

Does the Evolution of Drone Warfare in Ukraine Constitute a Revolution in Military Affairs or a Military Revolution?

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ABSTRACT

The widespread use of unmanned aerial vehicles, or drones, in the Russia-Ukraine war has significantly affected the way that conflict has been conceptualised, strategized, resourced, and fought by both sides. Major technological developments, coupled with innovations in how those technologies are integrated and used in warfare, can result in either a revolution in military affairs (RMA) or a military revolution. Whereas RMA refers to technological, tactical, doctrinal, or organisational changes limited to the military sphere, military revolutions not only affect how wars are fought but also reshape military organisations, societies, and states. Military revolutions are far less commonplace than RMAs; in fact, some military historians assert there have been

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just five military revolutions in the Western world since the 1648 Treaty of Westphalia. According to Andrew Krepinevich, then with the Pentagon's Office of Net Assessment, a military revolution has four components: Technological change, military systems evolution, operational innovation, and organisational adaptation. Given the considerable impact that drone warfare in Ukraine has had not only on combat and combatants, but on the organisations and societies that support them, would it be accurate to characterise drone warfare as a military revolution? Considering drone warfare in Ukraine through the prism of Krepinevich's four criteria enables us to understand how and why drone warfare in Ukraine indeed qualifies not only as an RMA but as a military revolution.

KEYWORDS: *unmanned aerial systems, drone warfare, military revolution, revolution in military affairs, Russo-Ukrainian war*

Introduction

Military revolutions

Two related but distinct terms used by strategic thinkers to characterise significant changes in how conflicts are waged are *military revolutions* and *revolutions in military affairs* (RMA). Historian Michael Roberts is credited with coining the phrase *military revolution* in 1956, then using it to describe “fundamental changes to the framework of war, recasting societies and states in addition to military organizations” (Morris, 2024). In 1992, Andrew Krepinevich of the Pentagon's Office of Net Assessment, identified four factors as contributing to military revolution: Technological change, military systems evolution, operational innovation, and organizational adaptation (Krepinevich, 1992). Murray and Knox (2001) identified five military revolutions that have occurred in the Western world since the 17th century: The first was the creation of the modern state and modern military institutions stemming from the 1648 Treaty of Westphalia, the second was the French Revolution and its *levée en masse* approach to national conscription, and the third was the Industrial Revolution. Morris (2024) concisely described the fourth military revolution, World War I, as “the combination of the first three revolutions” (para. 1). The fifth military revolu-

tion stemmed from the development of ballistic missiles and nuclear weapons (Murray & Knox, 2001).

Revolutions in Military Affairs (RMA)

Less expensive than a military revolution, but consequential, are RMAs, which are “clusters’ of technological, tactical, doctrinal, or organizational changes that are confined to the military sphere” (Morris, 2024). All five of the previously listed military revolutions were “associated with and resulted in certain RMAs” (Morris, 2024). Technology *alone* does not create an RMA; rather, that technology “requires organizational and doctrinal adaptation before the tactical and strategic potential of new weapons systems can be realized” (Murray & Knox, 2001). As an example, Murray and Knox pointed to the British longbow. This weapon had existed for at least half a century before doctrinal and organisational changes enabled it to achieve its devastating effectiveness fully (Murray & Knox, 2001). A more recent example of an RMA was Nazi Germany’s Blitzkrieg in France, which was based upon the exploitation of multiple “enabling technologies—tanks, radios, close air support—that had individually been around for some time” (Alach, 2008). More recently, the RMA concept gained renewed attention from American strategic thinkers in the 1990s, in the wake of the 1991 Gulf War, where the doctrinal, organizational, and operational synergy of multiple new technologies and capabilities enabled President Bush’s 35-nation Coalition to impose a crushing defeat on the fourth largest army in the world in just 100 hours (Collmer, 2007; Krepinevich, 1992).

The emergence and implications of drone warfare

Like the British longbow or the Nazi Blitzkrieg of 1940, drones and drone warfare have also been around awhile. However, recent technological developments have not only expanded the roles and missions of battlefield drones but also altered the very nature of armed conflict itself. Even non-state actors have become inspired to engage in drone warfare: The terror group ISIS “developed its own infrastructure, munitions, and aircraft without state patronage” (Achambault & Veilleux-Lepage, 2024). Hamas employed drones on 7 October 2023 to attack Israeli observation towers, while the Houthis in Yemen continue to use drones to attack commercial shipping and Western naval forces in the Red Sea (Ibid.).

This article addresses the question, “To what extent does the evolution of drone warfare in the Russia–Ukraine conflict constitute a military revolution rather than merely a revolution in military affairs (RMA)?” The answer to this question is not simply a theoretical matter: Given its low cost and high battlefield impact, drone warfare is already of considerable interest to both state and non-state actors, and the implications of drone warfare have already been revealed to have serious implications for military commanders, defence planners, and defence industries around the world.

We assert that drone warfare not only meets all the criteria for being considered an RMA but also Krepinevich’s four factors of military revolution: technological change, military systems evolution, operational innovation, and organisational adaptation.

