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KONDAVALETS INTELLIGENCE TEAM
SNAKE ISLAND INSTITUTE

HOLDING BACK THE SKY

UKRAINE'S AIR DEFENSE CAMPAIGN, 2022-2025

With thanks to our partner units.

This report is grounded in their operational experience and shaped through interviews, field insights, candid feedback, and professional expertise.

Authors:

- **Maksym Terzi** – Snake Island Institute
- **Yelyzaveta Khomovska** – Snake Island Institute
- **Konovalets Intelligence Team** – Colonel Yevhen Konovalets Military School

Editorial & Design Team

- **Catarina Buchatskiy** – Editor, Director of Analytics at Snake Island Institute
- **Olha Kovalenko** – Layout Design
- **Nizar Al Rifai** – Layout Design

SNAKE ISLAND INSTITUTE

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Editor's Notes

Vladyslav Sobolevskyi & Catarina Buchatskiy

President, Director of Analytics Snake Island Institute

In 2026, the Military Commanders' School marks ten years as one of Ukraine's most respected training units, setting the standard for preparing personnel from recruit to specialist and commander. As part of the growing partnership between Snake Island Institute and the School, we identified an entirely new field for cooperation: the School maintains a strong analytical department that supports not only training and operational readiness within the unit, but also contributes expertise across broader defense challenges, including air defense. It is a privilege to produce this report together, drawing directly on the knowledge and lived experience of our military partners.

One of the core challenges of modern air defense is that, in a war of industrial and economic scale, the attacker will almost always be able to send more threats than the defender can afford to stop. Time favors the side that can produce and launch at volume.

Russian cruise missiles, ballistic missiles, glide bombs, drones, decoys, and more have been exhausting Ukraine's air defense over the last four years of full-scale invasion, and consequently, Ukrainian air defense was forced to evolve continuously, not to achieve total protection, but to remain viable.

Ukraine in 2022 did not boast a modern, integrated air defense architecture. It inherited fragmented legacy systems, limited stocks, and uneven coverage. Western systems arrived incrementally, under political and logistical constraints that shaped how they could be used. Meanwhile, Russia adapted its strike methods continuously, forcing Ukrainian air defense to evolve in parallel—or fail.

This report traces this evolution.

What emerged was a system built through necessity: layered, improvised, uneven, and constantly reconfigured. Ukraine learned to defend selectively, prioritizing critical infrastructure and population centers, integrating heterogeneous systems, and accepting tradeoffs that peacetime planning rarely confronts directly. The lesson is uncomfortable but unavoidable, which is that **air defense is not a solved problem.** It is an exercise in managing scarcity under pressure. Performance matters, of course, but so does sustainability. And, just as so much else in this war, adaptation determines whether air defense holds long enough to matter.

Konovalets Intelligence Team

Colonel Yevhen Konovalets Military School
354th Training Mechanized Regiment

Russia's missile-and-drone terror campaign, conducted systematically since the start of the full-scale invasion in 2022, has created a new dimension of air warfare by turning it into a tool of economic attrition and pressure on the civilian population. Behind the dry statistics of cruise-missile launches and strike UAV sorties lies not only the destruction of energy and industrial assets, but a deliberate enemy strategy aimed at undermining Ukrainians' resilience and morale. Regular strikes on civilian infrastructure and residential areas, which result in significant civilian casualties, are clear evidence of this approach. As Ukraine has mounted effective resistance, this confrontation has evolved into a technological race. On one end, Russia is expanding production of strike systems and continuously adjusting tactics. On the other, Ukraine is developing its air-defense system, integrating Western weapons, and relying on the adaptability and ingenuity of the Defense Forces of Ukraine.

For the Colonel Yevhen Konovalets Military School (KMS), this threat is not abstract. Frequent air-raid alerts disrupt the training process, forcing instructors to adapt curricula, modify the structure of instruction, and reschedule exercises to protect personnel. These challenges underscore the school's mission. Training infantry soldiers and junior leaders to the highest standards requires a solid understanding of all components of modern war, not only ground tactics. Today's NCOs and officers must understand the scale of strategic threats in order to act as effectively as possible within their level of responsibility.

The need for rigorous analysis of these processes, and the recognition that modern war demands technological literacy, prompted the establishment of the Konovalets Intelligence Team (KIT) within KMS. Drawing from the school's existing technical reconnaissance capabilities and OSINT tools, the team examines various aspects of the Russo-Ukrainian war. In this study, we focus on the analysis of aerial attack means, the evolution of enemy tactics, and Ukraine's countermeasures. The purpose of this work is to provide stakeholders with data to strengthen the protection of Ukraine's skies and to develop a coherent picture of air threats in contemporary warfare.

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Modern air defense is not a set of separate systems working in parallel; it is an adaptive, continuous system that has to endure not only a singular threat, but a volume, their combinations, and the pace at which attacks arrive. The advantage will rarely come from having one "perfect" weapon, but from being able to keep the system running while facing repeating waves of attack. That requires sustained situational awareness, reliable command and control, disciplined allocation of scarce interceptors and sensors, an interception approach that remains economically sustainable, and rapid recovery after damage.

Ukraine's experience is valuable because it is the most intense real-world test of integrated air defense in this era; it provides lessons on what air-defense attrition looks like in a war of massive scale, how it can be mitigated, and what types of systems, in practical terms, need to be scaled.

The report is structured as a sequential analysis of Ukraine's air defense campaign—from initial conditions to practical conclusions:

- **Initial conditions (2022):** the air defense configuration with which Ukraine entered the war and the inherited constraints it imposed.
- **Evolution of threats (2022-2025):** how the types of aerial attacks and Russian objectives evolved—from attempts to dismantle air defense as a system to combined operations designed to overload detection, interception, and command-and-control.
- **Partner deliveries and integration:** how Western systems and their integration affected the defensive architecture, throughput capacity, and the ability to protect critical areas.
- **New challenges for air defense operations:** shortages of air defense assets, ammunition deficits, the mass employment of Shahed-class UAVs, the emergence of decoy targets, and the combination of strike means aimed at long-term attrition of the system through sustained flows of cheaper threats.
- **Practices of effective countermeasures:** which approaches and practical cases proved effective in Ukraine, what should be scaled further, and which technological and organizational directions will shape the future development of air defense.

Key findings on the evolution of Ukraine's air defense:

- **Air defense must be a layered architecture.** Outcomes depend on how well detection, command and control, diverse interceptors, mobility, and repair and recovery work together.
- **A shift in the success metric: from kills to throughput.** In wave-based attacks, the critical question is not only what can shoot targets down, but how many targets the system can process in a short window without losing control or mismanaging priorities.
- **Air defense is an economic duel.** The goal is not simply to intercept a target, but to match the right effector to the right threat so that expensive missiles are not spent on cheap drones or decoys. An attacker depletes air defense by forcing it into unfavorable exchanges and accelerating the burn rate of limited stocks.
- **Resilience equals recovery, rotation, and organization.** A strike against one air-defense element should not stop the system. Advantage goes to the side that can restore capability quickly, relocate and reconfigure assets, build redundancy, train continuously, and adapt procedures based on experience.

Emerging threats and how they scale beyond Ukraine:

- **Massed, combined strikes are the default model.** This approach can, and will, be replicated by other adversaries. Different strike systems are used at the same time to overload the defender's air-defense network rather than to defeat any single battery.
- **Cheap drones and decoys are important.** They force air defenses to spend limited interceptors and attention, creating openings for higher-priority weapons to get through.
- **Adversaries are increasingly targeting command, control, and communications.** Disrupting data links, coordination, and the speed of target assignment can be as decisive as physical strikes. This raises the requirement for resilient procedures, redundancy, and decentralized decision-making.

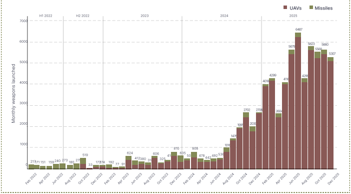

Figure 1. Air Force Command of the UA Armed Forces. Monthly totals of missile and drone weapons employed by the Russian Federation against targets across Ukraine (excluding combat activity near the line of contact).

Since Russia's full-scale invasion of Ukraine on 24 February 2022, securing the air domain has been a critical condition for state survival, economic continuity, and protection of daily life. Russia viewed air strikes,at the outset, as an instrument to enable the ground offensive; later, as a tool of sustained pressure designed to exhaust defenses and degrade rear-area infrastructure. In this context, Ukraine's air defense faced the long-term requirement to hold the airspace under continuous enemy adaptation.

The scale of this campaign is best captured in numbers, because it defines the real demands imposed on the defense system. Based on publicly available Air Force statistics, Snake Island Institute and the analytical group of the Colonel Yevhen Konovalets Military School estimate that, from the start of the full-scale invasion through early 2026, Russia launched more than 8,180 missiles and more than 73,870 Shahed-type strike UAVs against Ukraine.

The dynamics of aviation-delivered munitions are equally indicative. In 2025 alone, Russia employed more than 60,000 guided aerial bombs against frontline areas while continuing to refine these capabilities. Taken together, these figures indicate a sustained, systematic campaign rather than a series of isolated episodes, where the decisive factor is the defense's ability to absorb a continuous flow of threats over timeIn this kind of war, air defense outcomes are determined not by the number of kills in a single raid, but by system resilience.

Over time, the scale and regularity of strikes increased, and the economic asymmetry became more pronounced. The threat of relatively cheap strike capabilities forced defenders to expend expensive and limited resources. As a result, air defense effectiveness became increasingly determined not by the peak performance of the individual systems, but by the ability to build a layered, scalable architecture with a clear division of roles:

- different engagement ranges;
- different interception costs;
- different throughput capacity.

This report examines Ukraine's air defense campaign in 2022-2025 as an example of a defense system that evolves in real time under enemy pressure. The framework adopted by Ukrainian command—to hold back the sky—means that the system must be able to:

- maintain uninterrupted air situational awareness;
- preserve command and communications under mass attacks;
- rapidly restore damaged elements;
- allocate scarce assets across different threat types while accounting for the economics of interception.

The report aims to answer several applied questions relevant both for Ukraine and for the broader Western security environment, including:

- what initial air defense configuration Ukraine entered 2022 with, and what inherited constraints shaped its options;
- how aerial threats evolved in 2022-2025, and what objectives Russia pursued through successive waves of attacks;
- which decisions proved decisive for defense resilience as attack mass and resource scarcity increased;
- what role partner deliveries and the integration of Western systems played;
- which technological and organizational directions are shaping air defense development on the 2026+ horizon, particularly in the context of interception economics.

Methodologically, the study draws on a combination of open-source data, official communications, available statistics on mass attacks, and interviews with serving air defense personnel. The interviews play a central role by providing applied context on how the system functions in practice and enabling analytical hypotheses to be formed and tested through cross-verification with open sources.

At the same time, the limitations of this approach must be acknowledged. A large share of relevant information remains classified for operational reasons, official data may be incomplete, and certain elements of the system are intentionally not detailed. Accordingly, the conclusions of this report focus primarily on campaign logic, development trends, systemic bottlenecks, and scaling directions—not sensitive tactical details.

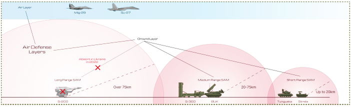

Figure 2. Air defense echelons prior to 2022.

Ukraine entered the full-scale phase of the Russo-Ukrainian war with an echeloned air defense system built primarily around Soviet assets and operating under conditions of constrained equipment and ammunition stocks.

At the time of the invasion, Ukraine fielded approximately 250 S-300 launchers and 72 Buk-M1 launchers [1]. The air defense aviation echelon consisted of MiG-29 and Su-27 fighters, capable of carrying up to six and ten air-to-air guided missiles (R-27, R-73, R-60), respectively. By the end of 2021, Ukraine's active inventory included 43 MiG-29s and 26 Su-27s. However, actual flight readiness at the start of 2022 was below nominal levels: the total number of combat-capable aircraft in the first weeks of the campaign was approximately 40 [2]. By comparison, during the same period Russia fielded more than 772 fighter aircraft [3].

These systems provided a baseline level of airspace coverage, but the aging Soviet systems, on their own, could not guarantee sustained effectiveness in a prolonged campaign in which the decisive factors for defensive performance would be the serviceability of launchers, the availability of ready-to-use missiles, the repairability of radar stations, and the resilience of command-and-control under attack [5].

Prior to 2014, the state of Ukraine's air defense capabilities was largely in a downward spiral. A large share of inherited air defense equipment was sold, decommissioned, or degraded due to insufficient funding, maintenance, and life-extension programs. Russia's occupation of Crimea in 2014 not only reduced Ukraine's air defense capabilities through the loss of units and infrastructure in the southern direction, but also fundamentally altered the regional balance. The peninsula became a forward stronghold where long- and medium-range systems, including S-200, S-300 and Buk, were integrated into a broader air defense architecture, strengthening Russia's control over regional airspace.

After 2014, Ukraine's air defense entered a phase of recovery and accumulation, in an attempt to reverse the downward spiral. The Soviet-era systems were repaired, modernized, and serviced again, though the attention was not necessarily evenly spread. The air component remained constrained by the limited number of combat-ready fighters; in 2014, the Air Force could field only around 50 aircraft capable of flying [6].

And so, by the start of the full-scale war, Ukraine entered the campaign with a limited and largely outdated air defense arsenal centered on Soviet systems and affected by shortages of munitions and components, although this arsenal had been restored, consolidated, and prepared as much as possible for what the Ukrainians imagined a large-scale invasion might look like.

But Russian attacks, while perhaps predictable or expected in the beginning of 2022 did not stay that way for long,

The following sections examine how threats to Ukraine's air defense evolved, the tactical countermeasures applied, and how air defense effectiveness shifted during Russia's most intensive mass attack campaigns throughout the war.

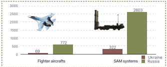

Figure 3. IISS, FlightGlobal, Andrii Kharuk. Comparison of the number of air defense assets of Ukraine and Russia. January 2022 [4].

February-June 2022. The Failed Blitzkrieg and the Onset of the Full-Scale Invasion

Stage Overview

Russian intent: to rapidly cripple Ukraine's air defense as a system—through strikes on air bases, radars, command posts, and depots; in parallel, through repeated small salvos of cruise and ballistic missiles.

Ukraine's response: to preserve mobility and command-and-control—dispersion and maneuver, early readiness of units, reduced time on firing positions, and rapid restoration of communications and control after strikes.

Effects: Ukraine's air defense did not lose command-and-control in the first weeks, forcing Russia to limit deep aviation operations over controlled territory and shift toward a longer attrition campaign; in parallel, Ukrainian strikes against the Black Sea Fleet reduced the ability to launch Kalibr missiles from the northwestern Black Sea, pushing carriers eastward and increasing launch distances.

Key targets: military infrastructure (air bases, air defense assets, command posts, military depots, ports), with selective strikes against civilian infrastructure.

Russian pressure tools:

- Salvo strikes with cruise and ballistic missiles.
- Attempts to gain air superiority: fighter aviation and helicopter raids.
- rapidly restore damaged elements;
- allocate scarce assets across different threat types while accounting for the economics of interception.

Ukrainian countermeasures:

- S-300 and Buk-M1 surface-to-air missile systems;
- MANPADS;
- Fighter aviation MiG-29 and Su-27.

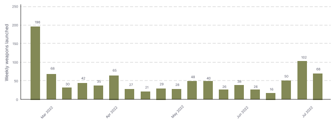

Figure 4. Air Force Command of the UA Armed Forces. Weekly number of missile and drone systems employed by Russia against Ukraine, February-June 2022 (excluding combat activity near the line of contact).

1. Kharuk, Andrij. "Ukraine's air defence in the Russian-Ukrainian War (2022-2024): Progress in regression." Faces of War, no. 2 (December 31, 2024): 141-54. https://doi.org/10.18778/3071-7779.2024.2.09.
2. "How Many Combat Aircraft Ukraine has According to FlightGlobal's Annual World Air Forces Report │Defense Express," December 13, 2021. https://en.defence-ua.com/news/how_many_combat_aircraft_ukraine_has_according_to_flightglobals_annual_world_air_forces_report-2021.html. The New Voice of Ukraine. "Ukraine had just 40 operational fighter jets in February 2022 — Zaluzhnyi," November 1, 2023. https://english.nv.ua/nation/ukraine-had-just-40-operational-fighter-jets-in-february-2022-zaluzhnyi-50365049.html. Newsroom Infobae. "This is how the modest Ukrainian Air Force fights against Russian planes." Infobae, March 24, 2022. https://www.infobae.com/en/2022/03/24/this-is-how-the-modest-ukrainian-air-force-fights-against-russian-planes/.
3. FlightGlobal and Embraer. "World Air Forces 2022." FlightGlobal, 2021. https://www.flightglobal.com/download?ac=83735.
4. FlightGlobal and Embraer, "World Air Forces 2022."Kharuk, "Ukraine's Air Defence in the Russian-Ukrainian War (2022-2024): Progress in Regression," December 31, 2024.

On 24 February 2022, Russia launched its full-scale invasion with an initial wave of missile strikes, including cruise and ballistic missiles such as Kh-101, Kh-55, Kh-555, Kh-22, Kh-32, Oniks, Kh-59, Kalibr, Tochka-U, Kh-35, Kinzhal, and Iskander.

The opening concept was typical of a rapid-campaign scenario: degrade Ukrainian aviation and weaken air defense as a system. As a result, the first strikes focused primarily on military targets. This included airfields—specifically in Vasylkiv, Lutsk, Ivano-Frankivsk, Chuhuiv, and Kramatorsk—as well as the ports of Odesa and Ochakiv, depots, and command nodes 7. In parallel, Russia targeted critical enablers of integrated air defense operations. This target set included fixed early-warning radars, fixed S-125 positions, air bases, ammunition depots, and known positional areas of mobile S-300 systems 8. Along the axes of advance in Kyiv, Kharkiv, Donetsk, and Zaporizhzhia oblasts, these strikes were accompanied by artillery and air strikes against civilian infrastructure.

At this stage, Russian air strikes typically took the form of repeated small salvos. Most often this meant two to three separate attacks with one to three launches per attack—approximately three to ten missiles per day. The largest spring strike of this type occurred on 1 April 2022: roughly 30 missiles, including Iskander, against Odesa and Dnipropetrovsk oblasts; targets included railway infrastructure, including in Synelnykove Raion.10

In parallel, Russia sought to destroy Ukrainian aviation, command posts, and to damage the defense-industrial base, including Kalibr strikes against the Antonov plant in Kyiv and the Lviv Armored Plant. Missile strikes against civilian targets also continued, but at this stage they were not yet systematic and were often framed as derivative of purported military objectives; a representative example was the strike on the Retroville shopping center in Kyiv on 20 March 2022 11.

These strikes were likely part of a blitzkrieg concept, based on the assumption that precision attacks on key command centers and nodes of resistance could quickly break organized defense. If Ukraine's integrated defense had collapsed and resistance had fragmented, small-salvo strikes against individual pockets could have produced the tangible effects Russia was hoping for without them having to shifting strategies to sustained mass strike waves.

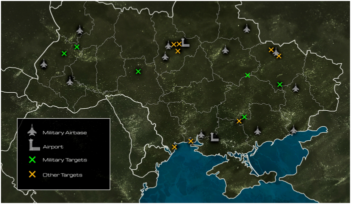

Figure 5. Key targets of the Russian Federation. February 24, 2022 9.

5. Kharuk, "Ukraine's Air Defence in the Russian-Ukrainian War (2022-2024): Progress in Regression," December 31, 2024.
6. Kharuk, "Ukraine's Air Defence in the Russian-Ukrainian War (2022-2024): Progress in Regression," December 31, 2024.
7. MWCOE. "Ukrainian Air Defense Strategies Against the Russian Invasion," n.d. https://www.mwcoe.org/docs/lesson-learned-2024-workshop-summary/06-current-russo-ukraininan-conflict-ukrainian-air-defence-strategies-against-the-russian-invasion/.

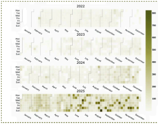

Figure 6. Air Force Command of the UA Armed Forces. Daily density of aerial targets launched against Ukraine since 24 February 2022, 2022-2025.

In the first months of the full-scale invasion, the Ukrainian Air Force's priority was to preserve the combat capability of existing air defense assets. A second task was to restore command and communications at a tempo that allowed the system to operate coherently after being hit. Mobile units were brought to readiness ahead of 24 February and, after receiving warnings from Ukraine's partners, were able to relocate most mobile assets before the first wave of missile strikes.

