "The machine tool industry and the effects of technological change." *Technology Shocks: Origins, Managerial Responses, and Firm Performance* (2003): 59-97.

Based on the classification by the Russian Ministry for Industry and Trade, we can classify key global producers into three categories⁹:

- 1. The Workshop of the World:** Continental Western Europe and Japan. Old industrial powers well-adapted to the recent change in technology. High capabilities, high capacities. These countries count for most of the global higher-end production.
- 2. Flying Geese:** Taiwan, South Korea, China. Catching development countries. Limited capabilities, high capacities. Of these three Taiwan and South Korea are on the advanced stage of their learning process, while China is newcomer whose capabilities are particularly limited.
- 3. The Rust Belt:** United States, United Kingdom. Old industrial powers poorly adapted to the disruptive change, High capabilities, limited capacities. Higher-end production retained but is insufficient for covering the domestic demand.

Table 1: Global machine tool production

	High Capacity	Limited Capacity
High Capability	Western Europe, Japan	United States, United Kingdom
Limited Capability	Taiwan South Korea, China (heavily limited)	Most industrial countries

Source: Rhodus Intelligence

In 2023, the global supply of precision machinery, tooling and software is controlled by the **Western European and Japanese producers**. Combining technological superiority with the difficult to emulate tradition of craftsmanship, they have effectively monopolized a range of strategically important sub-sectors, especially at the higher end. Their dominance is particularly pronounced in the production of critical machine components and tooling. Supply chain for the higher-end equipment almost invariably starting in Western Europe/Japan for the lack of alternatives is a major factor of risk for the military producers of developing world¹⁰.

⁹ This is an improved version of the classification by the Russian Ministry of Industry and Trade. Министерство промышленности и торговли Российской Федерации. Стратегия развития станкоинструментальной промышленности до 2030 года. 2017. P. 37-38.

¹⁰ It is noteworthy that Europe and the United States hold an effective monopoly on the integrated manufacturing solutions of military grade quality. Due to the fresh workforce effect, new industrial countries like Russia or China must rely upon the system integration more heavily compared with the old industrial powers. Meanwhile, the military grade solutions are provided by only a handful of companies in the world all located in Western Europe and in the United States. As of 2023, Siemens (Germany) is the one singular company in the world capable of providing the pipeline from CAD to CNC controller, making it uniquely important for the military production of new industrial powers.

Flying Geese of East Asia have started their progress only recently and from the very low base. Consequently, their capabilities are limited, albeit to a various degree. As Taiwan and South Korea are on the very advanced stages of their learning process, the quality and technology gap dividing them from the old industrial powers is narrower. This makes them an often-viable alternative for the Russian military industry. Still, even these advanced catching development producers cannot fully substitute the European and Japanese manufacture.

China, on the other hand, **lags far behind in term of quality and technology**. Its output is heavily lopsided with the outsized share of low-end manufacture¹¹. At the same time, its capabilities at the higher end are heavily limited¹². This explains the **almost complete invisibility of Chinese machines** in the Russian missiles industry. Going through an earlier stage of improvement, China had been rarely capable of meeting the Russian demand on CNC machines and, even more so, machine parts and tooling. As of 2023, Chinese machines will be almost invariably equipped with the imported mechatronic (including CNC controllers), mechanic components, and tooling.

The problems of the United States are largely opposite to those of China. If Chinese problems are the problems of a nascent industry, the problems of the US are those of an industry in decline. As a former industrial powerhouse, the US have lost much of their production capacities, especially at the lower end. Still, they have high capabilities, retaining the sophisticated production and even the leading edge in certain sub-sectors. The America equipment and software¹³ being well-represented in the Russian missiles industry reflects the ability of the US producers to satisfy the higher-end demand from the Russian military. China struggling with quality, the US primarily struggle with quantity.

Machine tools supply as a strategic chokepoint

Machine tools supply is a **key chokepoint of the global military industry**. Most major military producers do not have the machine tool industry that could satisfy the needs of their weaponry manufacturing, either because they already lack the capacity (United States) or because they have not yet developed the capability (China). Consequently, their production relies upon the continuous import of machines, parts, and expendables from abroad. **Russia, however, makes a special case of a major weaponry producer with almost no machine tool production capacity of its own.**

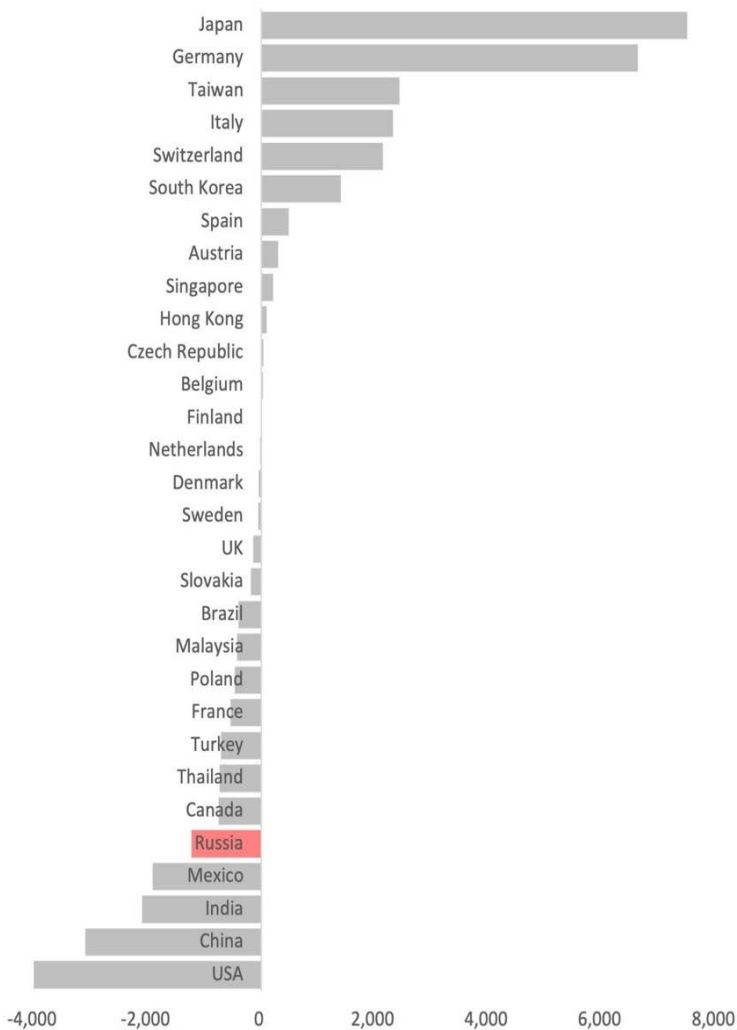
¹¹ Including conventional, manually controlled [machines](#).

¹² Some of the catching development-associated problems include:

- a) heavily lopsided production structure, with the outsized share of low-end manufacture
- b) strong to absolute import dependency in critical components, mechanic or electronic or
- c) dependence upon the import of ready solutions from the old industrial powers

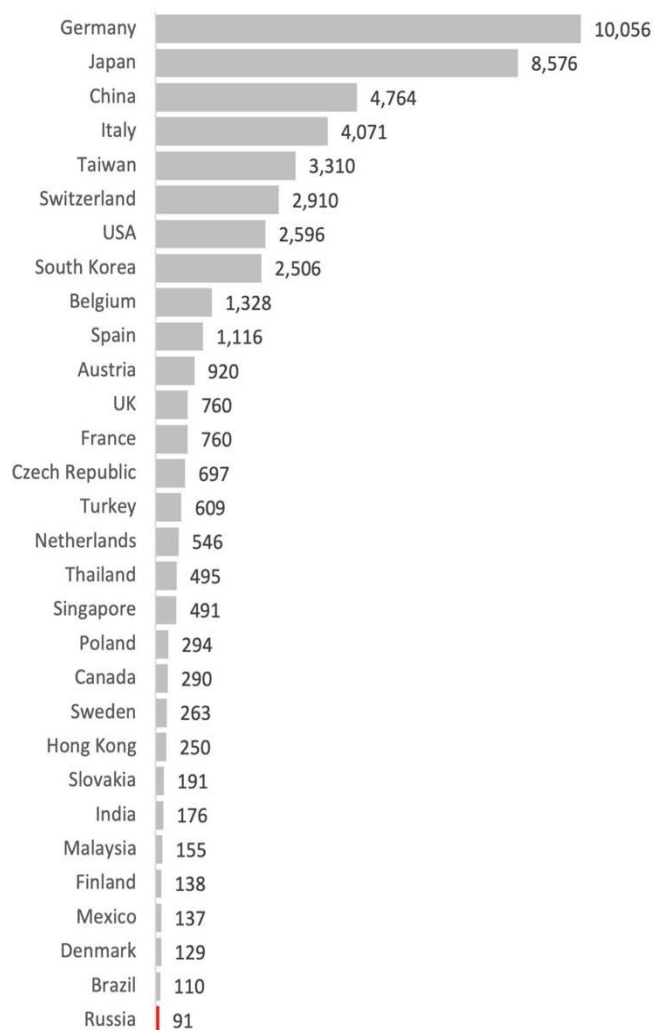
¹³ Although Russian missiles producers rely upon the American software, they tend to use it in the form of separate, non-integrated solutions. American software is often deemed optimal for executing specific tasks within the production process. Yet, it is widely seen as inferior in terms of an overall system integration. It does not and cannot exclude the individual decision making and, therefore, human factor to the same extent the Siemens does. Requiring a higher level of human involvement, they are easier to switch away from should the necessity arise. The system integration trap is first and foremost the Siemens integration trap.

Figure 10: Trade balance in machine tools in 2019, Millions of USD



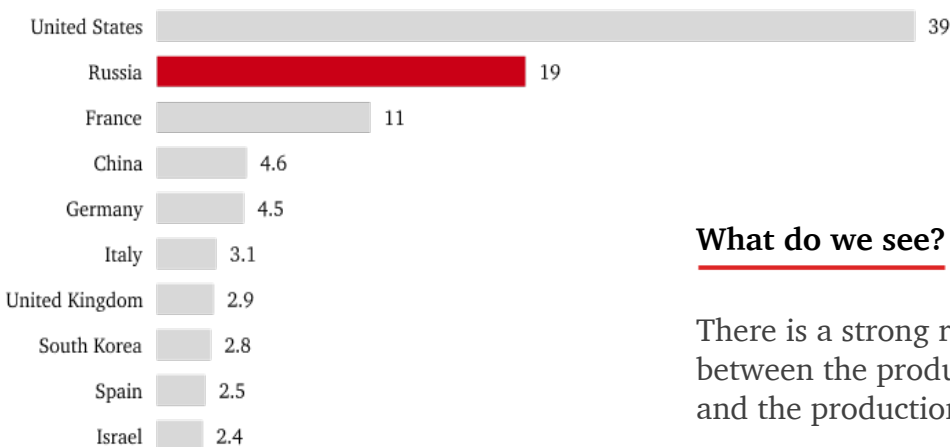
Source: Rhodus Intelligence

Figure 11: Top 30 machine tools exporters in 2019, Millions of USD



Source: Rhodus Intelligence

Figure 12: Top 10 largest major arms exporters, 2019



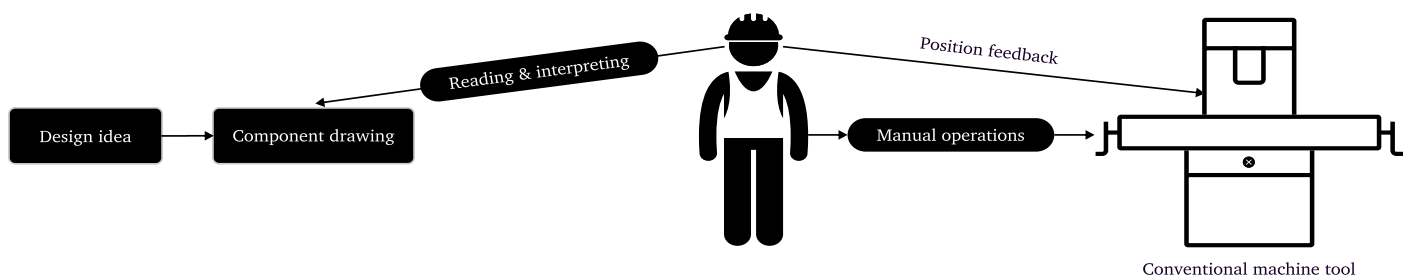
What do we see?

There is a strong regional asymmetry between the production of weaponry and the production of machine tools

Part 3. THE MECHATRONIC REVOLUTION¹⁴

From the heyday of Industrial Revolution till the late 20th c., manufacturing relied on conventional machine tools. Conventional machines were controlled by a human operator. An operator read the blueprints, interpreted them, and designed the machining strategy based on his interpretation. After that, he directed a machine manually, getting the feedback from it with his eyes, hands, and ears. **Quality and consistency of the final product heavily depended upon the machinist's personal skills and expertise.** Much of the operator's knowledge was not codified. This implicit, undocumented knowledge was passed from senior to junior workers, in the process of apprenticeship. Training a skilled operator was long, expensive, and necessarily included learning from a personal example of his seniors.

Figure 13: Conventional Machine Tool



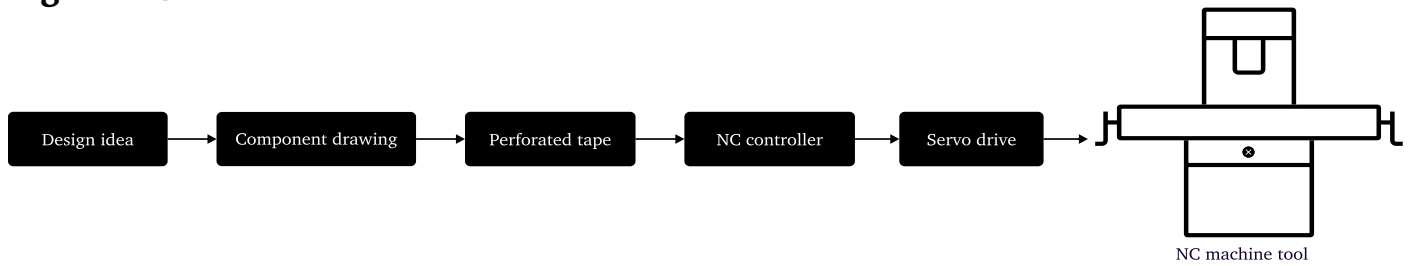
Source: Own improved depiction based on Youssef, Helmi A., and Hassan El-Hofy. Machining technology: machine tools and operations. CRC Press, 2008

Conventional machining required a large input of qualified labor. Each machine needed a skilled machinist during the entire production process. The length and difficulty of training as well as the distinctive character of skills required for different types of operations made the labor supply highly inelastic. As a result, **the quantity of skilled operators was the major constraint of military production.** In most cases, components of high precision and convoluted geometries could be produced only in small quantities. Anything that was to be mass-produced had to be simpler with looser tolerances, constraining the types of mechanisms suitable for the mass production.

Starting from the 1960s, manufacturing was revolutionized through the implementation of numerical control (NC). NC machines were operated by a hardwired electronic controller. A technician fed it a perforated tape with the program and the controller moved the tool according to the instructions. This made the quality more consistent and reduced dependency on an operator's personal skills and abilities. Furthermore, an NC operator did not need to be present during the entire production process. NC machines loosened the labor related constraints on the military production, allowing to partially substitute the qualified manual labor that major military producers now increasingly lacked.

