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Evolution Not Revolution

Drone Warfare in Russia's 2022 Invasion of Ukraine

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TABLE OF CONTENTS

01	Executive Summary
03	Introduction
05	Types of Drones Used in the Ukraine War
07	Survey of the War's Different Phases
08	Coup de Main Decapitation Strike February 24-28, 2022
09	Regrouping and Reattacking March 2022
10	Refocusing on the Donbas April-August 2022
11	Ukraine's Fall 2022 Offensive September-November 2022
13	Russia's Winter 2023 Offensive January-May 2023
13	Ukraine's Summer Counteroffensive June 2023-September 2023
14	The Deep Fight: Strategic Strikes February 24, 2022-September 2023
16	Types of Drones
16	Military Drones
23	Commercial Drones
28	Kamikaze Drones
36	Drone Boats
37	Tactical Battle Networks and Communications
38	Conclusion

Executive Summary

This report concludes that drones have transformed the battlefield in the war in Ukraine, but in an evolutionary rather than revolutionary fashion.¹ While tactical innovation abounds and drones offer some new capabilities, their impact falls short of the truly disruptive change that constitutes a so-called revolution in military affairs. For the most part, Russian and Ukrainian drones remain piloted by humans, are not broadly networked together, and are small, which means their effects tend to be localized. In part, drones have not offered Ukrainians or Russians a decisive edge on the battlefield because both parties are engaged in a fast-paced two-sided cycle of innovation and emulation. Because many drone technologies are commercial or dual use, they can be easily acquired, meaning that innovations quickly diffuse to the enemy. Russian forces have been fast followers in adopting commercial and do-it-yourself (DIY) kamikaze drones. Similarly, Ukrainian forces have tried to match the quantity and quality of Russia's military drones, but given the military-specific technologies involved, the Ukrainians have been unable to fully close this gap.

This report is part of a larger project exploring how drones are affecting great-power competition and a potential future war between the United States and China. It focuses on lessons learned from drone operations in Ukraine. It offers a novel typology for the widely varied drones available today—military, commercial, and kamikaze—to enable more precise discussion of their impact; it provides an overview of the Ukraine conflict to date; and it includes an in-depth analysis of major developments seen for each drone type in this war.

Beyond this general assessment about whether a revolution in military affairs has occurred, this analysis yielded a number of insights about the war in Ukraine and drone warfare more broadly.

In the Ukraine war:

- **Ukraine has consistently out-innovated Russia with commercial technologies and software, but Russian forces have quickly adapted and emulated Ukrainian successes.** In a key example, Ukraine pioneered the use of first-person view (FPV) racing drones in kamikaze attacks and began creating DIY cheap kamikaze drones. Russia was a fast follower and employed FPV kamikaze drones to contest Ukraine's summer 2023 counteroffensive.
- **Volunteer networks have performed an unprecedented role in acquiring, modifying, and building commercial and DIY drones for both Ukrainian and Russian troops.** Because of a heavy reliance on commercial or dual-use technologies, patriotic civilians have been able to bolster drone production. They have also led broader efforts to professionalize the use of drones by identifying best practices and establishing training courses.
- **Russia has an edge in military drones, which enables its forces to see and strike farther behind the front lines, while Ukrainian forces have gaps in this area.** Russia entered the war with a reasonable inventory and bolstered production of its most effective military drones to meet the current demand. Russia now has enough Orlan-10 and ZALA surveillance drones that Ukrainian forces sometimes do not bother trying to shoot them down because the Ukrainians know that the drones will be replaced. In contrast, Ukraine has smaller inventories of military drones—both intelligence, surveillance, and reconnaissance (ISR) and kamikaze variants—which limits its forces' visibility and reach behind the front lines. This gap may eventually close as Ukraine's government is investing heavily in its indigenous drone industry.
- **In the Ukraine war, drones have operated in stacks rather than swarms.** Drones are more effective when operated as a part of larger team of uncrewed systems. Swarms typically consist of a greater number of units that autonomously coordinate their behavior. The drone stacks used by both sides in the war in Ukraine have been coordinated through multiple drone operators using software-based battle networks, traditional means of communication, or commercial communications platforms. Both parties claim to be using artificial intelligence to improve the drone's ability to hit its target, but likely its use is limited.
- **Russian and Ukrainian forces are using long-range kamikaze drones for penetrating strategic strikes.** Ukrainian forces would not have a capability to strike deep targets inside Russia and Crimea without these drones. Russian forces use kamikaze drones to complement their more expensive long-range cruise and ballistic missiles by soaking up Ukrainian surface-to-air missile (SAM) interceptors, identifying the location of air defenses, and creating complex heterogeneous attacks. It is not clear that strategic strikes weaken public support for the war, but they may be diverting scarce air defense assets from the front lines.

- **In the Ukraine war, both sides are experimenting with counterdrone capabilities.** Electronic warfare (EW) is the most effective way to stop drones, but Ukrainian and Russian forces are trying counters that range from simple barriers such as wire nets to drone dogfighting. A key part of the drone-counterdrone competition has been finding and attacking drone operators using drone tracking software such as AeroScope and WindtalkerX. Because commercial and FPV kamikaze drone operators must remain near the drone's operating area, they are vulnerable to discovery and attack.

More general lessons about drone warfare include:

- **The accessibility and affordability of drones is creating new capabilities at a scale that previously did not exist and transforming the battlefield.** The three primary examples of this are the ubiquity of commercial drones on the front lines, FPV kamikaze drones for beyond-line-of-sight antipersonnel and antivehicle attacks, and long-range kamikaze drones for strategic strikes. All of these missions could be completed by more expensive military systems, such as military drones, traditional manned air forces, and antitank weapons or artillery. The biggest difference is that because the commercially derived versions employed in Ukraine are cheap and plentiful, there are deeper stockpiles of uncrewed aircraft than have previously been available, enabling drones' widespread use.
- **Surveillance and targeting missions remain more important than drone strikes.** Despite the prevalence of videos on social media showing commercial quadcopters dropping grenades on soldiers or crashing into tanks, the most consequential mission for drones has been collecting intelligence and obtaining targeting information. Ground forces at all echelons are employing different types of drones to improve their situational awareness, planning, and operations.
- **Commercial drones are making it more difficult to concentrate forces, achieve surprise, and conduct offensive operations.** By providing greater visibility into enemy troop movements beyond the front lines, drones have made it difficult for the Ukrainian and Russian militaries to mass forces. Offensive operations are difficult but not impossible in this environment. If strong defenses are in place, prolonged periods of bombardment can weaken the enemy and gradually enable territorial gains.
- **Kamikaze FPV drones offer cheap precision strike capabilities but are tactical beyond-line-of-sight weapons that primarily extend the reach of ground forces.** FPV drones are essentially very cheap antitank weapons, but their range is roughly six times that of the most advanced antitank weapon. Their biggest drawbacks are their small payload capacity, which limits their destructive power, and the fact that FPV drones, unlike modern antitank weapons, are not automated fire-and-forget systems. Instead, FPV drone pilots require training and must be very skilled to effectively steer the fast drones and crash them into vulnerable parts of an armored target. Even though experienced or lucky FPV operators might destroy a tank, more often FPV attacks at best will disable large vehicles, which can then be destroyed by follow-on artillery or air strikes.
- **Even large numbers of small drones cannot match the potency of artillery fire.** Collectively, drone strikes supplement indirect fire weapons, but they are not substitutes for howitzers. Common artillery shells pack a bigger explosive punch and can be fired rapidly in large salvos. Thus, artillery barrages far outstrip the firepower that many small drones can collectively deliver.
- **Drones provide affordable airpower, but they have not replaced traditional air forces or been able to obtain air superiority.** A core mission of most air forces is obtaining and maintaining air superiority—that is, the freedom to conduct operations in the air, which include protecting against enemy aerial attacks and conducting offensive air-to-ground operations. Obtaining air superiority typically entails destroying an opponent's air force through air-to-air engagements or attacks against air bases and suppressing or destroying ground-based air defenses. There have been a few instances of drone dogfighting and kamikaze drone strikes against Russian bomber air bases, but these missions have been few and far between. Russian forces have conducted effective suppression of enemy air defense (SEAD) operations involving drones near the front lines but have not disabled Ukraine's long-range air defenses. Because neither side has obtained air superiority, they have both relied on standoff attacks instead of direct attacks against deep targets.
- **Drones are not more survivable than crewed aircraft, but instead enable greater risk acceptance.** Drones are vulnerable to many countermeasures, especially electronic warfare, guns, and SAMs. Like countries discovered the hard way with bomber

aircraft in World War II, the drone “will not always get through.” Because drones are cheap and do not have humans aboard, both sides have been willing to send them on risky missions that may have a low probability of succeeding.

- **Drones do not have to be survivable if they are cheap and plentiful because one can have resiliency through reconstitution.** Because they are vulnerable, drones must be cheap enough and easy enough to manufacture that they can be readily replaced. Instead of hardening commercial drones against electronic attacks, which would notably raise the costs, both parties have opted to instead buy more cheap drones. The logic of resiliency through reconstitution also applies to military drones.

In the Ukraine war, drones have become an increasingly important weapon, but they have not revolutionized warfare. Nonetheless, Ukrainian forces have extensively employed drones to gain an asymmetric edge over a superior Russian force. Russian forces have been fast followers and emulated Ukraine's use of commercial drones to a surprising degree given the reluctance of the Russian Ministry of Defense (MOD) to officially embrace private-sector technologies. Russian forces have employed their military-grade and kamikaze drones as a part of the reconnaissance fires complex, allowing them to increasingly leverage their greater firepower. Throughout the war, there have been rapid cycles of adaptation as both sides have learned from each other, adopting tactics and technologies that have been used successfully and developing counters to improve defenses. This pattern is likely to continue as the war drags on. It is clear that drones alone will not determine who prevails in this conflict, but they will certainly play a prominent role in the ongoing war in Ukraine and in other battlefields in the future.

Introduction

Russia's 2022 invasion of Ukraine initiated a conventional war of a scale and intensity that had not been seen in Europe since World War II. In many ways, the fighting in Ukraine seems anachronistic, with large-scale artillery barrages and the heavily defended front lines that resemble the trench warfare of World War I. In other respects, however, the war in Ukraine gives a glimpse at how future battlefields may look. One of the most notable differences between Ukraine and past wars is the extensive use of drones or uncrewed systems by both parties, earning this conflict the moniker

of the “first full-scale drone war.”² In the early days of the war, high-flying Ukrainian TB2 drones dropped guided bombs on advancing Russian forces, arresting their march toward Kyiv. In recent months, Russian ZALA surveillance drones and Lancet-3 loitering munitions have worked together to find and destroy Ukrainian howitzers. While military drones have played an important role, over the front lines commercial off-the-shelf drones are omnipresent. Ground forces at all echelons use small commercial quadcopters to monitor their environs and to direct artillery fire. Over time, both Russian and Ukrainian forces have also employed different types of kamikaze drones—those that crash into their target—for strategic attacks against cities and deep targets.

The prevalence of drones in Ukraine and other recent conflicts has led some observers to conclude that drones are revolutionizing warfare.³ Others maintain that drones are incremental improvements to existing technologies. According to this view, drones perform the same roles and missions as traditional weapons systems but remove the human from the platform. Critics also point out that drones are not superweapons but remain quite vulnerable to electronic warfare (EW) and air defenses, while typical defensive measures such as dispersion and concealment continue to dilute drones' lethality. Thus, according to the skeptics, drones are not fundamentally shifting the character of war.⁴

This report concludes that drones have transformed the battlefield in Ukraine, but in an evolutionary rather than revolutionary fashion.⁵ While tactical innovation abounds and drones offer some new capabilities, this falls short of the truly disruptive change that constitutes a revolution. For the most part, Russian and Ukrainian drones remain piloted by humans, are not broadly networked together, and are small, which means that their effects tend to be localized. In part, drones have not offered Ukrainians or Russians a decisive edge on the battlefield because both parties are engaged in a fast-paced two-sided cycle of innovation and emulation. Because many drone technologies are commercial or dual use, they can be easily acquired, meaning that innovations quickly diffuse to the enemy. Russian forces have been fast followers in adopting commercial and do-it-yourself (DIY) kamikaze drones. Similarly, Ukrainian forces have tried to match the quantity and quality of Russia's military drones, but given the military-specific technologies involved, they have been unable to fully close this gap.

The most important roles for drones in the Ukraine war have been as intelligence platforms and artillery spotters. The proliferation of drones over the front lines

has made it hard to concentrate forces and launch surprise attacks. Yet while offensive operations are difficult, they are not impossible. Moreover, mass artillery fires still dominate battlefield outcomes. Drones enhance artillery firepower by making it more accurate but, as noted analyst Michael Kofman has observed, by themselves drones are not a “substitute for mass.”⁶ Because small drones can only carry meager payloads, even large drone swarms cannot rival the potency of artillery salvos. Similarly, small drones cannot match the volume of fires that bombers could provide if either side had air superiority. Drones are clearly an important military innovation and are increasing the effectiveness of Russian and Ukrainian artillery and ground operations.⁷ Over time, as drones become more autonomous and are more broadly connected with other weapons, they may fundamentally reshape military doctrine and organizations and truly revolutionize warfare. But thus far in Ukraine, drone warfare has been an evolution, not a revolution.

This report is part of a larger project that is exploring how drones are affecting great-power competition and a potential future war between the United States and China. A forthcoming report by the Center for a New American Security (CNAS) examines this broader issue. A first step in answering this question involved analyzing three recent conflicts that employed drones, including the war in Ukraine, and determining what lessons they provide. The Ukraine case study merited its own report because the volume of pertinent information on this war could not be incorporated into the broader comparative historical analysis. This report also serves a broader audience that is following and trying to understand developments in the ongoing war between Ukraine and Russia.

A few caveats are in order. This report is not a full political or military history of the war in Ukraine. Instead, it synthesizes information on how both Ukrainian and Russian forces have employed drones across time and attempts to identify key insights from this analysis. It builds on foundational studies from organizations such as the Royal United Services Institute (RUSI) and CNA that document and analyze the conflict and the impact of drones in it. Many

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of these studies, however, focus on one side or one moment in time and do not systematically compare Ukrainian and Russian troops’ use of drones, and how this unfolded in different phases of the war. This report aims to fill these gaps and to offer an initial analysis that can be built on and revised by future researchers.

To explore these issues, the author drew heavily on secondary sources, including think tank reports, newspaper and magazine articles, and videos and photos posted on social media. The videos and pictures posted by Ukrainian and Russian sources are a part of a larger information and propaganda war that is trying to shape public opinion. Thus, they are certainly biased and must be treated with caution. The author has used these as evidence that different types of drones have been employed against specific targets or have been involved in different phases of the war. Unsurprisingly, almost all the videos show successful drone strikes, but they are clearly not a representative sample. Because observers cannot know the percentage of attempted strikes represented by these videos, the videos do not shed much light on the overall efficacy of these weapons.⁸ Additionally, the author conducted interviews with U.S. government and NATO officials and with experts on the Russian and Ukrainian militaries but did not undertake field research in Ukraine. All interviews were conducted in confidentiality, and the names of interviewees are withheld by mutual agreement.

The remainder of this report is divided into four sections. The first section offers a typology of drones that have been used by Ukrainian and Russian forces. The second provides a brief overview of the major phases of the war between February 2022 and September 2023 and notes major developments related to drone warfare. The third section is a functional discussion focused on the different types of drones, with each section describing the most significant drones for both Russia and Ukraine, how they have been employed, and what has been used to counter them. The functional discussion concludes with an overview of the battle networks that have linked drones to other forces. The final section offers conclusions about how drones have been used in the Ukraine war and explains why this does not constitute a revolution.

Types of Drones Used in the Ukraine War

Drones have played a prominent role throughout the war, although the drone types and their roles have evolved over time. In the war in Ukraine, drones can be differentiated by two major attributes: whether they are built for commercial or military use and whether they are intended to be single-use or reusable systems. These two variables and examples of different drones that fit into each category are presented in Figure 1.

The first factor matters because commercially available or DIY drones made from commercial or dual-use subcomponents are widely available and quite affordable. These drones have GPS and high-definition cameras, and are remotely operated with smartphones or controllers that stream real-time video feeds.⁹ Most commercial drones are quadcopters used by the agricultural industry, by photographers, or for recreational racing. Because they are marketed to amateur users, they tend to be relatively easy to operate, although first-person view (FPV) racing drones require additional skill. The downside of these systems is they tend to be small, with low endurance and small payloads, and must be modified to be armed or hardened against electronic attack. Common examples of reusable commercial drones used by Russian and Ukrainian troops include DJI Mavic 3, DJI Matrice, and Autel EVO II quadcopters.

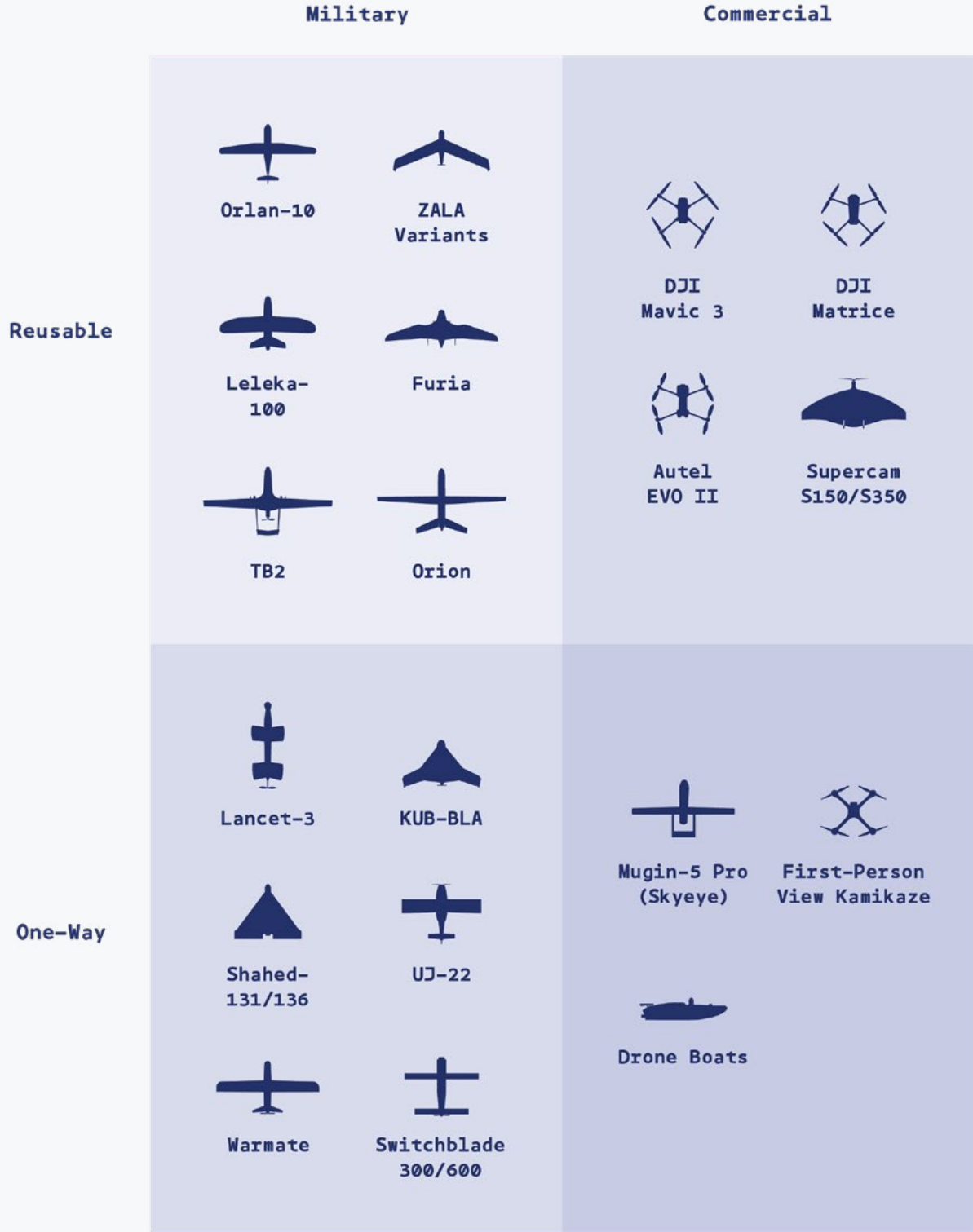
In contrast, military drones are built specifically for use by professional military personnel in a combat setting. This means the systems tend to have additional features that harden them against attacks and equip them for offensive operations by either carrying weapons or being integrated into a broader battle network. Military drones may carry sophisticated precision-guided

weapons, dumb bombs, or jammers. They also may be unarmed but have sensors to help them accurately calculate the range to a target or to illuminate targets that can then be engaged by other weapons. Military drones require specialized training to operate and include additional features that prepare them to deal with adversaries that are trying to interfere with their operations or hide from them. For example, they may be resistant to jamming and cyberattacks and, in addition to cameras, have sensors that can pick up signals or electronic intelligence. Russia's most common military drones are the Orlan-10 and ZALA 421 variants, while the Ukrainians have the Leleka-100, Furia, and PD-1s. Additionally, both parties have a smaller number of larger medium-altitude long endurance (MALE) drones, including the Russian Forpost-R and Orion and the Ukrainian TB2.

The other key attribute is whether a drone is intended to fly multiple missions or is a single-use weapon more akin to a munition. The former is often a more expensive system because it is expected to return after completing a sortie and to fly again. Additionally, reusable drones tend to be configured for multiple different missions, most notably intelligence, surveillance, and reconnaissance (ISR) and sometimes strike. In contrast, single-use drones tend to be cheaper systems primarily used for strikes. These drones are also called loitering munitions because they can search for targets after they have been launched. They are in many respects similar to cruise missiles, especially if they fly to preprogrammed coordinates. Many kamikaze drones are controlled by humans or may have autonomous systems that identify and engage targets even if the connection to the human operator is broken. Both Russia and Ukraine have made extensive use of kamikaze drones, including military grade systems and commercial FPV drones. Only Ukraine has developed and employed kamikaze drone boats.

In the war in Ukraine, drones can be differentiated by two major attributes: whether they are built for commercial or military use and whether they are intended to be single-use or reusable systems.

