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Australian Army Occasional Paper No. 29

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Serving the Nation

ISSN (Print) 2653-0406
ISSN (Digital) 2653-0414

DOI: https://doi.org/10.61451/267513

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Cover image: A group of Ukrainian soldiers stand triumphantly on a hill at sunset, raising their national flag while a drone flies overhead. Photographer Viktoriia (Source: Adobe Stock Images)

Abstract

Drone operations have added a new chapter to modern warfare. In Ukraine, uncrewed aerial systems (UAS) have become an important weapon to gain an asymmetric edge over Russian forces. The lessons learnt from the use of UAS in Russia's war against Ukraine are almost innumerable and extend from the individual soldier level to tactical, strategic and government levels. This paper summarises highlights from the first evidence-based research on the lessons learnt from the use of UAS to date in the war in Ukraine, drawing on both Ukrainian and Australian expertise.

Overall, multi-domain and cross-domain uncrewed systems (UxS) represent a transformative advance in military technology, reflecting significant investment and development worldwide. As nations continue developing and deploying these systems, it is crucial to understand their implications and integration into Australian tactics, techniques and procedures (TTPs). By maintaining an accelerated cycle of innovations and learning from Ukraine, nations such as Australia have the opportunity to stay ahead of their adversaries, ensuring that they are prepared to meet contemporary and future strategic challenges during conflicts.

One lesson from the war in Ukraine remains clear—uncrewed systems are disrupting the way modern warfare is being fought, and rapid technological adaptation and continuous innovation in UxS will be critical in future warfare. This paper provides recommendations for the Australian Defence Force (ADF) to understand both the opportunities and the limitations that drones bring to inform future doctrine, training and planning, as well as future investments in these technologies that can have an asymmetric effect on the battlefield.

Contents

Introduction

UAS, commonly known as drones, have altered the dynamics of military operations, offering unique tactical advantages and enhancing operational efficiency in various combat scenarios.[1] The war in Ukraine is the first war that has seen drone warfare used on an unprecedented scale. Drones are being used for various purposes, including surveillance, reconnaissance, and targeted strikes. Drone technology has proliferated in the air, in the sea, and recently on Ukrainian soil. Uncrewed systems operations have included uncrewed aerial vehicles (UAV) that track enemy forces, identify targets, guide artillery, and drop ordnance and other weapons; uncrewed combat aerial vehicles (UCAV) used for long-range strikes deep into Russian territory; uncrewed surface vehicles (USV) used to launch attacks on Russian naval forces in the Black Sea; and uncrewed ground vehicles (UGV) used for logistics and mining or de-mining purposes.[2] It is fair to say that drone technology has become a critical weapon in Ukraine's efforts to gain an asymmetric edge over Russian forces. This paper will explore how this technology has been used in the war, drawing heavily from interviews with Ukrainian operators.

The war in Ukraine is making one observation very clear: uncrewed systems have a place in modern warfare. In Ukraine, drones have become an important weapon in the fight against Russian forces. Their availability, rapid development, and ease of deployment and use make them indispensable in military operations. While this technology had already altered the character of modern warfare prior to the war in Ukraine, UAS have not previously had such a decisive effect on the adversary.[3]

The ADF recognises that UAV technology is changing the character of the modern battlefield, and this fact is well documented in relevant security studies and military literature. However, the literature on drone warfare to date has focused on two decades of Western counterterrorism operations and has showcased the use of large drones in remote warfare; the transformative effects of drones on international security and stability; and the legal and ethical implications of 'dronified' foreign policy.[4] The war in Ukraine is the first large-scale, high-intensity war where both sides have extensively deployed military and commercial drones in warfare. As such, the war is revealing lessons previously missed by the existing literature on UAV technology.

Overall, UAS warfare has become less about technological sophistication and more about the ability to deploy 'high volume, low-cost' technology, as well as the need for multi-spectrum and layered combinations of both kinetic and non-kinetic countermeasures to achieve effective air defence.[5] The Ukrainian government's partnership with private companies and its work outside of the traditional military procurement processes have illustrated the advantages of integrating commercial systems that are relatively cheap and often quick to produce and deploy.[6] These new methods of operating have been spurred by the 'Army of Drones' initiative—a project between the Ukrainian government's digital transformation ministry and the President of Ukraine's UNITED24 fundraising platform. This initiative has facilitated rapid expansion of the domestic drone industry by delivering streamlined procurement measures that have enabled a massive increase in production (i.e., from seven to 200 manufacturers of UAS just over a year). Associated with this, there has also been an exponential increase in repair capabilities and the number of trained drone operators.[7]

Systematically drawing lessons from Ukraine's use of UAS provides important evidence-based insights into the technology–security nexus. It addresses gaps in security studies and military literature about the current 'drone challenge', drone proliferation and the future of ongoing innovations. It also offers important examples for the Australian Army and the integrated force as it considers Australia's own future capability and technology requirements. These lessons will be important for integrating this 'new weapon' into the ADF's operational and strategic strike concepts, as well as in efforts to adapt to the new epoch in warfare.

The findings of this paper may confirm some existing assumptions about the role and proliferation of UAS on the modern battlefield. They may also highlight shortfalls in the pre-UAS era doctrine. When considering future force structure and capability acquisitions, this research offers valuable insights into the implications of using UAS now and into the future. The findings have relevance to the use of UAS systems and counter-UAS (C-UAS) systems, and also to the associated logistical demands of achieving survivability among a dispersed force.

Drone operations have added a new chapter to modern warfare. They may not guarantee immediate territorial gains, but they can significantly influence the ideological and political alignment of an adversary at a much lower cost than is possible using conventional technologies. Although previous research and publications on the lessons learnt from the Ukraine war were based on experts' observational analysis, this paper offers the first evidence-based research drawn from interviews. In doing so, it offers an in-depth review of the up-to-date lessons learnt from the war, supported by data provided by experts in both Ukraine and Australia. It is important to note that much of the information in this paper is based on open-source material. Further, given that the war is ongoing, the views published here should not be perceived as universal and definitive. Lessons need be continuously learnt and research should be ongoing to understand the fast-evolving nature of drone and counter-drone technological innovations. Nevertheless, this paper makes a substantive contribution to the ongoing debate on drone technology and the changing nature of modern warfare.

For the purposes of this paper, the term 'drone' is used to refer to an uncrewed aircraft. The term will be used interchangeably with the concepts of UAV, UAS, remotely piloted aircraft, and remotely piloted aircraft systems, to signify a flying drone that is 'uncrewed' or 'remotely piloted'. Some of these systems have a degree of autonomy. The overarching aim of the research was to understand how drones are changing modern warfare and to summarise the lessons learnt from the use of UAVs in the Russia–Ukraine war. For the purposes of this paper, the research seeks to answer two questions:

1. What are some of the lessons that can be learnt from the use of drones in the Russia–Ukraine war?
2. What are the recommendations to the ADF based on this analysis?

Methodology

Participants

In total, 27 participants took part in interviews as part of this research. Participants were all over 18 years old, were Ukrainian or Australian citizens, and had both military and non-military expertise. Specifically, participants were defence staff or experts in aviation, had a focus on UAS and C-UAS, and worked in the fields of academia, industry or government. The industry representatives varied from drone operators and manufacturers to future warfare, military operations and technology experts. Figures 1 and 2 show a summary of demographic information. The research contained in this paper was completed in June 2024. The research was approved by the Departments of Defence and Veterans' Affairs Human Research Ethics Committee.

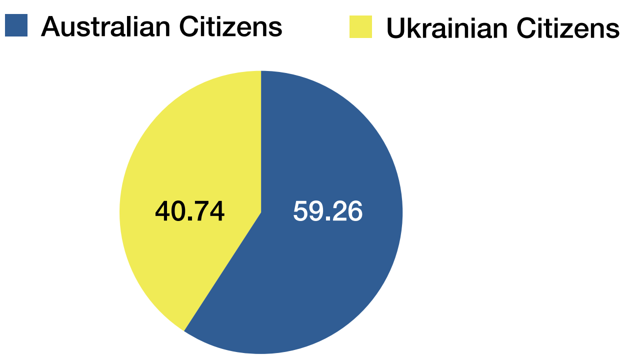


Figure 1. Demographic data: distribution by country of residence

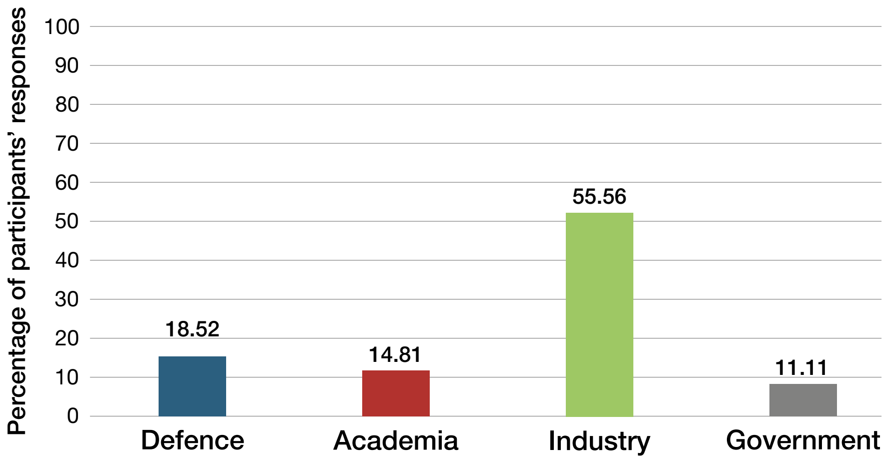


Figure 2. Demographic data: distribution by area of work

Materials

This study employs qualitative research methodology. A semi-structured interview process was selected as the most suitable approach to explore the perceptions and opinions of respondents. This method enabled more information to be probed and for clarification to be sought about the answers, examples and comments provided on the topics of interest.[8] The interview method met the research aims and enabled multifaceted exploration of the lessons learnt from the use of drones in the Ukraine war. It has allowed the production of qualitative data that is sufficiently rich and nuanced to shed light on these complex issues.

Data collected as part of research is classified as OFFICIAL—that is, available in the public domain. The interview sessions were conducted online and took no longer than one hour to complete. The virtual platforms contained built-in recording functionalities that ensured accurate documentation of interview sessions. User-friendly interfaces reduced technical barriers, ensuring smooth interview experiences. Instead of a recorded session, some interviews comprised written notes when that approach was preferred by a respondent.

Data Analysis

On completion of each interview, the collected data was transferred to secure storage for transcription and translation (10 interviews were translated from the Ukrainian language). A further stage of data interpretation and analysis was conducted using NVivo 14 software for qualitative analysis. The data files were imported into NVivo 14 software, where they were coded. Thematic analysis was employed to identify recurring patterns, themes and insights within the dataset, following Braun and Clarke's six-stage approach.[9] This iterative process involved becoming familiar with the data, generating initial codes, searching for patterns, reviewing and refining themes, and writing up the thematic analysis. NVivo's visualisation features allowed word clouds and concept maps to be generated, which provided clarity around the presentation of results.