Methodology

This study draws on a moderated technological determinist perspective, which holds that technological innovation, when coupled with doctrinal and institutional adaptation, can be a primary driver of social, organisational, and military change (Salsoni et al., 2020). As Williams and Edge (1996) observed, Technological Determinism argues that “technological change thus produces social and organisational change” (p. 868). Also relevant to this study was Davis’ (1989) Technology Acceptance Model (TAM), which posits that perceived ease of use and perceived usefulness of a new technology drive user adoption of that technology. The way and extent to which Russian and Ukrainian armed forces embraced the use of drones on the battlefield not only changed how battles are fought but also had demonstrable, second- and third-order impacts on each side’s approach to targeting, defence, military resource allocation, logistics, and strategy. This study seeks to answer the question, “To what extent does the evolution of drone warfare in the Russia–Ukraine conflict constitute a military revolution rather than merely a revolution in military affairs (RMA)?” To answer this question, we examined drone warfare in the Russia-Ukraine conflict through the lens of Krepinevich’s (1992) four factors of military revolution: Technological change, military systems evolution, operational innovation, and organizational adaptation. Our qualitative methodology was two-fold: First, we reviewed publicly available literature on drone warfare and analysed it through the prism of Krepinevich’s four factors. Then, we conducted semi-structured

interviews with 10 subject matter experts (SMEs) on drone warfare in the Russia-Ukraine conflict and performed content analysis to interpret their responses thematically and in context (see Appendix A). Researchers compiled a list of individuals they collectively knew to have relevant, recent expertise on drones, drone warfare, and the Russia-Ukraine conflict. Using the “snowball effect” method to identify prospective interviewees (Noy, 2008), researchers first approached these individuals and asked whether they knew others with comparable backgrounds and experiences. Researchers created a semi-structured interview guide that enabled them to ask all interviewees the same core questions (for consistency) while also permitting follow-up questioning when deemed useful (Adams, 2015). Researchers requested, and received, approval from Mercyhurst University’s Institutional Review Board (IRB) to interview the identified prospective sources. Once the interviews were transcribed, researchers familiarised themselves with the data, coded and categorised it, identified themes, and developed a framework (Tumiran, 2025). The semi-structured interviews referenced in this article were conducted by the authors between March and July 2025; selected quotations are drawn from the co-author’s 2024 master’s thesis, which reports on the same interview corpus. Researchers acknowledge that, while the 10 interview respondents were extremely knowledgeable and forthcoming, they represented only a small sample of Western military thinking on the subject.

Findings

Our findings below are clustered according to Krepinevich’s (1992) four factors of military revolution: Technological change, military systems evolution, operational innovation, and organisational adaptation. Following this are our findings regarding some implications of developments in drone warfare.

Technological Change

The use of unmanned aerial vehicles in warfare is not new; in fact, the first recorded use of an unmanned aerial system to attack an enemy was in 1849, when Austrian forces dispatched explosives-laden balloons over Venice, Italy, as they besieged the city (Kozera, 2018). The U.S., U.K., and Nazi Germany all tinkered with unmanned aerial systems in World War II (Kindervater, 2016).

Interest in unmanned aerial systems continued during the Cold War, spurred in part by both the success and limitations of the U-2 spy plane. While the overhead imagery provided by the U-2 was incredibly useful, putting U-2 pilots at risk of capture or death made that imagery potentially too costly (Ibid.). For the U.S. and NATO, surveillance drones really attained operational maturity in Bosnia-Herzegovina in the 1990s and during the 78-day bombing campaign against Serbia in 1999, where “drones could direct a bomber to a target, watch the target (often undetected), and assess the aftermath of the bombing” (Ibid.). Weaponised drones are a more recent development; during the first two decades of the 21st century, the U.S. successfully conducted nearly 4,000 Predator and Raptor drone strikes in Afghanistan, Iraq, Pakistan, Yemen, Somalia, Syria, and Libya (Clark, 2024). Significantly, though, those operations all targeted technologically inferior enemies, rather than any peer or near-peer opponents (Bartosiak, 2019). In the fall of 2020, Azerbaijan achieved strategic surprise (and lopsided battlefield success) over Armenia when it employed both bomb-dropping and suicide drones to destroy very large numbers of Armenian tanks, armoured vehicles, anti-aircraft systems, and artillery (Reed & Rife, 2022). Although the Armenian military also possessed drones, their drone capabilities were limited to reconnaissance and surveillance (Reed & Rife, 2022). Today, the use of weaponised drones by both Russia and Ukraine in a major, peer-to-peer conflict represents a new chapter in the history of drone warfare.

The early success of Turkish Bayraktar-2 drones

Taking a page from the Azerbaijan-Armenia conflict two years earlier, Ukraine responded to Russia’s invasion in 2022 by using Turkish Bayraktar TB-2 drones, which “played an eye-catching role in Ukraine’s fight back during the initial stages of the invasion” (Milasauskas and Jaškūnas, 2024). In those early days of the war, Ukrainian TB-2s successfully struck “five tanks, six towed artillery pieces, six naval ships, two logistics trains, two multiple rocket launchers, two anti-aircraft guns and over a dozen surface-to-air missiles” (Gosselin-Mallo, 2023). After such initial success, however, Ukrainian commanders asserted that Russian air defense improvements had severely reduced the utility of those drones (Ibid.). As Interviewee C observed, larger drones achieved success early in the conflict. However, as air defences and electronic warfare became more sophisticated and involved, “there started to be very severe limitations to stuff like the Bayraktar” (Ruth, 2024).

First Person View (FPV) drones

Interviewee G asserted that Russia's four-to-one advantage in artillery was one of the main drivers for the Ukrainian military to turn to FPV drones:

The Russians, I do not know the exact ratios, but it was at least a four-to-one advantage [in artillery]. Their artillery capabilities meant that they were utterly pulverising Ukrainian positions and able to win ground, and Ukrainian soldiers were trying to find any way to equalise this imbalance. That is why FPVs came in, because soldiers on the ground were like, 'Well, we can take these little drones we have been using for reconnaissance, we can strap [on] a grenade, maybe we can find an artillery position.' That is what really drove it: this realisation that they can attempt to equalise the massive material disparities between the two armed forces in the field by using FPVs (Ibid.).