On the morning of 24 February, air defense units continued redeployment, and at approximately 03:50 command launched military aircraft and dispersed forces to reduce vulnerability to the initial strike. This disrupted Russia's attempt to rapidly disable Ukrainian aviation and a significant share of air defense assets. Losses among mobile components in the first days were limited, mostly isolated S-300 launchers that failed to leave positional areas due to short warning time or technical malfunctions. At the same time, fixed early-warning radars were struck and at least temporarily taken out of action, and several fixed S-125 positions were destroyed. Electronic warfare during the opening strikes further complicated air defense operations. Detection and tracking degraded, communications became unstable, and unit-level control was fragmented 12.

This is why maneuver, dispersion, and reducing time spent in predictable positional areas became the key countermeasure.

To strike a mobile air defense unit, Russia first had to detect it, confirm coordinates, transmit them to a strike asset, and only then deliver an attack. According to one GUR representative, in the first weeks of the war this cycle often took longer than a unit remained on position, and so Russian missiles frequently hit already-obsolete locations. This reduced Ukrainian losses among mobile assets and preserved their combat capability under constant fire 13.

Figure 7. Target detection and engagement cycle.

The speed of restoring command and communications proved critical. I among air defense elements was disrupted not only by physical damage, but also because of the constant reconfiguration of command-and-control after strikes in order to restore coherent operations across dispersed units. During this period, Ukraine's interception effectiveness against Russian cruise missiles declined even when some radars and launchers remained intact, because they were operating without stable communications and coordinated control. In the first phase of the campaign in March-April, the cruise-missile interception rate was approximately 20-30%; after command-and-control was restored and coordination stabilized by June, it rose to 50-60% 14.

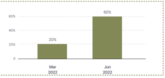

Figure 8. Air Force Command of the UA Armed Forces. Share of intercepted Russian cruise missiles, March-June 2022.

8. Bronk, Justin, Nick Reynolds, and Jack Watling. "The Russian Air War and Ukrainian Requirements for Air Defence." RUSI, November 7, 2022. https://static.rusi.org/SR-Russian-Air-War-Ukraine-web-final.pdf.
9. "Ukrainian Air Defense Strategies Against the Russian Invasion."
10. NV. "37-й день війни — головне. ЗСУ звільнили Бучу, відбувся другий обмін полоненими, Росія завдала удару по Одеській області [Day 37 of the war—key developments: The Armed Forces of Ukraine liberated Bucha, the second prisoner exchange took place, and Russia struck Odesa Oblast]." April 1, 2022. https://nv.ua/ukr/ukraine/events/viyna-v-ukrajini-peregovori-z-rosiyeyu-sogodni-golovni-podiji-obstrili-boji-novini-ukrajini-50230111.html.

Ukraine's air defense assets, despite being under the stress of withstanding a full-scale Russian assault, adapted rapidly and began systematically destroying Russian aviation. In the first weeks of the war, fixed-wing aircraft and helicopters were among the key threats, as Russia attempted to establish de facto air dominance in support of airborne operations around Kyiv and other major cities. Aviation was expected to provide air cover for airborne units, rapid force movement, and direct fire support for the advance. Had these efforts succeeded, Ukrainian ground operations could have unfolded on a fundamentally different trajectory—with sharply constrained mobility, degraded control, and substantially higher losses.

Instead, active employment of Ukrainian air defense and fighter aviation disrupted these plans. By 30 June 2022, at least 107 Russian aircraft and helicopters had been recorded destroyed, effectively forcing Russia to abandon deep aviation operations over territory controlled by Ukrainian forces. Ukrainian pilots played an important role, operating despite the adversary's numerical and technological advantages, despite the fact thatUkrainian aircraft were significantly inferior to modern Russian platforms in avionics, detection ranges, and weapons options. Ukrainian pilots compensated through tactics, risk acceptance, and individual skill [15].

The emblem of this phase became the Ghost of Kyiv—a generalized image of Ukrainian fighter pilots who fought aerial engagements in the first days of Kyiv's defense, constraining Russian aviation at the cost of extraordinary strain and losses. While the Ghost of Kyiv is a Ukrainian national myth, a symbol to rally around, rather than a particular individual,it reflects the real impact of Ukrainian aviation in denying Russia air superiority and preventing Moscow from imposing its preferred tempo of war [16].

June-December 2022. Transition to the Tactic of Energy Terror

Stage Overview

Russian intent: to systematically reduce Ukraine's resilience by striking power generation, substations, and transmission nodes—through waves of cruise missiles and Iranian UAVs, combining means to overload air defense; and to pressure maritime logistics by striking ports in order to undermine export routes, disrupt the grain deal, and complicate Ukraine's maritime connectivity.

Ukraine's response: to sustain the functioning of the power system and cities—deploying layered protection around key nodes, strengthening the short-range layer against UAVs, adapting radar and fires regimes to mass waves, and increasing coordination between units and command posts.

Effects: Russia failed to achieve its strategic objective of breaking state functionality, but the attacks produced prolonged outages and increased the cost of defense; air defense shifted from reacting to isolated strikes to systematic operations against serial waves and began building an interception economics framework for a protracted campaign.

Key targets: energy infrastructure (TPPs/CHPs, substations, transmission nodes), critical urban systems (water, heat), and selective strikes on command and logistics nodes.

Russian pressure tools:

- Employment of S-300 surface-to-air systems against ground targets to terrorize the civilian population.
- Mass waves of cruise missiles against energy infrastructure and transmission nodes.
- Initial use of Shahed-class UAVs.
- Combined missile-drone strikes.

11. Yavorovych, T. "У Києві через ракетний обстріл загинули вісім людей — ОГПУ [In Kyiv, eight people were killed in a missile strike—Office of the Prosecutor General]." Suspilne, March 21, 2022. https://suspilne.media/219757-u-podilskomu-rajoni-kieva-prolunali-vibuhi/.
12. Bronk, Reynolds, and Watling, "Russian Air War,"
13. Bronk, Reynolds, and Watling, "Russian Air War,"
14. Bronk, Reynolds, and Watling, "Russian Air War,"

Ukrainian countermeasures:

- S-300 and Buk-M1 surface-to-air missile systems;
- MANPADS;
- Fighter aviation MiG-29 and Su-27.

New:

- Western air defense systems (Gepard, NASAMS, IRIS-T, HAWK);
- Mobile fire groups;
- Western air defense systems (Gepard, NASAMS, IRIS-T, HAWK);
- ePPO.

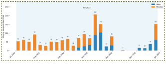

Figure 4. Air Force Command of the UA Armed Forces. Weekly number of missile and drone systems employed by Russia against Ukraine, February-June 2022 (excluding combat activity near the line of contact).

In the second half of 2022, Western air defense systems began to arrive, expanding the short- and medium-range layers of defense and reducing the burden on Ukraine's Soviet-era SAM inventory. In July 2022, Germany began transferring Gepard self-propelled anti-aircraft guns—armored air defense vehicles equipped with twin 35 mm cannons and organic radar for target detection and tracking [17]. Their practical value in the 2022 campaign was that Gepard addressed precisely the mass low-altitude targets that are difficult, and economically inefficient, to engage systematically with medium- and long-range interceptors.

Typically, in this phase, the first emerging Shahed-131/136 UAVs flew slower than cruise missiles, often at low altitudes and in groups, creating many targets within a short time window. Under these conditions, a radar-directed gun system could defeat targets at short range without expending scarce interceptor missiles, reducing the risk of rapid SAM stock depletion under drone pressure. At the time, a single UAV could cost approximately $193,000 [18]. Meanwhile, one PAC-3 MSE interceptor for the Patriot system costs around $4 million, and one Gepard round is estimated at roughly $600 [19].

At that point, engaging a single Shahed-class UAV could require approximately 7-11 shots, running the cost asymmetry of engagement up significantly [20]. In autumn 2022 Ukraine also received the first IRIS-T systems from Germany and NASAMS from the United States—medium-range systems with engagement ranges up to 40 km [21].

Against the backdrop of a stabilized frontline, successful Ukrainian operations in the north and northeast, and the introduction of Western air defense systems, Russia gradually shifted from attempts to strike military targets to attacks on civilian infrastructure. Russia's strike arsenal expanded accordingly: cruise and ballistic missiles were supplemented by the use of S-300 and S-400 systems firing 5V55 surface-to-air guided missiles in a ground-attack mode. The first such strikes against civilian infrastructure occurred in June 2022 and became massive starting from July 2022 [23]. Russia attacked Ukraine's frontline communities at least five and 19 times in June and July, respectively [24].

This tactical shift indicates a shortage of high-precision ballistic missiles coupled with an intent to terrorize the population, and intercepting these Russian missiles with available air defense assets was practically impossible due to their short flight times. The shelling of frontline cities allowed Russia to sustain their strike intensity, even amid shortages of high-precision missiles (Kh-101, Kalibr, Iskander-M).

In autumn 2022, a new type of aerial threat emerged: the Iranian-origin Shahed-131/136 strike UAVs, known in Russian nomenclature as Geran-1/2. Russia's intent to employ Iranian drones against Ukraine became publicly evident in June 2022, when a Russian delegation reportedly visited the Kashan air base in Iran at least twice and were shown the Shahed strike UAVs, and the first deliveries reportedly occurred that summer, with Iranian specialists involved to support operations from temporarily occupied Crimea [25]. By 13 September, Russia was already employing the Geran-2 in Kupiansk, during the Kharkiv counteroffensive [26].

Shahed-class UAVs were designed as low-cost systems for mass employment, where effects are generated by volume and repetitiveness. Early variants could fly between 900 and 2,000 km and had modest speed (up to 200 km/h), making them a relatively accessible interception target. Their warhead was limited—10-15 kg for Shahed-131 and 40 kg for Shahed-136—which did not always produce the desired level of destruction with a single hit against more hardened or dispersed objects [29]. At the time, the unit cost of a UAV was approximately $193,000, while an Iskander-M missile cost around $3 million and a Kh-101 around $13 million [30].

Figure 10. Sofinov T. Gepard self-propelled anti-aircraft system in service with the Ukrainian Armed Forces. 2023 22.

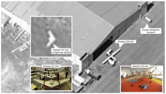

Figure 12. The White House, CNN. Demonstration of Iranian Shahed-type UAVs to a Russian delegation at Kashan Air Base. June 2022 27.

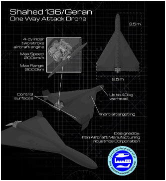

Figure 11. Wikipedia. Shahed-136.

Figure 13. Wreckage of an Iranian Shahed (Geran-2) drone near Kupiansk. September 2022 28.

15. Wikimedia. "Втрати російської авіації під час вторгнення в Україну [Losses of Russian aviation during the invasion of Ukraine]." Wikipedia, January 30, 2026. https://uk.wikipedia.org/wiki/%D0%92%D1%82%D1%80%D0%B0%D1%82%D0%B8_%D1%80%D0%BE%D1%81%D1%96%D0%B9%D1%81%D1%8C%D0%BA%D0%BE%D1%97_%D0%B0%D0%B2%D1%96%D0%B0%D1%86%D1%96%D1%97_%D0%BF%D1%96%D0%B4_%D1%87%D0%B0%D1%81_%D0%B2%D1%82%D0%BE%D1%80%D0%B3%D0%BD%D0%B5%D0%BD%D0%BD%D1%8F_%D0%B2_%D0%A3%D0%BA%D1%80%D0%B0%D1%97%D0%BD%D1%83.
16. Peter, Laurence. "Привид Києва. Як народилась легенда, яка підняла дух українців [The Ghost of Kyiv: How the legend that lifted Ukrainians' morale was born]." BBC News Ukraine, May 1, 2022. https://www.bbc.com/ukrainian/features-61291455.
17. Павлюк, Олександр. "Стало відомо, коли Україна отримає від Німеччини САУ Gepard [It became known when Ukraine will receive Gepard self-propelled anti-aircraft guns from Germany]". Суспільне, 20 травня 2022. https://suspilne.media/241658-stalo-vidomo-koli-ukraina-otrimae-vid-nimeccini-sau-gepard/.
18. Ofer Yaron, "Gold for Drones: Massive Leak Reveals the Iranian Shahed Project in Russia", Haaretz, February 21, 2024, https://www.haaretz.com/israel-news/security-aviation/2024-02-21/ty-article-magazine/gold-for-drones-massive-leak-reveals-the-iranian-shahed-project-in-russia/0000018d-bb85-dd5e-a59d-ffb729890000.
19. Norskluftvern. "What Does the Patriot Air and Missile Defense System Cost?" Norsk Luftvern, December 11, 2025, https://norskluftvern.com/2024/04/06/what-does-the-patriot-missile-system-cost/. Hambling, David. "Why Vital Anti-Drone Artillery Comes at a Sky-High Price." Forbes, September 10, 2025. https://www.forbes.com/sites/davidhambling/2025/09/10/why-some-anti-drone-artillery-comes-at-a-sky-high-price/.
20. Litnarovych, Volodymyr. "Germany Sends 200,000 Rounds for Ukraine's Gepard Guns—Enough to Down Thousands of Drones." UNITED24 Media, July 22, 2025. https://united24media.com/latest-news/germany-sends-200000-rounds-for-ukraines-gepard-guns-enough-to-down-thousands-of-drones-10077.
21. "Унікальна система ППО - IRIS-T пройшла бойове хрещення в Україні" ["A unique air defense system, IRIS-T, has seen its combat debut in Ukraine"]. Укрінформ, October 24, 2022. https://www.ukrinform.ua/rubric-technology/3600403-unikalna-sistema-ppo-irist-projsla-bojove-hresenna-v-ukraini.html.Чайковська, В., Р. Губа, В. Сааков, and О. Куницький. "Україна отримає дві батареї ЗРК NASAMS" ["Ukraine will receive two NASAMS surface-to-air missile batteries"]. DW, September 16, 2022. https://www.dw.com/uk/ukraina-otrimae-dvi-batarei-zrk-nasams/a-63145228.

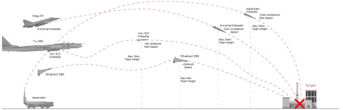

Figure 14. Flight profiles of Russian missiles and unmanned aerial vehicles (UAVs).

In October 2022, Russia introduced a tactic of mass combined strikes, synchronizing within a single wave different strike means with different flight profiles and speeds—cruise and (aero)ballistic missiles alongside strike UAVs. The simultaneous use of multiple missile types and drones aimed to reduce reaction time, complicate target allocation across air defense assets, and increase the probability of penetration to key objects. An early representative strike of this type occurred on 10 October 2022, when Russia launched 84 missiles and 24 UAVs against Ukraine's energy infrastructure 31.

For Ukraine's air defense, responding to this required tighter resource management and target allocation.

First, it became critical to avoid expending scarce medium- and longer-range interceptors on the cheaper, mass, and relatively slow targets used to overload defenses. This became especially true due to the fact that Soviet-era air defense systems, including the S-300, rely on components and munitions now produced in Russia, making replenishment possible only from pre-war stocks and by sourcing leftovers in third countries. Although Western were beginning to arrive in phases, they primarily reinforced the short- and medium-range layers, and the Soviet-era systems were not immediately unburdened. Time elapsed between the political decisions and the physical delivery, with extra time for unit training and deployment, and systems arrived in limited batches; meaning that still, Ukraine was mainly straining to support itself during this phase and had to be careful to expend scarce resources on the ample threats.

Second, air defense needed clear target allocation across layers so that each threat type was engaged by a tool aligned with its characteristics and without disproportionate cost. According to this logic, the Buk-M1 was used closer to the line of contact against aviation, while the S-300 more often covered large cities and critical infrastructure against cruise missiles. In parallel, the role of short-range systems (Gepard, Stinger) grew, absorbing part of the load against drones and low-flying targets 32.

Another solution that emerged for countering strike drones was the employment of mobile fire groups as a distinct short-range defense tool. A typical group consists of four to eight personnel and employs a heavy machine gun (M2 Browning), a light anti-aircraft gun (ZU-23-2), or MANPADS (Stinger). These groups operate on light vehicles and, upon an air-raid warning, move to positions along likely approach routes and engage targets with direct fire. They are placed in areas with good visibility and reduced risk to civilians—near roads and rivers, and on approaches to bridges and overpasses. Most importantly for Ukraine, the dispersion of the mobile fire groups and their maneuverability increased the density of short-range coverage around cities and critical infrastructure where continuous coverage with standard SAM systems was not feasible. Mobile fire groups also shifted a significant share of engagements against mass targets onto cheaper capabilities, preserving SAM missiles for aircraft and cruise and ballistic missiles 33.

22. Safronov, Taras. "Gepard: 'Predator' of the Ukrainian Air Defense." Militarnyi, July 22, 2023. https://militarnyi.com/en/articles/gepard-predator-of-the-ukrainian-air-defense/.
23. Суспільне. "Російські війська 18 червня обстріляли 11 населених пунктів Донеччини. Є загиблі та поранені" [Russian forces shelled 11 населених пунктів in Donetsk Oblast on June 18; killed and wounded reported]. Суспільне | Новини, June 19, 2022. https://web.archive.org/web/20240826184728/https://suspilne.media/donbas/251677-rosijski-vijska-18-cervna-obstrilali-11-naselenih-punktiv-doneccini-e-zagibli-ta-poraneni/.
24. Бурда, В. "С-300" та "С-400": головні характеристики ЗРК, якими можуть стріляти по Києву [S-300 and S-400: key characteristics of SAM systems that can be used to strike Kyiv]. chas.news, January 16, 2023. https://chas.news/current/s-300-s-400-yak-rosiya-obstrilyue-ukrainski-mista-z-kompleksiv-ppo. Вікімедіа. "Перелік наземних ударів з С-300/С-400 під час російського вторгнення" [List of ground strikes using S-300/S-400 during the Russian invasion]. n.d. http://bit.ly/3LodYN5.

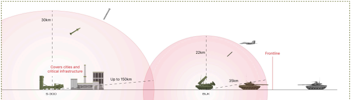

Figure 15. Approximate tactics for using S-300 and Buk-M1 at the beginning of a full-scale invasion.

At the same time, these groups remain a supplement to medium- and long-range systems and cannot replace them—firstly, mobile fire groups are limited to low-altitude engagements. A ZU-23-2 can engage targets up to 1.5 km altitude, and the M2 Browning up to 1.8 km 34. Second, they still require time for training and for building an echeloned deployment. Given that a significant share of mobile fire groups were formed on the basis of volunteer territorial community formations, personnel often consisted of civilians without military status who contributed to protecting their communities outside of their primary employment. Before deploying, personnel required training for firing at aerial targets, night-aiming equipment, and rehearsed coordination with command posts and adjacent groups.

Command, in turn, had to pre-designate positions and areas of responsibility, establish communications, and arrange groups in lines so they covered likely flight corridors and provided mutual backup. Without this preparation and networked deployment, mobile fire groups would operate unevenly—some failing to reach positions in time, others concentrating on the same directions — eroding the very advantage they are intended to provide: dense, controlled short-range coverage.

Beyond mobile fire groups, civilians were also tapped to help with target detection. In autumn 2022, Ukraine's ePPO mobile application was officially launched, enabling civilians to report low-altitude airborne targets. This observation channel was particularly useful in areas where ground-based radars have unstable tracking due to terrain and radar-horizon limits 36.

In September 2022, air defense intercepted 80% of missile targets and 71% of enemy UAVs; in December, the respective rates were 72.3% and 89% 37. The lower interception rate for missiles corresponded with the mass combined strikes against Ukraine's energy sector, where time-compressed target density, mixed flight profiles, and a limited interceptor inventory forced the defense into harsher prioritization choices and inevitably allowed some missiles through. By contrast, Ukraine increased effectiveness against Shahed UAVs faster because the target set enabled systematic shifting of engagements to the short-range layer, which was easier to scale, faster to train, and cheaper to sustain with ammunition. The arrival and deployment of Gepard, alongside further reinforcement of the medium-range layer with NASAMS and IRIS-T, improved night-wave defensive control and reduced some of the burden on Soviet-era SAM systems.

Figure 16. Militarnyi. Ukrainian mobile air defense fire groups 35.