The Role of UAS in the War in Ukraine

Historical Evolution of UAVs: a Brief Overview

UAS have played a pivotal role in shaping the course of military history. From the first remote-controlled aerial target in the First World War to the 21st century, UAS of different shapes, sizes and purposes have continued to evolve.[10] Early types of drones were developed to attack German airships during the First World War (i.e., drones by the British Royal Flying Corps), to deliver a payload of explosives (the US unmanned biplane), or for aerial targets (the UK Queen Bee drone).[11] In the Second World War, both Axis and Allied forces used drones; for example, small drone aerial targets were produced in the US for the army and navy, while Germany developed drones for surveillance missions.[12] During this period, drones were used in reconnaissance and surveillance missions and for intelligence gathering behind enemy lines, providing critical real-time data from the battlefield. Artillery units used drones to extend the range of observation for target acquisition and this remained unchanged for decades.[13]

In modern warfare, drones have become far more technologically advanced, from the MQ-1 Predator and MQ-9 Reaper used for targeted strikes, to the RQ-4 Global Hawk and MQ-4C Triton used for high-altitude surveillance. Following the September 11 terrorist attacks on the United States in 2001, MQ-9 Reapers used by the Central Intelligence Agency were equipped with advanced sensors and precision-guided munitions like the AGM-114 Hellfire missile. From this point, the role of drones shifted from being that of a mere observer to that of an active combatant, capable of conducting targeted strikes with pinpoint accuracy. As the global war on terror pivoted coalition states away from conventional strategies focused on occupying territory and towards a strategy that dismantled enemy networks using intelligence-led strike systems, drone technology enabled high-value individuals to be targeted by ground forces or directly with weapons carried on the drones themselves. These systems also moved beyond the control of intelligence agencies into widespread military use. Drones had now taken on the role of terrorist ‘hunter-killers’.[14]

A characteristic of drone technology is that the use of these platforms is sufficiently inexpensive for state and non-state actors alike. The US military first encountered the use of commercially available drones by a terrorist group when they were employed by ISIS to carry out aerial attacks (dropping grenades) in Mosul, Iraq, in 2016.[15] This event marked a new type of threat, requiring US forces to adapt to the possibility of attacks coming from the sky rather than just from the horizon. While previously benign, the auditory cue of a drone overhead now signalled imminent danger as it meant that a grenade or other explosive device could be dropped at any moment. Since that time, almost all American soldiers deployed to Iraq have been trained on drone recognition, most have received basic training on drone defeat, and some have been armed with commercially available counter-drone systems. This training has significantly reduced experiences of ‘a shock’ from seeing a drone in action.[16]

In the past two decades, the US has utilised drones in counterterrorism operations in regions such as Iraq, Syria, Afghanistan, Pakistan and Yemen, highlighting their capability to execute precise strikes with reduced risk to friendly personnel. In 2020, another notable example was the use of drones in the Nagorno–Karabakh conflict, deployed for precision strikes and surveillance, which significantly affected the conflict’s outcome by providing superior aerial intelligence and strike capabilities.[17] However, the war in Ukraine has seen the first large-scale deployment of smaller drones—by both Ukrainian and Russian forces—for real-time intelligence gathering and direct combat engagements, illustrating the tactical versatility of these systems.[18] This unprecedented use of drones on a large scale offers valuable lessons for the ADF. It is essential that these lessons are understood and acted upon if Australia is to develop the capacity to use drone capabilities and tactics in future warfare.

Evolution of the Use of Drones in the War in Ukraine between 2022 and 2024

At the beginning of Russia's full-scale invasion of Ukraine on 24 February 2022, the Armed Forces of Ukraine (AFU) perceived drones as 'toys'. However, they were already saving the lives of Ukrainian soldiers.
The DJI Mavic commercial drone (the so-called 'wedding drone' due to its prior use in recording weddings) was not technologically advanced but was originally used by the AFU for intelligence, surveillance and reconnaissance (ISR) operations, watching enemy forces in Irpin, Gostomel, and elsewhere across Ukraine. The DJI drones were affordable (the cheapest option being US$500) and accessible (available off the shelf).[19] Previously, during the first outbreak of conflict in 2014, drones had not been widely used by the AFU. Nevertheless, volunteers were buying drones and soldiers were trying to learn how to use them. Since February 2022, any UAV that can record the situation on the ground from above has become highly valuable because they provide information in real time.

> *We started using these drones from 2016 in the Donbas region, sometimes to watch what's enemy doing. At that time, volunteers were supplying drones to the soldiers, who were experimenting with their use and operation. But since 2022, soldiers who could operate a drone were 'on cost of gold' because they could obtain information in real time. All the drones which could film anything in the air in 2022, in the first stage of war, were used. (P21)*

By 2024, the Ministry of Defence of Ukraine had already adopted and operated more than 300 models of UAVs of various types, including reconnaissance drones (see Figure 3), strike drones, 'kamikaze' drones and loitering munitions.[20] Today, drones are regarded by Ukraine as a powerful military capability and their weapons payloads are useful not only in the air but also on the sea and land. Drones now have a range of roles including adjusting artillery fire, conducting aerial reconnaissance, maintaining situational awareness, striking enemy targets, mining and de-mining some areas, delivering cargo, and evacuating the wounded.

It is important to remember that the AFU first employed uncrewed systems not because they were unique or innovative, but because of a lack of other resources at the time. Attaching a grenade to the DJI Mavic was not a novel solution, but it could be used in the absence of artillery or other weapons to protect territory and save human lives. Ukrainian military forces, including the AFU and the Territorial Defence Forces of Ukraine (TDFU), had to innovate to stop the adversary's invasion.

Figure 3. Magyar Birds prepare for a mission
(Source: reproduced with the permission of the owner)

> *In 2023, when Ukraine Defence Forces faced a shortage of artillery shells, and armoured vehicles, that's why the armed forces started to rely on drones, robots and electronic warfare. While more weapons are needed, only drones are allowing us to stop Russians at this point. (P14)*

In August 2022, the Magyar Birds squad was formed. The Magyar Birds soldiers were a group of men who were mobilised as part of the TDFU (a military reserve component of the AFU). They formed a group that started to use drones, and to innovate and expand their application, and was the first separate unit of UAVs in the AFU. They were the first to use both first-person view (FPV) drones and kamikaze drones (see Figure 4).

Figure 4. The Magyar squad during a mission
(Source: reproduced with the permission of the owner)

One of the Magyar soldiers stated:

> *So, first we were soldiers with weapons just to shoot someone on the battlefield, and we knew nothing. When I used a drone for the first time in August 2022, I was so excited when I could understand what was in front of me, what enemy were doing there, because when you see it in your trench—you can only see the line of horizon and that's all. But when you raise this drone, and you see that there's not too many of them (Russians) or they have no machine. And everything changes, we understand the battlefield better, you can secure your squad from unexpected enemies shooting, etc. The best drone which was used and is still being used is DJI Mavic 3 Combat ($1,600). While the Chinese manufacturers are doing now everything for us to not to use these drones in our area, our research teams do special PC boards which are installed in the DJI drones, and they cannot do anything to us. It's not a secret. It's used from both sides, Russian and ours, but we were first. (P21)*

Since its establishment, the Magyar squad has become instrumental in the ongoing conflict against Russian forces through its innovative use of drones for various military operations. The unit primarily used the DJI Mavic to locate enemy forces, patrol the front line, spot artillery, conduct kamikaze drone attacks, and occasionally drop explosives on enemy positions (see Figure 5). The technology was also used in more complex missions during major battles such as those conducted in Bakhmut and for the destruction of Russian equipment in the Kherson region. The Magyar squad's drone operations provided critical reconnaissance and offensive capabilities, significantly contributing to the AFU's efforts to hold and retake key positions.

Figure 5. Magyar Birds setting the UAV for a mission
(Source: reproduced with the permission of the owner)

> *The first rule for the 'Magyars' is to secure our people. Soldiers [need] to be protected. All algorithms of using drones must be organised to prioritise safety. In 2023 we first launched FPV drones. It was difficult … In Bakhmut, they were flying within distance of 2 km maximum. But these 2 km helped to understand what to do next. Once we knew which algorithms worked, we shared information with other soldiers, drone pilots to increase the use of drones. (P21)*

The Magyar Birds have demonstrated how UAVs can be used not only for reconnaissance but also for direct action against enemy forces. Their activities underscore the increasing importance of integrating advanced technologies and flexible tactics to adapt to the dynamic battlefield conditions.

Classification and Types of UAS in Ukraine

Table 1 shows an overview of how UAS are being used in the war in Ukraine, including their classifications. Drones are generally classified based on distinct characteristics such as function, size, payload, geographical range, flight endurance and altitude. According to the NATO classification, the drone dynamics in Ukraine have showcased Class I and Class III drones, where Class I drones are less than 150 kg and Class III drones are greater than 600 kg.[21] In the war in Ukraine, small military drones—both fixed-wing and rotary, integrated with the ground units—have been commonly used for surveillance, target acquisition, battle damage assessment and information warfare.[22] Class III medium altitude long endurance (MALE) drones are large surveillance and strike drones. They are useful for gathering information over extended periods of time (between 12 and 26 hours, with a General Atomics MQ-9 Reaper now achieving up to 40 hours) and they can execute remote strikes. The focus of drone use in Ukraine has been on Class I to III drones that can be used in four ways:

1. precise payload delivery (dropping explosives or kamikaze attacks)
2. surveillance (scouting enemy positions, coordinating an attack, or artillery observation)
3. nuisance/loitering (infrastructure disruption, using drones to jeopardise the safe operation of major facilities such as airports)
4. cyber/hacking (using proximity to enemy networks to hack in via drone and degrade/infiltrate the networks).

Table 1. Overview of the use and classification of UAVs in the war in Ukraine

Level of need/ importance of the task of UAVs	UAVs purpose of use	NATO classification (based on max take-off weight)	UAVs used in Ukraine based on class	UAVs most often used by Ukrainian forces	Foreign-made UAVs most often used	UAVs most often used by Russian forces
• Tactical (at the level of platoon, company, battalion) • Operational-tactical (battalion-brigade) • Operational (brigade, connection of several brigades) • Operational-strategic • Strategic (Army Headquarters or General Staff)	• ISR drones • Corrective drones • Kamikaze drones • Attack drones • Loitering munitions • Transport and evacuation drones • Repeater drones and electronic reconnaissance (EWD) drones	• Class I drones: Small (<150 kg), Mini (<15 kg) and Micro (<2 kg) • Class II tactical drones (between 150 and 600 kg) • Class III drones: HALE, MALE/ combat (>600 kg)	• Class I: • Small: Baba Yaga, Switchblade-600 • Mini: DJI Mavic, DJI Phantom, R18, Warmate, HERO-120 • Micro: DJI Mini • Class II medium-range drones: Stork-100, Fury, UJ-22, UJ-23 Topaz, UJ-26 Beaver • Class III operational-tactical drones: PD-2, Raybird-3, TB2 Bayraktar • Class IV (strategic UAVs capable of spending 24 hours in the sky): Atlas	• Punisher • PD-2 • Leleka-100 • A1-SM Fury • ACS-1 Valkyrie • Raybird • Sorcerer • R-18	• TB2 Bayraktar (Turkey) • Switchblade (US) • Fly Eye (Poland) • DefendTex D40 (Australia) • Autel EVO (US and other manufacturers) • DJI (China) • Quantix Recon UAS (US) • Atlas Aerospace (Latvia)	• Sea Eagles: Orlan-10, Orlan-30 (Russia) • Lancet (Russia) • Shahed-136 (Iran) • Aileron (Russia) • Lastochka-M (Russia) • Griffin-12 (Russia) • DJI (China)

Class III UAS were prominent during the early stages of the war. For Ukraine, this involved use of the Turkish TB2 Bayraktar, carrying four smart laser-guided munitions, as well as a capable multi-spectral sensor payload for information collection and targeting.[23] Russia used the Kronshtadt Orion, Lorsar, and Forpost-R MALE fleet. These types of drones were valuable in offensive air operations as well as for gathering information over a long duration. However, their survivability is poor in non-permissive environments like that found in the frontline areas of the Ukraine–Russia war. Provided neither of the sides had established air superiority, both sides relied heavily on small, attritable and commercial-off-the-shelf UAS capabilities.[24]

To date, both Ukraine and Russian military forces have used a range of UAS. Ukraine has employed the ‘Wild Hornet’ FPV UAS, the Punisher, which is a low-cost reusable attack drone that is domestically produced. It has also used the SHARK and Leleka-100, as well as ScanEagle and Puma ISR UAS (provided by Western partners), and the Chinese-made DJI Mavic quadcopters. Russia has used DJI Mavics and the Orlan-10 (and later Orlan-30) multi-use UAS, which can be equipped with various payloads and electronic warfare (EW) capabilities. Furthermore, both sides have employed, in a single platform, UAS that are fitted with loitering munitions (LM) for a broad range of missions including the suppression and destruction of enemy air defences, ISR, communication nodes, data transfer and strike.[25] LM are autonomous missiles designed to stay airborne for some time, identify a target and then attack. These systems blend features of both drones and precision-guided weapons. The term ‘loiter’ indicates the amount of time between launch and detonation. LM UAS represent a bridge between precision-guided weapons and future autonomous weapon systems.[26] FPV UAS, a commercial version of a military loitering munition, have been dubbed the ultimate asymmetric weapon. They may cost from a few hundred to a few thousand US dollars. In contrast, military-grade loitering munitions are more expensive; for example, the cost of the Russian-made ZALA Lancet loitering munition may be between US$35,000 and US$60,000.