¹⁴ This is a necessarily abridged and simplified account of how the machine tool industry developed historically. For a more holistic picture, including the history of mechanic automation see Carlsson, Bo. "The development and use of machine tools in historical perspective." Journal of Economic Behavior & Organization 5, no. 1 (1984): 91-114

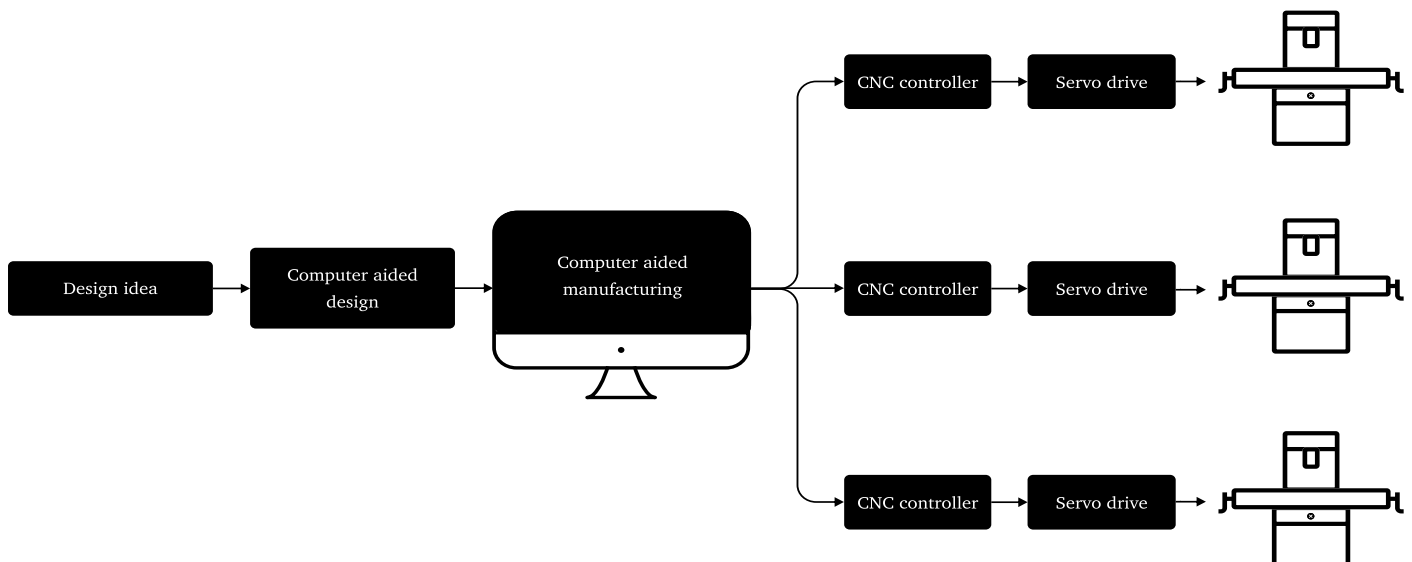
Figure 14: Numerical Control Machine Tool



Source: Own improved depiction based on Youssef, Helmi A., and Hassan El-Hofy. Machining technology: machine tools and operations. CRC Press, 2008

The computer numerical control (CNC) technology increased the productivity of manufacturing further. Unlike the hardwired NC tools, CNC machines were programmable, allowing for the use of software. The 1990s saw development of PC-based CNC machines supported with the Computer Aided Design (CAD) and the Computer Aided Manufacturing (CAM) software. The CAD decreased the time required for designing a component, sometimes by an order of magnitude or more. Meanwhile, **the graphic CAM allowed the hastily trained workforce with little mechanical or programming skills to produce precise components** of consistent quality. Whereas in the past training an operator took years, now it could be done in months¹⁵.

Figure 15: Computer Numerical Control Machine Tool



Source: Own improved depiction based on Youssef, Helmi A., and Hassan El-Hofy. Machining technology: machine tools and operations. CRC Press, 2008

Each step in the progress of digital control technology increased productivity and consistency while decreasing the minimal requirements for operator's skill level. Integrated manufacturing solutions streamlining the production process from a design shop to the factory floor allowed to minimize human decision making at every stage of the process. **What had previously required a large input of qualified labor, could now be done with only a minimal input of the semi-skilled one.** This mitigated the fresh workforce effect that the new industrial/post-Soviet countries were suffering from, at the cost of higher dependency on the solution provider¹⁶.

¹⁵ Early CNC machines required to write and modify the G-code manually, a major constraint in terms of capacity and capability. The graphic CAM allowed to generate and modify the code automatically, decreasing requirements to an operator's personal skills and allowing for designs that had been previously impossible to execute.

¹⁶ While the Russian missiles industry has been experimenting with Siemens (Germany), Dassault (France), PCT (USA) and Ansys (USA) solutions, the Siemens integration is unique and has no alternatives.

The effect of mechatronic revolution on the metalworking has been asymmetric. Whereas transition to the computer control affected a broad range of production processes, it affected them unevenly. Cutting and, most importantly, machining operations were fully revolutionized, while forging, pressing and casting were generally less affected¹⁷. **The asymmetry in technological progress transformed the economy of military production.** Soviets tended to purposefully minimize expensive and labor-intensive machining operations. Once the mechatronic revolution loosened machining-related constraints, **the CNC machining became the universal instrument of Russian military production.**

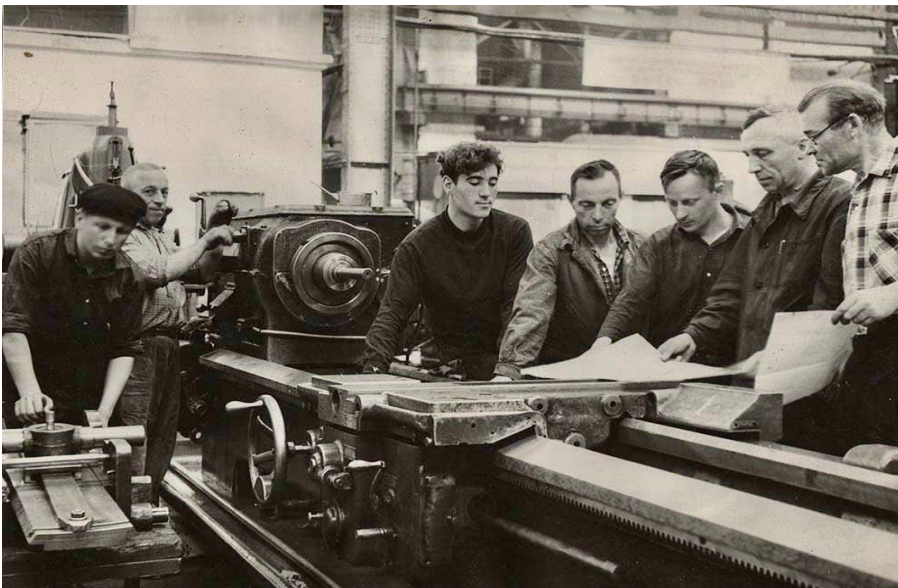
¹⁷ As a result, Russian military producers prioritized replacing their cutting equipment over the forging-pressing stock. Due to the slower pace of technological improvement in forging-pressing, the latter was often seen as less obsolete. Meanwhile, the revolutionary progress in machining made the replacement of existing machining stock a top priority.

Part 4. FROM THE MANUAL TO COMPUTER CONTROL

Fall and Decline, 1991-1996

By the moment of its dissolution, Soviet Union was going through an early stage of transition from the manual to computer control. Its military industry was still primarily equipped with conventional machines. As they required a large input of qualified labor, **Soviet capacity to produce weaponry was hard constrained by the number of experienced operators.** The operator expertise could not be bought, nor forced under a gunpoint. Including a significant element of tacit knowledge, it was passed from a master to an apprentice in the process of years-long one-on-one mentorship. Considering the length, and difficulty of training, it took a decades-long nation scale effort for the USSR to foster the workforce capable of mass producing the complex weaponry manually¹⁸.

Figure 16: Machining at the Kalinin Machine-Building Plant, late 1970s



Source: <https://zavodfoto.livejournal.com/5676104.html> Industrial Blogger Zavodfoto (Igor Yagubkov)

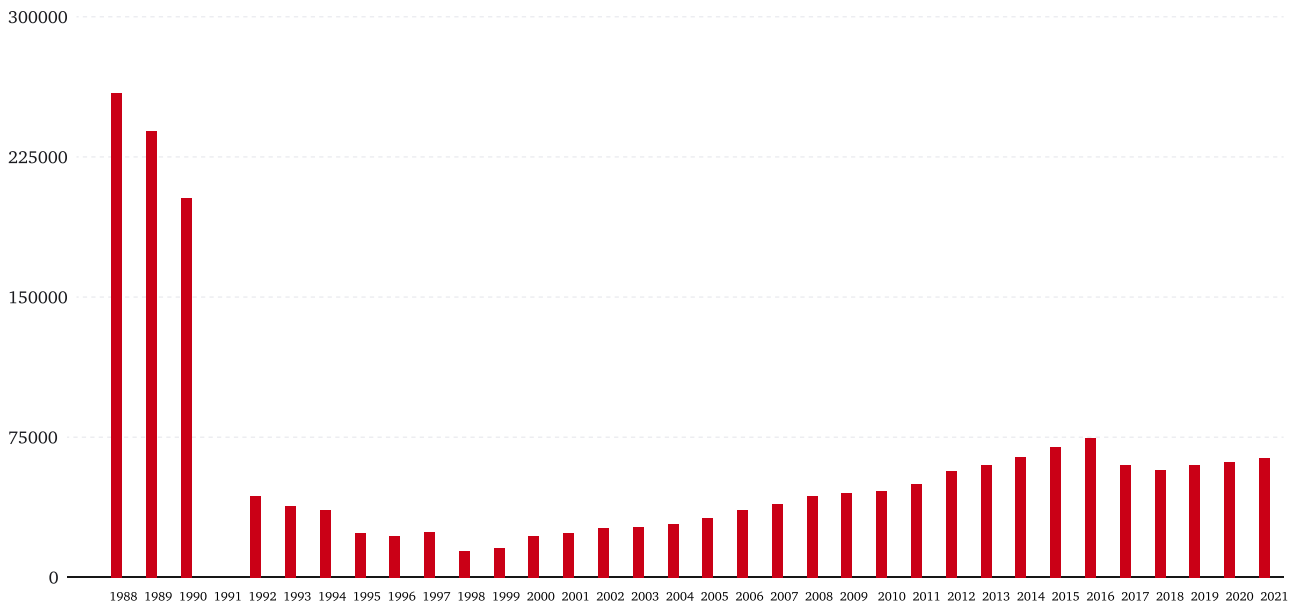
With the fall of the USSR, **the Soviet tradition of apprenticeship was interrupted**, and the implicit knowledge of operators was lost. As the government cut its purchases of weaponry, **the military output collapsed by over 90%**¹⁹. Paradoxically, this did not result in formal bankruptcies of military producers at any significant scale. Being unable to fund them, and unwilling to let them disappear, the Kremlin chose a middle way: no funding, no closure. On paper, most enterprises persisted through the 1990s. In practice, **the military industry was ruined, suffering irreversible losses in its physical and human capital.** As a result, much of its former supply chain was wiped out, and the knowledge ecosystems it used to support were obliterated²⁰.

¹⁸ On the labor related constraints of Soviet military production, see: Соколов, А. К. «От военпрома к ВПК: советская военная промышленность. 1917–июнь 1941 гг» (2012). P. 152–155.

¹⁹ Rivlin, Paul. *The Russian Economy and Arms Exports to the Middle East*. No. 79. Jaffee Center for Strategic Studies, Tel Aviv University, 2005. P. 18.

²⁰ The budget cuts were very much exacerbated by the non-payments. Through the 1990s non-payments became semi-normalized in the Russian economy with all types of economic actors delaying payments on their bills (often indefinitely). The non-payments tended to trickle down the supply chain, gradually wiping it out.

Figure 17: Soviet/Russian military expenditures, 1988-2021



Source: Based on SIPRI Military Expenditure Database

Table 2: Russian military industry production, 1992-1999

Indicator	1965	1970	1975	1980	1985	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
ICBMs	1000	380	150	200	100	125	100	55	35	25	10	10	10	10	10
SLMBs	15	170	175	175	100	65	50								
SAMs	5200	25000	40000	50000	50000	47000	43000	N\D	N\D	N\D	N\D	N\D	N\D	N\D	N\D
Bombers	46	7	20	30	50	40	30	20	10	2	2	1	0	0	1
Fighters\ Fighter Bombers	850	1000	1200	1300	650	575	250	150	100	50	20	25	35	40	40
Helicopters	80	390	630	750	600	175	350	175	150	100	95	75	70	40	75
Tanks	2600	3300	2500	3000	3000	1300	850	500	200	40	30	5	5	15	30
Armoured vehicles	1700	3500	4300	5500	3500	4400	3000	700	300	380	400	250	350	250	300
SP Artillery	200	600	900	900	1000	400	300	N\D	N\D	N\D	N\D	N\D	N\D	N\D	N\D
Submarines	14	15	10	13	8	12	6	6	4	4	3	2	2	2	0
Major Combatant Ships	12	5	10	11	8	8	3	N\D	N\D	N\D	N\D	N\D	N\D	N\D	N\D

Source: Hartley, Keith, and Jean Belin, eds. The economics of the global defense industry. Routledge, 2019

What do we see?

As the military expenditures collapsed, the output of weaponry scaled down, often by orders of magnitude. The collapse in output became a major factor interrupting the continuity of Russian military manufacturing tradition. The Soviet model died to be never restored again in its former complexity. The new military industry resurrected from the ashes of the 1990s was to be built upon the different principles.

The financial ruin of military production resulted in a rapid erosion of its workforce. In the Soviet era, military industrial workers used to be the aristocracy of labor, now the situation reversed. By 1996, their **wages dropped to only 60% of the average** in the manufacturing sector and were paid highly irregularly²¹. For the most part, struggling enterprises avoided laying off their workers, choosing to delay the payments for months and years instead. As youngsters could realistically hope to find an employment elsewhere, the junior and the middle generation eroded from the military production. By the end of decade, it turned into the Old Man Country with **an average age of 59 years old**²².

At the same time, **no replacement was trained**. Previously, hard manual jobs at the military plants had been at least well-compensated financially. Now they were not. Consequently, a trend for the shrinking size of and for the negative selection among the manual labor oriented vocational tracks (that had been already visible in the late Soviet era) rapidly accelerated²³. With the former economic incentives gone, students were rarely motivated to invest their lives into a trade that offered no future. As a result, vocational schools increasingly ended up with smaller and less motivated classes. Due to the defunding of vocational education, students had limited opportunity to acquire quality training or practical experience anyway²⁴.

Figure 18: NPO Saturn in the 1990s



Source: <https://www.youtube.com/watch?v=FEwWFvluPAw>

The footage from the NPO Saturn, the leading Russian aircraft/cruise missile engine producer.

²¹ Кузык, Б. «Оборонно-промышленный комплекс (ОПК)». *Большая Российская энциклопедия. Электронная версия (2017)*; <https://old.bigenc.ru/text/5045275> Дата обращения: 20.12.2023

²² Шлыков, В. "Оборонная экономика в России и наследие структурной милитаризации." *Под редакцией Стивена Э. Миллера и Дмитрия Тренина. Вооруженные силы России: власть и политика. Американская академия гуманитарных и точных наук (2005)*: Р. 196.

²³ By the 1980s, prestige of manual labor was already falling, with less and less youngsters choosing vocational track – despite economic incentives. Once the incentives were gone, the trend accelerated manifold. See Московская, А. *Проблемы становления модели профессии: российский опыт в западном исследовательском контексте. Мир России: Социология, этнология. 2010. Т. 19. № 3, Р. 101-102.*

²⁴ The federal government deprioritized vocational education, subordinating it to the struggling regional administrations. The latter defunded it by necessity. Seldom closed formally, vocational classes shrank quantitatively and degraded qualitatively. Schools trained fewer students, for a narrower range of vocations and at a far lower level than before.

