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Professor Miller – Capstone – Administrative Version

Kalibr Production and Russia's Non-Nuclear Deterrent

Introduction:

As the modern Russian state has evolved since its inception in 1991, so too has its nuclear doctrine. Contemporary research suggests that the Russian military has undergone a series of theoretical and practical reforms since the mid-2000s that have enabled it to be comparatively less reliant on its nuclear forces for deterrence at all stages and scales of conflict than it was during the 1990s. Many scholars, both Western and Russian, credit this policy shift to Russia's acquisition of conventional precision-strike capabilities that began during the late 2000s. In turn, experts have traced the decision to develop precision-strike capabilities to earlier doctrinal discussions among Russian strategists seeking to mirror existing American capabilities and ensure the credibility of their country's nuclear deterrent. [1] [2]

Although such analysis, prevalent in the Western academic community, correctly describes the general contours of the theoretical transformation of Russian nuclear strategy, it does not sufficiently address whether observed doctrinal changes can be operationalized by the Russian military. In the open literature, Russia's possession or employment of a type of weapon (especially nuclear arms) is often interpreted to mean that it is capable of using it for its intended, doctrinally defined purpose. This is a dangerous assumption; without knowledge regarding states' specific capabilities, military analysis is at best misleading and of limited utility to policymakers. Notably, such information is largely absent in public analysis examining whether the Russian military has reduced its historical reliance on nuclear arms for escalation

1. Dave Johnson, *Russia's Conventional Precision Strike Capabilities, Regional Crises, and Nuclear Thresholds*, Lawrence Livermore National Lab.(LLNL) (Livermore, CA, 2018), 38.
2. Kristin Ven Bruusgaard, "Russian nuclear strategy and conventional inferiority," *Journal of Strategic Studies* 44, no. 1 (2020): 9-17, https://doi.org/10.1080/01402390.2020.1818070.

management in favor of precision-guided munitions (PGMs).[3] While generations of scholars have developed quantitative estimates of Russia's nuclear forces, far less has been publicly written about its PGMs.[4] Accordingly, although substantial evidence indicates that Russia possesses the requisite doctrinal framework for the employment of conventional PGMs as a means of achieving strategic deterrence, it has remained unclear whether it has the material capability to do so.[5]

This paper contributes to the analytic community's knowledge of Russia's nuclear doctrine and capabilities by exclusively using publicly available information to assess its industrial capacity to manufacture a modern, versatile family of cruise missiles: Kalibr, known by NATO as the Sizzler (SS-N-27 or SS-N-30A, depending on the variant). This missile, produced by the Yekaterinburg-based contractor *OKB Novator* (Novator), was selected for use as a case study for three reasons. First, it is functionally aligned to the roles envisioned for PGMs by prominent Russian strategists advocating "strategic non-nuclear deterrence".[6] Although land and air-launched variants exist, the Kalibr is best known as a sea-launched missile that has been stationed on Russian corvettes, frigates, and submarines. The first two launch platforms allow Russia to hold European targets at risk from deep within its territory, while the latter affords Russia a precision, non-nuclear means of threatening the U.S. homeland. Second, Russian leaders have repeatedly cited the missile's performance to showcase Russia's advanced munitions capabilities, suggesting its importance both as a weapon and object of national pride.[7] Third, information regarding its development history, technical specifications, and production is relatively available compared to similar Russian arms, such as the Kh-10 air-launched cruise missiles.

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3. Nikolai Sokov, "The Origins of And Prospects for Russian Nuclear Doctrine," *The Nonproliferation review* 14, no. 2 (2007): 215, https://doi.org/10.1080/10736700701379278.
4. Hans M. Kristensen and Matt Korda, "Russian nuclear weapons, 2021," *Bulletin of the Atomic Scientists* 77, no. 2 (2021), https://doi.org/10.1080/00963402.2021.1885869.
5. Kristin Ven Bruusgaard, "The Myth of Russia's Lowered Nuclear Threshold," *War on the Rocks*, 2017, https://warontherocks.com/2017/09/the-myth-of-russias-lowered-nuclear-threshold/.https://warontherocks.com/2017/09/the-myth-of-russias-lowered-nuclear-threshold/
6. А.Е. Стрелин, А.А. Протасов, and С.В. Крейдин, "Современные Трансформации Концепций и Силовыж Инструментов Стратегического Сдерживания," (Военная Мысль, 08/01/2019 2019). https://vm.ric.mil.ru/Stati/item/203864.
7. "Владимир Путин о Сирии: «Лучше тратить боезапас в бою, чем на полигоне»," БизнесOnline, updated 03/17/2016, 2016, accessed 04/26/2022, 2022, https://m.business-gazeta.ru/article/305041.

I begin by introducing generally accepted theories regarding Russian perceptions of escalation management. These foundational concepts are then used to contextualize the argument, made by several prominent experts, that Russia's growing conventional military capacity has made it increasingly less reliant on its nuclear arsenal as a strategic deterrent across the range of conflict scenarios it expects to confront. The paper then pivots to a case study estimating Russia's annual output of Kalibr missiles, the findings of which are used to inform a discussion about the potential future directions of Russian nuclear strategy.

Methodologically, although every effort has been made to verify the information presented, it must be noted that data collection challenges have long hampered analysts' efforts to objectively assess the Russian military's means and procurement priorities. In general, unlike in the U.S., the public is not privy to the details of Russia's defense orders, which are conducted using a closed website.[8] Additionally, defense companies are given wide latitude to withhold details in their annual reports, or not publish them at all.[9] Regarding the Kalibr missile family, the Russian government has offered little information concerning each unit's cost (technically a state secret) or production rate. Contemporary information from the relevant contractors is largely unavailable, and production statistics must be indirectly inferred from historical contract data, financial statements, and officials' public remarks. Even when these sources exist, however, they are often incomplete and limited to a narrow timespan. Therefore, although specific sources of error are noted in the analysis, there are simply too many "unknown unknowns" for open-source researchers to accurately ascertain the modern state of the Kalibr program, or of Russia's cruise missile industry more generally. The Kalibr production figures presented in this paper are thus best regarded as threshold estimates: quantities that Russia is known to have been able to produce.

Background:

Although they continue to debate the details of Russia's nuclear strategy, Western

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8. The MOD's contracting website is available at: https://www.astgoz.ru/page/index
9. "Об особенностях раскрытия и предоставления информации, подлежащей раскрытию и предоставлению в соответствии с требованиями Федерального закона "Об акционерных обществах" и Федерального закона "О рынке ценных бумаг"," in *N0001201904120008* ed. Правительство Российской Федерации (04/12/2019 2019). https://docs.cntd.ru/document/554180581.

analysts have identified several generalizable concepts regarding conflict, deterrence, and nuclear employment shared by Russia's strategic community. While a comprehensive analysis of these concepts is outside the scope of this paper, several points are critical to understanding why some scholars have argued that Russia has shifted towards a greater reliance on conventional arms for its deterrence needs.

In the Russian, and former Soviet, military-political tradition, the English term "deterrence" can be translated as either *ustrashenie* or *sderzhivanie*. The former word is often interpreted to mean, roughly, deterrence by fear inducement, whereas the latter is more analogous to the English term "containment". These terms do not exclusively reference military action, but, rather, refer to a wide range of activities intended to shape adversaries' decision making to guarantee the security of the Russian state.[10] Activities within this spectrum are referred to as "strategic" if their principal aim is to preserve Russian sovereignty and territorial integrity. Kofman et al. portray the Russian concept of "strategic deterrence" as a "framework":

> [It]…provides a unifying model for aligning perceptions of the military-political threat environment with the state's instruments of national power intended to shape that environment positively for Russian interests…Strategic deterrence represents both a state's theory of how to attain security in peacetime, and an inclusive national security concept to coordinate the various means at its disposal to manage escalation.[11] (5)

As part of its mission, the Russian military must also fulfill non-strategic deterrence requirements set by political leaders. The distinction between strategic and nonstrategic deterrence reflects the granular distinctions made by Russian military strategists when discussing the types and phases of conflicts. Russia generally regards conflicts as existing along a time and intensity spectrum; periods of military danger are seen as preceding conflicts, which can range in scale from local to nuclear.

To achieve strategic deterrence, Russia prefers to hold critical adversarial targets at risk, rather than relying on its defensive forces to impose costs over the course of a conflict.

10. Andrey Pavlov et al., *Nuclear Russia: International and domestic agendas* (2020), 23.
11. Michael Kofman, Anya Fink, and Jeffrey Edmonds, "Russian Strategy for Escalation Management: Evolution of Key Concepts" (2020), 5.

Throughout the Soviet Era and continuing into the modern day, both strategic and tactical nuclear weapons have been theoretically and operationally assigned to this role.[12] [13] Doing so presented Soviet strategists with a critical challenge, however, that became apparent during the late 1980s and early 1990s: the U.S.S.R.'s reliance on nuclear weapons undermined its nuclear credibility in its relations with the U.S. and limited its ability to fight a conventional war. This issue became exacerbated after the collapse of the Soviet Union as Russia simultaneously became conventionally weaker even as its strategists anticipated a proliferation of low-intensity conflicts.[14] [15] [16]

Recognizing the challenge posed by the U.S.S.R.'s reliance on nuclear weapons and anticipating the incipient proliferation of precision-guided munitions, late Soviet and early Russian military planners established the doctrinal foundations for their use. [17] By virtue of their accuracy and ability to threaten critical targets, PGMs were understood to afford their operators two important benefits over nuclear arms. First, their users could more credibly strategically threaten adversaries with PGMs, because their employment would not break the nuclear taboo. Second, the anticipated damage from PGM use could be tailored for a desired psychological effect. Their first significant combat use, by the U.S. in the Gulf War, confirmed their utility as warfighting instruments that could effectively neutralize targets with minimal direct risk to the operator. Accordingly, in his study of Russia's precision strike capabilities, Dave Johnson found that Russian military strategists began to call for Russia to develop its own PGM capabilities shortly after the collapse of the U.S.S.R.:

> Russia's leaders found their high level of dependence on nuclear weapons during the lean years of the 1990s constraining and dangerous. In their view, nuclear weapons were not credible responses to the security threats and challenges pressing in on Russia in the immediate post-Cold War era. The Russian military assessed the growing U.S. conventional precision strike capabilities as a significant future threat to Russia. Russian

12. Jacob W. Kipp, "Russian Military Doctrine: Past, Present, and Future," in *Russian military politics and Russia's 2010 defense doctrine*, ed. Stephen Blank (Carlisle, PA: Strategic Studies Institute, U.S. Army War College, 2011), 84 - 85.
13. Ven Bruusgaard, "Russian nuclear strategy and conventional inferiority," 14 - 15
14. *Ядерное сдерживание и нераспространение*, Carnegie Moscow Center (Moscow: Carnegie Endowment for International Peace, 2005), 25, https://carnegieendowment.org/files/9268Nuclear_Deterrence_and_Non-Proliferation.pdf.
15. Kofman, Fink, and Edmonds, "Russian Strategy for Escalation Management: Evolution of Key Concepts," 54.
[16] Johnson, *Russia's Conventional Precision Strike Capabilities, Regional Crises, and Nuclear Thresholds*, 38.
17. Pavlov et al., *Nuclear Russia: International and domestic agendas*, 27.

> strategists determined that the most effective response would be the development of an analogous countervailing capability…Consequently, the development and fielding of conventional precision strike capabilities have been high priorities in Russia's intensive military modernization efforts undertaken since 2008. (38)[18]

This conceptual acceptance of the value of PGMs by the Russian political and military establishment, he argues, has resulted in the use of both conventional precision and nuclear weapons as instruments of strategic deterrence.[19] [20]

Johnson's argument regarding the centrality of precision-guided munitions in Russia's contemporary strategic deterrence concept is shared by other scholars. In her study examining the impact of Russia's modernization of its conventional forces on its nuclear strategy since the early 2000s, Kristin Ven Bruusgaard argues that "…conventional inferiority can produce increased reliance on nuclear threats, but some states seek to improve conventional capabilities to overcome this dependency. Russia is one such state: its preferred escalation management option is not, by default, nuclear weapons."[21] Partly basing her findings on Russian-language military science writings, she echoes Johnson's framing of the development of Russian PGM strategy:

> By the late 1990s, Western conventional military capabilities had evolved far above and beyond Russian capabilities. Western precision strike capabilities were perceived as a growing threat to Russian security, with an ability to define future war. Conventional capabilities could be used in what Russian strategists started calling strategic first strikes, potentially inflicting critical or unacceptable damage on an adversary. This notion that advanced conventional precision weapons could have a destructive potential like nuclear weapons would have severe repercussions for how Russian strategists sought to influence adversary intentions. (12 – 13) [22]

Reforms were therefore undertaken during the early 2000s to develop and sustain a PGM arsenal, so that "…by the mid-2010s, Russian conventional precision strike capabilities had started to fill a role in the Russian strategic deterrence concept".[23] Similarly, in their study