Purchasing or building multimillion-dollar drones under license was not an option for Ukraine, whose per capita GDP of \$5,760 is one seventh that of the Western European average of \$38,270 (Watling et al., 2023). Therefore, rather than attempt to build sophisticated, multimillion dollar drones like the Predator, Raptor, or TB-2, the Ukrainian Armed Forces (UAF) instead "began purchasing huge numbers of off-the-shelf fliers worth a few hundred dollars apiece – the kind used by filmmakers and enthusiasts – and turned them into highly lethal weapons" (Pultarova, 2025). Ukrainian First Person View (FPV) drones, costing as little as USD \$500 each, thus became "the preferred platform for mounting explosives and executing targeted strikes" (Milasauskas & Jaškūnas, 2024). As Interviewee D noted, "There has been a dramatic shift towards large numbers of locally made multicopters, in particular FPV attack drones" (Ruth, 2024).

The expansion of drone sizes and configurations

Initially, the UAF favoured seven-inch FPV drones because they were easy to assemble, "but growing operational demands have shifted preferences toward 9-10 inch quadcopters capable of carrying heavier payloads and achieving longer ranges" (Bondar, 2025). Modularity has enabled UAF operators to quickly transform a basic FPV platform into "a kamikaze drone; a bomber; an intelligence, surveillance, and reconnaissance (ISR) system; or a relay node" (Ibid.).

EW and EW countermeasures

Ukraine has employed a variety of techniques to combat Russian drones, ranging from pickup trucks mounted with machine guns and military aviation to FPV interceptor drones and laser weapons (Hunder, 2025). But the most significant threat to drones is EW jamming: at one point, Ukraine was losing around 10,000 drones a month, primarily due to EW jammers (Watling et al., 2023). “There are now tens of thousands of jammers straddling the front lines of the war” (Pultarova, 2025). FPV drones rely on radio control, so an adversary’s electronic warfare (EW) capabilities remain “the Achilles’ heel of FPV drones” (Milasauskas & Jaškūnas, 2024), Ukraine has also introduced drone control systems that use frequency-hopping systems and frequencies outside the standard range of Russian EW jammer systems (Pultarova, 2025). As one side develops a new technique, the other side soon counters it. As Interviewee G observed, “If the Ukrainians come out with a new prototype of FPV, within a month or two the Russians have already wised up in terms of EW countermeasures. So that is where the Russians are quite good” (Ruth, 2024).

Fiber optic guided (FOG) drones

In early 2024, the Russian military introduced fibre-optic-guided (FOG) drones that used spools of optical fibre, which could not be jammed by EW systems (Watling et al., 2023). As Interviewee I explained,

The drone flies from its launch position on a fibre-optic cable, and the cable can transfer all power and data, or it can be configured to do so. So, the signal emission is very low off of the platform. So, it is literally impossible to jam. ...We have seen in reporting [drones] flying missions up to thirty kilometres and hitting their targets. So that is a tremendous amount of fibre optic. But I would say that, predominantly, they fly on spools of fibre somewhere between 15 and 20 kilometres. Then they try to hit their target below 15 kilometres, so they have some extra fibre in the spool to divert the mission elsewhere (Ruth, 2024).

Drones controlled by fibre optic cables “are resistant to electronic warfare interference” (Ukrainian drones, 2025). One of the Ukrainian countermeasures used to defeat Russian FOG kamikaze drones was to deploy anti-drone nets over military positions (Hambling, 2025a).

Countering EW through AI and autonomous navigation

Both the Russian and Ukrainian armed forces use electronic warfare, or EW, to jam or disrupt the communication signals between drone operators and their drones (Hunder, 2025). This has not only forced the development of EW-immune fibre optic guided (FOG) drones, but also the development of automated targeting that guides the drone to its target using artificial intelligence (Hunder, 2025). Not surprisingly, the UAF now “sees the future in autonomous navigation” (Watling et al., 2023). The UAF’s enthusiasm is understandable: By incorporating artificial intelligence (AI) into their drones, Ukrainian forces have increased targeting accuracy by up to 80 percent (Bondar, 2025). Using smaller datasets “enables fast and efficient onboard processing on the limited computing power of small and inexpensive chips” (Ibid.). In addition to being more accurate, drones possessing AI guidance reduce the cost of drone strikes because one or two AI-enabled drones can now achieve the effect of eight or nine earlier drones (Ibid.). Interviewee D asserted that, “AI-enabled drones have a higher hit rate than manually guided ones in a jamming environment” (Ruth, 2024). Another benefit of incorporating AI software is that UAF drone operator training has been dramatically reduced (Bondar, 2025). Just like Russia’s FOG drones, UAF’s autonomous drones can also evade jamming; however, unlike Russian FOG drones, which must sacrifice range and payload to compensate for carrying a spool of fibre optic cable, AI-enabled autonomous drones can carry more, and farther, while placing less demand on their operators (Watling et al., 2023). The Russians, too, have fielded AI-enabled drones: A new Russian kamikaze drone, first observed in May 2025, features a 14 MP camera, a laser rangefinder, and a 100 GB hard drive with a Jetson AI computing module, enabling it to navigate without GPS (Roy, 2025c). Interviewee C said, “Even if an FPV drone is jammed, say twenty yards from the thing it is trying to hit, if it is jammed, it could have that autonomous system kick in and continue that last twenty yards. If it loses signal, it does not just fall out of the sky unless it has been told to do that” (Ruth, 2024).

Military Systems Evolution

According to Krepinevich, *military systems evolution* refers to the integration of technologies and capabilities “into – and across – networks of systems” (Krepinevich, 1992). Some drone-related examples of this have been evident in the Russia-Ukraine conflict.