25. Saric, Ivana. "U.S. Has Evidence of Iranian Troops "On the Ground" in Crimea." Axios, October 20, 2022. https://www.axios.com/2022/10/20/iranian-troops-crimea-drone-strikes-ukraine.
26. VGI-9. "The Evolution of Shaheds: How Russia Scaled Its Drone Warfare." VGI-9, October 13, 2025. https://vgi.com.ua/en/the-evolution-of-shaheds-how-the-enemys-weapon-developed/. kms_d4k, "Spotted Iran striker UAVs in Kupyansk region. Presumably used by Russian forces," X, September 13, 2022.
27. Ivana Saric, "U.S. Has Evidence of Iranian Troops 'On the Ground' in Crimea," Axios, October 20, 2022.
28. kms_d4k, "Spotted Iran striker UAVs in Kupyansk region. Presumably used by Russian forces," X, September 13, 2022.
29. Росія масовано атакувала Україну "шахедами": у чому різниця між дронами Shahed 136 та Shahed 131" ["Russia launched a mass "Shahed" attack on Ukraine: what is the difference between the Shahed 136 and Shahed 131 drones"]. NV. May 25, 2023. https://nv.ua/ukr/ukraine/events/krimskiy-mist-mozhna-zruynuvati-vibuhivkoyu-de-zakladati-inzhener-novini-ukrajini-50326971.html.

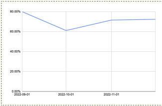

Figure 17. Petro Ivaniuk. Massive Missile Attacks on Ukraine. Effectiveness of Russian missile interception by Ukrainian air defense, September-December 2022.

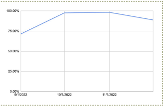

Figure 18. Petro Ivaniuk. Massive Missile Attacks on Ukraine. Effectiveness of intercepting Russian Shahed-type UAVs, September-December 2022.

Stage II (2023) Missile Defense and Repelling the First Combined Attacks

Stage Overview

Russian intent: to exhaust the missile-defense segment of air defense and create a window for (aero)ballistic missile penetration against the most protected targets; to overload detection, tracking, and target allocation through combined waves of cruise missiles, ballistics, and mass UAVs, forcing Ukraine to expend scarce interceptors and stretch defenses across sectors.

Ukraine's response: concentration of missile-defense capabilities around major cities and critical infrastructure, economical use of interceptor missiles, development of a nationwide spoofing network, and modernization of Soviet-era SAM systems to employ Western munitions.

Effects: Ukraine achieved a repeatable missile-defense capability in priority areas and was able to more strictly deconflict targets across defense echelons; combined waves became more manageable through improved prioritization, reinforcement of the short-range layer, and expansion of the sensor network, increasing overall system resilience under mass attacks.

Key targets: major cities and critical civilian infrastructure (power generation, substations, transmission nodes, heat and water), with selective strikes on critical command and logistics nodes.

Russian pressure tools:

- Localization and scaling of Shahed UAV production and a rising share of drone waves within overall attack packages.
- Combined missile-drone strikes to overload detection/tracking and expose positions.
- Emphasis on ballistic missiles against the most protected targets to penetrate priority coverage areas.

Ukrainian countermeasures:

- S-300 and Buk-M1 surface-to-air missile systems;
- MANPADS;
- Fighter aviation MiG-29 and Su-27

30. Artemchuk, O. "Morning Attack on Ukraine Cost Russia Almost US$1.3 Billion." Ukrainska Pravda (English), August 26, 2024. https://www.pravda.com.ua/eng/news/2024/08/26/7472003/. Yaron, "Gold for Drones."
31. Рощіна, Олена. "Ракети РФ вразили інфраструктуру 20 населених пунктів, загроза зберігається - Генштаб" ["Russian missiles hit infrastructure in 20 localities; threat remains - General Staff"]. Українська правда, October 10, 2022. https://www.pravda.com.ua/news/2022/10/10/7371291/.
32. Bronk, Reynolds, and Watling, "Russian Air War".
33. Мобільні групи ППО у боротьбі з дронами РФ ["Mobile air-defense groups in the fight against Russian drones"]. Мілітарний, October 7, 2023. https://militarnyi.com/uk/articles/mobilni-grupy-ppo-u-borotby-z-dronamy-rf/.

- Western air defense systems (Gepard, NASAMS, IRIS-T, HAWK);
- Mobile fire groups;
- Army aviation (helicopters);
- ePPO.

New:

- Introduction of long-range Patriot SAM systems;
- Short-range gun-based systems (Skynex, Skyhawk, SAMP-T);
- FrankenSAM: modernization of Soviet-era SAM systems to employ Western air-to-air missiles;
- Development of Pokrova electronic warfare and an acoustic sensor network.

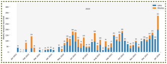

Figure 19. Air Force Command of UA Armed Forces. Weekly number of missile and drone assets employed by the Russian Federation against Ukraine. 2023 (excluding combat activity near the line of contact)

Evolution of Threats from Russia

By the end of 2022, a practical defense model against mass attacks had taken shape: drones were delegated as much as possible to the short-range layer, while missile interceptors were conserved for cruise missiles and critical targets. At the same time, a structural limitation remained: Ukraine lacked a sufficient number of long-range systems capable of systematically increasing interception probability against ballistic missiles 38.

Unlike 2022, when missiles were the primary strike means, by early 2023 attack UAVs increasingly became the main instrument of Russian attacks, likely reflecting the depletion of Russia's missile stocks. In 2022, Russia expended approximately 89% of its Iskander-M inventory, 91% of Kalibr, and 84% of Kh-101 missiles 39.

As a result, in January-April 2023 the number of missiles launched declined to roughly 23-145 targets, compared to approximately 180-265 aerial targets in the second half of 2022. During this period, Russia began localizing Shahed UAV production at the Alabuga special economic zone in Tatarstan, enabling scaling by mid-2023 41. While Russia launched between 68 and 116 UAVs in January-April, the number rose to 424 targets in May, allowing allowed Russia to sustain their attack tempo while rebuilding its missile arsenal.

Although Ukraine already had experience countering Russian cruise missiles and UAVs and had organizational mechanisms for economical resource use, at that time it lacked sufficient modern capabilities that could reliably reliably raise interception probability against targets such as S-300/400, Iskander-M, or Kh-47 Kinzhal over a prolonged campaign 42.

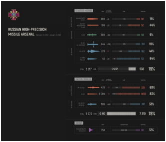

Figure 20. RBC-Ukraine. Number of assets employed by the Russian Federation, February 2022-January 2023 40.

34. Sof, E. "M2 Browning: The World's Most Famous Machine Gun." Combat Operators, April 6, 2025. https://combatoperators.com/firearms/machine-guns/m2-browning/.Сили територіальної оборони ЗСУ. "Загальні відомості про установку ЗУ-23" ["General Information on the ZU-23 Mount"]. N.d. https://sprotyvg7.com.ua/wp-content/uploads/2023/03/%D0%97%D0%A3-23-2-%D0%97%D0%B0%D0%B3%D0%B0%D0%BB%D1%8C%D0%BD%D1%96-%D0%B2%D1%96%D0%B4%D0%BE%D0%BC%D0%BE%D1%81%D1%82%D1%961.pdf.
35. Sof, "M2 Browning: The World's Most Famous Machine Gun."Сили територіальної оборони ЗСУ, "Загальні відомості про установку ЗУ-23" ["General Information on the ZU-23 Mount"]

Ukrainian Countermeasures

The Ukrainian response was to concentrate missile-defense capabilities where the consequences of a breakthrough would be most severe—around major cities and critical military and civilian infrastructure. This required forced prioritization, as even with effective systems it is impossible to provide uniformly dense coverage nationwide at the same time. The principle of economical use of expensive interceptors, established in 2022, remained a core practice to ensure missile-defense resources were not expended on targets that could be defeated with cheaper means.

Interception effectiveness against ballistic targets changed beginning in April 2023, when Germany (followed by the Netherlands and the United States) delivered the first battery of the long-range Patriot SAM system, and i, the Air Force successfully intercepted an aeroballistic Kh-47 Kinzhal missile for the first time 43. Ukraine continued to strengthen its air defense by combining Western missiles with Soviet-era SAMs—an effort known as the FrankenSAM project. One such example is a Buk-M1 launcher adapted to employ RIM-7 Sea Sparrow. Adaptation proceeded rapidly; by autumn 2023, U.S. specialists reportedly modified five Buk launchers in just one month 44. This allowed Ukraine to sustain Soviet-era SAM operations during the time required for delivery of new Western systems, which often remain scarce.

In parallel, Ukraine began fielding foreign short-range gun systems, including Skynex, to enhance interception of strike UAVs and, in some cases, cruise missiles in their terminal phase 45. Skynex operates as an integrated system in which command, radar, and electro-optical sensors cue 35 mm guns firing programmable AHEAD (Advanced Hit Efficiency and Destruction) ammunition.

These rounds detonate near the target and defeat it with a cloud of preformed fragments, reducing reliance on direct hits against small objects. Public Air Force materials showed Skynex engaging Shahed-type targets, where a short burst of roughly ten rounds was sufficient per target 46. As with other systems, the first weeks after deployment rarely yielded maximum effect: units must train, select positions, and rehearse integration with other air defense layers before achieving stable results and predictable ammunition expenditure during night mass attacks.

Russia to impose local air dominance, including airborne operations and support to ground forces. With the advent of mass Shahed waves, this role became more operationally concrete. Helicopters effectively turned into "mobile fire groups in the air," able to engage targets where ground units lacked time, visibility, or advantageous positions. Ukrainian Mi-8 and Mi-24 helicopters have suitable weapon configurations for low-altitude aerial targets, primarily machine guns, and historically, the Mi-24 can also be adapted to other solutions, including air-to-air missiles 47. Army aviation therefore effectively complemented ground-based mobile fire groups and air defense systems, particularly where rapid reaction and flexible sector-to-sector movement are required.

Another adaptation to increasingly mass nighttime combined attacks was the development of an acoustic sensor network. This network consists of arrays of microphones and computers capable of detecting the sound of UAVs or missiles, determining direction of travel, and transmitting data to air defense command posts.

Overall in 2023, the share of intercepted missiles stood at approximately 78% in January and 66% in December, while successful interceptions of enemy drones reached 89% and 82%, respectively 48. In April, missile interception rates increased noticeably, coinciding with Patriot deliveries and the emergence of additional capabilities to counter more complex missile threats. These dynamics unfolded against a sharp increase in load on Ukrainian air defense assets: in 2023, Russia launched 4,568 aerial targets, with 212 in January and 825 in December 49. This growth raised demands on detection, tracking, and throughput, and amplified the impact of interceptor shortages on missile defense outcomes, while interception rates against drones remained higher due to the more systematic use of short-range engagement layers.

36. NV, "За підтримки ЗСУ. В Україні запустили застосунок для допомоги силам ППО у знищенні ворожих дронів і ракет" ["With the Support of the Armed Forces of Ukraine: Ukraine Launches an App to Help Air Defense Destroy Enemy Drones and Missiles"], October 13, 2022, http://techno.nv.ua/ukr/it-industry/dopomoga-ukrajinskiy-ppo-50276457.html.
37. P. Ivaniuk, "Massive Missile Attacks on Ukraine," dataset, 2026, https://www.kaggle.com/datasets/piterfm/massive-missile-attacks-on-ukraine?resource=download.
38. As of early 2023, Ukraine's arsenal of the long-range SAMs consisted of aging S-200 systems.
39. Дощатов, Юрій. "Балістичний терор. Якими ракетами Росія б'є по Україні та як це зупинити" ["Ballistic Terror: What Missiles Russia Uses to Strike Ukraine and How to Stop It"]. РБК-Україна, January 20, 2023. https://www.rbc.ua/rus/news/balistichniy-teror-kimi-raketami-rosiya-b-1674234745.html.
40. Дощатов, "Балістичний терор" ["Ballistic Terror"].

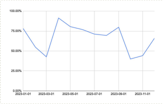

Figure 21. Petro Ivaniuk, Massive Missile Attacks on Ukraine. Effectiveness of Ukrainian air defense interception of Russian missiles. 2023.

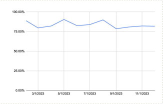

Figure 22. Petro Ivaniuk, Massive Missile Attacks on Ukraine. Effectiveness of Ukrainian air defense interception of Russian Shahed UAVs. 2023.

Stage III (2024) Deterring Mass Combined Strikes Amid Ammunition Shortages

Stage Overview

Russian intent: to shift into a mode of sustained air pressure, anchored by mass Shahed waves with missiles used as a supplementary tool for breakthrough strikes against the most sensitive targets; to exploit interceptor shortages and delivery delays to increase the share of successful hits; and to raise the burden on detection and target allocation through decoy UAVs, new flight profiles, and the emergence of new missile types and external supplies.

Ukraine's response: to preserve air defense throughput under mass conditions—maximizing drone defeats through the short-range layer and non-kinetic means while conserving expensive interceptors for cruise and ballistic threats; to strengthen the fighter component and mobile response assets; and to expand sensor and electronic warfare architecture to reduce expenditure of scarce missiles.

Effects: air defense retained command-and-control and continued to intercept large numbers of targets in absolute terms, but percentage rates declined due to the growing volume of targets and the introduction of decoys; the most vulnerable point became power generation in spring 2024 amid a temporary interceptor shortfall and uncertainty over replenishment timelines.

Key targets: Key targets: the energy sector (from substations and the grid in winter to generation in spring: TPPs/HPPs), major cities and civilian infrastructure, ports and selected industrial enterprises, with selective strikes on command and logistics nodes.

Russian pressure tools:

- Mass combined strikes against critical and civilian infrastructure.
- Scaling Shahed as the primary instrument of sustained air pressure.
- Mass employment of decoy UAVs and "false targets" to overload air defense and expose positions.
- Expansion and modernization of the missile arsenal and use of external supplies (including North Korea).

Ukrainian countermeasures:

- FrankenSAM upgraded surface-to-air missile systems;
- MANPADS;
- Fighter aviation MiG-29 and Su-27;

- FrankenSAM upgraded surface-to-air missile systems;
- MANPADS;
- Western air defense systems (Gepard, NASAMS, IRIS-T, SAMP-T, HAWK, Patriot, Skynex);
- Mobile fire groups;
- Army aviation (helicopters);
- ePPO;
- Electronic warfare.

New:

- F-16;
- Scaling of existing capabilities.

Not relevant:

- S-300 and Buk-M1 surface-to-air missile systems due to missile shortages.

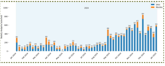

Figure 23. Air Force Command of UA Armed Forces. Weekly number of missile and drone assets employed by the Russian Federation against Ukraine. 2024 (excluding combat operations near the line of contact).

Evolution of Threats from Russia

By late 2023, a temporary decline in the intensity of missile strikes became evident, suggesting a pause to rebuild strike inventories, and the logic of Russia's air threat shifted. Instead of waves separated by relatively long intervals, Russia moved to a regime of sustained air pressure: attacks were anchored by strike UAVs of the Shahed family, while missiles were employed intermittently as force multipliers and as a breakthrough tool against the most sensitive targets. As President Zelensky noted, under sustained strike intensity Ukraine risked "depleting" its air defense missile stocks 50.

During this period, Russia's strategic priority remained the energy sector and civilian infrastructure. In winter 2023-2024, Russia attempted to recreate blackout scenarios by targeting electricity transmission and distribution elements—primarily substations and grid nodes that determine supply resilience for large cities and industrial areas. By spring 2024, however, the focus shifted toward destroying generation capacity, particularly thermal and hydroelectric power plants (TPPs/HPPs). This shift coincided with a temporary shortage of interceptor missiles for high-end air defense systems such as Patriot and broader uncertainty over replenishment timelines amid political delays in the United States 51. The spring 2024 attacks were significant: on 22 March, the largest energy-sector strike to date was recorded, hitting, among other targets, the Dnipro HPP and multiple generation facilities 52. On 11 April, the Trypillia TPP was destroyed, sharply degrading the generation balance in central regions 53.

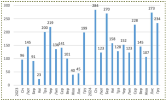

Figure 24. Number of missiles launched by the Russian Federation, 2023-2024.

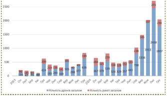

Figure 25. Number of missiles and drones launched by the Russian Federation, 2023-2024.

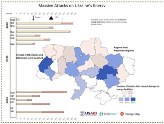

Figure 26. DiXi Group. Intensity of Russian strikes against Ukraine's energy sector, 2022-2024 54.

Alongside Shaheds, low-cost decoy UAVs were increasingly emerging to force air defense to expend ammunition and to help expose mobile positions. These platforms were typically built from simple materials (foam/plywood), carried cameras, and used Ukrainian SIM cards to transmit imagery. By autumn 2024, this practice became widespread. The adversary employed "false targets" such as Gerbera, including variants with elements that improved target simulation for detection systems. While Russia launched up to 800 UAVs per month between January and August, from September to December 2024 monthly launches could reach nearly 2,500 drones.

During the summer, the missile strikes lacked a systematic pattern. Areas with dense residential development were shelled, resulting in continuous damage to housing and civilian casualties. Port infrastructure and civilian enterprises were also targeted, aiming to reduce Ukraine's economic potential and sustain terror against the civilian population.

Figure 27. Launches of Russian UAVs in 2024.

At the same time, strike drones themselves evolved. Isolated test variants were observed with darker paint schemes to complicate nighttime detection, as well as versions with warheads designed specifically to damage buildings. Drones were also fitted with 4G modems using Ukrainian operators and Starlink connectivity.

Figure 28. Main Directorate of Intelligence of Ukraine (GUR). Russian decoy UAV 55.

Figure 29. Modem and a SIM card of the Ukrainian mobile operator Kyivstar installed on the body of a Shahed UAV.

41. Defense Express. "Як РФ розгортає виробництво Shahed-136: проєкт "Алабуга" у цифрах, строках та важливих деталях" ["How Russia Is Scaling Up Shahed-136 Production: The "Alabuga" Project in Numbers, Timelines, and Key Details"]. July 4, 2023. https://defence-ua.com/people_and_company/jak_rf_rozgortaje_virobnitstvo_shahed_136_projekt_alabuga_u_tsifrah_strokah_ta_vazhlivih_detaljah-12096.html.Глуховський, М. "Де Росія бере "Шахеди". Інтерв'ю з розслідувачем, який викрив фабрику у Татарстані" ["Where Russia Gets "Shaheds": Interview with the Investigator Who Exposed the Factory in Tatarstan"]. Главком. July 11, 2023. https://glavcom.ua/interviews/de-rosija-bere-shakhedi-intervju-z-rozsliduvachem-jakij-vikriv-fabriku-u-tatarstani-940376.html.
42. Ржеутська, Л. "Ракети Х-22, С-300 і С-400: чому їх не збиває ППО України?" ["Kh-22, S-300, and S-400 Missiles: Why Doesn't Ukraine's Air Defense Shoot Them Down?"]. DW. January 17, 2023. https://www.dw.com/uk/raketi-h22-s300-ta-s400-comu-ih-ne-zbivae-ukrainska-ppo/a-64427508.

Figure 30. Defense Express. Downed Geran-2 drone equipped with a Starlink terminal 56.

In parallel, Russia expanded its missile arsenal and supply sources. This included deliveries of KN-23 ballistic missiles from North Korea, which began to appear as a significant element of the strike inventory in early 2024 57. During this period, Russia also used the 3M22 Zircon against Kyiv and the Kh-69 against the Trypillia TPP—hypersonic tactical aviation cruise missiles with very low-altitude flight profiles that complicate timely detection 58. Signs of Kh-101 modernization were also recorded: some missiles featured cluster warhead modules and additional countermeasures in the terminal phase.

In November 2024, Russia for the first time employed the Oreshnik intermediate-range ballistic missile against the city of Dnipro, a system capable of carrying nuclear warheads 60.

At the strategic level, the UAV segment was also institutionalized within the Russian military. In July 2024, the establishment of the Rubikon Center for Advanced Defense Technologies and the "Judgment Day" units—elite formations within Russia's unmanned systems forces—became public. These units comprise the most highly trained operators, rapidly scale new tactics, and receive priority access to resources.

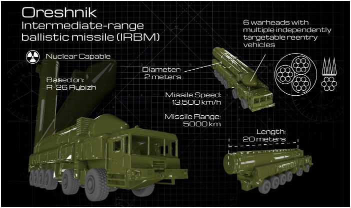

Figure 31. Slovo i Dilo. Characteristics of the Oreshnik missile 59.