FIGURE 1: EXAMPLES OF DIFFERENT TYPES OF DRONES IN THE UKRAINE WAR



*Drones featured in this graphic are not to scale

Survey of the War's Different Phases

The war in Ukraine has evolved over time and so has the use of drones. First, it is important to note that there are two battles being waged concurrently: the close fight and the deep fight.¹⁰ The close fight occurs between troops in contact or near the front lines, while the deep fight consists of long-range attacks against strategic targets. There have been six major phases of the close fight: the initial failed decapitation attack (February 24–28, 2022), the Russian regrouping and reattacking (March 2022), the Russian attack on Donbas (April–August 2022), the autumn 2022 Ukrainian offensive (September–November 2022), the winter 2023 Russian offensive (January–May 2023), and the summer 2023 Ukrainian offensive (June 2023–September 2023).¹¹

The deep fight has occurred across all of these periods, but it was largely one-sided in 2022. Russia had a large inventory of long-range cruise and ballistic missiles that it fired at Ukraine, while Ukraine had few long-range strike capabilities. After depleting its stockpiles of missiles, Russia began to employ Iranian kamikaze drones for standoff attacks in fall 2022, and Ukraine developed its own long-range kamikaze drone aircraft and drone boats to attack Crimea and Russia. The deep fight, therefore, became more symmetrical in 2023 as Ukrainian kamikaze drone attacks into Russia significantly increased. This section of the report provides an overview of the six phases of close combat in the Russia-Ukraine war and deep strikes through September 2023, including a high-level description of major developments in the war and major trends in drone warfare.

FIGURE 2: OVERVIEW OF THE CLOSE AND DEEP FIGHTS DURING KEY PHASES OF THE UKRAINE WAR (WINTER 2022–SEPTEMBER 2023)

Time	Phase	Ground Offensives	Major Trends in Drone and Counterdrone Warfare (Close Fight)	Strategic Strikes (Deep Fight)
February 24–28, 2022	Coup de Main Attack	<ul style="list-style-type: none"> Russian main attack on Kyiv from Belarus and Russia Russian attack on Kharkiv, fixing operation in Donbas, and attack in south from Crimea 	<ul style="list-style-type: none"> Little Russian use of drones except decoys, despite having many military drones Restrictive Russian rules of engagement limited use of surface-to-air missiles (SAMs) Ukrainian forces used commercial and military drones to find Russian forces, direct artillery fire, and directly attack Ukrainian TB2 interdiction strikes against Russian troops 	<ul style="list-style-type: none"> Russian cruise and ballistic missile strikes focused on Ukrainian military targets
March 2022	Regrouping and Reattacking	<ul style="list-style-type: none"> Russian forces transitioned to deliberate combat operations Russian forces continued to focus on Kyiv 	<ul style="list-style-type: none"> Russia began to employ ground-based air defenses and electronic warfare (EW) Ukrainian forces made extensive use of commercial and military drones for intelligence, surveillance, and reconnaissance (ISR); artillery targeting; and strike Large medium-altitude long endurance (MALE) drones (e.g., TB2s and Orion) experienced many losses and largely disappeared from the battlefield Russia began to use military ISR drones (e.g., Orlan-10 and ZALA) to target ground-based fires and KUB kamikaze drones for attack 	<ul style="list-style-type: none"> Russian cruise and ballistic missile strikes focused on Ukrainian military targets, defense industry, and communications infrastructure
April–August 2022	Refocusing on Donbas	<ul style="list-style-type: none"> Russian forces attacked from multiple axes but northern attack stalled Russian forces made slow gains from east in province of Luhansk 	<ul style="list-style-type: none"> Ukrainian forces retained an advantage in commercial drones, while Russian forces had an advantage in military drones Ukraine began its “army of drones” project Extensive electromagnetic interference due to the dense network of Russian EW systems and growing number of man-portable Ukrainian jammers Many losses of all kinds of Russian and Ukrainian drones Russia ran low on Orlan-10s 	<ul style="list-style-type: none"> Russian cruise and ballistic missile strikes focused on economic targets, such as oil refineries, and transportation infrastructure Ukrainian kamikaze drone attack on Russian oil refinery Ukrainian kamikaze drone attacks on Crimea

Coup de Main Decapitation Strike

FEBRUARY 24–28, 2022

On February 24, 2022, Russia began an unprovoked war of aggression against Ukraine. Moscow believed Ukrainian resistance would be minimal and that through a large show of force and rapid assault, Russia could achieve a coup de main in several days. Russia’s attack began with a large-scale campaign of air and missile strikes focused on military targets, including Ukrainian air bases, command and control infrastructure, munitions stores, and air defenses.¹² To bait Ukrainian air defense radars into exposing themselves, Russia deployed E95M target drones as decoys.¹³ This was one of the few uses of Russian drones in the opening phase

of the war. After the missile strikes, Russia’s unrealistic strategy had shorthanded, unprepared battalion tactical groups racing into Ukraine along multiple axes of advance, leaving them vulnerable to Ukrainian counterattacks.¹⁴ Russian forces invaded southern Ukraine from Crimea, advanced toward Kharkiv from the east, and conducted a fixing operation in Donbas, but the main Russian attack was focused on Kyiv.¹⁵ In an effort to depose the Ukrainian government, Russian mechanized forces in Belarus and Russia approached Kyiv from both sides of the Dnieper River, while helicopters transported Russian airborne forces (VDV) to Hostomel Airport, just 12 miles from the capital.¹⁶

Ukrainian military forces and volunteers used a wide array of drones in their defensive operations. The Ukrainian air force flew the Turkish-made TB2, a

Time <i>continued</i>	Phase	Ground Offensives	Major Trends in Drone and Counterdrone Warfare (Close Fight)	Strategic Strikes (Deep Fight)
September–November 2022	Ukraine’s Fall 2022 Offensive	<ul style="list-style-type: none"> Ukrainian attack overwhelmed weak Russian defenses near Kharkiv Ukrainian forces eventually attrited Russian defenses in Kherson 	<ul style="list-style-type: none"> Russian and Ukrainian drones’ most common missions were intelligence and spotting for artillery units Increasing Russian use of Lancet kamikaze drones Russian Ministry of Defense (MOD) began to encourage soldiers to bring commercial drones, and large numbers of volunteer-supplied commercial drones reached Russian troops 	<ul style="list-style-type: none"> Russia fired Shahed kamikaze drones at Odesa Russian Shahed drone and missile attacks on critical infrastructure (e.g., electric grid) began Ukrainian drone boats and aircraft attacked Black Sea Fleet headquarters in Sevastopol
January–May 2023	Russia’s Winter 2023 Offensive	<ul style="list-style-type: none"> Russian forces counterattacked on multiple fronts in Donbas but made few gains Russia finally secured Bakhmut in May 	<ul style="list-style-type: none"> Commercial drones had become ubiquitous Russia achieved near parity in commercial drones with Ukraine Russian and Ukrainian troops increasingly used more advanced commercial drones with thermal cameras Ukraine began to employ first-person view (FPV) kamikaze drones to attack moving Russian forces 	<ul style="list-style-type: none"> Ukrainian defenses intercepted most Shahed drone and missile attacks Increasing Ukrainian kamikaze drone attacks in Russia against oil fields, air bases, transportation infrastructure, and the Kremlin
June–September 2023	Ukraine’s Summer 2023 Offensive	<ul style="list-style-type: none"> Ukrainian forces attacked along three axes: Orikhiv, Velika Novosilka, and Bakhmut 	<ul style="list-style-type: none"> Front lines saturated with all types of drones Ukrainian forces often refrained from firing SAMs at common Russian military drones to conserve interceptors Russia mimicked Ukraine FPV drones. FPV kamikazes proliferate on battlefield for antipersonnel and antivehicle attacks Extensive Russian use of ZALA Lancet-3 for counterbattery fire 	<ul style="list-style-type: none"> Ukrainian kamikaze drone hit skyscraper in Moscow Ukraine launched simultaneous drone attacks on multiple sites in Russia Increased Ukrainian drone boat attacks

medium-altitude long endurance military drone, to hunt for and interdict Russian forces.¹⁷ Similarly, Ukrainian ground forces employed smaller military drones, such as the Punisher and Leleka-100, and commercially adapted drones, such as the R18 and DJI Mavic, to find and track Russian troops.¹⁸ Sometimes armed drones, such as the R18, dropped bombs on unsuspecting Russian forces, but more often the drones provided vital intelligence that directed Ukrainian artillery fire or hidden Ukrainian ground teams to ambush them. Ukrainian drones had free rein because Russia's air defenses were operating under strict rules of engagement (ROE) that limited the use of surface-to-air missiles (SAM) to avoid friendly fire incidents.¹⁹

Regrouping and Reattacking

MARCH 2022

Over the next month, Russian forces regrouped from their shambolic initial attack and gradually transitioned to deliberate combat operations while trying to advance

their original objectives.²⁰ As Russia continued its offensive, the fighting became more contested, and there was a real chance the much larger invading force might overwhelm defenses around Kyiv. Ukrainians contested all Russian axes of attack but focused their resources, including special forces and reserves, on defending the capital, leaving other areas with shortfalls.²¹ Russian forces had the most success in their southern offensive, in part because of insufficient Ukrainian artillery in the region and also because they had previously destroyed Ukrainian air defenses in the south with cruise missile strikes.²² In contrast, the attack on Kyiv encountered fierce resistance and was quickly bogged down, and Russian troops suffered heavy casualties. By the end of March, the Russian attack on the capital had completely stalled. On March 25, the Russian Ministry of Defense (MOD) proclaimed that, having met its initial goals, Russia's main objective would now be conquering and annexing the remainder of the Donbas region of eastern Ukraine.²³

Drones became more prominent during this period because they continued to play an important role in

FIGURE 3: THE RUSSIAN INVASION PLAN

This map shows the initial axes from which Russian forces advanced in Ukraine in February 2022. While there were multiple avenues of attack, the focus was on Kyiv, the Ukrainian capital.



Map adapted from "Maps: Tracking the Russian Invasion of Ukraine," *The New York Times*, June 9, 2023, <https://www.nytimes.com/interactive/2022/world/europe/ukraine-maps.html>.

Ukrainian forces' operations and Russian troops began to employ them in the surveillance and target acquisition roles outlined by Russian military doctrine.²⁴ Russian forces used their military drones, such as the ZALA, Orlan-10, Orlan-30, and Eleron-3, for situational awareness and to direct artillery strikes, while Ukrainian forces bolstered their smaller fleet of military drones with commercial off-the-shelf or homemade drones for the same missions.²⁵ Russian troops were slower to adopt commercial drones for tactical reconnaissance than were Ukrainian forces, which included many civilians who volunteered to fight and had little choice but to rely on commercial technology and improvised weapons. Around the same time, the airspace in Ukraine became more contested as Russian forces began operating their ground-based air defenses and EW systems.²⁶ With each side actively searching for its opponent's drones and employing man-portable air defenses (MANPADs), anti-aircraft guns, jammers, and SAMs, drone losses began to pile up. The widespread use of SAMs, which prevented either side from obtaining complete air superiority over Ukraine, made it far too dangerous for MALE military

drones. Russia briefly conducted Orion and Forpost strikes against Ukrainian forces, but several were shot down, after which such strikes were rarely employed.²⁷ Similarly, Russian SAMs shot down most of Ukraine's TB2s during this period, and the much-hyped Turkish drone largely disappeared from the battlefield.²⁸

Refocusing on the Donbas

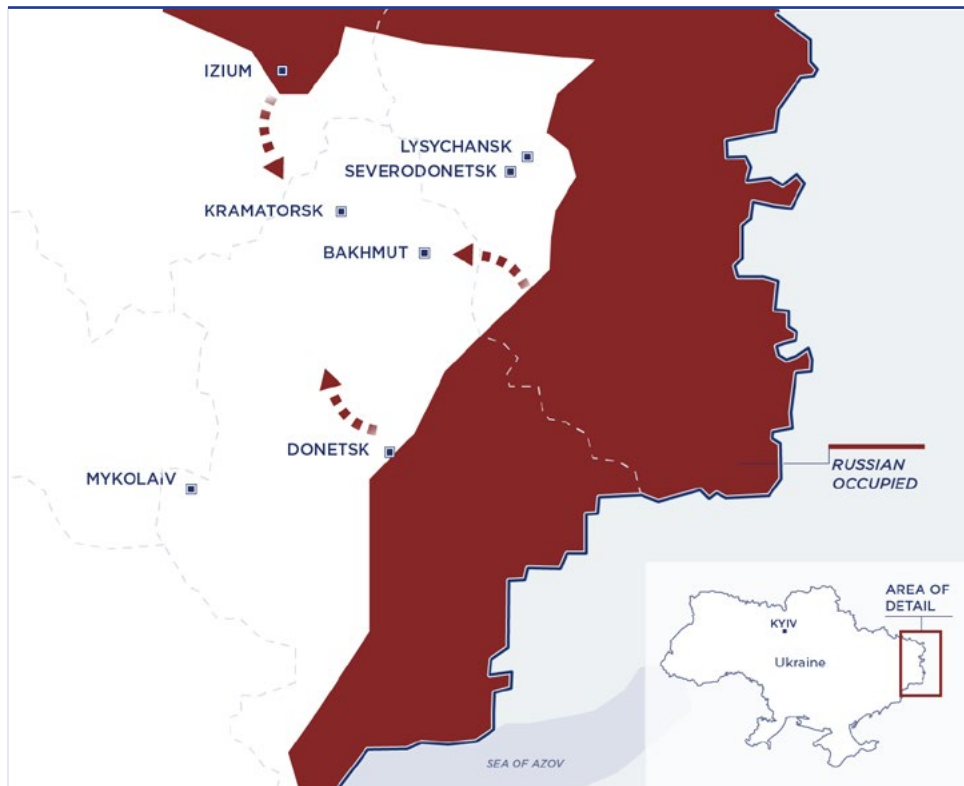
APRIL–AUGUST 2022

After battered and demoralized Russian forces retreated from Kyiv in April, the front lines shifted to the eastern regions of Luhansk and Donetsk.²⁹ As the battlefield contracted, the character of the war shifted from being a war of maneuver to being one of attrition dominated by artillery duels. At this time, Russia had a 12-to-1 advantage in ground-based firepower in Donbas, which enabled its forces to slowly grind forward after devastating an area with tube and rocket artillery.³⁰ To conquer the remainder of Donbas, Russia sought to squeeze Ukrainian defenders simultaneously from

the north, south, and west, including the key cities of Kramatorsk and Slovyansk. Russian forces relocated from Kyiv and massed near Iziium to drive south toward Slovyansk, while troops near the city of Donetsk tried to move north toward Kramatorsk. Russia already controlled most of the territory in Luhansk, and its troops there attacked from the west. By late May, due to slow progress on the Iziium and Donetsk axes, Russia reinforced its attack from the west with troops from Mariupol and focused its efforts on encircling Sievierodonetsk and Lysychansk, the remaining two cities under Ukrainian control in Luhansk.³¹ At the end of June, Russian forces finally seized Sievierodonetsk, and shortly after, in early July, Lysychansk fell.³²

FIGURE 4: RUSSIA'S 2022 OFFENSIVE IN DONBAS

Russian forces withdrew from Kyiv and refocused their operations on Donbas, seeking to attack from the north and south.



For both sides, drones became the principal reconnaissance and target acquisition platform for artillery units and were used at most echelons of the ground forces. Instead of being used as a strike platform, military and commercial drones were primarily used as spotters or forward observers, sent to find time-sensitive targets for engagement by artillery units.³³ At the tactical levels, Ukrainian and, increasingly, Russian troops used commercial or improvised drones.³⁴ Typically, only brigade- and higher-level echelons had fixed-wing military drones, such as the ZALA, Orlan, Furia, or Leleka-100, and they were used primarily for target acquisition.³⁵ Russian forces also used their superior military drone fleet for suppression and destruction of enemy air defense (SEAD/DEAD) missions and consequently gained a degree of air superiority.³⁶ Because of their scarcity and greater cost, MALE drones were only committed in lower-threat environments and were seldom seen on the battlefield.³⁷ Ukrainian TB2s' last major employment was the battle to recapture Snake Island in May and June 2022.³⁸

In general, the airspace near the front lines became more inhospitable, resulting in high losses of all types of drones. In addition to both parties more effectively operating their ground-based air defenses, Russia deployed a very dense network of EW systems in Donbas, which resulted in pervasive jamming of navigation and communications.³⁹ Ukraine also used man-portable EW guns to attrit Russian drones, including the Orlan-10.⁴⁰ A RUSI report estimates that 90 percent of Ukrainian drones used up to this point were destroyed during this period.⁴¹ On average, Ukrainian quadcopters tended

In general, the airspace near the front lines became more inhospitable, resulting in high losses of all types of drones.

to survive for just three flights, while military drones survived for an average of six.⁴² Yet Russian EW forces might have been their drones' own worst enemy. Russian EW tactics did not emphasize deconfliction or discrimination, so while they effectively countered Ukrainian drones, Russian drones also suffered from considerable fratricide.⁴³ To replace drone losses, in July Ukrainian President Volodymyr Zelenskyy launched Ukraine's "army of drones" initiative, which aimed to crowdsource funding for military drones and to spur donations of commercial drones.⁴⁴ The Ukrainian initiative aims to raise \$100 million to buy drones for the Ukrainian

military and train drone operators.⁴⁵ In its first seven months, the program purchased several thousand drones and trained 10,000 drone pilots.⁴⁶ Similarly, the Russian government sought to bolster its military drone production, which the Russian Ministry of Defense had admitted was not meeting the needs of the war in Ukraine.⁴⁷

By midsummer 2022, Russia's offensive in Donbas had stalled.⁴⁸ Around the same time, Ukrainian forces were assimilating one of their first big batches of Western military equipment, including American-made High Mobility Artillery Rocket System (HIMARS) and long-range precision rockets.⁴⁹ This set up the next phase of the conflict, when the Ukrainians would launch their first counteroffensive.

Ukraine's Fall 2022 Offensive

SEPTEMBER–NOVEMBER 2022

Ukraine launched a successful attack to liberate Kharkiv and the west bank of Kherson in fall 2022. Russia's grinding prior offensive in Donbas enabled Ukraine's counterattack by consuming Russian manpower, artillery shells, and drones.⁵⁰ Russia did not have enough forces to defend everywhere, and Ukraine's buildup of forces in Kherson and Zaporizhzhia forced Russian officials to decide whether to prioritize Kharkiv or Kherson.⁵¹ They elected to reinforce Kherson, leaving Kharkiv inadequately defended by a motley collection of understrength and demoralized forces.⁵² Ukraine preceded both offensives with HIMARS attacks. Western nations provided targeting information on Russian logistics nodes, which were hit by Ukraine's precision long-range rockets.⁵³ The HIMARS strikes against ammunition depots reduced the number of shells available to Russian forces, but the Russians quickly adapted and moved their depots farther back, which decreased the impact of the rocket strikes. More than these precision strikes, prior attrition suffered by Russian forces drove Ukraine's successful counteroffensives.⁵⁴

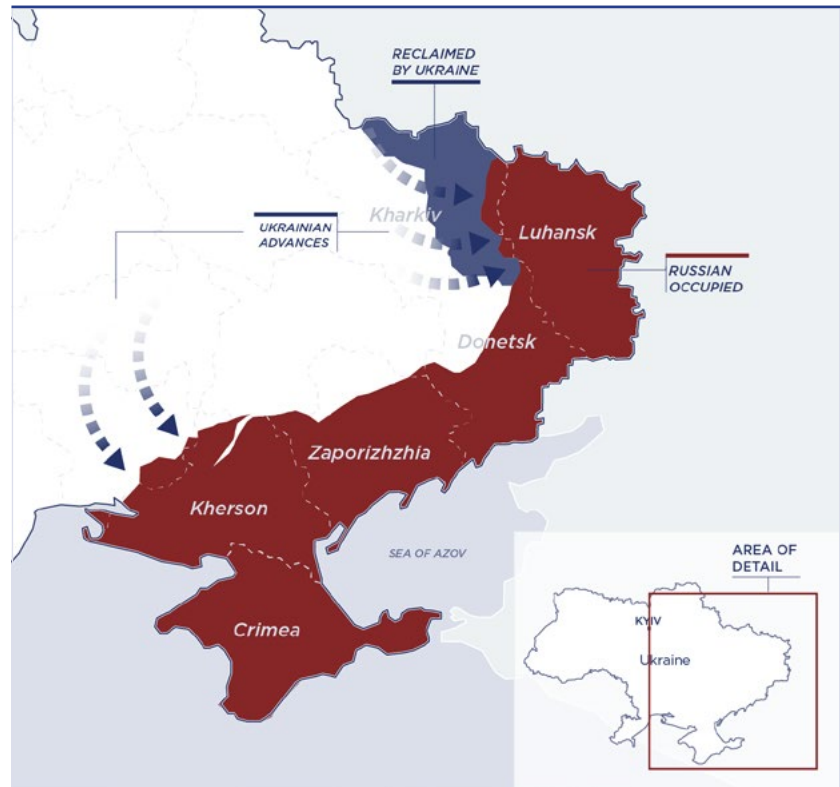
Ukrainian forces quickly penetrated the weakly defended Russian front lines in Kharkiv and outflanked exhausted Russian defenders, who could not effectively respond. Consequently, Ukrainian troops regained 2,300 square miles of territory in 10 days.⁵⁵ Ukraine did not replicate the success of its blitzkrieg in Kharkiv in the Kherson province, where prepared defensive lines were manned by higher-quality Russian

forces augmented by reservists and new recruits.⁵⁶ Fierce Russian resistance made this a grinding offensive where only after extended artillery, rocket, and drone strikes could Ukrainian forces slowly advance village by village.⁵⁷ The Ukrainian offensive in northern Kherson accelerated in early October, and on November 9, Russia announced that its forces were withdrawing to the eastern side of the Dnieper River.⁵⁸ This deliberate retreat represented a humiliating loss, but unlike in Kharkiv, Russian forces had inflicted significant losses on the Ukrainians and withdrew in an orderly fashion, which enabled the Russian forces to consolidate in a more defensible position behind the river.⁵⁹ With the partial mobilization that Russian President Vladimir Putin ordered in September, Russia reinforced its front lines.