Russian importation and use of Iranian suicide drones

Russia has purchased and has made extensive use of Iranian Shahed suicide drones in its war with Ukraine. In April 2025, Russia launched nearly 2,500 Shaheds against Ukraine; while over 80% were shot down, almost 20% got through (a, 2025a). Shaheds originally carried a 100-pound warhead, and some were found to have been packed with ball bearings and other intended shrapnel; more recently, the Shahed warhead was upgraded to a more powerful thermobaric warhead (Hambling, 2025a). In addition to carrying an explosive warhead, Shaheds have also reportedly dropped delayed cluster munitions before impacting their targets (Hambling, 2025a).

Ambush drones

Ambush drones are the name given to Russian FOG drones that land near roads and are activated when approaching vehicles are detected. “Fiber drones need relatively little power to communicate, so they can perch in this way for long periods” (Hambling, 2025b).

The fielding of drone defence systems

Ukraine has deployed anti-drone systems, such as Sky Hunter, to direct FPVs against larger Russian fixed-wing drones, including the Shahed, Zala, Supercam, and Orlan (Roy, 2024). Sky Hunter software “automates the process of downing enemy UAVs with FPV drones, minimising human involvement in this process” (Yan 2025).

Operational Innovation

Krepinevich (1992) asserted that, “Having advanced technological capability and military systems does not guarantee success for those states seeking to realise a military-technical revolution. The manner in which these capabilities are employed also will determine whether their full combat potential is realised”. Both the UAF and the Russian armed forces (RAF) have been innovative in their use of drones, both offensively and defensively.

The expanding list of drone functions

Over the last three years in Ukraine, drones have been called upon by both sides to perform an expanding range of functions, to include intelligence, surveillance, and reconnaissance (Kunertova, 2023), land mine detection and elimination (Baur, 2024; Kasianchuk & Lastivka, 2023), serving as an airborne communication node for deployed FPV drones (Bondar, 2025), artillery spotting (Reed & Rife, 2022), dropping bombs and returning (Axe, 2025), suicide drones that fly one-way kamikaze missions (Hambling, 2025a), “mother ship” drones (Hunder, 2025), shooting down enemy drones with onboard shotguns (Baker & Epstein, 2025), and serving as ambush drones (Hambling, 2025b). Interviewee B described how Ukrainian drones were used to conduct battle damage assessments (BDA) after M142 High Mobility Artillery Rocket System (HIMARS) munitions strikes (Ruth, 2024).

Conceptualisation of the drone battlespace

Drone warfare has changed how combatants conceptualise the battlespace. The airspace above the battlefield is now characterised as “small air” (low-level, where FPVs operate), “middle air” (where reconnaissance drones tend to operate), and “big air” (where fighter jets operate) (Roy, 2025b).

The integration of drones into both sides’ military strategy

In August 2024, Ukraine’s surprise incursion into Russia’s Kursk region, which resulted in the capture of approximately 500 square miles of Russian territory, was enabled by Ukraine’s effective use of drones and EW (Hambling, 2025a). “Radio reconnaissance had established the operating frequencies of Russian drones flying in the area. At the start of the attack, these frequencies were jammed by a barrage of electronic warfare, sweeping the skies clear of Russian reconnaissance drones. The advantage would only be temporary until the Russians were able to change frequencies, but Ukraine used this window to send in its own attack drones in ‘an incessant barrage of high-precision FPVs, which go in swarms’” (Ibid.). After stabilising the front, the Russians deployed a large number of new FOG drones that were impervious to Ukrainian EW jamming; this, coupled with the introduction of North Korean troops, enabled the Russians to recapture most of the territory they had previously lost (Ibid.).

Soliciting foreign expertise (but on a shoestring budget)

Since the start of the war on February 24, 2022, both Ukraine and Russia have solicited outside expertise in the conduct of drone warfare. In 2022, Iranian military personnel were observed on Russian-occupied territory in Ukraine, advising Russian forces on how to make the most effective use of Iranian-made Shahed drones (Vergun, 2022). Ukraine, too, has benefited from foreign advice, expertise, and equipment; for example, the Estonian firm KrattWorks continues to provide Ukraine with its Ghost Dragon ISR quadcopter, now in its third generation (Pultarova, 2025). UAF soldiers liked foreign-made drones, such as the U.S.-provided Switchblade, but found them too expensive. Cheaper, Ukrainian-built models are often preferred because it is easier to obtain tech support for them (Gallagher, 2025).

Increasing drone range

In addition to short-range tactical drones, both the UAF and RAF possess and employ medium- and long-range drones. For example, Ukraine successfully operates drones like the Rubaka, which has a range of up to 500 km and a payload capacity of two to 15 kg, to target and disable Russian air defence systems or their critical components in Crimea (Khomenko, 2025).

Long-range drone strikes against targets in Russia

Ukraine has also successfully used long-range drones to conduct strikes on critical targets deep inside the Russian Federation. In April 2025, DeepStrike (long-range drones) hit 62 targets in Russia, destroying military facilities and undermining the aggressor's (Russian) military-industrial complex, according to UAF Commander-in-Chief, Oleksandr Syrskyi (Kirichenko, 2025). "Moscow's military planners now wake to urgent calls about facilities they thought untouchable, destroyed by weapons that didn't exist last year" (Ibid.).

Counter-drone team tactics

One tactic Ukrainians have recently developed to combat Russian fibre-optic-guided (FOG) drones is to attach a device to the fibre-optic thread of an impacted Russian drone that provides a traceable trail back to the immobile launch site of the drone. "Now if they stay in place, Russian FOG-FPV drone operators die too" (Telenko, 2025).