At the tactical level, Ukraine and Russia have employed short-range UAS for reconnaissance and targeting and for long-range platforms, some capable of striking over 1,000 km.[27] For example, Russia employed Shahed long-range attack drones in the autumn of 2022 to fly into Ukrainian targets, including civilian infrastructure and energy facilities. At the same time, Ukraine has developed its own drones to strike targets deep inside Russia such as military factories and oil refineries. The Ukrainian UJ-22 Airborne can fly up to 800 km autonomously or be controlled by a pilot and deliver precision bombing strikes on static targets within a smaller range, while the UJ-26 Beaver can carry 20 kg of payload and fly over 1,000 km.[28] While large drones with missiles can be destructive under conditions of air superiority, small drones are proving crucial for battlespace awareness of infantry and manoeuvring units. Additionally, low-cost, one-way kamikaze attack drones offer another way to deliver explosives.[29] The success of UAS-enabled targeting networks currently depends on their effective integration into a battle management architecture that leverages multi-modal information across command and control (C2) nodes, and on their ability to remain resilient to degraded communications environments.[30]

In recent months, the AFU has started to use 'mass effect' drone operations where several drones, sometimes with diverse capabilities like electro-optical, infrared, communications link, and kinetic capabilities, are flown in concert. Each drone is controlled by a single pilot with the intention of confusing (if not overwhelming) the enemy and their counter-drone systems. The effectiveness of these operations has not been rigorously tested but participants generally agreed this could be highly effective, perhaps for no other reason than that operators on the ground in Ukraine—from both sides—are traumatised by the sounds made by drones and tend to take cover whenever they hear a drone's high-pitched buzz.

The process of deploying this technology begins with reconnaissance drones equipped with high-spec cameras that transmit real-time video back to their pilot's control screen, allowing the operator to look for enemy targets from above (see Figure 6). Meanwhile, larger winged reconnaissance drones fly further back from the front line and see much further into enemy territory. When targets are spotted, their coordinates are relayed to commanders through secure messengers and entered into an Automatic Tactical Management System, 'Kropyva', that allows commanders to enter target coordinates into a tablet, and then the direction of firing and the distance to the target are calculated automatically (see Figure 7).[31] Following this process, commanders then determine the best method to strike a specific target. The software is reminiscent of 'Uber for Artillery' in that it assigns targets to the nearest artillery battery or missile launcher.[32] Combined with the systematic use of drones for fire correction, Kropyva has increased the effectiveness of Ukrainian artillery. It has led to shortening the time required to deploy a howitzer battery to three minutes, the time required to engage an unplanned target to one minute, and the time required to open counter-battery fire to 30 seconds.[33]

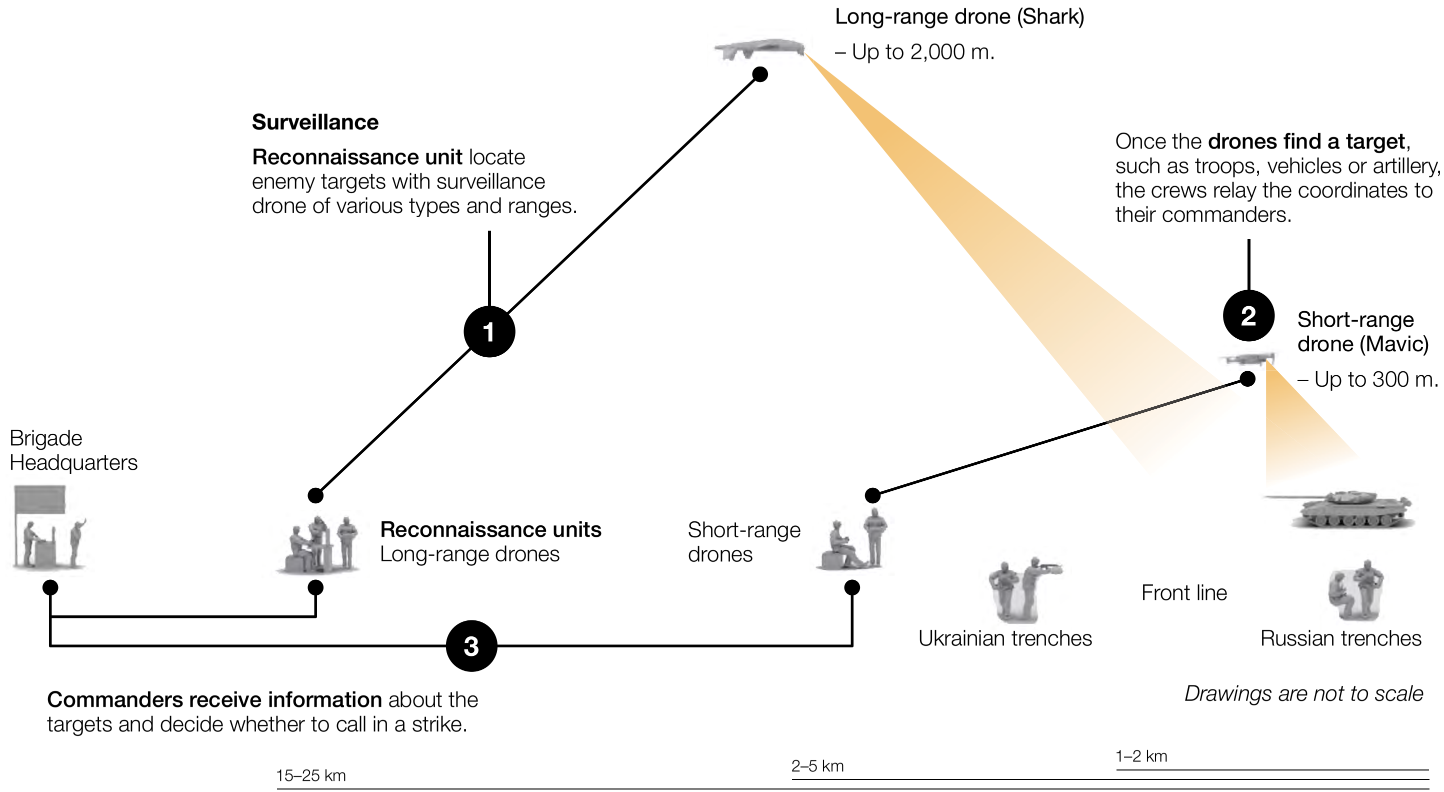


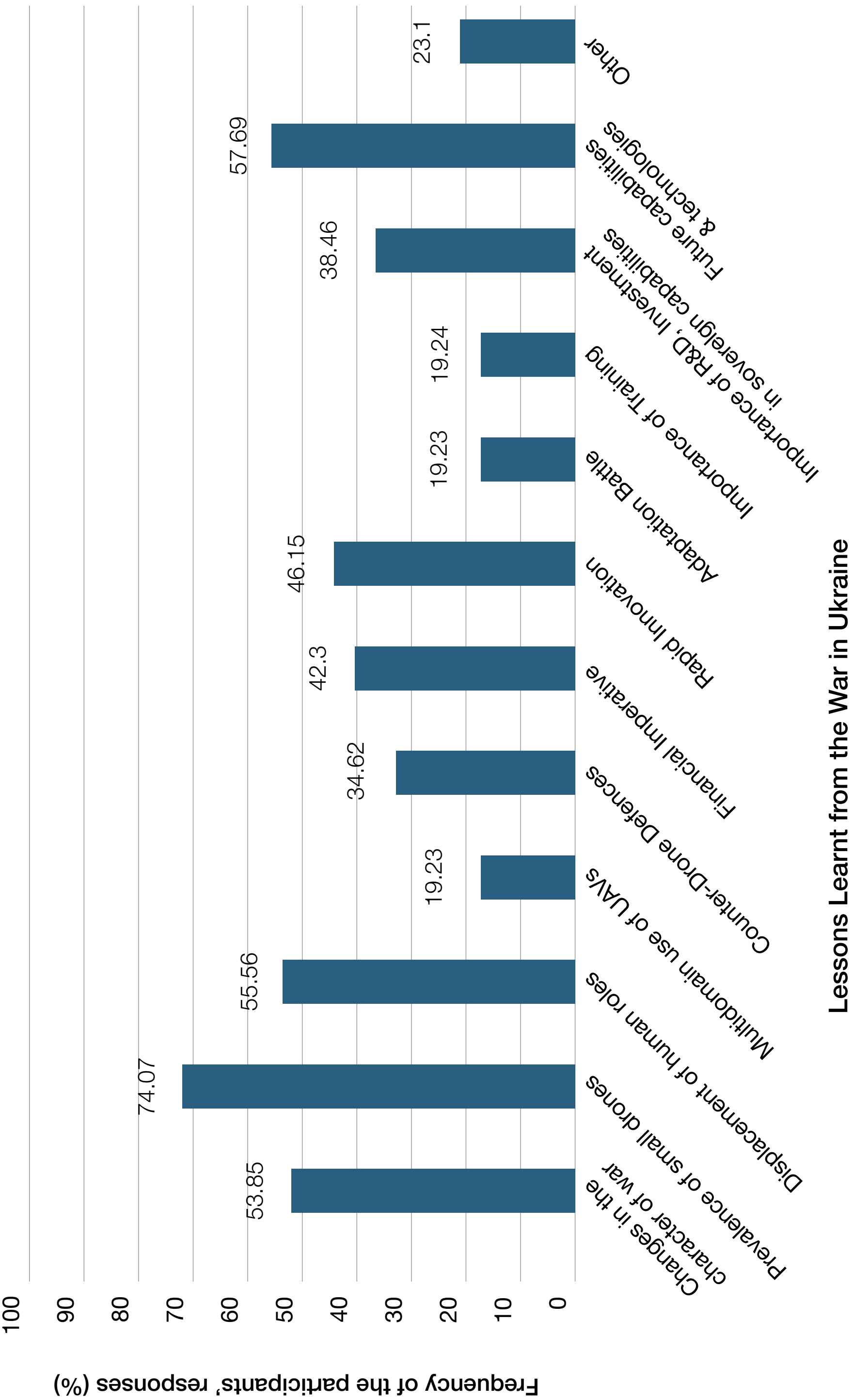
Figure 6. Process of deploying UAS technology on the battlefield (Source: Reuters, How drone combat in Ukraine is changing warfare accessed 22 May 2024)

Figure 7. Magyar Birds UAS team completing a mission using a laptop, a phone and a tablet (Source: reproduced with the permission of the owner)

Lessons from the Use of Drones in the War in Ukraine

Table 2 shows a summary of the lessons learnt from the use of drones in the war in Ukraine. As shown in the table, the 21 categories represent the main themes as elicited from experts' responses to interview questions. The percentage represents the frequency of these themes in the interviews rather than their importance. Their order and numbers do not indicate significance on the Ukrainian battlefield. More details of the most frequently identified lessons are discussed further in this section.

