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Open-source analysis of the potential configuration and kinetic performance of the Oreshnik ballistic missile

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Purpose. This article presents an analysis of the tactical and technical characteristics of the Oreshnik medium-range ballistic missile, which, according to open-source data, was employed in a precision strike against an infrastructure facility in Dnipro in November 2024. The study focuses on the missile's configuration, warhead type, and aerodynamic behavior using open-source information. **Design / Method / Approach.** An interdisciplinary methodology was applied, comprising Sentinel-2 satellite imagery analysis, kinetic-energy and aerodynamic-heating modeling, and comparative assessment against the Russian Avangard, Rubezh, and UR-100N UTTKh platforms. Missile debris and factory markings were used to reconstruct manufacturing chronology and identify design features. **Findings.** It was determined that Oreshnik is equipped with a hypersonic non-explosive kinetic warhead capable of destructive impact via high-velocity collision. The missile likely follows a suborbital trajectory, achieving speeds of 11–12 km/s and surface temperatures in excess of 4300 K. Markings indicate key components were manufactured in 2017, suggesting reuse of legacy platforms. **Theoretical Implications.** This work advances the theory of kinetic-impact systems by elucidating thermal-loading mechanisms and energy-transfer processes in hypersonic vehicles, thereby bridging contemporary implementations with the historical "Rods from God" concept. **Practical Implications.** The findings reveal limited strike effectiveness owing to high costs and moderate destructive yield, yet underscore the system's value as a demonstrator technology and its utility for hypersonic-system testing. **Originality / Value.** This study constitutes the first technical analysis of an Oreshnik missile strike based exclusively on open-source data, illustrating the growing role of civilian satellite imagery and interdisciplinary modeling in arms-monitoring. **Research Limitations / Future Research.** The analysis relies solely on open-source information. Future work should include detailed damage assessment, thermal-protection analysis, and expanded trajectory modeling with advanced software tools. Enhanced monitoring of high-velocity conventional weapons is recommended to support arms-control and humanitarian-law frameworks. **Article Type.** Applied research.

Keywords:

Oreshnik, kinetic warhead, suborbital trajectory, aerodynamic heating, propulsion configuration, ballistic missile

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Мета. У статті проведено аналіз тактико-технічних характеристик балістичної ракети середньої дальності «Орєшнік», яка, за даними відкритих джерел, застосовувалася для високоточного удару по інфраструктурному об'єкту у місті Дніпро в листопаді 2024 року. Дослідження зосереджене на конфігурації ракети, типі бойової частини та аеродинамічній поведінці з використанням відкритих джерел. **Дизайн / Метод / Підхід**. Застосовано міждисциплінарний підхід: аналіз супутникових зображень Sentinel-2, моделювання кінетичної енергії й аеродинамічного нагріву, порівняння з платформами «Авангард», «Рубєж» і УР-100Н УТТХ. Уламки та заводські маркування слугували для відтворення хронології виготовлення й виявлення конструкційних особливостей. **Результати**. Встановлено, що «Орєшнік» оснащено гіперзвуковою невибуховою бойовою частиною, здатною руйнувати цілі завдяки кінетичному удару. Імовірна суборбітальна траєкторія забезпечує швидкість 11–12 км/с і температуру поверхні понад 4300 К. Маркування свідчать про виробництво ключових компонентів у 2017 році, що вказує на повторне використання старих платформ. **Теоретичне значення**. Робота поглиблює теорію кінетичних систем ураження, демонструючи механізми теплового навантаження й передачі енергії в гіперзвукових блоках, наближаючи сучасні рішення до історичної концепції «Rods from God». **Практичне значення**. Результати виявляють обмежену ефективність ураження через високі витрати й помірну руйнівну потужність, проте підкреслюють демонстраційний потенціал технології й її значення для випробувань гіперзвукових систем. **Оригінальність / Цінність**. Це перший технічний аналіз удару ракетою «Орєшнік» на основі відкритих джерел, який ілюструє зростаючу роль цивільних супутникових зображень та міждисциплінарного моделювання у моніторингу озброєнь. **Обмеження дослідження / Майбутні дослідження**. Дослідження базується на відкритих даних; майбутні роботи мають охопити деталізовану оцінку ушкоджень, аналіз теплозахисту й розширене моделювання траєкторії з сучасними програмними засобами. Рекомендовано посилити спостереження за високошвидкісною неядерною зброєю для контролю над озброєннями та гуманітарного права. **Тип статті**. Прикладне дослідження.