When senior workers were dying, leaving, or retiring they rarely had the juniors to have passed their knowledge to. As a result, the continuous tradition of apprenticeship that the Soviet military industry had been based upon, was interrupted. **Much of the tacit knowledge accumulated over the generations of Soviet military production was gone**²⁵. By the time the Russian military industry started bouncing back, it had neither the labor that the Soviet production relied upon, nor the system of training, nor the skills. While some of the lost Soviet technologies were later reverse engineered, the overall capacity to conduct precision operations manually had been lost irreversibly.

A New Hope, 1997-1999

Starting from 1996-1997, the Kremlin aimed to halt the effective demilitarization ongoing since the fall of the USSR. They investigated what remained from the military industry, identified «survivors», and supported them with very limited funding and, far more importantly, export contracts²⁶. This reversal of policy happened even before Russia passed through the bottom of its economic crisis. As the resources of Yeltsin's administration were limited, fruits of their policy were limited as well. Still, they laid foundations for the future Putinist policy of military buildup²⁷. The government focused on picking the winners and providing them with funds. For the most part, this resulted in incentivizing the import-based modernization rather than any efforts to revive the Soviet manufacturing base.

By the late 1990s, **the preference of import had been established as a collective choice of the military industrial management**. In the 1990s, plants found themselves in a survival situation, being unable to maintain their Soviet base with a fraction of Soviet funding. A small minority of the most successful exporters found a solution in digitizing some of their design and production processes through the import of CNC machines and CAD/CAM software²⁸. Transition to the computer control brought an immense increase in productivity, largely compensating for the consequences of the post-Soviet collapse. In the 1990s the technological transition was primarily funded via export earnings. The resurgence of government demand in the 2000s allowed to scale this already proven model up.

Surviving through the 1990s was a pre-condition for receiving government funding in the 2000s. And surviving through the fall and decline era required an adaptation to the new socio-economic reality, including the new scale of output. **Darwinian pressures of the 1990s forced successful exporters to disproportionately allocate their resources into the CNC machining equipment**. Offering higher productivity compared with the Soviet conventional stock, it was simultaneously more advantageous for the small scale of output compared with the Soviet mode of production²⁹. Once Putin pumped money into the winners of the 1990s, their survival strategy was scaled up.

²⁵ By 2000, around 300 weaponry production technologies have been lost irreversibly. Шлыков, В. "Оборонная экономика в России и наследие структурной милитаризации." Ibid.

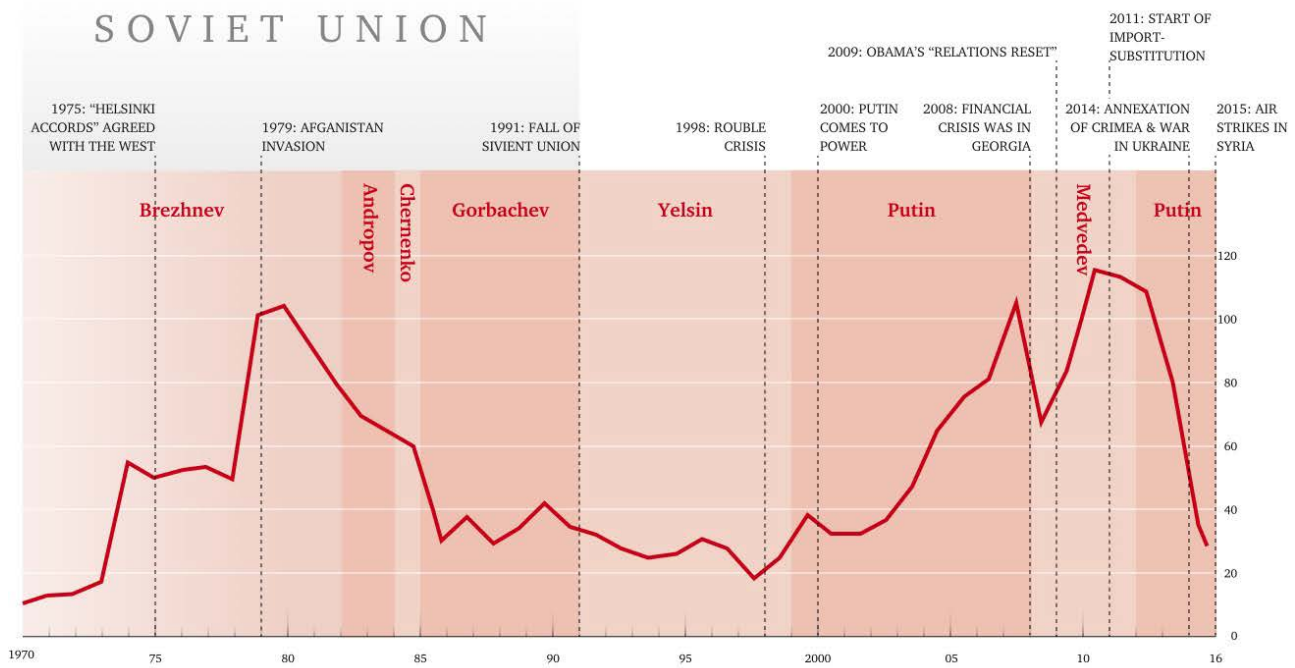
²⁶ See an OKB Novator example in Вольман В. Ракетами по стереотипам. Эксперт Урал №46 (263) 11 декабря 2006

²⁷ On the continuity between late Yeltsinist and Putinist policy of military buildup. Патрушев Николай, "На сильных не нападают", Военно-промышленный курьер, (ВПК). №12, March 26, 2013.

²⁸ It was the exporters of weaponry who pioneered transition to CAD/CAM/CNC. As foreign customers demanded the documentation to be produced in the electronic form, exporters were forced to implement the CAD software. Once they did, the massive increase in productivity would make a transition to the computer-based workflow unobjectionable. At the same time, export earnings allowed to fund the technological transition. See Теверовский Л. Опыт применения программных продуктов семейства КОМПАС при выполнении крупного контракта в сфере военно-технического сотрудничества. САПР и графика 8 (2002)

²⁹ Aiming for the gigantic volumes of output, Soviets developed a strong preference of casting and forming processes. Meanwhile, more wasteful and labor-intensive machining operations were minimized. The revolutionary progress in CNC technology changed the production economy, turning CNC into the universal tool of Russian military industry.

Figure 19. Soviet/Russian political history vs oil price

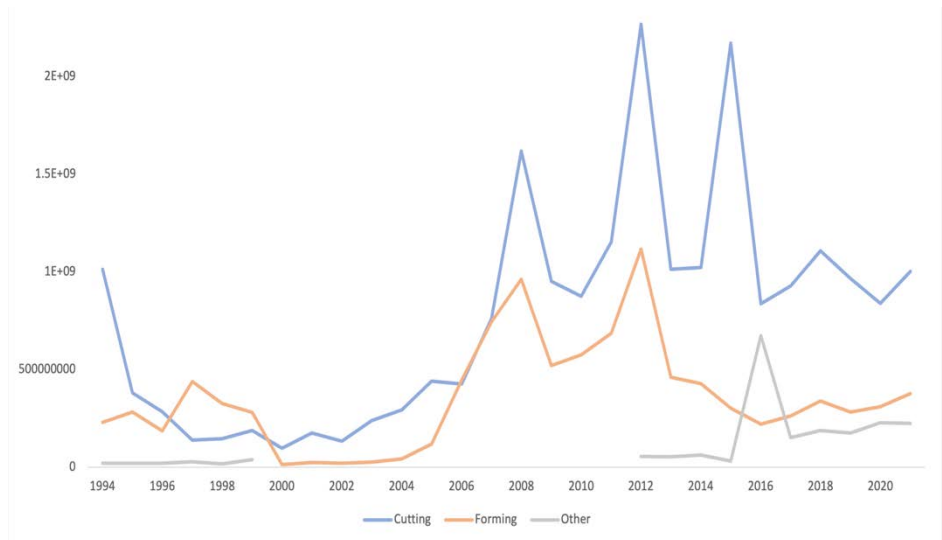


Source: BP; Thomson Reuters

Figure 20: Imports by Broad Categories, 1994-2021, Millions of USD, adjusted to 2023 value

The great cashfall of the 2000s allowed to reequip the Russian military industry with imported CNC machinery and reboot the production of sophisticated weaponry.

Source: Rhodus Intelligence based on the Federal Customs Service data



Bouncing Back, 2000

Starting from 2003, Putin brought the military industry back from the dead with the mass import of CNC equipment from the U.S. allies. **Transition to the computer control allowed Russia to reboot the production of weaponry, after having lost the Soviet human capital.** The implementation of modern CNC technology in combination with the CAD and CAM software has vastly improved productivity and consistency of the final product. Allowing to produce parts with only a minimal input of what would have been previously considered as the semi-qualified labor, CNC cutting machines became a universal instrument of the Russian military industry. Consequently, the military industrial management prioritized the replacement of its cutting equipment over almost anything else. Machining is where its resources have been disproportionately allocated.

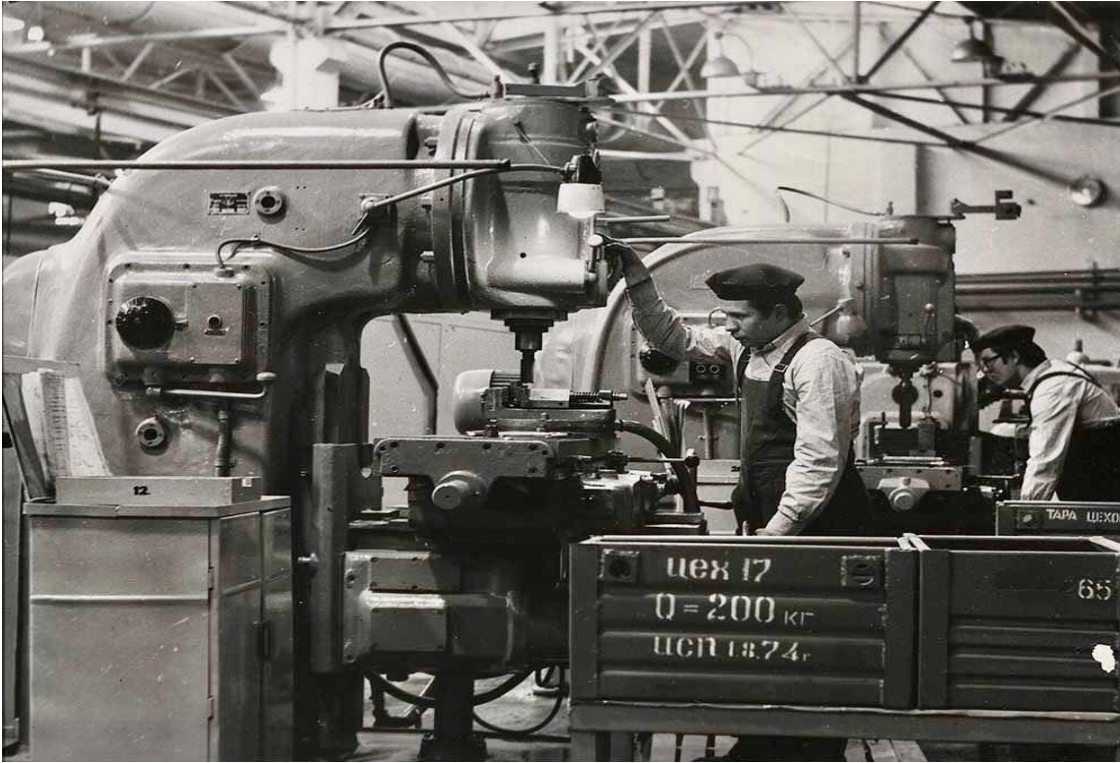
Transition to the computer control went hand in hand with the demographic change. Senior workers were sometimes allowed to operate conventional machines until their death or retirement. The juniors, however, tended to work on the CNC from the very beginning. The minimal training of a CNC operator was an order of magnitude shorter and less demanding compared with the pre-computer era. **This allowed Russia to rapidly build the workforce capable of executing the Soviet designs of weaponry precisely and consistently.** Once the computer-based workflow has been implemented, maintaining two workflows at once became increasingly difficult and counter efficient. Consequently, skills required for maintaining the paper-based flow were rapidly dying out.

Whereas the CAD/CAM/CNC workflow decreased the overall labor input, it still required a fair deal of decision making on each stage of the production process. Considering the freshness of workforce³⁰, and its uneven (generally low) quality, each personal decision presented a potential point of failure. **To minimize failure, the military industrial management had to minimize the human factor.** For this reason, the most sophisticated enterprises of Russian military industrial complex developed the overreliance upon the integrated manufacturing solutions provided by only few companies in the world. Whereas the various missiles producers have experimented with the Dassault (France), PCT (USA) and Ansys (USA) software, the Siemens solutions proved to have no parallels or competitors.

Overall, the mechatronic revolution had a double effect on the Russian military industry. On the one hand, it was the massive increase in productivity brought by digitalization that has largely compensated for the consequences of the post-Soviet collapse, allowing Russia to revive the production of weaponry. On the other hand, the disruptive change in technology widened the gap between Russia and the top global producers so far that it became unbridgeable. It is not only that that the mass import of CNC equipment became a coup de grace to what remained of the Russian machine tool industry, making Russia the most reliant upon the equipment it was the least able to produce. It is also that **the most complex and strategically important enterprises in the Russian military were caught in the single integrated solution trap.**

³⁰ For the most part, it did not inherit the Soviet technical expertise. Much of the Soviet tacit knowledge has been lost irreversibly.

Figure 21: Machining at the Kalinin Plant, 1976



Source: <https://zavodfoto.livejournal.com/5676104.html> Industrial Blogger Zavodfoto (Igor Yagubkov)

Figure 22: Machining at the Kalinin Plant, 2012



Source: "SC "Kalinin Machine-Building Plant (ZIK)": on the State Defense Order volumes". Nakanune TV, 201

Part 5. HOW IMPORT DEPENDENT IS RUSSIA?

This question may be surprisingly hard to answer. **The highly distinctive structure of the machinery market makes it difficult for the state bureaucracy to count.** For this reason, state agencies tend to publish highly uneven and highly aggregated figures that are nearly impossible for the external researchers to cross compare. For the lack of better alternative, we must resort to official self-estimates, that are available only for the post-Crimean era.

Self-estimates

Based on the Russian official self-estimates, we can describe the pre-war state of the Russian cutting machines market with the 90/90 formula:

- **Over 90% of machine tools were imported**
- **Over 90% were purchased by the military producers**

This 90/90 formula serves as the first approximation aimed to grasp two crucial characteristics of the Russian machine tool market: the nearly total import dependency, combined with the extreme level of militarization.

Over 90% import dependency (Minpromtorg)

We are unaware of any credible self-estimates of Russian import dependency for the pre-2014 period³¹. Between 2014-2016, the Ministry of Industry and Trade (Minpromtorg)³², produced the most authoritative quantitative estimates we currently have³³. It rated the **import dependency at over 90% in value** and over 60% in quantity³⁴. While almost certainly overoptimistic, these estimates serve as the best approximation available.

Table 3: Russian import dependency in machine tools (self-estimates), 2014 - 2016

	2014	2015	2016
Value	92%	92%	91%
Quantity	71%	64%	68%

What do we see?

The mass obfuscation of import by the machinery suppliers suggests that these figures must be overoptimistic. The actual level of import dependency is higher

Source: Бутов, А. М. "Рынок продукции станкостроения." М.: НИУ ВШЭ. Центр развития (2020). Р. 68

³¹ It is not implausible that Russia remained unalarmed, until its relations with the West started rapidly deteriorating.

³² Overseeing the entire «strategic» sector, including the military/dual use and the machine tool industry, the Minpromtorg serves as the most authoritative source on the Russian machine tool market.

³³ Минпромторг РФ. Приложение 1. Перечень приоритетных и критических видов продукции, услуг и программного обеспечения с точки зрения импортозамещения и национальной безопасности. (2015) С. 3-8, 16-17.

³⁴ Бутов, А. М. "Рынок продукции станкостроения." М.: НИУ ВШЭ. Центр развития (2020). Р. 68.