Table 2. Summary of the frequency in participants' responses of the themes related to the lessons learnt from the use of drones in the war in Ukraine



Lesson 1: UAS Have Changed the Character of Warfare

One of the important lessons from the war in Ukraine is that UAS—cheap and ubiquitous— play an important role in warfare, at both the tactical and operational levels.[34] They have underscored the importance of defensive tactics, utilising camouflage and dispersal methods that are difficult to detect. If war fighters are static, they are destroyed. Drones have changed the tactical perspective on the ground and represent a three-dimensional threat. Operationally, drones are vital for ISR to inform commanders' decision-making. They provide a wealth of data, enabling commanders to analyse and prioritise information effectively for informed decision-making.

During the Ukrainian counteroffensive in the summer of 2023, the situation on the front line was heavily influenced by the presence of drones. Previously, military strategy had involved gathering personnel and equipment at a specific location before launching a breakthrough offensive. However, this approach has needed to evolve with the advent of drone technology on the battlefield. Now, as soon as forces begin to amass equipment and troops, drones from both sides continuously monitor the area, providing real-time intelligence. This constant surveillance allows for precise artillery strikes, inflicting significant damage and disrupting the build-up before an offensive can be launched.

> *For example, Ukrainians were using, at times, hundreds or thousands of Javelin shots per day. That said, a missile (approx. $100,000) was used to kill a battle tank (approx. $3 million). The disadvantage is that that a Javelin operator must be out in the open to see the tank by the missile. It is a dangerous mission, because when you launch that missile, it has a huge dust cloud, a huge heat signature. So, it has a*

visual and an infrared signature. But an FPV kamikaze operator does not have to be in the open. They can be located several kilometres away and not in line of sight. However, the FPV might not kill from the first shot, as an FPV operator might not have that level of precision as a Javelin, but they can hit the tank every time, and with one or more grenade drops can destroy a $3million tank. Then spy another one and another one … (P1)

Both Ukraine and Russia have been using drones for various purposes, from collecting real-time imagery and intelligence to launching one-way attacks and long-distance strikes. UAS have provided approximately 86 per cent of all targets to the AFU.[35] UAS are enablers of remote warfare via ground surveillance from the sky and through remote strikes. They also provide a cheap way to deliver explosives precisely.

Overall, drone intelligence and strikes have contributed to reducing the number of shells needed to deliver military effect in Ukraine and have therefore reduced the logistics burden for both Ukraine and Russia. Drone intelligence has also changed the operational tempo of artillery, shortening time-critical targeting and firing cycles from around 30 minutes to three to five minutes.[36] This has helped to increase the precision and pace of artillery fires and has helped to keep soldiers safer in an observer role.

Drones are enhancing the lethality of modern battlefields and will likely drive a shift in how large-scale offensive operations are conducted in the future. Further, drones operated by war fighters on the ground provide their units with tactical flexibility.

I think I describe it as disrupting and transforming warfare. There's absolutely no doubt they're doing that. They are disruptive, they are transforming war, they are transforming military institutions, and how they think about war, how they think about tactics, how they think about strategy. It is the most intense period of innovation and adaptation in uncrewed systems that we've ever seen since they arose late in the Second World War. They're now ubiquitous on the battlefield and beyond. They're just going to be everywhere: on the ground, in the air, and in the maritime space. We're going to have to learn to live side by side with them. So, I think that's a really important place, and it doesn't matter whether you're in a continental fight or in a maritime fight, like we will be in the Pacific in many areas, these things are going to be ubiquitous. (P22)

The war in Ukraine has clearly demonstrated that, in high-intensity conflicts, the immediate pressures of the battlefield are stronger than normative and ethical pressures that might otherwise hold autonomous weapons system in check.[37] During the war in Ukraine, UAS have contributed to 'freezing' the front line, offsetting Russia's battlefield advantage. They have improved the pace and precision of artillery strikes and have provided intelligence to individual soldiers. Cheap and small drones loaded with explosives have increased the number of actors that can contest the skies. The battleground now includes both the space around ground troops and the space immediately above them, creating minefields in the air. The widespread use of inexpensive armed and single-use attack drones has the potential to make close air support and ground attack aircraft even more obsolete in future conflicts with denser and more capable air defences (see Figure 8). The war in Ukraine confirms that drones are becoming stealthier, speedier, smaller, more lethal and easily operable, and available to more actors.[38] To sum up, drones are enhancing the lethality of modern battlefields and will likely drive a shift in how large-scale offensive operations are conducted in the future.

The information provided by drones and shared on new digital battle command networks greatly increases the speed of decision and action. This means that the time between when a target is detected and the time when it can be destroyed by a variety of weapon is reduced. This detection to destruction time in Ukraine is now about one to two minutes and it has many implications for the mobility of combat and support systems on the modern battlefield. Precision of strikes has improved, as FPV drones with warheads allow for precise targeting at a cost that is an order of magnitude cheaper than older precision munitions. Loitering munition drones are also capable of providing this precision as they are accurate, lethal and used in large numbers by Ukraine and Russia (P22).

Figure 8. Ukrainian soldier prepares to launch a drone (Source: Oleksandr Volosyanskyi)

Drone use in military operations in Ukraine involves more than infantry units using commercial drones that they have adapted to see over the hill. It also involves the use of commercial drones that are adapted to achieve long-range fire against designated targets. For example, systems like the HIMARS long-range missile system can receive targeting information from drones. Such drones can be launched and operated effectively with an iPhone-type-controller to direct precision long-range fires.[39] This capability is significant because it opens up the possibility for future ground forces—including the most basic infantry-level unit of 12 people—to have their own organic air power. This will be significant in terms of their tactical ability to conduct reconnaissance, strike targets and generate firepower. For a low-cost investment, drones deliver a disproportionately high rate of return in terms of battlefield effectiveness.

Despite their proven capability, it is important to remember that drones alone cannot and will not win wars or battles. Drones cannot achieve the ultimate goal of war: they cannot seize and hold terrain. Drones have not eliminated close combat, and they can only be effective if they are operated by skilled personnel and integrated with other multilayered and conventional combat systems. Further, the disruptive effect of drones inevitably depends on the operational concept that guides their use and on the capacity of military forces to integrate drones with their other weapons systems.[40] To achieve effective offensive and defensive operations, Ukraine requires more than just more drones; it also needs greater numbers of tanks, armoured vehicles, artillery pieces, ammunition, and personnel. The battlefield dynamics in 2022–2023 suggest that despite the growing prevalence of uncrewed systems and the increasing use of tactical strike drones, the capacity that mattered the most was the availability of artillery ammunition and infantry capable of sustaining offensive action.[41]

In determining the future role of drone technology on the battlefield, it is important to remain focused on combat systems rather than on single technologies. As has been demonstrated in the war in Ukraine, infantry cannot work without tanks; tanks and infantry cannot operate without artillery; and artillery cannot remain safe without control of airspace, underscoring each system's unique role. In this context, UAS augment rather than replace existing systems, and they create new opportunities to engage targets. Interviewees mentioned that:

> *We should look at the effectiveness of the UAS but not at the cost alone. If I have to fly 20 drones to hit a target, then it is not $500 a drone, it is $500 by 20. Then we should think about the batteries that have to be charged, the logistics changes required to bring it forward, and the dependencies of that chain, and the biggest problem you have with UAS in future conflict is China. You know anyone who doesn't think about China and the supply chain doesn't understand the nature of UAS and even though we've moved to no Chinese components in the platforms that we make, we are kidding ourselves if we think there is no dependency, whether that's [the] critical minerals that sit behind it, lithium and the like or whether that's just the effect of the of the supply chain. Most of the parts we get come out of Taiwan. While Taiwan's not China today, does not mean it will not be China tomorrow.*

And if we lose the semiconductor foundries that are in Taiwan, no one is making drones that it comes to a stop. So, this reliance on technology provides you with a differentiation, but also provides you with a vulnerability, whereas artillery is just chemicals. I can make artillery rounds all day long if I have access to the chemical supply chain which does not involve China, and that's why you have to be careful about looking at the shiny new toy and the new capabilities that it generates without thinking about the massive new vulnerabilities that it introduces that could take that capability away. And if you move your resources away from capability A to invest in capability B, you need to be careful that you are not falling into an unforeseen vulnerability, which is the risk. (P6)

Strategically, utilising low-cost technologies to deliver significant effect. Developing the means to do low-cost, high-volume production can dramatically increase striking power at long-range utilizing these technologies. The Ukrainians have demonstrated that very effectively. (P16)

Lesson 2: UAS Are Changing the Nature of Military Institutions

The changing density of humans and uncrewed systems, particularly in close combat, has the potential to change the nature of military institutions, especially when uncrewed systems outnumber humans. Currently, the tactics, training, and leadership models of military institutions are designed for humans, and those humans exercise close control of the machines. Soon, however, the ratio of humans and uncrewed systems will flip and many of those uncrewed systems will be capable of partnering with humans, not just of being used by them. Changing programs of education and training to prepare humans to partner with machines is a necessary but difficult cultural evolution. It requires major adjustments to military institutions and their processes, including how people are recruited, trained, educated and incentivised.[42]

By the end of 2024, the Ukrainian government is expected to produce over one million FPV drones. Importantly, Ukraine's Ministry of Strategic Industries has recently stated the country has the capacity to produce up to three million drones annually.[43] Acknowledging the significance of drone technology in its fight against Russian forces, the AFU have introduced a new, separate branch aimed at supporting and developing uncrewed systems.[44] The novel Uncrewed System Forces (USF) is the world's first branch of the military to employ uncrewed aerial, surface, subsurface and ground systems and robotics in combat operations. This branch will be responsible for 'planning operations involving uncrewed systems, ramping up training, systemising their use, increasing production, pushing innovation'.[45] In addition to these developments, the Ministry of Defence of Ukraine has taken the complementary measure of creating a special structure—the Innovation Development Accelerator—responsible for optimising the process of adopting new weapons and military equipment into service within the military. As the outcome of this initiative, the process of integrating weapons and equipment into the service of the AFU has been streamlined from over two years to one and a half months.[46]

> *This decision was made as a result of the use and application of these systems since 2014 to 2023 inclusive, to introduce separate units that would specialize in the work of uncrewed systems. This is important because in the military context, if you had a specific military role of a shooter, and if you say that you are an IT specialist who knows how to program, then you will be forward as the Main operators of the Uncrewed Aerial Vehicles unit. However, you'll still have a mark of your military registration document that you are a shooter. Before that as an operator of UAV you can be anyone (cook, driver, etc), but at the frontline you went and launched the FPV drone etc. (P20)*

Restructuring within the AFU and the Ministry of Defence of Ukraine was a deliberate institutional effort to capitalise on the operational potential of drone technology. Instead of uncrewed systems being managed through chaotic bottom-up efforts, a vertical management system has been introduced with a clear organisational structure, uniform rules and associated doctrine. This development is expected to increase the effectiveness both of the use of UAVs by the AFU and of the budgeting and production processes that support growth and scaling. As a direct outcome of these changes, the process of integrating weapons and equipment into the service within the AFU has been streamlined to just one and a half months, a substantial improvement from the previous timeline of over two years. The influence of the restructure has been especially pronounced in the incorporation of new drone technologies, particularly given the continuous emergence of innovative technological developments among Ukrainian companies.[47] In addition, the Ministry of Digital Transformation also created Brave1, a cluster to promote the development of military technologies.[48] The main task of Brave1 is to coordinate the activities of government agencies in the development of defence technologies and production.