Ключові слова:

Орєшнік, кінетична боєголовка, суборбітальна траєкторія, аеродинамічний нагрів, конфігурація ракетного двигуна, балістична ракета

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The advent of hypersonic weapon systems has introduced new dimensions to strategic deterrence, arms control, and the geopolitical balance of power. The missile strike on the industrial facility in Dnipro, Ukraine, in November 2024 - allegedly involving the previously unknown "Oreshnik" medium-range hypersonic missile - offers a rare case study of a real-world application of such a system. However, this incident has yet to receive a systematic, scholarly assessment grounded in scientific methodology and critical literature analysis. The relevance of studying the Oreshnik system stems from several converging factors. First, the emergence of kinetic, non-nuclear hypersonic strike systems challenges existing military doctrines and missile defense strategies. Second, the growing integration of open-source intelligence (OSINT), satellite imagery, and modeling tools into arms monitoring enables unprecedented transparency. Third, the strike itself demonstrated characteristics distinct from traditional ballistic or cruise missile attacks, suggesting a shift in Russia's approach to strategic signaling. Despite the significance of these developments, existing scholarly literature contains few technical analyses of kinetic hypersonic systems based on verifiable evidence. Previous studies have mostly focused on the theoretical feasibility of systems such as the American "Rods from God" (Hitchens et al., 2006), Chinese kinetic energy weapons (Gubrud, 2011), and the physical modeling of aerodynamic heating during reentry (Meng et al., 2020). However, no peer-reviewed work has addressed the "Oreshnik" incident or attempted to reconstruct its parameters using publicly available data. This work seeks to fill that gap by building on the authors' previous research on propulsion and warhead behavior during hypersonic flight (Bondarenko & Gabrinets, 2023), and by incorporating recent developments in kinetic strike systems and hypersonic missile technologies. The novelty of the study lies in its open-source technical reconstruction of a missile strike, using a multidisciplinary approach. This work contributes both to the theory of kinetic strike systems and to practical arms monitoring methodology. The research is grounded in the hypothesis that the "Oreshnik" missile employs a kinetic warhead configuration, adapted from existing hypersonic platforms such as "Avangard" or "Rubezh". The aim of the study is to reconstruct the tactical and technical characteristics of the "Oreshnik" missile system, assess its design and mode of operation, and evaluate its implications for military efficiency and strategic stability. The analysis logically proceeds from a review of empirical satellite data, through aerodynamic modeling, to comparative assessment and discussion.

Methodology

To analyze the tactical and technical parameters of the "Oreshnik" missile system, this study applies a structured sequence of computational and analytical methods grounded in publicly accessible data. The research design integrates remote sensing analysis, aerodynamic and thermodynamic modeling, classical mechanics, and OSINT. This multidisciplinary approach enables the reconstruction of the missile's flight characteristics, impact behavior, and potential origin, based on visual evidence, debris data, and comparative assessment with known Russian missile platforms.

Object and Conditions of Study

The object of study is the warhead of the "Oreshnik" missile, presumably of a kinetic (non-explosive) type. The research is based entirely on publicly available data - Sentinel-2 satellite imagery, debris photos and videos, official public statements, and associated analytical sources. No classified or restricted information was used at any stage.

Research Stages

1. Data collection. Satellite imagery from before and after the strike was obtained, along with visual records of debris and serial markings. Additionally, a historical timeline of political and military developments preceding the attack was compiled to contextualize the event and assess its strategic significance.
2. Trajectory and motion analysis. Based on visual traces, entry angle, and a typical suborbital flight profile (up to 100 km altitude), a hypothesis was formed regarding a kinetic terminal phase of impact
3. Aerodynamic heating modeling. The nose cone temperature was calculated at different altitudes. Calculations were performed for velocities from Mach 1 to Mach 10 at altitudes between 0 and 20 km.
4. Kinetic energy estimation. The impact energy was calculated under the assumption of a 500 kg warhead traveling at a velocity of 2000-3000 m/s. The resulting values were converted into TNT equivalents to facilitate comparison with conventional explosive munitions.
5. Serial number analysis. Factory markings dated April 12, 2017 were identified on debris, providing a key argument against the system being entirely new.
6. Comparative analysis. Technical comparison was made with Russian platforms such as "Avangard", "Rubezh", and "Kedr" regarding carrier configuration, velocity, trajectory, and warhead design.