Drone versus drone systems

Ukraine uses its Techno Taras interceptor drone “to shoot down Russian reconnaissance UAVs” (Kozatskyi, 2025). “The Ukrainian ‘Techno Taras’ UAV intercepts and destroys Russian fixed-wing reconnaissance UAVs like ‘Zala-16’ and ‘Supercam-S350,’ and costs only \$1600. This is remarkably cost-effective as a “Zala-16”, for example, which costs the Russians approximately \$70,000 (Roy, 2025d). The Techno Taras drone system includes 20 drones (15 for daytime operations and 5 for nighttime operations), a ground control station, and a catapult (Kozatskyi, 2025). By late April 2025, 160 of the 274 deployed Techno Taras drones had shot down 133 Russian UAVs, giving them a success rate of 83% (Ibid.). Another Ukrainian counter-drone system involves equipping a reusable FPV drone with a modified 12-gauge shotgun (creating a so-called “shotgun drone”) that shoots down Russian Mavic drones “just like a fighter jet” (Zhluktenko, 2025).

The development of counter-countermeasures

Alarmed by the success of the Techno Taras system, the RAF began installing additional cameras atop their reconnaissance drones to detect Ukrainian interceptors (Yan, 2025). Whenever such UAF drones appear and approach, “the reconnaissance drone automatically executes a programmed manoeuvring algorithm to avoid the strike” (Ibid.). In addition to rear-facing cameras, other Russian countermeasures designed to protect their reconnaissance drones include net throwers, “dedicated jamming or decoy drones,” and flying their drones at four to five km altitudes to exceed the capabilities of Ukrainian anti-drone FPVs (Roy, 2024). The RAF have also experimented with installing EW systems on its reconnaissance drones intended to detect and disrupt Ukrainian FPV radio communications with its ground controller (Ibid.).

Infecting enemy drones with malware

Captured Ukrainian drones have allegedly been enabled to infect Russian systems with malware that burns out the USB port and prevents reflashing or hijacking the repurposed (captured) FPV while “revealing the operator location” (Mittal, 2025). An additional benefit of this capability is that it would impede the Russians’ ability to reverse-engineer a captured drone and develop countermeasures. UAF encryption of a drone’s onboard AI software prevents

the Russians from reverse engineering it, enabling Ukraine to maintain its technological advantage (Bondar, 2025).

Targeting of a Russian fibre optic cable factory

Because Russian FOG drones are reliant upon spools of fibre optic cable to operate, on 4 April 2025, UAF long-range drones struck Russian fibre optic and munitions factories in the Samara and Mordovia districts near Moscow (Ukrainian drones, 2025).

Development of reusable bomber drones

The UAF originally took the propeller-powered Aeroprakt A-22 civilian sport plane and modified it to serve as a long-range suicide drone; more recently, the UAF further modified it to fly up to 2,000 km away, carrying a 250 kg bomb – and return, making it “potentially the most powerful reusable drone” in the war (Axe, 2025).

The development of drone “mother ships”

Ukraine has reportedly developed a mothership drone capable of carrying a pair of FPV drones up to 70 miles, releasing them, and then acting as a communications relay back to the drone operators (Hunder, 2025). Interviewee C opined, “I think that that is something where we can see drones replacing manned operations entirely. Such operations would allow future military planners the option to approach targets from unexpected directions while also extending the range of smaller systems” (Ruth, 2024).

Ukrainian development of missile-drone hybrids

To increase both range and lethality, Ukraine has developed long-range missile-drone hybrids, such as the *Palianytsia* and *Peklo* models, “which use turbo-jet engines as cruise missile alternatives” (Taradiuk, 2025).

The increased scale of drone attacks

Seeking to overwhelm and confuse defenders, the Russians regularly launch more than a hundred drones into Ukraine at a time, mixing Shahed suicide

drones with “much cheaper, flimsier decoy models that can use up Ukraine’s limited stockpiles of air defence missiles” (Hunder, 2025).

Investing in technology to gain a technological edge

Colonel Vadym Sukharevskyi, head of Ukraine’s Unmanned Systems Forces, asserted that Ukraine is using AI, an increasing number of ground drones, and laser weapons to combat Russian drones (Hunder, 2025).

Organisational Adaptation

Although the UAF and RAF both use drones extensively, there are clear differences in their strategic intent and priorities. “While Ukrainian long range drone strikes target Russian weapons factories, oil storage sites and military airbases, Russia is focusing its efforts on waging a campaign of terror against civilians” (Hambling, 2025b). For example, Russia’s largest-ever drone attack in the war occurred in November of 2024, when 188 Russian drones were sent against the electric power grid in Ternopil in western Ukraine, cutting off water supplies and heat at the onset of winter (Malenko, 2024). Another key Ukrainian goal is to “remove warfighters from direct combat and replace them with autonomous unmanned systems” (Bondar, 2025). This objective stands in stark contrast to repeated instances of Russian human wave infantry assaults that invariably result in enormous Russian personnel and equipment losses. For Ukraine, given the numerical superiority of Russian forces, reducing combat losses has been “an existential necessity” (Ibid.).

The fielding of tactical drone teams

Ukraine’s establishment of drone warfare units that “typically serve in specialized teams located around two to five kilometers away from the front line”, which “provides them with relative security” (Milasauskas & Jaškūnas, 2024). Ukrainian drone teams are such “prized targets” for the Russian military that they routinely use 1,000-pound glide bomb munitions to attack them (Santora, 2024).

Establishment of the Unmanned Systems Forces

On 16 September 2024, the UAF established its “Unmanned Systems Forces (*Сили безпілотних систем*)” as a separate branch of its armed forces, “co-equal with the Special Operations Forces and the Territorial Defence Forces” (Matlack et al., 2025). Its commander, Colonel Vadym Sukharevskyi, “was simultaneously appointed to serve as a deputy to the Commander-in-Chief Oleksandr Syrskyi, underscoring the centrality of drones to the war effort” (Ibid.).