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18. Johnson, *Russia's Conventional Precision Strike Capabilities, Regional Crises, and Nuclear Thresholds*, 38.
19. Валерий Герасимов, "Уважаемая сила," *Военно-Промышленный Курьер*, 11/14/2017 2017, https://vpk-news.ru/articles/39882.
20. Johnson, *Russia's Conventional Precision Strike Capabilities, Regional Crises, and Nuclear Thresholds*, 24.
21. Ven Bruusgaard, "Russian nuclear strategy and conventional inferiority," 27.
22. Ven Bruusgaard, "Russian nuclear strategy and conventional inferiority," 12 - 13.
23. Ven Bruusgaard, "Russian nuclear strategy and conventional inferiority," 23.

tracing the development of Russian thought concerning escalation management, Kofman et al. argue:

> Today, Russian military thinkers believe that strategic conventional capabilities give Russia the flexibility to inflict a specific or tailored amount of damage on various structural elements of an adversary, critically important objects that underpin their military and economic systems, in order to achieve a level of strategic deterrence. As they became available, conventional weapons proved more attractive as a means by which to inflict this type of deterrent damage against an adversary, particularly in conflicts short of large-scale war. (57 – 58) [24]

Russian and Western experts generally disavow the notion that Russia's acquisition of PGMs has made it less reliant on nuclear arms for strategic deterrence purposes than it otherwise would be.[25] [26] Rather, conventional PGMs are regarded as complementary to strategic nuclear weapons because they expand Russia's range of options in a conflict, especially (but not exclusively) those at the lower end of the scale and intensity spectrum.[27] Johnson, for example, summarizes the interdependence of nuclear and conventional arms in Russia's deterrence strategy by arguing that "non-nuclear and nuclear deterrence are conceptually linked because strategic nuclear deterrence is viewed as creating the necessary preconditions for non-nuclear deterrence (by conventional precision weapons) to be effective."[28] McDermott and Bukkvoll frame this modern strategy as stemming from Russian strategists' longstanding fears:

> …any realistic assessment of Russia's continued and future interest in [PGMs] must take account of the historical intellectual context in which it emerged. The country was and is ultimately driven by concern over maintaining strategic deterrence and developing new capabilities to meet modern warfare challenges through a range of potential conflicts." (10-11) [29]

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24. Kofman, Fink, and Edmonds, "Russian Strategy for Escalation Management: Evolution of Key Concepts," 54 - 58.
25. The theoretical debate over the extent to which PGMs can replace nuclear weapons is ongoing. *See*: Евгений Холоднов, "Гиперзвуковые Вооружения и Неядерное Сдерживание," *Индекс Безопасности* 25, no. 11 (2021), http://www.pircenter.org/media/content/files/14/16276399460.pdf.
26. Стрелин, Протасов, and Крейдин, "Современные Трансформации Концепций и Силовыж Инструментов Стратегического Сдерживания," 5.
27. Т. Аничкина, "Конвенциональное Высокоточное Оружие в Современном Стратегическом Контексте," *Мировая Экономика и Международные Отношения*, no. 5 (2012): 109, https://doi.org/10.20542/0131-2227-2012-5-103-111, https://www.imemo.ru/publications/periodical/meimo/archive?article_id=814.
28. Johnson, *Russia's Conventional Precision Strike Capabilities, Regional Crises, and Nuclear Thresholds*, 26.
29. Roger N McDermott and Tor Bukkvoll, "Russia in the Precision-Strike regime–military theory, procurement and operational impact," *Kjeller: Norwegian Defence Research Establishment* (2017): 10 - 11,

Accordingly, the analytic community has interpreted Russia's increased reliance on conventional arms for deterrence purposes as signifying a higher threshold for nuclear use, as both the political costs of nuclear employment and likelihood of subsequent escalation increase alongside the availability of non-nuclear deterrents.[30]

Despite the consequences of a purported growing Russian reliance on non-nuclear instruments of strategic deterrence, scholars have expended far more effort in assessing the theoretical ramifications of such a policy shift than ascertaining whether Russia's procurement priorities reflect doctrinal changes. Although some discrepancies between general military strategy and Russian leaders' statements have been noted for their practical implications, experts writing about nuclear strategy for public consumption have typically hedged their analysis by citing the deployment of certain types of PGMs as implied evidence of alignment of theory and practice. [31] [32] [33] [34] [35] In other instances, key claims are made with no citations.[36] Fink, for example, theoretically deduces that "Russia does not have sufficient conventional precision-strike capabilities to credibly threaten the full range of Western counterforce targets", a conclusion likely reached as an extension of her finding that Russian military analysts "focus on limited strikes to inflict 'deterrent damage' on 'vitally' important military targets".[37] More precise estimates of Russia's PGM capacity have occasionally been openly published, although these typically base their conclusions on calculating the number of launch platforms Russia

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https://www.ffi.no/en/publications-archive/russia-in-the-precision-strike-regime-military-theory-procurement-and-operational-impact.

30. Подберёзкин А.И. and Жуков А.В., "Оборона России и Стратегическое Сдерживание Средств и Способов Стратегического Нападения Вероятного Противника," *Вестник МГИМО-Университета* 63, no. 6 (2018): 8, https://doi.org/https://doi.org/10.24833/2071-8160-2018-6-63-141-158.

31. Nikolai Sokov, "Russian military doctrine calls a limited nuclear strike "de-escalation". Here's why. ," *Bulletin of the Atomic Scientists*, 03/08/2022, 2022, https://thebulletin.org/2022/03/russian-military-doctrine-calls-a-limited-nuclear-strike-de-escalation-heres-why/.

32. Johnson, *Russia's Conventional Precision Strike Capabilities, Regional Crises, and Nuclear Thresholds*, 46.

33. Pavel Luzin, "Fifth-generation Fighter Jets," *Ridl.io*, 01/20/2022, 2022, https://ridl.io/en/fifth-generation-fighter-jets/.

34. McDermott and Bukkvoll, "Russia in the Precision-Strike regime–military theory, procurement and operational impact."

35. Valeriy Akimenko, *Russia and strategic non-nuclear deterrence*, Chatham House: The Royal Institute of International Affairs (2021), 8 - 9.

36. Anya Loukianova Fink, "The Evolving Russian Concept of Strategic Deterrence: Risks and Responses," *Arms Control Today* 47, no. 6 (2017): 17, https://www.jstor.org/stable/90011081.

[37] Fink, "The Evolving Russian Concept of Strategic Deterrence: Risks and Responses."

possess, rather than industrial output of weapons themselves.[38] [39] While such analysis is helpful in tracing the contours of the development of Russia's nuclear strategy, it risks conflating Russia's capabilities and theoretical doctrine. Furthermore, although Russia's PGM production capacity has undoubtedly been well-studied by intelligence services, this information is publicly unavailable, limiting important debate to a narrow subset of experts and potentially shielding policy choices from informed external scrutiny.

This is not to suggest that deterrence is purely contingent on quantifiable means; generations of researchers have demonstrated the salience of human psychology and other factors. Establishing universally accepted threshold values for the number of PGMs Russia must procure to enable its strategy of non-nuclear strategic deterrence is therefore impossible.[40] However, it is equally true that strategies must be adequately resourced.[41] In the present case, if Russia is unable to produce PGMs in sufficient quantities to meet its defined needs, or is otherwise unable to utilize them for their intended purpose, doctrinal debates over their salience (or lack thereof) in Russian nuclear strategy are moot. Even with a "surplus" of PGMs, Russia may reconsider its approach to attaining strategic deterrence. Reliable and verifiable estimates of Russia's PGM production capacity are therefore necessary for analysts to ascertain the extent to which Russia can reduce its reliance on nuclear weapons as instruments of deterrence.

The following section attempts to resolve this information gap by utilizing open-source information to develop estimates of Russia's annual output of the Kalibr family of cruise missiles. From a technical perspective, the Kalibr is well-suited to the non-nuclear deterrence mission envisioned by leading Russian strategists.[42] Estimates of its performance vary by source,

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38. Michael Kofman and Jeffrey Edmonds, "Why the Russian Navy Is a More Capable Adversary Than It Appears," (The National Interest, 2017). https://nationalinterest.org/feature/why-the-russian-navy-more-capable-adversary-it-appears-22009?nopaging=1.
39. H.I. Sutton, "Russia Increasing Submarine Cruise Missile Capacity as US Navy Decreases Its Own," (RUSI, 08/19/2021 2021). https://rusi.org/explore-our-research/publications/commentary/russia-increasing-submarine-cruise-missile-capacity-us-navy-decreases-its-own.
40. Russian military scientists have attempted to quantify damage thresholds necessary to deter adversaries in this way. However, such assessments are inherently subjective. Furthermore, aligning them with known Russian non-nuclear capabilities is beyond the scope of this paper.
41. Dmitry Adamsky, "If War Comes Tomorrow: Russian Thinking About 'Regional Nuclear Deterrence'," *The Journal of Slavic Military Studies* 27, no. 1 (2014): 171, https://doi.org/10.1080/13518046.2014.874852.
42. Alexander Yermakov and Dmitry Stefanovich, "Is Non-Nuclear Deterrence Possible?," (Russian International

but all non-export variants of the Kalibr are generally considered to have a range of at least 1,500 KM, enabling Russia to hold at risk a vast amount of NATO member states' critical civilian and military infrastructure from within its borders. Furthermore, the modularity of the basic missile design has enabled Russia to develop both land-attack and anti-ship variants that can be mounted on both land and sea platforms, including standardized shipping containers and cheap corvettes - design choice aligned with the doctrinal shift towards non-nuclear strategic deterrence that has occurred over the previous decade. The Kalibr's flexibility allows Russian mission planners to more precisely "assign" damage to correlate to a given psychological effect, while its ability to be concealed (in either submarines or common shipping containers) enhances its utility as a deterrent by bolstering its survivability. [43] Accordingly, while the Kalibr is not the only precision-guided munition Russia has developed in recent years, its design and explicit association by President Putin with the goals of strategic non-nuclear deterrence indicate its utility as a representative case study in understanding Russian PGM production capacity. [44] [45] [46]

Research Procedure:

Two related approaches were identified for estimating Russia's annual Kalibr output. Because of the secrecy surrounding missile production figures and costs, little precise open information is available regarding deliveries of completed units. Russian political, military, and industrial leaders typically decline to cite precise quantities. For example, a 2017 article in the official magazine of the Russian Ministry of Defense (MOD) quoted the Chief of the General Staff General V.V. Gerasimov as stating that the number of "precision cruise missiles" had increased by "more than 30 times" over the 2012 - 2017 period, without referencing a baseline

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Affairs Council, 06/30/2020 2020). https://russiancouncil.ru/en/analytics-and-comments/analytics/is-non-nuclear-deterrence-possible/.

43. Kofman, Fink, and Edmonds, "Russian Strategy for Escalation Management: Evolution of Key Concepts," 29.

44. Виктор Сокирко, "«Бастион» для «Циркона». Куда приземлят гиперзвуковую ракет. ," *Газета.Ру* (Moscow), 12/01/2017 2021, https://www.gazeta.ru/army/2021/12/01/14268355.shtml.

45. "Путин сообщил об увеличении числа ракет «Калибр» более чем вдвое к 2023 году," Рамблер, updated 12/03/2019, 2019, accessed 03/26/2022, 2022, https://news.rambler.ru/army/43278737-putin-soobschil-ob-uvelichenii-chisla-raket-kalibr-bolee-chem-vdvoe-k-2023-godu/.

46. Алексей Курильченко and Николай Баранов, "Крылатая ракета «Калибр» поразила цель в рамках учений сил стратегического сдерживания," (TV Zvezda, 02/19/2022 2022). https://tvzvezda.ru/news/20222191840-eNQJp.html.

amount.[47] Nonetheless, Russian leaders with access to comprehensive production information have occasionally cited specific amounts of missiles that have been delivered to the armed forces.[48] However, given the incentives to obfuscate these figures, any official information was verified by additional means. Research efforts were therefore primarily directed towards unearthing information regarding the missile's subcomponent supply chain. The technological complexity of modern cruise missiles facilitates this type of research, as the human, industrial, and financial resources necessary to make these components provides a high barrier to entry, limiting the relevant information search space and raising the public presence of the companies in the market. This approach has three key drawbacks, however. First, the available data often lack the necessary details to estimate output; in these instances, they must be inferred from secondary sources or using assumptions, introducing error. Second, no public information exists concerning the output of different types of Kalibr missiles; production estimates can therefore only reflect the production of Kalibr-type munitions. Finally, chronological gaps in the data constrain the inferential value of estimates and make them impossible to normalize or project over time.

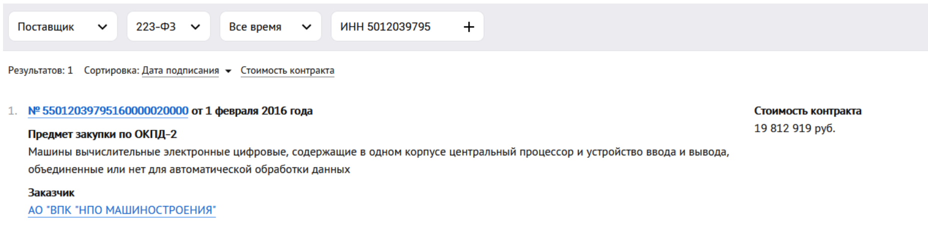
With limited exceptions, the information presented in the case study consists of compiled primary-source material. All was available, at the time of initial access, to users without needing to register for websites and services.