Lesson 3: Prevalence of Small Drones

> *The war in Ukraine demonstrates the importance of the small drone systems. The big systems are no longer used, because it's easier to detect and shoot them down, they cannot cover all areas, and the cost is high. (P11)*

The war in Ukraine has provided critical insights into the tactical use of small UAS in modern warfare. The conflict has underscored the importance of these systems in both reconnaissance and combat operations. As exemplified by their use by both Ukrainian and Russian forces, small UAS have proven to be tactically and operationally crucial in contemporary warfare. The conflict has highlighted the pivotal role of drones in reconnaissance and combat, showcasing the seamless integration of commercial technologies into military tactics.

There remains debate about the ability of large drones to convey offensive advantage. The reality is that, without air superiority, they are vulnerable to air defence and electronic countermeasures and are expensive to replace ($5 million for one TB2 Bayraktar). The large drones initially used by the AFU did not survive once Russian air defence and EW systems were properly integrated.[49] This situation contrasts with the effective performance of TB2 in Libya, Syria, and during the second Nagorno–Karabakh war in 2020—conflicts without a dense layer of air defences.[50] Many scholars from the security studies community argue that large drones have limited utility in high-intensity conflicts, and their success depends on the failure of an adversary's air defence.[51]

While debate exists around the utility of large drones, no such doubt remains in regard to small drone technology. Weaponised with hand grenades, mortar shells or anti-tank missiles, these repurposed small (Class I) drones have become anti-personnel and anti-tank/armour vehicle weapons in the form of makeshift guided ammunition with variable accuracy.[52] Small drones have been rapidly amassed and reproduced by operators for specific effects. For example, FPV drones (commonly used for racing and wedding filmmaking) have been retrofitted with makeshift explosives and flown to strike fixed targets at relatively low cost. These small FPV drones ('cruise missiles in a backpack'[53]) are becoming a force multiplier as they have the capacity both to achieve precision strikes and to offer real-time video feedback from the drone's perspective, providing soldiers with information that aids them to track enemies, direct artillery, monitor battlefield conditions and make informed decisions without exposing themselves to danger. The use of FPV drones allows a smaller number of soldiers to cover a larger area more effectively. For example, a single soldier equipped with an FPV drone can gather intelligence, spot targets, and coordinate attacks that would typically require a larger team. Further, FPV drones can assist in precision targeting by artillery and snipers by providing a bird's-eye view of the battlefield. Drone capabilities therefore increase overall combat effectiveness of tactical-level units.

FPV drones extend the operational range of soldiers. They can be used to inspect areas that are otherwise inaccessible or too dangerous to approach. This capability is particularly useful in urban warfare, where buildings and other structures can obstruct line of sight. Usually, such drones are operated in small groups of three or four, consisting of operators and their assistants. Sometimes FPV kamikaze drones or other drones with an ejection function act in tandem with reconnaissance helicopters. This provides greater situational awareness for operators (see Figure 9).

Figure 9. Magyar Birds work in a team during a mission (Source: reproduced with the permission of the owner)

FPV drones are particularly challenging to detect and intercept for several reasons. Firstly, their small size makes them hard to spot visually and audibly, especially from a distance. They are small and agile, often flying low to the ground, which complicates detection by radar (they can be detected by a target detection radar at only 3–4 km). Secondly, there is the speed of these systems: they can reach speeds of up to 160 km/h, which makes them challenging to intercept. Finally, the strong signal strength from the radio controller to the drone and the video transmitter to the pilot means that the FPV drone operator can manoeuvre and change direction to avoid an adversary's identification systems. Overall, this means that FPV drones can be used in large volumes at high speeds to overwhelm an opponent's defences, making it extremely difficult to intercept all of them effectively. Depending on the amount of explosives installed on board, the speed may decrease, but it remains incredibly fast.

While the Ukraine battlefield has demonstrated the prevalence and utility of small drones in combat zones,[54] there is still scholarly debate around the effectiveness of small UAS in transforming military doctrine, especially given their vulnerability in GPS-denied environments. Initially, Ukraine effectively used drones, but Russian forces countered with electronic jamming, disrupting drone communications. Consequently, Ukraine is developing software solutions to combat Russian jamming, emphasising the need for advanced counter-UAS capabilities alongside the expansion of the UAS fleet.

Lesson 4: UAS Can Save (and Have Saved) Human Lives

Drones displace rather than replace humans on the battlefield. This displacement reduces risk in dangerous situations and preserves human life. Drones can provide greater persistence over various missions, maintaining optimal performance without the limitations of human endurance.[55] For example, whether they are ground-based, aerial or maritime, drones are still controlled by humans. They nevertheless replace people in the surveillance chain, removing them from frontline exposure and risk.

> *I think this is significant in the sense that what it does is it opens up the possibility whereby in the future, i.e. ground forces, including the most basic level infantry level unit of a squad of 12 people, will have their air power, which will be significant in terms of reconnaissance and strike and their ability to utilize that advanced technology at very low cost to generate long-range firepower. So, it is that potential for low-cost investment delivering a high rate of return in terms of effectiveness on the battlefield. (P12)*

The most important lesson learnt from the war in Ukraine is that UAVs can save, and have saved, human lives. When equipped with multiple sensor packages, drones can detect enemy movements, locations and force compositions during the day or night. Small Class I drones have changed the operational tempo of artillery, shortening time-critical targeting and firing cycles from about 30 minutes to three to five minutes,[56] helping to increase precision and pace of artillery fires and keeping soldiers safer in the observer role. Much like harassing and interdiction artillery fire, the presence of drones has disturbed and exhausted Russian forces. Importantly, this technology has been used to minimise human participation on the battlefield, as well as providing an asymmetric response to the enemy's numerical superiority.

In a situation where there is an asymmetry in the availability of personnel, for example, drone technology can mean that fewer people need to be put in harm's way and can ensure a better return on investment in human resources over time. In the war in Ukraine, the AFU has repeatedly mitigated the battlefield risks to humans by conducting surveillance and reconnaissance with longer-range drones that are capable of moving at rapid speed and maintaining their presence for long periods of time. In addition to supporting force preservation efforts, UAVs can enhance the capabilities of human and machine teams, optimising performance and effectiveness in various operations. The ability to blend humans and machines has led to improved outcomes and operational efficiencies for the AFU. Some of the tactics and strategies for using UAVs as part of the 'team' were described by one respondent:

> *The UAVs served as part of the team for the adversary. For example, in Bakhmut, they had two lines of drones, land drones and aerial drones, and they directed drones in waves. For example, 7–10 soldiers, who had only primitive Kalashnikov weapons, only 1 radio transmitter (walkie-talkie), and 1 grenade and were sent to take on a position. Mavic was sent with them, that was always hovering over them. There was always an officer standing next to the operator of Mavic, who communicated with soldiers via walkie-talkie, saying now run to the right, now turn to the left, now fall to the ground, now shoot to the left. The soldiers performed as told by the radio communication. We (Ukrainians) used our EW to determine the coordinates of the enemy's drone operator, artillery fired at the drone operator and Russian soldiers, realizing that no one was looking at them, raised their hands and surrendered. The war ended for them when Mavic was shot down. Now, unfortunately, there are no such soldiers anymore. We 'miss those Russians very much', because present Russian soldiers who are now at the front line are extremely motivated, professional, no one gives up, and they all came to fight because they have been paid to do so, and absolutely all of them, when we take prisoners, say: 'you will exchange me, I will return home because I came to work for money to kill you'. These Russian soldiers still perform the function of ground-based kamikaze drones. When they can burn 40,000 soldiers just take a small settlement or village—they perform a function of kamikaze drones. Russia has this resource, so in addition to the aerial swarm of drones, they use 'so-called ground swarms—soldiers'. Ukraine doesn't have this resource. Ukraine treats soldiers' lives differently. (P.8)*

Lesson 5: Multi-domain Use of Drones

In Ukraine, the use of drones in the air, land and sea domains has been proven to be effective at range, at low cost, and with economy of effort. The capability that drones provide to see farther more accurately, coupled with associated cost savings, has made UAVs indispensable for both Ukrainian defensive and offensive operations.[57] The use of technology in the war in Ukraine began with flying drones and will continue with seaborne and ground-based ones. Further innovative uses of drones may herald the proliferation of multi-domain drones and may even introduce a third drone age defined by full-spectrum drone warfare.[58]

Naval Drones

In 2014, after occupation of Crimea, the Ukrainian fleet lost 80 per cent of its vessels. Since 24 February, the Russian army has launched more than 4,500 missiles in Ukraine, 20 per cent of which were launched from the sea.[59] Ukraine has effectively employed dual-use technologies, naval drones or uncrewed surface vehicles (USVs) to compensate for its lack of an operational navy in its conflict with Russia. Ukraine developed its own USVs, robot boats loaded with explosives that are capable of attacking and destroying the enemy's warships. On 29 October 2022, naval drones hit Russian ships. This was the first attack in history to be carried out exclusively by unmanned vessels.[60] Ukrainian naval drones have demonstrated high effectiveness in real combat conditions, highlighting the importance of innovative technologies in modern warfare.[61]

Differences in the effectiveness of various models can be attributed to technical characteristics, tactical application, and operational conditions.

Ukraine has demonstrated the use of commercial aerial drones alongside military air and sea drones to overwhelm Russian defensive capabilities. Table 3 shows examples of the USVs and uncrewed underwater vehicles (UUVs) that were used in the Ukraine maritime domain. As shown in Table 3, the first stages of maritime drone development were based on Mamay and Mykola USVs. Mamay first appeared in September 2022, while Mykola was used in the attack on Sevastopol on 29 October 2022. These drones did not carry a lot of explosives but were capable of hitting large targets at great distances. Examples of other USVs that were able to damage and destroy targets in the Black Sea are described below.

MAGURA V

The Maritime Autonomous Guard Uncrewed Robotic Apparatus (MAGURA V) is a Ukrainian USV, named after the goddess of war and victory in Slavic mythology. This multipurpose surface uncrewed boat is notable for its versatility and capability to perform a wide range of tasks. It is operated by the Defence Intelligence, the Main Intelligence Directorate of Ukraine's Defence Ministry (DIU), and it is used for surveillance, reconnaissance, patrolling, search and rescue, mine countermeasures, maritime security, and combat missions. The MAGURA V5 was designed as a hunter-type drone. As the developers explained, this model was created specifically for hunting warships at sea and destroying them, so it is smaller, faster, and much more manoeuvrable than other similar drones. It was designed specifically to intercept ships.[62]

With a hydrodynamic hull and V-profile, it offers high manoeuvrability and stealth capabilities. One of the notable aspects of the MAGURA V5 is its propulsion system, which can be either electric or hybrid, ensuring stealthiness in operations (see Figure 10). The guidance of the vessel can be conducted manually via a wireless mesh network, satellite communication, or autonomously. Its additional equipment includes a dual-view electro-optic system with a gyroscope, marine radar, and laser rangefinder.

The MAGURA V5 was first used on 24 May 2023 during an attack on the Russian reconnaissance ship *Ivan Khurs*. On 11 June 2023, Ukrainian drones demonstrated impressive range by attacking the Russian ship *Priazovye* 300 km from Sevastopol. MAGURA V5 became the first uncrewed vehicle in the world to completely destroy an enemy ship.[63]

It demonstrated high efficiency, hitting and destroying the largest number of enemy vessels.[64] Throughout 2023, the main task of the MAGURA V5 was simply to hit warships, and fewer drones were used in one task. Now they ‘hunt in packs of swarms’ of five or six to try to overwhelm the target ship’s weapon systems, allowing each USV in a swarm to take on individual tasks in the order of attack. According to a member of MAGURA’s manufacturing team:

> *The USV swarm attacks in a three-phase operation: The main goal of the first phase of the attack is to immobilise the target, so the first strike is usually to the engines. In the second phase, the most vulnerable part of the ship is hit. If a hole is blown in the hull, additional drones are driven into it and detonated. Then the third and final phase is to watch the ship sink.*[65]

Figure 10. MAGURA V5 (Source: National Military Historical Museum of Ukraine Facebook)

Sea Baby

The Sea Baby is a multipurpose platform that can be used for striking static targets such as bridges and can be mounted with its own weapons on it (see Figure 11). It was developed by the Security Service of Ukraine (SSU) and named after Vasyl Maliuk, Chief of SSU. It can carry an explosive payload for kamikaze attacks. The drone can be adapted to carry military or civilian cargo and can also play a reconnaissance role.