The development of a drone ecosystem

Matlack et al. asserted that rather than just the drones themselves, “it is the ecosystem comprising the military, volunteers, NGOs, drone schools - in short, ‘the crew’ - that produces positive results” (Ibid.). “Private companies, civilian volunteer organisations, NGOs, and the Ground Forces and Unmanned Systems Forces of the AFU comprise the primary actors within this constellation” (Ibid.). The drone ecosystem draws on the civilian sector for specialised skills and critical contributions in software development, production, and fundraising. Matlack et al., labelled this “indispensable” civilian-military collaboration as “War DevOps,” where “high-velocity pressures from war accelerate iterative cycles of drone development to warp speed” (Ibid.), “Within three years of the February 2022 Russian invasion, Ukraine produced a world-class defense-tech ecosystem that is not only attracting Western innovators into its fold, but also regularly surpassing them” (Watling et al., 2023). By November 2024, Ukraine’s Ministry of Defence had approved more than 30 schools for military drone operators to qualify for Military Occupational Speciality (MOS) 216, “UAV External Crew Members” (Matlack et al., 2025).

Increased investment in Ukraine’s drone sector

Krepinevich noted that, “An adaptive, flexible, and innovative acquisition system will become increasingly important as the rate of technological change increases” (Krepinevich, 1992). That appears to have been the case in Ukraine. “What began as a grassroots effort in 2014 has evolved into full-scale production: by late 2023, nearly 40% of frontline weapons were domestically made. In 2024 alone, Ukraine produced 1.5 million drones — with over 95% of those used at the front now built at home” (Kirichenko, 2025). In 2024, Ukraine produced 1.5 million drones, with over 330 approved drone models, the majority

of which were kamikaze drones (Ibid.). The success of Ukraine's long-range drones in entering and operating within Russian airspace, and in conducting precision drone strikes hundreds of miles inside Russian territory, led Ukraine to increase its production of long-range drones 100-fold, to over 500 per month (Haynes, 2025).

The pros and cons of crowdfunding

In this study, 9 of 10 interviewees noted that crowdfunding positively impacted the UAF's ability to acquire and field drones (Ruth, 2024). Crowdfunding enables UAF units to acquire the drones they need directly. As Interviewee D said, "Crowdfunding has been a key enabler on both sides [...], and many units would not have drones without crowdfunding" (Ibid.). Unfortunately, crowdfunding also has a downside: As Interviewee C noted, UAF units with English-speaking, social media-savvy members or supporters have an advantage in acquiring a drone through crowdfunding. Another downside of crowdfunding that Interviewees mentioned is the risk that donated funds could be misused or stolen (Ibid.).

The scale of investment in drones and related technology

Another indication of the impact drone use has had on this conflict is the massive expansion in drone production and use. "Since Russia invaded Ukraine in 2022, there has been a vast expansion in drone use. Ukraine says it made 2.2 million small First Person View (FPV) drones and 100,000 larger, long-range ones in 2024. Russia previously gave estimates that it would make 1.4 million FPV drones in the same year" (Hunder, 2025).

Conclusions

Thomas (2025) opined that, in Ukraine, "the use of drone warfare at the tactical level has signified a new epoch in modern warfare. Innovations in doctrine, specialized units, and technological advances, such as fibre-optic guided uncrewed systems, have all contributed to the drone supplanting contemporary military platforms as the prime lethal threat". Drone warfare certainly meets all the criteria to be considered an RMA, and as we have shown, it would also appear that drone warfare also meets Krepinevich's four factors of military rev-

olution: Technological change, military systems evolution, operational innovation, and organizational adaptation. As a military revolution, drone warfare has dramatically changed the way both state and non-state actors think about, strategize, equip for, and wage war – both offensively and defensively. A dozen or so of the implications of this tectonic shift are listed below.

The Appeal of Drone Warfare

Drones are a relatively low-cost option for combatants. “FPV drones can be produced for 500 USD and fixed-wing reconnaissance drones for 1,500 to 3,000 USD” (Matlack et al., 2025). Ukraine’s Serhiy Prytula Charity Foundation asserted that the cost of one Techno Taras drone, used to target Russian reconnaissance drones and with a range of around 35 km, is only USD \$1,600 (Kozatskyi, 2025). A larger, more sophisticated Russian reconnaissance drone, such as the Merlin, costs around USD 300,000. If Ukraine successfully uses a USD 1,600 drone to take down a Merlin, or a USD 2,000 FPV drone to destroy a Russian tank, armoured vehicle, or other weapons system costing millions of dollars, that is pretty favourable math (Ibid.). As one executive from a Kyiv-based EW firm explained, “A missile is worth perhaps a million dollars and can kill maybe 12 or 20 people. But for one million dollars, you can buy 10,000 drones, put four grenades on each, and they will kill 1,000 or even 2,000 people or destroy 200 tanks” (Pultarova, 2025). For Ukraine, cost is far from the only consideration; another one of the drivers causing the UAF to place so much emphasis on drone warfare is that using drones enables them to minimize exposing friendly soldiers on the battlefield (Rickli & Mantellassi, 2024).

The Battlefield Impacts of Drone Warfare

As Kunertova (2023) asserted, “The war in Ukraine is clearly changing military thinking about drones and their deployment”. Drone warfare is what allows Ukraine to hold its own against numerically superior Russian forces: “If it wasn’t for drones, everything would be a lot worse. Drones are the things which allow us to give an asymmetrical response (when) the enemy is larger, stronger and on the attack” (Hunder, 2025). The proliferation of drones at lower tactical levels results in what Interviewee D described as “a pervasive, persistent sensor web which sees everything within 10km of the frontline” (Ruth, 2024). Interviewee H noted that drones provide a key component of the battlefield intelligence picture because drones provide “sensor fusion data integration into

battle management systems...I think this system is the most important development that we see, but it is always overlooked” (Ibid.). Not only are drones responsible for helping Ukraine hold their own against larger Russian forces, but they are also responsible for causing a staggering 80% of Russian casualties (Santora, 2024). At the end of April 2025, Ukrainian army chief Oleksandr Syrskyi claimed that Ukrainian drones had struck over 160,000 enemy targets in March and April of 2025 alone, enabling Ukraine to inflict heavy losses on Russian forces from a distance without putting infantrymen’s lives at risk (Zadorozhny, 2025). The Ukraine conflict “is by far the most lethal in generations and has brought industrial-level slaughter to Europe, only this time through the use of drone- and digital-era technology and efficiency” (Thomas, 2025).