Avionics System Analysis:

According to the prominent weekly military newspaper *Voenno-Promyshlennyi Kur'er* (Military-Industrial Courier), the Kalibr's seeker head (model "AGRS-14E") is made by *NPP-Radar MMS* (NPP Radar), a St. Petersburg firm specializing in radar systems and microelectronics for civilian and defense industries.[49] Although neither the firm's annual reports, accounting statements, or publicly available contracts provide direct evidence of the amount of

47. Дмитрий Семёнов and Александр Тихонов, "Армия России: динамика развития " (Красная Звезда, 11/08/2021 2017). http://archive.redstar.ru/index.php/2011-07-25-15-57-07/item/35001-armiya-rossii-dinamika-razvitiya.
48. "ВМФ РФ получил в первом полугодии 47 ракет "Калибр" и 72 зенитные управляемые ракеты ", Тасс, 2016, accessed 02/26/2022, 2022, https://tass.ru/armiya-i-opk/3457551.
49. Максим Климов, "Бенефис «калибров»," *Военно-Промышленный Курьер* 2015, https://vpk-news.ru/articles/27516.

seeker heads of this model sold, a February 2016 business record indicates that it had a relationship with a larger firm specializing in rocket production, *NPO Mashinostroyeniye*, itself part of a larger state-owned conglomerate, the *Tactical Missiles Corporation*.



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Although this record for the sale of an "automated data signal processor in one [physical] case" does not directly indicate that NPP Radar sold seeker heads to NPO Mashinostroyeniye , the evidence of a business relationship between the two firms suggests a degree of mutual understanding over acceptable prices for goods. [50]

Price estimates for a cruise missile seeker head used by NPO Mashinostroyeniye can be derived from a video (since deleted) posted by an official military-affiliated television channel called "Zvezda" ("Star") on YouTube on approximately December 1. The video, which discusses the Kalibr's technical specifications and uses, includes a shot taken inside NPO Mashinostroyeniye's production facilities, in the Moscow suburb of Reutov.[51] In the shot, the host bends down and gestures with his hands to the seeker and avionics compartment of a cruise missile, stating, roughly "my understanding is that this section is worth approximately two apartments." Although NPO Mashinostroyeniye does not produce the Kalibr, its products, such as the anti-ship P-800 ("Yahont") missile are sufficiently similar from a technical perspective to the Kalibr to allow for rough comparison. For example, both can be launched from the same container, and the avionics package each uses are designed for the same purpose (guidance over water). [52] [53] Therefore, although it is impossible to verify where the apartments referred to by the

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50. Most public records of this contract have been deleted since it was identified in March 2022. The screenshot is taken from the business records site *checko.ru*. *See*: "Contract: 55012039795160000020000," (ClearSpending, 02/03/2016). https://clearspending.ru/contract/55012039795160000020000/.
51. "Unknown," ed. Unknown (TVZvezda, 12/01/2015 (Approximately) 2015). https://www.youtube.com/watch?v=xtLX7qjugAU.
52. А.В. Карпенко, "Ракетный Комплекс с Противокорабельной Ракетой «оникс» (»яхонт»). Новости 2011-2014," (Оружие Отчества, 2014). http://bastion-opk.ru/yahont-2014/.
53. Илья Крамник, "Нехватка «калибровки»: как проваливается модернизация подлодок," *Известия*,

video’s host in his comment regarding the avionics system’s cost are located, this information can nonetheless be used to calculate its cost in rubles, if it is assumed that he was referring to the apartment prices in Reutov. This is a reasonable assumption in this author’s view, as such information would likely have been provided on-site, prior to filming, by employees within commuting distance of the facility.

Although access to historical housing prices in Reutov is limited, a July 13, 2015 analysis by a Russian real estate brokerage website indicates that the average cost of an apartment on its secondary market at the time was 8,016,264 rubles, placing the cost of the avionics package at 16,032,528 rubles.[54] Using the average ruble-to-dollar exchange rate for December, 2015 of 70 Rubles/ USD, the cost of a single avionics package for Kalibr-like cruise missiles is determined to be approximately $230,000. For comparison, upgrading the American Tomahawk cruise missile to have similar anti-ship capabilities cost the U.S. approximately$250,000 per unit in 2015 dollars, and required physical modification of the seeker head, in addition to software reprogramming. [55] [56]

These figures can be used to derive approximate production rates for avionics systems suitable for use in Kalibr missiles. In its 2015 report, NPP Radar stated that its VAT-inclusive revenue, likely derived exclusively from defense-related work, was 6,049,760,000 rubles.[57] The same report also reported the revenue derived from contracts with companies in which it had a financial stake. These companies (which are unlikely to be avionics resellers to Novator) and their associated transaction amounts with NPP Radar in 2015 are as follows:

1) *R.E. Alekseeva Central Construction Bureau for Hydrofoils:* 596,640,670 rubles

2) Petrostroy SPB: 112,686,880 rubles

12/06/2022 2018, https://iz.ru/820554/ilia-kramnik/nekhvatka-kalibrovki-kak-provalivaetsia-modernizatciia-podlodok?_x_tr_sl=ru&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=sc.

[54] "Самый дорогой город Подмосковья — Реутов, самый дешевый – Ликино-Дулево," Мир Квартир, updated 07/13/2015, 2015, accessed 03/20/2022, 2022, https://www.mirkvartir.ru/journal/analytics/2015/07/13/samii-dorogoi-gorod-podmoskov_a-reytov-samii-desevii-likinodylevo/.

55. Aaron Mehta, "Pentagon Budget Requests $2B for Tomahawks, $2.9B for SM-6," 02/03/2016 2016, https://www.defensenews.com/2016/02/03/pentagon-budget-requests-2b-for-tomahawks-2-9b-for-sm-6/.

56. "Delivery Order (DO)- PIID: N0001917F2001," (usaspending.gov: U.S. Department of the Treasury, 2017). https://www.usaspending.gov/award/CONT_AWD_N0001917F2001_9700_N0001915G0003_9700.

57. "АО "НПП "Радар ммс": Годовые Отчеты," in *Центр Раскрытия Корпоративной Информации* (Интерфакс, 03/02/2022). https://e-disclosure.ru/portal/files.aspx?id=2527&type=2&attempt=1.

3) *Morinfosystem-Agat Concern*: 44,136,220 rubles

4) *NPO Mars*: 20,000,000 rubles[58]

Excluding the sum of these contracts, 773,463,770 rubles, approximately 5.3 billion rubles of NPP Radar's 2015 revenue remains publicly unassociated with a source. If all this revenue is assumed to be derived from the production of seeker heads, the company would have been capable of producing 329 units per year in 2015.

Aluminum Body Analysis:

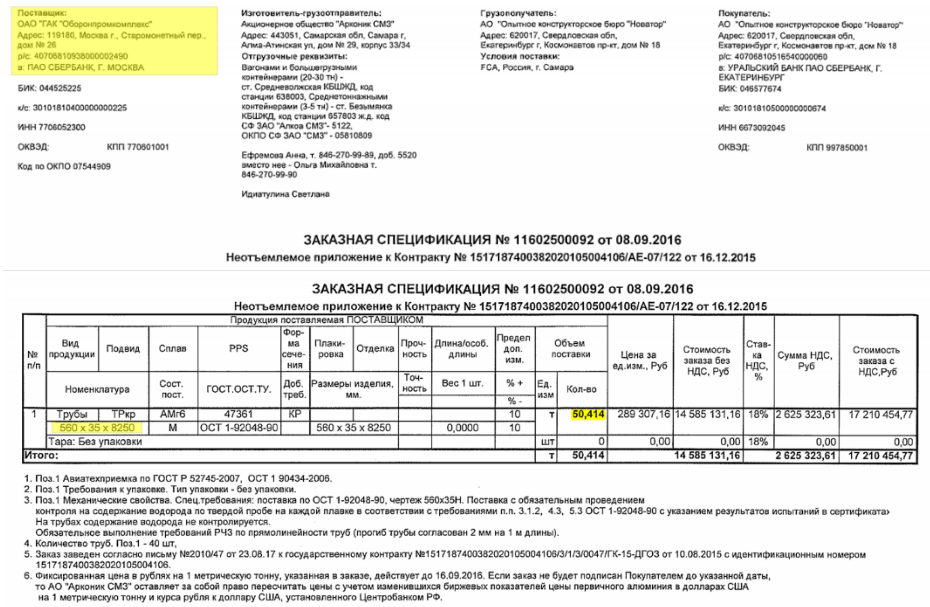
Although OKB Novator has its own computerized metalworking machines, purchasing records suggest it has occasionally chosen to outsource production of the Kalibr missile's body to other companies. In 2016, Novator concluded a series of contracts for aluminum tubes, specifying its desired weight in the purchase order. These tubes were comprised of an alloy, AMg6M, suitable for rocketry and the dimensions specified in the orders closely approximated the dimensions of several varieties of the missile.[59] [60] Furthermore, the end user listed on the contracts is a state-owned defense procurement organization, "Oboronpromkompleks". For example, contract number 31604106874, renewed on September 19, 2016, specifies that the aluminum supplier "Arkonik SMZ" is to deliver 50.414 metric tons of AMg6M tubes, each measuring 560 x 35 x 8250mm.[61]

58. The annual report indicates that it signed a contract for 5,000,000 rubles, but government data indicate that NPP Radar received at least 20,000,000 rubles in 2015 work from NPO Mars. It could be that NPP Radar's annual reporting reflects the value of that same contract executed during that year; this is unlikely however, as the period of performance indicated in the contract ended in March 2015. *See*: https://zakupki.gov.ru/epz/contractfz223/card/supplier-info.html?id=151213

59. "Russia says local Alcoa unit abused monopoly," Thomson Reuters, updated 03/03/2011, 2011, accessed 03/30/2022, 2022, https://www.reuters.com/article/alcoa-russia-idUSLDE7221WH20110303.

[60] Sergey Mokrushin et al., "Research of dynamic properties of alloys of AMg6BM and AMg6M in shock-wave experiment on a gas gun," *EPJ Web of Conferences* 94 (01/01 2015), https://doi.org/10.1051/epjconf/20159401055.

61. Contract signature dates used in this section are taken from the official Russian registry site zakupki.ru and may not always correspond to the associated documentation.



Поставщик:
ОАО "ГАК "Оборонпромкомплекс"
Адрес: 119180, Москва г., Старомонетный пер., дом № 26
р/с: 40706810938000002490
в: ПАО СБЕРБАНК, Г. МОСКВА

БИК: 044525225

к/с: 30101810400000000225

ИНН 7706052300

ОКВЭД: КПП 770601001

Код по ОКПО 07544909

Изготовитель-грузоотправитель:
Акционерное общество "Арконик СМЗ"
Адрес: 443051, Самарская обл, Самара г, Алма-Атинская ул, дом № 29, корпус 33/34
Отгрузочные реквизиты:
Вагонами и большегрузными контейнерами (20-30 тн) - ст. Средневолжская КБШЖД, код станции 638003, Среднетоннажными контейнерами (3-5 тн) - ст. Безымянка КБШЖД, код станции 657803 ж.д. код СФ ЗАО "Алкоа СМЗ"- 5122, ОКПО СФ ЗАО "СМЗ" - 05810809

Ефремова Анна, т. 846-270-99-89, доб. 5520 вместо нее - Ольга Михайловна т. 846-270-99-90

Идиатулина Светлана

Грузополучатель:
АО "Опытное конструкторское бюро "Новатор"
Адрес: 620017, Свердловская обл, Екатеринбург г, Космонавтов пр-кт, дом № 18
Условия поставки:
FCA, Россия, г. Самара

Покупатель:
АО "Опытное конструкторское бюро "Новатор"
Адрес: 620017, Свердловская обл, Екатеринбург г, Космонавтов пр-кт, дом № 18
р/с: 40706810516540000060
в: УРАЛЬСКИЙ БАНК ПАО СБЕРБАНК, Г. ЕКАТЕРИНБУРГ
БИК: 046577674

к/с: 30101810500000000674

ИНН 6673092045

ОКВЭД: КПП 997850001

ЗАКАЗНАЯ СПЕЦИФИКАЦИЯ № 11602500092 от 08.09.2016

Неотъемлемое приложение к Контракту № 1517187400382020105004106/АЕ-07/122 от 16.12.2015

ЗАКАЗНАЯ СПЕЦИФИКАЦИЯ № 11602500092 от 08.09.2016

Неотъемлемое приложение к Контракту № 1517187400382020105004106/АЕ-07/122 от 16.12.2015

№ п/п	Продукция поставляемая ПОСТАВЩИКОМ: Вид продукции	Подвид	Сплав	PPS	Форма сечения	Плакировка	Отделка	Прочность	Длина/особ. длины	Предел доп. изм.	Объем поставки		Цена за ед.изм., Руб	Стоимость заказа без НДС, Руб	Ставка НДС, %	Сумма НДС, Руб	Стоимость заказа с НДС,Руб
	Номенклатура		Сост. пост.	ГОСТ.ОСТ.ТУ.	Доб. треб.	Размеры изделия, мм.		Точность	Вес 1 шт.	% + / % -	Ед. изм	Кол-во					
1	Трубы	ТРкр	АМг6	47361	КР					10	т	50,414	289 307,16	14 585 131,16	18%	2 625 323,61	17 210 454,77
	560 x 35 x 8250		М	ОСТ 1-92048-90		560 x 35 x 8250			0,0000	10							
	Тара: Без упаковки										шт	0	0,00	0,00	18%	0,00	0,00
Итого:											т	50,414		14 585 131,16		2 625 323,61	17 210 454,77

1. Поз.1 Авиатехприемка по ГОСТ Р 52745-2007, ОСТ 1 90434-2006.
2. Поз.1 Требования к упаковке. Тип упаковки - без упаковки.
3. Поз.1 Механические свойства. Спец.требования: поставка по ОСТ 1-92048-90, чертеж 560x35Н. Поставка с обязательным проведением контроля на содержание водорода по твердой пробе на каждой плавке в соответствии с требованиями п.п. 3.1.2, 4.3, 5.3 ОСТ 1-92048-90 с указанием результатов испытаний в сертификата› На трубах содержание водорода не контролируется. Обязательное выполнение требований РЧЗ по прямолинейности труб (прогиб трубы согласован 2 мм на 1 м длины).
4. Количество труб. Поз.1 - 40 шт,
5. Заказ заведен согласно письму №2010/47 от 23.08.17 к государственному контракту №1517187400382020105004106/3/1/3/0047/ГК-15-ДГОЗ от 10.08.2015 с идентификационным номером 1517187400382020105004106.
6. Фиксированная цена в рублях на 1 метрическую тонну, указанная в заказе, действует до 16.09.2016. Если заказ не будет подписан Покупателем до указанной даты, то АО "Арконик СМЗ" оставляет за собой право пересчитать цены с учетом изменившихся биржевых показателей цены первичного алюминия в долларах США на 1 метрическую тонну и курса рубля к доллару США, установленного Центробанком РФ.