43. Defense Express. ""Гіперзвуковий" Х-47 "Кинжал" успішно збито ЗСУ: уламки й пояснення причини сильного вибуху уночі 4 травня над Києвом (оновлено)" ["'Hypersonic' Kh-47 'Kinzhal' Successfully Shot Down by Ukraine's Armed Forces: Debris and Explanation of the Powerful Explosion on the Night of May 4 over Kyiv (Updated)"]. Defense Express. May 5, 2023. https://defence-ua.com/weapon_and_tech/giperzvukovij_h_47_kinzhal_uspishno_zbito_zsu_foto_ulamkiv_j_pojasnennja_prichini_silnogo_vibuhu_unochi_4_travnja_nad_kijevom-11498.html.
44. Defense Express. "FrankenSAM для України від США: перші гібридні ЗРК вже у ЗСУ - на що вони здатні" ["FrankenSAM for Ukraine from the U.S.: The First Hybrid SAM Systems Are Already in the Armed Forces—What Can They Do?"]. Defense Express. October 29, 2023. https://defence-ua.com/weapon_and_tech/frankensam_dlja_ukrajini_vid_ssha_zrk_vzhe_protestovani_ta_do_kintsja_oseni_budut_u_zsu_na_scho_voni_zdatni-13313.html.
45. Defense Express. "Що це за системи Skynex, які уже отримала Україна для боротьби з ракетами чи Shahed-136 рашистів" ["What Are the Skynex Systems Ukraine Has Already Received to Fight Russian Missiles or Shahed-136 Drones?"]. Defense Express. April 28, 2023. https://defence-ua.com/weapon_and_tech/scho_tse_za_sistemi_skynex_jaki_uzhe_otrimala_ukrajina_dlja_borotbi_z_raketami_chi_shahed_136_rashistiv-11425.html.

Ukrainian Countermeasures

Within this tactical framework, Ukrainian air defense sought to reinforce the short-range layer while balancing the management of scarce munitions. In practical terms, this meant:

- **Cost-based target allocation:** maximizing the defeat of drones with short-range assets while conserving missiles for more complex threats.
- **Dispersion and concealment:** to reduce the effectiveness of Russian decoys and reconnaissance.
- **Expansion of external supplies:** of air defense systems and ammunition.

In spring 2024, this approach was complicated by an ammunition crisis. Delays in U.S. assistance led to an acute shortage of interceptor missiles for systems such as Patriot and IRIS-T, enabling the adversary to strike generation assets more effectively.

Against this backdrop, mobile fire groups (MFGs) remained one of the core tools for countering mass drone attacks. Public Ukrainian Air Force statistics for the first half of 2024 state that from 1 January to 25 June, Russia launched 2,277 Shahed UAVs against Ukraine, of which air defense destroyed 1,953 (≈86%), with more than 80% of these shoot-downs attributable to MFGs [61]. Over the year as a whole, amid evolving UAV modifications and employment tactics, MFGs continued to account on average for up to 40% of UAV defeats, sustaining interceptor conservation for higher-end threats [62].

A separate breakthrough was the introduction of F-16 fighters in summer 2024, which mattered not only as a political milestone but as a practical reinforcement of the fighter component at a time when the Soviet-era MiG-29/Su-27 fleet faced structural limits in air-to-air missile stocks and replenishment. F-16s addressed a core resilience gap by opening access to a more reproducible Western weapons ecosystem and a more technologically advanced fighter fleet [63].

In parallel, the role of EW expanded, particularly through networked solutions that aim not to destroy drones kinetically but to disrupt their navigation via spoofing and satellite signal disorientation. In public discourse, this was often described through the concept of a nationwide system akin to "Pokrova," which, according to open assessments, can force a portion of Shahed UAVs off course without expending ammunition—producing an effect that scales more cheaply than kinetic interception [64].

In 2024, the share of intercepted missile targets fell from 66% in December 2023 to 48% in January 2024. It then recovered to 69% by December, but remained volatile throughout the year, with pronounced declines during periods of peak load and interceptor shortages. This volatility likely reflected delays in U.S. assistance and the resulting contraction of available missile stocks for high-end systems, which limited the ability to sustain a stable interception tempo under combined attacks and forced more frequent risk-laden prioritization decisions. In parallel, the share of destroyed or "locationally lost" UAVs increased from 77% to 97%, consistent with the scaling of short-range and mass-intercept tools that are easier to expand quantitatively: mobile fire groups, Gepard, MANPADS, Skynex, the involvement of fighter and army aviation, and electronic warfare. Together, these measures were able to strengthen detection and cueing and generated a significant share of "locational losses" without expending costly missiles. The recovery of missile interception rates toward year-end aligns with the gradual stabilization of military assistance flows and improved integration of available layers, including Western air defense systems and modernized Soviet complexes under FrankenSAM. Nevertheless, the gap between 69% missile interception and 97% UAV defeat underscores that the missile segment remained the most sensitive to ammunition shortages and replenishment timelines.

46. Texty. "Відео дня. Український екіпаж німецького комплексу ППО Skynex знищує російський "шахед"" ["Video of the Day: A Ukrainian Crew of the German Skynex Air Defense System Destroys a Russian 'Shahed'"]. Texty. October 6, 2025. https://texty.org.ua/fragments/116022/video-dnya-ukrayinskyj-ekipazh-nimeckoho-kompleksu-ppo-skynex-znyshuye-rosijskyj-shahed.
47. Мілітарний. "Гелікоптери у протиповітряній обороні" ["Helicopters in Air Defense"]. Мілітарний. September 6, 2023. https://militarnyi.com/uk/articles/gelikoptery-u-protypovitryanij-oboroni.
48. Ivaniuk, Massive Missile Attacks on Ukraine.
49. According to data collected by Snake Island Institute and Colonel Yevhen Konovalets Military School.
50. Balmforth, Tom, and Yuliia Dysa. "Ukraine's Zelenskiy Warns of Dwindling Air Defence Missiles." Reuters, April 6, 2024. https://www.reuters.com/world/europe/ukraine-may-run-out-air-defence-missiles-if-russia-keeps-up-bombardment-2024-04-06/.
51. Cafarella, Jennifer. "How Delays in Western Aid Gave Russia the Initiative: From the Ukrainian Counteroffensive to Kharkiv." Institute for the Study of War, August 31, 2025. https://understandingwar.org/research/russia-ukraine/how-delays-in-western-aid-gave-russia-the-initiative-from-the-ukrainian-counteroffensive-to-kharkiv/.

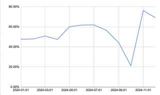

Figure 32. Petro Ivaniuk. Massive Missile Attacks on Ukraine. Effectiveness of Ukrainian air defense in intercepting Russian missiles. 2024.

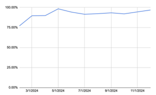

Figure 33. Petro Ivaniuk. Massive Missile Attacks on Ukraine. Effectiveness of Ukrainian air defense in intercepting Shahed-class UAVs. 2024.

Stage IV (2025-early 2026) Scaling Air Defense Throughput Under Mass Combined Missile-Drone Strikes

Stage Overview

Russian intent: to shift the air campaign into a sustained air-defense saturation regime by sharply increasing target volume and maintaining a high attack tempo throughout the year; to impose unfavorable economics on the defender by forcing the expenditure of scarce interceptors on mass low-cost targets and decoys; to raise penetration probability through qualitative UAV improvements and routing complexity, including jet-powered variants, altitude changes, repeated ingress corridors, and supporting infrastructure; and to broaden the strike set through an expanded missile inventory and regionally patterned strikes against energy and urban nodes.

Ukraine's response: to develop interceptor UAVs as a tool to lower interception costs and offload scarce missile inventories; to strengthen early detection, cueing, and target allocation in order to shorten the reaction cycle; to scale electronic warfare and countermeasures against UAV navigation/communications to reduce the share of targets requiring kinetic engagement; and to refine and institutionalize a three-layer echeloning logic with defined zones of responsibility to better deconflict targets across layers.

Effects: higher absolute interception volumes and improved resilience under high monthly attack intensity; the key outcome was the ability to sustain tempo, prioritize targets, and economize ammunition under prolonged pressure; at peak periods, however, a persistent gap between launched and destroyed targets remains an indicator of saturation and continued dependence on ammunition and system availability.

Key targets: energy infrastructure with a focus on gas facilities, CHPs, and distribution nodes; major cities and civilian infrastructure as instruments of terror and destabilization; industrial and logistics objects in a regionally structured strike logic.

Russian pressure tools:

- Mass employment of Shahed UAVs and decoy drones.
- Jet-powered and high-altitude UAV variants, more complex flight profiles, and enhanced controllability via Starlink terminals and mesh networks.
- Scaled missile production, work on new missiles and loitering munitions (Kh-95, Banderol, etc.).

52. "ДніпроГЕС, Запоріжжя, Харків, Хмельницький... Все про наслідки атаки РФ 22 березня (фото) ["Dnipro HPP, Zaporizhzhia, Kharkiv, Khmelnytskyi... All About the Consequences of Russia's March 22 Attack (Photos)"]." Радіо Свобода, March 22, 2024. https://www.radiosvoboda.org/a/naslidky-rosiskykh-udariv-22-bereznya/32872559.html.
53. Доцатов, Юрій. "Одна з найпотужніших станцій в Україні. Що відомо про знищену росіянами Трипільську ТЕС ["One of Ukraine's Most Powerful Plants: What Is Known About the Trypilska TPP Destroyed by Russia"]." РБК-Україна, April 11, 2024. https://www.rbc.ua/rus/news/odna-naypotuzhnishih-stantsiy-ukrayini-shcho-1712827778.html.

- Regular combined missile-drone strikes with periodic missile peaks.
- Expanded launch geography and repeated ingress corridors.
- Enhanced ISR enabling strikes (satellite data, UAV reconnaissance-for-strike).
- Use of Belarusian territory to deploy drone-control relay infrastructure for attacks on northern oblasts of Ukraine.

Ukrainian countermeasures:

- FrankenSAM upgraded surface-to-air missile systems;
- MANPADS;
- Fighter aviation MiG-29 and Su-27;
- Western air defense systems (Gepard, NASAMS, IRIS-T, HAWK, Patriot, Skynex);
- Mobile fire groups;
- Army aviation (helicopters);
- ePPO;
- Electronic warfare.

New:

- Interceptor UAVs;
- Mirage aircrafts;
- AEW&C (Airborne Early Warning and Control) aircraft ASC 890.

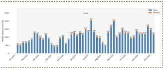

Figure 34. Air Force Command of UA Armed Forces. Weekly number of missile and drone assets employed by the Russian Federation against Ukraine. 2025 (excluding combat activity near the line of contact).

Evolution of Threats from Russia

In 2025, Russia's air campaign shifted into a maximum-load mode aimed at Ukraine's air-defense throughput. The defining feature of this period was the simultaneous scaling of aerial terror assets and an organizational buildup of Russian capabilities in unmanned systems and long-range strike. This enabled Russia to sustain a high attack tempo throughout the year, rather than operating in discrete waves. Compared to 2024—when the adversary launched more than 15,700 targets in total [65]—the 2025 volume increased to approximately 56,568 [66].

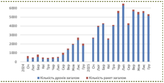

Figure 35. Number of missiles and UAVs launched, 2024-2025.

54. Щербак, І. "За два роки рф здійснила 25 масованих атак на енергетику України - DiXi Group ["Over Two Years, Russia Carried Out 25 Mass Massed Attacks on Ukraine's Energy Sector – DiXi Group"]." DiXi Group, October 10, 2024. https://dixigroup.org/za-dva-roky-rf-zdijsnyla-25-masovanyh-atak-na-energetyku-ukrayiny/.
55. Головне управління розвідки Міністерства оборони України. "Гербери" з фанери, що включають іноземну електроніку — деталі будови чергового російського дрона ["Plywood 'Herbera' Drones Featuring Foreign Electronics: Design Details of Another Russian Drone"]. November 14, 2024.https://gur.gov.ua/content/herbery-z-fanery-ta-inozemnoi-elektroniky-detali-budovy-cherhovoho-rosiiskoho-drona.html.
56. Defense Express. "РФ встановила Starlink на Shahed-136: це про необмежну дальність зв'язку для БПЛА, що літає на 2000 км ["Russia Installed Starlink on the Shahed-136: This Means Essentially Unlimited Communications Range for a UAV Flying 2,000 km"]." September 25, 2024. https://defence-ua.com/news/rf_vstanovila_na_shahed_136_starlink_ochevidno_tse_bulo_lishe_pitannja_chasu-16716.html.
57. Long, Colleen, and Aamer Madhani. "US says Russia used North Korean missiles in Ukraine." AP News, January 4, 2024. https://apnews.com/article/3601a979e91d19c94e7d0fe27a398669.
58. Defense Express. "рф для удару по Трипільській ТЕС використала найновіші Х-69 і це гірше за "Кинжал" ["Russia Used the Newest Kh-69 to Strike the Trypilska TPP, and That's Worse Than a 'Kinzhal'"]." April 11, 2024. https://defence-ua.com/weapon_and_tech/rf_dlja_udaru_po_tripilskij_tes_vikoristala_najnovishi_h_69_i_tse_girshe_za_kinzhal-15016.html.

For mass strikes, Russia continued to rely on low-cost targets that are easy to scale in production. This included strike and decoy UAVs such as the Gerbera, which often lacked a warhead. According to Ukraine's Defense Intelligence (GUR), by the end of 2025 Russia was producing roughly 170 Shahed drones per day (5,100 per month) and 2,500 decoy drones, with total production exceeding 6,000 units per month 67. A further complicating factor was the use of jet-powered UAVs such as the Shahed-238 (also known as Geran-3): with speeds above 500 km/h, these targets are harder for mobile fire groups to engage and reduce the time window between detection and opening fire.

Figure 36. Serhii Sternenko Foundation. Shahed-238 jet-powered UAV (Geran-3) 68.

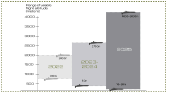

Figure 37. Approximate flight altitudes of Shahed-type UAVs.

Russian UAV flight profiles also evolved, with a portion of drones operating at higher altitudes (3-4 km instead of the typical 500-700 m). At these heights, they are more difficult to engage using small arms and light-caliber systems (generally effective up to ~2 km), forcing the defender to employ medium-range air defense systems or fighter aviation 69.

In addition, Russia enhanced its unmanned systems with machine-vision solutions, self-destruct mechanisms, evasion algorithms, and infrared illuminators intended to dazzle night-vision devices used by firing units. Among other adaptations was the installation of MANPADS on the drone airframe (a modification referred to as Geran-4) 70.

Russia also expanded the launch geography for Shahed-class UAVs. As of 2025, this involved ten launch points (droneports) located in Smolensk, Oryol, Bryansk, Rostov oblasts, Krasnodar Krai, and temporarily occupied Crimea.

At the largest of these locations, Russia has deployed supporting infrastructure that includes runways, fixed launchers, storage for warheads, buildings for drone assembly, storage for completed UAVs, pre-launch preparation areas, warehouses, and air defense positions to protect these sites. Some locations were built from scratch, while others were converted from older airfields. Student labor, including minors, has been used to build "droneports" and produce Shahed UAVs 72. After this network was established, Russia typically relied on repeated UAV ingress corridors. Routes from specific launch sites quickly became standardized, shaped by available navigation, terrain, and the need to coordinate flights within Russian airspace alongside Russian air defense operations. As a rule, the flight routes followed patterns such as:

- **From Shatalovo and Tsymbalova** (Smolensk and Oryol oblasts): via the Chernihiv axis toward Kyiv;
- **From Navlia and Khalino** (Bryansk and Kursk oblasts): via Sumy oblast, then diverging toward Poltava, Chernihiv, or Kyiv directions;
- **From Millerovo** (Rostov oblast): into eastern and central oblasts via Donetsk/Luhansk, exiting toward Dnipro;
- **From Primorsko-Akhtarsk** (Krasnodar Krai): into southern oblasts via the Azov Sea coastline and the Zaporizhzhia axis;
- **From temporarily occupied Crimea** (Hvardiiske, Chauda, Kacha): into southern oblasts via Kherson/ Mykolaiv with possible divergence toward Odesa or central oblasts;
- **From temporarily occupied Donetsk:** into eastern and central oblasts.

59. "Орєшнік" путіна: що відомо про нову російську ракету ["Putin's 'Oreshnik': What Is Known About the New Russian Missile"]. Слово і Діло, November 26, 2024. https://www.slovoidilo.ua/2024/11/26/infografika/bezpeka/oryeshnik-putina-vidomo-pro-novu-rosijsku-raketu.
60. Мельник, Р. "росія вдарила по Дніпру міжконтинентальною балістикою та крилатими ракетам. ППО перехопила 6 цілей ["Russia Struck Dnipro with an ICBM and Cruise Missiles; Air Defense Intercepted 6 Targets"]." Hromadske, November 21, 2024. https://hromadske.ua/viyna/234918-rosiia-vdaryla-po-ukrayini-mizkontynentalnoiu-balistykoiu-ta-krylatymy-raketam-ppo-perekhopyla-6-tsiley.
61. Краєвська, Т. "На рахунку мобільних вогневих груп понад 80% із збитих "шахедів" - Повітряні сили ["Mobile Fire Groups Account for Over 80% of Downed 'Shaheds'—Air Force"]." Українські Національні Новини (УНН), June 25, 2024. https://unn.ua/news/na-rakhunku-mobilnykh-vohnevykh-hrup-ponad-80percent-iz-zbytykh-shakhediv-povitriani-syly.

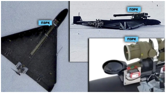

Figure 38. Serhii Beskrestnov (Flash). Russian Shahed UAV equipped with a MANPADS (Geran-4) 71.

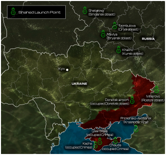

Figure 39. Shahed drone launch sites.

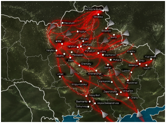

Figure 40. Texty. Approximate approach routes of Russian drones toward Kyiv based on monitoring data. April 2025 73.

Russia also strengthened auxiliary infrastructure for UAV control by using Belarusian territory to deploy relay systems near the border with Ukraine, enhancing reconnaissance, targeting adjustment, and strike effectiveness in northern oblasts 75.

Beyond expanding its UAV arsenal, Russia pursued the expansion of its long-range missile inventory. It continued testing the Kh-95 hypersonic missile, reportedly with a range of up to 1,500 km and intended for launch from Tu-22M3 bombers. Russia also tested loitering munitions and guided aerial bombs—for example, the Banderol cruise missile with a jet engine, a 140 kg warhead, and a stated range of 700 km. Some experimental systems have already undergone combat validation through attempted strikes on targets in Ukraine, indicating an intent to move new solutions rapidly from testing to employment 76. An additional factor is the deployment in Belarus—at an airfield near Krychev—of the Oreshnik (Kedr) missile complex. This could increase pressure on the northern axis and complicate coverage planning by expanding the number of directions requiring sustained monitoring and readiness to respond 77.

Figure 41. Molfar Intelligence Institute. "Droneport" in Tsymbalova village, Oryol Oblast 74.

Figure 42. Overclockers. Kh-95 missile prototype 78.

62. "Ефективність мобільних вогневих груп становить 40% — Сирський ["Mobile Fire Groups' Effectiveness Is 40%—Syrskyi"]." Мілітарний, June 22, 2025. https://militarnyi.com/uk/news/efektyvnist-mobilnyh-vognevyh-grup-stanovyt-40-syrskyj/.

Figure 43. War & Sanctions. Banderol cruise missile.

Figure 44. Airfield near the city of Krichev, where infrastructure for the deployment and launch of Oreshnik-class missiles is being established.

The underlying logic was to increase the burden on detection, tracking, and interception and to raise the probability of cruise and ballistic missile penetration. At the tactical level, Russia also aimed to exhaust Ukrainian resources ahead of the next resupply cycle. Under these conditions,a relatively effective interception system faced a steadily rising load [79].

After the large-scale damage to thermal generation in 2024, Russia in 2025 shifted its focus to other nodes of the energy system—particularly gas infrastructure and the distribution equipment of nuclear power plants, aiming to trigger emergency shutdowns of power units. With the onset of prolonged cold weather in Ukraine in December 2025, Russia scaled strikes against combined heat and power plants (CHPs) and related infrastructure and continued targeting them in January 2026. The adversary operated in a regional pattern, concentrating strikes on one area and shifting to another in subsequent attacks. In practice, Russia alternated concentrations on major-city infrastructure, including Odesa, Dnipro, Kharkiv, and Kyiv, leading to localized disruptions in electricity, water, and heat supply for 1-2 days or longer [80].To improve strike effectiveness, Russia more actively employed satellite reconnaissance ahead of attacks, including its own systems and dual-use satellite data. Russia may also have used data from foreign satellites, including China, Iran, and Egypt [81]. In addition to satellite reconnaissance, the adversary used UAVs—likely Orlan-10 or ZALA—for additional reconnaissance and strike adjustment.