Limitations

Due to the lack of precise specifications of the missile (geometry, materials, exact warhead mass), all numerical estimates are approximations based on clearly stated assumptions. Factors such as the role of missile defense systems, combined strikes with other munitions (e.g., Kh-101), and the internal composition of the warhead could not be fully accounted for.

Political-Military Context and Background

The strike on the production complex in the city of Dnipro in November 2024 became one of the most widely discussed examples of the use of high-precision missile weapons with hypersonic characteristics (Malinowski, 2020). The discovery of fragments of the warhead, the nature of the destruction, and the absence of signs of an explosion led to the assumption that a kinetic-impact munition was employed (Senglaub, 1996). This article is dedicated to the analysis of the technical indicators of the attack, the possible characteristics of the weapon used, as well as an examination of hypotheses regarding its origin and its connection to existing Russian strategic missile programs. To provide a complete context, a brief overview of the key events preceding the strike on Dnipro, as well as the politico-military situation that developed immediately before the event, is presented below. At the time of the strike on Dnipro, the war in Ukraine had already been ongoing for 33 months, and the events of mid-November 2024 unfolded against the backdrop of a sharp escalation of the international politico-military situation. On October 14, the President of the Russian Federation submitted to the State Duma a bill on the ratification of a treaty on a comprehensive strategic partnership between Russia and the DPRK (Lee, 2024). On October 18, according to South Korean intelligence, the DPRK authorities decided to send 12,000 troops, including a special forces unit, to participate in the war against Ukraine (Won, 2025). On November 17, representatives of the U.S. administration announced that, in response to Russia's decision to involve North Korean forces in combat operations, President Biden had authorized the first use by Ukraine of U.S.-supplied long-range missiles to strike targets on Russian territory, in defense of Ukrainian forces during an operation in the Kursk region (Usman, 2025). Following the United States, the governments of France and the United Kingdom authorized Ukraine to use their long-range SCALP/Storm Shadow missiles to strike targets within Russian territory (Tanevski, 2025). Depending on the modification, these missiles have a range of between 270 and 560 kilometers. Within 24 hours, Ukraine launched American ATACMS tactical missiles, followed a day later by Anglo-French Storm Shadow cruise missiles targeting the Bryansk and Kursk regions. On November 18, the Speaker of the Russian State Duma announced the possible deployment of new weapon systems against Ukraine. On November 19, the President of the Russian Federation signed a decree updating the country's nuclear doctrine (Smetana & Onderco, 2025), expanding the conditions under which Russian nuclear weapons could be used. The updated document states that Russia would consider aggression by a non-nuclear state with the participation or support of a nuclear power as a joint attack on Russia. On November 20, the U.S. Embassy in Ukraine suspended its operations, publishing information about an impending air attack (similar actions were taken by many other foreign embassies). On November 21, launches of Kh-101 cruise missiles and a Kh-47M2 Kinzhal aeroballistic missile were recorded, along with the launch of an intercontinental ballistic missile of an unknown type from the

Astrakhan region missile test range in Russia. At approximately 5:30 a.m., a non-nuclear hypersonic variant of one of these missiles struck a military-industrial facility in Dnipro. The strike was carried out using the newest medium-range missile system known as Oreshnik. According to eyewitness footage, the Russian military indeed employed some form of new weapon against a strategically important enterprise, although the exact type of munition remains unclear. Later, in statements to the media, when discussing the new complex, the President of the Russian Federation emphasized that existing missile defense systems, including American ones, are unable to intercept the Oreshnik missile (Kadyshev & Kütt, 2024). This missile is reported to strike its target at speeds of 2–3 kilometers per second. Prior to the attack, there had been no mention of this complex either in the media or in Western analytical reports. However, following the strike, numerous assessments were made regarding the system. Some experts referred to it as a modification of the Russian mobile ground-based Rubezh system, while others described it as a simplified variant of the Avangard hypersonic complex (Graef, 2024). This article compiles and analyzes all available information regarding Oreshnik in an attempt to assess the nature of the missile used in the November 21 strike on Dnipro.