Although the purchase orders specify the quantities of tubes ordered, the amounts can be verified by mathematically deriving the total length of pipe in each contract from the orders' dimensions and the alloy's weight (2,640 KG/M^3). The following table uses this approach to calculate the number of tubes ordered in the single largest (by order quantity and cost) publicly available contract (number 31604585629, dated December 28, 2016) concluded by OKB Novator. [62]

Tube Dimensions (mm)	Quantity in KG	Number of Tubes
560x35x8250	88,200	70
560x35x7750	106,560	90
Total	194,760	160

Several indicators can be used to ascertain how quickly OKB Novator intended to utilize the pipes. Per the available purchase documentation, each contract for aluminum alloy procurement is tied to a larger government contract between the MOD and Novator. For contract 31604585629, the master contract is 1617187400922412209010034, signed April 08, 2016.

62. "Contract #31604585629," (Закупки.ру, 03/14/2022). https://zakupki.gov.ru/223/purchase/public/purchase/info/common-info.html?regNumber=31604585629.

1. Поз.1-5 Техприемка по ГОСТ Р 52745-2007; ОСТ 1 90434-2006.
2. Поз.1-5 Требования к упаковке. Тип упаковки - без упаковки.
3. Поз.1-5 Механические свойства. Спец. требования: 1. Поставка по ОСТ 1-92048, чертеж 560х35Н. 2. Поставка с обязательным контролем на содержание водорода по твердой пробе на каждой плавке в соответствии с требованиями п.п. 3.1.2, 4.3, 5.3 ОСТ 1-92048 с указанием результатов испытаний в сертификатах. На трубах содержание водорода не контролируется.
4. Количество труб. Поз.1 - 45 шт., поз.2 - 25 шт., поз.3 - 20 шт., поз.4 - 45 шт., поз.5 - 25 шт.
5. Заказ заведен согласно письму №2717/47 от 21.11.2016 к государственному контракту №1617187400922412209010034 от 08.04.2016 с идентификационным номером 1617187400922412209010034.
6. Фиксированная цена в рублях на 1 метрическую тонну, указанная в заказе, действует до 30.12.2016. Если заказ не будет подписан Покупателем до указанной даты, то АО "Арконик СМЗ" оставляет за собой право пересчитать цены с учетом изменившихся биржевых показателей цены первичного алюминия в долларах США на 1 метрическую тонну и курса рубля к доллару США, установленного Центробанком РФ.

Although detailed information about the master contract is unavailable, funds allotted to it were spent on materials besides tubes that are uniquely used, as consumables, in the production of cruise missiles (such as forgings made from the same alloy). However, within the same period, contracts for capital goods, such as hydraulic presses, were not associated with a government contract, suggesting that the money for the execution of a state defense order is treated separately from operating funds at Novator's disposal.[63] [64] Under this assumption, relevant contracts for raw materials can be treated as reflective of Novator's Kalibr output.

The timeline of the alloy purchases lends additional insight into Novator's production patterns and capabilities. Contracts 31604106874 and 31604228233 for tubes were signed with Arkonik in September and October 2016, respectively, and were both associated with a master contract signed in August 2015. The first contract was far larger in terms of quantity than the second (40 tubes compared to 3), but the producer had far less time to fulfill it than the second (70 days compared to 131). Although it is not conclusive evidence of such, this discrepancy suggests that Novator was working at capacity and could not absorb the additional raw material until it had utilized the original. Furthermore, although there is no documented evidence of deliveries of AMg6- type aluminum prior to September 2016, and therefore no way of knowing how much remaining inventory Novator had prior to Fall 2016, the timing of the letters of intent it signed to purchase tubes and related aluminum goods reveal its planning operations.

The earliest available contract, for the delivery of 40 tubes by November 28, 2016, was signed on September 19, 2016, in accordance with a letter of intent dated August 23, 2016, giving a planning period of 97 days, and a production time of 70 days.[65] Prior to the fulfillment

63. "Contract #31604585629."
64. "Проблемные Вопросы Гособоронзаказа, Предложения По Их Решению и Повышению Эффективности Выделяемых Средств," *Научный вестник оборонно-промышленного комплекса России*, no. 1: 33, https://cyberleninka.ru/article/n/problemnye-voprosy-gosoboronzakaza-predlozheniya-po-ih-resheniyu-i-povysheniyu-effektivnosti-vydelyaemyh-sredstv.
65. There is a typographical error in the source document.

of the September 19 contract, Novator chose to conclude another, on October 20, for the purchase of 3 tubes, with a delivery date of February 28, 2017. A month later, on November 21, it signed a new letter of intent for 160 tubes, and the contract was executed on December 28, 2016. Delivery dates for the line items in the December contract were staggered: Novator was to receive 45 tubes by March 29, 2017, 45 by May 7, 45 by July 1, and 25 by September 8. These dates correspond to a planning and production period of 128 and 91 days, respectively, from the signing of the letter of intent and contract to the first delivery. Subsequent deliveries under the December contract required 39 days (March - May), 55 days (May-July), and 70 days (July-September). This timeline is summarized as follows:

- September 19, 2016: Novator signs a contract for delivery of 40 tubes by November 28, 2016.

- October 20, 2016: Novator purchases an additional 3 tubes to be delivered by Feb 28, 2017, using the September 19 contract.

- November 21, 2016: Novator signs a letter of intent to deliver 160 tubes with a staggered delivery schedule.

- November 28, 2016: 40 new tubes are in Novator's possession.

- December 28, 2016: Novator signs a contract for the delivery of 160 tubes of varying dimensions.
  - March 29, 2017: 45 units of 560 x 35 x 8250mm tubes.
  - May 7, 2017: 25 units of 560 x 35 x 8250mm tubes, 20 units of 560 x 35 x 750mm tubes.
  - July 1, 2017: 45 units of 560 x 35 x 7750mm tubes.
  - September 8, 2017: 25 units of 560 x 35 x 7750mm tubes.

- February 28, 2017: Novator receives the final tubes per its September 19, 2016, contract.

If Novator is assumed to fully utilize all existing tubes by the time it receives a subsequent delivery, this information can provide approximate lower and upper boundaries for Novator's annual Kalibr output. Purchasing patterns indicate that Novator procures around 45 tubes at a time (except for those due in September 2017). Lower production rates can be determined by dividing this figure by the interval between the November 2016 and March 2017 dates, resulting in an output of 135 Kalibrs per year.[66] The upper boundary can be established using the same procedure, but using the smaller interval between deliveries in 2017. Between March 29 and July 1(95 days) Novator received 90 tubes, indicating a manufacturing capacity of 346 units per year.[67]

Additional information suggests a narrower range of estimates. As noted above, if Novator expected to be working at capacity by the time it received the 40 tubes from its September purchase when it signed the October 2016 contract for 3 additional tubes, it would be capable of annually producing 157 Kalibrs.[68]Alternatively, if Novator is assumed to have utilized 135 tubes between March and September 2017, as suggested by the December 2016 contract, its annual rate would be 300 units per year.[69] Finally, besides procuring prefabricated tubes, Novator also signed several contracts for AMg6M forgings, rails, and stampings. While these are unlikely to have been used to create new rocket bodies, the amount of forgings bought on a December 29, 2016 contract indicates that Novator was able to process at least 316 560 x 35 x 8250mm rocket casings worth of aluminum per year.

Two pieces of evidence suggest that the contracts examined here are comprehensive and capture most of Novator's tube procurement activity for the calendar year beginning September 01, 2016. First, Novator signed a letter of intent to procure 160 tubes on November 21, 2016, prior to receiving a previously ordered batch of 40. This suggests that its purchasing department

66. $\frac{45}{122} \times 365 = 134.63$
67. $\frac{90}{95} \times 365 = 345.78$
68. $\frac{40}{93} \times 365 = 156.98$
69. $\frac{134}{164} \times 365 = 298.23$

plans its operations in 3–4-month increments (an average of 110 days).[70] This timespan corresponds roughly with the 122-day period in which Novator had received an order of tubes and was waiting for a new delivery between November 2016 and March 2017. Additionally, these acquisition timelines are aligned with production estimates offered by Oleh Korostelyov, the Soviet-born director of Ukraine's Luch design bureau that manufactures cruise missiles. While discussing the differences between his company's R-360 Neptun missile and analogous Russian systems, he noted that it takes "three months to procure all the requisite materials and components".[71] Accordingly, while additional related contracts could be hidden from the public domain, the likelihood of that occurring is diminished given the availability of these sets of contracts and their alignment with an expert's estimate of cruise missile procurement patterns.

Engine Analysis:

According to the *Military-Industrial Courier*, all variants of the Kalibr use engines developed and produced by the *Omsk Engine Construction Bureau* (OMKB, in Russian). [72] [73] OMKB specializes in turbine production, and is a subsidiary of *NPO Saturn*, which is in turned owned by the Russian state through its stake in the *United Engine Corporation* (UEC).[74] Unlike other companies involved in the Kalibr's production, OMKB's annual reports indicate specific production capacity challenges at a component-level of detail.

Documents published by UEC indicate the model number of the turbojet engine used in