During this period, the most important roles for drones remained intelligence and targeting for artillery units. In preparation for the attack in the Kharkiv region, Ukrainian drone teams—called “ochi,” meaning eyes—surveilled the area and compiled a list of Russian high-value targets, including ammunition stores, artillery guns, command posts, and EW systems that Ukrainian artillery units later engaged.⁶⁰ Commercial drones redirected artillery fire that missed its mark and verified that targets were destroyed. Because of a shortage of Orlan-10s, which could not quickly be replaced, Russian forces in Kharkiv increasingly relied on other models of military drones and commercial drones for intelligence and target acquisition.⁶¹ By September, the Russian MOD, which had previously impeded efforts of Russian soldiers to obtain and employ commercial drones, finally began to encourage its troops’ acquisition of these useful off-the-shelf quadcopters and to offer training on how to operate them.⁶² During the battle for Kherson, artillery again dominated and Russian and Ukrainian drones located enemy targets and directed fires.⁶³ Because this was the priority theater, Russian forces in Kherson still had many military drones for ISR and increasingly employed KUB and Lancet-3 kamikaze drones to conduct precision counterbattery attacks.⁶⁴ The Ukrainian troops also used their drones for direct attack, often dropping weapons on camouflaged Russian infantry vehicles or tanks.⁶⁵

FIGURE 5: UKRAINE’S FALL 2022 OFFENSIVE

Russian forces anticipated Ukrainian counterattacks in Kherson and Kharkiv but elected to send reinforcements to Kherson, leaving Kharkiv with thin defenses.



Map adapted from “Maps: Tracking the Russian Invasion of Ukraine,” *The New York Times*, June 9, 2023, <https://www.nytimes.com/interactive/2022/world/europe/ukraine-maps.html>.

Russia’s Winter 2023 Offensive

JANUARY–MAY 2023

After Ukraine’s fall offensive, the conflict settled into a period of fixed front lines and attrition warfare punctuated by efforts by both parties to break out of the stalemate. Russia attempted to seize the initiative in January 2023 by launching a much anticipated offensive in Donbas that sought to envelop and capture Bakhmut.⁶⁶ Russian Wagner units attacked Soledar and seized the small mining town just north of Bakhmut.⁶⁷ Soledar was the first city Russia had taken since July 2022, but conquering the city required committing significant manpower and accepting high casualty numbers.⁶⁸ Soledar ended up being one of few successes as Russian attacks faltered elsewhere due to a lack of quality forces, experienced leaders, and artillery ammunition.⁶⁹ By April 2023, the Russian counteroffensive had petered out with paltry territorial gains, with the exception of Bakhmut, which was secured in May.⁷⁰

Both sides sustained significant losses during this period. Russia's leadership seemed willing to continue the costly offensive mainly to prolong the war in the belief that Russia would outlast Kyiv and its Western supporters in a protracted attritional war.⁷¹

By early 2023, small commercial quadcopters had become ubiquitous, erasing Ukraine's initial 3-to-1 advantage in tactical drones.⁷² While the Russian Ministry of Defense was slow to catch up, Russian troops had quickly realized the utility of commercial quadcopters and volunteer groups had emerged to provide frontline soldiers with drones and the necessary training.⁷³ Moreover, the type of commercial drones preferred began to change as troops on both sides increasingly sought out advanced models with thermal cameras that could be used on night missions.⁷⁴ As other weapons were depleted, combatants increasingly relied on kamikaze drones for precision strikes. Russia had an advantage in military kamikaze drones, but Ukrainian forces developed creative new ways to use commercial racing or FPV drones in kamikaze strikes.

Ukraine's Summer 2023 Counteroffensive

JUNE 2023–SEPTEMBER 2023

Russian forces used the winter and spring to heavily fortify their front lines, especially in the south. The dense network of layered Russian defenses included overlapping minefields, concealed and hardened machine gun and antitank positions in the tree lines, concrete reinforced trenches, antitank trenches, and rows of concrete barriers known as dragon's teeth.⁷⁵ Russia's heavily entrenched defenses ensured that any Ukrainian effort to breach the lines and reclaim territory would be challenging and costly. In preparation for this effort, Western nations rushed additional arms to Ukraine and trained Ukrainian forces in combined arms operations—which entails simultaneously employing different types of capabilities to produce a greater effect. In addition to howitzers and artillery shells, the West provided new heavy weapons, including Leopard and Challenger tanks and Bradley fighting vehicles.⁷⁶

Ukraine's summer counteroffensive began on June 4 and had three major axes: the main focus was attacking Orikhiv, the second was Velika Novosilka, and the third was counterattacking in Bakhmut.⁷⁷ Despite securing a number of towns near Velika Novosilka in the second week and making gains around Bakhmut, progress quickly stalled.⁷⁸ Early on, the Ukrainians conducted a mechanized assault on the Orikhiv axis in the attempt to

During the Ukrainian counteroffensive, drones of all types saturated the airspace, limiting maneuver near the front.

achieve a rapid breakthrough, but this proved too costly. Ukrainian vehicles quickly drew Russian artillery and antitank fires, often cued by drones. Many other Ukrainian vehicles ran into mines and then were picked off by artillery.⁷⁹ After suffering notable losses with few territorial gains, the Ukrainians adjusted their tactics and fell back onto a more practiced and deliberate approach: seeking to significantly attrit Russian forces with artillery and long-range strikes before slowly and incrementally advancing in platoon- and company-sized units.⁸⁰ At the time of this writing, the Ukrainian offensive continued but had not made major territorial gains.⁸¹ The fighting was producing significant attrition on both sides, but it was unclear which side was taking more losses.⁸²

During the Ukrainian counteroffensive, drones of all types saturated the airspace, limiting maneuver near the front. Because drone-directed artillery fire has been so lethal, each side sought various ways to defeat the other's drones and to use drones to find their opponent's counterbattery radars, howitzers, and rocket launchers. The drone-counterdrone competition was fast-paced with quick adaptations, but given the sheer number of drones, it was also increasingly driven by cost considerations.⁸³ Ukrainian forces continued to rely on drones as spotters for ground-based fires but had to adapt their tactics, only flying drones when they found EW gaps and frequently changing radio frequencies to evade Russia's layered EW systems.⁸⁴ They also increasingly experimented with drones made from foam or plastic that are less likely to be seen by Russian radars and, if detected and lost, are cheap enough to be easily replaced.⁸⁵

The other cheap drone that proliferated was the FPV kamikaze because it offers an extremely inexpensive precision strike capability when operated by skilled pilots.⁸⁶ Because FPV drones are very fast and highly maneuverable, they can run down and accurately hit mobile targets, but piloting these drones requires more skill and training than does a traditional quadcopter.⁸⁷ By June, Russian forces had emulated the Ukrainians and regularly were employing commercial or DIY racing drones to run down Ukrainian vehicles and troops.⁸⁸ Ukrainian and Russian volunteers produced tens of thousands of cheap FPV drones a month as these one-way drones were rapidly being expended. FPV drones provide an affordable way of attacking mobile targets, especially people

and fast-moving vehicles.⁸⁹ But the FPV drones miss more often than not. Even if they find their mark, they might not critically damage, let alone destroy, a hardened vehicle because they carry relatively small payloads. Nevertheless, they are another plentiful weapon that makes the battlefield in Ukraine extremely lethal.

The omnipresent Russian military and commercial drones made it difficult for Ukraine to mass forces, break through defense lines, and exploit advances. Russia's defense industry had responded to the increased demand and increased production of ISR drones, such as the Orlan-10 and ZALA, as well as Lancet-3 kamikaze.⁹⁰ Ukraine did not have enough air defenses to defend everywhere and sought to preserve these critical weapons by keeping them in safer locations in their rear areas. Even when Ukrainian SAMs could have shot down an Orlan-10, they often did not, preferring not to expend a scarce and expensive interceptor on a much cheaper drone that Russia could easily replace.⁹¹ Consequently, largely uncontested Russian drones provided intelligence on Ukrainian force positions behind the front lines.⁹² Moreover, Russian

troops have effectively coordinated ISR drones, kamikaze drones, and artillery fire to engage Ukrainian vehicles that approach the front.⁹³

The Deep Fight: Strategic Strikes

FEBRUARY 24, 2022–SEPTEMBER 2023

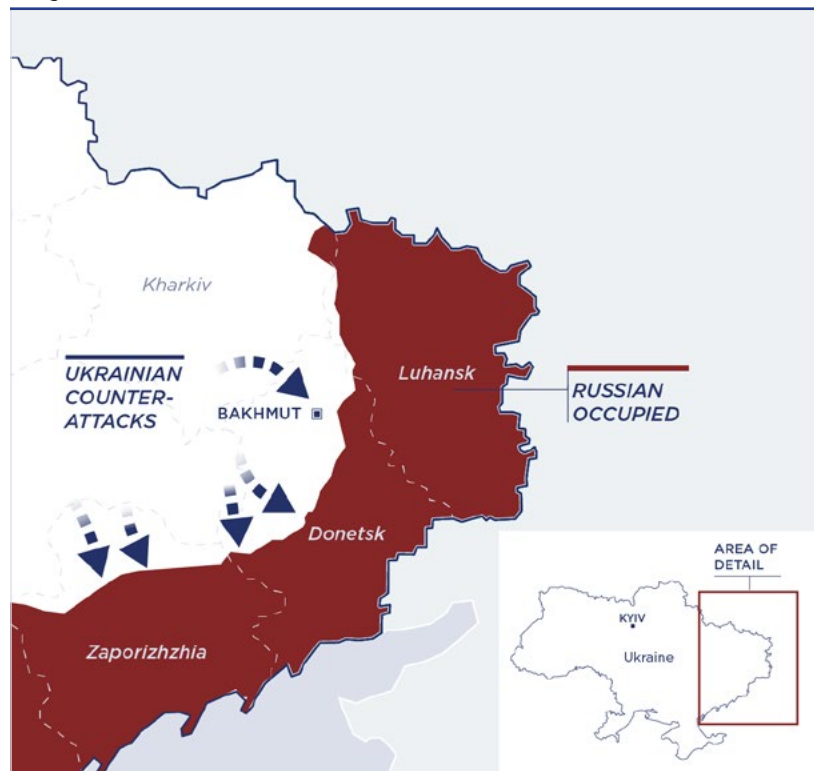
In parallel to the close fight on the front lines, there was a largely separate ongoing battle of strategic strikes between Moscow and Kyiv. Strategic attacks are those that, independent of what is happening at the operational level, weaken an adversary's will or ability to fight and therefore may achieve overarching political goals.⁹⁴ Historically, strategic target sets include deep military bases, the defense industry, enemy leadership, and critical economic targets, such as oil or energy. In the first few phases of the war, Russia had a monopoly on strategic attacks because of its large stockpile of missiles. Over time, Ukraine eroded but did not eliminate Russia's advantage in this space. Drones became the weapon of choice for deep strikes because of the lack of alternatives.

Russia has launched long-range air and missile attacks since the first day of the invasion. Strikes initially focused on Ukrainian military targets, then emphasized defense industry and communications infrastructure target sets, and by spring 2022 were aimed primarily at rail infrastructure and fuel storage and production.⁹⁵ By that point, Russia's stockpiles of preferred long-range munitions were reportedly running low, leading it to repurpose surface-to-air and antiship missiles for land attacks.⁹⁶ These strikes became increasingly indiscriminate and resulted in a growing number of Ukrainian civilian casualties.⁹⁷

In response, Ukraine began an effort to develop an indigenous capability to strike targets within Russia with long-range drones.⁹⁸ This initiative was shrouded in mystery, and typically, Kyiv denied responsibility for the attacks in Russia. Consequently, it was often difficult to determine whether an explosion in Russia was executed by long-range drones or Ukrainian special forces or was simply an accident. Yet over time, it has become clear that adapted commercial or homemade kamikaze drones played an increasingly important role and enabled Ukraine to hit targets deep inside Russia.

FIGURE 6:
THE THREE AXES OF ATTACK IN UKRAINE'S SUMMER 2023 OFFENSIVE

Ukrainian forces counterattacked in Zaporizhzhia, Donetsk, and Bakhmut but made few gains in the first few months.



Map adapted from "Maps: Tracking the Russian Invasion of Ukraine," *The New York Times*, June 9, 2023, <https://www.nytimes.com/interactive/2022/world/europe/ukraine-maps.html>.

The first evidence that Ukraine was using long-range kamikaze drones appeared in the summer of 2022. In June, two Ukrainian drones struck a Russian oil refinery in Novoshakhtinsk in the Rostov region adjacent to the border. One analysis suggested that Ukrainians used a Chinese Skyeye 5000, a commercially available drone that costs \$5,000 to \$10,000 on Alibaba, and modified it for a kamikaze mission.⁹⁹ By August, the focus of Ukraine's long-range attacks shifted from nearby targets across the Russian border to Crimea, which Russia had illegally annexed in 2014.¹⁰⁰ As a spokesperson for Ukraine's southern command, Natalia Gumenyuk, explained, "Ukraine's armed forces are carrying out activities to liberate our occupied territories." She said they exclusively struck military targets, but not "on the territory of the Russian Federation," and she emphasized that "Crimea is Ukraine."¹⁰¹ Russia claimed that a Ukrainian drone attack against its Black Sea Fleet headquarters in Sevastopol forced it to cancel its Navy Day celebration on August 1.¹⁰² On August 9, unexplained explosions at Russia's Saki air base on the Crimean Peninsula significantly damaged or destroyed at least 10 aircraft.¹⁰³ Later in August, Russia's Black Sea Fleet headquarters was again targeted, this time by another weaponized Chinese-made drone, which crashed into the roof of the headquarters building.¹⁰⁴

While Ukraine experimented with long-range kamikaze drone attacks, Russia purchased Iranian Shahed-136 drones to augment its dwindling stockpiles of long-range missiles and uncrewed systems.¹⁰⁵ Russia's first reported Shahed-136 strategic strike was in September 2022, when it fired the kamikaze drones at Odesa for three consecutive days, killing several civilians and hitting an administrative building.¹⁰⁶

The deep-strike war escalated in October 2022. On October 7, Ukraine launched a kamikaze drone attack 140 miles north of the Ukrainian border at Shaykovka air base and damaged two Russian Tu-22M Backfire bombers.¹⁰⁷ On October 8, a large explosion damaged the Kerch bridge linking Crimea to Russia. The Ukrainian domestic intelligence agency later claimed responsibility for the truck bomb attack that destroyed the bridge.¹⁰⁸ Russia began an extended air campaign aimed at Ukrainian's power grid on October 10. Moscow launched a massive missile and drone barrage against critical

infrastructure in more than 10 Ukrainian cities, including those deep in western Ukraine.¹⁰⁹ The attack consisted of 95 missiles and at least 21 Shahed drones and marked a new concerted effort to make ordinary Ukrainians suffer by depriving them of electricity and heat during the cold winter months.¹¹⁰

Putin claimed the attack was solely in retaliation for the destruction of the Kerch bridge, but evidence shows that Russia had planned to inflict pain on Ukrainian citizens by turning out the lights and turning off the heat in Ukraine before the bridge explosion.¹¹¹ Over the next several months, Russia regularly launched complex attacks that included cruise and ballistic missiles and kamikaze drones against Ukraine's energy grid.¹¹² Despite Russia's damaging or destroying nearly 40 percent of Ukraine's energy infrastructure and causing rolling blackouts, the Ukrainian electrical grid did not collapse, nor did the Ukrainian public's will to fight decline.¹¹³ The West provided additional air defenses to shoot down incoming drones and missiles.¹¹⁴ Additionally, Ukrainian forces refined their tactics and developed innovative solutions for defeating the long-range strikes. For instance, Ukraine developed a crowd-sourced smart phone application for early detection of incoming

missiles and drones, providing defenders time to get in position to shoot down the drone or missile before it reached its target.¹¹⁵

This quickly became an attritional battle as Russia sought to exhaust Ukrainian air defense interceptors

before it ran out of its long-range strike weapons. Over time, the salvo size and frequency of Russian strategic attacks declined as its weapons inventory ran low.¹¹⁶ Concomitantly, the Ukrainian air force's rate of intercepting the smaller attacks of incoming missiles and drones improved, but its interceptor stockpiles ran low.¹¹⁷ Neither side was completely exhausted, and this strategic battle was still underway at the time this report was written.

As Russian strikes on Ukraine's cities continued, Ukraine conducted novel drone attacks against deep targets in Russia and Crimea. On October 29, 2022, Ukraine launched a coordinated air and maritime attack against the naval base at Sevastopol. Nine aerial drones and seven improvised kamikaze drone boats participated in the attack against the Russian Black Sea Fleet flagship the *Admiral Makarov*.¹¹⁸ Another drone boat damaged the oil terminal in Russia at Novorossiysk in November.¹¹⁹ In

This quickly became an attritional battle as Russia sought to exhaust Ukrainian air defense interceptors before it ran out of its long-range strike weapons.

December, Ukrainian drone operators turned their sights on the Russian bombers that had been conducting missile strikes against many Ukrainian cities. Ukraine armed several Tu-141 Strizh 1970s-era Soviet reconnaissance drones and sent them on kamikaze strike missions against two Russian bomber air bases.¹²⁰ Two Russian bombers were reported slightly damaged at Engels airfield, 300 miles inside of Russia, while three military personnel were killed and four wounded in the strike on Dyagilevo air base.¹²¹

By mid-2023, Ukraine's commitment to building long-range kamikaze drones began to bear fruit, and there has been a significant uptick in drone attacks against Russia. The BBC tabulated 190 attacks in Russia and Crimea from January through September 2, 2023.¹²² *The New York Times* reported that the number of kamikaze drone strikes into Russia from May through July alone was double the total for all of 2022.¹²³ These attacks used a diverse array of drones against a range of targets, including oil fields, air bases, and transportation infrastructure. A growing number of Ukrainian drone strikes targeted Moscow, including two drones that hit the Kremlin in May and strikes against skyscrapers in central Moscow in July.¹²⁴ Some were launched within Russia, such as the quadcopters that damaged bombers at Soltsy-2 air base near Novgorod in August 2023.¹²⁵

Ukraine has also made extensive use of its expanding number of long-range drones. The UJ-22, the Bober ("Beaver"), the Morok ("dark spirit"), and the Mugin-5 drone were identified in these attacks.¹²⁶ Russia claimed to have defeated a large Ukrainian drone salvo at Crimea in August, shooting down 14 of the incoming kamikazes and using jammers to disable the other four.¹²⁷ The largest Ukrainian drone attack, as of the writing of this report, was on August 30, when Ukrainian drones struck at least six locations in Russia and Crimea.¹²⁸ One of these strikes was against Pskov air base, 370 miles from Ukraine, and reportedly damaged at least four Russian military cargo aircraft.¹²⁹

Drones enabled Ukraine to take the war home to Russia and impose costs on Moscow. The intended impact, however, was likely psychological, bolstering Ukrainian morale and convincing the Russians that the "special operation," as Putin dubbed the war in Ukraine, was not worth the cost. As Zelenskyy noted: "Gradually, the war is returning to the territory of Russia – to its symbolic centers and military bases," which "is an inevitable, natural and absolutely fair process."¹³⁰

Types of Drones

This section provides more detail on the types of drones and the tactics and countermeasures used by Ukrainian and Russian forces. It provides an overview of the major military, commercial, and kamikaze drones used by each party, as well as Ukrainian maritime drones. It also covers the tactical battle networks and communications systems used to control the drones.

Military Drones

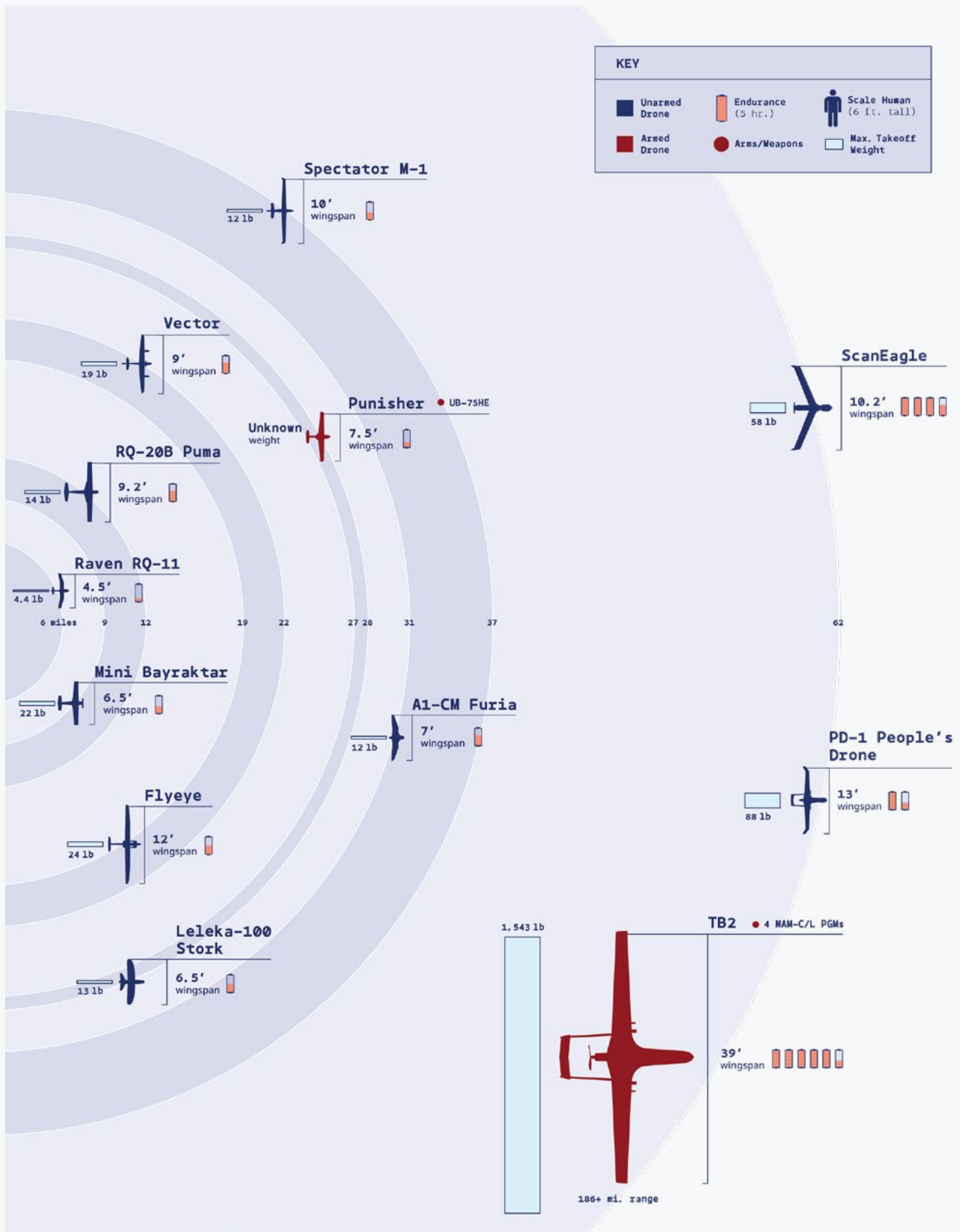
Both the Ukrainians and Russians have used military drones extensively, but not the military drones that many might expect. The image that often springs to mind for military drones is large, high-flying, armed drones, such as the Bayraktar TB2 or the Russian Orion, but MALE drones have played a relatively small role in this war. The most common and important Russian and Ukrainian military drones have been smaller, recoverable fixed-wing systems that are integrated with ground units and used primarily for surveillance, target acquisition, and battle damage assessment (BDA). Like all drones, military drones have also been used for information warfare and propaganda purposes.