Technical Examination of the Missile Strike

Domestic and NATO specialists carried out radiation level measurements and surveyed the perimeter of the facility and adjacent areas to collect fragments of the Russian hypersonic Oreshnik missile. Their objective was to locate remnants of the missile's structure and traces of propellant at the site, which had been impacted by a missile strike. The Oreshnik missile is capable of reaching speeds up to ten times the speed of sound. The results of the analysis of the recovered missile fragments (Figs. 1-2) have not been disclosed in the media.

Figure 1 – Debris of the Oreshnik missile (Source: social media, open access)

Figure 2 – Debris of the Oreshnik missile (Source: social media, open access)

Similarly, there has been no public information regarding the damage caused in the industrial district of Dnipro by the impact of the hypersonic missile. However, an analysis of available satellite imagery taken in clear weather conditions before and after the strike (Figs. 3-4) suggests that the enterprise did not suffer significant destruction. The images reveal zones of fire damage resulting from ignition caused by the impact of a separating warhead (Seo, 2024), which were subsequently extinguished by firefighting services. Some of the observed impacts are also attributed to Kh-101 cruise missiles, which were launched against the plant alongside the Oreshnik missile on the same day. The buildings outside the plant's perimeter did not appear to be damaged, which may indicate a very limited damage radius characteristic of kinetic weapons. Unlike explosive munitions, they do not generate a wide blast wave or fragmentation field, which significantly reduces the extent of secondary damage.

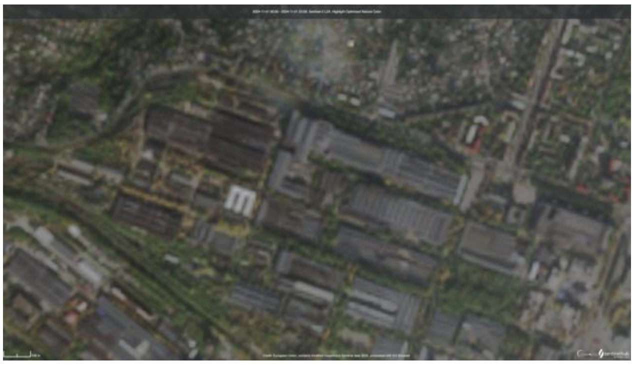

Figure 3 – Sentinel-2 L2A satellite image of the area on 2024-11-01, before the strike (Source: https://apps.sentinel-hub.com)

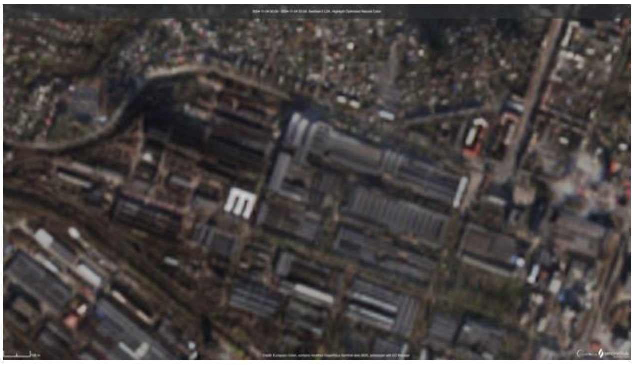

Figure 4 – Sentinel-2 L2A satellite image of the area on 2024-11-24, after the strike (Source: https://apps.sentinel-hub.com)

In video footage of the strike available online (Fig. 5), a series of impacts from six individually guided blocks can be clearly distinguished, each estimated to weigh up to 200 kg.

Figure 5 – Surveillance camera footage capturing the moment of the strike (Source: CCTV footage, compiled from open-access video)

According to Russian statements, the missile was equipped with a non-nuclear hypersonic payload. The payload likely consisted of inert projectiles made from high-strength metallic alloys. Due to their extreme velocity, such projectiles possess substantial kinetic energy (Gubrud, 2011), allowing them to penetrate protective layers, such as reinforced concrete; however, they are highly imprecise. Based on the analysis of satellite imagery, it appears that roof penetrations of industrial workshop buildings may have occurred, with an estimated impact accuracy within a margin of ±50 meters. The intense luminosity is associated with the high temperature of the falling missile fragments (Swaminathan et al., 1996).