By the end of 2023, the Sea Baby had transformed from a kamikaze attack vehicle into a multipurpose platform capable of carrying different loads, including guided missile launchers and laser guidance systems. In early March 2024, the improved Sea Baby 'Avdiivka' was revealed by the SSU with advanced capabilities. The new Sea Baby 2024 is more manoeuvrable, capable of delivering almost a ton of explosives over a distance of more than 1,000 km. Its guidance system includes passive sonar identification and direction finding of underwater and surface objects using a system of hydrophones. Ultrasonic sonars (active sonar) are also included for close-range detection, tracking, and identification of objects by size. These USVs have been adapted and deployed in the Black Sea region, targeting strategic locations such as Sevastopol in Crimea and extending operations to Novorossiysk, demonstrating their ability to evade Russian defences and pose significant threats to Russian naval assets.[66]

Figure 11. The new Sea Baby 2024 (Source: Security Service of Ukraine Telegram)

Impact of Naval Drones in the Black Sea

Weaponised USVs pose a formidable challenge to an adversary due to their speed and manoeuvrability, and to the difficulty of detecting them at long range. These capabilities have made USVs a crucial part of Ukraine's asymmetric warfare strategy, leveraging advanced technology to offset the conventional naval superiority of the Russian naval fleet. A string of attacks on targets far from the south-west Ukrainian coast—in and around Sevastopol in Crimea to the Russian port of Novorossiysk—have shown that these USVs have the capability to evade Russian defences. These USVs pose serious threats to Russian naval assets and restrict Russian freedom of navigation. They represent an example of off-the-shelf, cheaper technological alternatives being used to rebalance the power dynamics on the battlefield and threaten much more advanced and expensive systems such as frigates, cruisers and even Russian flagships.

Ukraine has destroyed 40 per cent of Russia's naval tonnage in the Black Sea with asymmetric warfare, using a combination of USVs and cruise missiles.[67] By October 2023, strikes with drones and cruise missiles forced the Russian navy to rebase its larger combatants from its main base in Crimea to the eastern part of the Black Sea, in Novorossiysk.[68] The Russian Black Sea fleet found itself increasingly cornered, fighting a defensive battle without much combat utility beyond resupply missions and launching missile strikes. The fleet lost several vessels from strikes in port or dry dock, as well as a number of amphibious ships at sea.[69] Subsequently, Russia lost the initiative in the Black Sea in 2023, and Ukraine was increasingly able to effect sea denial, if not sea control, in the north-west by the end of the war's second year.[70] Ukraine's maturing strategic strike complex—the combination of intelligence, military planning and aerial and naval drones to strike Russian targets at long range—is making significant progress in the Black Sea. This capacity, which is improving in its reach and effectiveness, will be a key part of future Ukrainian operations.[71] The commencement of large-scale production of underwater drones has the potential to further alter the dynamics in the Black Sea. The Russian Black Sea Fleet may face challenges in detecting and countering these underwater drones, thereby posing a considerable threat to Russian warships.

> *The lesson about the use of USVs is important for places like Japan, Taiwan, and Australia, where sea gap is critically important. This is because it is better to sink a ship with 100 tanks on it before it lands.*

This has always been identified in Australia strategic reviews that guarding the sea gap is so vitally important. (P2)

In terms of organisational and doctrinal changes in response to naval drones, the DIU has created a separate department for the use of uncrewed systems, named ‘Group 13’. Ukrainian units, including the DIU, the SSU and the AFU, developed tactical approaches and the operational training of personnel in real combat conditions.[72] Group 13’s initial approach was to modify existing water vehicles by installing remote control systems and explosive charges on items such as jet skis, scooters and motorboats, so that they can be used for surveillance or kamikaze attacks on rivers. Indeed, such operations were conducted on the Dnipro River in the Zaporizhzhia region in 2023.[73]

At the time of writing, Ukraine had started assembling the world’s first naval fleet of drones. It plans to assemble a fleet of 100 USVs to defend Ukrainian waters from Russian missile-carrying ships and to protect merchant ships. Drones can participate in long-range maritime reconnaissance and coastal surveillance, escorting and supporting the traditional fleet, convoying merchant ships, zoning in artillery fire, defending bases and countering amphibious operations.[74]

Naval strike drones have emerged as a critical asset in the war in Ukraine, demonstrating exceptional effectiveness in neutralising enemy vessels and influencing maritime warfare strategies. Among these, the MAGURA V5 drone stands out with its advanced technical capabilities and successful tactical deployment. The AFU has developed a highly effective drone tactic, positioning the MAGURA V5 as the most formidable maritime drone in its class. The experience gained by Ukraine has not only altered the dynamics of warfare in the Black Sea but has also made a substantial contribution to military science, paving the way for the development and enhancement of uncrewed maritime technologies. Further analysis of these operations will be important in refining the technical specifications of drones and their applications in future conflicts. The lessons learnt from this conflict will drive advancements in both offensive and defensive naval systems, influencing the evolution of future naval warfare strategies.[75] Hence, experience gained by Ukraine has not only altered the dynamics of warfare in the Black Sea but also made a substantial contribution to military science, paving the way for the development and enhancement of uncrewed maritime technologies.

Table 3. Examples of naval drones in the war in Ukraine[76, 77]

Name	Type	Technical specifications, design and features	Areas of use	Effect/confirmed targets
MAGURA	USV	• Length: 5.5 metres • Width:1.5 metres • Weight: less than 1,000 kg • Range: up to 400 km, with an operational range extending to 800 km • Battery life: 60 hours • Combat load: 200 kg • Cruising speed: 41 km/h, with a maximum of 80 km/h • Communication: mesh radio with an aerial repeater or satellite communication • Navigation methods: automatic GNSS, inertial, visual • Video transmission: up to 3 HD video streams • Crypto protection: 256-bit encryption	• Designed as a hunter, to hunt warships at sea and destroy them • Designed to intercept ships • Used for reconnaissance, patrol, rescue operations, mine warfare, fleet protection, and combat missions • With a hydrodynamic hull and V-profile, offers high manoeuvrability and stealth capabilities • First recorded use was on 24 May 2023 during an attack on the Russian reconnaissance ship Ivan Khurs	• Became the first uncrewed vehicle in the world to completely destroy an enemy ship • Demonstrated high efficiency, hitting and destroying the largest number of enemy vessels • Attacked 18 ships • Destroyed 9 ships
Mamay	USV	• Flat hull for maximum speed up to 60 knots (110 km/h) • Equipped with one or two satellite communication antennas and an electro-optical camera • Warhead activated by any of the three impact sensors on the bow	• Used to attack the landing ship, tanker, and other ships • Larger than other canoe-like models • First appeared in September 2022, allowing more fuel and increased range of operation	Used in the attacks on 2 warships

Name	Type	Technical specifications, design and features	Areas of use	Effect/confirmed targets
Mykola	USV	• Length: 5.5 metres • Full weight: up to 1,000 kg • Range: up to 430 nautical miles (800 km) • Autonomy: up to 60 hours • Combat load: up to 200 kg • Maximum speed: 43 knots (80 km/h) • Navigation methods: automatic GNSS, inertial, visual • Video transmission: up to 3 HD video streams • Crypto protection: 256-bit encryption	Used to attack ships in port	Attacked the Russian fleet in port, damaging 2 warships: the frigate *Admiral Makarov and the minesweeper Ivan Golubets*
Sea Baby	USV	• Length: 6 metres • Width: 2 metres • Height above waterline: 0.6 metres • Speed: 49 knots max • Range: 540 nautical miles (1,000 km) with additional fuel tanks • Combat load: 850 kg • Communication: satellite communication	• First used as a kamikaze drone in October 2022 • Further transformed into a multipurpose platform mounted with its own weapon • Can be used for striking static targets (e.g., bridges, ships docked in port)	• Attacked 11 ships in the Russian Black Sea fleet (data from 6 March)

Name	Type	Technical specifications, design and features	Areas of use	Effect/confirmed targets
Marichka	UUV	• Length: 6 metres • Diameter: 1 metre • Operational range: 1,000 km	• An autonomous underwater vehicle • Capable of targeting warships, boats, submarines, missile carriers, coastal fortifications, and bridge supports • Can also carry military or civilian cargo and conduct reconnaissance missions	• Successful testing completed on 24 August 2023 • No information about its participation in combat operations is available
Toloka	UUV	**TLK 150** • Length: 2.5 metres • Range: up to 100 km • Propulsion: electric motor • Warhead or payload capacity: 20–50 kg **TLK 400** • Length: 4–6 metres • Range: up to 1,200 km • Warhead or combat load: up to 500 kg **TLK 1000** • Length: 4–12 metres • Range: up to 2,000 km • Warhead or combat load: up to 5,000 kg	• Smaller in size compared to surface kamikaze boats • The only parts above the water surface are the antenna and cameras, making detection by radar and visual means more of a theoretical discussion • Its warhead strikes below the waterline, likely causing significant damage	No information about its participation in combat operations is available

Land Drones

Land drones or unmanned ground vehicles (UGV; ground robots) could be the next frontier in military innovation.[78] The main purpose of UGVs has been to minimise participation of the AFU on the battlefield, helping to the preserve the lives of Ukrainian soldiers. Use of UGVs is an asymmetric response to Russia's numerical advantage.[79] UGVs have performed tasks such as remotely mining and de-mining positions, protecting fiercely contested areas with automatic weapons, and using anti-tank equipment against heavy vehicles, which have also been found vulnerable to UAV drones. UGV development has also focused on logistical tasks and casualty evacuation roles. Three types of most commonly used UGVs are:[80]

1. Combat robots—Lyut, MOROZ, D-11, ShaBlya M2
2. Minelayers and self-destructive robots—Ratel S, ARK-1
3. Logistical robots—Volya-E, Ratel H, Termit, Rys Pro, KNLR-E, Sirko-S1.

For example, according to Nataliia Kushnerska, a Chief Operations Officer at the Ukrainian defence technology cluster Brave1, ShaBlya is used to effect remote fire on enemy personnel, equipment, and positions (see Figure 12); the Volya-E robot has evacuated injured Ukrainian soldiers and delivered ammunition to the front lines (see Figure 13); and the ARK-1 can be used as a kamikaze UGV, which was key for Russian logistics along the front line (see Figure 14). According to the Minister of Digital Transformation of Ukraine, Ukraine is starting mass production of robotic ground platforms. At the time of writing this article, Ukrainian developers have showcased over 200 UGV developments, with at least 50 systems having undergone testing in operational settings, and 15 developments codified according to NATO standards.[81]

ShaBlya

ShaBlya is one of the first robots on the front line that fights side by side with the military units. It is a remote-controlled combat module for 7.62 mm (ShaBlya 7.62) and 12.7mm (ShaBlya M240) turrets machine guns. A unique development from a team of Ukrainian engineers, it helps fighters destroy the enemy remotely.