UKRAINIAN MILITARY DRONES

Ukraine has a diverse fleet of indigenously developed and internationally procured military drones. Far more important has been Ukraine's mixed fleet of smaller drones that have provided vital intelligence to ground forces and directed artillery, rocket, and mortar fire. Figure 7 lists the major Ukrainian military drones.¹³¹ As is evident from this list, most Ukrainian military drones cannot fly more than 50 miles or stay aloft over 10 hours. They, therefore, are tactical systems that provide Ukrainian ground forces with previously unavailable levels of local situational awareness and improve the accuracy of indirect fires.

At the beginning of the war, the Ukrainian drone that captured headlines and the public imagination was the Turkish-built TB2.¹³² The TB2 was one of the few armed military drones that Ukraine had at the war's start, and the only one that carried precise laser-guided bombs. Ukraine had 24 TB2s when the war began.¹³⁴ During the first days of the war, social media sites were littered with viral videos of TB2 attacks on Russian forces, including columns of Russian vehicles, air defenses (likely nonoperating), trains transporting fuel, and infantry fighting vehicles.¹³⁵ Because of the strict ROE that prohibited Russian forces from launching SAM interceptors for fear

FIGURE 7: UKRAINIAN MILITARY DRONES¹³²



of hitting Russian planes, TB2s patrolled the skies unmolested, enabling them to effectively interdict invading Russian forces.¹³⁶

TB2s offered the Ukrainians an important capability in the early weeks of the war. These drones supplemented manned Ukrainian jets and provided a limited precision ground-attack capability, but their success was entirely contingent on Russia's decision not to operate its air defenses. Oryx, an open-source intelligence website, tallied all the successful TB2 strikes, which included five Russian tanks, eight armored fighting vehicles, nine pieces of artillery, 15 SAMs, two anti-aircraft guns, 10 helicopters, seven ships, two fuel trains, 29 other vehicles, four command and communications posts, and six other targets.¹³⁷ Given the hype and Turkish propaganda surrounding this drone, these kill numbers are likely inflated, but they still indicate that the TB2s offered the Ukrainian air force a ground strike capability that did not endanger its pilots and helped to attrit Russian forces in those critical first few days and weeks.

About 10 days into the war, when Russia began to activate its air defense and EW systems, TB2 losses began to appear.¹³⁸ The aircraft has large electromagnetic and radar signatures and is vulnerable to Russian short- and medium-range air defenses, especially those now attuned to the drone threat. Over this period, Ukrainian forces became more careful about when they employed TB2s and increasingly committed them only in favorable circumstances.¹³⁹ The TB2s were too expensive to put at risk and clearly not survivable in the heavily contested front lines. Although Ukrainian air force TB2 pilots adjusted their tactics and began flying at lower altitudes and then popping up for strikes to reduce the chances of detection, most of the drones were shot down in March 2022.¹⁴⁰

One of the last high-profile TB2 missions occurred in the spring and summer of 2022 over Snake Island in the Black Sea. The TB2s

could contribute to the Ukrainian counterattack on Snake Island because in April Ukrainian antiship cruise missiles sank the Russian Black Sea Fleet's flagship, the *Moskva*.¹⁴¹ Consequently, the threat of Ukrainian cruise missiles pushed Russian ships farther from the shore, thinning the air defenses over the island and opening a window for the TB2s to operate.¹⁴² The TB2s picked off Russian Raptor boats carrying supplies and destroyed the short-range SAM protecting the island.¹⁴³ With the SAM threat eliminated, the long-endurance TB2s could conduct lengthy patrols around the island, watching

for further Russian attempts to supply the outpost, and then interdict any attempted reinforcements, which included a Russian transport helicopter and a Serna-class landing craft.¹⁴⁴ Despite these interdiction strikes, Russia eventually landed reinforcements on the island. But the Ukrainian harassment of the small island continued unabated. At this point in the battle, for unknown reasons, Ukrainian manned aircraft strikes assumed center stage, while TB2s filmed the attacks. Finally, on June 30, Russia withdrew.¹⁴⁵

In contrast to the TB2s, Ukrainian smaller military drones, such as the Leleka-100, the Furia, and the PD-1, have been used continuously throughout the war in the close fight. Although Ukrainian military drones are fewer than Ukrainian quadcopters, they offer more capability than most commercially available models because they are often hardened against electronic attack and have extended ranges, more endurance, and better sensors. Their most important missions are finding enemy targets, providing accurate target data to artillery units, adjusting fires, and assessing whether the target is destroyed. Very few of Ukraine's military drones are armed.

This has been a war in which ground-based firepower working in concert with drones often drives battlefield outcomes. By directing artillery fire, drones increase the accuracy of strikes and enable Ukrainian forces to fire fewer shells to destroy a target. One example of the deadly effects of drones and howitzers comes from early in the war, in March 2022, when a large column of Russian forces approached Kyiv.¹⁴⁶ As Russia's offensive slowed due to harassing attacks from Ukrainian special forces armed with small drones, larger Ukrainian units screened the flanks of the advancing Russians, pinning

them down with artillery fire.¹⁴⁷ Ukrainians dubbed this stretch of road the "highway to hell" because so many Russian vehicles were destroyed. Leleka-100 drones searched for the enemy

and passed target coordinates via Starlink terminals to Ukrainian artillery units armed with 152mm guns.¹⁴⁸ The Russian troops could not recover from the drone-directed artillery strikes and eventually retreated.

In another famous battle, in May 2022, Flyeye drones participated in an attack against a Russian unit crossing the Seversky Donets river on a pontoon bridge.¹⁴⁹ The Flyeyes watched the Russian troops traverse the bridge and then directed artillery to destroy the bridge, trapping the Russian forces on the Ukrainian side of the river, where they were eliminated.

About 10 days into the war, when Russia began to activate its air defense and EW systems, TB2 losses began to appear.

Compared with commercial drones, military drones such as the Furia and Flyeye offer additional capabilities.¹⁵⁰ Both the Furia and Flyeye have thermal cameras and could be used to find and target Russian forces at night when they are more likely to move around. These drones also have better battery life and can patrol larger areas for hours instead of minutes. These systems are usually remote controlled, but some military drones, including the Furia, have the ability to fly autonomously on preprogrammed routes.¹⁵¹ Despite Ukraine's public-private "army of drones" initiative, which has tried to acquire additional military drones for Ukrainian forces, this is an area where Russia retains an edge.

RUSSIAN MILITARY DRONES

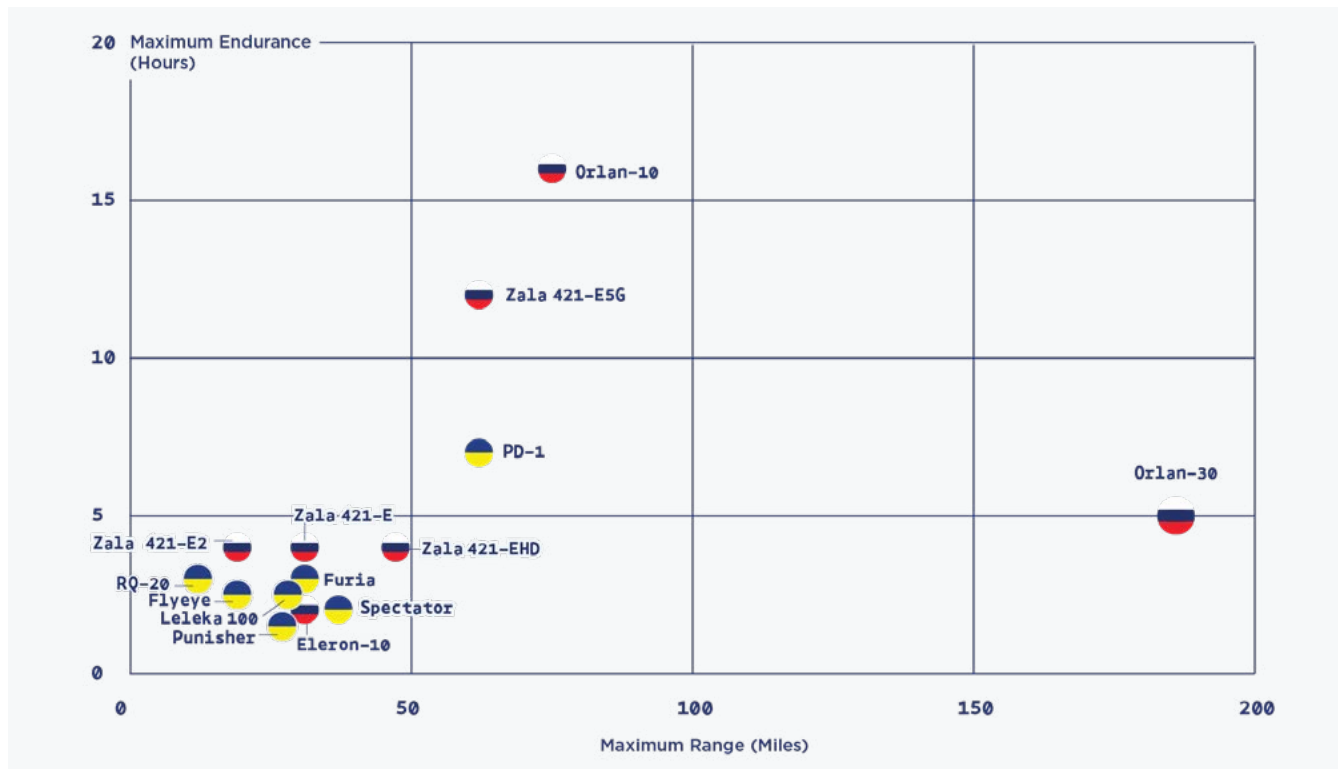
Russia has a robust fleet of military drones that includes a few armed MALE drones and a larger number of smaller, mainly unarmed, drones that are controlled by ground forces. In the first few days of the war as Russian forces raced forward, they did not employ many military drones, even though the Russian military had prioritized investment in uncrewed and autonomous systems.¹⁵² That quickly changed over the next month. Russia's military drones proved an enduring strength and area

where Russian forces had a comparative advantage over Ukraine's less numerous and capable military drone fleet.

By early March 2022, Russian forces were flying their drones and suffering notable losses from Ukrainian air defenses.¹⁵⁴ Russia had long-endurance armed drones such as Forpost-R and Orion, which flew some combat operations.¹⁵⁵ There is a video of an Orion MALE drone dropping Kornet-D antitank weapons on a Ukrainian T-72 tank in April 2022.¹⁵⁶ According to Oryx, Orion drones damaged at least three Ukrainian tanks and seven other vehicles, while Forpost-R drones damaged seven Ukrainian vehicles.¹⁵⁷ Yet because of the small size of the fleets of long-range armed drones and their vulnerability to Ukrainian air defenses, Russia appears to have employed them sparingly.¹⁵⁸

Instead, most Russian military drones are shorter-range, smaller ISR systems that supported the Russian army's reconnaissance strike complex by collecting intelligence, rapidly acquiring targeting data, and passing that information to artillery units that then engaged the target.¹⁵⁹ Russian operational concepts aim to achieve battlefield information dominance and use this information superiority to close kill chains faster than their enemy. Military drones are the critical sensors

FIGURE 8: COMMON UKRAINIAN AND RUSSIAN MILITARY DRONES USED BY GROUND FORCES¹⁶³



In general, Russian military drones have longer ranges than the military drones embedded with Ukrainian ground forces. This chart excludes MALE and HALE drones that are operated by air forces.

and communications nodes that gather and distribute information across ground forces using Russia's Strelets tactical command and control system.¹⁶⁰ The Strelets system integrates feeds from multiple drones and other sensors into a computer that helps to accurately direct fires.¹⁶¹ Russian forces have a wide variety of military drones with greater range and endurance than those of Ukraine. This means Russian drones can cover larger areas and fly much longer missions, providing Russian forces with broader and more persistent surveillance. While Russian forces struggled to execute the idealized version of the reconnaissance strike complex in Ukraine, they improved over time and military drones did enable responsive, dynamic targeting of enemy forces by artillery units. With an organic drone, Russian units could accurately fire on a newly detected enemy target in three to five minutes.¹⁶²

The Orlan-10 is the most common Russian military drone employed in Ukraine and plays a critical role in the reconnaissance strike complex. At \$87,000 to \$120,000 per system, the Orlan-10 is a relatively inexpensive but capable military drone that flies above the reach of MANPADs on missions out to 75 miles and carries several different payloads.¹⁶⁴ While it can be equipped with weapons, this is not common and most Orlan-10s in Ukraine are unarmed.¹⁶⁵ Often, multiple Orlan-10s fly over an area at once, because each Russian regional commander has an orbit and each artillery brigade commander has several Orlan-10 orbits.¹⁶⁶ For example, during an attack, Russia ideally would have multiple Orlan-10 drones, with each monitoring a different part of the battlespace, providing real-time information about the situation back to headquarters, facilitating maneuver and enabling responsive fires on emergent enemy targets.¹⁶⁷

Russia's many different ZALA 421-E variants tend to be slightly smaller than the Orlan-10 but provide another sophisticated ISR capability that can reach out 16 to over 60 miles and fly missions that last several hours. When combined, the Orlan-10 and ZALA 421-E variant fleets provide Russian forces with a dense layered network of surveillance drones that can watch over the depth of the battlespace and help coordinate artillery and kamikaze drone strikes on Ukrainian targets.¹⁶⁸

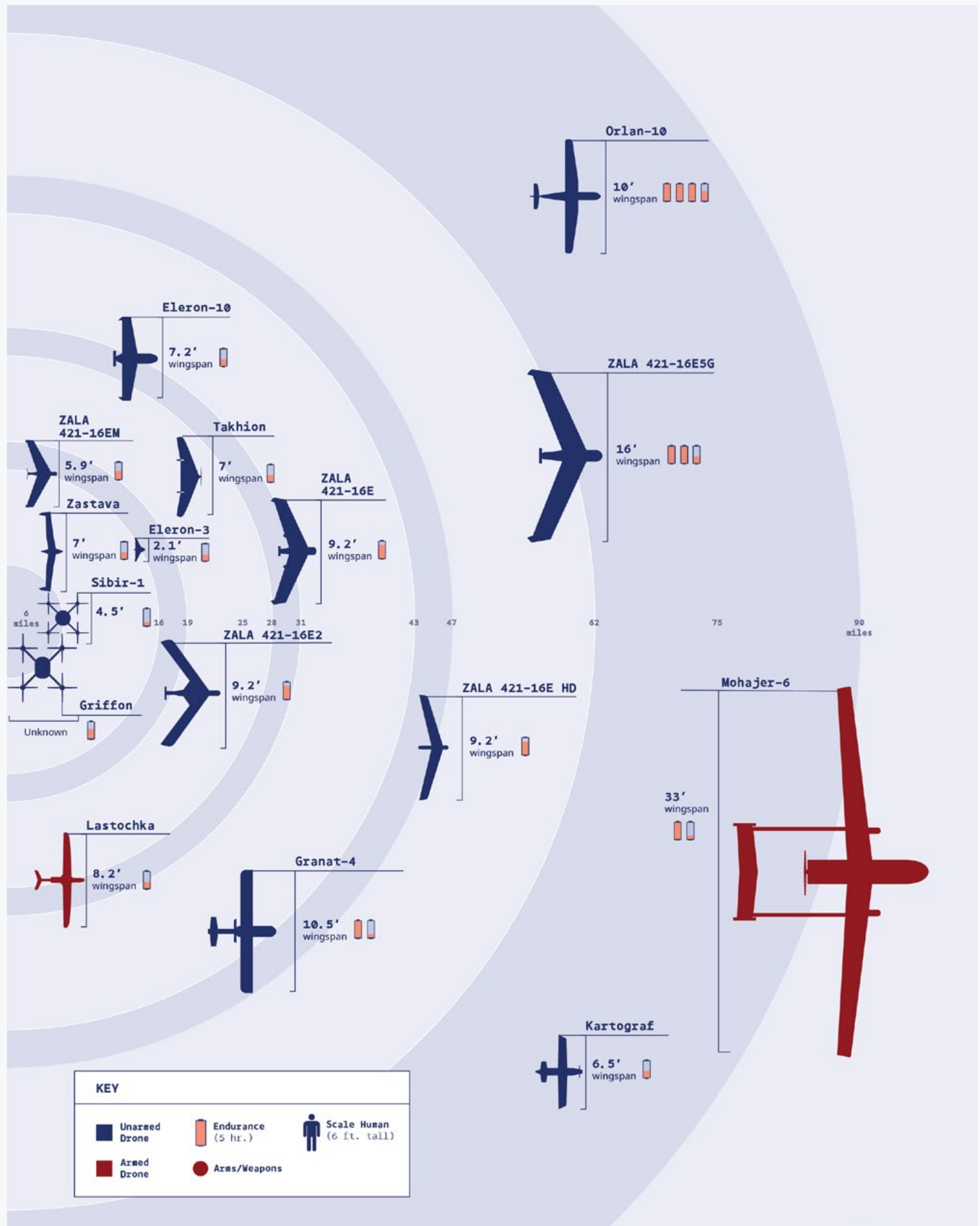
In addition to general reconnaissance and targeting, Russian drones played an important role in SEAD and DEAD operations. Although some Orlan-10s and Orlan-30s (another variant) were lost while hunting Ukrainian air defenses, they played a vital role in destroying many Ukrainian SAMs by finding the air defense radars and launchers, marking them for strike,

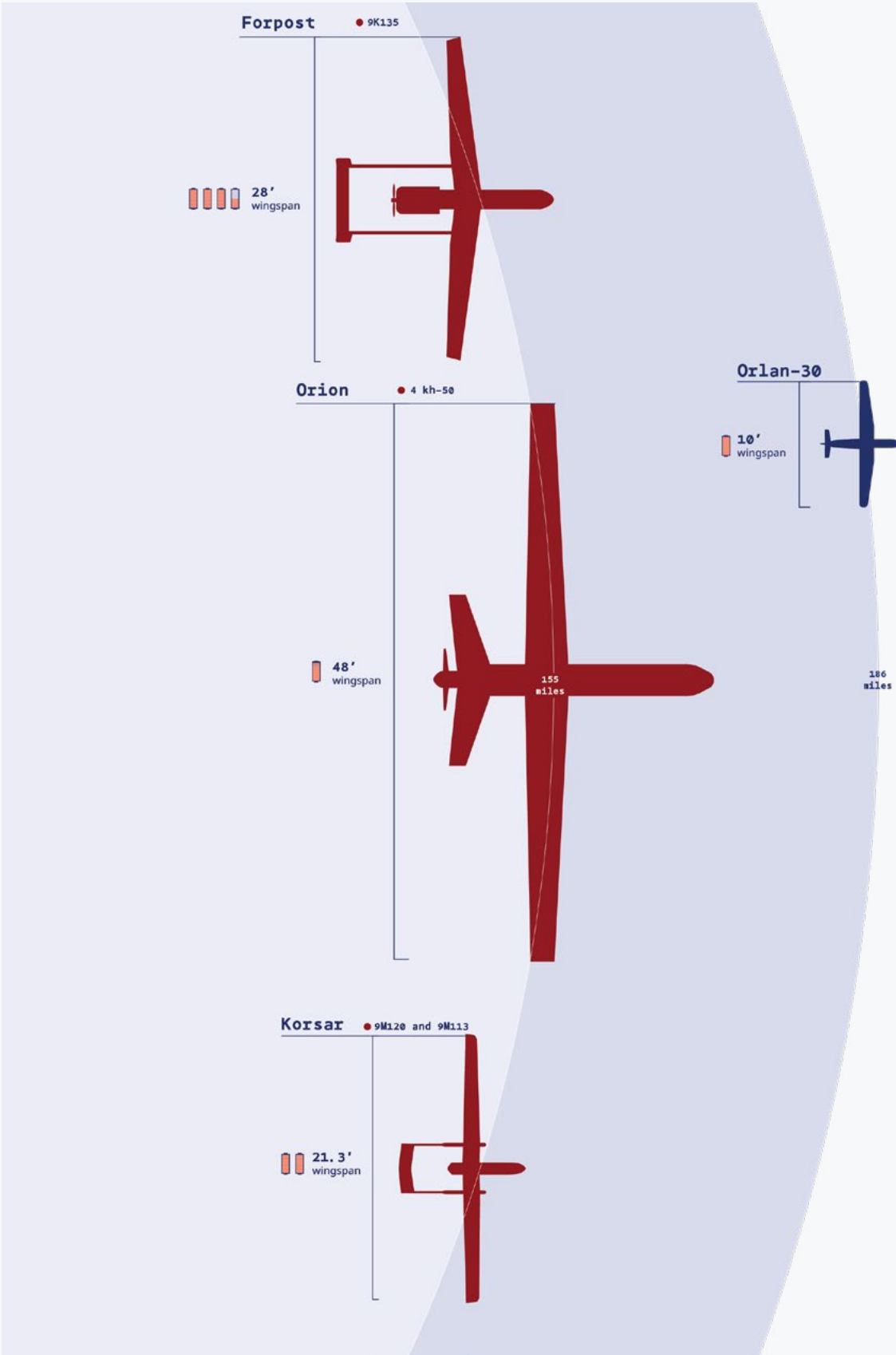
and then passing that information to artillery units.¹⁶⁹ Additionally, an Orlan-10 variant armed with EW payloads, called the Leer-3, has been used in jamming and SEAD missions.¹⁷⁰ For SEAD missions, Leer-3s would fly at high altitudes to bait Ukrainian SAMs to shoot, revealing their positions. The Leer-3 might survive because of its ability to jam air defense interceptor proximity fuses. A lower-flying Orlan-10 equipped with an electronic intelligence payload would gain targeting coordinates on the SAM that fired, while another Orlan-10 with an electro-optical sensor would designate the launcher as a target and pass this information to an artillery battery.¹⁷¹ This was not a swarm in the sense that the drones were autonomously collaborating or even controlled by one operator, but the combination of a Leer-3, several Orlan-10s, and artillery was effective. To preserve their short- and medium-ranged SAMs in the face of the drone and artillery threat, the Ukrainians moved them away from the front lines, opening up the airspace for largely uncontested Orlan-10s to provide the Russians with real-time intelligence on the disposition of Ukrainian forces and their activities.¹⁷²

The Orlan-30 can fly farther than the Orlan-10 and is equipped with a laser designator rangefinder, enabling it to illuminate targets for precision strikes.¹⁷³ In fall 2022, for example, Russian Orlan-30s illuminated Ukrainian howitzers that were then hit with Krasnopol precision-guided 152mm round shells.¹⁷⁴ To ration artillery shells, some Russian forces have worked to lessen their traditional reliance on mass fires in favor of more precise salvos aided by drones, which makes the Orlan-30s particularly valuable.¹⁷⁵ Given their longer range, Orlan-30s also have been observed conducting battle damage assessment for Iskander missile strikes and providing long-endurance overwatch to help cue other drones, such as the cheaper and shorter-range ZALA 421-16E5.¹⁷⁶ In this situation, the Orlan-30 would first detect a possible target, then send the ZALA to validate the target and obtain precise coordinates, which would then be passed to an FPV drone operator who would crash a kamikaze drone into a target.¹⁷⁷

Throughout the war, Russian forces have generally maintained more persistent coverage and visibility above and beyond Ukraine's front lines because of their large fleet of military drones.¹⁷⁸ While both Ukraine and Russia have made extensive use of military drones throughout this war, in many respects they have been overshadowed by the cheaper and more plentiful commercial or DIY drones that have proliferated at all echelons.