This elevated temperature of all missile components is caused by external aerodynamic heating. The intensity of heating on the surface exposed to airflow depends on the flight velocity (Bondarenko & Gabrinets, 2023). At low speeds, this heating is negligible, and the resulting temperature increase can generally be disregarded. However, at high velocities, the aerodynamic heating of the missile's nose cone and the surrounding air can become highly significant. The rise in temperature of the missile's external surface due to aerodynamic heating is caused by both the viscosity of the surrounding air and the compression of air at the frontal surfaces (Meng et al., 2020). As a result of viscous friction in the boundary layer, the velocity of air particles decreases, leading to a temperature increase across the missile's surface. Air compression also contributes to a temperature rise, although primarily in localized regions. The nose cone and leading edges of the structure are particularly affected, where temperatures may reach levels dangerous to structural integrity. In such cases, almost direct collisions between the airflow and the surface occur, resulting in full dynamic deceleration. According to the principle of energy conservation, all the kinetic energy of the flow is transformed into thermal energy and pressure energy at the stagnation points. This corresponding temperature increase is directly proportional to the square of the relative flow velocity before deceleration (or, neglecting wind effects, to the square of the missile's speed) and inversely proportional to the flight altitude. During gas flow deceleration, the kinetic energy of the gas decreases, leading - according to the law of conservation of energy - to an increase in the internal energy and temperature of the gas (Lees, 1965).

The maximum heat content (enthalpy) of 1 kg of gas during its deceleration near the surface of a body is close to the stagnation enthalpy, as shown in equation (1):

$$H_0 = H_s + \frac{v^2}{2} \quad (1)$$

where H_s is the enthalpy of the incoming flow, and v is the flight velocity. If the flight velocity is not too high ($v \leq 1000$ m/s), the specific heat at constant pressure C_p can be considered constant, and the corresponding stagnation temperature of the gas can be determined using the following expression (see equation (2)):

$$T_0 = T_n + \frac{v^2}{2C_p} \quad (2)$$

The results of the surface temperature calculations for the warhead as a function of altitude and flight velocity are presented in Table 1. From the data in the table, it is evident that when passing through two atmospheric layers, 1-10 km and 11-20 km, at a speed of 10 Mach, the temperature increase will be 5763K and 4333K, respectively. The total temperature increase for the blocks is 10 096K. The nature of the impact - with an almost vertical trajectory - suggests the use of a warhead that followed a suborbital or quasi-ballistic flight profile, with a trajectory extending beyond the mesosphere (Singh et al., 2013). Such a flight profile is typical for hypersonic glide vehicles or maneuvering warheads. Boosting the warhead to a higher altitude (over 100 km) significantly reduces the thermal load due to the low air density in the upper layers of the atmosphere, which is critical at speeds exceeding Mach 10. In a rarified environment, aerodynamic resistance and, consequently, the heat flux on the body are minimal, ensuring the structural integrity of the warhead during the final phase of flight (Khanolkar et al., 2017).

Table 1 – Surface temperature of the warhead depending on altitude and flight velocity (developed by authors)

	Mach 1.0	Mach 2.0	Mach 3.0	Mach 5.0	Mach 10.0
Flight Altitude 0–10 km					
Flight Speed (m/s)	340.3	681	1021	1701	3403
Flight Speed (km/h)	1225	2450	3675	6125	12250
Stagnation Temperature (K)	346	519	807	1729	6051
Temperature Increase (K)	58	231	519	1441	5763
Flight Altitude 11–20 km					
Flight Speed (m/s)	295	590	885	1475	2950
Flight Speed (km/h)	1062	2124	3186	5310	10620
Stagnation Temperature (K)	250	390	606	1300	4550
Temperature Increase (K)	43	173	389	1083	4333

The final phase is executed along a steeply descending trajectory, increasing the kinetic impact and making interception by missile defense systems more difficult. This perspective on the attack on the production complex suggests the use of kinetic weapons based on the principle of converting kinetic energy into heat upon impact (Zhu et al., 2024). In this case, the energy of motion is the accelerated movement of the warhead's separating blocks, propelled by rocket engines, from space towards Earth. Upon impact with the target, the kinetic energy of the rapidly moving blocks is released, causing destruction similar to that of a meteorite strike. It is assumed that molybdenum-tungsten cores were used for the warhead. The lack of data on the scale and nature of the damage makes it difficult to assess whether additional explosives were used in the Oreshnik.