Over 90% military consumption (Rostec corporation)

The Rostec corporation is the largest military producer in Russia, controlling most of the aircraft, navy, and land army weaponry production. It is also a major player in the production of missiles. Back in 2013, Rostec estimated the military industry to purchase 80% of cutting machines in Russia. This estimate of the pre-Crimean era must understate the *current* share of military consumption.

Starting from 2014, the Russian manufacturing industry went through gradual militarization. Dual-use enterprises were steadily increasing the share of military output at the expense of civilian one. Consequently, they were stocking up with military production-oriented equipment, primarily with cutting machines.

2014 - Early 2022. Partial mobilization

Military producers routinely outsource forming and casting to the civilian industry. Cutting processes though are very rarely outsourced to civilians.

In the second half of 2022, the manufacturing sector was effectively mobilized. First, the dual use enterprises cut their civilian output even further, focusing on the military production. Second, the military producers have been increasingly outsourcing an increasingly broad range of production processes to the supposedly civilian industry.

Mid 2022 – till now. Full mobilization

All metalworking processes, including the cutting are increasingly outsourced to the civilian producers.

Therefore, we can conservatively estimate that between 2014-2021 era the military industry counted for 90% of the machine tools purchases. With the start of the Special Operation and the subsequent mobilization of the Russian industry, **the share of military consumption must have risen to almost 100%**. At this point we can safely assume that any metal-cutting machine, component or expendable shipped to or produced in Russia can and will be used for the purposes of military production.

Part 6. THE RUSSIAN MACHINE TOOL INDUSTRY

The Soviet Union had a very large machine tools industry of a very uneven quality³⁵. Starting from the late 1960s, **the mechatronic revolution was turning the Soviet machine tools industry increasingly obsolete** and the military industry increasingly reliant upon the high-end Western machinery. In the mid-1980s, the USSR made its final attempt to close the technological gap with the leading global producers³⁶ prioritizing development of the domestic CNC industry³⁷. At its peak in 1989 Soviets produced about 17 800 metal-cutting and 2 500 forming CNC machine tools per year making the USSR the largest producer of the (low-end) digital control tools in the world. Technology transfer, largely through the establishment of joint ventures contributed to the qualitative improvement of Soviet manufacture.

With the fall of the USSR in 1991, Russia lost its machine tool industry. As the manufacturing output including the output of weaponry dropped, demand on the machine tools collapsed accordingly. The machine tool production crashed quantitatively and primitivized qualitatively, while the production of quality machine components largely ceased to exist³⁸. The innovative CNC industry suffered disproportionately, with the CNC machine producers either ceasing production at all or switching back to manufacturing obsolete (but cheap) conventional tools³⁹. If the aggregate output of cutting machines decreased by almost 9 times between 1991 and 1999, **production of CNC machines dropped by more than 1200 times.**

In 2000, Putin came to power. Starting from 2003, Russia received the greatest and the most uninterrupted cash fall in its contemporary history. The subsequent increase in military expenditures and, therefore, in the production of weaponry revived the domestic machine tool market. Counterintuitively, **the rise in demand did not increase the domestic production of machine tools.** To the contrary, domestic output continued to shrink. By the late 1990s, the preference of import had already been established as a collective choice of the military industrial executives. In the 2000s their preference was effectively endorsed by the political leadership⁴⁰. Once the financial constraints were loosened, the military industry outsourced production industrial equipment to the West almost fully.

Dynamics of machine tool sub-industries have been largely determined by the disruptive effect of mechatronic revolution. As their survivability relied on exploiting the Soviet legacy, **technological disruption resulted in economic destruction.** Since transition to computer control affected forming processes less, the pressing/forging equipment industry fared relatively better. In contrast, the cutting machines production was wiped out almost completely. Its remnants survived in a few economic

³⁵ Most studies underestimate the Soviet output which probably was the largest in the world. See The UNIDO Secretariat (1991): The World Machine-Tool Industry – Background paper, United Nations Development Organisation. P. 65.

³⁶ National Foreign Assessment Center (US). Soviet Economy in a Time of Change: A Compendium of Papers. US Government Printing Office, 1979. P. 562-563, 568, 574, 577-578.

³⁷ See: CIA Intelligence Assessment. The 27th CPSU Congress: Gorbachev's Unfinished Business.

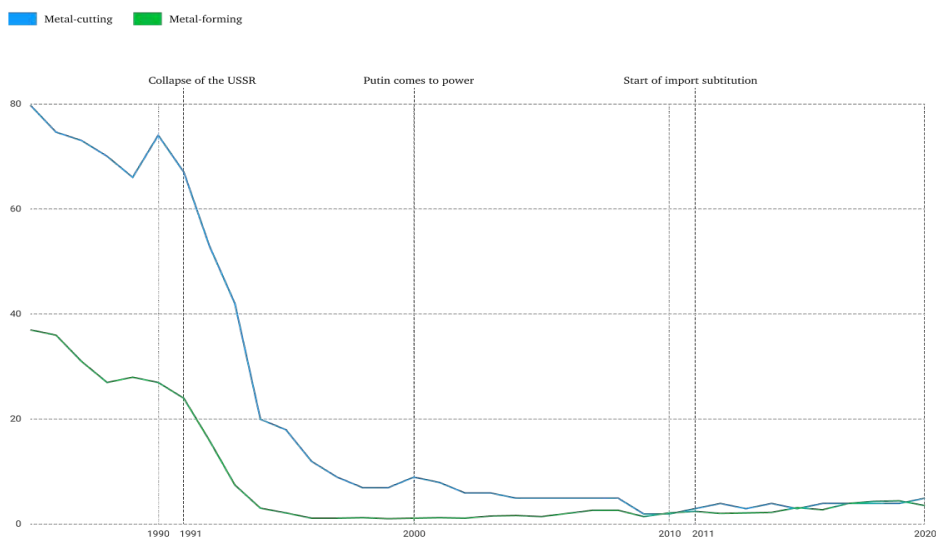
³⁸ As the domestic production of machine components was lost, the Russian machine tool industry was reduced to assembly from the imported parts. See: Ткаченко С. С. О стратегии развития отечественного станкостроения до 2030 г. с позиции заготовительного производства // «Литейное производство». №5/2019. С. 3.

³⁹ The Moscow Machine Tool Building Plant «Red Proletarian» is an example of a producer that chose to consciously primitivize its output. In 1991, they ceased production of the digital control machines, focusing on conventional tools instead See http://stanki-katalog.ru/st_krprolet.htm

⁴⁰ See Паничев, Н. А. "Эра болтунов. Власть сама разрушает свое будущее-отечественное станкостроение." Аргументы Недели. Общество. № 33(274), 2011.

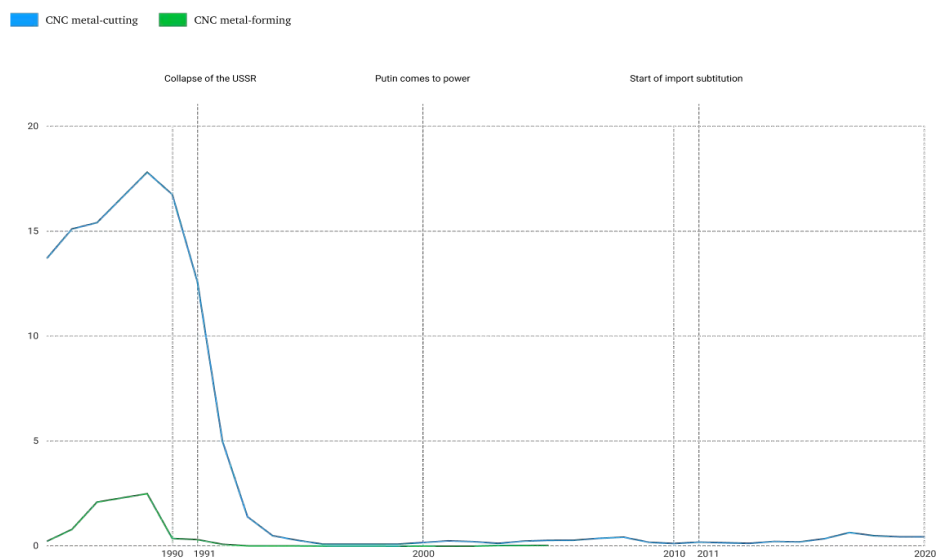
niches, including the distribution and maintenance of the imported equipment, as well as the maintenance and modernization of Soviet-era stock. In exceedingly rare cases they retained capacity for assembling high-end machines customized for specific needs of individual customers. This business model, however, was impossible to scale up⁴¹.

Figure 23: Manufacture of metal-cutting and metal-forming machine tools in Russia, 1985-2020 (thousands)



Source: Rhodus Intelligence calculations based on Rosstat data.

Figure 24: Manufacture of CNC metal-cutting and metal-forming machine tools in Russia, 1985-2020 (thousands)

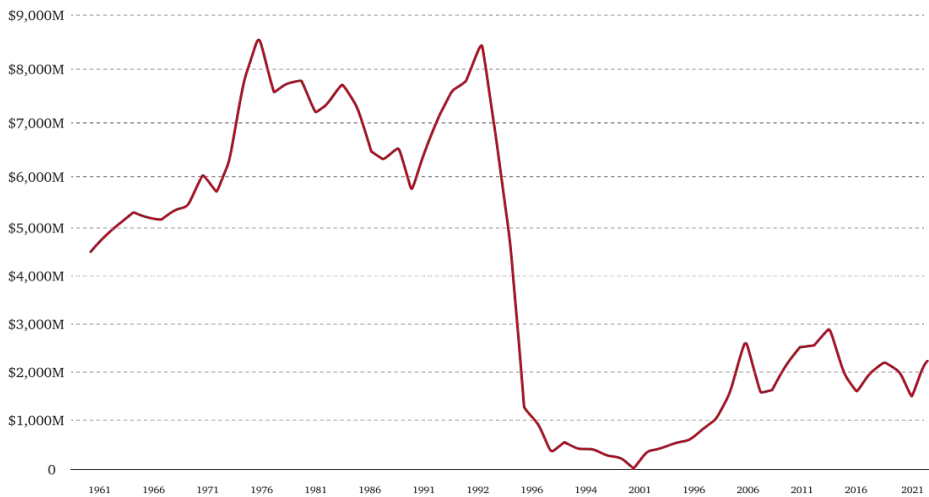


The machine tool output crashed quantitatively and primitivized qualitatively. The innovative CNC machines productions virtually ceased to exist

Source: Rhodus Intelligence calculations based on Rosstat data.

⁴¹By 2009, the Sterlitamak Machine Building Plant was the only Russian enterprise capable of manufacturing the sophisticated 5-axes tools. Its business model was based on assembling the customized high-end machines from the imported (mostly European) mechatronic elements. Our investigation confirms the relative popularity of its manufacture within a relatively narrow niche of the ad hoc cutting equipment for the missiles/aerospace industry.

Figure 24: Real machine tool consumption in USSR/Russia, 1961-2021



Source: Gardner Intelligence. The World Machine Tool Survey, 2021

What do we see?

1990s as the demand on machine tools drops to nearly zero, production collapses as well

2000s demand bounces back, but the production continues to shrink.

It was only after the Russian-Georgian war of 2008 that the political leadership became first concerned about the exorbitant import dependency. Starting from 2011, authorities launched the import-substitution policy aimed to increase the output of metal-cutting equipment. Its rationales were strategic, rather than economic. The asymmetric disruptive effect of technological transition created a mismatch between what the domestic military industry needed and what the domestic machine tool industry could produce. It was the **mismatch between the military demand and the domestic supply** in machine tools that the policy aimed to address. Consequently, it was almost exclusively focused on fostering the production of CNC cutting machines for the military industrial complex.

In practice, the import substitution policy resulted primarily in the **obfuscation rather than substitution of import**. Before 2011, producers and distributors of foreign-made equipment had little motivation to mystify its origins. As a result of the new incentives, the intermediary link started either producing machinery in Russia or (a more common case) portraying its import/screwdriver assembly as the domestic manufacture⁴². The effective distributors framing themselves as «domestic producers» became a stable strategy on the post-2011 market. As the government regulations grew increasingly strict and unenforceable, supply chain of the Russian military industry was increasingly obfuscated – to comply with the impossible demands of the state.

In 2023, domestic production of machine tools is small in quantity and limited in the range of equipment produced. **The thinly veiled import makes for most of the declared domestic output, especially in the high-end sector**. Domestic production of critical parts is (with few exceptions) nonexistent. Most of the spare parts and consumables supply comes from the US allies in Western Europe and East Asia with limited possibility to substitute them with the Chinese manufacture. Production of tooling and expendables exists, yet it is insufficient and heavily dependent upon the imported machinery and spare parts.

⁴² Through the 2010s a few established foreign suppliers chose to localize their production in Russia. Examples include the DMG Mori AG, TOS Varnsdorf, Kovosvit MAS, EMCO, and Okuma, all of them well represented in the Russian missiles industry. With the single exception of the DMG Mori, their production can qualify as the screwdriver assembly. Unlike the foreign localizers or pseudolocalizers, Russian domestic machine tool brands such as Stan or BPK have almost no representation at the missiles producing plants.

Pre-2011. **Unobfuscated supply chain**

Foreign machinery producer -> Russia-based importer -> Russian military producer.

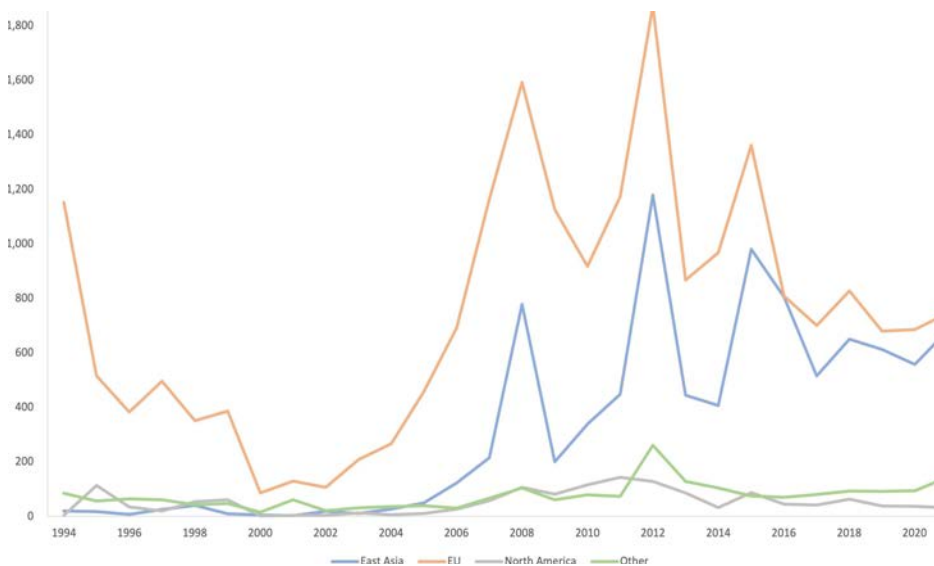
Post-2011. **Obfuscated supply chain**

Foreign machinery producer -> Russia-based importer/producer/pseudo-producer -> Russian military producer.

For the practical purposes of sanction policy, there is no reason to distinguish between producers, distributors and pseudo-producers. All must be regarded as an intermediary link in the military industry's supply chain.

Part 7. WHO SELLS MACHINE TOOLS TO RUSSIA?

Figure 24: Equipment imports in 1994-2021, Millions of USD, inflation adjusted to 2023



Source: Rhodus Intelligence calculations based on the Federal Customs Service data

Short answer:

As Russia lost its machine tool industry, its production of manufacturing equipment was outsourced abroad. In the 2000s, Western Europe was an almost non-alternative supplier, especially in the high-end sector. Starting from the 2010s, the gradual improvement of East Asia allowed Russia to partially diversify its supply chains. By the end of decade, the East Asian supplies almost equaled the Western European ones, at least quantitatively. Still, the qualitative gap persists. If the Taiwanese and South Korean production was deemed as sufficiently good by circa 2014, Chinese manufacture had been largely undesirable until 2022. As China has limited capacity to satisfy the demand of the Russian military production, the import from the U.S. allies plays the key role in keeping the Russian military production afloat.