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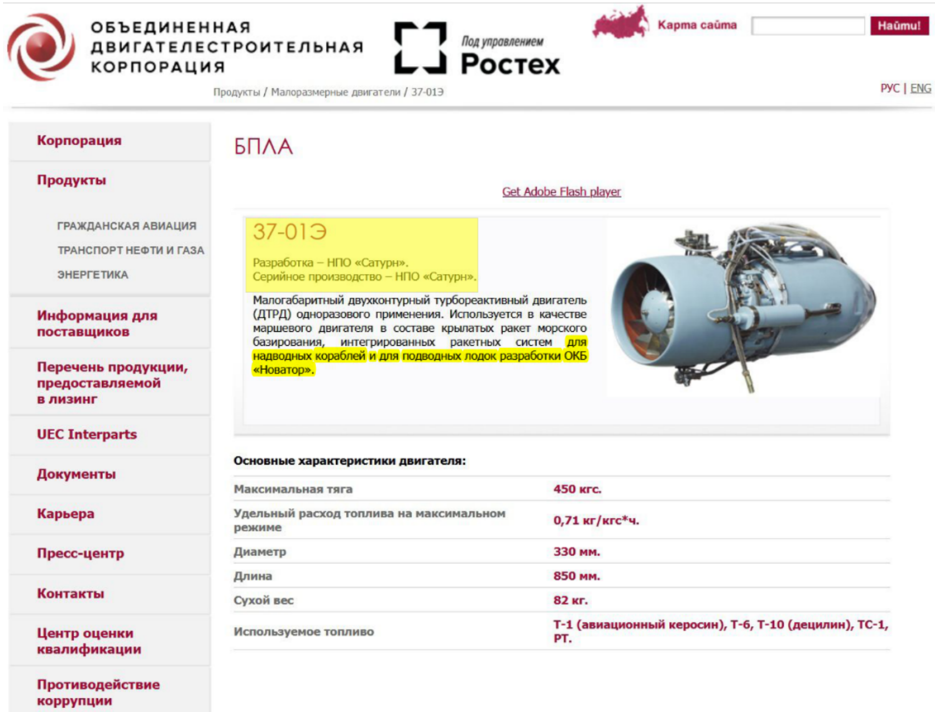
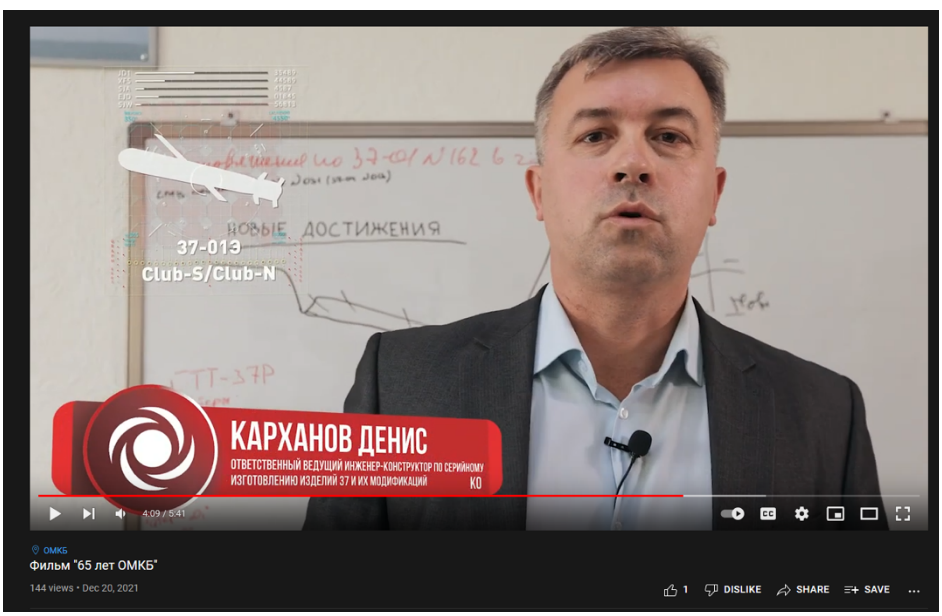
70. The letter of intent for the September contract was signed August 23, with an eventual delivery date of November 28. The December contract letter of intent was signed November 21 for a March 29 initial delivery date.
71. "Ukraine designer profiles Neptun, Vilkha missile systems," *BBC Monitoring Former Soviet Union* (London), 08/24/
2020 Aug 24 2020, https://login.ezproxy.library.tufts.edu/login?url=https://www.proquest.com/wire-feeds/ukraine-designer-profiles-neptun-vilkha-missile/docview/2436359689/se-2?accountid=14434
https://tufts-primo.hosted.exlibrisgroup.com/openurl/01TUN/01TUN_SP??genre=article&issn=&title=BBC+Monitoring+Former+Soviet+Union&volume=&issue=&date=2020-08-24&atitle=Ukraine+designer+profiles+Neptun%2C+Vilkha+missile+systems&spage=&aulast=&sid=ProQ:ProQ%3Aabitrade&isbn=&jtitle=BBC+Monitoring+Former+Soviet+Union&btitle=&id=doi:.
72. Климов, "Бенефис «калибров»."
73. "37-01Э," (Объединённая Двигателестроительная Корпорация). https://www.uecrus.com/rus/products/bpla/37-01e/.
74. "АО "ОМКБ": Годовые Отчеты," in *Центр Раскрытия Корпоративной Информации* (Интерфакс, 03/21/2022). https://www.e-disclosure.ru/portal/files.aspx?id=14139&type=6&attempt=1.

the production of Kalibrs. [75]



Максимальная тяга	450 кгс.
Удельный расход топлива на максимальном режиме	0,71 кг/кгс*ч.
Диаметр	330 мм.
Длина	850 мм.
Сухой вес	82 кг.
Используемое топливо	Т-1 (авиационный керосин), Т-6, Т-10 (децилин), ТС-1, РТ.

Additional verification of the engine's use in the Kalibr family is found in a promotional video for OMKB's 65th anniversary celebrations.[76]



75. "37-01Э."
76. Unknown, "65 Лет ОМКБ," (YouTube: Егор Худояров 12/20/2021 2021). https://www.youtube.com/watch?v=SuUvXNjlQ48.

The identification of the model number is critical to tracing the evolution of OMKB's attempts to manufacture the engine. In its 2012 report (the earliest available), the Company suggests that the development of the engine is still nascent:

При создании ТРД-500 разрабатываются и проходят проверку следующие уникальные технические решения:

- упрощение кинематической схемы изделия за счет отсутствия коробки приводов и организация электрического привода топливного насоса;
- уход от традиционной масляной системы смазки и охлаждения опор ротора за счет внедрения системы топливовоздушной смазки опор ротора и применения подшипников с керамическими телами качения;
- внедрение системы воздушного запуска от баллона ограниченного объема.

- создание модификации изделия 37-01 с улучшенными тягово-экономическими показателями;

- создание ТВД с толкающим винтом;

- создание малоразмерного дешевого ТРД тягой 60 кгс в условиях Н=0; М=0,7; σ_{BX}=0,97.

The 2013 report indicates the Company initiated research efforts into developing suitable engines for Novator's purposes and estimates that the cost to serially produce such engines would be 1,197,081.05 rubles/unit in 2011 terms.

Создание малоразмерного дешевого ТРД с тягой до 90 кгс.

Работы проводились в период август – октябрь 2011 г. на основании ТЗ № 77-07-11 от ОАО «ГосМКБ "Радуга" им. А. Я. Березняка».

В ходе работ были определены:

- тягово-экономические характеристики двигателя;
- схема и состав двигателя, функции основных систем;
- возможные предприятия-соисполнители для проведения ОКР по созданию ПКИ и предприятия-смежники изготовители серийных ПКИ;
- объем ОКР по созданию малоразмерного ТРД-77 и ориентировочные сроки выполнения этапов ОКР (26 месяцев от момента начала финансирования работ в соответствии с условиями заключенного договора на проведение ОКР).
- произведена предварительная оценка стоимости опытного (3 122 705,71 руб.) и серийного (1 197 081,05 руб.) образцов двигателя (в ценах 2011 года).

В 2013 году с ОАО «ОКБ «Новатор» поступил запрос на создание ТРД близкого по характеристикам. С октября 2013 года ведутся работы по предварительному определению облика ТРД.

A year later, in 2014, OMKB was able to start serially producing the 37-01 engine and began to rely heavily on this revenue stream for its solvency.

10. ИНФОРМАЦИЯ О ПОЛУЧЕНИИ ОБЩЕСТВОМ ГОСУДАРСТВЕННОЙ ПОДДЕРЖКИ

В 2014 году ОАО «ОМКБ» государственной поддержки, в том числе субсидий не получало.

11. ОПИСАНИЕ ОСНОВНЫХ ФАКТОРОВ РИСКА, СВЯЗАННЫХ С ДЕЯТЕЛЬНОСТЬЮ ОБЩЕСТВА

В связи с тем, что финансирование производственной деятельности ОАО «ОМКБ» в 2014 году осуществлялось, в основном, за счёт кредитных средств, предприятие в большой степени было подвержено финансовым рискам, связанными с изменением (ухудшением) финансового состояния, изменением (ростом) процентной ставки за пользование кредитными средствами, изменением (уменьшением) объёмов ГОЗ в АО «ОКБ «Новатор» в зависимости от политических изменений в РФ, а также возможным выходом на рынок конкурента (ОАО «НПО «Сатурн»).

Учитывая утрату финансовой независимости, ОАО «ОМКБ» ограничено в выборе действий в случае наступления вышеуказанных негативных факторов (падение спроса на продукцию, повышение ставок за пользование заёмными средствами, ухудшение финансового состояния основного заказчика, уменьшение объёмов ГОЗ для АО «ОКБ «Новатор», заключение заказов с ОАО «НПО «Сатурн» и др.).

В 2014 г. ОАО "ОМКБ" в рамках этих направлений проводило следующие работы:
- серийное изготовление изделий 37-01 и его модификаций;
- работы по применению изделия 37-03 в составе изделия 715 (изделие 37-04);
- опытно-конструкторские работы по модернизации изделия 37-04 (изделие 37М);
- ремонт и продление ресурса по техническому состоянию двигателя ТВД-10Б;
- конструкторское сопровождение серийного производства и эксплуатации двигателей собственной разработки (ТВД-20, ВСУ-10, изделие 13, изделие 37-01Э).

The 2015 report indicates that the 37-01 engine continued to be serially produced, and clarifies that the 37-series of engines are designated for use in cruise missiles through the reference to the use of the 37-04 and 37-05 series engines being developed for *GMKB Raduga*, a defense contractor producing missiles with similar operational requirements and characteristics to the Kalibr:

В 2015 г. АО «ОМКБ» в рамках этих направлений проводило следующие работы:
- серийное изготовление изделий 37-01 и его модификаций;
- работы по применению изделия 37-03 в составе изделия 715 (изделие 37-04);
- опытно-конструкторские работы по модернизации изделия 37-04 (изделие 37М);

Планируемые инвестиционные проекты:

На 31 декабря 2015 года утверждены или находящихся в стадии оформления и решения вопросов финансового обеспечения следующие инвестиционные проекты:

1. «Строительство и техническое перевооружение АО "ОМКБ" в 2015 - 2018 годов с целью выполнения программы изготовления изделий 2015-2020 годов».
2. «Развитие производственных мощностей, строительство и техническое перевооружение АО "ОМКБ" в 2017- 2018 годах с целью выполнения программы выпуска продукции для ОАО "ГМКБ "Радуга" им. А.Я. Березняка»;
3. «Развитие производственных мощностей, строительство и техническое перевооружение АО "ОМКБ" в 2016- 2017 годах с целью обеспечения программы выпуска продукции для АО "ОКБ "Новатор"»;
4. «Строительство и техническое перевооружение АО "ОМКБ" в 2016- 2018 годах с целью изготовления изделий 37-04 для ОАО "ГМКБ "Радуга" им. А.Я. Березняка»;
5. «Строительство и техническое перевооружение АО "ОМКБ" в 2019- 2020 годах с целью изготовления изделий 37-05 для ОАО "ГМКБ "Радуга" им. А.Я. Березняка»;
6. «Строительство и техническое перевооружение АО "ОМКБ" в 2019- 2020 годах с целью изготовления изделий 73Б для ОАО "ГМКБ "Радуга" им. А.Я. Березняка»;

OMKB's 2016 report is the first to explicitly link the 37-01 engine to the 3M-14 platform, and notes that the Company has taken preliminary steps to produce a purported extended-range version of the existing missile (the 3M-14M).

В 2016 г. АО «ОМКБ» в рамках этих направлений проводило следующие работы:

- серийное изготовление изделий 37-01 и его модификаций;
- работы по применению изделия 37-03 в составе изделия 715 (изделие 37-04);
- опытно-конструкторские работы по модернизации изделия 37-04 (изделие 37М);
- выполнение эскизно-технического проекта по теме «Создание изделия 73Б в соответствии с требованиями ТЗ»;
- научно-исследовательские работы по теме «Исследование возможности создания малогабаритного ТРД»;
- работы по теме «Подготовка материалов по модернизации изделия 37-01 для применения в составе изделия 3М-14М»;
- ремонт и продление ресурса по техническому состоянию двигателя ТВД-10Б;
- конструкторское сопровождение серийного производства и эксплуатации двигателей собственной разработки (ТВД-20, ВСУ-10, изделие 13);
- работы по увеличению назначенного ресурса двигателя ВСУ-10-02 с 4500 часов (6300 циклов) до 10000 часов (10000 циклов).

The final publicly available annual report, from 2017, states that OMKB will continue to develop 37-series cruise missile engines, but suggests that it is facing severe production challenges due to its financial situation, depleted equipment, and a worker shortage:

> The primary issues facing OMKB are as follows: 1) the age and degradation of equipment and a lack of own funds for the modernization and technical upgrades of the production line, intended to grow production capacity owing to the increase in orders, as well as insufficient throughput of the testing station located in a production facility built in 1941, whose technical defects limit the work that can take place, pose a risk to safety, and create a risk collapse. 2) A deficit of qualified specialist personnel. 3) The repayment of obligations owed to creditors… and the interest on borrow funds.[77] (14)

77. Author's translation

The report also provides insight into specific factors output-limiting factors. In section 7.6, titled "Maximum Allowable Production Capacity", OMKB writes that its output is limited by the testing stage of production (taking place at Stand 4), and provides a breakdown of its output, using the example of 37-series products. According to the report, each engine takes 20 hours to evaluate and configure, and the testing station has an annual availability of 5,868 hours, accounting for repair and maintenance. Therefore, the throughput for the 37-series engines is $\frac{5{,}868}{20} = 293$ units per year.

7.6. Максимально допустимая проектная мощность по выпуску продукции в отрасли (натуральный показатель, его размерность)

Максимально допустимая проектная мощность предприятия по выпуску продукции определена по слабому звену – Испытательной станции.

Длительность проведения испытаний изделия «37» на стенде № 4 составляет 20 часов (с учетом выполнения дополнительных настроек).

Годовой фонд работы стенда № 4 – 2445 * 3 * 0,8 = 5868 часов,

Где 2445 ч – фонд времени работы стенда в 1 смену с учетом работы по субботам;

3 – сменность работы;

стр. 15

Годовой отчет АО «ОМКБ»

0,8 – время полезного использования стенда – с учетом простоев в ремонте и техническом обслуживании.

Мощность равна: 5868 : 20 = 293 изделия.

The report later confirms that there is only one suitable testing stand for the 37-series engine.

2 Выход из строя стендового оборудования

№ п/п	Риски	Мероприятия по снижению рисков
1	Старый корпус.	Разработан проект по созданию испытательного комплекса.
2	Высокая загрузка и изношенность испытательного комплекса.	
3	Зависимость от единственного стенда (стенд № 4) по испытанию изделия 37 и его модификации с наддувом.	Начаты работы по оснащению стенда №15 системой наддува для имитации полета.