The absence of explosive warheads reduces potential collateral damage and adds an element of surprise due to the high velocity (around 2-3 km/s) and the difficulty of detecting such blocks before impact. This concept continues to generate interest and concern when discussing military and space policy.

Analysis of the serial markings of the recovered components

An image of a missile warhead fragment, presumably used in the strike on the production complex, was recorded in open sources (Fig. 6). A factory marking with a manufacturing date of April 12, 2017, is clearly visible on one of the components. This fact deserves particular attention, as earlier public statements by the President of the Russian Federation claimed that the Oreshnik system represented a brand-new development, having entered testing in 2024 (Bin, 2024).

Figure 6 – One of the components of the Oreshnik missile dated April 12, 2017 (Source: social media, open access)

The presence of components manufactured in 2017 allows several conclusions to be drawn:

1. The actual development history of the system is significantly deeper than officially stated. It is possible that the Oreshnik is a modernization of earlier designs rather than an entirely new project.
2. The production cycle of the missile or its warhead may have lasted several years, involving previously manufactured elements, which is typical for low volume or experimental weapon systems.
3. Claims about the system's "novelty" may serve political or propagandistic purposes and may not reflect the actual timeline of critical component development.

The presence of a manufacturing date from 2017, particularly in the context of a supposedly cutting-edge hypersonic weapon, suggests a potential discrepancy between the declared and actual stages of readiness and deployment of the system. This, in turn, may influence the assessment of Russia's production capabilities and the logistics of serial manufacturing of hypersonic weapons.

Kinetic strike and the «Rods from God» concept

The idea of destroying targets solely through kinetic energy without the use of explosives has a long history in military theory. One of the most well-known concepts is the American Rods from God project, which proposed placing tungsten rods in space that, when falling to Earth from orbital heights, would reach speeds of around 11-12 km/s (Hitchens et al., 2006). Upon impact with the surface, such a rod would possess colossal kinetic energy, sufficient to destroy fortified targets, comparable to the destructive effect of a small nuclear warhead - but without radiation and explosion. According to the formula for kinetic energy from classical mechanics (see equation (3)):

$$E_k = \frac{1}{2}mv^2 \quad (3)$$

For a mass of 500 kg and a speed of 3 km s^{-1}, the kinetic energy is 2.25×10^9 J, which is roughly equivalent to 538 kg of TNT. For heavier blocks and speeds of 5-6 km/s, this value can reach several tons of TNT.

However, such a scheme has significant limitations:

– To achieve kinetic energy comparable to that of a high-explosive charge, a significant mass is required, making the deployment of such blocks to orbit extremely expensive.

– Unlike conventional warheads, kinetic blocks do not have the ability to vary the power - the effect strictly depends on mass and speed.

– The use of conventional explosives can achieve comparable destructive effects at much lower costs, especially in tactical scenarios.

Thus, despite the technical feasibility, the concept of kinetic destruction remains probabilistic. Its advantages - small signature, lack of explosives, and reduced secondary damage - are offset by high cost, limited applicability, and logistical complexity. Therefore, in practice, such solutions are not implemented purely, but as part of hypersonic systems combining both kinetic and explosive effects. From the perspective of economic efficiency, kinetic damage systems significantly lag behind traditional weapons (Moric & Kadyshev, 2025). For example:

– Launching a heavy kinetic block with a mass of 500-1000 kg requires a carrier rocket or ICBM with the corresponding payload capacity and accurate guidance system. The cost of one launch of an intercontinental missile or a heavy rocket carrier can range from \$50 to \$100 million.

– Hypersonic glide blocks require high-temperature composites, control systems, and heat protection - the block alone may cost several million dollars.

– In total, such an impact may cost \$60–100 million or more.