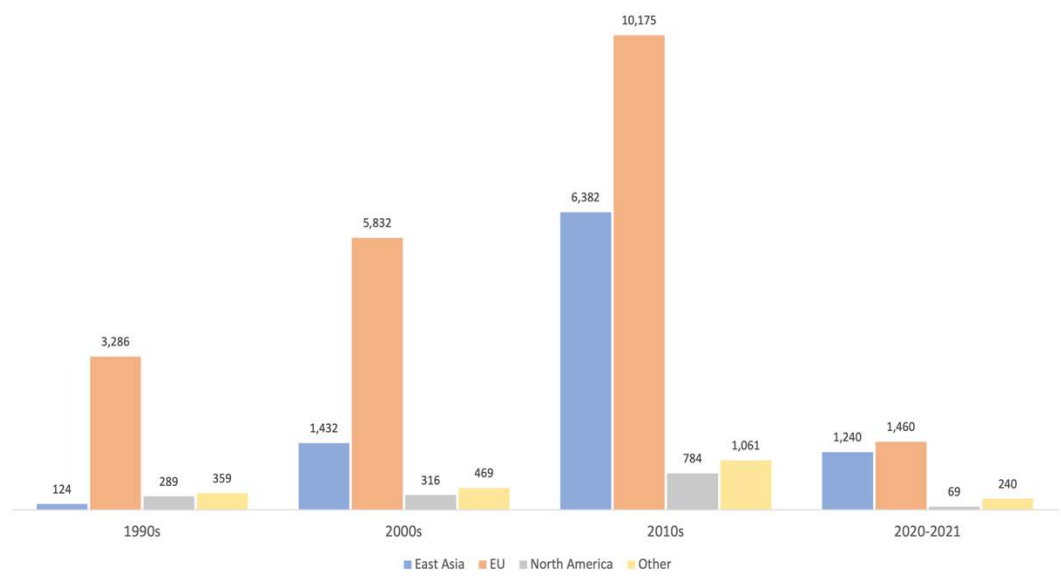
Long answer:

The Soviet collapse of 1991 destroyed the Russian demand for machine tools. Still, large shipments from Western Europe pre-ordered in the Soviet era continued coming to Russia for years. The manufacturing industry and its supply chains being in havoc, shipments would seldom reach their intended customers and find them in functional state. Machine tool imports of the early to mid 1990s appear to be largely lost, stolen or a mix of both. We have little evidence of the Russian missile producers replacing their equipment until 1997 when a handful of the most successful enterprises commenced their import-based modernization. Overall, the **missile industry operates with a mix of the pre-1991 and post-2003 purchases**. There is almost nothing in between.

Through the 2000s, the lion share of Russian imports came from Western Europe, most importantly Germany. **It was the European CNC equipment that compensated for the loss in Soviet craftsmanship**. The role of North America was minor, although the gradual lifting of the US export restrictions may have contributed to its gradual growth. More importantly, the 2000s saw a steady

rise of East Asia. In the Soviet era, Japan was the only substantial non-Western supplier. By the 2000s flying geese of Taiwan and South Korea advanced far enough to rival, at least in the low-end sector. Nevertheless, the Tigers could not really challenge the Western European and Japanese monopoly on the high-end equipment until the next decade.

Figure 25: Regional imports by decade, Millions of USD, adjusted to 2023 value

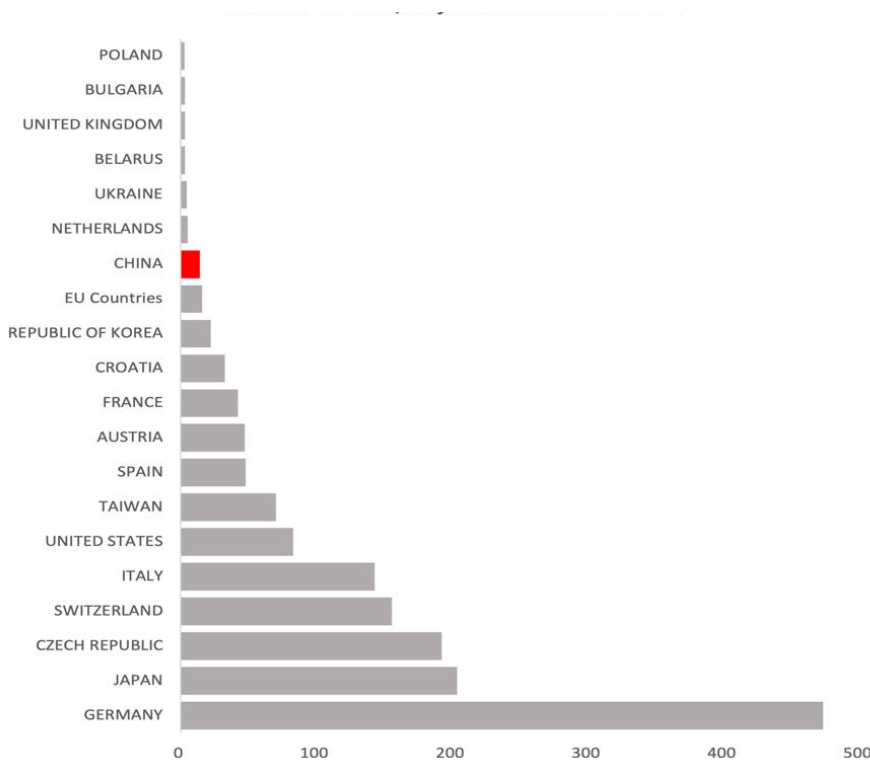


Source: Rhodus Intelligence calculations based on the Federal Customs Service data

Starting from the 2010s, the newly industrialized East Asia increased its share on the Russian market. In the post-Crimean era, the Taiwanese and South Korean machinery was considered as politically preferential and (often) sufficiently good. This combination of political and technological rationales turned it into an acceptable second choice for the Russian missile producers. The 2015 Minpromtorg estimates (see Appendix 3) reflect the growing role of Tigers in the post 2014 era. Our investigation demonstrates the wide use of the Taiwanese and to a lesser degree Korean machinery on the Russian missile plants. Starting from 2022, the role of Tigers has only increased, although they are still considered as somewhat subpar producers compared with Europe and Japan.

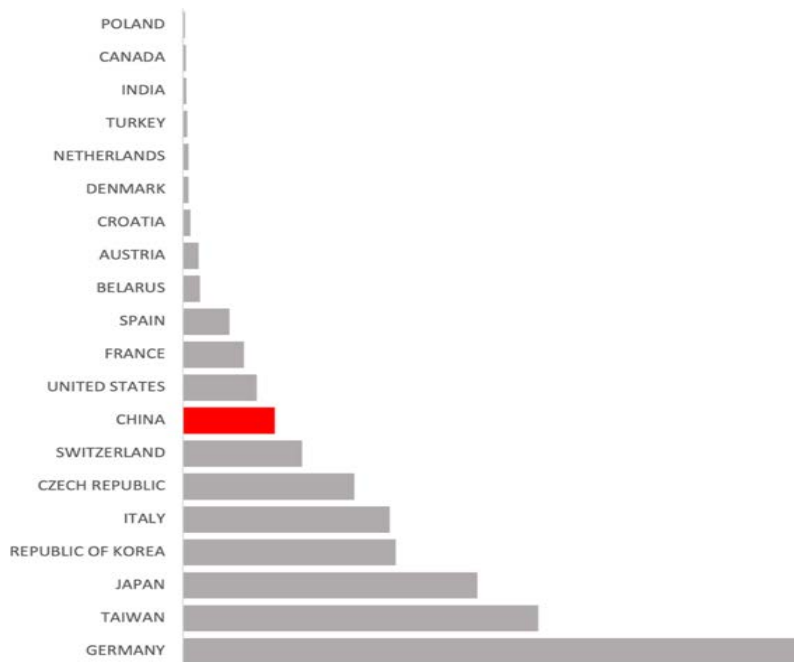
In contrast to Taiwan and South Korea, China has been seen as an undesirable supplier. First, it was rarely capable of meeting the Russian demand for precision metalworking equipment of consistent quality. Second, it appears that the Russian military plants avoided using Chinese machinery even when the Chinese alternative existed. The deliberate semi-exclusion of China would explain the **almost complete invisibility of Chinese machine tools in the Russian missiles industry**. It was only with the start of the Special Operation, that the use of Chinese machine tool brands was normalized. Still, China remains a last choice supplier in the high-end sector, the Russian military producers seeking to secure Western European and Japanese, or at least Taiwanese and Korean production whenever possible.

Figure 26: Top 20 Suppliers in 2000-2010 for machining centers, Millions of USD, adjusted to 2023 value



Source: Rhodus Intelligence calculations based on the Federal Customs Service data

Figure 27: Top 20 Suppliers in 2011-2021 for machining centers, Millions of USD, adjusted to 2023 value



Source: Rhodus Intelligence calculations based on the Federal Customs Service data

Part 8. WHAT WE DID

The Rhodus Intelligence team has investigated 28 ballistic, cruise, anti-ship and air defense missiles producers belonging to or associated with the four corporations of Roscosmos, JSC Tactical Missiles Corporation, JSC Almaz-Antey and Rostec. Based on a broad range of documental, visual, and narrative sources, **we have been able to reconstruct a representative picture of the manufacturing base supporting the Russian nuclear/nonnuclear deterrence system.** We have been able to identify the equipment the missile producers operate with, the composition and qualifications of their workforce, as well as the structural patterns of their supply chains. Identifying the bottlenecks and the chokepoints of the missiles production, our investigation allows for the more efficient targeting of sanctions.

The methodology and the instruments we have developed enables more practical implementation of sanctions. Based on the full database of the military industry's public procurements for 2011-2022 we compiled, authorities, media and independent investigators will be able to **track the specific supply chains of the missiles industry.** Our database will serve as a publicly available instrument for monitoring purchases of equipment, parts and expendables by the missiles' producers and identifying their suppliers, domestic and international. Moreover, as it includes data on the missiles producers outsourcing their production operations, the database allows to track and target the entire production chain involved in the missiles production, including its supposedly civilian part.

Scope of investigation:

Roscosmos: JSC Titan-Barrikady, JSC Votkinsk Machine Building Plant, JSC Zlatoust Machine-Building Plant, JSC Miass Machine-Building Plant, JSC Krasnoyarsk Machine Building Plant

Almaz-Antey: JSC Obukhov State Plant, JSC MMZ Avangard, PJSC OKB-Novator, JSC Kalinin Machine-Building Plant, JSC IEMZ Kupol, JSC Design Bureau KB-1 (Socium)

Tactical Missiles: JSC NPO Mashinostroyeniya, JSC UNIKM, JSC PZ Mashinostroitel, JSC NPO of Electromechanics, JSC Avangard, JSC PA Strela, JSC GosMKB Raduga, JSC Tactical Missiles Corporation (Head Plant)

Rostec: JSC KB Mashinostroyeniya, JSC ODK Saturn

Investigation Process

Although the Russian strategic missiles industry operates under the regime of secrecy, secrecy considerations come into conflict with other rationales requiring a producer itself, its counteragents, or the state to disclose potentially sensitive information to the public rather than to hide it.

First, it is the *propaganda needs*. The military buildup is the major source of national pride and, therefore, of the regime's legitimacy. Consequently, authorities and producers themselves feel pressured to convey the picture of well-equipped, modernized military industry to the general audience. This makes the federal and regional TV channels, as well as the social media the principal source of visual evidence on the Russian military production.

Second, it is the *market needs*. Since the fall of the USSR, the military industry has been directly engaged in the competitive market, both as a seller and as a buyer. Whereas higher secrecy plants can be selective about the information they publish themselves, they are not always capable of censoring what their counteragents, including their employees, suppliers or service companies chose to publish.

Third, it is the *accountability needs*. The military plants' direct engagement into the market exacerbated the pre-existing principal-agent problem in relations between the state and the state-owned military enterprises. Aiming to check the managerial corruption, the state developed an extensive and transparent system of public procurements. As it developed, it became an invaluable tool both for the state controllers and for our investigation.

1. Propaganda

Sources: *Federal and regional TV channels, Military producers' corporate and social media*

Translating an image of the productive, up-to-date military industry (contrasting with the desolation of Yeltsin's era) is of major importance both for the central government and for the military producers. Much of Putin's legitimacy is based on reviving the Russian hard power after the fall and decline of the 1990s. This makes the military industrial buildup a regular theme on the Russian **federal and regional TV channels**. Some of the more common topics include a) a big boss visiting a military plant b) a plant's modernization c) a specific model of weaponry produced by a plant. All of them provide abundant visual material on the military industry's manufacturing equipment and the production lines.

Figure 28: The Russian Minister for Industry and Trade Denis Manturov inspects Titan-Barrikady



Source: [Глава Минпромторга осмотрел «Красный Октябрь» и «Титан-Баррикады»](#) 0:38

On the background, you see an Italian machining center «Shark». Volgograd Municipal TV. October 2022

If the official propaganda aims to confer legitimacy to the regime, individual missile producers primarily aim to advertise themselves. This may be especially important in the context of the loss in status they suffered through the 1990s. Seeking publicity and prestige, they self-represent themselves in the corporate⁴³ and social media. This includes printed magazines, online blogs, social media pages and video channels run by or associated with the missile producers. These sources provide unusually rich visuals and narratives on their operations. Aimed at a far narrower audience, these self-advertisement materials tend to be lengthier, more informative and supplemented with a higher quality technical commentary.

Figure 29: Machining at The «Votkinsk Plant»



Source: https://vk.com/video-199960779_456239137

2:38

The «Votkinsk Plant» movie posted at the Votkinsk Plant official social media page. 9 minutes 55 seconds long, it includes extensive footage from the production facilities. Foreground: Kovosvit MAS (Czechia) machining centers. Background: Tos Varnsdorf (Czechia) milling boring machines.

One major advantage of the propaganda-related sources is that they give us an insight into what purpose does the equipment serve for. The connection between a specific machine and the production of a specific weaponry may be difficult to impossible to establish other than based on visuals. Either the narrative sources or the documentation rarely specifies that a particular machine or an instrument is used to manufacture a particular weaponry. Visuals from the production sites allow us to confirm it with certainty. And most of the visuals we have are propaganda related.