Social media and the psychological, legal, and ethical impacts of drone warfare

Thanks to the widespread availability and use of social media, adversaries in a conflict can (and do) use drone footage to produce propaganda material. Drone footage captured by the UAF during the Russians’ bogged-down ground assault on Kyiv in 2022 is but one example of this (Ruth, 2024). While Interviewee G noted that, “it is also great fun to show your enemy you can get to him,” Interviewee E pointed out that there may be serious legal and ethical concerns associated with posting drone video to social media:

I think the whole problem is that even though I think that it is beneficial to spread that you are winning the war, and here you can see two or three Russian or Ukrainian soldiers, depending on which side you’re cheering for, being killed. It is not legal to do that. It is not lawful. You are not supposed to be able to identify who it is, so it is a war crime de facto, regardless of if it is on the Ukrainian or Russian side (Ibid.).

Have drones made infantry weapons like mortars and machine guns obsolete?

This is precisely the argument offered by Pukhov (2025), the director of the Moscow-based think tank Centre for Analysis of Strategies and Technologies, in a 17 February 2025 essay for the Russian state-run newspaper *Rossiyskaya Gazeta*. Pukhov argued that drones have brought about “almost total ‘transpar-

ency' of the battlefield," as a result of which "any covert transfer, deployment, concentration and use of forces become, in essence, systemically impossible". Drones have already replaced artillery as the main cause of casualties (Martyniuk, 2025), accounting for nearly 80% of Russian battlefield casualties in Ukraine (Thomas, 2025).

The West needs to develop and field inexpensive and effective counter-drone solutions

The financial disparity between a USD 500 FPV flying into and demolishing a multi-million dollar main battle tank (and killing its crew) has been evident for years. Unfortunately, the converse is also true: High-end NATO air defence systems conceptualised and built to counter ballistic missiles and jet aircraft are not cost-effective for engaging enemy drones. More suitable options now under development include the Leonidas system, developed by Epirus, Inc., in California, which uses a solid-state, high-powered microwave to emit electromagnetic pulses to disable drones individually or across a wide area (Khosia, 2025).

Air superiority no longer means what it once did

Air superiority describes a situation in which one side dominates a conflict, controlling the skies and denying the enemy the use of its airpower. For nearly a century, air superiority virtually ensured the success of land forces. But what if both sides in a conflict have drones capable of the range of missions both the UAF and RAF have conducted against each other?

Drones now put supply lines, high-value targets, and critical infrastructure at risk

As Ukraine's advance into Kursk and then Russia's recapture of its lost territory revealed, "drone strikes seem to have been an important factor" (Hambling, 2025b). In 2024, Ukraine began building so-called "tunnel nets" over main supply routes to guard against attack by Russian FPVs (Engineering Support Brigade, 2024). The drone threat to supply lines is not just tactical, but strategic as well: Russia has thus far proven unable to prevent Ukrainian precision, long-range drone strikes against petrochemical facilities, military airfields, Shahed drone storage sites, and fuel and ammo dumps deep inside Russia (Haynes,

2025). These long-range strikes allegedly reduced Russian petrochemical production by 10% and resulted in the loss of 3,000 Shahed drones (Ibid.).

Waging drone warfare against peer or near-peer competitors will be a new experience

While it is true that the U.S. has successfully conducted nearly 4,000 Predator and Raptor drone strikes in Afghanistan, Iraq, Pakistan, Yemen, Somalia, Syria, and Libya (Clark, 2024), those operations all targeted technologically inferior enemies, and not peer or near-peer opponents (Bartosiak, 2019). Interviewee C compared those types of drone strikes to ones more commonly seen in Ukraine, saying:

If you think about how the U.S. used Predator drones and stuff like that, there is a trailer in Nevada and a guy overseeing it, who is pretty far away from Afghanistan or Iraq or wherever. ...but now it is getting to the point where you would integrate a drone squad into very low levels, like in the order of battle, the platoon level, the company level (Ruth, 2024).

Every boat can now conceivably be an FPV aircraft carrier - or other kinetic threat

Although this article has singularly focused on *aerial* unmanned vehicles in the Ukraine conflict, UAF maritime drones have also been successfully used in this conflict. Not only can ships and boats be used to transport and launch airborne drones, but they can also be uncrewed and serve a variety of military purposes ranging from intelligence collection and resupply to kinetic attacks. Both Russia and Ukraine possessed maritime drones in 2022. Ukraine, which no longer has any manned surface ships in its navy, has nevertheless achieved tactical successes against Russia's Black Sea Fleet using maritime drones. On 29 October 2022, Ukraine used Mykola maritime drones to attack the Russian naval base on Sevastopol in Crimea, damaging the frigate *Admiral Makarov* and minesweeper *Ivan Golubets* (Sutton, 2024). On 2 May 2025, a pair of Ukrainian Magura uncrewed surface vehicles (USV) operating near the strategic Russian naval base at Novorossiysk achieved a historic "first" when they reportedly shot down two Russian Su-30 Flanker fighter aircraft with short-range, air-to-air missiles (Sutton, 2025).

Unmanned tactical vehicles

In addition to aerial and maritime drones, the UAF has successfully fielded unmanned, mobile weapons systems mounting heavy machine guns. The UAF fielded 600 unmanned weapons systems in 2024; this number will increase to 8,000 for 2025 (Naumov, 2025).