Ukrainian Countermeasures

At the tactical level, the key countermeasure novelty for Ukrainian air defense in 2025 was the introduction of interceptor SAM drones—high-speed FPV interceptors used against reconnaissance UAVs (including Zala, Orlan/ Lancet) and strike drones such as Shahed. The objective was to reduce interception costs and offload scarce air-defense missiles, especially as drone attacks continue to grow as a share of the threat set. Beyond UAV defense, FPV interceptors allow Ukraine to impose unfavorable economics on the attacker, where the value of destroyed targets exceeds interception costs by multiples. As of June 2025, 281 interceptor drones with a total cost of roughly

63. Malenko, Anastasia. "Ukraine finally deploying US-made F-16 fighter jets, Zelenskiy says." Reuters, August 5, 2024. https://www.reuters.com/world/europe/ukraine-finally-deploying-f-16-fighter-jets-says-zelenskiy-2024-08-04/.
64. Hambling, David. "Ukraine's Pokrova spoofing system tells Shaheds to get lost." Forbes, February 16, 2024. https://www.forbes.com/sites/davidhambling/2024/02/12/ukraines-pokrova-spoofing-system-tells-shaheds-to-get-lost.
65. Слово і Діло, "У Повітряних силах розповіли, скільки російських цілей знищила ППО у 2024 році" [The Air Force Reported How Many Russian Targets Air Defense Destroyed in 2024], December 31, 2024, https://www.slovoidilo.ua/2024/12/31/novyna/bezpeka/povitryanyx-sylax-rozpovily-skilky-rosijskyx-czilej-znyshhyla-ppo-2024-roczi
66. Snake Island Institute and the Colonel Yevhen Konovalets Military School calculations
67. Forbes Ukraine, "Росія виробляє 2700 «шахедів» на місяць, майже стільки ж імітаторів – ГУР" [Russia Produces 2,700 'Shaheds' per Month, Almost as Many Decoys – HUR], June 9, 2025, https://forbes.ua/news/rosiya-viroblyae-2700-shakhediv-na-misyats-mayzhe-stilki-zh-imitatoriv-gur-09062025-30369
68. Ivan Khomenko, "Ukraine's Interceptor Drone Downs Russia's Jet-Powered Shahed for the First Time," UNITED24 Media, November 30, 2025, https://united24media.com/latest-news/ukraines-interceptor-drone-downs-russias-jet-powered-shahed-for-the-first-time-13885
69. Андрій Кузьмін, "Мутація «шахедів». Як Путін удосконалює дрони-вбивці" [The 'Shahed' Mutation: How Putin Is Improving Killer Drones], ГЛАВКОМ, December 17, 2025, https://glavcom.ua/publications/mutatsija-shakhediv-jak-putin-udoskonaljuje-droni-vbivtsi--1092969.html

$450,000 downed 258 enemy UAVs with an estimated total value of approximately $25,000,000 [82]. In other words, for every $1 spent, Ukraine imposed about $55 in losses by value of destroyed Russian targets. Ukrainian interceptors have also demonstrated the ability to engage larger aerial platforms: in October 2025, an FPV drone reportedly shot down a Russian Mi-8 helicopter [83].

Figure 45. Serhii Prytula Charitable Foundation; Militarnyi. Ukrainian interceptor drone Taras-P [84].

The role of early warning and cueing also increased, shortening reaction time against low-flying targets and enabling more effective management of aviation and ground-based assets. In this context, an important reinforcement was the ASC 890 airborne early warning aircraft (Saab 340 AEW&C) included by Sweden in its assistance package to Ukraine [85]. Together with the expanding role of fighter aviation, this improved Ukraine's ability to intercept a portion of targets at longerapproaches and to allocate tasks more effectively across defense layers.

In parallel, Ukraine began constraining the adversary's ability to use satellite internet on strike UAVs. In late January 2026, following a request from the Ministry of Defense, SpaceX introduced temporary restrictions on Starlink operations in Ukraine to complicate Russian drone use in air attacks. Terminals moving faster than roughly 75-90 km/h can be automatically blocked, while a whitelist mechanism for verified Ukrainian terminals is being prepared. In practical terms, this reduces the value of integrating Starlink into drones such as Shahed / Gerbera / Molniya, since the attacker risks losing the communications channel precisely while the platform is moving toward the target or maneuvering along its route [86].

In 2025, the share of intercepted missiles was 36% in January and 64% in December, while UAV interception stood at 97% and 81%, respectively.

These indicators diverged amid a sharp increase in the number of launched targets (including decoys) and regular combined strikes that exhausted air defenses under ammunition constraints. The drop in missile interception to 36% in January is consistent with missile peaks in combined attacks, a higher share of more complex missile targets, and a forced economy mode—conserving interceptors and narrowing coverage. The rise to 64% by December can be explained by improved target allocation across echelons and more stable employment of available tools, including Western air defense systems, FrankenSAM, and the use of fighter aviation with F-16s. Conversely, the decline in UAV interception from 97% to 81% aligns with mass employment of improved Shahed variants alongside decoy drones, more complex flight profiles, and repeated ingress corridors that overload detection and the short-range layer even when mobile fire groups, EW, and interceptor drones are present.

Figure 46. Petro Ivaniuk, Massive Missile Attacks on Ukraine. Effectiveness of Ukrainian air defense measured by the number of intercepted missiles. 2025.

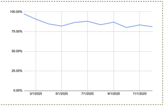

Figure 47. Petro Ivaniuk, Massive Missile Attacks on Ukraine. Effectiveness of Shahed-class UAV interceptions. 2025.

70. Defense Express, "Як має працювати ідея рашистів встановити ПЗРК 'Верба' на 'Шахед' і який компонент насправді є головним" [How the Idea of Installing a 'Verba' MANPADS on a 'Shahed' Is Supposed to Work and Which Component Is Actually the Key One], January 5, 2026, https://defence-ua.com/news/jak_maje_pratsjuvati_ideja_rashistiv_vtsanoviti_pzrk_verba_na_shahed_i_jakij_komponent_naspravdi_je_golovnim-21391.html

Overall, in 2022 through the first half of 2024, the volume of launched strike assets fluctuated in waves without sustained long-term growth. From the second half of 2024, a stable upward trend began, and in 2025 it shifted into a regime of high monthly intensity with pronounced peaks.

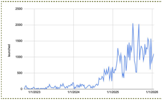

Figure 48. Petro Ivaniuk, Massive Missile Attacks on Ukraine. Number of hostile aerial assets launched, September 2022-January 2026.

Against this backdrop, the absolute number of destroyed targets also fluctuated. Given the growth in launched targets since the start of the full-scale invasion, air defense intercepts more in absolute terms than in earlier years—evidence of adaptation and capability growth. At the same time, in the highest-load months the gap between launched and destroyed targets widens, indicating saturation of air defense systems and shortages of Western defense assets. This means that in 2025 the key metric was not only interception percentage, but the system's ability to sustain tempo, prioritize targets, and economize ammunition under prolonged pressure.

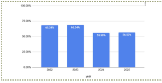

Figure 49. Petro Ivaniuk, Massive Missile Attacks on Ukraine. Effectiveness of Ukrainian air defense measured by the number of intercepted Russian missiles, September 2022-January 2026.

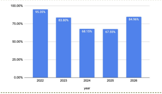

Figure 50. Petro Ivaniuk, Massive Missile Attacks on Ukraine. Effectiveness of Ukrainian air defense measured by the number of intercepted Shahed-class UAVs, September 2022-January 2026.

Given the current level of air threats, Ukraine is still searching for an optimal echeloning scheme. The working model consists of three conditional belts that are continuously refined. The first is the forward belt (0-30 km from the line of contact), where brigades operate. They provide immediate cover in a short time-of-flight environment and along the most likely axes, using primarily short-range assets (MANPADS, gun systems, mobile fire groups) against UAVs and other low-altitude targets. Their priority is the defeat of reconnaissance drones and FPV threats within their area of responsibility. The second belt (30-80 km from the line of contact) is reinforced by the Unmanned Systems Forces. It provides dense short-range interception on approaches to major nodes and offloads medium- and long-range missile systems by focusing on mass targets and repeated ingress routes. The third, rear belt (beyond 80 km from the line of contact), is under Air Force responsibility. It includes medium- and long-range systems and aviation that cover key cities and infrastructure and engage more complex targets, including cruise missiles and (aero)ballistic threats.

This division should be treated as a working model and a direction of development rather than a fixed structure. In practice, the system often operates less linearly: some forward-belt air defense units are regularly pulled back to protect strategic objects in depth, and the Unmanned Systems Forces (as well as brigades and the Air Force) cannot always hold their belt due to shortages of trained crews, limited equipment, and the absence of a continuous detection field.

71. Оксана Рекун, "'Шахед' з ПЗРК та нові трофеї: які російські БпЛА знаходять українські військові на Чернігівщині" ['Shahed' with a MANPADS and New Trophies: Which Russian UAVs Ukrainian Troops Are Finding in the Chernihiv Region], Суспільне, January 10, 2026, https://suspilne.media/chernihiv/1210498-sahed-z-pzrk-ta-novi-trofei-aki-rosijski-bpla-znahodat-ukrainski-vijskovi-na-cernigivsini/
72. Molfar Intelligence Institute, "Орландо, Мілан, Шанхай: звідки росіяни запускають 'Шахеди'? Molfar Intelligence Institute читає секретні документи з 'Алабуги'" [Orlando, Milan, Shanghai: From Where Do Russians Launch 'Shaheds'? Molfar Intelligence Institute Examines Secret Documents from 'Alabuga'], January 6, 2026, https://www.molfar.institute/orlando-milan-shanhaj-zvidky-rosiyany-zapuskayut-shahedy-molfar-intelligence-institute-chytaye-sekretni-dokumenty-z-alabugy/

Figure 51. Approximate structure of Ukraine's layered air defense system and zones of responsibility as of late 2025.

73. Надя Кельм and Олександр Шульман, "Чому «Шахеди» стало важче збивати і як вони летять на Київ (карти)" [Why 'Shaheds' Have Become Harder to Shoot Down and How They Fly Toward Kyiv (Maps)], Texty.org.ua, April 15, 2025, https://texty.org.ua/articles/114887/chomu-shahedy-stalo-vazhche-zbyvaty-ta-yakymy-marshrutamy-vony-letyat-na-kyyiv/
74. Кельм and Шульман, "Чому «Шахеди» стало важче збивати...".
75. Дмитро Андрущенко, "Російські ретранслятори на білорусько-українському кордоні" [Russian Signal Repeaters on the Belarus–Ukraine Border], PSDinfo, December 17, 2025, https://www.psdinfo.pro/post/%D1%80%D0%BE%D1%81%D1%96%D0%B9%D1%81%D1%8C%D0%BA%D1%96-%D1%80%D0%B5%D1%82%D1%80%D0%B0%D0%BD%D1%81%D0%BB%D1%8F%D1%82%D0%BE%D1%80%D0%B8-%D0%BD%D0%B0-%D0%B1%D1%96%D0%BB%D0%BE%D1%80%D1%83%D1%81%D1%8C%D0%BA%D0%BE-%D1%83%D0%BA%D1%80%D0%B0%D1%97%D0%BD%D1%81%D1%8C%D0%BA%D0%BE%D0%BC%D1%83-%D0%BA%D0%BE%D1%80%D0%B4%D0%BE%D0%BD%D1%96
76. NV, "Запускають із безпілотників Оріон. Як влаштована нова російська крилата ракета Бандероль і як далеко вона летить — інфографіка NV" [Launched from Orion Drones: How Russia's New Banderol Cruise Missile Is Designed and How Far It Flies — NV Infographic], May 24, 2025, https://nv.ua/ukr/ukraine/events/raketa-banderol-tehnichni-harakteristiki-dalnist-boyova-chastina-i-riziki-infografika-i-opis-50516338.html
77. Радіо Свобода, "Що відомо про дислокацію «Орєшніка» у Білорусі, який «заступив на бойове чергування»" [What Is Known About the Deployment of 'Oreshnik' in Belarus, Which Has 'Entered Combat Duty'], December 31, 2025, https://www.radiosvoboda.org/a/dyslokatsiya-oryeshnik-bilorus/33637396.html
78. Overclockers.ru, "Что известно о новой гиперзвуковой ракете РФ Х-95: облик и боевые возможности" [What Is Known About Russia's New Kh-95 Hypersonic Missile: Design and Combat Capabilities], August 2, 2024, https://overclockers.ru/blog/Hardware_inc/show/171777/Novaya-giperzvukovaya-raketa-RF-H-95-oblik-i-boevye-vozmozhnosti
79. Укрінформ, "Зеленський: У нас не стало менше ракет ППО, побільшало ракет у росіян" [Zelenskyy: We Do Not Have Fewer Air Defense Missiles; Rather, Russia Has More Missiles], January 20, 2026, https://www.ukrinform.ua/rubric-ato/4082264-zelenskij-u-nas-ne-stalo-mense-raket-ppo-pobilsalo-raket-u-rosian.html
80. Руслана Сивак, "Росія зосередилася на регіональних відключеннях світла: експерт пояснив чому" [Russia Has Shifted Focus to Regional Power Outages: An Expert Explained Why], TCH.ua, January 23, 2026, https://tsn.ua/ukrayina/rosiia-zoseredylasia-na-rehionalnykh-vidkliuchenniakh-svitla-ekspert-poiasnyv-chomu-3006530.html
81. Ray Furlong, "Are China's Spy Satellites a Lifeline for Russia's Struggling Space Intelligence?" Radio Free Europe/Radio Liberty, October 29, 2025, https://www.rferl.org/a/china-spy-satellites-russia-space-intelligence-/33560397.htm
82. One "Taras-P" drone costs UAH 69,300, which is about $1,600 at an exchange rate of UAH 43.41 per US$1 (as of late January 2025). For 281 interceptors, Ukraine spent UAH 19,534,298 (about $449,964). The total cost of 258 Russian drones was UAH 1,083,751,750 (about $24,963,760).Тарас Сафронов, "Перехоплювачі 'Тарас-П' збили вже 258 дороговартісних російських дронів" ['Taras-P' Interceptors Have Already Shot Down 258 High-Value Russian Drones], Militarnyi, June 16, 2025, https://militarnyi.com/uk/news/perehoplyuvachi-taras-p-zbyly-vzhe-258-dorogovartisnyh-rosijskyh-droniv/
83. Ігор Бережанський, "'Не випадковість, а кропітка робота': у ЗСУ розповіли про збиття російського гелікоптера FPV-дроном" ["Not an Accident but Meticulous Work": Ukraine's Armed Forces Explained the Downing of a Russian Helicopter with an FPV Drone], TCH.ua, October 1, 2025, https://tsn.ua/ato/ne-vypadkovist-a-kropitka-robota-u-zsu-rozpovily-pro-zbyttia-rosiyskoho-helikoptera-fpv-dronom-2924174.html
84. Бережанський, "'Не випадковість, а кропітка робота'...".

Partner Deliveries

Partner-provided air defense systems were primarily intended to progressively close capability gaps and address challenges faced by the Ukrainian Air Force across different phases of Russia's strike campaign. The sections below summarize how the mix of transferred systems evolved over time.

2022

- **Delivery objective:** address shortages in short- and medium-range air defense to protect cities and critical infrastructure during mass strikes.
- **Key systems:** S-300 (Slovakia), IRIS-T SLM, IRIS-T SLS, Gepard (Germany), NASAMS (United States), Crotale NG (France), Skyguard/Aspide (Spain, Italy).

2023

- **Delivery objective:** strengthen defense against (aero)ballistic targets.
- **Key systems:** MIM-104 Patriot (Germany, Netherlands), SAMP/T (France, Italy), Skyguard (Italy, Spain).

2024

- **Delivery objective:** increase the resilience and sustainability of the existing air defense inventory.
- **Key systems:** MIM-104 Patriot (Germany, Netherlands, United States, Romania), IRIS-T SLM, IRIS-T SLS, Gepard (Germany), NASAMS (United States, Norway), Skynex (Germany), MIM-23B I-Hawk (France), F-16 (Denmark, Netherlands), MiG-29 (Poland, Slovakia).

2025

- **Delivery objective:** expand short- and medium-range capacity to broaden coverage volumes and reduce the burden on long-range systems under mass combined missile-drone attacks.
- **Key systems:** IRIS-T SLM, IRIS-T SLS, Patriot (Germany), Raven, Gravehawk (United Kingdom), Mirage (France), ASC 890 (Sweden).

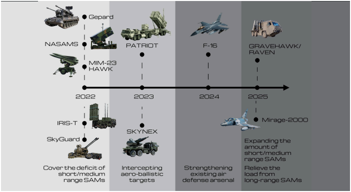

Figure 52. Key directions of strengthening Ukraine's air defense through Western deliveries and the introduction of new capabilities, 2022-2025.

85. "ASC 890 Transfer to Ukraine on Track, Linked to F-16 Upgrades," Militarnyi, March 21, 2025, https://militarnyi.com/en/news/asc-890-transfer-to-ukraine-on-track-linked-to-f-16-upgrades/
86. Інтерфакс-Україна, "Радник міністра оборони повідомив про обмеження функціонування мережі Starlink в Україні" [An Adviser to the Defense Minister Reported Restrictions on the Operation of the Starlink Network in Ukraine], January 31, 2026, https://interfax.com.ua/news/general/1141113-amp.html

Table 1. Deliveries of Key Air Defense Systems from Partners (2022-2026)

Type of System	Quantity	Origin	Year of Delivery
Anti-Aircraft Artillery Systems			
Gepard	112	Germany	From 2022
Skynex	4	Germany	From 2023
Man-Portable Air Defense Systems (MANPADS)			
Stinger	At least 3000	United States, Germany, Latvia, Lithuania, Denmark, Netherlands, Greece	From 2022
Strela (-2/2M/3)	At least 3000	Germany, Montenegro	2022-2023
Short-Range Surface-to-Air Missile Systems			
Osa	—	Poland, Equador	2022
Strela-10	10	Czech Republic	
S-125	At least 2	Poland	2022
Crotale	2	France	2022
Skyguard/Aspide	At least 2 systems	Spain, Italy	2022-2023
Stormer HVM	40	United Kingdom	2022
Raven	13		From 2025
Gravehawk	17		From 2026
Medium-Range Surface-to-Air Missile Systems			
NASAMS	At least 12	United States, Canada, Lithuania, Norway	From 2022
IRIS-T SLM	At least 9	Germany	From 2022
MIM-23 Hawk	At least 4	United States, Sweden, Spain, France	From 2022
S-300	1	Slovakia	2022
Long-Range Surface-to-Air Missile Systems			
MIM-104 Patriot	At least 8 complexes	United States, Germany, Netherlands, Romania	From 2023
SAMP-T	Up to 5	France, Italy	2023, 2025
Fighter Aircrafts			
F-16	85	Netherlands, Denmark, Norway, Belgium	From 2024
Mirage	6	France	From 2025
MiG-29	At least 36	Poland, Slovakia	From 2023

Sources: IISS; Interfax-Ukraine; German Aid to Ukraine, Wikipedia 87.

Air Defense Systems

Even when ammunition is available, a key limitation is the throughput capacity of the ground-based air defense layer. This capacity is defined by the number of operational launchers and radar assets, the availability of spare parts and repair facilities, and the ability to command and control these assets in a dispersed environment under kinetic strikes and electronic warfare pressure.

According to Oryx, Ukraine has lost at least 176 launchers, including elements of Buk-M1 and S-300PS/PT launchers, 56 self-propelled anti-aircraft guns and artillery systems, as well as 143 radar stations 88. Operationally, each loss reduces not only coverage area and density, but also the system's throughput during mass attacks—from early detection and tracking to target allocation and missile launches 89.

87. "Ukraine's Ground-Based Air Defence: Evolution, Resilience and Pressure," International Institute for Strategic Studies, February 24, 2025, https://www.iiss.org/online-analysis/military-balance/2025/02/ukraines-ground-based-air-defence-evolution-resilience-and-pressure/; Інтерфакс-Україна, "UK Confirms Delivery of Raven and Gravehawk Air Defense Systems to Ukraine – Media," January 8, 2026, https://en.interfax.com.ua/news/general/1134618.html; German Aid to Ukraine, "List of Military Aid Confirmed Delivered by Germany to Ukraine during 2025," December 30, 2025, Telegram post, https://t.me/deaiduaTG/2582; Вікіпедія, "Постачання протиповітряної зброї в Україну під час російського вторгнення, [Deliveries of Air Defense Weapons to Ukraine during the Russian Invasion]" n.d., https://bit.ly/469FXag

Losses are especially consequential for Western systems with limited fleet sizes and long replacement cycles, particularly IRIS-T and Patriot. The loss of even individual components, without rapid replenishment, reduces the number of available fire channels and therefore the maximum number of intercepts per attack. For ballistic and aeroballistic threats, this forces a narrowing of defended areas to the most critical assets, increasing the probability of breakthroughs in regions with thinner coverage.