⁴³ Self-advertisement can be also conducted via the professional magazines. It is noteworthy that the Tactical Missiles Corporation relatively bypassed by the media attention is issuing the most informative and detailed magazines in the entire missiles industry

Figure 30: Iskander 9M723 ballistic missile on the factory floor at the KBM (Kolomna)



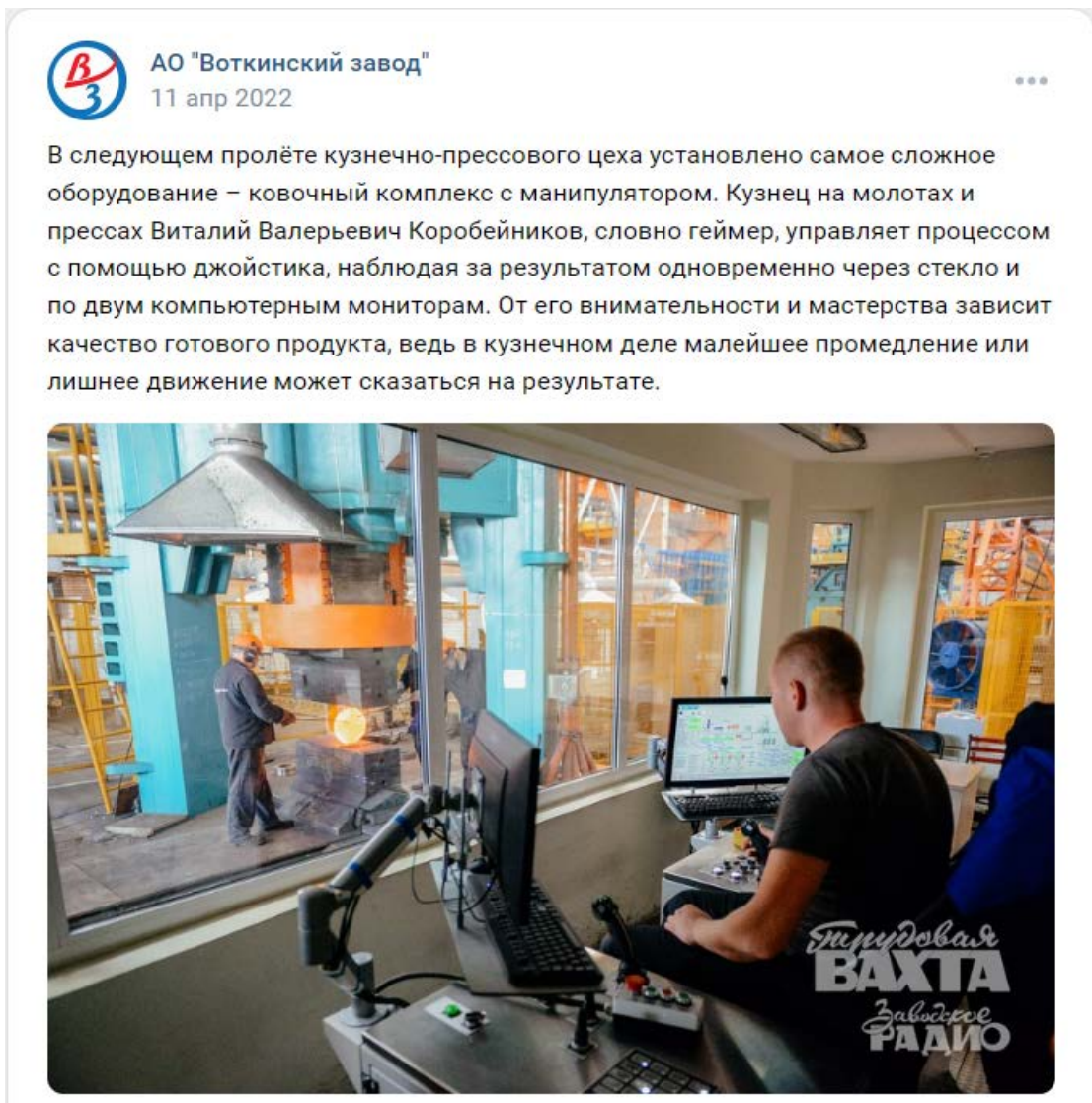
Source: <https://rutube.ru/video/9d58d38a88740a2989127ebdb308d894/>

On the background you see a Tos Varnsdorf (Czechia) machine framed as the Russian «domestic production». The Russian Ministry of Defense TV Channel «Zvezda», October 2022

Propaganda-related visuals allow us to see the equipment not reflected in other types of sources. For example, equipment acquired via the classified procurement system (ACT Г03), equipment acquired via the non-competitive procedures, or the equipment purchased before the early 2010s⁴⁴ is not reflected in the publicly available procurements that most OSINT investigations are based upon. This makes it effectively invisible for most investigators. Based on the propaganda sources, we can get insight both into the pre-2011 purchases and to the purchases of post-2011 era conducted via a classified procedure or non-competitively.

⁴⁴ The centralized system of public procurements has not been released until 2011 and it took until mid to late 2010s for it to cover most of the military industry.

Figure 31: Factory floor at the Votkinsk Plant



Source: The Votkinsk Plant official social media page https://vk.com/wall-199960779_4755

Danieli Breda CNC forging press (Italy) at the Votkinsk Plant. Aiming for self-advertisement, this ICBM producer provided us with the only proof of this high-tech [equipment](#) being used at its new forging facility.

Finally, propaganda sources shed light on the secrecy regime in the Russian missile industry. Both the state and the military producers must constantly find the balance between the considerations of secrecy and those of prestige. Based on where they draw the line, we can identify what equipment, processes and facilities they aim to hide. Based on how they redefine this balance with time, we can track the evolution of the secrecy regime in the Russian military industrial complex. Finally, based on which enterprises avoid publishing visuals, we can identify the more secretive weaponry producers in Russia⁴⁵.

⁴⁵ Especially producers of long-range cruise missiles. OKB Novator, GosMKB Raduga, KB Mashinostroyeniha (Kolomna)

In short, propaganda shows us what equipment is there⁴⁶...

Figure 30: Trumpf (Germany)⁴⁷



Source: <http://eurasian-defence.ru/?q=node/29046>

Figure 30: Hermle (Germany)



Source: <http://eurasian-defence.ru/?q=node/29046>

Figure 32: LVD (Belgium)⁵⁰



Source: <https://saidpvo.livejournal.com/174706.html>

Figure 31: Deckel Maho⁴⁸ (Germany)⁴⁹



Source: <http://eurasian-defence.ru/?q=node/29046>

Figure 31: Tos Varnsdorf (Czechia)



Source: <http://eurasian-defence.ru/?q=node/29046>

Figure 33: LVD (Belgium)⁵¹



Source: <https://saidpvo.livejournal.com/174706.html>

⁴⁶ Obukhov Plant, Almaz-Antey corporation.

⁴⁷ TruMatic [6000](#) punch laser machine

⁴⁸ Now part of the DMG Mori AG

⁴⁹ DMU 125 duoBLOCK 5-axes machining center

⁵⁰ LVD Axel 015 laser cutting machine

⁵¹ LVD MVS 3100 x 16 mm hydraulic shear

... and what it is being used for

Figure 34: Tos Varnsdorf (Czechia) machine tool⁵² milling an erector



Source: the Obukhov Plant, Almaz-Antey <https://saidpvo.livejournal.com/174706.html>

Figure 35: S400 missile defense complex



Source: the Obukhov Plant, Almaz-Antey <https://saidpvo.livejournal.com/174706.html>

⁵² This is probably a WRD 170Q horizontal boring mill (Tos Varnsdorf, Czechia)

2. Market Sources

Sources: *Vacancy listings, Resumes, Corporate reports, Counteragent companies' reports*

The missiles producers are heavily integrated into the competitive market relations. They sell and they buy. They sell their manufacture to the state, to the foreign and domestic purchasers. They buy the production equipment, raw materials and weaponry components. They outsource their machining, forging, casting, and other production processes to each other and to the civilian sector. They hire labor. Optimizing for the market competition, both missile producers and their counteragents have been regularly disclosing potentially sensitive information online. All of this made the strict secrecy regime impossible to enforce.

It is the missiles producers themselves who have been a major source of leaks. Most publish meaningful information online to facilitate their economic activities. To attract suppliers they publish **tenders**, to attract the (foreign) customers they publish **corporate reports**. It is no coincidence that the most export-oriented missile producers tend to be simultaneously the most transparent ones. As the industry could sell weapons to the foreign governments at a significantly higher profit margin than to its own, competitive producers aimed to maximize the exports, even at the expense of secrecy. Finding customers abroad has always been more lucrative than working for the State Defense Order.

Some of the more classified producers avoid disclosing sensitive information to the public. Still, they are rarely capable of controlling what their counteragents chose to publish. The hardware companies, repairing and modernizing equipment as well as the IT companies implementing the software have been publishing **reports** on their activities. Some of them even chose to use the footage or the data in their **advertisements** and **commercials**. Finally, suppliers of equipment and parts could be less discreet than their clients. It is the counteragents rather than the missile producers themselves that produced some of the most informative sources on the Russian missile industry's manufacturing base.

The military industry operates in a competitive job market. Producers compete for workers; workers compete for jobs. Companies post **vacancies**⁵³, describing their generalized expectations of labor⁵⁴. Employees (including executives) publish **resumes**, describe their individual qualifications and history⁵⁵. Combined altogether, HR sources produce a comprehensive picture of the Russian military industrial labor, its strengths and weaknesses. They also indirectly produce a representative picture of the military industry's machine tool park, the hardware and software solutions implemented.

Finally, it is the professional community that produces some of the most informative sources on the military production. Aiming to get the collegial recognition, executives and engineers share their experiences in the **professional magazines** and websites. They publish **academic papers** and **dissertations**. Professional **forums** allow us to see the production process from a technician's perspective. Machinists, setup operators, technologists consult each other, describing problems they face and sharing their solutions. Much like the IT forums, military industrial forums serve as a major platform of professional communication, and education.

⁵³ Most common sites include corporation websites, enterprises' websites and the HeadHunter vacancy listing website.

⁵⁴ Including their qualification, education, work experience and skills. They also specify the paygrade.

⁵⁵ This makes job search websites such as the SuperJob.ru a major source of information on the most classified enterprises of the Russian military industrial complex. While the high secrecy enterprises can publish the uninformative vacancy listings, their employees are typically less discreet.

Our open-source database compiles such resumes and vacancy listings postings for the entire Russian missile production industry.

Figure 36: Vacancy listing of CNC Operator at Obhukhov Plant (Almaz-Antey)

A prospective CNC operator may be expected to work on:

Carousel lathe: SPV (Czechia)
Lathes: MASTURN (Kovosvit MAS, Czechia), DUS-400 (VDF Boehringer, Germany)
Turning-milling: NG-200 (VDF Boehringer, Germany)
Milling: DMC-160 (VDF Boehringer, Germany), MAG (Germany), Mikron (probably Switzerland), SPV (Czechia)

Source: <https://www.goz.ru/vakansii/>

363-95-55, 363-96-70, 363-91-73.

Присылайте свое резюме по e-mail: goz.ru@goz.ru В поле «subject» письма необходимо указать название вакансии. Отправляя свое резюме, Вы соглашаетесь на обработку и проверку Ваших персональных данных. Также, Вы можете прислать Ваше резюме, заполнив форму: [+](#)

Условия:

- официальное оформление в соответствии с действующим трудовым законодательством;
- выплата заработной платы два раза в месяц, без задержек;
- начисление 13 заработной платы (ежегодная поощрительная премия);
- бесплатное дополнительное медицинское обслуживание, наличие своего медицинского центра на территории завода;
- наличие своего спорткомплекса с бассейном для работников и их семей;
- дополнительные стимулирующие выплаты, специальные социальные программы.

Звонить с 8.00 до 12.00 или с 13.30 до 16.00
ТЕЛ. 363-95-55, 363-96-70, 363-91-73

СОБЕСЕДОВАНИЕ по рабочим дням в 9.00 по адресу: ст. метро. Пролетарская, пр. Обуховской обороны 120 (главная проходная Обуховского завода) 1 этаж 125 кабинет.
На электронных картах - проспект Обуховской Обороны, 120с13

С собой ОБЯЗАТЕЛЬНО иметь паспорт, трудовую книжку (либо ее копию), документ об образовании, документы воинского учета.

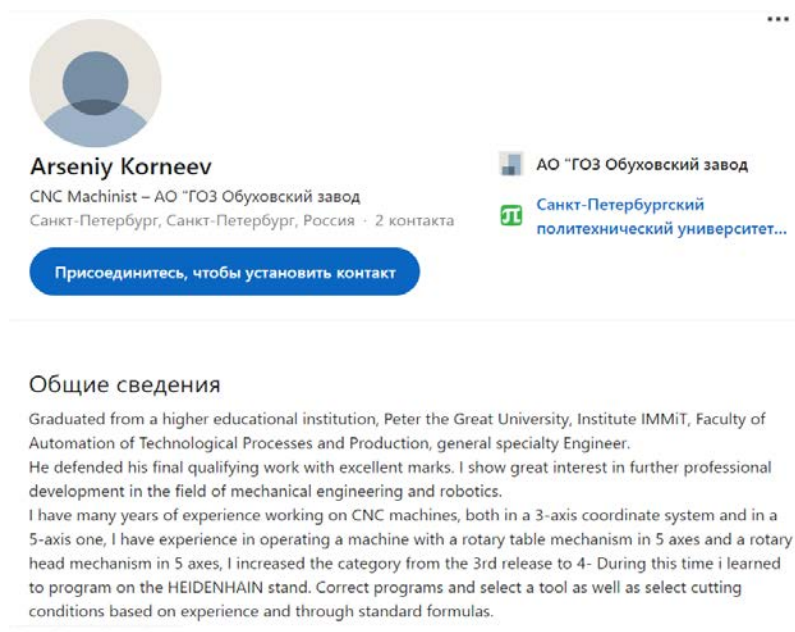
ВАКАНСИИ

Оператор станков с ЧПУ (от 110 000 руб.)
График сменный 3/3 по 12 часов с ночными

Обязанности:
ведение процесса обработки с пульта управления сложных деталей на станках с ПУ (обрабатывающие центры фрезерной группы 3-5 координат: токарные и карусельные станки);
подбор инструмента;
перечень станков на которых возможна работа:
- Карусельный: SPV
- Токарные: MASTURN ; DUS-400
- Токарно-фрезерная NG-200;
- Фрезерные DMC-160 ; MAG; Mikron, SPV

Требования:
подтвержденный опыт работы на аналогичном оборудовании;
чтение машиностроительных чертежей;

Figure 36: LinkedIn page of an Obukhov Plant CNC machinist



Arseniy Korneev
CNC Machinist – АО "ГОЗ Обуховский завод
Санкт-Петербург, Санкт-Петербург, Россия · 2 контакта

Присоединитесь, чтобы установить контакт

АО "ГОЗ Обуховский завод
Санкт-Петербургский политехнический университет...

Общие сведения
Graduated from a higher educational institution, Peter the Great University, Institute IMMiT, Faculty of Automation of Technological Processes and Production, general specialty Engineer.
He defended his final qualifying work with excellent marks. I show great interest in further professional development in the field of mechanical engineering and robotics.
I have many years of experience working on CNC machines, both in a 3-axis coordinate system and in a 5-axis one, I have experience in operating a machine with a rotary table mechanism in 5 axes and a rotary head mechanism in 5 axes, I increased the category from the 3rd release to 4- During this time i learned to program on the HEIDENHAIN stand. Correct programs and select a tool as well as select cutting conditions based on experience and through standard formulas.

What do we see?

This Obukhov Plant CNC machinist indicates that while working at the Obukhov he learned to work with 3-axis and 5-axis machine tools, rotary tables and mechanisms. Specifically, he learnt to program on one of three most common CNC types in the Russian military industry (Heidenhain)

Source https://www.linkedin.com/authwall?trk=bf&trkInfo=AQEgy01telMNCwAAAYzWRSIQ3jq0Zs-9qy9SADOFBfuNpWfUSZmQCaEEU3saBjn9dN9iPitL-GWmnLrE8rSVDGZI35WL-u1Wdz4WBBaHclza805jke9yNjrmF82DPZMMXF48Ncg=&original_referer=&sessionRedirect=https%3A%2F%2Fru.linkedin.com%2Farseniy-korneev-697704199963Ftrk%63Dpeople_directory

3. Accountability

Sources: *Public tender platforms, Unified information system (2011 – till now)*

The Russian state-owned enterprises engaging into the market relations exacerbated the pre-existing principal-agent problem in their relations with the state. The non-transparency of their economic activities allowed executives to plunder the enterprises, funneling the money from the state-owned to the privately-owned legal entities. Buying goods and services from the private companies at the inflated price was one of the easier and more common ways to plunder the government property. Aiming to check the managerial corruption and to align their economic activities with the broader policies of the state, authorities started looking for the new regulatory approaches.