FIGURE 9: RUSSIAN MILITARY DRONES¹⁵³





Commercial Drones

The widespread use of commercial off-the-shelf (COTS) drones by both parties has differentiated this war from others.¹⁷⁹ Commercial drones are less capable than many larger military systems, but they have provided Russian and Ukrainian forces with an affordable and easy to use tactical ISR capability that did not previously exist. Commercial drones have become indispensable for ground force operations and saturate the front lines.¹⁸⁰ They are essentially performing roles a person could fill as a reconnaissance scout or an artillery spotter, but they reduce the danger to the operator and can be easily replaced. Equally importantly, they complete these missions better than a person could. Drones can cover more ground faster than a human scout on foot who would have to move slowly to try to remain concealed. Drones can also reconnoiter exposed areas such as long stretches of roads, where a person on foot or a car would be at risk. Also, because drones are operating at a higher altitude, their view is not impeded by many ground obstacles. Because of all these factors, more enemy targets of opportunity are likely to be found with commercial drones than without, even though their sensors have a relatively narrow soda straw view of the world. If a commander has access to information from multiple drones (even if the data are not truly fused), her situational awareness is further enhanced. As analyst Michael Kofman observed, the presence of so many drones has

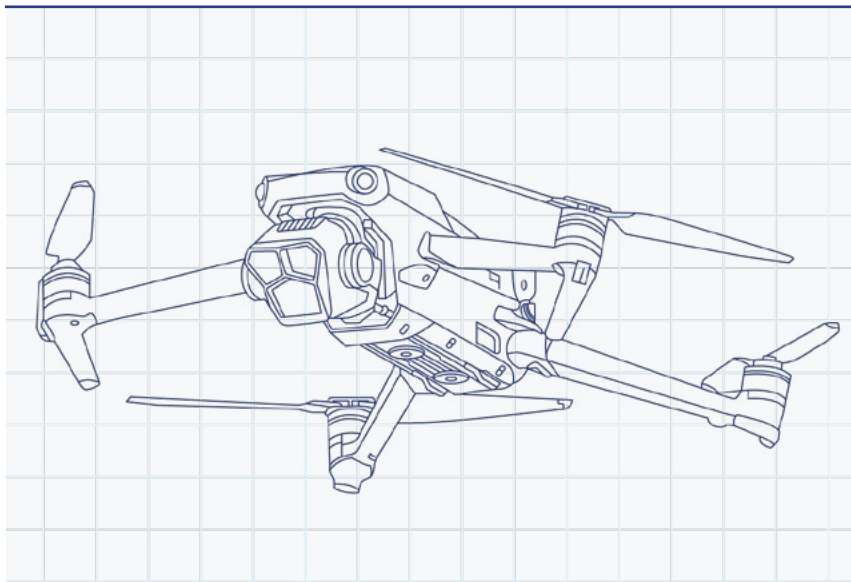
made it difficult for either side to concentrate its forces, break through the defensive lines, or achieve surprise.¹⁸¹ While the Ukrainians were ahead of the Russians at the beginning of the war and initially better at harnessing commercial technology, the Russians have emulated their adversary and largely caught up.

Because this is an attritional war dominated by artillery, the most important role of commercial drones (and military drones) is serving as spotters for artillery units and dramatically improving the accuracy of indirect fires. It is not simply that drones can see enemy forces, but that because the drones are connected to artillery units, they can call significant firepower onto troops that are discovered. Although in Ukraine it has become inconceivable to conduct ground operations without commercial drone scouts, these drones have not fundamentally changed the nature of the fight, which still resembles a classic artillery duel. In this duel, commercial drones perform the roles of tactical aerial reconnaissance and fire support. Even with these eyes in the sky, the battlefield is not entirely transparent; small, dismounted units can use natural features for cover and make use of camouflage to complicate targeting.¹⁸³ Moreover, the short range and limited endurance of commercial drones combined with limited connectivity means their effects are localized.¹⁸⁴

In addition to using drones for their direct effect on the battlefield, Russian and Ukrainian forces have used commercial drones for psychological effect and to influence public perceptions of the war. Because drones can directly attack targets or call in additional fires, their presence overhead keeps soldiers on edge and could degrade morale.¹⁸⁶ A tertiary impact, therefore, of some drone flights is simply to harass enemies and keep them flustered. It is hard to measure this or to determine what actual effect it has had on the course of different battles, but there are many anecdotal reports of the psychological dimension. Moscow and Kyiv have also used the videos from drone feeds to fuel their ongoing information war and to try to shape international and domestic opinion.¹⁸⁷ It is not surprising that commercial drones often marketed for photography play a prominent role in this space.

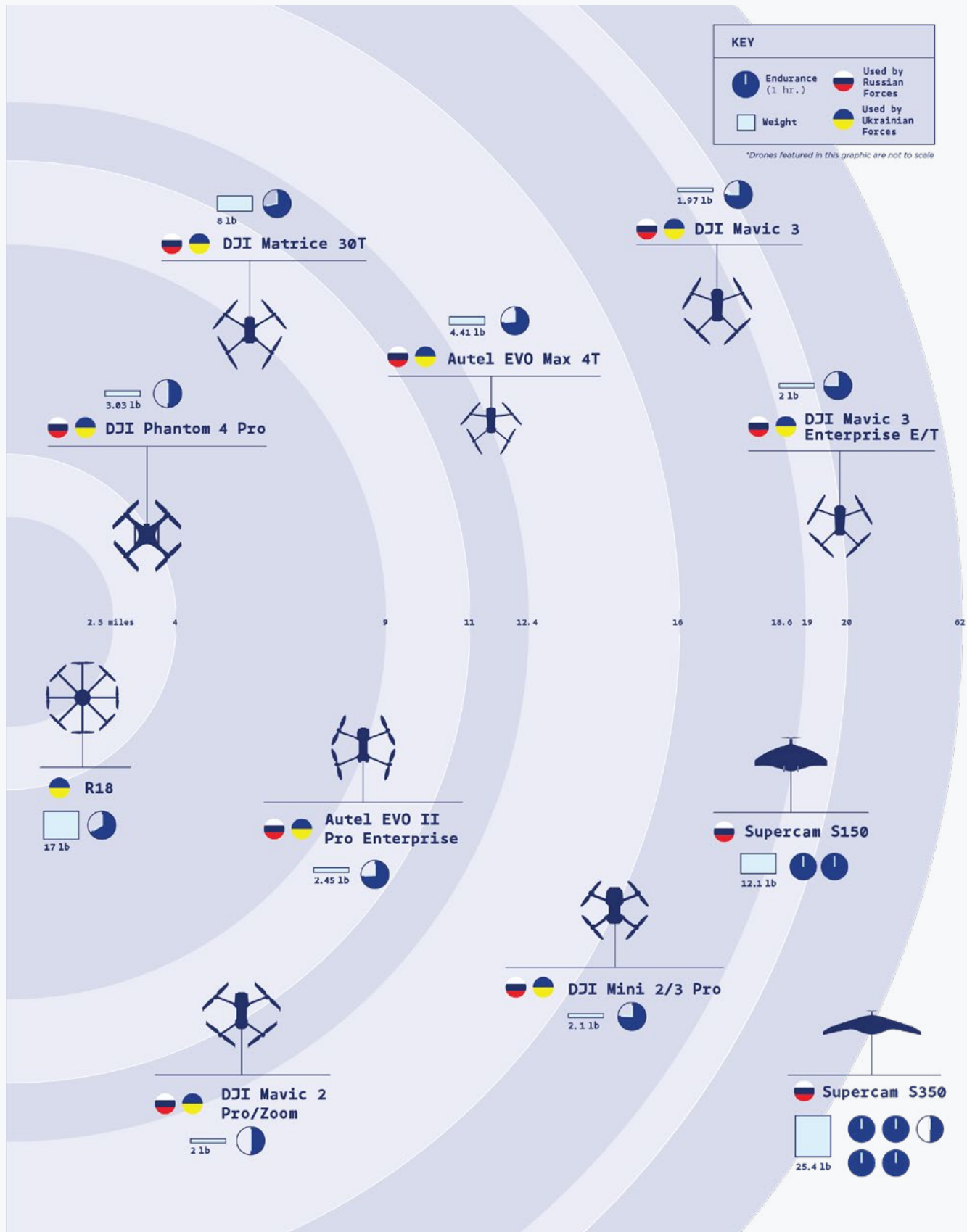
FIGURE 10: DJI MAVIC 3

DJI Mavic 3 drones have been the most common commercial quadcopter used by Ukrainian and Russian forces.¹⁸⁵



Drawing is approximate and based on DJI Mavic 3 Pro (DJI RC), DJI Store, <https://store.dji.com/product/dji-mavic-3-pro?site=brandsite&vid=137691>.

FIGURE 11: COMMON COMMERCIAL DRONES USED BY RUSSIAN AND UKRAINIAN FORCES¹⁸²



UKRAINIAN COMMERCIAL DRONES

The Ukraine war is notable because of the significant role that volunteer organizations have played in acquiring and modifying commercial drones for combat and in training troops to effectively use these platforms. After the 2014 Russian invasion of Donbas, a group of Ukrainian volunteers created Aerorozvidka, a civilian organization focused on using drones for aerial reconnaissance in defense of Ukraine.¹⁸⁸ By February 2022, Aerorozvidka could modify commercial drones for combat and had designed and produced its own homemade drones from commercial parts, including the R18 octocopter, which can carry up to four grenades.¹⁸⁹ Equally importantly, Ukrainian volunteers formed a cadre of highly skilled and experienced drone operators who joined forces with the Ukrainian military and brought their drones to the fight to resist the latest Russian invasion.¹⁹⁰ While many reports and videos show R18s and other modified quadcopters dropping grenades on Russian forces, their primary missions and roles were, again, reconnaissance and targeting.¹⁹¹

Early in the war, the bulk of commercial drones were operated by specialized Ukrainian units, soldiers who were able to procure quadcopters, and ad hoc volunteer teams.¹⁹² Territorial defense units, such as the Karlson aerial surveillance team, also used commercial drones.¹⁹³ Some individual Ukrainian soldiers acquired quadcopters, often by purchasing them with their own money, but general-purpose forces tended to have less training and experience than dedicated drone units and were often less proficient at operating the drones.¹⁹⁴ While volunteer drone teams were often more skilled, in the early phases of the war, they would just show up in an area and append themselves to nearby military formations.¹⁹⁵ Because they roamed where they pleased and were not formally under military command, these independent drone operators were known as “feral” or “wild” teams.¹⁹⁶ As a result, there was significant variability among commercial drone operators in terms of their organization, tactics, equipment, and aptitude.¹⁹⁷ Of the nongovernmental groups that eventually joined the military, Aerorozvidka has had the most capable drone pilots.¹⁹⁸ In summer 2022, Aerorozvidka reportedly had 50 drone teams carrying out approximately 300 drone flights a day.¹⁹⁹ Other high-end drone operators included Ukrainian special operations forces units and intelligence organizations such as the Security Service of Ukraine and Main Intelligence Directorate.²⁰⁰ Over time, more Ukrainian troops have received training on commercial quadcopters, although there remains a disparity between specialized drone units and general-purpose forces.

Over time, more Ukrainian troops have received training on commercial quadcopters, although there remains a disparity between specialized drone units and general-purpose forces.

Ukrainian drone operations and tactics have also evolved over time. In the first few phases of the war, Ukrainian drone teams typically drove to the front lines, found a location to hide, launched their drone, and searched for targets. They usually left when they found Russian forces or exhausted their drone's battery life.²⁰¹ As the conflict progressed and the front lines stabilized, Ukrainian forces have increasingly operated quadcopters in pairs or groups, which provides redundancy and the ability to execute different tasks simultaneously, and have been closely linked to nearby fires units. For instance, the BBC shows two Ukrainian drone operators searching for targets and correcting artillery fire, a mission they can complete even though one drone is lost.²⁰² At other times, an unarmed quadcopter has looked for targets while an armed quadcopter has loitered nearby, prepared to engage any enemy forces that are found.²⁰³ In December 2022, analyst Sam Bendett noted that Russian soldiers on Telegram were reporting that Ukrainian drone operators had adopted a new tactic to expose Russian targets at night. One drone with a light shining would fly overhead to attract Russian fire, while another drone that was dark and hovering at a different altitude recorded the location of the firing unit.²⁰⁴

RUSSIAN COMMERCIAL DRONES

Russian forces have also used commercial drones since the war's beginning, although initially they had fewer quadcopters and their troops were less skilled than the Ukrainians at employing them.²⁰⁵ In the early days of the war, artillery units controlled most of the military drones, leaving regular infantry units with only quadcopters for aerial reconnaissance. Yet there were not enough commercial drones available to equip all the Russian units because the Russian Ministry of Defense was slow to embrace the use of commercial technology.²⁰⁶ The MOD even discouraged and hindered the efforts of troops to obtain quadcopters independently, which stands in stark contrast to the Ukrainian government's policy.²⁰⁷ The official Russian policy failed to deter Russian troops and volunteers from obtaining quadcopters and sending them to the Ukrainian front lines, where they have been employed extensively.

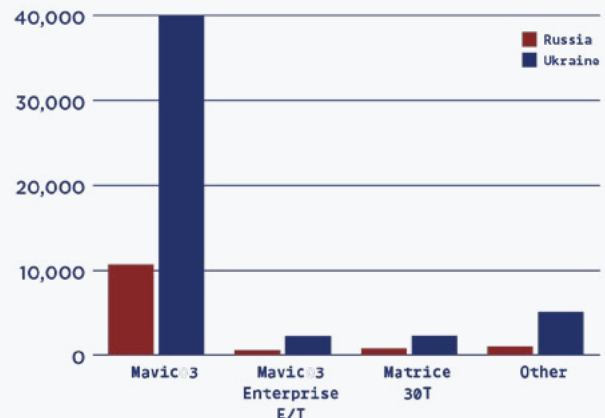
Crowdfunded civilian organizations have purchased drones for Russian soldiers, 3D printed the parts to arm commercial drones, and taught soldiers drone piloting tactics.²⁰⁸ One Russian volunteer organization, Dronnitsa, formed in September 2022 and sought to create a training pipeline for Russian quadcopter pilots with a train-the-trainer program.²⁰⁹ By the end of the month, the Russian MOD relented and announced that newly mobilized soldiers could bring their own quadcopters when they deployed. Although the Russian government has gotten out of the way of the volunteers, it has not enabled or supported them like the Ukrainian government has.²¹⁰ More recently, the Russian MOD finally began offering quadcopter training, which ranges from several days to two weeks.²¹¹

Tactically, the Russians employ the quadcopters like the Ukrainians, mainly for surveillance and spotting.²¹² They often fly in pairs, with one drone tasked with finding the targets, monitoring the attack, and conducting BDA, while the other drone drops the weapon.²¹³ This approach offers better situational awareness and ability to correct for aiming errors. To flush Ukrainian forces out of their defensive positions, Russian drones have dropped tear gas grenades followed by additional strikes.²¹⁴ Russian fighters conducting an urban assault often use more quadcopters—at least three—with two scouting ahead and looking for enemy forces and ambushes, while one stays above the troops, tracking their progress.²¹⁵ Frequently, commercial Russian drones also coordinate with military drones. Small commercial drones often find Ukrainian forces and cue an Orlan-10, which precisely locates the enemy forces and passes the information to the gunline.²¹⁶ At other times, Russia has used microdrones, such as the DJI Mini or Mavic Air 2 or Air 3, to gauge the extent of electronic interference before committing larger quadcopters.²¹⁷ In this case, these microdrones act as canaries in the coal mine—early warning systems that indicate that whether enemy jamming is present.

Data provided by the American company Edgesource, which produces the WindtalkerX sensor that detects and tracks the location of commercial drones and their pilots, suggest that by early 2023 Russia had caught up to Ukrainian commercial drone use.²¹⁸ While these data are drawn from a limited slice of the battlespace and the time periods have some overlap, it does support other anecdotal observations about commercial drone use in Ukraine.²¹⁹ From June through December 2022, the four WindtalkerX

FIGURE 12: DJI DRONE DETECTIONS IN UKRAINE, JUNE-DECEMBER 2022

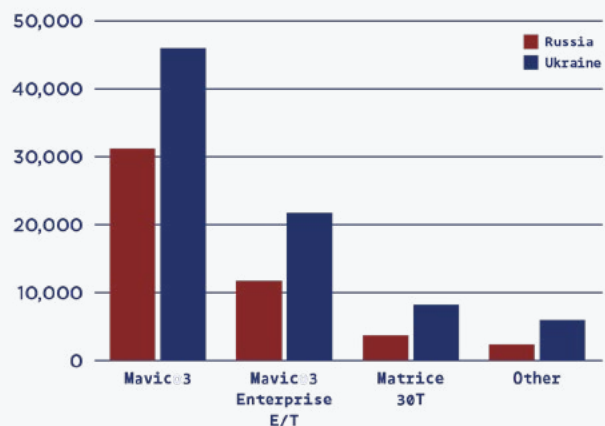
Because of their larger inventory of commercial drones, Ukrainian DJI drones were much more active during this period than Russian DJI drones. The Mavic 3 was the most common drone for both parties. This graphic shows how many times the 2,624 unique Ukrainian DJI quadcopters and 284 Russian DJI drones were detected by the WindtalkerX. The number of detections gives a sense of how many sorties or flights the drones flew.



This information is drawn from the briefing Edgesource, "Commercial Drones in War a C-UAS Perspective," unpublished, undated.

FIGURE 13: DJI DRONE DETECTIONS IN UKRAINE, OCTOBER 2022-MARCH 2023

Although more Ukrainian DJI drones were detected during this period, Russian DJI drone activity had increased significantly. The DJI Mavic 3 remained the most common commercial drone. This graphic shows how many times the 3,901 unique Ukrainian DJI quadcopters and 3,817 Russian DJI drones were detected by the WindtalkerX. The number of detections gives a sense of how many sorties or flights the drones flew.



This information is drawn from the briefing Edgesource, "Commercial Drones in War a C-UAS Perspective," unpublished, undated.

systems in Ukraine detected 2,624 unique Ukrainian DJI quadcopters and only 284 Russian DJI drones. Thus, during 2022 Ukraine had a 9-to-1 advantage in commercial drones. From October 2022 through March 2023, Ukraine's lead in commercial drones had essentially disappeared, with WindtalkerX observing 3,901 unique Ukrainian DJI drones and 3,817 Russian DJI drones. The overall number of commercial drone flights also increased dramatically between the two periods, and the composition of the DJI drones in the air changed. While the most ubiquitous commercial drone in this conflict remains the Chinese-made DJI Mavic 3 quadcopter, there was a notable uptick in Mavic 3 Enterprise E/T and Matrice 30T drones, which have thermal cameras and can conduct night operations.²²⁰

COUNTERING THE QUADCOPTERS

Because quadcopters play a critical role in enabling precise artillery fire, both parties have prioritized defeating them. Operators treat these relatively cheap drones as expendable and often send them on missions where they are likely to be lost. Moreover, commercial drones have a very high utilization rate, with many quadcopters flying 10 to 15 missions a day.²²¹ For these reasons, loss numbers for commercial drones are incredibly high. According to a RUSI report, Ukraine lost approximately 10,000 drones a month, and most of those were commercial or DIY drones.²²² On average, a Ukrainian quadcopter only survived for three flights, although there is one instance of a single quadcopter completing more than 700 sorties.²²³ While this is certainly an anomaly, it does indicate the most competent drone pilots can extend the life of a drone.