Ammunition and Replenishment Rates

As Russia increasingly relies on mass employment of low-cost UAVs and decoys, the decisive factor for air defense is the ability to sustain a high daily interception tempo without depleting missile stocks required for cruise and ballistic threats. Under these conditions, delays in deliveries or production constraints among partners shift from logistical inconvenience to a direct military risk.

Reduced interceptor availability forces a contraction of the list of assets that can be reliably protected and increases reliance on lower-tier or non-kinetic means against mass targets. At the same time, limited stocks must be preserved for the most dangerous missile threats, making prioritization increasingly difficult during combined attacks.

Infrastructure and Command-and-Control

Strikes against energy infrastructure, communications nodes, repair facilities, and logistics degrade air defense effectiveness even without direct destruction of launchers or radars. This produces three operational effects.

- First, reaction time is reduced due to degradation of the information environment and slower dissemination of targeting data.
- Second, a higher share of targets is detected late or tracked inconsistently, narrowing the engagement window.
- Third, recovery and restoration are slowed, as repairs and redeployment depend on power supply, spare parts, transportation, and stable command-and-control.

As a result, the same nominal number of air defense systems can deliver very different real coverage densities depending on the state of power, communications, and repair capacity.

Efficiency of Resource Employment

Resource efficiency determines whether air defense can endure a war of attrition, not merely repel individual strikes. Russia deliberately designs its campaign to create a cost imbalance: inexpensive mass targets force defenders either to expend costly interceptors or to accept higher breakthrough risk.

The key metric here is the cost and resource expenditure per interception—how many and which types of interceptors are used against a single target, and how this affects stockpiles over weeks and months.

Regular use of medium- and long-range missiles against Shahed UAVs or decoys rapidly depletes scarce inventories, reduces available fire channels in subsequent days, and leaves critical infrastructure more vulnerable precisely when missile salvos intensify.

For this reason, Ukrainian air defense increasingly operates under the principle of the minimally sufficient interceptor: mass UAV targets are engaged by short-range layers (mobile fire groups, FPV interceptors, gun-based systems), while expensive missiles are reserved for targets that lower tiers cannot physically reach or intercept in time.

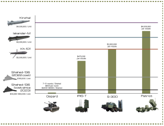

Figure 53. Cost-effectiveness comparison of intercepting Shahed-class UAVs and Kh-101, Iskander-M, and Kinzhal missiles using Gepard anti-aircraft gun systems and IRIS-T, S-300, and Patriot surface-to-air missiles.

88. Oryx, "Attack on Europe: Documenting Ukrainian Equipment Losses during the Russian Invasion of Ukraine," February 24, 2022, https://www.oryxspioenkop.com/2022/02/attack-on-europe-documenting-ukrainian.html
89. "Ukraine's Ground-Based Air Defence: Evolution, Resilience and Pressure," International Institute for Strategic Studies, February 24, 2025, https://www.iiss.org/online-analysis/military-balance/2025/02/ukraines-ground-based-air-defence-evolution-resilience-and-pressure/

Mass Shahed Attacks: Economics, Industrial Base, and Threat Evolution

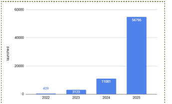

Figure 54. Air Force Command of UA Armed Forces. Statistics of Shahed UAVs launched against Ukraine on an annual basis.

From the start of Russia's full-scale invasion through the end of 2025, Russia launched more than 69,409 Shahed-type strike UAVs against Ukraine. This figure matters not as a record, but as a scale indicator: Shaheds quickly shifted from a new weapon in the background of the war to a factor that sets the tempo of the air campaign almost daily. To understand Shahed as a campaign instrument, we highlight three interconnected parameters.

Mass and the economics of attrition

From the outset, Russia used Shahed in the logic of cheap mass targets, where results are measured not by a single hit, but by forcing the defender to maintain high readiness and expend expensive resources over a long period.

Public estimates of Shahed unit cost vary widely—reflecting not only different methodologies, but also Russia's transition across phases (import → localization → industrialization). Early document leaks and references to Russia-Iran negotiations in 2022 indicated high import-package prices: roughly $193k per unit for an order of 6,000, about $290k for an order of 2,000, or $340k at smaller quantities. In parallel, analytical estimates often cited much lower production-cost ranges (tens of thousands of dollars), consistent with the platform's relative simplicity and component availability [90].

This shift toward industrialization is visible in the so-called Alabuga project (Alabuga, Tatarstan). According to specialized research and leaks, in early 2023 an agreement was signed—described as a licensing/franchise framework with Iran—for $1.75B, aimed at delivering/producing 6,000 drones within a defined horizon. Leaks also referenced a target of major price reduction under near-full localization —down to approximately $48.8k per unit (a project price assuming maximum production transfer and minimized Iranian components) [91].

In 2024-2025, the key variable becomes not the factory's existence, but rate and scale. Public estimates citing Ukrainian intelligence stated that in 2023 Alabuga produced 2,738 Shahed-like drones, and in the first nine months of 2024 5,760—more than double the previous year's output in a shorter interval. In 2025, open reporting features estimates of production pace around ~2,500-2,700 Shahed-like drones per month, alongside large volumes of decoy targets to overload air defense [92]. Additional intelligence-linked public estimates referenced scaling targets and plans for tens of thousands per year, including both strike drones and decoys (e.g., an estimate of 40,000 strike Shahed-type and 24,000 decoys in 2025) [93].

Importantly, Russia appears to be building multiple production nodes to reduce dependence on a single site and accelerate output. Beyond Alabuga, open reporting frequently mentions Izhevsk (IEMZ Kupol, part of Almaz-Antey), where—according to European intelligence-source reporting—Shahed-like strike UAVs were produced using imported components (including Chinese), with production starting in summer 2023 and scaling to thousands of units [94].

Technological evolution of modifications

The second Shahed problem is a fast modernization cycle. The platform remains relatively stable, but the payload (navigation, communications, warhead, flight algorithms, deception measures) changes in response to Ukrainian air defense and EW countermeasures. Russian variants move through iterative upgrades that increase survivability and combat effect (sometimes at the cost of higher unit price) [95].

The most persistent directions of evolution can be grouped into five blocks:

90. "Hackers Find Out Worth of Iranian Drones Sold to Russia," Ukrainska Pravda, February 6, 2024, https://www.pravda.com.ua/eng/news/2024/02/06/7440648/
91. Oded Yaron, "Gold for Drones: Massive Leak Reveals the Iranian Shahed Project in Russia," Haaretz, February 21, 2024, https://www.haaretz.com/israel-news/security-aviation/2024-02-21/ty-article-magazine/gold-for-drones-massive-leak-reveals-the-iranian-shahed-project-in-russia/0000018d-bb85-dd5e-a59d-ffb729890000; "Як РФ розгортає виробництво Shahed-136: проєкт 'Алабуга' у цифрах, строках та важливих деталях," Defense Express, July 4, 2023, https://defence-ua.com/people_and_company/jak_rf_rozgortaje_virobnitstvo_shahed_136_projekt_alabuga_u_tsifrah_strokah_ta_vazhlivih_detaljah-12096.html

- **Counter-EW via navigation upgrades.** In 2024-2025, Ukrainian specialists and media repeatedly documented more EW-resistant antenna solutions such as CRPA with larger element counts (8 → 16), improving resistance to GNSS jamming/spoofing [96]. In parallel, there were references to adaptive navigation modules (Kometa) and analyses of faster variants, indicating systematic Russian focus on this race [97]. In early 2026, reports emerged about Starlink terminals being used as a communications/control channel on Russian strike UAVs. A satellite link can reduce dependence on standard navigation schemes and complicate certain countermeasures. Ukraine's response was rapid: on 1 February 2026, reporting stated that—at Ukraine's Ministry of Defense request—SpaceX implemented initial technical restrictions/countermeasures, with a follow-on approach where only authorized (verified) terminals would operate and unidentified ones would be disabled [98].
- **Alternative comms channels and remote-control elements.** In August 2025, Ukraine's intelligence publicly described a variant with a camera and LTE modems, potentially enabling data transmission via mobile networks and command reception for course correction [99].
- **High-speed variants.** In 2025-early 2026, reporting referenced faster (including jet-powered) versions, shrinking the detect-track-decide timeline and complicating interception by short-range means [100].
- **Warhead evolution.** In 2024-2025, variants with heavier warheads (including thermobaric) and changes in lethality design were reported, increasing damage even when only a fraction breaks through [101].
- **Attempts to make Shahed anti-interceptor.** Variants were observed that aim to create risks for Ukrainian aerial interceptors (including via integration of air-to-air missiles) [102].

Taken together, this means: Ukraine's current means are effective, but the required performance threshold keeps rising, and defense must scale and update its tools as quickly as the adversary updates navigation and platform behavior.

Operational use

The third Shahed problem is how Russia uses them, and how they fit into the broader campaign. In early 2022, public overviews noted launches from occupied territories against southern regions and major cities, often in small groups of 6-8 drones per wave, flying at low altitude, using paired/grouped approaches and betting that not all targets would be detected and intercepted in time [103].

The key challenge was detecting Shahed drones as slow, low-altitude targets with a very small radar cross-section (RCS), which makes them hard to reliably pick up on radar. In 2022, Ukraine's air defense relied heavily on S-300 and Buk radars designed for different threat profiles—faster and more radar-visible targets at medium and high altitudes. Combined with Shahed flight at low altitudes (≈60–500 m), this reduced reliable detection range and compressed reaction time.

Early Shahed attacks caught defenders off guard, forcing them to rely on available means—from SAMs and MANPADS to small arms [104]. In cities and aroundkey facilities, Ukraine deployed mobile fire groups with heavy machine guns (12.7-14.5 mm) and MANPADS, hunting Shaheds mainly at night using night vision, thermal optics, and spotlights. They often detected drones by sound and engaged them with dense fire.

This manual air defense was exhausting but effective: by autumn 2022, dozens of mobile groups nationwide materially improved counter-UAV coverage. The characteristic low-frequency engine buzz became a key input for detection solutions. That is how Sky Fortress emerged—a Ukrainian network of acoustic sensors for detecting, identifying, and tracking Shahed-type loitering munitions.

As of 2025, the network reportedly exceeded 14,000 acoustic sensors, each costing roughly $400-$1,000. It enabled near-real-time route visualization and improved coordination of mobile fire groups.

92. "Russia Produces over 2,500 Shahed Drones Each Month — HUR," NV, June 9, 2025, https://english.nv.ua/russian-war/russia-produces-2-500-shahed-drones-each-month-hur-50520725.html
93. Sofiia Syngaivska, "Ukrainian Intelligence Reveals: Russia to Build 40,000 Shahed Drones and 24,000 Decoys in 2025," Defense Express, August 2, 2025, https://en.defence-ua.com/industries/ukrainian_intelligence_reveals_russia_to_build_40000_shahed_drones_and_24000_decoys_in_2025-15334.html
94. "Exclusive: Russia Produces Kamikaze Drone with Chinese Engine," Reuters, September 13, 2024, https://www.reuters.com/world/europe/russia-produces-new-kamikaze-drone-with-chinese-engine-say-european-intel-2024-09-13
95. "Іранські дрони Shahed-136: збивати їх уже можна, але це ще не просто," Укрінформ, September 26, 2022, https://www.ukrinform.ua/rubric-ato/3580083-iranski-droni-shahed136-zbivati-ih-uze-mozna-ale-ce-se-ne-prosto.html
96. Matthew Loh, "Russia Is Leveling Up Its Shahed Drones with New Chinese Antennae to Defeat Kyiv's Jammers, Ukrainians Say," Business Insider, March 25, 2025, https://www.businessinsider.com/russia-level-up-shahed-drones-chinese-antenna-bypass-jammers-2025-3
97. Vladyslav Khomenko, "Ukrainian Intelligence Releases Detailed Analysis of Russian Geran-3 Jet-Powered UAV (Series U)," Militarnyi, September 16, 2025, https://militarnyi.com/en/news/ukrainian-intelligence-releases-detailed-analysis-of-russian-geran-3-jet-powered-uav-series-u/

From 2023 onward, Russia increasingly used Shahed for saturation: mass launches force defenders to expend expensive interceptors, reveal positions, and make decisions under overload. In practice, this often looks like a multi-wave attack: drones and decoys to trigger responses; then route adjustments and specifications; then new waves combined with other strike means designed to exploit local depletion or temporary gaps in coverage.

Even with interception rates around ~90%, localization-driven low costs allow Russia to generate mass salvos almost daily [105]. Shahed drone strikes cost Russia approximately $350,000 per successfully hit target (assuming that only about 10% of launched Shahed drones reach their target), compared to around $1 million per target for the most effective missile systems [106]. This cost asymmetry makes Shahed drones an efficient tool for large-scale attacks aimed at exhausting the adversary's air defense system.

A critical campaign effect of Shahed is regularity. Even if most targets are intercepted on a given night, Russia achieves a different outcome: it sustains constant strain on air defense, forces dispersion of resources, increases repair and replenishment cycles, and keeps significant forces in a near-continuous combat-ready posture. That is how Shahed functions as a mass attrition technology, where effects accumulate and defense must respond not episodically, but systematically.

Patriot: the only system that has consistently proven effective against ballistic missiles

Operational use

Before the first Patriot system arrived in April 2023, Ukraine effectively had no air-defense capability that could reliably intercept ballistic and aeroballistic missiles in operational conditions, including Iskander, KN-23, and the hypersonic Kinzhal. The systems available at the time, whether Soviet- or Western-made, were geared primarily toward aerodynamic threats such as aircraft, cruise missiles, and drones. In their existing configurations, Soviet S-300 and Buk batteries lacked both the radar performance and the interceptor missiles needed for consistent engagements against high-speed ballistic trajectories. Western systems delivered prior to 2023, including NASAMS and IRIS-T SLM, substantially improved defense against cruise missiles and UAVs, but they were not designed for ballistic or quasi-ballistic interception and therefore could deliver only limited, non-repeatable results in certain scenarios [107].

Before 2023, one of the main limits on Ukraine's air defense was not only interceptors, but radar performance. The characteristics of Russia's missiles further compounded the problem. Systems such as Iskander and Kinzhal combine very high speed (roughly above 2-3 km/s) with ballistic or quasi-ballistic flight profiles and terminal maneuvering. A quasi-ballistic profile typically involves lower altitudes (around 30-60 km) than a classic ballistic trajectory, along with course and trajectory changes that sharply compress reaction time. As a result, until spring 2023 Ukraine's air-defense network could often detect a launch or observe these missiles in flight, but it lacked the tools to defeat them consistently and repeatedly [108].

Why is Patriot effective against ballistic threats?

The picture shifted significantly when Ukraine received its first Patriot battery from partner countries in April 2023. Its deployment gave Ukraine a reliable ability to engage ballistic threats and materially improved the defense of major cities and critical infrastructure against this class of missile strike [109].

98. "Musk Says Steps to Stop Russia from Using Starlink Seem to Have Worked," Reuters, February 1, 2026, https://www.reuters.com/sustainability/sustainable-finance-reporting/musk-says-steps-stop-russia-using-starlink-have-worked-2026-02-01/
99. Головне управління розвідки Міністерства оборони України (HUR), "War & Sanctions: Russia Deploys New UAV with LTE Connectivity and Remote Control Capabilities," August 20, 2025, https://gur.gov.ua/en/content/warsanctions-rf-zastosovuie-novyi-bpla-z-ltezviazkom-ta-mozhlyvistiu-viddalenoho-keruvannia
100. Peter Beaumont, "Russia Deploys New High-Speed Drones amid Claims They Contain Western Parts," The Guardian, January 24, 2026, https://www.theguardian.com/world/2026/jan/23/russia-deploys-new-high-speed-drones-amid-claims-they-contain-western-parts
101. ArmyInform, "DIU: New Geran Modification Carries Both a MANPADS and a Warhead Simultaneously," January 12, 2026, https://armyinform.com.ua/en/2026/01/12/diu-new-geran-modification-carries-both-a-manpads-and-a-warhead-simultaneously/
102. Головне управління розвідки Міністерства оборони України (HUR), "War&Sanctions: Defence Intelligence of Ukraine Unveils Details of a New Russian 'Geran' Modification Armed with an R-60 Air-to-Air Missile," December 15, 2025, https://gur.gov.ua/en/content/warsanctions-hur-rozkryvaie-detali-novoi-modyfikatsii-rosiiskoi-erani-z-aviatsiinoiu-raketoiu-r60

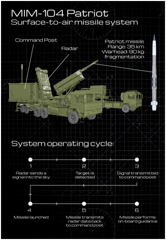

Figure 55. Fakty. How the Patriot air defense system works 110.

A Patriot is not a single launcher. It is a full battery that works as an integrated system, including the radar, the engagement control station, multiple launchers, interceptor missiles, communications, and power support. The key component is the AN/MPQ-65 phased-array radar, which combines detection, tracking, and guidance and is built to handle targets flying steep trajectories at very high speeds. In practice, the Patriot operates through a centralized engagement chain: detect → identify and decide → launch → provide guidance updates through intercept 111.

Against ballistic threats, the decisive interceptors are PAC-3 missiles, including the PAC-3 MSE, which rely on hit-to-kill kinetic interception. PAC-2 missiles are better suited to aerodynamic targets such as aircraft and cruise missiles, and their ballistic-missile role is more limited. In practical terms, Patriot's ability to defeat Iskander and Kinzhal strikes depends above all on having enough PAC-3 interceptors available 112.

Operational results and the deterrent effect on Russian aviation

Figure 56. Ukrinform. Patriot on operational duty in Ukraine 113.

Once Patriot was deployed in Ukraine, it gave the country its first consistently reliable way to intercept ballistic and aeroballistic missiles, which had previously been largely out of reach for Ukrainian air defenses. That capability made Patriot the only system that could realistically protect major cities and critical infrastructure from this class of threat, and it became a key factor in reducing the effectiveness of Russian missile strikes.

Patriot also proved valuable beyond missile defense. In Ukrainian service, it demonstrated the ability to engage manned aircraft at long range. Public reporting has cited engagement distances of roughly 100-150 km in some cases. A widely noted episode occurred on May 13, 2023, over Russia's Bryansk region, when five Russian aircraft were lost, including Su-34 and Su-35 fighters and two Mi-8MTPR-1 electronic warfare helicopters. The Ukrainian Air Force later officially confirmed that Patriot was used in that engagement 114.

This episode had strategic implications that went well beyond a single combat success. The shootdowns over Russian territory showed that, when operated by trained Ukrainian crews, Patriot can meaningfully constrain Russian aviation even beyond the immediate front line. The loss of electronic-warfare helicopters was particularly important, since these platforms help escort strike packages and attempt to suppress Ukrainian air defenses.

103. "Іранські дрони Shahed-136: збивати їх уже можна, але це ще не просто" [Iranian Shahed-136 Drones: They Can Now Be Shot Down, but It's Still Not Easy], Укрінформ, September 26, 2022, https://www.ukrinform.ua/rubric-ato/3580083-iranski-droni-shahed136-zbivati-ih-uze-mozna-ale-ce-se-ne-prosto.html
104. "How Territorial Defense Units Protect Kyiv from Enemy Drones — First-Hand Account," NV, 2024, https://english.nv.ua/nation/how-territorial-defense-units-protect-kyiv-from-enemy-drones-first-hand-account-50397322.html

Public reporting suggested that by early 2024 Patriot systems may have been involved in the loss of at least 18 Russian aircraft, with repeated cluster engagements noted in December 2023 and again in January-February 2024. Taken together, these incidents pushed Russia to adjust how it used tactical aviation. It increased stand-off distances for guided bombs and missiles and reduced activity in areas where a Patriot threat was assessed to be present 115.

Ukrainian crews also adapted quickly. Public assessments suggest they mastered Patriot in roughly three months, whereas standard operator training cycles in NATO countries can take up to a year. Operational results indicate that this compressed timeline did not reduce effectiveness. Instead, it enabled Ukraine to integrate Patriot rapidly into its existing air-defense architecture 116.

Patriot's limitations in Ukraine

Despite its effectiveness, Patriot has structural and operational constraints.

The first critical factor is **limited mobility**. Open sources indicate that deploying or displacing a Patriot battery typically takes around 25 minutes or more, which reduces flexibility for rapid repositioning. By comparison, Russian S-400 systems are publicly described as having a much shorter time to redeploy, on the order of about five minutes, which gives them an advantage in "shoot-and-scoot" scenarios 117. During combined attacks—Shahed drones, cruise missiles, and ballistic or aeroballistic missiles—keeping Patriot's radar active for extended periods increases the risk that the battery's general area will be detected, while relocating during an active air-raid alert is difficult in practice.