In the 2000s, the government directed much of its oil revenues into the military buildup. Consequently, it needed to force the executives to buy from the lowest, rather than from the highest bidder. And yet, the early attempts for it were largely unsuccessful. Many or most tenders of the 2000s still proceeding in paper form, they are hardly transparent either to the state controllers, or to the OSINTers. Furthermore, as the early digital procurements of the 2000s⁵⁶ were scattered around thousands of websites (now often defunct), they are difficult to impossible to find and to aggregate. When it comes to the purchases of production equipment, everything acquired before 2011 is now largely covered by the fog of war.

2011 was the turning point. **The legislative amendments coming into effect in 2011 turned the public procurements into a mass and aggregable source.** Their form was standardized, the list of the platforms to post procurements was determined. Most importantly, all the procurements had to be registered in the state-managed Unified Information System (EIC). This effectively allowed to track, analyze and aggregate them. While the pre-2011 purchases are covered with the fog of war, post-2011 procurements are becoming transparent. Starting from 2011, a series of legislative and executives.

Moreover, whereas previously the public procurements system extended only to public bodies, such as the federal, regional and municipal authorities, now it included a specific category of the state-owned enterprises (unitary enterprises) as well. With the new legislative acts and executive orders coming into effect through the subsequent years, by the mid to late 2010s the bulk of the Russian military manufacturing included into the public procurements system.

⁵⁶ The efforts to build a transparent system of public procurements had been ongoing since 1999. Yet, it was not until the mid to late 2010s when most of the Russian military production was covered by an extensive and efficient procurement system.

Figure 36: Quantity of public procurements by year (all types)

	Procurements
2011	1 991 947
2012	2 226 445
2013	3 311 160
2014	4 733 448
2015	5 014 465
2016	5 180 794
2017	5 114 963
2018	5 688 800
2019	6 966 928
2020	7 656 364
2021	8 828 002
2022	9 261 979

Public procurements are the most mass and the most informative source on the military industry's economic activities. Within the 2011-2020s time frame they are as close as we can get to an exhaustive source. As a result, most investigations of the Russian military industry's machine tool park tend to rely on this single type of source, which has its own limitations

Source: The Kontur database

And yet, this source has limitations:

First, **chronology**. The functional system of electronic public procurements in Russia did not emerge until 2011. And it took until the mid-to late 2010s for most of the military industry to fully adopt it. As public procurement systems existing prior to 2011 were only semi-functional, and the military producers were not obliged to use them anyway, the military producer's procurements published before 2011 are limited in quantity. In addition to that, they are difficult to impossible to locate and find and aggregate.

Second, **unevenness**. There is a significant variance in the character of procedures used and policies implemented through the 2010-2020s era. This variance is partially shaped by the (largely untransparent) legal framework guiding the procurements policy. While we have access to the legislative acts, our knowledge of the government's executive orders and the companies' internal regulations and the is limited. What we know however, is that the existing legislation gives all the four key missiles manufacturer corporations significant discretion in defining their internal procurement policies.

Whereas much of the procedure and policy unevenness may be based on the existing legal framework, this may not be necessarily always the case. The military producers' arbitrary (and possibly illegal) decisions, their mistakes and finally the informal agreements with the central authorities may also play a major role in how their procurement practice looks like.

Third, the **conflict of interests**. As the public procurements were developed as a solution to the principal-agent problem in the Russian military industry, it is effectively an instrument of the state to control its agents (the military producers). As a result, military producers can and do attempt to avoid the stifling governmental control. Much of the difficult to interpret and fragmentary character of the public procurement information results from the military manufacturers trying to bypass the existing regulations.

Finally, the existence of the **classified** procurements. Transparency of the public procurements system inevitably came into conflict with the considerations of secrecy (and sometimes, corruption). As a result, the already digitized system of transparent public procurements co-existed with the offline, paper-based system of «closed», classified procurements through early-to-mid 2010s. It was not until 2017, when the latter was digitized as well.

As a result, the transparent system of electronic procurements coexists with the untransparent one of an unknown size. Theoretically, any procurement relating to the State Defense Order (Гособоронзаказ) can and should be classified according to the letter of the law. In reality it does not happen. On the one hand, the classified platform is less functional than most of the transparent ones. On the other hand, mechanisms of securing secrecy contradict the main purpose of the public procurements system, namely, preventing corruption and increasing competition in order to allocate the public resources more efficiently.

Part 9. WHAT WE FOUND

The Russian missile industry's **machining** park is new and often top tier. It consists of the CNC equipment imported from Western Europe, developed East Asia and North America between 2003 and 2023⁵⁷. The import-based transition to computer control made Russia permanently reliant on the Western, Japanese, Taiwanese and Korean spares and tooling that are generally impossible to substitute with the Chinese manufacture⁵⁸.

In contrast, the **pressing and forging** stock tends to be more mature and less high-tech⁵⁹. Less revolutionized by the transition to computer control, the Cold War era equipment tends to be modernized rather than replaced. This ancient Soviet stock is supplemented with modern Western and developed East Asian machinery, Chinese machinery and the domestic Russian production.

The missile industry's **precision foundry** capacity relies on the modern Western equipment, including Canada, the US, the UK and continental Europe. Most of the **robotic equipment** we identified is installed at the precision casting and molding facilities.

The missile industry's **assembly** operations rely on the unautomated manual labor, largely low paid and female.

As a result of the post-Soviet collapse, Russia ended up with **labor** of highly uneven (generally low) quality. Low paid⁶⁰, low in prestige, hastily trained, it lacks solid mechanical or software skills and rarely inherits the tacit knowledge gone with the fall of USSR. The Russian missiles industry has adjusted to operating with what would have been previously considered as semi-skilled labor.

Facing the labor related constraints, the missiles producers developed high reliance upon the **integrated manufacturing solutions**, especially by Siemens. Minimizing the human factor and improving consistency of the product, these all-in-one turnkey solutions have simultaneously reduced flexibility of military manufacturing. Once the vertical integration has been implemented, going back to the non-integrated separate products will be difficult.

⁵⁷ It may also include late Soviet and Eastern Block CNC machines equipped with modern CNC controllers. Modernization of Soviet equipment played a particularly important role on the ICBM/SLBM plants (Votkinsk, Krasnaya Polya). Being highly prioritized in the Soviet era, they had been provided with best CNC machinery the USSR could buy or produce. In the 2000-2010s, much of the late Soviet CNC stock appeared to be modernizable.

⁵⁸ The de facto exclusion of Chinese machines from the Russian missile industry was abruptly reversed with the start of the war. As of now, Russia is on an early stage of its adoption of the Chinese CNC machinery. Yet, limitations of Chinese capabilities imply that the Chinese equipment remains less desirable quality and technology wise. The current hierarchy of preference is: Western Europe & Japan, Taiwan & South Korea, China. Furthermore, many critical spare parts and consumables cannot be acquired outside of the West and Japan with inclusions of Taiwan and South Korea.

⁵⁹ Due to the slower pace of technological improvement as well as the higher durability of pressing-forging machinery

⁶⁰ Until 2022

List of brands:

Machinery:

CNC Machines: EMCO 🇸🇰, Haas 🇺🇸, Kovosvit Mas 🇨🇪, DMG MORI 🇩🇪, Hermle 🇩🇪, GF 🇨🇭, Tos Varnsdorf 🇨🇪, Skoda 🇨🇪, Hyundai 🇰🇷, Walter 🇩🇪, Schaublin 🇨🇭, Index (Traub) 🇩🇪, PARPAS 🇮🇹, Hardinge 🇺🇸, Fanuc 🇯🇵, TDZ Turn 🇨🇪, Leadwell 🇨🇪, VDF Boehringer 🇩🇪, DOOSAN 🇰🇷, Heller 🇩🇪, Mazak 🇯🇵, Okuma 🇯🇵, Kitamura 🇯🇵, Hanwha 🇰🇷, Trumpf 🇩🇪, Biglia 🇮🇹, NSH 🇺🇸, Spinner 🇩🇪, Prima 🇮🇹, ANCA 🇦🇺, Techni Waterjet 🇦🇺, LVD 🇧🇪, Mazak 🇯🇵, Stan 🇷🇺, DMTG 🇨🇳 + minor producers, mostly Western European & Taiwanese

Coating: Kovofiniš 🇨🇪, Aquaflot 🇨🇪

Foundry: Shell-O-Matic 🇨🇪, Cleveland 🇺🇸, VA technology 🇬🇧

Robots: ABB 🇨🇭, Fanuc 🇯🇵, Kuka 🇩🇪 (*mostly found at precision casting & molding facilities*)

Parts and components:

CNC Controllers: Fanuc 🇯🇵, Siemens 🇩🇪, Heidenhain 🇩🇪

PLC Controllers: Siemens 🇩🇪

Measuring: Renishaw 🇬🇧, Hexagon 🇬🇧, Zeiss 🇩🇪, Bosch 🇩🇪

Tooling: Sandvik 🇸🇪, Seco 🇸🇪, Guhring 🇩🇪, Erowa 🇨🇭, Walter 🇩🇪, Zoller 🇩🇪, Kyocera 🇯🇵, Tungaloy 🇯🇵, Korloy 🇰🇷, Iscar 🇮🇸, Eroglu 🇹🇷

Software:

Integrated solutions: Siemens 🇩🇪, Dassault 🇫🇷, PTC 🇺🇸, Ansys 🇺🇸

NB: Siemens is the only company in the world capable of providing the all-in-one CAD to CNC solution, minimizing the human factor at any stage of the production process.

CONCLUSION

Russian capacity for the nuclear blackmail relies upon the uninterrupted supply of metal-cutting machinery from and the software support by the U.S. allies. As a result of the post-Soviet collapse Russia lost the workforce capable of doing precision machining, and thus executing the Soviet designs of weaponry manually. Starting from 2003, Putin brought the missile production back from the dead with the mass import of CNC equipment from Western Europe, developed economies of East Asia and North America. This put the missile production on a permanent needle of spares, tooling and software services from the U.S. allies. Most importantly, it made Russia highly dependent upon the integrated solutions provided only by a handful of companies in the world.

The fall of the USSR in 1991 interrupted the continuity of Russian manufacturing tradition. The output of weaponry collapsed, ruining missiles producers and obliterating the knowledge ecosystems they used to support. The middle and the junior generation of workers eroded from the industry. As vocational schools were defunded, no replacement was trained. When the senior workers were dying, leaving, or retiring they seldom had juniors to have passed their knowledge to. By the time Putin succeeded to power, the industry had neither the qualified labor, nor the system of vocational training, nor tacit knowledge the Soviet military production was based upon. With the Soviet craftsmanship gone, capacity for producing sophisticated weaponry manually was lost irreversibly.

Transition to computer control became the answer. The mass implementation of CNC technology in combination with the CAD and CAM software brought an immense increase in productivity, largely compensating for the consequences of post-Soviet collapse. Vastly increasing the efficiency of machining, it has particularly benefited the machining-centric missiles (and aircraft) industry. It was the global progress in hardware and software that allowed Putin to revive the production of missiles after the Soviet craftsmanship was lost. On the other hand, the disruptive change in technology widened the gap between Russia and the top global machinery producers so far, that it became unbridgeable. The military production was rebooted, but at the cost of absolute import dependency.

Most of the 2000s import came from the established producers in Western Europe and Japan, Germany being the largest supplier by far. Through the 2010s, catching development producers of East Asia were catching up quantitatively and qualitatively. Still, the gap in quality and in technology persists. If Taiwanese and South Korean machines were usually deemed as sufficiently good by 2014, Chinese production had been effectively excluded from the Russian missiles industry until 2022. Limitations of Chinese capabilities are particularly pronounced in the production of critical machine parts and consumables. As of 2023, Chinese machines will be almost invariably equipped with the imported mechatronic components (including CNC controllers) and tooling for the lack of alternative.

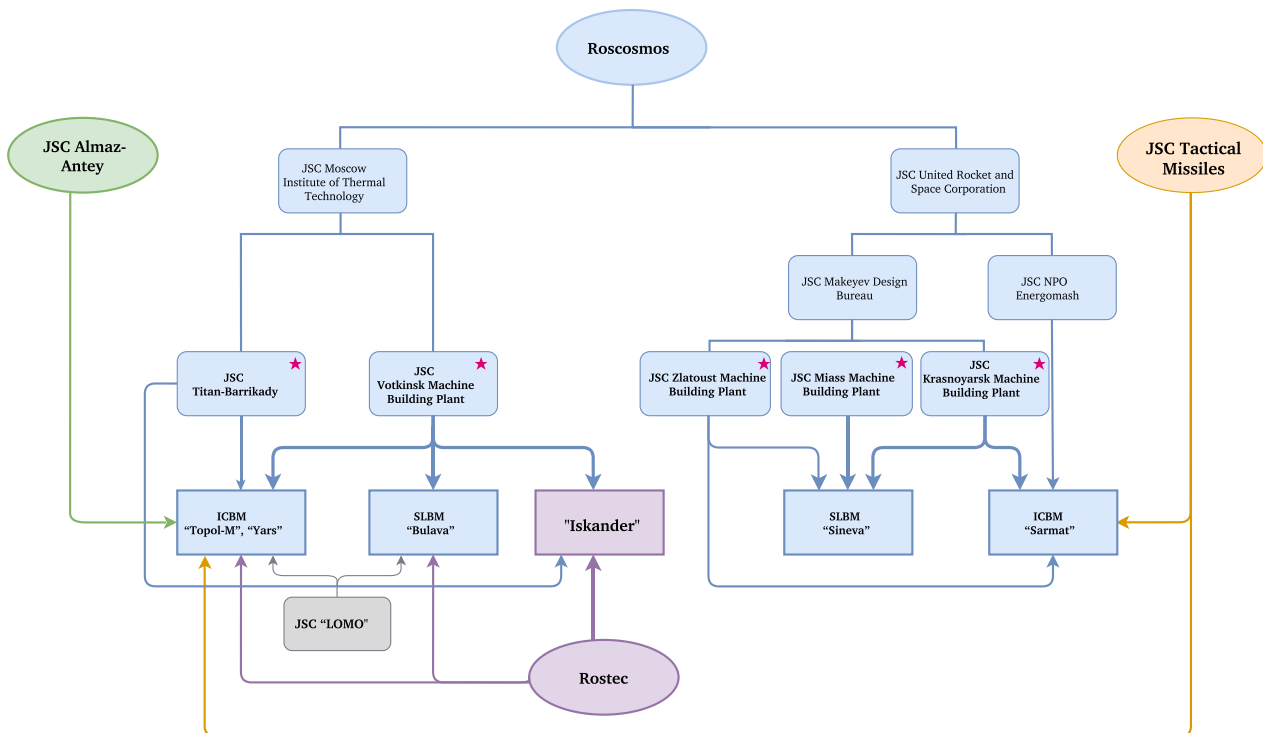
The mass import of computerized equipment has effectively wiped out the Russian machine tool industry. Its remnants were largely reduced to the distribution and maintenance of the imported equipment. In exceedingly rare cases they had capacity for assembling individual ad hoc machines from the imported parts, but not for scaling the production up. Despite the import-substitution policy launched in 2011, the Russian machine tool industry is still a child learning to walk, being severely limited both in production capabilities and capacities. Based on the official government self-estimates we can rate the import dependency in machine tools at well over 90%. The thinly veiled import makes for most of the declared domestic output, especially in the high-end sector.

The problem of import dependency is exacerbated by overreliance on the integrated manufacturing solutions, especially by Siemens. To execute Soviet designs of weaponry, Russia had to compensate the low quality of its labor with the high-quality hardware and software. Integrated systems provided by only a few companies in the world presented a foolproof, all-in-one solution, minimizing the human factor in production. While various missile producers experimented with Dassault, PTC and Ansys; Siemens has been the one singular company capable of providing a sealed chain from the CAD to CNC controller. Excluding any third-party hardware or software, Siemens solutions allow to minimize the human involvement on any stage of the production process. This comes at the cost of lower flexibility, compared with non-integrated solutions, and higher dependency upon a single supplier.