There are a variety of ways to protect against commercial drones. The most effective way to disable or destroy commercial drones is electronic warfare, and Russia has long invested heavily in this.²²⁴ A senior Ukrainian official estimated that Russia's electronic attacks have caused half of Ukraine's drone losses.²²⁵ Russia has larger truck-based EW systems that can jam drone communications, resulting in the pilot's loss of control, or disrupt the drone's navigational system, causing it to go off course. Additionally, Russian forces employ more tactical EW systems that include mobile directional jammers and systems that can hijack the controls of a quadcopter, enabling the attacker to commandeer the system and exploit its data.²²⁶ In spring 2023 in Bakhmut, electronic interference was so extensive that Ukrainian soldiers reported that their quadcopters could only fly 500 meters before losing control, leading them to fear that commercial drones were no longer effective on the battlefield.²²⁷

Russian forces used layered handheld jammers and larger EW systems in Bakhmut and frequently moved them around.²²⁸ As a result, Ukrainian troops often refrain from sending commercial drones on missions if Russian EW systems are operating.²²⁹

Yet, Russia cannot jam everywhere all the time.²³⁰ It does not have enough EW systems to blanket the front lines and protect strategic sites within Russia and Crimea. Moreover, as EW also disrupts Russian military systems and has resulted in considerable fratricide, Russian forces must turn off their jammers to conduct offensive operations.²³¹ Thus, electronic interference is common, but not continuous, giving Ukrainian forces windows of opportunity to operate commercial drones.²³² Because of its effects on drones, Ukraine has prioritized targeting Russia's larger EW systems, which have large electronic signatures and are easily identified by American signals intelligence.²³³ For instance, a Ukrainian special forces team operating in Russian-controlled territory disabled a Russian EW system by remotely flying a Styrofoam kamikaze drone into its

In this 'aerial game of spy vs. spy,' drone operators spend much of their time searching for their enemy counterparts.

antennas. This paved the way for a rocket strike fired by Ukrainian HIMARS, which was guided precisely into the tower in the absence of GPS jamming.²³⁴

Instead of hardening commercial drones against electronic attack, which is expensive and does not guarantee survival, Ukraine and Russia have simply bought more cheap drones.²³⁵ Realizing the high loss rate, in July 2022, the Ukrainian government launched its "army of drones" project. As a part of this effort, Ukraine has sought to bolster its indigenous drone industry. To expedite and encourage drone production, Ukraine has removed taxes and relaxed import restrictions on key drone components, such as GPS systems and cameras.²³⁶ In contrast, the Russian government does not officially support the volunteer-run crowdfunding efforts to buy drones. Still, reports show that additional DJI quadcopter shipments from China have reached Russia, despite DJI's claims of not selling to either belligerent.²³⁷

Because Russian and Ukrainian forces use many of the same commercial drones, it is often hard to discriminate between one's own drones and the enemy's. Commercial drones are easily countered and frequently downed by electronic attacks, but neither party has developed

a way of countering the enemy's commercial drones and obtaining tactical air superiority while allowing one's own drones to continue to operate. Electronic interference is quite effective but often indiscriminate. One alternate approach is drone-on-drone aerial combat, where one quadcopter collides with another and attempts to knock it out of the sky or deploys a net that downs the enemy drone.²³⁸ Ukrainian drone pilots have refined their tactics by attacking other quadcopters from above, typically a blind spot, and aiming for the enemy's fragile rotors. This type of diving attack can fatally damage the targeted drone but leave the other unscathed.²³⁹ Given the number of quadcopters in the sky over the front lines, drone dogfighting is becoming more common, but it is still a relatively nascent tactic.

Most of the counters discussed thus far focus on disabling or destroying the drone itself. The other approach is to find and target the drone operators. Most quadcopters are remotely piloted and therefore not autonomous. There usually are two or more operators, one flying the drone and one acting as a spotter, helping with targeting by correlating the drone's video feed with a map.²⁴⁰ In this "aerial game of spy vs. spy," drone operators spend much of their time searching for their enemy counterparts.²⁴¹ Since commercial quadcopters and DIY drones have limited ranges, the operators need to be relatively proximate to the drone, which makes them vulnerable to attack. If one's adversary can determine the location of operators by, for example, hijacking the drone's radio controls, they can then send an armed drone to attack them or fire mortars or shells at them.²⁴²

As part of this competition, both sides have extensively used a DJI system called AeroScope that tracks the positions of drones and operators more than 20 miles away. There were two AeroScope systems offered by DJI: a small portable one with shorter range and larger stationary system with more capability. AeroScopes, thus, could be used to track all DJI drone users within their range and compile longitudinal information on each drone, including the flight paths each had taken, at what altitude and speed it had operated, and where its pilot had been located.²⁴³ This could help track patterns in enemy drone units' operations and identify trends in commercial drone activity around specific locations. Ukraine eventually developed software that could be uploaded onto DJI drones to disable the tracking, and DJI stopped selling the commercial AeroScope system.²⁴⁴ Edgesource donated five WindtalkerX systems, which perform a similar function to AeroScope, to Ukraine to detect and track Russian commercial drones. The WindtalkerX is a cyber-hardened system that provides

real-time feeds on drone flight paths, with an added capability that filters out spoofed drone tracks from real ones. WindtalkerX, thus, is a secure system that has helped Ukrainian forces find and target Russian drone operators and interdict or evade approaching Russian commercial drones, but there are only four of these systems, so they can provide coverage of a relatively small area.²⁴⁵

Commercial drones have played an unexpectedly important role in this war.²⁴⁶ Combatants have used them for direct strikes, surveillance, propaganda, and psychological attacks. But their most important role has been as spotters improving the accuracy of unguided artillery fire.²⁴⁷ Despite being incorporated in an ad hoc way into the Ukrainian and Russian militaries, commercial drones have provided a "surprising amount of tactical clarity and coordination."²⁴⁸ Although Ukraine initially dominated commercial drone warfare, Russian forces quickly adapted and copied their enemy. Thus, commercial drones have not decisively advantaged either party. As the conflict continues to trudge on, these cycles of adaptation and counters continue, with the latest developments occurring around DIY kamikaze drones.

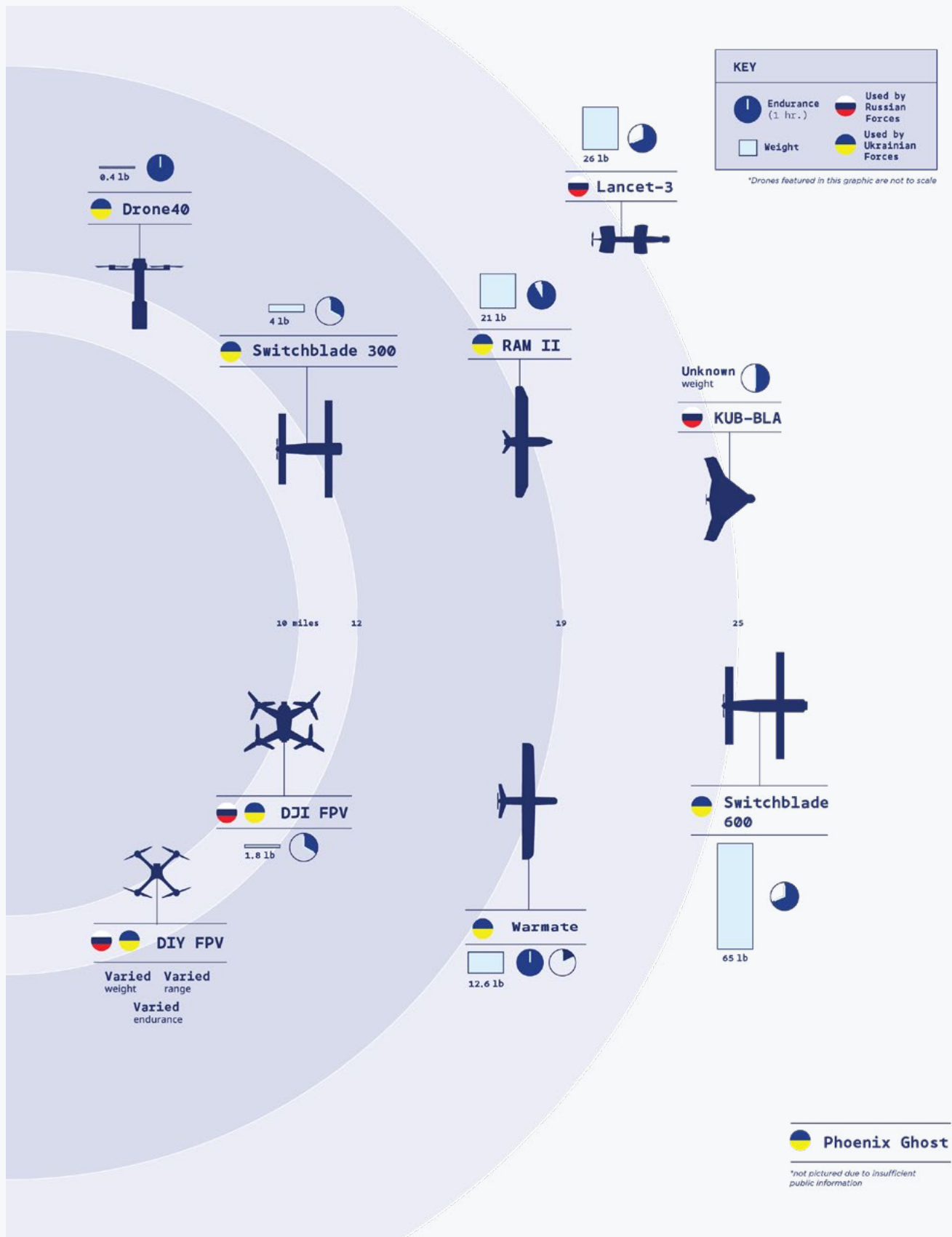
Kamikaze Drones

The final drone type that has proliferated in the Ukraine war is the kamikaze drone or loitering munition, which has been used for strategic and tactical strikes. Kamikaze drones range from military-grade medium-range loitering munitions, to long-range Ukrainian drones and Iranian-built Shahed-136s, to very short-range modified commercial FPV drones. Despite the differences among them, they are all one-use uncrewed weapons that crash into targets like a kamikaze. Kamikaze drones, therefore, are primarily used as strike weapons and often paired with surveillance drones in hunter-killer teams or larger drone groups.²⁴⁹ While the use of kamikaze drones in Ukraine far outstrips any prior war, most of these weapons are not fully autonomous, as a human operator still selects the target and when to engage it. There are reports that some of these systems have autonomous capabilities, but this is hard to verify.²⁵⁰ Instead, it is likely that most of the kamikaze drones used thus far in Ukraine are controlled by a human operator or hit pre-programmed coordinates.

BATTLEFIELD KAMIKAZE DRONES USED IN THE CLOSE FIGHT

In general, Russia has had more kamikaze drones than Ukraine. In particular, Russia has maintained an advantage in military-grade loitering munitions, which are

FIGURE 14: COMMON KAMIKAZE DRONES USED BY RUSSIAN AND UKRAINIAN FORCES ²⁵⁶



capable of damaging high-priority mobile targets such as howitzers and SAMs. Ukraine has acquired kamikaze military drones from various international supporters but has not used them to the same effect because it either does not have enough of the one-way drones or they are less capable systems. As a result of this disparity, Ukrainian forces began employing commercial or DIY FPV kamikaze drones to hit mobile targets. Russian forces quickly copied this innovation and have largely matched the Ukrainians' use of these homemade drones.

Russia entered the war with two military-grade loitering munitions in its inventory—the KUB-BLA and the Lancet-3. Although these Russian kamikaze drones appear similar with two- to six-pound warheads and a range of 25 miles, they have performed very differently on the battlefield.²⁵¹ Several weeks into the invasion there was evidence the Russians were using KUB drones around Kyiv.²⁵² By October 2022, Russia reported that it had employed several hundred KUBs and Lancets against air defenses, radars, and personnel.²⁵³ Overall, the KUB's performance was disappointing. Videos and pictures showed KUBs missing their targets and the remnants of ones that had been shot down by small-arms fire.²⁵⁴ The KUB's warhead also frequently malfunctioned. Not surprisingly, by the second half of 2022, KUB use declined, and the Russians began employing the Lancet-3s, which proved more effective and tended to be operated by experienced drone pilots.²⁵⁵

Unlike the KUB, the Lancet-3 was advertised as having autonomous target identification and engagement, although these claims are unverified and reportedly the Lancets are flown by the most skilled Russian drone operators.²⁵⁷ Typically, Lancet-3s have been reserved for priority missions, such as counterbattery fire and SEAD. As of March 2023, Oryx had confirmed 54 Lancet-3 hits on howitzers and multiple rocket launchers, and two short-range, one medium-range, and two long-range air defense systems.²⁵⁸ In the subsequent months, Russia has become increasingly reliant on battlefield kamikazes, and they have reportedly become the preferred weapon for attacking Ukrainian artillery.²⁵⁹ Typically, an unarmed military drone, such as an Orlan-10 or ZALA 421-16E, finds a target, and then operators launch a Lancet-3 to perform the strike.²⁶⁰ Hunter-killer teams of ZALAs and Lancets have also been used to immobilize armored vehicles that are then destroyed by artillery fire.²⁶¹ Improvements to the latest variant of the Lancet-3, including arming it with a

By comparison, Ukraine has not employed military kamikaze drones to significant effect on the battlefield.

heavier five-kilogram warhead, have enhanced its performance.²⁶² Although Russian loitering munitions can be deadly, the Ukrainians have developed many counters, including using small-arms fire and shoulder-fired MANPADs to shoot down the slow-moving drone.²⁶³ One of the most prevalent counters has been a simple metal screen or mesh net that stops the drone short of the target and forces it to detonate prematurely.²⁶⁴ Decoys have also effectively fooled loitering munitions.²⁶⁵

By comparison, Ukraine has not employed military kamikaze drones to significant effect on the battlefield. In general, Ukrainian kamikazes, such as the Switchblade 300, Warmate, D40, or RAM II, are smaller than the Russian drones and optimized for attacks on personnel or tanks.²⁶⁶ For instance, the tube-launched Switchblade 300 is a small drone with a 15-minute loiter time that Ukrainian special forces have used primarily against exposed Russian troops.²⁶⁷ Although American special forces found the Switchblades effective against insurgents in Iraq and Afghanistan, they are not user friendly and have performed poorly in the heavily disrupted communications and navigation environment in Ukraine.²⁶⁸ If a Switchblade 300 does not find its target within 15 minutes, the warhead disarms and the drone crashes into the ground. Russian jamming has reportedly frequently triggered the Switchblades' disarmament

protocol.²⁶⁹ Near the end of 2022, the first of the larger Switchblade 600 was delivered to Ukraine, although there are few reports on how

these antitank drones have performed.²⁷⁰ The United States also gave Ukraine 1,800 Phoenix Ghost drones, which supposedly require significant training, which has probably limited their use.²⁷¹ There is little evidence on social media that they have been employed at all.²⁷²

The Ukrainians do not have large numbers of loitering munitions for SEAD or counterbattery missions.²⁷³ In the fall of 2022, Ukraine used money from its "army of drones" campaign to purchase around 40 Polish-made Warmate kamikaze drones.²⁷⁴ The larger Warmate has a longer time of flight than many other Ukrainian loitering munitions and has a variety of warheads that can be used against different target sets. Ukrainian defense intelligence units have used the Warmate effectively against radars, EW systems, and air defenses, but the inventory of these kamikaze drones is limited.²⁷⁵ While exact stockpile numbers are unknown, Ukraine likely has not acquired large numbers of any of these systems, in contrast with Russia, which has ramped

up production of Lancet-3s. Because kamikaze drones can only be used once, one needs many to appreciably affect the battlefield.

Ukrainian and Russian forces have increasingly relied on cheap commercial or DIY FPV kamikaze drones, which can be quickly manufactured by volunteers and purchased in large numbers.²⁷⁶ FPV kamikaze drones present a cost-effective way of attacking exposed and moving targets beyond visual range.²⁷⁷ FPV drones are fast enough to catch moving vehicles but can only fly about six miles.²⁷⁸ Most of these racing drones are assembled by volunteers and cost between \$400 and \$700.²⁷⁹ Compared with the price tag for Switchblade 300s—at least \$6,000 each—or for Lancet-3s—\$35,000 apiece—FPVs are a bargain.²⁸⁰ They also are a fraction of the cost of the Javelin, an American antitank weapon that costs \$368,778 per missile.²⁸¹ Because FPV drones have powerful engines, they can carry slightly larger payloads than typical commercial drones, up to three to five pounds of explosives.²⁸² Pilots of FPV drones, located

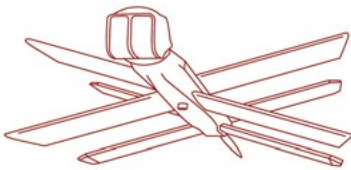
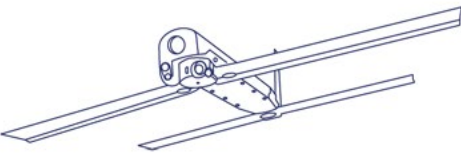


nearby and wearing augmented reality goggles, steer the kamikaze racer on its short journey and try to crash it into the most vulnerable point on a target. For instance, FPV pilots have flown drones through the open doors of armored vehicles where they then detonate.²⁸³ Therefore, skilled FPV drone pilots can disable or destroy even armored vehicles, such as tanks, by aiming for their weak points. Becoming a proficient FPV drone pilot requires more training than is needed for typical commercial drones, which limits who can effectively operate these drones. Ukrainians put their FPV pilots through a monthlong training program, and only 60 percent to 70 percent of students pass.²⁸⁴ The Russians have shortened their FPV drone training to two weeks to more quickly qualify additional operators.²⁸⁵

July 2022 saw the first recorded instance of a Ukrainian FPV racing drone flying through the doorway of a house to reach its target.²⁸⁶ Since then, Ukrainian FPV production has ramped up to thousands of drones a month, enabling troops to use these weapons against

self-propelled mortar trucks, tanks, transport trucks, and infantry fighting vehicles.²⁸⁷ They reportedly played an important role in the Ukrainian defense of Bakhmut.²⁸⁸ Ukrainian drone operators admit that the kamikaze drones do not have as high a success rate as more expensive antitank weapons, but they argue that because the drones are inexpensive and still hit their target half of the time, mass could compensate for FPVs' inferior performance.²⁸⁹ Although there are many videos of FPV drones seemingly successfully striking targets, it is unclear whether these systems do enough damage to seriously harm or disable them. This is

FIGURE 15: COMPARISON OF COMMON RUSSIAN AND UKRAINIAN KAMIKAZE DRONES

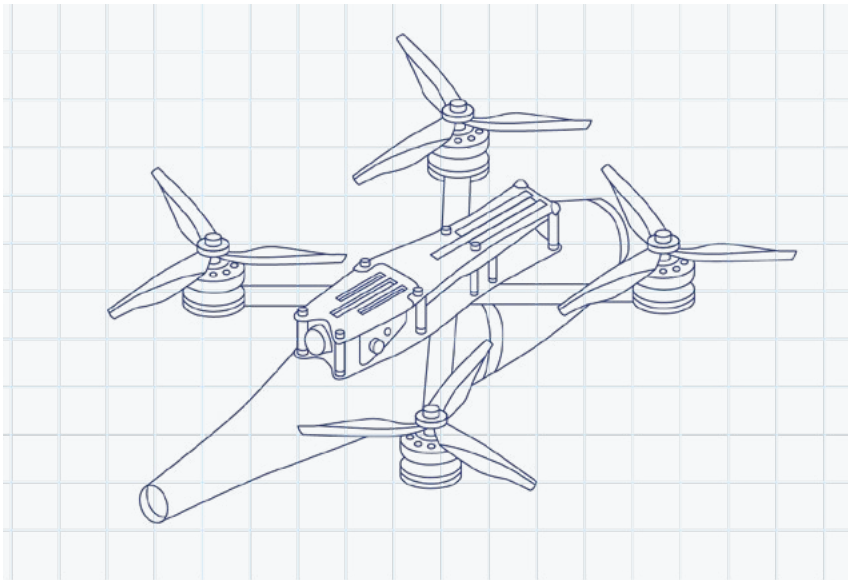
Russia has boosted production of its Lancet-3 kamikaze drone and is increasingly using these weapons for precise counterbattery fire. Ukrainian forces have a variety of kamikaze drones, including the American-made Switchblade 600, but these have not been as effective on the battlefield as the Russian drones.

			
 Russian Lancet 3M		 U. S. -Made Switchblade 600	
Length	5' 5"	Length	4' 3"
Max. speed	186 mph	Max. speed	115 mph
Max. weight	26.5 lb	Max. weight	65 lb
Range	40 miles max	Range	25 miles
Max. altitude	16,404'	Max. altitude	>15,000'

Drawing is approximate and based on Alistair MacDonald and James Marson, "This Russian Suicide Drone Is Blunting Ukraine's Advance," *The Wall Street Journal*, November 3, 2023, <https://www.wsj.com/world/this-russian-suicide-drone-is-blunting-ukraines-advance-8241a0e4>.

FIGURE 16: DO-IT-YOURSELF FIRST-PERSON VIEW KAMIKAZE DRONES

Ukrainian and Russian forces are using modified or do-it-yourself first-person view racing drones with bombs strapped to them to hit moving targets.



Drawing is approximate and replicated from Jarrod Fankhauser's illustration in Annika Burgess, "Why Ukraine's Kamikaze Racing Drones Are Causing a Buzz on and off the Battlefield," Australian Broadcasting Corporation News, March 31, 2023, <https://www.abc.net.au/news/2023-04-01/fpv-racing-drone-kamikaze-attacks-ukraine-russia-war/102155702>.

an especially important question because FPV drones carry relatively small payloads compared with artillery and antitank missiles.