For comparison:

– Conventional warheads with explosives, capable of causing comparable damage, are an order of magnitude cheaper - from \$50,000 to \$500,000 depending on the type (Air Bomb, Short-Range Ballistic Missile, Medium-Range Ballistic Missile, etc.).

– Precision-guided cruise missiles with explosive or submunitions warheads cost \$1-2 million per unit in mass production.

Thus, the cost of the destructive effect per kilogram of destruction for kinetic warheads can be tens of times higher than that of traditional weapons (estimated cost of warheads is presented in Table 2). This makes them impractical for mass use, despite their unique physical advantages.

For explosives, the energy is presented based on the calorific value of TNT (4.184 MJ kg^{-1}). Although the concept was never fully realized in weaponry, its principles are reflected in modern hypersonic weapon systems (Kalvinkar et al., 2024). Maneuverable warheads traveling at speeds of 5-20 Mach along steep descending trajectories implement a similar damage mechanism by utilizing purely mechanical energy.

Table 2 – Kinetic energy and estimated cost of warheads and aerial bombs at characteristic collision velocities (developed by authors)

Weapon	Warhead, kg	Impact velocity	Energy	TNT, kg	Estimated cost
Hypersonic kinetic block	500	3.0	2250	~538	\$60–100 million
Warhead of Iskander-M	~480	~2.1	~1058	~253	\$3–5 million
Kalibr cruise missile	~400	~0.3	~18	~4.3	\$1–2 million
FAB-500	500	0.3	~22.5	~5.4	\$25–50 thousand
Rods from God	1000	11	60 500	~14 466	\$150–300 million

Unlike nuclear or high-explosive warheads, kinetic strikes reduce collateral damage, offer greater political flexibility, and are potentially harder to detect by early warning systems. The current analysis of the alleged strike by the Oreshnik missile system on the production complex indicates that, despite the high level of technical sophistication, the pure kinetic impact concept demonstrates limited practical effectiveness. Even at an impact velocity of approximately 3 km s^{-1}, the kinetic energy of a 500 kg warhead is roughly equivalent to 538 kg of TNT, which is comparable to the effect of a standard high-explosive warhead.

However, the cost of delivering a kinetic block to the target - considering the launch of an ICBM, the use of high-temperature materials, and precision guidance systems - can reach tens of millions of dollars, making such a strike economically unjustifiable in most combat scenarios. In contrast to traditional munitions with explosives, which provide similar or even greater destructive effects at a much lower cost, hypersonic kinetic weapons are inferior in terms of cost-effectiveness (Bondarenko & Vorobei, 2024).

Thus, the use of the Oreshnik in this mode should be viewed either as a demonstration of technological superiority, as a deliberate compromise aimed at minimizing collateral damage (for example, when striking strategic targets), or as a tool of political and psychological influence. From a purely military efficiency perspective, the concept remains extremely niche.

Potential technological continuity of the Oreshnik system

Various theories regarding the origin of the system used in the strike on the industrial facility, provisionally designated as Oreshnik, are discussed in public sources and among experts. Among the possible analogs and prototypes, the following Russian developments are most frequently mentioned: Avangard, Kedr, Rubezh, Temp-2S, as well as advanced modifications of intercontinental ballistic missiles such as Sarmat and systems based on the UR-100N UTTKh platform.

Overview of the Kedr Project

On November 22, 2024, the Main Directorate of Intelligence of the Ministry of Defense of Ukraine published information about a new ballistic missile that was used in the strike on Dnipro. According to their report, it was a ballistic missile associated with the Kedr missile complex (Kristensen et al., 2023). Kedr is a project of a next-generation ICBM designed to replace the Yars and Topol-M systems. The first mention of the project appeared in the media on March 1, 2021, describing it as being at the very early stages, with funding allocated through 2027. By 2023, the project was expected to transition to the phase of experimental design work. One of the key features of the Kedr system was reported to be enhanced mobility. This suggests that the complex might be smaller than its predecessors, Topol and Yars. It is unlikely that Kedr is already fully operational - as of 2025, there are no reports of a completed testing cycle. However, it is possible that technologies from the Kedr project were tested within a separate program, which externally could be perceived as the Oreshnik system.