If the Russian military doctrine is missile-centric, the missile production is machining-centric. And the modern machining is fully reliant upon the CAD, CAM and CNC. In terms of hardware, Russian machining capacity relies upon the uninterrupted supply of spares, expendables and tooling from the U.S allied countries. Due to the wide gap in technology, critical supplies from Western Europe and developed East Asia are difficult to impossible to substitute with the Chinese manufacture. Moreover, the generally low quality of labor forces missiles producers to choose between the high reliance on standardized turnkey solutions, particularly by Siemens, and the unacceptable variance in product. This makes Russia extremely dependent upon the continuous software support from the West.

Appendix. Scope of investigation

Roscosmos



Roscosmos is a state corporation responsible both for civilian aerospace programs and for maintaining the Russian nuclear deterrence system. **It is the sole producer of intercontinental ballistic missiles in Russia, including strategic ICBMs and SLBMs.** The missiles production of Roscosmos is concentrated within its two defense-oriented holdings: the Makeyev Design Bureau (liquid-propellant) and the Moscow Institute of Thermal Technology (solid-propellant)⁶¹

Our sample:

Our sample of the Roscosmos military manufacturing base is nearly exhaustive. There are two military-oriented holdings within Roscosmos, and we have investigated both. Our sample includes its only solid-propellant missiles producer⁶², both of its liquid propellant missiles producers⁶³, as well as the key producers of components⁶⁴ and launch systems⁶⁵.

⁶¹ In both sub-holdings, the parent company is responsible for the R&D, while its subsidiaries do the manufacturing.

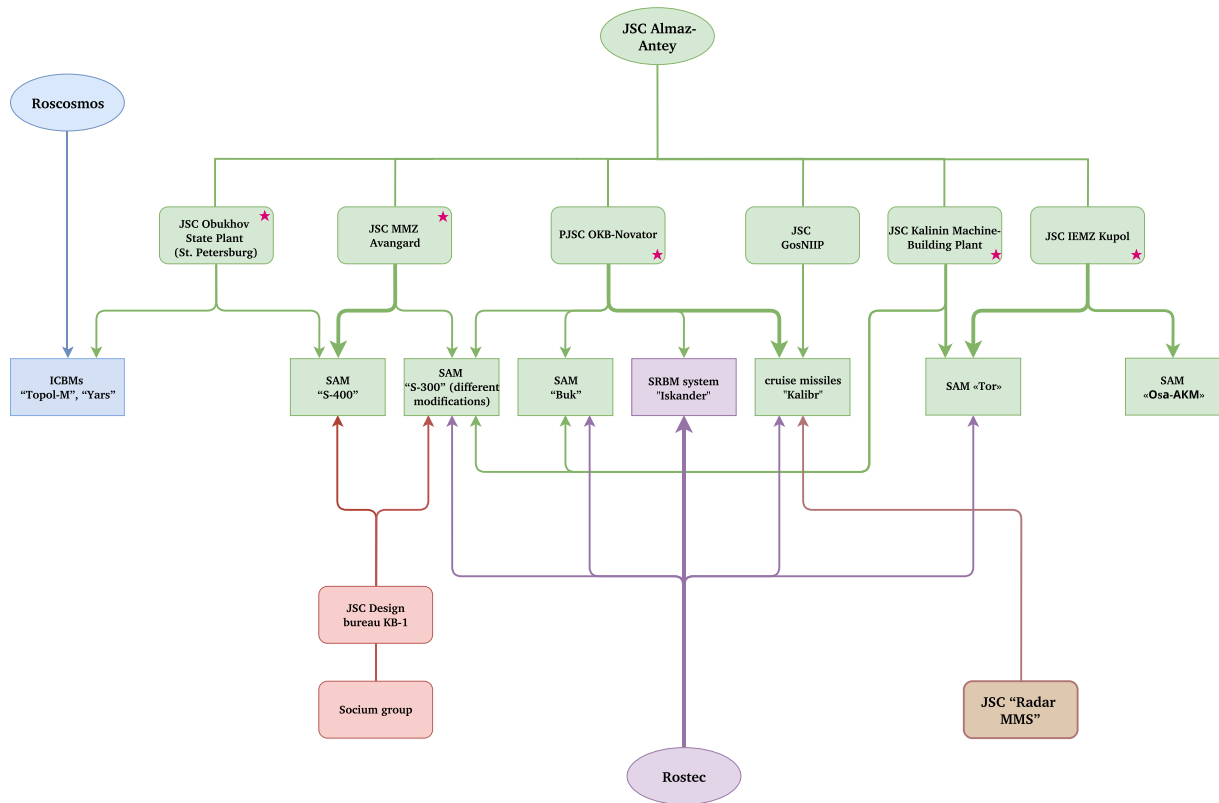
⁶² The Votkinsk Machine Building Plant is the sole producer of solid propellant ICBMs/SLBMs in Russia. It also plays a major role in the production of SRBM Iskander system.

⁶³ The Krasnoyarsk Machine Building Plant (Krasmach) and Miass Machine Building Plant are two liquid propellant ICBMs/SLBMs producers in Russia.

⁶⁴ Zlatoust Machine Building Plant (Zlatmash)

⁶⁵ Titan-Barrikady. Originally an artillery plant, it is an uncharacteristically transparent production facility within this secretive defense corporation.

Almaz-Antey



The Almaz-Antey is the **monopolist producer of air defense and missile defense systems** in Russia⁶⁶. In addition, it manufactures cruise missiles of the Kalibr family. As the principal Russian exporter of weaponry, Almaz-Antey is an uncharacteristically rich and transparent company, as well as the most outspoken advocate for the import of machinery and software from the West⁶⁷.

Our sample:

For the purposes of our investigation, we have selected a geographically diverse sample of plants producing the key air defense and missile defense weaponry that this narrowly specialized military corporation focuses on⁶⁸. Furthermore, we have investigated its less characteristic and more secretive cruise missiles production⁶⁹.

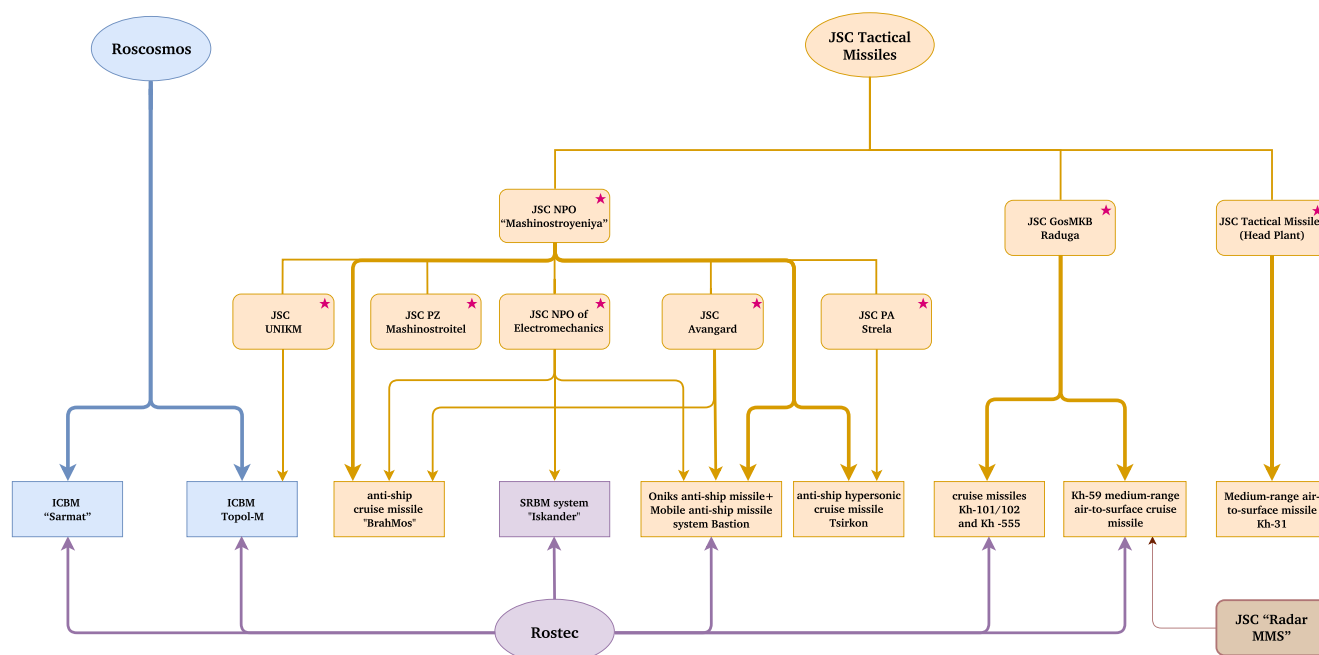
⁶⁶ Supported by Rostec.

⁶⁷ As a result, most previous attempts to investigate the Russian missiles industry's import dependencies focused exclusively on the Almaz-Antey.

⁶⁸ For the purposes of our investigation, the Socium group can be also considered as a part of Almaz-Antey. Established by the chief designer of Almaz-Antey, Igor Ashurbeily, it primarily sells its manufacture to the Almaz-Antey. Consequently, we investigate it here as a part of the Almaz-Antey structure.

⁶⁹ Being originally a cruise missiles producer, the OKB Novator is an uncharacteristic element of this highly specialized, air defense-oriented holding. This is reflected in its secrecy policy, the OKB Novator being the most classified enterprise within the entire Russian missiles industry. After the Russian invasion of Ukraine, the cruise missiles production has been increasingly outsourced to other, historically air defense oriented and less secretive enterprises of the Almaz-Antey.

Tactical Missiles



The Tactical Missile Corporation manufactures almost all the **cruise and anti-ship missiles in Russia, as well as guided bombs**. It is the second most export-oriented and transparent defense corporation in Russia after Almaz-Antey. As a result, sources on the Tactical Missiles manufacturing base and solutions implemented are particularly abundant and informative⁷⁰.

Our sample:

We have chosen a sample of Tactical Missiles plants producing its longest-range cruise and anti-ship missiles, as well as the enterprises most important in the context of Roscosmos military production⁷¹. This brings us to the Tactical Missiles' head plant, the NPO Mashinostroyeniya sub-holding⁷², and to the particularly secretive and strategically important cruise missiles producer GosMKB Raduga⁷³.

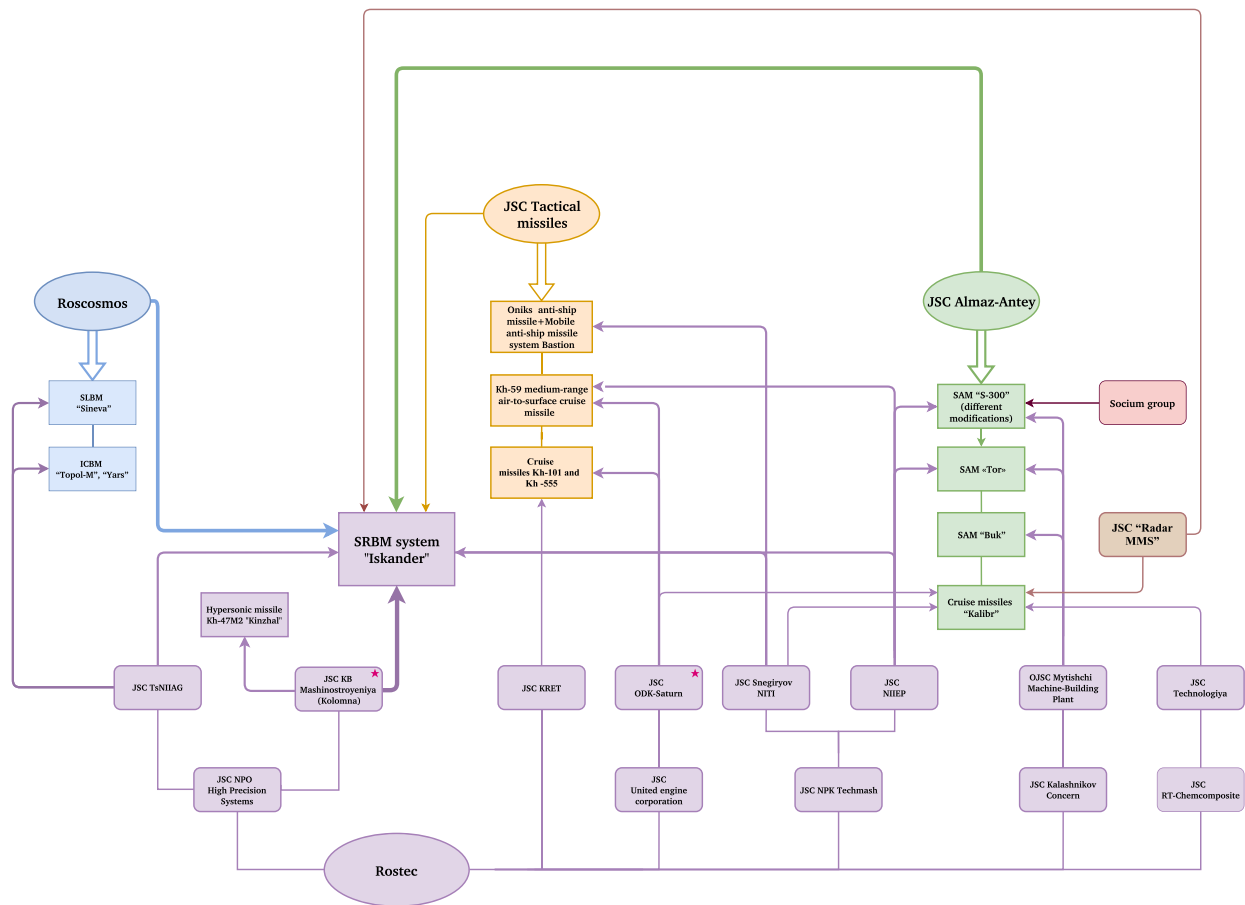
⁷⁰ What it lacks for representation by the official propaganda, it compensates with the self-representation, including in the professional literature.

⁷¹ Much of the JSC Tactical Missiles Corporation structure left behind here will be reviewed in our paper on the Russian navy. This includes torpedoes, sea mines as well as the anti-ship missiles production.

⁷² Until 2012 when it was merged with the Tactical Missile Corporation, the NPO Mashinostroyeniya had been an independent company, specialized on the anti-ship missiles production, but also conducting the R&D and manufacturing components for the Russian aerospace industry.

⁷³ The GosMKB Raduga is the only plant in Russia capable of mass-producing strategic air-launched cruise missiles: Kh-101 and Kh-555. It is the second most classified plant within the Russian military industry after the OKB Novator.

Rostec



Rostec is the largest and the most eclectic Russian defense corporation. It encompasses most of the land army weaponry, military aircraft and naval production⁷⁴. While its own output of missiles is limited, **Rostec plays a major role manufacturing critical parts, components and equipment** for other missiles producers and supporting their production processes⁷⁵.

Our sample:

Within this investigation we focused on two of Rostec's enterprises: the KB Mashinostroyeniya (Kolomna) and the ODK Saturn. The first is involved in the SRBM Iskander and most probably in the hypersonic missile Kinzhal production⁷⁶. The second is manufacturing engines for all the long-ranged cruise missiles in Russia, such as the Kh-101, Kh-555, Kh-59 and the Kalibr family missiles⁷⁷.

⁷⁴ Being led by Putin's old St. Petersburg friend Sergey Chemezov, it unites everything he could and chose to take over.

⁷⁵ Chassis for the air defence systems (Mytishchi Machine Building plant), electronic components (JSC NIIEP, JSC Snegiryov NITI, JSC KRET), navigation systems (TsNIAG), fairings (JSC Technologiya).

⁷⁶ The KB Mashinostroyeniya appears to be the third most classified missile production facility in Russia after the OKB Novator (Almaz-Antey) and GosMKB Raduga (Tactical Missiles)

⁷⁷ Despite its role in cruise missiles and military aircraft production, the ODK Saturn has been able to import an advanced manufacturing technology from a NATO country (Germany) thanks to the dual-use loophole.