The West needs to study and learn battlefield lessons from Ukraine

NATO countries such as Estonia, Denmark, Finland, and Canada are among those stepping up investment in drone-related facilities, activities, training, and production (Martyniuk, 2025).

Western countries need to reassess their training practices

A pair of British parliamentarians told a *Financial Times* reporter that British soldiers on a field training exercise in the U.K. were prohibited from “flying drones over their comrades or using signal-jamming equipment” (UK military prevented, 2025). “The MPs warned that stringent rules potentially leave British troops heading to the Russian border without sufficient training in modern warfare” (Ibid.).

Western countries must better secure their drone production supply chain

U.S. drone manufacturers rely on China, which “controls close to 90 per cent of the global commercial drone market” for key drone components like “airframes, batteries, radios, cameras, and screens” (Jeans, 2025). On 1 June 2025, the Security Service of Ukraine (SBU) conducted a covert operation deep inside Russia, sending 117 FPV drones against five major Russian airbases. Reflecting on that operation, Participant I said:

The lesson learned from that is that all militaries are going to have to completely address that potential of an attack and also acknowledge that, in military operations, normally there is a forward line of troops, there is a front line. Then there is a more secure area where you have maybe logistics taking

place and then you might have medical facilities and things of that nature. Even in the homeland, you have the industrial base. None of those areas is secure given the advent or evolution of this technology. Everything is what we would call ‘touchable’ at this point (Ruth, 2024).

The enemy always gets a vote

Drones can be used in a variety of creative ways by both state and non-state actors, so it is more necessary than ever for Western countries to adequately understand how a state or non-state adversary thinks, know what their military doctrine and capabilities are, and avoid surprise by anticipating how (and where) their adversaries *could* conceivably employ drones in a conflict. As Interviewee A observed, events on the battlefield in Ukraine can influence the thinking and capabilities of state and non-state actors worldwide through the “seepage of information outside the conflict” (Ruth, 2024). Interviewee A said:

The internet enables the instantaneous, global transmission of information. We know that non-state armed groups (NSAG) across Africa coordinate and collaborate. We know they share information with criminal groups in South America, and that they talk to Middle Eastern NSAG and Asian NSAG organisations. This stuff is out there, so if it is just loose inspiration or specific manuals being disseminated, the more you do this, and let us say in Ukraine, the more this stuff is publicised, the more you are potentially going to spread the inspiration and the know-how around the world (Ibid.).

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Appendix A: Interviewees

Table 1. Interview Participants

Participant	Participant Background	Date of Interview	Length of Interview	Location of Interview
Participant A	British military	18 March 2025	45 minutes	Virtual (Microsoft Teams)
Participant B	United States military	24 March 2025	1 hour 30 minutes	Virtual (Microsoft Teams)
Participant C	United States Intelligence community	26 March 2025	1 hour 18 minutes	Virtual (Microsoft Teams)
Participant D	Journalist covering war in Ukraine	26 March 2025	1 hour	Virtual (Microsoft Teams)
Participant E	Swedish military	14 May 2025	58 minutes	Virtual (Microsoft Teams)
Participant F	United States military, United States intelligence community	20 May 2025	56 minutes	Virtual (Microsoft Teams)
Participant G	Researcher on drone warfare	25 May 2025	1 hour 45 minutes	Virtual (Microsoft Teams)
Participant H	Researcher on drone warfare, AI expert	27 May 2025	49 minutes	Virtual (Microsoft Teams)
Participant I	United States Military, drone consulting	8 July 2025	45 minutes	Virtual (Microsoft Teams)
Participant J	United States Military	12 July 2025	1 hour	Virtual (Microsoft Teams)

Predstavlja li evolucija dronskog ratovanja u Ukrajini revoluciju u vojnim poslovima ili vojnu revoluciju?

SAŽETAK

Široka upotreba bespilotnih letjelica, ili dronova, u ratu između Rusije i Ukrajine značajno je utjecala na način na koji zaraćene strane koncipiraju, strateški planiraju, opremaju i vode taj sukob. Značajni tehnološki razvoj, u kombinaciji s inovacijama u načinu na koji se te tehnologije integriraju i koriste u ratovanju, može rezultirati ili revolucijom u vojnim poslovima (RMA) ili vojnom revolucijom. Dok se RMA odnosi na tehnološke, taktičke, doktrinarne ili organizacijske promjene ograničene na vojnu sferu, vojne revolucije ne utječu samo na način na koji se vode ratovi, već također preoblikuju vojne organizacije, društva i države. Vojne revolucije su daleko rjeđe od RMA; zapravo, neki vojni povjesničari tvrde da je od Vestfalskog mira 1648. u zapadnom svijetu bilo samo pet vojnih revolucija. Prema Andrewu Krepinevichu, tada zaposlenom u Pentagonovom Office of Net Assessment, vojna revolucija ima četiri komponente: tehnološke promjene, evoluciju vojnih sustava, operativne inovacije i organizacijsku prilagodbu. S obzirom na značajan utjecaj koji je ratovanje dronovima u Ukrajini imalo ne samo na borbe i borce, već i na organizacije i društva koja ih podržavaju, bi li bilo točno opisati ratovanje dronovima kao vojnu revoluciju? Promatranje ratovanja dronovima u Ukrajini kroz prizmu Krepinevicheva četiri kriterija omogućuje nam da shvatimo kako i zašto ratovanje dronovima u Ukrajini doista nije samo RMA, već i vojna revolucija.

KLJUČNE RIJEČI: *bespilotni sustavi, dronsko ratovanje, vojna revolucija, revolucija u vojnim poslovima, rusko-ukrajinski rat*