Overview of the Rubezh Project

During a briefing following the missile strike, Sabrina Singh, Press Secretary of the United States Department of Defense, stated that the ballistic missile used by Russia to strike Ukraine was based on the Russian RS-26 Rubezh missile. Rubezh is an intercontinental ballistic missile based on a modified Yars missile complex (Fig. 7) (Bartles, 2017). The RS-26 Rubezh was presumably developed as a successor to the RSD-10 Pioneer missile, which was dismantled under the INF Treaty (Maloney, 2015). According to publicly available information, the development of the Rubezh missile began no later than 2006, incorporating experience from the Topol-M and Yars ICBM programs as a lighter variant (Bondarenko et al., 2024).

Testing reportedly started in 2011, but the program was suspended in 2016. In 2018, it was officially announced that the Rubezh project had been excluded from the state armament programs (Schneider, 2024). The RS- 26 Rubezh is closer in size to a medium-range missile. In the case of the Oreshnik, the event involved an almost vertical impact with high kinetic energy -

which could correspond to a maneuverable reentry vehicle from the Rubezh system, or its modified version without an explosive payload.

Figure 7 – Presumed appearance of the RS-26 Rubezh mounted on an MZKT-79291 chassis (Source: social media, open access)

Overview of the Avangard Project

Avangard is a strategic hypersonic missile system equipped with a detachable maneuverable hypersonic glide vehicle (Fig. 8) (Zhouwei et al., 2022). The system was placed on combat duty in 2019. As a carrier for the warhead, the UR-100N UTTKh Stiletto ballistic missile (figure 8), developed during the Soviet era, is used.

Figure 8 – The UR-100N UTTKh missile, carrier of the Avangard warhead (Source: social media, open access)

In addition, the RS-28 Sarmat ICBM is expected to become the primary carrier for the Avangard warhead in the future. It was reported that during tests in December 2018, the Avangard glide vehicle exceeded 27 times the speed of sound (Gady, 2019). The nature of the target impact corresponds to the characteristics of the Avangard system. Although Avangard was originally designed as a strategic nuclear weapon, its technology could feasibly be adapted to create a non-nuclear modification capable of delivering a kinetic strike against a precision target. It should also be noted that during the hypersonic approach of the glide vehicle to the target, the vehicle's body heats up to extremely high temperatures.

As a result, the object becomes highly visible, which is clearly observable in footage from the Oreshnik strike and is consistent with the known behavior of the Avangard system.

Thus, it is most likely that the Oreshnik system is either a modification of the Avangard warhead implemented in a non-nuclear configuration, or an experimental system based on the technological groundwork of the Avangard, but adapted for use with other missile carriers or for non-nuclear precision strike missions. At the same time, a direct connection to the Avangard appears more plausible than a connection to prospective but still incomplete programs such as Kedr.

Conclusions

The deployment of the Oreshnik missile system during the strike on the industrial plant represents a precedent that deserves separate consideration from both military-technical and military-political perspectives. For the first time in open sources, the use of a warhead exhibiting signs of hypersonic kinetic impact without the use of explosives has been documented. Prior to the strike, information regarding the existence of the system itself was absent from both Russian and international analytical materials.

The analysis of the nature of the destruction, the presumed trajectory, the observed physical effects (aerodynamic heating, light emission, impact accuracy), as well as economic and production-related aspects, allows for several key conclusions:

1. It is highly probable that Oreshnik represents a modified or experimental version of already existing hypersonic platforms, such as Avangard, rather than an entirely new development.
2. Kinetic impact without explosives demonstrated limited effectiveness against industrial targets: despite the high velocity and penetrating capability, no significant damage beyond localized perforations was recorded.
3. The economic efficiency of deploying Oreshnik raises serious questions: comparable or even greater damage could be inflicted by much cheaper means, rendering such weapons impractical for mass deployment.
4. However, the political and psychological effect of using a new hypersonic weapon against a highly protected target in the rear is considerable. It serves as a signal of Russia's capability to breach missile defenses in a non-nuclear configuration.

Thus, the deployment of the Oreshnik system should be viewed not purely as a military action, but as a demonstrative act combining the testing of advanced technology, exertion of political pressure, and assessment of the international community's reaction. At this stage, Oreshnik remains a unique but niche system, not intended for large-scale use, yet potentially capable of influencing future approaches to the development of high-speed non-nuclear weaponry.

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