A second systemic constraint is the **limited number of Patriot systems available to Ukraine**. As of January 2026, public reporting and outside estimates suggest Ukraine fields only a small number of Patriot batteries, roughly 7-8 in different configurations and with varying levels of completeness. That is enough to protect only a few major cities or a handful of critical sites. It is not enough to provide broad, layered coverage at the national level 118.

Analysts and military experts often argue that Ukraine would need at least 20-25 Patriot batteries to maintain a reasonably resilient defense of key regions against ballistic threats. This number would still not create full nationwide coverage. It would, however, allow Ukraine to distribute systems across major metropolitan areas, energy nodes, and military hubs, reducing the most dangerous gaps in missile defense 119.

A third systemic problem is **interceptor stockpiles**, especially PAC-3 MSE. The practical issue is not only the number of batteries, but the missiles. Without sufficient PAC-3 MSE interceptors, Patriot loses a significant portion of its core ballistic-missile defense function. President Volodymyr Zelenskyy indirectly underscored the severity of this problem in a public statement on February 19, 2025, describing a real operational episode:

"The commander calls me and says: we are now near this city, and we have no missiles for the Patriot systems. We have used them up."

This implies that interceptor shortages already influence air-defense decisions even when batteries are deployed and technically serviceable 120.

The shortage of PAC-3 MSE interceptors is a global issue, not a uniquely Ukrainian one. Demand has surged because of the war in Ukraine and the parallel requirements of allied militaries, while scaling production quickly is difficult.

Lockheed Martin, which manufactures Patriot interceptors, reported that it produced roughly 500 PAC-3 MSE missiles in 2024, a record at the time. In 2025, the company exceeded its own plan. It produced about 620 missiles instead of the planned 600. Even so, these figures remain limited in the context of high-intensity warfare and worldwide demand for Patriot interceptors 121.

Over the longer term, Lockheed Martin has set out an ambitious plan to raise annual PAC-3 MSE production to 2,000 missiles within seven years, meaning by 2033. Even if the company meets that target, output at 2,000 missiles per year would still have to cover the requirements of all Patriot operators worldwide, not only Ukraine.

105. E. Grynszpan, "Ukraine's Air Defense Is Struggling to Keep Up with Intensifying Russian Strikes," Le Monde, May 26, 2025, https://www.lemonde.fr/en/international/article/2025/05/26/ukraine-s-air-defense-is-struggling-to-keep-up-with-intensifying-russian-strikes_6741666_4.html
106. N. Hollenbeck, M. H. Altaf, F. Avila, J. Ramirez, A. Sharma, and B. Jensen, "Calculating the Cost-Effectiveness of Russia's Drone Strikes," Center for Strategic and International Studies (CSIS), 2025, https://www.csis.org/analysis/calculating-cost-effectiveness-russias-drone-strikes
107. "Балістична траєкторія: якими ракетами росіяни обстрілюють Україну" [Ballistic Trajectory: What Missiles Russia Is Using to Strike Ukraine], Radio France Internationale (RFI), January 17, 2023, https://www.rfi.fr/
108. RFI, "Балістична траєкторія."
109. "США передадуть Україні ЗРК Patriot: що про них відомо" [The US Will Transfer Patriot Air Defense Systems to Ukraine: What Is Known About Them], Суспільне Новини, April 19, 2023, https://suspilne.media/343238-ssa-peredadut-ukraini-zrk-patriot-so-pro-nih-vidomo/

That is why the interceptor shortage remains a systemic challenge for missile-defense architectures broadly, rather than a problem confined to Ukraine.

A fourth constraint is the economics of employment and target prioritization. Patriot is a high-cost capability. Open sources often cite figures of around $1 billion for a Patriot system and roughly $2-4 million per interceptor.

In Ukrainian conditions, this makes Patriot most appropriate for the most dangerous and technically demanding targets, especially ballistic and aeroballistic missiles. Cheaper, high-volume threats such as Shahed drones and some cruise missiles are typically more efficiently handled by other air-defense assets 122.

EW as an asymmetric force multiplier when air-defense interceptors are scarce

Electronic warfare (EW) became a critical capability for Ukraine because shortages of air-defense systems and interceptors coincided with a sharp rise in the volume of aerial threats hitting Ukrainian cities and infrastructure.
In this setting, EW offers an asymmetric advantage. It does not have to destroy the target physically. Instead, it disrupts the electronics that make the attack possible—communications, navigation, and control links—causing a drone or missile to drift off course, lose control, or crash without achieving its intended effect.

How strategic electronic warfare works

In simple terms, electronic warfare (EW) means interfering with an adversary's electronic systems through radio-frequency emissions. In practice, EW almost always works hand-in-hand with electronic intelligence (ELINT). You first have to detect what frequencies and protocols the target uses, and only then can you disrupt them effectively.
In modern military practice, EW is commonly described across three broad employment levels, which differ in scale, range, and purpose.

- **Tactical level**—portable or vehicle-mounted EW systems used directly on the battlefield that work at short range against FPV drones and small UAVs and provide immediate protection for units.
- **Operational level**—medium-range systems that cover specific front sectors, logistics routes, or key sites, which disrupt drone groups and their control links.
- **Strategic level—**larger, more technologically complex systems that operate at significant distances, which can affect not only drones, but also aviation communications, navigation systems, and elements of the adversary's command and control. Strategic EW complements classical air defense by reducing demand for scarce surface-to-air missiles and improving the resilience of the overall air-defense network 123.

The two core EW techniques are jamming and spoofing, which serve different purposes.

- **Jamming** creates radio-frequency interference that degrades or blocks navigation, communications, and control signals. As a result, a drone or missile loses the ability to update its route or transmit data.
- **Spoofing** does not just disrupt the signal. It replaces it with a false one, causing the target's navigation system to accept incorrect coordinates and drift off its intended route.

In practical terms, jamming tends to blind the target, while spoofing deceives it. Spoofing can sometimes steer a threat away from populated areas without the need to destroy it physically 124.

110. "Захист від балістики, крилатих ракет і ворожої авіації: що відомо про ЗРК Patriot" [Defense Against Ballistic Missiles, Cruise Missiles, and Enemy Aircraft: What Is Known About the Patriot Air Defense System], ФАКТИ ICTV, July 15, 2025, https://fakty.com.ua/ua/svit/ssha/20250714-zrk-patriot-chy-dopomozhe-czej-kompleks-ukrayini-ta-yaki-nyuansy-mozhut-vynyknuty/
111. Мілітарний, "MIM-104 Patriot: шлях до досконалості" [MIM-104 Patriot: The Road to Perfection], January 10, 2024, https://militarnyi.com/uk/articles/mim-104-patriot-shlyah-do-doskonalosti/
112. Мілітарний, "MIM-104 Patriot: шлях до досконалості."
113. Укрінформ, "Командувач Повітряних сил протестував системи Patriot в Україні" [Commander of the Air Force Tested Patriot Systems in Ukraine], YouTube video, April 26, 2023, https://www.youtube.com/watch?v=icRrDWPaD7Y

Evolution of Ukrainian EW: the launch of Pokrova system

Ukraine began developing its own EW capabilities well before the full-scale invasion. Some systems saw operational use in the combat zone as early as 2015-2016, and several solutions were developed or publicly presented prior to 2022. Open sources cite several Ukrainian EW systems that are described as strategic, or close to the strategic level. These include Bukovel (Proximus), which is used to detect UAVs and disrupt control links and satellite navigation; Anklav, which creates interference against GPS/GLONASS over longer distances; Nota, oriented toward communications suppression and counter-UAV missions; and Hekata, presented as a long-range system for detecting and affecting electronic systems and, in some accounts, aviation 125.

Figure 57. Militarnyi. Bukovel-AD electronic warfare system mounted on an off-road vehicle chassis. 2019 126.

A clear post-2022 example is Ukraine's Pokrova electronic warfare system, which emphasizes large-scale GNSS spoofing to reduce the accuracy of Shahed strikes and, in some cases, parts of the cruise-missile threat during the midcourse phase. The logic is not to blanket-jam the spectrum, but to feed the target a distorted navigation picture. The drone or missile may keep flying, but it does so on false coordinates, drifting off route, losing orientation, or deviating from its intended track 127.

One practical indicator is the reported loss of location for some drones and cases of UAVs straying outside their planned routes.

For example, during the September 5, 2024 attack, reports described some UAVs losing location, while others left Ukrainian-controlled airspace, including turning back toward Russia or flying toward Belarus. A secondary effect of large-scale spoofing is civilian GPS anomalies. During alerts, some people report their smartphone locations shifting. This is an indirect but characteristic marker of navigation deception rather than localized point jamming 128.

Figure 58. Militarnyi. Neutralized Shahed UAV over Ukraine as a result of electronic warfare activity 129.

Ukraine's experience shows that the fight in the electromagnetic spectrum has become an ongoing cycle of adaptation. Russia modifies antennas, communications links, and guidance methods. Ukraine responds by refining detection, spoofing, and jamming. In this dynamic, the goal is not perfect coverage or absolute effectiveness. It is to steadily drive down the success rate of enemy strikes over time. That is why electronic warfare has become a core layer of Ukraine's multi-tier air-defense system—alongside surface-to-air missiles and interceptors—and it is likely to remain that way.

114. NV, "Patriot та IRIS-T: Україні бракує ракет до найефективніших ЗРК у системі ППО" [Patriot and IRIS-T: Ukraine Lacks Missiles for the Most Effective Air Defense Systems in Its Air Defense Network], April 12, 2024, https://nv.ua/ukr/ukraine/events/patriot-ta-iris-t-ukrajini-brakuye-raket-do-nayefektivnishih-zrk-u-sistemi-ppo-novini-ukrajini-50409482.html
115. УНІАН, "ЗРК Patriot в Україні: знищено 18 російських літаків — експерт" [Patriot Air Defense System in Ukraine: 18 Russian Aircraft Destroyed — Expert], February 19, 2024, https://www.unian.ua/war/zrk-patriot-v-ukrajini-znishcheno-18-rosiyskih-litakiv-ekspert-12548373.html
116. Kokl.ua, "Скільки в Україні систем Patriot: повний огляд ППО" [How Many Patriot Systems Ukraine Has: A Complete Air Defense Overview], July 19, 2025, https://kokl.ua/skilky-v-ukrayini-system-patriot-povnyj-oglyad-ppo
117. AiTelly, "Patriot Missile System How It Works | Air Defence Missiles," YouTube video, May 7, 2023, https://www.youtube.com/watch?v=Clgmwm_D61Q
118. Експрес Online, "Україна отримала ще два Patriot — вони вже заступили на бойове чергування, — Міноборони" [Ukraine Received Two More Patriot Systems — They Have Already Entered Combat Duty, Says the Ministry of Defense], January 1, 2026, https://expres.online/podrobitsi/ukraina-otrimala-shche-dva-patriot-voni-vzhe-zastupili-na-boyove-cherguvannya-minoboroni

Why did interceptor drones emerge?

Russia's large-scale use of Shahed-136/131 strike UAVs forced Ukraine to rethink how it counters air threats. Using expensive surface-to-air missiles—ranging from hundreds of thousands to several million dollars—to shoot down comparatively cheaper drones (open estimates typically place them at roughly $20,000-$50,000, and in some cases $70,000-$100,000 depending on origin and year) creates an economic and resource imbalance that becomes acute during saturated attacks. The issue has also become more salient for Poland and other European states after incidents involving Russian UAVs, reinforcing demand for asymmetric counter-drone solutions 130.

Against this backdrop, Ukraine began building a dedicated drone air defense line: intercepting enemy UAVs with domestically operated interceptor drones. The logic is straightforward. It provides a scalable, relatively low-cost, quickly replaceable countermeasure that complements traditional air-defense layers and reduces pressure on scarce missile stocks.

Institutionalizing drone air defense and its role in a layered system

This approach first received public confirmation at the highest political level. In June 2025, President Volodymyr Zelenskyy said that Ukraine's Defense Forces were already fielding domestically produced interceptor drones in a systematic, effective way, and that over the course of 2025 they had shot down not just isolated targets, but dozens of Shahed drones.

Figure 59. Ukrainian interceptor drones.

This, in turn, laid the groundwork for institutionalizing the capability. On December 18, 2025, then-Defense Minister Denys Shmyhal said that procuring anti-Shahed UAVs would be a top priority for 2026 and that the ministry had already signed contracts with more than 10 Ukrainian interceptor-drone developers 131.

Military reports indicate that interceptor drones now serve as one of the first layers of defense against Shahed-type strike UAVs. Units deploy them within corps and brigade areas of responsibility, and teams from brigade UAV units and the Unmanned Systems Forces operate them directly along likely Shahed flight routes.

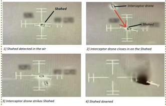

Figure 60. Air Force Command of the UA Armed Forces. Interceptor drone striking a Shahed.

Because these units have their own tactical-level detection tools and coordinate with adjacent formations' observation networks, they often pick up Shaheds early and can engage before targets reach the deeper zones typically covered by the Air Force. Brigade-level drone units still prioritize engaging tactical and operational-tactical reconnaissance UAVs, and Shahed interception has become an additional mission. Within a single area of responsibility, several interceptor teams can operate simultaneously, providing dense interception coverage and reducing the number of drones that reach deeper air-defense layers.

119. Defence UA, "Скільки Україна недоотримала Patriot та яка ще більша проблема за дефіцит ЗРК" [How Many Patriots Ukraine Did Not Receive and What Problem Is Even Greater than the Air Defense Missile Shortage], April 8, 2025, https://defence-ua.com/weapon_and_tech/skilki_ukrajina_nedootrimala_patriot_ta_jaka_sche_bilsha_problema_za_defitsit_zrk-18489.html

120. Defence UA, "Скільки Україна недоотримала Patriot."

How interception works: engagement cycle and technological approaches

A typical interceptor-drone crew operates in a rapid-response mode within a defined sector. The engagement chain usually consists of:

- detection / alert → movement to a firing position → preparation and launch → guidance / pursuit → target kill.

Crews often control the interceptor at short ranges, typically on the order of a few kilometers within the team's effective operating area. From there, the interceptor closes on the target in manual or semi-automatic mode and completes the engagement.

Open estimates put the cost of a small interceptor at roughly $3,000-$5,000. At the same time, it can engage a Shahed-class drone (about 180 kg) at ranges of up to roughly 20 km, which significantly extends the reach of ground-based fire [132].

Among Ukrainian systems reported to be in combat use and under continuous refinement are Sting, Techno-Taras, Hunter, Salyut, Bayonet, and other platforms. They differ in design, control links, and reliability, but they share one common feature—the segment is evolving quickly as Ukraine adapts to changes in Russian tactics.

Military assessments and specialist reporting also point to the US-made Surveyor/Merops interceptor as one of the more technologically mature options for countering Shahed-type threats. Its reported unit cost is about $14,500, which is higher than most Ukrainian interceptors, but still far cheaper than expending high-end SAM interceptors. Merops is positioned less as a mass expendable tool and more as a platform aimed at higher hit rates, enabled by enhanced control and automation [133].

What sets Merops apart is its higher level of automation. A semi-autonomous mode reduces the operator's workload in the final seconds of an engagement and limits the impact of human error. In practice, this means steadier guidance at speed and more consistent results in demanding scenarios, especially when the target is moving fast and the intercept window is tight. Public reporting also indicates that Merops went through non-public testing in Ukraine before it was folded into operational use, and it has since drawn interest for deployment in other NATO countries [135]. Figures cited as of November 20 claim that Merops/Surveyor interceptors have destroyed more than 1,000 Shahed drones, making it one of the most productive drone air defense platforms fielded so far [136].

Interviews with units tasked with countering Shahed drones indicate that Merops played a critical role during the initial phase of systematic interceptions in the spring of 2025. This was a time when details were intentionally kept from the public for security reasons. Service members describe the Merops platform as providing steadier guidance, better performance at high speeds, and reduced reliance on the operator's skill, but they also emphasize that Merops does not eliminate certain fundamental operational constraints. Factors such as weather and electronic warfare can still affect performance, targets may be lost, and crews might need to launch multiple interceptors to successfully bring down a single drone.

Figure 61. Militarnyi. Surveyor interceptor drone of the Merops anti-drone platform [134].

In this context, Merops/Surveyor has become a technological benchmark for Ukrainian developers. Nevertheless, domestic interceptors remain crucial for scaling operations, ensuring flexibility, and rapidly training teams—elements that are vital when confronting large-scale Shahed raids.

121. Defence UA, "США вироблятимуть утричі більше ракет MSE до ЗРК Patriot — і це завдання з розряду надважких" [The United States Will Produce Three Times More MSE Missiles for the Patriot Air Defense System — and This Is an Extremely Difficult Task], January 6, 2026, https://defence-ua.com/people_and_company/ssha_virobljatimut_u_trichi_bilshe_raket_mse_do_zrk_patriot_i_tse_zadacha_z_rozrjadu_nadvazhkih-21412.html
122. Kokl.ua, "Скільки в Україні систем Patriot: повний огляд ППО" [How Many Patriot Systems Are in Ukraine: A Complete Overview of Air Defense], July 19, 2025, https://kokl.ua/skilky-v-ukrayini-system-patriot-povnyj-oglyad-ppo
123. Ярослав Жахалов, "«Інколи від РЕБ очікують більше, ніж вона може». Як радіоелектронна боротьба працює проти FPV і «Шахедів»" ["Sometimes More Is Expected from EW Than It Can Deliver: How Electronic Warfare Works Against FPV and 'Shaheds'"], DOU, December 8, 2025, https://dou.ua/lenta/articles/how-reb-works/
124. Жахалов, "«Інколи від РЕБ очікують більше...»".
125. Вікімедія, "Засоби РЕБ України" [Means/Systems of Electronic Warfare of Ukraine], last modified n.d., https://uk.wikipedia.org/wiki/Засоби_РЕБ_України

Scaling, impact, and constraints: what is currently effective and where capabilities are heading?

Public indicators are already pointing to increased output and performance in interceptor drone production. As reported by Forbes in January, Ukraine was producing approximately 45,000 interceptor drones per month, aided in part by international support. The report also mentioned €2 billion in EU financing tied to urgent needs 137.

Higher production volumes are beginning to translate into operational successes. On January 12, President Volodymyr Zelenskyy stated that some interceptor models were achieving effectiveness rates of up to 90%, while others ranged between 40% and 50%, with an overall interception level of approximately 70% 138. The primary advantage of these drones is the cost-effectiveness. Interceptor drones can engage numerous lower-cost targets at a significantly reduced expense, allowing high-end missiles to be reserved for more formidable threats.

Another advantage is their flexibility in deployment. Teams can quickly reposition within their sectors, respond to isolated tracks, and cover gaps in traditional air defense layers. Interceptors reduce the workload for limited missile systems by addressing the bulk of lower-tier threats. Use of FPV and semi-autonomous methods enable precise engagements with reduced collateral risks, while software-driven architectures allow for rapid updates to tactics and programming as Russian methods evolve.

Despite these advantages, interceptor drones remain under active refinement. Units that operate them report that most current models need frequent engineering updates to aspects such as flight performance, communications resilience, guidance stability, and integration with other air-defense components. The main limitations fall into three categories:

- **Environment:** influences such as weather, visibility, wind, moisture, and low-altitude target profiles.
- **Spectrum and Links:** vulnerability to electronic warfare, potential loss of control or telemetry, necessitating repeat launches.
- **Human factors and command:** skills required from operators, target handoff between teams, and coordination challenges during mass-raid situations.

In the medium term, military operators and engineers see the next step as a shift toward highly automated or semi-automated interceptors. The aim is to reduce operator workload, stabilize targeting, and maintain performance during large-scale raids. In this model, automation—integrated with tactical radars, electronic warfare, and conventional air-defense layers—is viewed as the most practical path to strengthening Ukraine's long-term ability to blunt Shahed-type attacks.