The combat module is installed on the ground, on moving objects or on special vehicles. The fighter inserts a machine gun into the turret and coordinates fire with the help of a remote control, a camera, and a control monitor at a distance of 100 metres from the unit. Controlling the unit from a safe place, the operator is then capable of directing fire at a distance of up to 1.2 km or 2.2 km depending on the calibre of the machine gun. In this way, the ShaBlya contributes to forming a line of defence that can destroy manpower and lightly armoured enemy targets. Today, hundreds of ShaBlya modules are actively used in combat missions, and the Russians refer to them 'death scythes'.[82]

Figure 12. ShaBlya (Source: Reproduced with the permission of the image owner BRAVE1 LinkedIn)

Volya-E

Logistics robot Volya-E has been designed by a Ukrainian manufacturer in the Brave1 cluster. It is codified according to NATO standards and used by the Ukrainian military to evacuate wounded soldiers from the battlefield and deliver ammunition to the front line. Thanks to its tracked base, it has high manoeuvrability. It can carry loads weighing up to 150 kg. It can be remotely controlled at distances up to 3 km, and reach a speed of 12 km/h.

It is compact and can be transported in the trunk of an SUV, and it is easy to maintain and repair. In interviews, members of the AFU have highlighted that it helped recover over a hundred wounded and evacuated soldiers from the battlefield. Specifically, during a week of fighting in the Donetsk direction, it evacuated approximately 20 wounded soldiers.[83]

Figure 13. Logistics robot Volya-E (Source: Reproduced with the permission of the image owner, BRAVE1 LinkedIn)

ARK-1

This all-terrain, compact and nearly silent UGV can be used for various missions. It can deliver light ammunition, medical supplies and provisions to forward positions. It can also operate as a kamikaze, targeting and neutralising enemy equipment and fortifications. It can reach speeds of up to 45 km/h and overcome obstacles with an angle of inclination less than 45 degrees. Its key advantage is that the operator can control it from a safe distance of up to 20 km. It was developed by a Ukrainian manufacturer in the Brave1 defence technology cluster and codified according to NATO standards.[84]

Figure 14. Robot-kamikaze ARK-1 (Source: Reproduced with the permission of the image owner, BRAVE1 LinkedIn)

> *Uncrewed Ground Vehicles can be the next frontier in military innovation. These vehicles also can carry weapons and explosives or conduct reconnaissance. (P8)*

There are growing numbers of examples of incidents where unsophisticated robots have been used against other robots in Russia's war in Ukraine.

> *[I]n December 2023, in Avdiivka (Donetsk region), the UGVs are often paired to work with UAVs. This is because aerial drones can surveil or attack the enemy's UGV, while the UGVs can carry weapons and be loaded with explosives or conduct reconnaissance. (P8)*

In July 2022, the Army of Drones project was launched. This project focused on expanding UAS, enhancing processes for their repair and replacement at the request of the AFU, and plotting training courses.[85] One important lesson from here is the impact of volunteer and start-up communities in pushing new developments and TTPs. Following the successes of this project, the Deputy Prime Minister for Innovation, Minister of Digital Transformation of Ukraine announced the Army of Robots and the Army of EW projects that were scheduled to commence in 2024.[86]

The rapid proliferation of smaller, lighter combat and logistics UGVs across the Ukrainian front line to date underscores the immediate combat requirement to provide this capability.[87] In such cases, simpler and cheaper designs fielded in large numbers are likely preferable to larger, heavier and more expensive platforms fielded in smaller quantities.[88] With the projected expansion of UGVs to enter combat in the war in Ukraine, the focus is currently on developing tactics and concepts of integration in battlefield operations. Such tactics may include a degree of autonomy, which is currently constrained due to the natural obstacles that UGVs cannot overcome without additional and possibly costly assistance, and the difficulty in developing training models and datasets for a complex battlefield terrain in Ukraine. Other future developments may include the joint work of different UGV types or UGV-UAV ensembles for assault, ISR and other missions.

Lesson 6: Counter-Drone Systems

As uncrewed systems are continuously developing, the measures to counter these technologies are also developing in a cycle of rapid innovation. The initial strategy to counter an uncrewed aircraft (UA) involved shooting it down while it was airborne. However, preventing its launch by targeting its ground components can be also effective. This involves detecting the ground stations either visually or electronically and striking with artillery or drones.

One of the limitations of UAVs is that they are susceptible to countermeasures, especially by EW. Devices that use the electromagnetic spectrum to counter UAVs include jammers and spoofers, which act by deceiving enemy communication systems, radar, and other electronic devices. Jamming is conducted by directing a high amount of energy towards the UAS to mask the radio frequency control or data signals. Jammers—used by both Ukraine and Russia—send out powerful electromagnetic signals causing the target drone to fall down, veer off course, or turn around and attack its operator.[89] For example, in Bakhmut drone operators could not fly further than 500 metres due to Russian jamming or were leaving messages on the adversary drone operators' screens—'Slava Ukraini!' ('Glory to Ukraine!') before downing the drones.

> *An important task for kamikaze drones is to knock out Russian air defence and EW systems within the few kilometres, because there is a real wall, and it is impossible to get through. For example, in Bakhmut, they had at least 15-17 EW system installations per 1 km. Ukrainians 'joked' that brain melted from all the crackle there. It was impossible to use drones as they were knocked out. It's just that sometimes the guys had to send a surveillance drone*

to see 'what's there' using Mavic, if it flew at least 50 m it was considered as 'lucky', if 500 m—was almost impossible, and further than 500 m was simply unreal, that's all. The enemy has a wall of powerful electronic countermeasures, which are continuously modified, and they continuously create something new. In order to break through these installations, we need to continuously knock them out. For this purpose, you need anti-sensor drones that are 'dull, blunt, silent don't give any signal' but just fly onto a sensor, or source of jamming signal ('Home-on-Jam'). American company Anduril is producing them that are very expensive, but we like these systems. Since 4-5th month of full invasion, Anduril moved and lived in Ukraine, unlike other foreign companies like Lockheed others, Boeing trying to. Anduril's products are effective because they know what's happening at the frontline and continuously changing and improving their systems. I remember their (Anduril) first drone didn't even take off here, but now their drone (home-on-jamming) works perfectly. There are some nuances, but overall, they work well. Again, unlike Switchblade—they don't change anything, and they don't fly. They cost approximately $150,000 (USD per unit) but carry as much as a kamikaze drone for $300 USD. We were a bit shocked. Everyone has a different understanding of war … (P8)

Counter-uncrewed aerial systems (C-UAS) are specifically designed to detect, track, and neutralize UAVs. This can be achieved through detection systems (radar, electro-optical/infrared sensors, and acoustic sensors that identify UAVs in the airspace); jamming devices (portable or fixed); missile weapons (anti-missile systems, air to air weapons); kinetic weapons (shotguns, anti-air machine guns and cannons); directed energy weapons (high-energy lasers or microwave beams that can disable UAVs by damaging their electronics or propulsion systems); nets and drone-on-drone technologies (physically intercepting or capturing UAVs).[90]

Both Ukraine and Russia undertake an array of activities to counter enemy drone operations. Russia is innovating and investing significantly in drone countermeasure and EW capabilities. This will inevitably require Ukrainian drones to be fitted with more advanced electronics to evade ever more effective countermeasures.[91] The AFU has adapted its drone operations to ensure their losses are more sustainable as Russian EW operations can result in Ukrainian losses of up to 10,000 drones per month. This threat has driven more rapid procurement approaches by Ukraine.[92]

Electronic warfare is becoming a new arms race. As one respondent observed, '[i]t is fair to say that EW has been the comeback king of this war' (P22). Initially, the Russian invasion did not involve significant use of EW capabilities. This may be attributed to an initial underestimation of Ukrainian resistance, which resulted in a lack of preparedness for large-scale EW deployment. However, Russian forces have since learnt and adapted, integrating EW systems more comprehensively into their operations and coordinating these efforts with other military units. Their experience in Syria also contributed to this evolving strategy. Despite this, Russian EW deployment has faced limitations. An example of these challenges occurred in March 2023, when Russian EW systems attempted to disrupt the Starlink satellite communications network. However, SpaceX engineers, with support from the Pentagon, successfully mitigated the jamming attempts. Russian forces have struggled to fully utilise their EW capabilities due to the risk of inadvertently jamming their own systems. This issue underscores a broader challenge within modern military operations: how to effectively deploy sophisticated EW systems without compromising own-force communications.

> *Electronic warfare is key to defeating the current generation of drones but won't work once we reach full autonomy. We must invest in full autonomy if we're to counter the counter, and we need to do it today. (P25)*

In the same way that attention as is paid to learning from the use of drones in modern warfare, it is also necessary to learn about the technologies needed to counter them. An emerging challenge of counter-drone defence is its cost-effectiveness, where the counter-drone system must be cheaper than its target.

> *If there is a means of damage (i.e., UAS) there is something it damages where it strikes. For example, means of EW that reflect corresponding frequencies, for example, EW should be installed on artillery systems for assault, different equipment that transport personnel to the frontlines, and so on. It should not be installed only at the higher-level systems, but also those on the lower levels, both static and dynamic. Again, this lesson reflects the one on innovations, so you just need to be ready for this. (P15)*

For Western armed forces, the events in Ukraine underscore the complexities of EW in modern combat environments. The rapid advancement of both commercial and military technologies within the electromagnetic spectrum means that reliable communication can no longer be assumed. Effective coordination and deployment of EW capabilities are essential to maintaining operational superiority and ensuring uninterrupted communication on the battlefield. The confrontation of electronic warfare is becoming a significant factor in the conduct of war. Systems are becoming more powerful and, according to experts, very soon the tactics of war will change again.[93]

> *Defence needs to invest in low-cost interceptors (i.e., electromagnetic interception whether it is microwave and other EW sources) to flip the economics of destroying low-cost uncrewed aerial vehicles. We need to be thinking how to defend against UAS so that it doesn't impose cost on the defender. The question remains as to how to design and build defensive systems that are cheaper to shoot down a drone than it is to use a drone. This is a very important lesson. (P22)*

> *The Russians so far are focusing on electronic warfare and jamming, but eventually, they might do something more sophisticated with hyper microwave weapons and directed energy weapons. This is important not just in Ukraine, but what the lessons are coming out of Ukraine for other militaries. (P12)*

> *Electronic warfare is key to defeating the current generation of UAS but won't work once we reach full autonomy. We must invest in full autonomy if we are to counter the counter, and we need to do it today. (P6)*

> *Be ready to install C-UAS on various means/levels of operation. I think there's now a strong case for every naval warship, from the smallest patrol boat, up to an aircraft carrier to have effective counter-UAS capabilities, because these systems will be used in the air to attack ships at sea on the surface of the ocean, with USB's like, the Ukrainians have been doing and potentially even uncrewed underwater vehicles (UUVs). We need to understand the future threats, look at all of the technologies, for jamming drones, and how cyber warfare comes into disabled drones. We need to move our techniques beyond that, and now they are technical and then also not so-technical things like putting up nets over drones. It's not just all about radio waves to counter drones. It's about the physical technologies as well as everything else. (P16)*

The following list summarises the respondents' observations concerning the relevance and challenges in achieving counter-drone defence:

- EW systems are becoming more powerful and will drive continued changes to battlefield tactics.
- To maintain operational superiority and uninterrupted battlefield communication, EW capabilities must be effectively coordinated and deployed on the battlefield.
- Rapid advances in commercial and military EW technologies mean that reliable own-force communication can no longer be assumed.