Seeing Ukrainian success, Russia once again played the role of the fast follower and adopted FPV kamikaze drones. Russian volunteers set up their own factories to build FPV drones and have produced tens of thousands a month that have made an impact on the battlefield.²⁹⁰ Russia relied heavily on FPV kamikazes to blunt Ukraine's summer 2023 counteroffensive, striking Ukrainian moving vehicles. Videos show Russian FPVs ramming into Leopard tanks, Mine-Resistant Ambush Protected Vehicles (MRAP), Humvees, armored personnel carriers, and Bradleys.²⁹¹

Both Russian and Ukrainian forces often operate FPVs in groups. In a recent attack, four Ukrainian FPV drones flew together to hit a Russian self-propelled mortar truck.²⁹² More often, FPV drones are employed with a mix of other types of uncrewed systems in a "drone stack." A drone stack includes multiple drones operating in the same vicinity but at different altitudes.²⁹³ Unarmed drones—either commercial or military—with better endurance hover over the battlespace and watch for enemy targets to appear. A more persistent higher altitude drone may cue another surveillance drone to verify that something is a valid target and to obtain precise targeting coordinates for it. Then, an

FPV kamikaze drone is launched and catches up to and overtakes the target. Ideally, the drone commanders are also linked up with nearby artillery units that might then be called on to finish off a target that has been disabled but not destroyed by a kamikaze drone.²⁹⁴

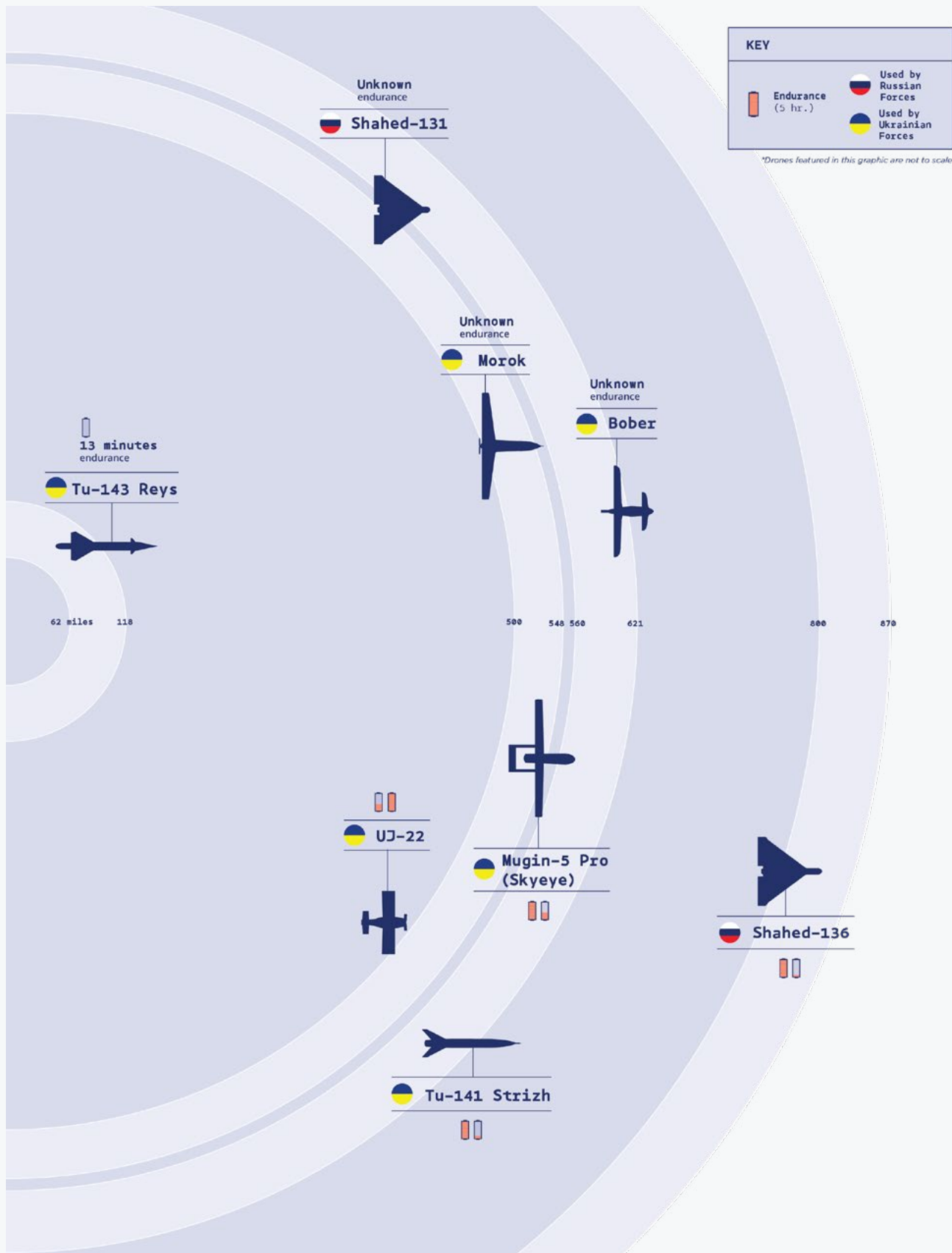
Compared with other drones, DIY kamikaze racing drones are difficult to counter. Because of their speed and size, gunfire is not particularly effective against them. Moreover, they do not rely on GPS, so they are not affected by navigational jamming.²⁹⁵ FPV drones do need radio communications to enable the pilot to fly the drone, and if those signals are jammed, the drone will fall to the ground.²⁹⁶ Because Russia makes extensive use of jamming, Ukraine is developing software that locks the FPV drone on to a predesignated target, such that if

the communications link breaks, the drone can autonomously reach its target.²⁹⁷ The widespread use of FPV kamikazes has increased the lethality of the close fight. Maneuver is dangerous because if an enemy ISR drone spots a target, the enemy can deploy a fast-moving FPV kamikaze that can run down even a moving vehicle. But these systems have not fundamentally shifted the balance on the battlefield because both Russian and Ukrainian troops are making widespread use of them.

KAMIKAZE DRONES FOR DEEP STRIKES

Beyond the battlefield, Ukraine and Russia have used kamikaze drones for strategic strikes against deep targets. These kamikaze drones are more akin to long-range cruise missiles than autonomous loitering munitions. For instance, most of Russia's Shaheds have preprogrammed fixed targets that they transit to and then perform a diving attack on instead of searching a wide area and selecting a target. As discussed previously, Ukraine began launching drone attacks into Russia in summer 2022 but dramatically increased these attacks in spring 2023.²⁹⁸ Ukraine developed at least four long-range drones—the Bober, UJ-22, the Mugin-5, and the Morok—for these kamikaze attacks.²⁹⁹ Little is known about where the drones are launched from, the tactics used, or how these drones have penetrated deep into heavily defended Russian airspace.

FIGURE 17: COMMON DEEP-STRIKE KAMIKAZE DRONES USED BY RUSSIAN AND UKRAINIAN FORCES ³⁰⁰



There is more information available about Russia's Shahed kamikaze drone strikes on Ukraine. Russia's strategic kamikaze drone attacks should not be examined alone, but in the context of its ongoing missile campaign. While Ukraine has limited long-range strike options, Russia has an array of different cruise and ballistic missiles that it has fired in addition to the Shaheds.³⁰¹ It acquired Shaheds to supplement decreasing stocks of precision-guided missiles and has employed them as an integral part of air and missile attacks. Konrad Muzyka, an independent defense analyst and founder of Rochan Consulting, compiled Ukrainian government reports on Shahed drone intercepts, Russian missiles fired, and the number of missiles intercepted, displayed in Figure 19.³⁰² These reports show that over time, the Russian missile and Shahed attacks have become increasingly sophisticated as Russia has experimented with different tactics and learned.³⁰³ It has packaged its missile attacks in different ways and launched Shaheds alone and as a part of more complex missile packages.³⁰⁴

Shaheds have played three primary roles in Russia's strategic strikes: interceptor *sponges*, *pathfinders*, and *complements*. These roles are not mutually exclusive as the Shaheds may perform multiple functions simultaneously. Russians have used the Shaheds to provide mass long-range fires to saturate and exhaust Ukrainian air defense interceptors.³⁰⁵ In this role as interceptor sponges, the

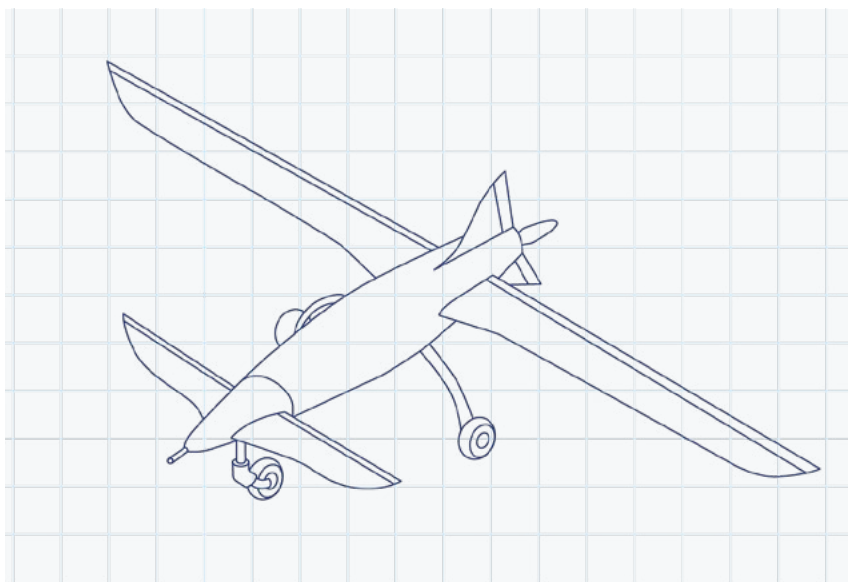
Shahed kamikazes are similar to decoys that distract defensive fires from the primary weapons. Shaheds are easy to manufacture, rely heavily on commercial and dual-use technologies and components, and are cheap, costing between \$20,000 and \$30,000.³⁰⁶ Because they fly slowly and have a loud acoustic signature, they are easy to intercept, which is part of the point. Russia uses them to bait Ukrainian air defenders into firing much more expensive and scarcer SAMs to shoot down the cheap and abundant Shaheds.³⁰⁷ Conserving Ukraine's SAMs for more advanced Russian missiles and aircraft has become increasingly important over time as Ukraine's ground-based air defenses are the primary weapon stopping the Russian air force from gaining air superiority over the entire country.³⁰⁸ Between September 11, 2022, and August 30, 2023, Russia fired 144 salvos into Ukraine, including more than 1,600 Shahed drones and 1,651 missiles. The Ukrainian government has not consistently relayed the number of Shaheds fired, but it has reported the number shot down, which as of August 30, 2023, was 1,570. Ukrainian air defenders have attempted to conserve SAMs for Russia's precision munitions and use anti-aircraft guns such as Gepard 2 against the kamikaze drones, but some number of Shaheds have been shot down by SAMs.³⁰⁹

Russia has also used the Shaheds as enablers for missile strikes by testing Ukraine's air defenses and looking for weaker points. In this pathfinder role, a group of Shaheds are fired at targets, but Russia does not necessarily expect them to complete the strike mission. The main purpose instead is to reveal important information on the posture of Ukrainian SAMs and to help identify air corridors for follow-on missile salvos.³¹⁰ Sixty-four percent of the attacks during this period were Shahed-only strikes, and many of these were likely used to keep pressure on Ukraine and soak up air defense missiles but also to identify avenues for missile strikes. Often, a missile-only or complex (i.e., Shahed and missile) attack followed several days of Shahed-only strikes. Missile-only attacks are relatively rare and constitute only 15 percent of the 144 reported strikes.

Finally, the Shahed drones have complemented the missiles in

FIGURE 18: UKRAINE'S BOBER LONG-RANGE KAMIKAZE DRONE

Ukraine has launched long-range strategic strikes into Russia with kamikaze drones such as the Bober.



Drawing is approximate and replicated from Adrienne Tong's illustration in Stephen Kalin, "Behind Ukraine's Deadly Drones: Putin's Invasion and Biden's Limits," *The Wall Street Journal*, August 2, 2023, <https://www.wsj.com/articles/behind-ukraines-deadly-drones-putins-invasion-and-bidens-limits-5f2f2cf>.

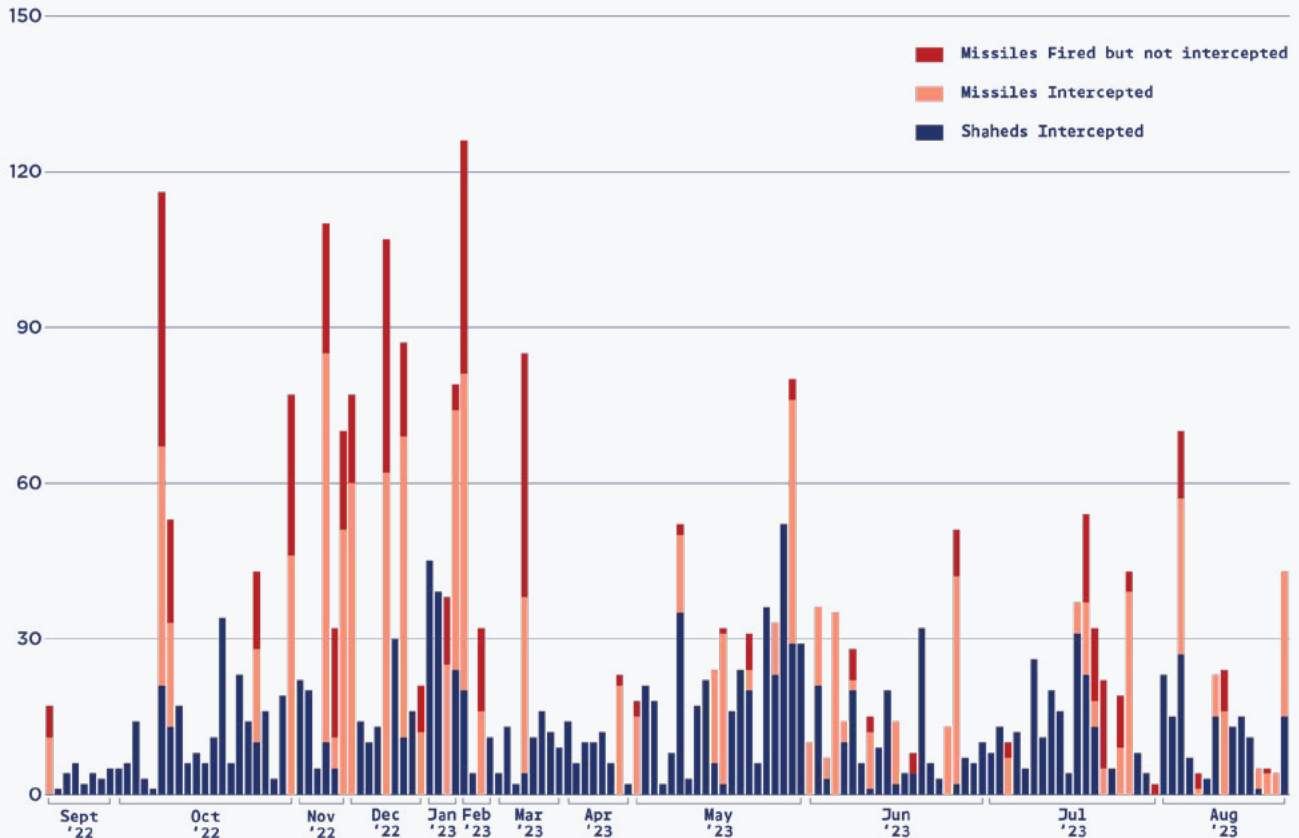
complex massed missile and drone attacks that are harder to defeat than a homogenous salvo. There have been 29 such attacks. As complements, the Shaheds serve as penetration aids that increase the chance that the missiles reach their targets by confusing and distracting defenders. These diverse strikes could stress and overwhelm Ukrainian defenders or take advantage of defenders' focus on one type of threat, leaving their radars and SAMs ill-positioned to stop other inbound weapons. More recently, Russia has deployed its Supercam commercial drones with its long-range attacks to improve BDA for these strikes.³¹¹

As Figure 19 shows, the Ukrainians have gotten better at intercepting Shaheds and missiles. One key innovation that has enabled this improvement is a crowdsourced smartphone application that allows users to geotag incoming air threats, providing early warning for drone and missile strikes.³¹² It is also likely that Western nations

are supplementing Ukraine's early warning with their own intelligence assets, which may be having a significant impact.³¹³ Ukrainian forces have gotten better at how they allocate their air defense weapons, preserving the more expensive SAMs for cruise and ballistic missiles and relying more heavily on guns and MANPADs to destroy less sophisticated threats. EW systems that jam the Shaheds' communications or navigation systems would seem to offer a cost-effective way of disabling these kamikaze attacks. Yet, because many Shaheds have preprogrammed targets, they are not as reliant on communications as most drones in this war. They do use Russia's satellite navigation system, GLONASS, to navigate to their targets but also have a backup inertial navigation system, making navigational jamming less effective.³¹⁴ Moreover, because many Shaheds fly into civilian areas, they can still cause significant damage even if they miss their intended target and crash into something else.

FIGURE 19: SHAHEDS INTERCEPTED AND RUSSIAN MISSILES FIRED AND INTERCEPTED

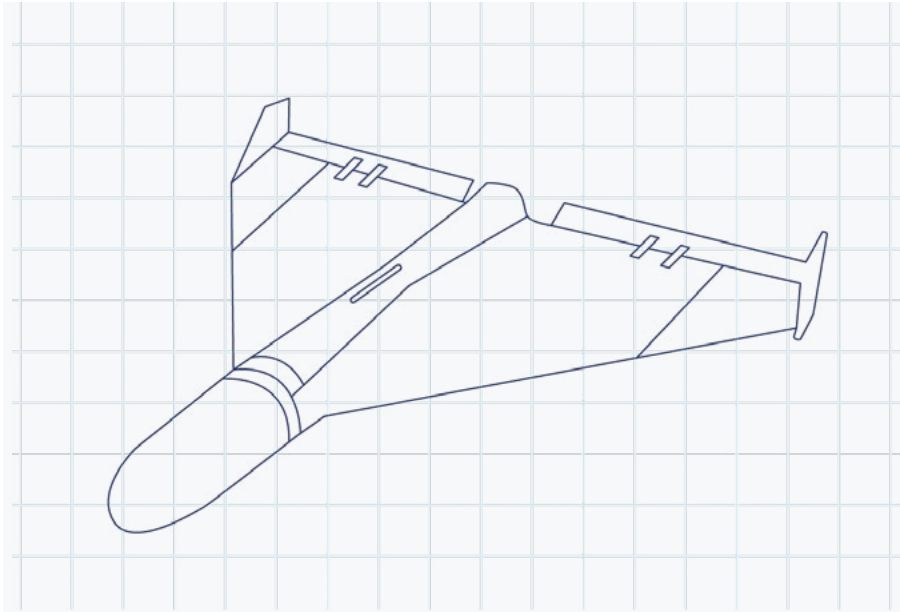
Ukraine reports the number of Shahed kamikaze drones that have been intercepted and Russian missiles fired and intercepted. Over time the size of the missile salvos has declined, and they have been supplemented with Shahed-only strikes. Ukraine has not consistently reported the number of Shaheds fired.



Rochan Consulting, "Datasets of Russian Missile Strikes and Shahed Strikes," provided September 22, 2023.

FIGURE 20: RUSSIA'S SHAHED-136 KAMIKAZE DRONE

Russia has fired thousands of Shahed-136 drones against Ukraine's energy infrastructure.



Drawing is approximate and replicated from William Neff's illustration for Annabelle Timsit, Isabelle Khurshudyan, Adam Taylor, and William Neff, "What Are kamikaze Drones? Here's How Russia and Ukraine Are Using Them," *The Washington Post*, October 18, 2022, <https://www.washingtonpost.com/world/2022/10/17/kamikaze-drones-russia-ukraine/>.

As the war has progressed, both Ukraine and Russia have increasingly utilized kamikaze drones as important tactical weapons to destroy mobile military forces and conduct strategic strikes against fixed deep targets. Tactically, loitering munitions or DIY FPV drones are best employed with other uncrewed systems that provide intelligence and targeting data on moving enemy forces to the kamikaze strike platform. Russian long-range kamikazes, such as the Shahed, have been most effective when fired with cruise and ballistic missiles. They should be seen as a part of the larger missile campaign that Russia has waged against Ukraine. In all cases, since these weapons are one-way systems, large quantities are needed.

Drone Boats

While aerial drones are the most prevalent uncrewed weapon in Ukraine, the Ukrainians have also used maritime kamikaze drone boats to attack Russian ships in the Black Sea. Because Ukraine does not have a large navy, its efforts to counter Russia in the maritime domain have been asymmetric. Ukraine has relied on antiship missiles, such as the Neptune or Harpoon, manned and unmanned aircraft attacks, and unmanned surface vehicles also known as drone boats or maritime drones.³¹⁵ In spring and summer 2023, Ukraine's

maritime kamikaze drone attacks escalated and enabled Kyiv to contest Russian control over the Black Sea.³¹⁶

The world first got a hint that Ukraine was developing maritime drones in early October 2022 when an unusual looking, sleek, small black boat washed up on the shores in Crimea. The boat, which was a custom altered jet ski, was small and low to the water.³¹⁷ Additional modifications, including a camera, a radio control link, and explosives, turned the recreational craft into a weapon.³¹⁸ Later in the month, Ukraine launched an air and maritime attack on the Russian naval base at Sevastopol.³¹⁹ At least seven drone boats penetrated the inner harbor and attacked docked Russian ships, including its flagship, the *Admiral Makarov*, and a minesweeper. It

is unclear how much damage this attack inflicted on the Russian warships, but it did prompt Russia to enhance defenses around the base and camouflage the bow and stern of its ships by painting them dark colors.³²⁰

Ukraine has now developed several variants of kamikaze drone boats and announced the creation of the 385th Separate Brigade, which operates these systems.³²¹ The drone boats tend to be around 16 feet long and weigh several thousand pounds. Because of their larger size, they can typically sail about 500 miles and carry a 600- to 700-pound payload, much more than most of Ukraine's aerial drones.³²² Because maritime drones can travel at up to 50 miles per hour and are low to the water, they can sneak up on larger ships undetected. Moreover, drone boats, which attack a ship at the waterline instead of from above, have the potential to cause more damage to a ship than aerial attacks because their explosive charge is aimed at the hull instead of the ship's superstructure.³²³ Each maritime drone costs about \$250,000 and is funded by Ukraine's "army of drones" project.³²⁴

In summer 2023, Ukrainian maritime drones supported attacks on the Kerch bridge, a Russian oil tanker, and a Russian landing ship in Novorossiysk.³²⁵ These attacks are part of Ukrainian's maritime denial strategy, which has sought to push Russia's naval forces away

from Ukraine's shoreline to bolster the security of its port cities. Maritime drones have been one of the few areas where Russia has not tried to copy Ukraine's ingenious use of uncrewed and commercial technology. Drone boat attacks have remained a niche part of the overall war effort but have offered Ukraine another means for taking the fight to Russia, potentially damaging its economy and forcing Moscow to divert more of resources to defensive operations instead of offensive ones.³²⁶

Tactical Battle Networks and Communications

The war in Ukraine is unique in the level of integration between drones and ground-based fires units, although these connections are not as automated as many assume. Although both Ukrainian and Russian troops have tactical battle networks, Ukrainian forces have excelled at developing open-sourced map-based software to fuse information from different sources and share it.³²⁷ Russia has developed similar propriety MOD systems that are not quite as user friendly. Additionally, Russia's more skilled forces use the military-developed Strelets tactical battle network.³²⁸ Virtual command and control networks that connect sensors—mainly on drones—with shooters have dramatically decreased the time required to engage dynamic targets.