The document also notes that Novator owed 984.9 million rubles for products it had received by the end of 2017, representing 92% of the outstanding debt owed to OMKB by purchasers. Raduga's debt was far less, 76.9 million rubles, and is insufficient to explain the substantial increase in accounts payable seen over the 2015 - 2017 period.[78]

9.4. Дебиторская задолженность (тыс. руб.). Динамика за последние три года

Вид дебиторской задолженности	31.12.2015	31.12.2016	31.12.2017
Задолженность покупателей и заказчиков	196 565,00	834 309,00	1 068 223,00

This spike in debt is indicative of a large purchase from Novator and allows for rough estimates to be made regarding annual purchase quantities. Precise calculations are infeasible, as there is no indication across the reports concerning when or by whom specific amounts of debts to OMKB were generated; all that is known is the outstanding balance owed to OMKB, which could have been incurred over a series of years. However, there is reason to believe that Novator consistently generated a large share of the total outstanding debt issued for a given year; OMKB designates it is one of its two primary customers, and the cumulative yearly growth in accounts receivable from 2015 to 2017 is smaller than Novator's debt. Assuming, therefore, that Novator was consistently responsible for generating 92% of the total outstanding debt held by OMKB for a given year, and that all Novator's engine purchases were financed, the following inflation-adjusted production figures can be derived: in 2016, OMKB delivered 328 engines, while in 2017 it delivered 116, for an average of 222 units per year.[79] Further information is unavailable, as earlier annual reports do not break down accounts receivable by the amount owed to OMKB by its customers.

Engine production rates can also be estimated using revenue. OMKB is known to have achieved-serial rate production of its 37-series engines by 2016, including presumably, those used by Novator, given its share of the total debt. Although no evidence regarding an identifiable cause exists, OMKB's 2016 revenue increased by 56% (1,027,327,000 rubles) compared to its 2015 results, outpacing a 7% national inflation rate. Anecdotal evidence suggests that 2016 was when Russia's leaders began to procure more Kalibrs, after some had been expended in Syria, as

78. Of the subcontractors to OMKB who owe it funds in repayment for an advance to purchase materials, the three largest debtors were OMashKB (102.2 million rubles), Lepse (76.9 million rubles), and VSIMPO-AVISMA (44 million rubles).
79. "Russian Inflation, 2011 - 2016," InflationTool, accessed 2022, 04/14/2022, https://www.inflationtool.com/russian-ruble?amount=1197081&year1=2011&year2=2016&frequency=yearly.

public figures cited production statistics beginning that summer. Anatoly Gulaev, the head of procurement for the MOD, noted in July 2016 that 47 Kalibrs had been delivered in the first half of the year, while vice-minister Yuri Borisov stated that October that an additional mix of 100 Onyx and Kalibr missiles had been received in the third quarter alone.[80][81] Additionally, the 2015 report notes that full scale production for Novator products was scheduled to take place from 2016-2017, whereas other customers were scheduled to have their products produced later (e.g., 2019 - 2020); 37-series engines were the primary product between 2016-2017.

3. «Развитие производственных мощностей, строительство и техническое перевооружение АО "ОМКБ" в 2016- 2017 годах с целью обеспечения программы выпуска продукции для АО "ОКБ "Новатор"»;

Therefore, assuming that costs between variants of the 37-series are equal (as suggested by the 2013 report) and that sales of these engines are exclusively responsible for the 2016 revenue increase, OMKB would have produced 573 units, adjusted for inflation.

Electronics Analysis:

Studying the procurement documents of an electronics-systems subcontractor to OKB Novator yields additional insights into Kalibr production rates. *NPP Konversia* produces electrical connectors used to create and terminate circuits, including the Kedr and VK/RK - 120 series that it is known to have sold to Novator until at least 2017.

3.12. . Изготовление и поставка электроразрывных соединителей
ЭНВ-У1-2-100 «Кедр-2».
По договору № 485 от 09.11.2012г. с **ОАО «ОКБ»Новатор»**, г. Екатеринбург, изготовлено и поставлено **60 соединителей «Кедр-2».**

Per Konversia's website and its procurement contracts with Novator, these connectors are intended to be used in military airborne applications:[82]

80. "ВМФ РФ получил в первом полугодии 47 ракет "Калибр" и 72 зенитные управляемые ракеты ".
81. "Российский флот получил за три месяца более сотни ракет «Оникс» и «Калибр»," Lenta.ru, updated 10/21/2016, 2016, accessed 04/27/2022, https://m.lenta.ru/news/2016/10/21/missiles/.
82. "Contract #31604585629."

ВОЗДУШНЫЕ

Соединители Электроразрывные Типа ЭНМ-У7-11, ЭКМ-У7-12, ЭКМ-У7-13 **«Бутан М»**

Соединители Электроразрывные Типа ЭНМ-У7-18, ЭКМ-У7-19, ЭКМ-У7-20 **«Бутан МР»**

Соединители Электроразрывные Типа ЭНМ-У7-24, ЭКМ-У7-25, ЭКМ-У7-25 **«Бутан ПМ»**

Соединители Электроразрывные Типа ЭКМ-П7-2-103 **«Береза»**

Розетка Проверочная Малогабаритная Типа РПМ-100

Соединители Электроразрывные Типа ВК-120 И РК-120

Соединители Электроразрывные Типа АЭР-250

Соединители Электроразрывные Типа АЭР1-3 **«Аргон»**

Соединители Электроразрывные Типа ЭНВ-Б11, ЭНВ-Б12, ЭНВ-Б13 **«Контакт»**

Соединители Электроразрывные Типа ЭНМ-Б2-1 **«Лазурит»**

Соединители Электроразрывные Типа ЭНВ-Б19 **«Рябина»**

Соединители Электроразрывные Типа ЭНВ- У1-3 **«Кедр-3»**

Соединители Электроразрывные Типа ЭНВ-У1-2 **«Кедр-2»**

Соединители Электроразрывные Типа ЭНВ-Б6-1 **«Кедр-1»**

КОСМИЧЕСКИЕ

ГЛУБИННЫЕ

НАЗЕМНЫЕ

ЭЛЕКТРОТЕХНИЧЕСКИЕ И РАДИО-

The connectors' technical specifications indicate that they are designed for an extreme range of operating conditions, including high g-force loads associated with rocketry. Their dissimilar appearance further suggests that they are intended to be used within the same rocket body, although this assertion cannot be validated without access to technical drawings. Versions of Konversia's annual reports with specific delivery quantities are available through the 2014 calendar year (amounts are shown in the table below):

Year	Type	Amount
2011	Kedr-1	20
2011	Kedr-2	50
2014	Kedr-2	60

Additional details concerning production quantities can be found in two procurement documents from sole-source contracts executed on 09/18/2017 and 10/24/2017. These denote purchasing agreements at a more granular level than Konversia's annual report, per the following table:

Delivery Date	Type	Amount
Nov-17	Kedr-2	330
Jan-18	Kedr-1	120
Dec-18	Kedr-2	210
Dec-18	Kedr-1	90
Mar-19	Kedr-2	120
Mar-19	Kedr-1	30

The contracts for the Kedr units also include explanatory statements by Novator's board detailing their reasons for pursuing a sole-source procurement effort. These documents show that on September 18, 2017, Novator expressed concern over its ability to meet government-mandated production deadlines. According to the board, for these to be met, Novator had to begin receiving Kedr-2 units in January 2018. Of the two available suppliers, Konversia and a competitor, Elekon, only Konversia would be able to make the deadline by delivering the first batch of connectors in November 2017. Conversely, Elekon would have required six months from the receipt of payment to provide units and quoted a price nearly 15% higher than Konversia.[83] It was therefore agreed to award the contract to Konversia to produce 660 Kedr-2 units; delivery would begin in November 2017 - although their utilization would not occur until January 2018 - and end in March 2019. A little over a month later, on October 24, 2017, Novator's board used similar reasoning to award Konversia another contract to produce 240 Kedr-1 units, also with a final delivery date of March 2019. Both contracts are affiliated with the same master government order (1719187401382412209017222), indicating that both Kedr-1 and Kedr-2 units are intended to be used in the same production cycle. This master order was also used to purchase AMg6M forgings in October 2017, strongly suggesting the connectors' use in Kalibr production.

These delivery figures lend themselves to three interpretations concerning the ratio of Kedr-1 to Kedr-2 units. Given the March 2019 delivery date of 30 and 120 units, respectively, it may be that each rocket uses them in a 1:4 ratio. However, the data also suggest a procurement plan that accounted for spares. The December 2018 and 2011 data indicated Kedr-1 to Kedr-2 ratios of 1:2.33 and 1:2.5, respectively, while the ratios for January 2018 utilization and the overall 2017 contract are both 1:2.75. In all cases, however, Kedr-1 units appear to be comparatively less utilized. Assuming, therefore, that the Kedr-1 is the more critical component and that each Kalibr uses one Kedr-1, these data can be used to calculate production estimates. If the first Kedr-1 units were utilized on Jan 1, 2018, and Konversia was able to produce similar amounts of connectors in 2019 given the same lead time as in 2017 (one and a half months), then Kalibr production between January 2018 and March 2019 is approximately 210 units, or approximately 181 units per year.

83. Konversia and Elekon quoted prices of ₽211,132,046.69 and ₽244,480,117.20, respectively

Kalibr Cost Estimates:

Verifiable official and semi-official information about the unit cost of a Kalibr is almost entirely unavailable. The most authoritative source regarding this figure is MOD spokesman General Igor Konashchenkov, who responded in August 2016 to a July article published that same year in the magazine *Independent Military Review* claiming that 44 missiles cost approximately USD41 billion in 2015 terms. General Konashchenkov disputed these figures, stating: "This would make the price of one Kalibr missile equal to almost USD1 billion. Even to the average man in the street, who is far-removed from the business of the defense industry, it would be obvious to see the stupidity of this amount. The estimates for the cost of these Kalibr missiles in this article are not only several tens or hundreds of times over-stated, but thousands of times too high."[84] This rebuttal suggests that the maximum per-missile price, in 2015 dollars, was no greater than USD1 million. It must be noted, however, that the article to which General Konashchenkov referred to, cites, by roughly converting Tomahawk launch costs to rubles, a total cost of $41.85 million for the launch of the 44 missiles (for a unit cost of approximately $951,000 in 2015 terms.) [85]

Lower boundaries for the Kalibr's cost can be established by comparing its comparable subsystems- in this case, the avionics, to known costs for the Tomahawk missiles. Previous analysis in this paper has, very roughly, suggested an approximately 9% difference in cost between each system's avionics. If that amount represents an average cost difference between the two weapons, this information, coupled with a 2015 per-unit Tomahawk cost of $1,092,000, suggests that each Kalibr cost approximately $993,720. This estimate is closely aligned with those of other experts, who offer per-unit launch cost figures ranging from $750,000-$900,000, in 2016 dollars, and with the upper limit indicated by General Konashchenkov.[86] Therefore, if

84. Reuben F Johnson, "Russian MoD slams published numbers on Kalibr missile pricing," in *Janes's Defence Weekly* (08/05/2016, Fort Lauderdale: Jane's Group UK, 02/22/2022 2016). https://customer.janes.com/Janes/Display/jdw62744-jdw-2016.
85. Владимир Гундаров, "Полгода работы и два часа войны обошлись почти в три миллиарда рублей," (Независимая Газета: Независимое Военное Обозрение, 07/22/2016 2016). https://nvo.ng.ru/nvoevents/2016-07-22/2_news220716.html.
86. Антон Баев, "Сколько стоил год войны," (Wayback Machine), 09/30/2016 2016, https://web.archive.org/web/20200810150635/https://www.rbc.ru/newspaper/2016/10/03/57ebb7199a7947db5bb2b309.

Novator's revenue is assumed to be solely derived from the sale of Kalibrs, its publicly available data indicate that it produced approximately 415 units in 2019. However, this figure does not account for the significant rise in production costs between 2014 and 2019, which, according to Novator's own data rose 69% over the period, far outpacing a 6.6% average inflation rate.[87] Although some of the rise in Novator's cost of goods is attributable to an increase in purchases, experts have long noted that the 2014 post-Crimean invasion sanctions affected Russia's defense industry, leading to costly import-substitution efforts. [88] [89] While specific figures regarding costs are unavailable, it is likely that the increased cost of critical subcomponents was passed on to the Russian government, resulting in fewer units produced than simple projections suggest.