126. "В Україні запрацювала система «Покрова», яка успішно нейтралізує «шахеди»" ["In Ukraine the 'Pokrova' System Started Operating, Successfully Neutralizing 'Shaheds'"], Militarnyi, February 13, 2024, https://militarnyi.com/uk/news/v-ukrayini-zapratsyuvala-systema-pokrova-yaka-uspishno-nejtralizuye-shahedy/
127. Defense Express, "РЕБ 'Покрова' чому це дійсно 'геймченджер' проти Shahed-136 та навіть крилатих ракет, а GPS-навігатори стануть безпорадними" [EW "Pokrova": Why It Really Is a 'Game Changer' Against Shahed-136 and Even Cruise Missiles, and Why GPS Navigators Will Become Helpless], November 4, 2023, https://defence-ua.com/weapon_and_tech/reb_pokrova_chomu_tse_dijsno_gejmchendzher_proti_shahed_136_ta_navit_krilatih_raket_a_gps_navigatori_stanut_bezporadnimi-13380.html
128. Sophie Vakulina, "Lost and Spoofed: How Ukraine Redirects Russian Drones to Belarus," Euronews, December 4, 2024, https://www.euronews.com/my-europe/2024/12/04/lost-and-spoofed-how-ukraine-redirects-russian-drones-to-belarus
129. Мілітарний. "В Україні почастішало падіння Shahedів неушкодженими" ["In Ukraine, Intact Shahed Crashes Have Become More Frequent"]. Мілітарний. https://militarnyi.com/uk/news/v-ukrayini-pochastishalo-padinnya-shahediv-neushkodzhenymy/.
130. Д. Черниш, "Росія здешевила виробництво 'Шахедів': скільки зараз коштує один дрон" [Russia Has Reduced the Cost of Producing 'Shaheds': How Much One Drone Costs Now], 24 Канал, August 25, 2025, https://24tv.ua/tsina-shahediv-yaki-viroblyayut-rosiyi-droni-stayut-deshevshimi_n2901000
131. Укрінформ, "Міноборони передає до війська майже 950 дронів-перехоплювачів на добу" [The Ministry of Defense Delivers Nearly 950 Interceptor Drones to the Armed Forces Per Day], December 18, 2025, https://www.ukrinform.ua/rubric-ato/4070911-minoboroni-peredae-do-vijska-majze-950-dronivperehopluvaciv-na-dobu.html
132. Ю. Кобзар, "Битва за українське небо близька до перелому: Forbes вказав на ключовий показник" [The Battle for Ukraine's Sky Is Near a Turning Point: Forbes Identified a Key Indicator], УНІАН, January 16, 2026, https://www.unian.ua/war/viyna-v-ukrajini-ukrajina-naroshchuye-virobnictvo-droniv-perehoplyuvachiv-13257903.html
133. Defense Express, "MEROPS проти 'Шахедів', яку секретно тестували в Україні, готується розгорнути вже друга країна НАТО" [MEROPS Against 'Shaheds,' Secretly Tested in Ukraine, Is Preparing to Be Deployed by a Second NATO Country], January 21, 2026, https://defence-ua.com/news/merops_proti_shahediv_jaku_sekretno_testuvali_v_ukrajini_gotujetsja_rozgornuti_vzhe_druga_krajina_nato-21568.html
134. Militarnyi, "Румунія озброїться антидроновою системою MEROPS, яка добре себе показала в Україні" [Romania Will Equip Itself with the MEROPS Counter-Drone System, Which Has Proven Effective in Ukraine], January 22, 2026, https://militarnyi.com/uk/news/rumuniya-ozbroyitsya-antydronovoyu-systemoyu-merops-yaka-dobre-sebe-pokazala-v-ukrayini/
135. MEROPS проти "Шахедів", яку секретно тестували в Україні, готується розгорнути вже друга країна НАТО | Defense Express. (2026, 21 січня). https://defence-ua.com/news/merops_proti_shahediv_jaku_sekretno_testuvali_v_ukrajini_gotujetsja_rozgornuti_vzhe_druga_krajina_nato-21568.html
136. Militarnyi, "Таємничий Merops перехопив понад тисячу «шахедоподібних» дронів над Україною" [The Mysterious Merops Intercepted More Than a Thousand 'Shahed-Like' Drones Over Ukraine], November 20, 2025, https://militarnyi.com/uk/news/tayemnychyj-merops-perehopyv-ponad-tysyachu-shahedopodibnyh-droniv-nad-ukrayinoyu/
137. David Hambling, "The Drone Interceptors Fighting Back Against Putin's Freezing Dark Age," Forbes, January 16, 2026, https://www.forbes.com/sites/davidhambling/2026/01/16/the-drone-interceptors-fighting--putins-freezing-dark-age/

Why do radars not provide continuous, full-coverage detection?

Air defense systems have traditionally relied on radar as their primary method for detecting and tracking targets. However, the full-scale war has demonstrated that even with radar coverage, forces cannot ensure continuous and uninterrupted detection of every threat. This is especially true during mass attacks and against low-altitude targets such as cruise missiles and UAVs. Ukrainian service members have highlighted several reasons for this challenge.

- Third, complex flight profiles—such as maneuvering, altitude changes, and routing around defended areas—combined with lower observability, often result in fragmented or delayed detection.
- Second, during large attacks, saturation forces air defense systems to prioritize certain targets. As a result, some tracks may be dropped at the initial detection or tracking stage, creating brief windows when targets can slip through unnoticed.
- First, the Earth's curvature and local terrain create radar "shadows". The lower a target flies, the less time it remains visible within a radar's direct line of sight. Cruise missiles and strike UAVs intentionally fly at very low altitudes, use terrain masking, and navigate through built-up areas and treelines to complicate detection.
- Lastly, radars themselves are high-priority targets. Russia systematically seeks to locate and strike them, which forces air-defense units to limit radar emissions, relocate, or temporarily shut down their systems, further increasing gaps in coverage.

Taken together, these factors point to the need for an additional sensing layer—one that is distributed, harder to disable with a single strike, and positioned to fill the gaps where technical sensors are least reliable.

The developers came up with this idea in March 2022, after low-flying cruise-missile strikes revealed that some targets were evading stable radar tracking. They created ePPO in the spring of 2022 to compress the cycle from initial detection to air-defense cueing to just a few seconds.

Conceptually, ePPO acts as a distributed, crowd-sourced layer for gathering first alerts. Users mark sightings, often based on sound, directly within the app. The key difference from traditional civilian alert systems is the reduced number of intermediaries. Reports flow into a central processing system, where they are automatically aggregated and combined into a usable stream of information.

Figure 62. Screenshot from the ePPO application.

ePPO: civilians as sensors

A practical solution to this gap is ePPO, a digital tool that enables civilians and service members to quickly report airborne targets and integrate those observations into the air defense system. By leveraging human sight and hearing as initial cues, ePPO helps fill radar blind spots and enhances the detection system's overall resilience against active enemy countermeasures.

Next, algorithms process clusters of reports from multiple users. They filter out accidental or erroneous entries, smooth the data, and generate a validated position and estimated direction of travel. The team says this takes 2-4 seconds, after which the output becomes available to air-defense personnel on their operational map. The visualization and predicted track are restricted to the military and are not publicly available.

Crucially, ePPO is built into the military operating picture rather than running alongside it. Only air-defense personnel can access the map with markers and projected trajectories, and the system was developed through sustained coordination with the Air Force and other responsible units. Over the life of the project, coordination reportedly spanned all levels, from mobile fire teams on the ground to brigade command and regional air-defense headquarters.

Operational impact and scaling

From an operational standpoint, ePPO fills several roles at once.

- First, it helps establish a target's direction of travel earlier and refine its route in areas where radar coverage is uneven.
- Second, it supports mobile fire teams, particularly during Shahed-type UAV attacks, where time-to-response is often the limiting factor.
- Third, the accumulated reporting allows analysts to build statistics and identify recurring employment patterns, which improves the overall air picture.

The pace of adoption also suggests practical value. The developers say that just eight days after launch, app-derived reports supported a Kalibr cruise-missile engagement 139.

By late 2025, they report more than 850,000 users and thousands of airborne targets tracked each month. In some cases, they also claim that the app enabled engagements where no radar track was available. This highlights the app's role as a complement to technical sensors, rather than as a parallel system.

Figure 63. Dev.ua. Screenshot of the ePPO app map during Russia's missile attack. July 26, 2023.

personnel can access the map with markers and projected trajectories, and the system was developed through sustained coordination with the Air Force and other responsible units. Over the life of the project, coordination reportedly spanned all levels, from mobile fire teams on the ground to brigade command and regional air-defense headquarters.

Hennadii Suldyn, one of the founders of the Odesa-based engineering group "Tekhnari," which developed the ePPO app in 2022, provided a practical demonstration of how the system works. Commenting on a map visualization from the app, he explained how the service processes citizen reports in real time and helps air-defense units identify and track hostile missiles:

"530 citizens helped protect other Ukrainians. After seeing or hearing a cruise missile, they pressed the large red button in the ePPO app. Within 2-4 seconds, ePPO's AI processed those alerts and displayed red dots on the map—coordinates of low-flying missiles detected by Ukrainians. Our AI also plotted missile tracks, estimating the most likely directions of travel and the most likely target speeds. It also predicted where the missile would be a few minutes later," — he said while describing the app visualization 140.

Figure 64. informer.od.ua. Screenshot of the ePPO map.

According to our interview with representatives of the Tekhnari group, as of early December 2025, ePPO had transmitted more than 4 million reports in total. This volume points to sustained day-to-day user participation and regular use of the system under wartime conditions. It also indicates that ePPO has moved beyond an early volunteer experiment and has become a widely used component of Ukraine's air-defense ecosystem, operating continuously across the country.

One important development has been the expansion of functionality. In 2023, the team introduced personalized, location-based warnings. Using the system's predicted flight path, these alerts can notify users who are likely to be in a risk area roughly 10 minutes before an overflight. This adds a civilian-protection dimension by helping reduce exposure to debris and secondary effects.

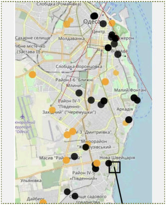

Figure 65. Odeske zhyttia. Map of Shahed's flying paths over Odesa during the air raid alert.

The developers report that within the first weeks of rollout, they received user feedback indicating that these alerts influenced immediate behavior. In one example, a user reported that she and her daughter moved from a room to a bathroom after receiving an ePPO warning during an air raid alert. Later, windows in the original room were damaged by shattered glass, illustrating how even a short lead time can reduce injury risk for civilians [141].

Overall, ePPO has introduced a new model of interaction between civilians and the air-defense system, where large-scale citizen participation contributes to resilience. The system does not replace radar or interceptors but adds a distributed, responsive sensing layer that continues to function even when the adversary applies active countermeasures.

At the same time, ePPO is only one part of a broader evolution in the command-and-control and sensing component of Ukraine's air defense. In parallel, other software tools and digital pipelines are being developed to integrate heterogeneous sensors and effectors into a single, managed architecture, allocate targets across units, and provide objective performance tracking. Taken together, these tools increase throughput, shorten reaction time, and reduce performance degradation during mass raids, where integration and control often matter as much as the individual platforms themselves.

138. Суспільне, "«Питання не в грошах, а в темпах»: Зеленський розповів про ефективність та дефіцит дронів-перехоплювачів" ["The Issue Is Not Money but Speed": Zelenskyy on the Effectiveness and Shortage of Interceptor Drones], December 22, 2025, https://suspilne.media/1195796-pitanna-ne-v-grosah-a-v-tempah-zelenskij-rozpoviv-pro-efektivnist-ta-deficit-droniv-perehopluvaciv/; Ю. Кобзар, "Битва за українське небо близька до перелому: Forbes вказав на ключовий показник" [The Battle for Ukraine's Sky Is Near a Turning Point: Forbes Identified a Key Indicator], УНІАН, January 16, 2026, https://www.unian.ua/war/viyna-v-ukrajini-ukrajina-naroshchuye-virobnictvo-droniv-perehoplyuvachiv-13257903.html

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Russia's air campaign from 2022 to 2025 evolved into a war of attrition, where the key defensive factor is not just the ability to intercept targets once but rather the system's capacity to function continuously amidst a steady stream of varied targets with different costs, flight profiles, and tactical approaches. The main takeaway is that effective air defense relies on a combination of dependable detection, efficient command and control, and a diverse set of interception options, with assigned roles that align with specific threats and to maintain an interception strategy that remains economically viable.

What baseline force posture did Ukraine have at the start of 2022, and what constraints influenced its air-defense capabilities?

When Ukraine entered the full-scale phase of the war, its air defense system was primarily based on aging Soviet technology, which had limited capacity for modernization and maintenance, and where many components were outdated, resulting in chronic shortages of interceptors. By 2022, the critical challenge was not just the number of launchers or aircraft available, but also the system's ability to withstand strikes, maneuver effectively, restore command and control, maintain communications, and ensure continuous air surveillance. Until spring 2023, a significant limitation was the lack of a reliable missile defense capability against ballistic and aeroballistic threats. Existing systems and radars were not optimized for effectively intercepting high-speed ballistic trajectories. As a result, this created an asymmetry, where Ukraine was able to engage aerodynamic targets more successfully but remained vulnerable to more complex missile threats.

How did the air threat develop between 2022 and 2025, and what objectives did Russia aim to achieve through its various waves of attacks?

The adversary's logic evolved from early attempts to rapidly dismantle Ukraine's air defense as a system at the start of the invasion to a sustained campaign of attrition. In 2022, Russia sought to paralyze command and control, strike aviation, and degrade radar and surface-to-air components. After its initial plan failed, it shifted toward attacks on critical infrastructure. In 2023-2025, the most visible change was the shift to combined waves of drones, cruise missiles, and ballistic or aeroballistic weapons, designed not only to cause physical damage but also to saturate defenses. By 2024-2025, the primary emphasis shifted toward the mass use of relatively low-cost technologies, particularly strike UAVs. This shifted the contest toward air-defense throughput, reaction speed, and interception economics.

Which decisions proved decisive for defensive resilience as attacks scaled up and resources grew more constrained?

Air defense resilience relies less on individual platforms and more on system-level choices that enhance defensive capacity, decrease interception costs, and improve the survivability of critical components. These choices can be organized into four mutually reinforcing categories.

First, **command-and-control and prioritization** decisions allowed Ukraine to manage air defense as a disciplined allocation of limited resources. Under varied waves of threats, the key was to separate roles across different layers: the most capable systems and the most expensive interceptors were designated for ballistic missiles and other high-end threats, while less expensive means were used for mass targets. This approach was both economically sound and operationally necessary. Without properly assigning targets to the appropriate means, air defense can quickly lose effectiveness due to interceptor depletion.

Second, **survivability and continuity measures** ensured the system remained operational under repeated strikes. This included tactics such as maneuvering and dispersing systems, reducing the radar and firing positions' signatures, and maintaining command links through redundant communication and repair cycles that brought systems back into operation. In practice, air defense performance depended less on peak specifications at any one moment and more on the ability to sustain surveillance and control over weeks and months of continuous attacks.

Third, **scaling the short-range layer and utilizing counter-UAS tools** increased capacity against low-altitude threats like Shahed drones. Mobile fire teams, army aviation, anti-aircraft artillery, and later interceptor drones offered options to address mass targets without depleting scarce missiles. This approach reduced the pressure on medium-range surface-to-air missiles (SAMs) and lowered the risk of major cities losing coverage solely due to exhausted stocks.

Fourth, **expanding the sensor layer and operating effectively in the electromagnetic spectrum** reduced the number of targets that needed kinetic interception. Electronic warfare became a systematic method for degrading the precision and effectiveness of attacks, while distributed detection—including contributions from civilian reporting via ePPO—helped close gaps in tracking low-altitude threats and sped up tactical responses. Together, these efforts enhanced resilience in situations where radar coverage was saturated or deliberately constrained by the threat to the radars themselves.

What role did partner deliveries and the integration of Western systems play in air defense development?

Partner deliveries gave Ukraine several capability jumps, but the outcome depended less on brochure performance and more on three practical variables: how well each system was integrated into the wider air-defense network, how consistently Ukraine could sustain interceptor stocks, and how quickly partners could deliver resupply, spares, and repair support. In effect, Western systems strengthened three functions: defeating cruise missiles and drones, reinforcing the mid-tier layer that protects cities and critical sites, and providing a limited but decisive ability to counter ballistic threats.

First, NASAMS and IRIS-T SLM expanded Ukraine's capacity to engage cruise missiles and drones and improved point defense for critical infrastructure. Second, bolstering the short-range layer with Gepard and other gun-based solutions became central to the cost-effective defeat of mass drone raids, because these systems can absorb volume without consuming scarce high-end missiles. Third, Patriot delivered what Ukraine largely lacked before 2023: repeatable, operationally reliable interception of ballistic and aero-ballistic threats, which materially raised protection for the most critical nodes.

Two dynamics often get lost in public discussion.

Integration and adaptation. Several systems required real-world adjustment before they became consistently effective in combat. Ukraine had to refine employment concepts, command arrangements, interoperability, maintenance chains, and in some cases software and procedures. That is normal in high-intensity war. What mattered was whether manufacturers and partner support structures treated iteration as part of the delivery, and whether they responded quickly to frontline feedback. The Skynex experience is a useful example of how this loop can turn a delivered system into a stable, repeatable combat capability.

Stocks and production tempo. The ceiling on performance is not just the launcher or radar. It is the flow of interceptors, spare parts, and repair capacity. In an attritional air campaign, sustained results depend on whether Ukraine can keep missiles coming in, return damaged systems to service, and expand defensive throughput as attack waves scale. That is why interceptor production rates and delivery timelines are not a secondary issue, but one of the main determinants of air-defense endurance.

What technological and organizational efforts are shaping air-defense development beyond 2026?

Looking ahead to 2026 and beyond, Ukraine's air defense will evolve into a layered system. Each layer will have a distinct mission, target specific threats, and operate according to its own cost logic.

Layer 1: Scalable counter-drone defense. This layer is designed to absorb the bulk of low-cost, high-volume threats—especially Shahed drones—so that advanced missile systems are preserved for more complex attacks. It relies on mobile fire groups, gun-based platforms, drone interceptors, and rapid repositioning along likely flight corridors.

Layer 2: The medium layer for cities and critical infrastructure. This tier is intended to reliably defeat cruise missiles, some UAV threats, and other aerodynamic targets, ensuring ongoing protection for priority areas. Its effectiveness depends less on any single system and more on integration, ammunition flow, repair and rotation cycles, and robust command-and-control during prolonged attacks. In essence, logistics and maintenance often determine its practical limits.

Layer 3: Selective missile defense against ballistic and aero-ballistic threats. As the most resource-intensive and difficult layer to scale, it will be focused on protecting the highest-value assets. In this layer, the availability of interceptors and production tempo directly determine defensive endurance.

Layer 4: The sensor mesh and resilient command-and-control that unify the entire system. This layer encompasses distributed sensors, data fusion, rapid detect-decide-assign cycles, and supplementary detection mechanisms to close low-altitude gaps.

Layer 5: Electromagnetic-spectrum operations as a permanent component of the architecture. Electronic warfare and intelligence will shape how many threats can be degraded or diverted without kinetic means, and how swiftly the defense can adapt as Russia modifies navigation, communications, flight profiles, and raid structures.

Overall, Ukraine faces some of the world's most demanding air-defense conditions: limited high-end interceptors, relentless attacks on major cities and infrastructure, an adaptive adversary, and ongoing mass drone raids. The critical shift is structural. Success now depends less on standout platforms and more on endurance, scale, and how seamlessly the layers operate as a unified system.

This is why the next phase of strengthening Ukraine's air defense relies less on one-off deliveries and more on sustained, scalable support:

First, NASAMS and IRIS-T SLM expanded Ukraine's capacity to engage cruise missiles and drones and improved point defense for critical infrastructure. Second, bolstering the short-range layer with Gepard and other gun-based solutions became central to the cost-effective defeat of mass drone raids, because these systems can absorb volume without consuming scarce high-end missiles. Third, Patriot delivered what Ukraine largely lacked before 2023: repeatable, operationally reliable interception of ballistic and aero-ballistic threats, which materially raised protection for the most critical nodes.

- **Ammunition stocks, production tempo, and predictable supply.** Expanding production capacity and guaranteeing a steady flow of air-defense systems, interceptors, and critical components is the most direct path to broader coverage. For international partners, this is also an investment in their own missile-defense architecture, since the shortage is global.

- **Building and scaling the counter-drone layer.** Accelerating procurement and co-financing of Shahed countermeasures—including gun-based systems, mobile fire groups, drone interceptors, and detection assets—offers the most cost-effective response to mass raids. For partners, Ukraine provides operational lessons with immediate relevance for European security.

- **Sensors, networking, and resilient command-and-control.** Investing in distributed detection, data integration, protected communications, and robust C2 under attack increases air-defense throughput without requiring proportionally greater spending on costly interceptors.

- **Electronic warfare and rapid adaptation.** This demands resources for updating EW/ELINT, testing countermeasures, and maintaining engineering cycles that enable Ukraine to respond swiftly and systematically as Russian tactics evolve.

- **Training, repair capacity, and spare parts.** Air defense ultimately depends on skilled personnel and effective maintenance. Ongoing support for crew training, repair pipelines, and component supply delivers the most reliable long-term gains.