While both sides use networks and software to connect drones with ground-based fires units, these systems are primarily at the tactical level and do not compile and provide real-time information from multiple sources. The most well-known mapping programs are Delta and Kropyvya, which were developed after the 2014 invasion of Ukraine.³²⁹ Aerorozvidka developed Delta, a mapping software for sharing information and tracking enemy force movements. Ukrainian troops manually upload information on Russian force locations from drones, satellites, social media, and human intelligence into Delta, which then displays this composite information as different layers on a map.³³⁰ Because information including drone footage is uploaded daily to Delta and is not given in real time, the information is not immediately actionable.³³¹ Still, Delta greatly enhances Ukrainian forces' situational awareness, enables them to more effectively and efficiently task drones to confirm targets, improves the routing of drone flights to avoid Russian EW systems and air defenses, and allows the sharing of BDA.³³²

Delta is widely employed by Ukrainian troops, but information is often segregated and not shared between different echelons and across units at the same echelon. For example, in fall 2022, there were significant

disconnects between higher headquarters and tactical echelons and between different tactical units, which is why each Ukrainian command insisted on having its own drones.³³³ Higher headquarters had more access to commercial satellite data and analytic tools, such as Palantir's AI target identification application, which was not shared with subordinate units. Meanwhile, tactical formations did not share data from their drones up the chain of command.³³⁴ In February 2023, the Ukrainian Ministry of Defence formally adopted the Delta application. There have been efforts to develop regional ISR centers to improve information sharing, but it is unclear how successful these have been.³³⁵

Additionally, Ukrainian soldiers use Kropyvya, more commonly known as "Uber for artillery," to coordinate ground-based fires.³³⁶ Kropyvya is another map-based application available on tablets and smartphones. Ukrainian soldiers upload data on their location and the location of Russian forces, which is displayed as a composite picture on a map.³³⁷ Commanders can use Kropyvya to help them match weapons to targets based on their availability and suitability.³³⁸ This helps optimize Ukrainian fires and conserve ammunition. When using Kropyvya, Ukrainian troops have been able to attack a Russian target in as little as 30 seconds after receiving

Russia has many command and control networks, but the one that has received the most attention in Ukraine is a tactical battle control network called Strelets.

coordinates obtained by drone.³³⁹ Using Kropyvya not only increases the responsiveness of Ukrainian fires, but also helps Ukraine to coordinate attacks from multiple directions to ensure a target is destroyed. Finally, by networking units together, Kropyvya enables Ukrainian artillery batteries to "shoot and scoot"—fire and then quickly move to another location—which increases their survivability.

Russia has prioritized infiltrating Ukraine's tactical battle networks because of their centrality to Ukrainian operations. Reportedly, a Russian hacker group associated with Russian military intelligence moved to the front lines to attempt a close-in infiltration of one of the Ukrainian systems.³⁴⁰ Russian hackers have also sent phishing emails to Delta users to access the system. Ukraine has attempted to bolster the cybersecurity of its networks and has taken steps to limit the information available to different users.

The backbone for all of Ukraine’s military communications and networks has been SpaceX’s Starlink satellite communications, which enable high bandwidth exchanges.³⁴¹ In the first 15 months of the war, Ukraine received over 30,000 Starlink terminals, which have been used by all frontline Ukrainian troops.³⁴² Starlink terminals enable applications such as Delta and Kropyvva to function and transmit drone video feeds to command posts. Although Starlink has proved quite resilient to enemy interference, SpaceX’s president, Elon Musk, reportedly geofenced Starlink signals so that they would not work in Crimea. Due to Musk’s earlier decision to limit Starlink’s reach, a planned Ukrainian attack on Sevastopol failed when Ukrainian operators lost control over their drone boats.³⁴³

Russia has many command and control networks, but the one that has received the most attention in Ukraine is a tactical battle control network called Strelets. Strelets has been a critical system tying together Russian military drones and artillery units in its reconnaissance strike complex. Early in the war, Russian forces either did not have or did not use Strelets, but over time, more elite units—such as the airborne or Wagner troops—increasingly employed this system.³⁴⁴ Strelets not only connects drones and other sensors to fires units, but also connects these lower echelon fires with a command post that can assign targets among the different batteries.³⁴⁵ Drone feeds simultaneously flow to lower level commanders, and the command posts and leaders at either echelon can authorize strikes.³⁴⁶ While Strelets helps Russian forces share information up and down a chain of command, they do not often share information across units, an area where Ukraine also struggles.³⁴⁷ Still, Russian artillery fires have become more responsive as its troops have made more widespread use of Strelets.³⁴⁸ Outside of Strelets, Russians have more heavily relied on radios and unencrypted analog military systems for communications, which are vulnerable to interception.³⁴⁹

Conclusion

In the ongoing war between Ukraine and Russia, both sides have employed drones to an extent never seen before. Because of the ubiquity of drones on the battlefield and the multiplicity of types, some observers conclude that drones are revolutionizing warfare. The findings of this report suggest the contrary. Drones have not fundamentally altered the character of war and will not determine who wins or loses this conflict.

Yet drones are transforming how Ukrainian and Russian troops fight. No Ukrainian or Russian unit

would try to maneuver or launch an assault without at least one small commercial drone to scout for the unit and enhance its situational awareness. Because quadcopters are readily available, Ukrainian and Russian troops at every echelon employ them, blanketing the front lines with eyes in the sky. Equally importantly, drones dramatically improve the accuracy of artillery fires, which are the dominant weapon in this war. Drone spotters enable imprecise indirect fire weapons to have precision effects. When drone operators use command and control networks to share information with artillery units, they can significantly accelerate targeting cycles, enabling responsive, precise fires. Small FPV kamikaze drones cost a fraction of other weapons and allow soldiers to attack moving targets beyond their line of sight, while Ukrainian and Russian forces employ long-range kamikaze drones as cheap cruise missiles to conduct strategic attacks. Individually these are notable advancements, but even cumulatively they do not add up to a revolution.

According to Andrew Krepinevich, revolutions in military affairs must “fundamentally alte[r] the character and conduct of a conflict” by “producing a dramatic increase—often an order of magnitude or greater—in the combat potential and military effectiveness of armed forces.”³⁵⁰ Revolutions in military affairs are so disruptive that they render old weapons, ways of fighting, and organizational constructs obsolete. Thus, revolutions require more than widespread adoption of new technologies. Additionally, militaries must develop new operational concepts, integrate new capabilities into broader military systems, and adapt their organizational culture and structure.³⁵¹ Not surprisingly, this wholesale sort of change does not often happen during a war because the combatants are focused on fighting and immediate tactical adaptations, not overhauling their doctrine and organization. In the Ukraine war, there have been rapid cycles of tactical innovation, emulation, and the development of new counters. Over time, these cycles could lead to more profound changes in operational concepts and how Russian and Ukrainian forces are organized, which could truly revolutionize warfare. By this standard, Ukraine represents, at best, the early stages of a revolution, as the effects of drones thus far have been more evolutionary.

Drones have had the most significant impact at the tactical level of warfare. They have provided cheap precision strikes either by directly attacking an enemy or, far more often, directing artillery shells to their intended aim point. Drones have been most impactful when networked together and connected to ground-based

fires units. While this type of battle network exists at tactical echelons, examples are rudimentary and still rely on soldiers manually inputting the data and making decisions that are often communicated through commercial channels, such as WhatsApp and Google Meet. Moreover, in both the Ukrainian and Russian militaries there are disconnects between units and up the chain of command that limit the operational effects of drones. Ultimately, most of the drones being used and lost today are relatively inexpensive military or commercial drones that have limited endurance, range, and payload and are susceptible to countermeasures, especially EW. Instead of investing in hardening these systems, both sides are simply buying or producing more of them. Moreover, the majority of drones are remotely piloted and not fully autonomous. Autonomy may be used in some systems, and it could become more prevalent, but currently, drones are tethered to human operators.

Beyond this general assessment about whether a revolution in military affairs has occurred, this analysis has yielded a number of insights about the war in Ukraine and drone warfare more generally:

In the Ukraine war:

- **Ukraine has consistently out-innovated Russia with commercial technologies and software, but Russian forces have quickly adapted and emulated Ukrainian successes.** Ukraine's volunteers and its private sector have been an engine for innovation and consistently led Ukrainian forces to be the first ones to adopt new drone technologies and tactics. Ukraine's ingenuity after the 2014 Russian invasion resulted in the creation of civilian organizations, such as Aerorozvidka, that developed homemade drones and software. This left Ukraine well positioned to immediately use commercial drones to defend against Russia's 2022 attack. Initially, Ukraine had an overwhelming advantage in commercial drones, but by the end of the year Russia had essentially caught up. At the same time, Ukrainian forces experimented with FPV racing drones for kamikaze attacks. They pioneered this new approach and began creating DIY cheap kamikaze drones. Once again, Russia was a fast follower and employed FPV kamikaze drones to contest Ukraine's summer 2023 counteroffensive. It is notable that a more centralized and top-down Russian military and society has been able to rapidly incorporate commercial technologies into its operations.
- **Volunteer networks have performed an unprecedented role in acquiring, modifying, and building commercial and DIY drones for both Ukrainian and Russian troops.** Because of a heavy reliance on commercial or dual-use technologies, patriotic civilians have been able to bolster drone production. They have also led broader efforts to professionalize the use of drones by identifying best practices and establishing training courses. Some of the most skilled drone operators on the Ukrainian side first emerged as volunteers, although they have subsequently been incorporated into the military.
- **Russia has an edge in military drones, which enables its forces to see and strike farther behind the front lines, while Ukrainian forces have gaps in this area.** Russia entered the war with a reasonable inventory of Orlan-10 and ZALA ISR drones and Lancet-3 and KUB-BLA kamikaze drones. These systems have considerably longer ranges and more endurance than commercial drones. Russia's military drone stockpiles proved to be insufficient given the number of Orlan-10s it lost early in the war and the quantity of loitering munitions it expended, but Russian industry has bolstered production of its most effective drones and seems to be meeting the current demand. Russia now has enough Orlan-10 and ZALA surveillance drones that Ukrainian forces sometimes do not bother trying to shoot them down because the Ukrainians know that the drones will be replaced. In contrast, Ukraine has smaller inventories of military drones—both ISR and kamikaze variants—which limits its forces' visibility and reach behind the front lines. This gap may eventually close as Ukraine's government is investing heavily in its indigenous drone industry. For now, Kyiv is encouraging thousands of flowers—or drones—to bloom. Eventually, the government will need to pick winners and losers so production can be scaled.
- **In the Ukraine war, drones have operated in stacks rather than swarms. Drones are more effective when operated as a part of larger team of unmanned systems.** In Ukraine, hunter-kill tactics—where one drone collects intelligence and targeting data and the other armed drone strikes the target—have been used extensively by both sides. Beyond tandem tactics, stacks of drones, not that dissimilar from stacks of manned aircraft, have become common. In a stack, drones are layered in the same vicinity but at different altitudes to prevent collision. Longer-range and endurance drones with better sensors are at the top of the stack providing persistent coverage of the battlespace

and cueing other drones if a potential target is spotted. Below them, there is another intelligence drone that obtains precise targeting information. A separate drone will often pass that information to ground-based fires units or to kamikaze drone operators, which will then strike the target. Drones provide intelligence, including battle damage assessment, and determine if the target needs to be reengaged. In contrast, swarms typically consist of a greater number of units that autonomously coordinate their behavior. The drone stacks in the war in Ukraine have been coordinated through multiple drone operators using software-based battle networks or traditional means of communication. Both parties claim to be using artificial intelligence to improve the drone's ability to hit its target, but likely its use is limited.

- **Russian and Ukrainian forces are using long-range kamikaze drones for penetrating strategic strikes.** Ukrainian forces would not have a capability to strike deep targets inside Russia and Crimea without these drones. Russian forces use kamikaze drones to complement their more expensive long-range cruise and ballistic missiles by soaking up Ukrainian SAM interceptors, identifying the location of air defenses, and creating complex heterogeneous attacks. It is not clear that strategic strikes weaken public support for the war, but they may be diverting scarce air defense assets from the front lines.
- **In the Ukraine war, both sides are experimenting with counterdrone capabilities.** EW is the most effective way to stop drones, but Ukrainian and Russian forces are trying counters that range from simple barriers such as wire nets to drone dogfighting. A key part of the drone-counterdrone competition has been finding and attacking drone operators using drone tracking software such as AeroScope and WindtalkerX. Because commercial and FPV kamikaze drone operators must remain near the drone's operating area, they are vulnerable to attack.

More general lessons about drone warfare include:

- **The accessibility and affordability of drones is creating new capabilities at a scale that previously did not exist and transforming the battlefield.** The three primary examples of this are the ubiquity of commercial drones on the front lines, FPV kamikaze drones for beyond-line-of-sight antipersonnel and antivehicle attacks, and long-range kamikaze drones for strategic strikes. All of these missions could be

completed by more expensive military systems, such as military drones, traditional manned air forces, and antitank weapons or artillery. The biggest difference is that because the commercially derived versions employed in Ukraine are cheap and plentiful, there are deeper stockpiles of uncrewed aircraft than have previously been available, enabling drones' widespread use. In the Ukraine war, every ground unit can be equipped with multiple commercial drones, which dramatically improves the units' tactical battlefield awareness. FPV kamikaze drones do not have the firepower of artillery or antitank weapons, but ground forces have a cheap capability to hold at risk moving targets from miles away. Long-range kamikaze drones are cheap enough to be used like decoys, yet also have the capability to damage a target, so the enemy must honor the threat they pose.

- **Surveillance and targeting missions remain more important than drone strikes.** Despite the prevalence of videos on social media showing commercial quadcopters dropping rocket-propelled grenades on soldiers or crashing into tanks, the most consequential mission for drones remains collecting intelligence and obtaining targeting information. Ground forces at all echelons are employing different types of drones to improve their situational awareness, planning, and operations. When drones are attached to artillery units, they replace human spotters and help to acquire targets, find their precise locations, track them, and then conduct battle damage assessment. Since howitzers provide most of the firepower on the battlefield and the biggest single constraint on artillery fires is the availability of ammunition, drones are helping conserve shells by making strikes more precise and thus effective.
- **Commercial drones are making it more difficult to concentrate forces, achieve surprise, and conduct offensive operations.** By providing greater visibility into enemy troop movements beyond the front lines, drones have made it difficult for the Ukrainian and Russian militaries to mass forces. Drones may launch harassing attacks on troops that are gathering or, more often, feed targeting information to tube artillery or long-range rockets to engage massed troops. Dispersion and concealment mitigate this vulnerability, but it is challenging for dispersed forces to launch large-scale offensive operations and break through heavily defended front lines. Intelligence collected from satellites also increases the transparency

of the battlefield, but drones enable a more rapid tactical response. Offensive operations are difficult but not impossible in this environment. If there are strong defenses in place, prolonged periods of bombardment can weaken the enemy and gradually enable territorial gains.

- **Kamikaze FPV drones offer cheap precision strike capabilities but are tactical beyond-line-of-sight weapons that primarily extend the reach of ground forces.** Ukrainian forces first experimented with using FPV drones in kamikaze attacks, but because these drones proved effective at hitting exposed and mobile targets, the Russians quickly also adopted them. FPV drones are essentially very cheap antitank weapons, but their range is roughly six times that of the most advanced antitank weapon. Nevertheless, they are still tactical weapons. Their biggest drawbacks are their small payload capacity, which limits their destructive power, and the fact that FPV drones, unlike modern antitank weapons, are not automated fire and forget systems. Instead, FPV drone pilots require training and must be very skilled to effectively steer the fast drones and crash them into vulnerable parts of an armored target. Even though experienced or lucky FPV operators might destroy a tank, more often FPV attacks will at most disable large vehicles, which can then be destroyed by follow-on artillery or air strikes.
 - **Even large numbers of small drones cannot match the potency of artillery fire.** Reusable military and commercial drones may be armed for ground attack, and kamikaze drones' primary mission is to conduct surface strikes. Collectively, drone strikes supplement indirect fire weapons, but they are not substitutes for howitzers. Common artillery shells pack a bigger explosive punch and can be fired rapidly in large salvos. Thus, artillery barrages far outstrip the firepower that even many small drones can collectively deliver. Moreover, drones must be individually piloted and their actions manually coordinated, which currently limits the size of offensive drone group attacks.
 - **Drones provide affordable airpower, but they have not replaced traditional air forces or been able to obtain air superiority.** A core mission of most air forces is obtaining and maintaining air superiority—that is, the freedom to conduct operations in the air, which include protecting against enemy aerial attacks and conducting offensive air-to-ground operations. Obtaining air superiority typically entails destroying an
- opponent's air force through air-to-air engagements or attacks against air bases and suppressing or destroying ground-based air defenses. There have been a few instances of drone dogfighting and kamikaze drone strikes against Russian bomber air bases, but these missions have been few and far between. Russian troops have effectively used hunter-killer teams of ISR and kamikaze drones for SEAD operations near the front lines. But Russian forces have not been able to destroy Ukraine's air defenses, especially its longer-range systems that are in rear areas. Early in the war, Ukraine used TB2s for interdiction strikes, but since Russian forces activated their air defenses, MALE drone air-to-ground strikes have largely ceased. Because neither side has obtained air superiority, they have both relied on standoff attacks instead of direct attacks against deep targets.
- **Drones are not more survivable than crewed aircraft, but instead enable greater risker acceptance.** Drones are vulnerable to many countermeasures, especially EW, guns, and SAMs. Like countries discovered the hard way with bomber aircraft in World War II, the drone “will not always get through.” But air defenses are not perfect and there are often seams that can be exploited if one is willing to undertake dangerous missions. Because drones are cheap and do not have humans onboard, both sides have been willing to send them on risky missions that may have a low probability of succeeding.
 - **Drones do not have to be survivable if they are cheap and plentiful because one can have resiliency through reconstitution.** Because they are vulnerable, drones must be cheap enough and easy enough to manufacture that they can be readily replaced. Thousands of commercial and DIY drones are lost each month to EW and small-arms fire. Despite China's ban on drone sales to both sides, commercial drones intended for hobbyists that are built by Chinese companies are readily available to both Russian and Ukrainian forces. These have been supplemented by DIY drones that rely on commercially available dual-use technology, such as FPV kamikazes, which are easy to manufacture. Instead of hardening commercial drones against electronic attacks, which would notably raise the costs, both parties have opted to instead buy more cheap drones. The logic of resiliency through reconstitution also applies to military drones. Russia, for example, has significantly bolstered production of its Orlan-10 and Lancet-3 drones, replenishing the systems that had been lost or expended throughout the conflict.

In the Ukraine war, drones have become an increasingly important weapon, but they have not revolutionized warfare. Nonetheless, Ukrainian forces have extensively employed drones to gain an asymmetric edge over a superior Russian force. Russian forces have been fast followers and emulated Ukraine's use of commercial drones to a surprising degree given the Russian MOD's reluctance to officially embrace private-sector technologies. Russian forces have employed their military-grade and kamikaze drones as a part of the reconnaissance fires complex, allowing them to increasingly leverage their greater firepower. Throughout the war, there have been rapid cycles of adaptation as both sides have learned from each other, adopting tactics and technologies that have been used successfully and developing counters to improve their defenses. This pattern is likely to continue as the war drags on. It is clear that drones alone will not determine who prevails in this conflict, but they will certainly play a prominent role in the ongoing war in Ukraine and in other battlefields in the future.

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6. Joshi, "Ypres with AI."
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9. Kelley Saylor, *A World of Proliferated Drones: A Technology Primer* (Center for a New American Security, June 2015), 11, https://s3.us-east-1.amazonaws.com/files.cnas.org/hero/documents/CNAS-World-of-Drones_052115.pdf?mtime=20160906082154&focal=none.
10. The author uses the terms "close fight" and "deep fight" to describe how drones were employed in different parts of the battlespace. This terminology comports with how the U.S. Air Force approaches counterland operations, which is delineated by the fire support coordination line (FSCL). Targets within the FSCL are considered close air support and require integration with ground forces, while targets beyond the FSCL are considered air interdiction or strategic strikes and do not require coordination with ground forces. This is not dissimilar to how the U.S. Army thinks about deep operations, although the U.S. Air Force's conception is broader than the Army's. The Russians also have a concept of deep attack. For more, see *Air Force Doctrine Publication (AFDP) 3-03 Counterland Operations* (U.S. Air Force, October 21, 2020), 9, https://www.dctrine.af.mil/Portals/61/documents/AFDP_3-03/3-03-AF-DP-COUNTERLAND.pdf; *Army Techniques Publication ATP 3-94.2 Deep Operations* (Headquarters Department of the Army, September 2016), 1-2, https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ATP%203-94x2%20FINAL%20WEB.pdf; and Jack D. Kem, ed., *Deep Operations: Theoretical Approaches to Fighting Deep* (Fort Leavenworth, KS: Army University Press, 2021), <https://www.armypress.army.mil/Portals/7/combats-studies-institute/images/LSCO%20DeepOps%20book%20interactive%20with%20cover%20spread%2012Nov21.pdf>.
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