Estimate Integration:

Kalibr production estimates vary based on the method and data used. Under the most unrealistic assumptions, which assume a subcontractor's revenue to be exclusively derived from a single source, and an unlimited production capacity of all other critical subcomponents, the Russian military could expect an output of between 329 - 573 missiles per year in 2015 and 2016, respectively, indicated by the delivery of guidance systems and engines. The lower range of estimates, based on analysis of aluminum tube procurement, suggests that Kalibr production in late 2015 ranged between 135 - 346 missiles per year. Averaging the derived figures from across five approaches results in an average output of 290 Kalibrs per year since 2015.[90]

Despite the wide range of estimates, the derived average annual production capacity is within around 1% of the figure given by the most specific available evidence - that of OMKB's 2017 annual report stating that 37-series engine throughput was limited to 293 units per year. Accordingly, even with an implausible test stand uptime rate of 95%, Novator would not be able

87. "Отчетность организации АО "ОКБ "Новатор"," (List-Org, 03/30/2022 2019). https://www.list-org.com/company/14089/report.
88. S. V. Novikov, V. V. Lastochkina, and A. D. Solodova, "Import substitution in the industrial sector: analysis and facts," *IOP Conference Series: Materials Science and Engineering* 537, no. 4 (2019/05/01 2019), https://doi.org/10.1088/1757-899x/537/4/042056, http://dx.doi.org/10.1088/1757-899X/537/4/042056.
89. M. Russell and European Parliament. Directorate-General for Parliamentary Research Services, *Russia's Armed Forces: Reforms and Challenges : In-depth Analysis*, European Parliamentary Research Service (2015), 16, https://www.europarl.europa.eu/thinktank/en/document/EPRS_IDA(2015)554213.
90 $\frac{329+135+346+157+300+316+293+328+116+573+181+415}{12} = 289.91$

to obtain more than 350 Kalibr engines per year. Recent modernizations to this equipment, conducted in early 2021, indicate that its electrical components were replaced, and are expected to have an uptime of 83% (20 hours per day), approximating the designated uptime of 80% indicated in the 2017 report.[91] Unless Kalibr engine production has been distributed among other companies, or additional testing facilities have been constructed, recent production rates are likely to be similar to those in 2017.

Перечень запасных частей

1. Перечень запасных частей и их объем.

№ п/п	Наименование запасных частей	Ед. изм.	Кол - во
1	Система управления для электродвигателей постоянного тока типа ГП-1100-1000, МПД-1360-1000	шт.	1
2	Трансформатор силовой сухой 1865/6/0,66 кВ	шт.	1

2. Требования технического характера запасных частей.

2.1. Система управления для электродвигателей постоянного тока типа ГП-1100-1000, МПД-1360-1000

№ п/п	Техническая характеристика	Требования
1	Номинальный выходной постоянный ток, А	1850
2	Номинальное выходное напряжение постоянного тока, В	800
3	Сетевой протокол для управления системой	Modbus RTU, Ethernet IP
4	Степень защиты, IP	21
5	Система вентиляции	Автономная
6	Доп. органы дистанционного управления	2 внешних цифровых панели управления с возможностью грубой (шаг не более 25 об/мин с погрешностью не более 4%) и точной (шаг не более 0,5 об/мин с погрешностью не более 5%) регулировкой оборотов вала двигателя, индикация «Сеть», «Работа», «Авария»
7	Точность регулировки оборотов	От 50 до 1080 об/мин
8	Режим пуска	Плавный
9	Режим остановки	Свободный выбег
10	Максимальное время непрерывной работы электродвигателя постоянного тока в сутки	20 часов
11	Количество одновременно работающих электродвигателей постоянного тока, шт.	1
12	Коммутация между используемыми электродвигателями постоянного тока	На лицевой панели управления
13	Среднее время работы одного электродвигателя в год	500 часов

Annual output estimates of 290-350 missiles are higher than those indicated by Russian officials. On April 12, 2019, for example, Defense minister Sergei Shoigu stated that 48 Kalibrs had been accepted by the Russian military since the beginning of the year, corresponding to an annual rate of 177 units, a decrease from the 240 units that he implied could have been produced

91. "Contract #32009809527 ", (Закупки.ру, 03/30/2022). https://zakupki.gov.ru/epz/order/notice/notice223/common-info.html?noticeInfoId=12057083.

in 2017. [92] [93] Although it is possible that Russian officials deliberately obfuscated Kalibr deliveries, or that the media omitted relevant details (the 2017 statement references only missile deliveries to the Navy, and not the other military branches, for example), the analysis of open-source materials demonstrates that such figures are probably within the reach of Russia's industrial capacity.

Discussion:

OKB Novator appears to be capable of manufacturing at least 300 Kalibr missiles per year, with an upper limit of approximately 350. Based on known Russian expenditures of precision-guided munitions in the Ukrainian conflict (including, but not limited to Kalibrs), such quantities appear to be insufficient for operational military purposes. Ukrainian forces have continued fighting despite strikes on government facilities and infrastructure, and, as of the time of this writing, appear to be mounting counteroffensives and regaining lost territory. [94] [95] [96] Russian PGM stocks may already be strained; U.S. defense officials reported on March 21, 2022 that "…we do think that they are beginning to face some inventory issues with precision-guided munitions, which is one reason why you're seeing the increasing use of what we would call dumb bombs, and we've also seen them suffer failures of some of their precision-guided munitions, where it -- they're just not -- they're not operating. They're not -- they're -- they're failing. Either they're failing to launch or they're failing to hit the target, or they're failing to explode on contact.

92. Павел Настин, "Шойгу назвал количество ракет «Калибр», поступивших в войска с начала 2019 года," (TVZvezda, 04/12/2019 2019). https://tvzvezda.ru/news/20194121232-ebxdY.html.
93. Евгений Калюков, "ВМФ России получил еще 60 крылатых ракет «Калибр»," (Wayback Machine: Росбизнесконсалтинг: РБК & The Internet Archive, 07/26/2017 2017). https://web.archive.org/web/20200901193837/https://www.rbc.ru/society/26/07/2017/59786f6b9a7947ca0d79ec68.

Shoigu stated that 60 had been delivered in the second quarter.

94. @Osinttechnical, "Mykolaiv, a camera captured a Kalibr hitting the regional administration building," (Twitter, 2022).
95. "Russia says it destroyed fuel depot outside Kyiv in missile strike," Thomson Reuters, updated 03/25/2022, 2022, accessed 03/30/2022, 2022, https://www.reuters.com/world/russia-says-it-destroyed-fuel-depot-outside-kyiv-missile-strike-2022-03-25/.
[96] Kateryna Stepanenko, Karolina Hird, and Mason Clark, "Russian Offensive Campaign Assessment, April 25," *Ukraine Conflict Updates*, *Institute for the Study of War & American Enterprise Institute* 04/25/2022, 2022, https://www.understandingwar.org/backgrounder/ukraine-conflict-updates.

So we're seeing them have some struggles with respect to precision-guided munitions." [97]

Although the Ukraine conflict is not a suitable case for analyzing Russia or the West's theories of strategic deterrence, the inability of PGMs to determine the outcome of the conflict suggests that Alexander Yermakov and Dmitry Stefanovich were correct in doubting the utility of these weapons as instruments of punishment. Referring to Western expenditures of cruise missiles in several Middle Eastern countries, they write: "If hundreds or even thousands of missiles were not enough to force a third-world country to surrender (not to mention the many thousands of airstrikes that were carried out at the same time), then how many are needed to deliver unacceptable damage to a major military power? Or to a bloc of powers that Russia needs to deter first and foremost. You can doubt the decisiveness of the European members of NATO all you like, but if the desire to build up forces to deter the adversary using non-nuclear means is declared, then an unimaginable number of such weapons would be needed."[98] Presently, Russia's reliance on cruise missiles in Ukraine, which has increased as it has lost territory it initially seized, suggests that its leaders have resolved the theoretical debate between utilizing PGMs as both deterrent and warfighting tools in favor of the latter. [99] [100]

Although it is impossible to discern at this time whether this operational shift reflects a longer-term doctrinal adjustment, its implications must be analyzed within the context of Russia's military industrial capacity. This paper has suggested that Russia cannot produce an "unimaginable number" of the weapon arguably best suited to the task of non-nuclear deterrence. Instead, the Kalibr can probably only be produced at a rate of around 300 per year. For context, a 1982 RAND study examining the acquisition process for the cruise missiles that eventually became the Tomahawk and Air-Launched Cruise Missile (ALCM) noted that American military planners anticipated needing a production rate of 10 cruise missile engines per day in 1977. [101]

97. Unknown, "Senior Defense Official Holds a Background Briefing ", 03/21/2022, 2022, https://www.defense.gov/News/Transcripts/Transcript/Article/2973395/senior-defense-official-holds-a-background-briefing/.
[98] Yermakov and Stefanovich, "Is Non-Nuclear Deterrence Possible?."
99. Jane Arraf, Ivan Nechepurenko, and Mark Landler, "Ukraine Says Russia Begins Assault in the East After Raining Missiles Nationwide," *The New York Times*, 04/18/2022 2022, https://www.nytimes.com/2022/04/18/world/europe/ukraine-russia-missiles-lviv-donbas.html.
100. Johnson, *Russia's Conventional Precision Strike Capabilities, Regional Crises, and Nuclear Thresholds*, 46.
101. E. H. Conrow, Giles K. Smith, and A. A. Barbour, *The Joint Cruise Missiles Project: An Acquisition History* (Santa Monica, CA: RAND Corporation, 1982). https://www.rand.org/pubs/reports/R3039.html.

Contemporary U.S. Navy budget documents indicate a much lower production rate of 60-120 Tomahawks per year, which are, in part, purchased to keep production facilities open, although the stated annual maximum output of Tomahawks is 450 units per year.[102] The U.S. Navy likely feels comfortable with a smaller actual annual production output compared to the Kalibr program because over 8,000 Tomahawks have been purchased since their first use in the Gulf War, while Russia has had insufficient time to establish a comparable stockpile.[103]

Systemic challenges facing the Russian defense industry likely similarly constrain the production rate of other PGMs and have contributed to their operational failures in Ukraine.[104] Many firms struggle financially, with low profit margins, and cannot adequately invest in production capacity. [105] OMKB, for example, wrote in 2015 that "the difficult financial and economic situation in Russia negatively affected the pace of production capacity modernization programs, reducing them to a minimum…There are currently no sources of funding for capital investments…"[106] A year earlier, a tender issued by Novator for upgrades to its machining facilities noted that over 55% of its equipment used for making Kalibrs was over 20 years old, while only 9.3% was under 5.[107] Others struggle to attract qualified personnel.[108] [109] Some sectoral corporate leaders have also noted the dampening effects of purely bureaucratic issues on output; Novator's general director, Farid Habibulovich Abrahmanov, stated at a 2018 meeting of the Union of Mechanical Engineers that he had been forced to create a new division to deal with

102. Weapons Procurement, Navy - Justification Book FY 2022, 45 - 46 (Washington, D.C.: Office of Budget, Financial Management and Comptroller, 2021).
103. The U.S. Navy's FY2016 budget request book noted that "Procurement of new missiles has been suspended beginning in FY17 because inventory will satisfy munition requirements. *See*: Weapons Procurement, Navy - Justification Book FY 2016, (Washington, D.C.: Office of Budget, Financial Management and Comptroller, 2015). ." (45)
104. Susanne Oxenstierna and Fredrik Westerlund, "Arms Procurement and the Russian Defense Industry: Challenges Up to 2020," *The Journal of Slavic Military Studies* 26, no. 1 (2013), https://doi.org/10.1080/13518046.2013.757135.
105. Владимир Иванов, "Оздоровление предприятий ОПК – приоритет власти," (Независимая Газета: Независимое Военное Обозрение, 02/14/2020 2020). https://nvo.ng.ru/nvo/2020-02-14/1_1081_priority.html.
106. OMKB 2015 Annual Report, page 20. *See*: "АО "ОМКБ": Годовые Отчеты."
107. "Извещение о проведении торговой процедуры "Запрос предложений (в форме ПДО) покупателя № 1240606" ", (Фабрикант.ру, 02/18/2022 2014). https://www.fabrikant.ru/market/view.html?action=view_pdo&type=4360&id=1240606. *See*: page 37 of Novator's work proposal.
108. Unknown, *Кадры решают все. Панорама 9 апреля 2021* (YouTube: RimMediaOfficial, 2021).
109. Каштанова Е.В. and Сувалова Т.В., "Современные тенденции кадрового обеспечения предприятий оборонно-промышленного комплекса России: проблемы системы подготовки кадров и пути решения," *E-Management* 4, no. 4 (2021), https://doi.org/https://doi.org/10.26425/2658-3445-2021-4-4-86-96.

the “18-20” legal issues related to R&D efforts per month brought by various prosecutors’ offices.[110] In a July, 2019 interview, vice-minister Yuri Borisov, who oversees the defense industry, noted that military contractors (including Novator’s parent firm, Almaz-Antey) were often living “hand-to-mouth” because of a high debt load that was eventually restructured. [111] [112] [113] Western sanctions imposed after Russia’s annexation of Crimea further harmed its PGM development efforts by forcing it to domestically rebuild, at high cost, the facilities needed to manufacture previously imported critical subcomponents, including those used in cruise missiles. [114] [115] New sanctions and the withdrawal of Western firms from Russia will exacerbate existing challenges in acquiring, maintaining, and replacing necessary machine tools and microelectronics. Many defense companies, including Novator, rely on newly-inaccessible Western technologies. Siemens, for example, maker of the *Sinumerik*-line of CNC controllers used by Novator, has halted its business in Russia, as has DMG Mori, which makes machine tools used by OMKB. [116] [117] Field analysis of Russian cruise missiles launched in Ukraine has revealed Russia’s heavy reliance on Western-manufactured subcomponents for its precision munitions, while Russia’s only tank manufacturer, Uralvagonzavod, has ostensibly halted

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110. "Горячая любовь прокуратуры ", Холдинг НИКС, updated 04/19/2019, 2019, accessed 03/18/2022, 2022, https://www.nix.ru/computer_hardware_news/hardware_news_viewer.html?id=198416.
111. "Юрий Борисов: у директорского корпуса не должно быть соблазна, что спишут все их долги," Интерфакс, updated 07/17/2019, 2019, accessed 03/30/2022, 2022, https://www.interfax.ru/interview/669359.
112. "Извещение о проведении торговой процедуры "Запрос котировок цен покупателя № 1147371" ", (Фабрикант.ру, 02/18/2022 2013).
https://www.fabrikant.ru/market/view.html?action=view_public_offer&type=4560&id=1147371.

Novator took out a 10.3% APR loan to finance expansion when the 2013 average was 9.467 %.

See: "Извещение о проведении торговой процедуры "Запрос котировок цен покупателя № 1147371" ". and "Lending Interest Rate (%) - Russian Federation," (The World Bank Group, 03/29/2022).
https://data.worldbank.org/indicator/FR.INR.LEND?end=2016&locations=RU&start=2005.
113. Andrey Biryukov and Evgenia Pismennaya, "Putin's Huge Military Buildup Leaves Industry With Debt Hangover," *Bloomberg*, 07/16/2019 2019, https://www.bloomberg.com/news/articles/2019-07-16/putin-s-huge-military-buildup-leaves-industry-with-debt-hangover.
114. Novikov, Lastochkina, and Solodova, "Import substitution in the industrial sector: analysis and facts."
115. Александр Тихонов, "Новое оружие высокой точности " *Красная Звезда*, 08/27/2021 2021, http://redstar.ru/novoe-oruzhie-vysokoj-tochnosti/.
116. Christoph Steitz, "Siemens Energy stopping all new business in Russia," 03/02/2022 2022, https://www.reuters.com/business/siemens-energy-stopping-all-new-business-russia-2022-03-02/.
117. "DMG Mori stops all business activities in Russia ", ETMM-Online, updated 03/14/2022, 2022, accessed 03/31/2022, https://www.etmm-online.com/dmg-mori-stops-all-business-activities-in-russia-a-1102716/.

production for lack of parts. [118] [119]

Strategically, Russia's comparatively limited stock of Kalibrs exacerbates its fear-inducement challenges by complicating its targeting policies. Recall that Russia's development of precision-guided munitions was partially motivated by the flexibility such weapons afford in delivering dosed, or "assigned" damage that could psychologically compel an adversary to seek a negotiated settlement before the employment of nuclear weapons. The fewer PGMs Russia possess, the greater its incentive to strike countervalue targets, and critical ones within that set (such as nuclear plants, dams, or substations), at the beginning of a conflict with the missiles allocated for deterrence purposes.[120] Doing so, however, would likely lead to more severe escalation from its adversaries than if it had targeted lower value units, undermining the missiles' utility as a deterrent. Russia could instead use PGMs to target low value units, but the comparatively limited damage that any single (or even grouped) cruise missile strike can inflict, along with its constrained production capacity, heightens the chance that its adversary will perceive a subsequent conventional strike on an equally valuable target as less credible because it knows that Russia would feel pressured to strike increasingly valuable targets up the escalation ladder to the nuclear threshold as it depletes its munition stocks. This case is a "conventionally"-modified version of the "magazine depth problem", with the roles of Russia and the United States reversed:

> The first debate is between risk manipulation and escalation dominance as the guiding approach to nuclear coercion. In this case, adopting a small number of **PGMs** to provide limited **conventional** options against **the U.S.** in the event it uses **PGMs** first represents a partial shift away from the former and toward the latter. Because **Washington** possesses a much larger and more diverse inventory of **PGMs**, however, major gaps in the escalation ladder still remain. Under these conditions, it is less likely that **the U.S.** would overreact to an ambiguous **Russian** reprisal by launching an all-out nuclear assault and more likely that it would persist with limited **conventional** attacks. In other words, when it comes to changes in **Russian** force structure, the most significant issue is not a warhead discrimination problem but a *magazine depth problem*. If so, **Russia** would soon find

118. Howard Altman, "Sanctions Are Strangling Russia's Weapons Supply Chain," *The Warzone*, 04/18/2022 2022, https://www.thedrive.com/the-war-zone/sanctions-are-strangling-russias-weapons-supply-chain.https://www.thedrive.com/the-war-zone/sanctions-are-strangling-russias-weapons-supply-chain
119. Jack Watling and Nick Reynolds, *Operation Z: The Death Throes of an Imperial Delusion* RUSI (04/22/2022 2022), 10, https://rusi.org/explore-our-research/publications/special-resources/operation-z-death-throes-imperial-delusion.
120. Andrei Afanas'evich Kokoshin, "Strategic nuclear and nonnuclear deterrence: Modern priorities," *Herald of the Russian Academy of Sciences* 84, no. 2 (2014): 65, https://doi.org/10.1134/s101933161402004x.

> itself in the very position it hoped to avoid: debating whether or not to employ [nuclear] weapons in response to **nonstrategic conventional attacks.”** (3) [121] [changes to the original text are in bold]

Accordingly, in this scenario, Russia’s limited precision strike capabilities enhance the credibility of its nuclear threats issued after the outbreak of conflict because its adversaries know that it has few means for imposing existential costs on its adversary’s civilian population short of using nuclear weapons. Ironically, this empirical finding contravenes the theoretical impetus behind Russia’s development of PGMs by reinforcing the centrality of nuclear arms to its strategic deterrence strategy. Thus, while a relatively limited Kalibr stockpile provides Russia an expanded target set and flexibility in “assigning damage” in the pre-nuclear phase of conflict, the availability of these choices may inadvertently hasten the escalation of a conflict by incentivizing countervalue strikes. [122]

In practice, the analysis of Russia’s Kalibr output and use suggests that nuclear weapons will remain “complementary” to precision-guided munitions as means of attaining strategic deterrence for the foreseeable future.[123] Its stocks of PGMs are likely insufficient to coerce the U.S. or the other leading military powers in NATO, and will probably doctrinally remain

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121. Evan Braden Montgomery, "Posturing for great power competition: Identifying coercion problems in U.S. nuclear policy," *Journal of Strategic Studies* (2021): 3, https://doi.org/10.1080/01402390.2021.1886932.

Original text:

The first debate is between risk manipulation and escalation dominance as the guiding approach to nuclear coercion. In this case, adopting a small number of nonstrategic weapons to provide limited nuclear options against Russia in the event it uses nuclear weapons first represents a partial shift away from the former and toward the latter. Because Moscow possesses a much larger and more diverse inventory of nonstrategic nuclear forces, however, major gaps in the escalation ladder still remain. Under these conditions, it is less likely that Russia would overreact to an ambiguous U.S. reprisal by launching an all-out nuclear assault and more likely that it would persist with limited nuclear attacks. In other words, when it comes to changes in U.S. force structure, the most significant issue is not a warhead discrimination problem but a *magazine depth problem*. If so, the United States would soon find itself in the very position it hoped to avoid: debating whether or not to employ strategic nuclear weapons in response to nonstrategic nuclear attacks. (3)

122. Michael Kofman and Anya Loukianova Fink, "Escalation Management and Nuclear Employment in Russian Military Strategy," *War on the Rocks*, 2020, http://warontherocks.com/2020/06/escalation-management-and-nuclear-employment-in-russian-military-strategy/.

123. Johnson, *Russia's Conventional Precision Strike Capabilities, Regional Crises, and Nuclear Thresholds*, 26.

instruments of warfighting, whose utility stems from their use, rather than fear-inducement capabilities. Based on the Russian government's rhetoric and acquisition patterns (to include the purchase of PGMs), the Russian military has seemingly grown to accept the view that escalatory dynamics between nuclear armed states are manageable.[124] If true, then its procurement of Kalibrs and other sophisticated PGMs has expanded its set of options in the escalation ladder but created new theoretical and practical gaps in its nuclear strategy.

Appendix:

1. Seeker Head Calculations:

Average Dollar-Ruble exchange rate, December 2015: 70.0163129 USD/RUB

Average cost of an apartment in Reutov's secondary market, July 13, 2015: ₽8,016,264

Estimated seeker head cost, in Rubles: 8,016,264 * 2 = ₽16,032,528

Seeker head cost, in Dollars = 16,032,538 / 70.0163129 = $228,982.89

Sum of contracts not likely to involve avionics-related work:

- ₽596,640,670 + ₽112,686,880 + ₽44,136,220 + ₽20,000,000 = ₽773,463,770

2015 NPP Radar revenue unassociated with a source:

- ₽6,049,760,000 - ₽773,463,770 = ₽5,276,296,230

Estimated annual seeker head production rate:

- ₽5,276,296,230 / ₽16,032,529 = 329.0944

2. Rocket Body Calculations:

The per-meter weight of each tube was calculated using an online resource that uses the pipe's outer diameter, wall thickness, and density according to the following formula: weight = π * density * wall thickness *(diameter - wall thickness). The density of AMg6 and AMg6M alloys is the same, 2,640 KG/M^3.

The weight of a single tube of the dimensions given in each order was derived by multiplying its per-meter weight by its length. The number of tubes in each order was found by

124. Montgomery, "Posturing for great power competition: Identifying coercion problems in U.S. nuclear policy."

deriving the weight of the order, in kilograms, by total weight of a single tube.

Example:

A line item in contract number 31604585629 denotes the purchase of 56,700 KGs of 560 x 35 x 8250mm AMg6M tubes.

The weight of each meter of tube is $\pi \times 2 \times .035 \times (.560 - .035) = 152.398659626$ Accordingly, each 8.25m tube weighs 1,257.2889419145 KG.

The total number of tubes ordered in the line item is $\frac{56{,}700}{1{,}257.2889419145}(KG) = 49.0970$ tubes.

Forging Weight Conversion:

Because the contract does not specify the dimensions of the forgings or their intended use, the most common tube dimension, 560 x 35 x 8250mm is used as a standard measure of a rocket body's mass, 1,257.29175 KG.

The December 29 contract indicates that a total of 133,840 KGs of forgings, equivalent to 106 rocket bodies, were to be delivered by April 30, 2017. These figures indicated a daily aluminum processing rate of .8654 casing-equivalent units, or 316 per year.

3. Engine Calculations:

Estimating Engine Output by Debt:

The unit cost of a 37-series engine in 2011 terms is 1,197,081.05 rubles. Adjusted solely for inflation, each engine cost 1,790,544.31 rubles in 2016and 1,856,497.22 rubles in 2017. [125]

OMKB's accounts receivable grew by ₽637,744,000 and ₽233,914,000 in 2016 and 2017, respectively. If Novator was consistently responsible for 92% of each year's increase, it would have purchased at least $\frac{637744000 \times 0.92}{1.79054431 \times 10^6} = 327.6793$ units in 2016 and $\frac{233914000 \times 0.92}{1.85649722 \times 10^6} = 115.9176$ units in 2017

125. "Russian Inflation, 2011 - 2016."

Estimating Engine Output by Revenue:

2015 Revenue: ₽1,831,397,000

2016 Revenue: ₽2,858,724,000

2015 - 2016 revenue difference and percent change: ₽1,027,327,000 (56.0953%)

2016 engine output: $\frac{1027327000\times 0.92}{1.79054431\times 10^{6}} = 573.7512$

1027327000/(1.79054431×10^6) = 573.7512 units

4. Electrical Connector Calculations:

For the connectors identified in the contracts, the earliest possible utilization date for the Kedr-1 units is January 1, 2018, while the latest known date is Feb 28, 2019 (a day before the final batch of 30 units was to be delivered). This is a 423-day difference, during which time 210 Kedr-1 units are believed to have been utilized. If each Kalibr requires a single Kedr-1 connector, Novator's annual output is 210/423×365 = 181.2056 missiles per year.

5. Financial Analysis Calculations:

Average USD/ RUB exchange rate in 2015: 61.2252 [126]

Estimated 2015 Kalibr cost in rubles: $1{,}092{,}000 \times 61.2252 = 66{,}857{,}918.4$ rubles

Estimated 2019 Kalibr cost, solely adjusted for inflation: 79,750,732.05 rubles [127]

Novator 2019 Revenue: 33,124,600,000 rubles. [128]

Estimated 2019 Kalibr output: $\frac{33{,}124{,}600{,}000}{79{,}750{,}732.05} = 415.3516$ units per year

126. "US Dollar to Russian Rouble Spot Exchange Rates for 2015," (Exchange Rates UK, 04/03/2020 2015). https://www.exchangerates.org.uk/USD-RUB-spot-exchange-rates-history-2015.html.
127. "Russian Inflation, 2015 - 2019," InflationTool, accessed 2022, 04/14/2022, https://www.inflationtool.com/russian-ruble?amount=66857918&year1=2015&year2=2019&frequency=yearly.
128. "Отчетность организации АО "ОКБ "Новатор"."

"37-01э." Объединённая Двигателестроительная Корпорация. https://www.uecrus.com/rus/products/bpla/37-01e/.

@Osinttechnical. "Mykolaiv, a Camera Captured a Kalibr Hitting the Regional Administration Building." https://twitter.com/Osinttechnical/status/1508773358489554948Twitter, 2022.

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