Lesson 7: Financial Imperative of UAS Use

Drones are cheap and easy to use, allowing users to leverage limited resources to achieve disproportionate effects (see Figure 5). The financial benefits of using drones are therefore compelling. They are a cheaper alternative to traditional military systems, creating cost imposition strategies that can burden adversaries financially. In a large conflict of long duration, cost is key: the fewer resources used to destroy a target, the better. Defeating a $1,000 drone with $3 million missiles may be effective, but not sustainable. By contrast, with a drone, a single operator can potentially destroy a tank from the protection of a fortified position up to 10 km away using a communications repeater system. As quantity matters, the more drones a state can produce, the more sustainable its drone operations and the more credible its threat to stay the course.[94]

UAVs provide cost-effective alternatives to traditional military systems, offering significant financial benefits. They impose financial burdens on adversaries by requiring them to use expensive countermeasures against inexpensive drones. This cost imposition strategy is critical in modern warfare, where financial constraints play a significant role in the longer term. The cost-effectiveness of these systems underscores their importance in contemporary and future conflicts. Ukraine has demonstrated the effective use of innovation due to necessity, adapting to survive by leveraging new capabilities. When considering the cost of acquisition and transportability of these drone systems, it becomes clear why it is important for countries like Australia to stay abreast of emerging threats and opportunities.

In the war in Ukraine, UAS have enabled the AFU to significantly impact the high-value assets of the Russian armed forces. Using small UAS, the AFU has destroyed hundreds of Russians tanks, artillery and other vehicles, and one third of the Russian Black Sea fleet has already been destroyed almost entirely by sea drones. Indeed, a multimillion-dollar warship was destroyed by a $250,000 USV. Because the AFU crewed fixed wing fleet has extreme difficulty conducting missions due to Russian air defence, small UAS have come to dominate the airspace. While they remain vulnerable to Russian EW countermeasures, they can nevertheless generate battlefield effects, at scale, at an affordable price. Similar to the cost-effectiveness of the UAS, counter-drone systems must be cheaper than their intended target. As observed by one Ukrainian respondent:

> *A price of a charge of absolutely every killed Russian or a charge that delivered to the frontline must be lower than that of Russians, than of the enemy. We don't have to talk about manufacturability, we have to constantly talk about how we have to be cheaper and more efficient. For their functions, drones are currently replacing artillery. Artillery works great, no doubt. When it is there. For example, there are units that do not have any support in artillery or aviation. Drones are replacing attack aircraft, helicopters (except for transport, combat). For example, the U.S. Army refused Bell some contracts because helicopters are being replaced by drones. (P8)*

The US Army ISR Task Force Chief highlighted that 'the use of the cheap aerial systems is a good ROI (return on investment), and hence we need to start thinking differently in how we acquire weapons systems and to understand what the right acquisition is'.[95]

Given the demonstrated potential of drone technology, Australia needs to build its own sovereign capability, bringing drone and counter-drone technology into service. This will require agility in procurement processes to enable investment in local manufacturing and local software to build up sovereign capability. This should be an urgent priority. The view of several Australian respondents reinforces the threats and opportunities posed by drone technology.

[Knowledge of drone technology] is particularly useful for Australia, because the ADF will not have the mass to defend Australia and or everything that needs to be defended, should the conflict arise. The lesson about the future of autonomous and robotic systems is an opportunity for Australia and its allies to be looked at now. It is important to invest in own sovereign capability to be competitive at the global scale. (P1)

We must learn the lessons from the use of robotics and autonomous systems in Ukraine, because we will need them for the next conflict, we are called on to fight. We need to win the adaptation battle. We need to use robotics and autonomous systems at scale; to generate the combat mass we need to defeat our potential adversaries. We must consider how to defeat adversary use of robotics and autonomous platforms against us. We must support a sovereign robotics and autonomous systems industry to allow us to generate and re-generate combat power. The development and deployment of autonomous technology in warfare is an inevitable reality, and Australia must ensure that it is prepared to take advantage of it. We must adapt the way we think about them so that we can fight, and win, at sea. (P2)

Benefits of drones is that if 1 to 5 drones (up to $2.5k USD total) can destroy a $2–3 million tank that can destroy cities (like Mariupol, Bakhmut, etc.), then we are destroying the cause of destruction. The states resources should be invested into working with this 'cause'—to destroy enemy's tanks and other armour. 'If we are not going to work with the cause, all our life we will be working with the consequences' (P7)

Lesson 8: Rapid Innovation

The rapidly evolving nature of modern warfare in Ukraine necessitates an accelerated cycle of innovation, which currently ranges from a week to approximately three months. New solutions or significant modifications to existing technologies are continuously required to maintain a competitive edge over the adversary.

> *Continuous innovations are about improving distance, power and noise of drones. So, it is basically, you know, the distance that people can employ the systems, the power that they are outputting or using and then the noise that is generated and filtering that out. (P3)*

This fast-paced environment shows the importance of continuous improvement and quick iterations in developing military strategies and technologies. Innovation needs to occur within both government and non-government sectors, and the focus must be on the strategic integration of these efforts, as both are essential. This concept has been evident in the war in Ukraine. Ukraine innovates—FPV drones with lethal effects; Russia responds—the use of 'cope cages'. Russia acts—the use of Iranian Shahed-136 drones to attack cities and infrastructure; Ukraine adapts—German Gepard air-defence systems. Any war will stimulate competition. Foremost among this is technological competition which can, in turn, stimulate an arms race.

> *The moment we started flying UAS, counter-UAS systems came out, and then we started to adapt our tactics, techniques, and procedures to counter those and back and forth. I think we should watch this conflict very carefully because what you have are two highly technologically capable nations that can rapidly innovate. (P11)*

By closely observing experiences on the battlefield in Ukraine, nations like Australia can draw valuable lessons from both successes and setbacks. To fully capitalise on this opportunity, it is crucial for allied nations to collaborate with Ukraine in joint innovation efforts. Such efforts allow allies to leverage their insights to accelerate their own innovation processes, ensuring that their forces remain technologically superior. In the context of the war in Ukraine, there are many examples of joint collaboration between the AFU and drone manufacturers. Drones are being developed, tested, evaluated and deployed in real time on the battlefield. Companies are sending their drones to pilots in Ukraine to get direct user feedback in the operating environment. Many study participants agreed that there is almost no way to have an impact with new drones without visiting operators on the front lines and getting their input. Battlefield tests are generating enormous insights for drone manufacturers, and those companies are rapidly innovating based on direct observations and feedback.

Ukraine has been able to successfully leverage the global 'big tech' ecosystem, its civilian commercial technology sector, domestic start-ups, and even individual civilians for its 'drone war'. With high levels of buy-in from the commercial sector, Ukraine has successfully shortened the loop between prototyping, experimenting, testing, producing and fielding drones, as well as achieving streamlined procedures to deliver drone technologies to the front line. This has enabled it to substantially increase its production and has facilitated the fielding of drones that more directly meet the needs of the field units. While only seven companies were making drones in Ukraine before the war, there are now numerous companies making over 300 types of drones, with 600 types of drones seen cumulatively from both Ukraine and Russia. According to one delegate of the Warsaw Conference, the Future of Drones in Ukraine, 'It will take you years to test [drones] in your country. We do in three days what NATO does in 3 months or 3 years.'[96]

Given the direct connection between drone manufacturers and drone users, Ukrainian war fighters themselves appear to have a prominent voice in drone innovation. This seems especially important given the claim of a three-month innovation cycle on the battlefield. In collating the interviews for this research, the author was reminded of a recent conversation in Washington when a retired senior decision-maker stated, 'We've lost the voice of the war fighter in D.C.' By contrast, it was refreshing to hear the loud and clear war fighter's voice among study participants, but their perspectives must be viewed in the context of battlefield analysis and not taken in isolation.

> *Every 3 months, you need completely new technology. Western allies have different mindset in this approach, but they need to understand that in our (Ukraine) war the current technology won't be used for the next 20 years, and if we have invested in the technology, we do not hope it will protect us for the next 5 years. We were receiving American sensors and radars, and I showed them that the frequencies have been changing every few weeks. For example, their drones are flying on new frequencies, and quite often EW or our sensors are not in the spectrum of action. Russians are very adaptable. (P11)*

> *You need to always be ready to innovate, to be ahead, be ready for something new, not only because the adversary will outplay you, but there will be new implementations. For example, if Ukrainians used to direct mobile artillery groups to hit Russians, now they can change flight routes, altitudes, cross the frontline with the quiet engines. So, always be ready for innovation, both in response to the adversary's innovations and introduce own innovations, because the more it is used, the more you get used to it. (P22)*

Despite collaborative efforts with its allies, Ukraine nevertheless faces a range of challenges to achieving the levels of rapid innovation needed to sustain and build its UAS capabilities. There are at least three obstacles. The first is beating Russia's quantitative and qualitative edge. Russia possesses a wide range of electronic warfare capabilities. They are used to block the AFU's radio signals and communication systems, creating interference that impairs or completely blocks radio communications, the operation of radars and other electronic systems. They are also used to disable FPV drones, to set false targets on the radars of air defence systems and to detect the location of the systems themselves, to change the flight path of high-precision ammunition and missiles, and to block access to the electromagnetic spectrum and to the communication systems needed for weapons guidance. To cope with this challenge, Ukrainian manufacturers need Western know-how and technological support to develop and integrate anti-jamming systems into their UAS. The second obstacle is reforming procurement and scaling up production. In 2024, over 90 per cent of the UAS currently being used on the front line in Ukraine are Ukrainian-made. While only seven local manufacturers were producing UAS in 2022, over 200 manufacturers are currently producing various types of UAS. Domestic manufacturers are highly dependent on donations from businesses and civilians, which limits their ability to scale and increase production. Therefore, it is necessary for Ukraine to have long-term engagement plans involving Western manufacturers and local production companies. The third obstacle is that Ukraine needs to reduce its dependency on Chinese drones and critical components. As China remains a key supplier for Ukraine, this dependency poses an increasing logistical and political problem. Ukraine needs to diversify its supply chains with a focus on NATO standard suppliers.[97]

> *It is important that the components for drones are not Russian, not Chinese and we're moving now, we've started making drones, we (Ukraine) are moving now little by little, to already have our own components, own production, own sovereign capability. (P8)*

> *You don't need a silver bullet solution that is 100% perfect, particularly if you invest in large numbers of drones that are low cost. If you lose a few because they fail because they do not assign or align the target well, then so what? You still get a result out of it, so I think that the speed of development and the speed of innovation will be critical. We cannot afford to take a long time to develop these things. What we must do is develop them fast and that means embracing new approaches to development, such as synthetic development simulation. For instance, testing out drones in simulated environments and altering the design because of that evaluation. And then when you're ready, you produce the piece of hardware, using 3D printing technologies, to mass produce them very quickly.*

> *We need to have a different mindset about drones—to what we need to do and what we do. We can afford to lose quite a few drones if enough get through to the target and do what we need to do. Whereas we do not want to lose people, if we need to use fighter jets and warships. So, it is a different approach, and this is a race to the swift in the sense that the victory is the side that matures as a technology first or which understands how technology will change warfare and exploits that the most rapidly. If we go slow, we lose. (P12)*

An important lesson that has come out of this research is about the 'learning cycle'. Several of the interviewees noted:

> *This is a generic lesson, which even not necessarily about drones, but it is about the fact that history shows us, and war zones show us. From the linear that when you are confronted with the existential threat of dying, you learn fast because sometimes when you learn fast, you survive instead of dying, and that can be everything from individual soldiers, all the way out to strategic decision making about how campaigns are being prosecuted. (P1)*

> *The biggest lesson learned is that the drone technology is showing us that it remains constant in warfare, and when people are faced with their death, they could learn quite quickly. (P11)*

Lesson 9: Adaptation Battle

Ukraine is a rapidly evolving battlefield. The things that worked well in the first six months of the war no longer work today. Accordingly, both the capability platforms and the tactics that underlie their use continue to evolve.

> *If to use a Javelin (cost $130,000 a pop), they are very heavy and by carrying one around you make yourself a much larger target and your survivability is low because Javelin has a large signature and when you fire it you get a plume coming at the back and then a smoke trail that points back to your point of origin. So, while you might destroy the first tank, the 2nd, 3rd, 4th and 5th tank know exactly where you are. Back when I was in the army, there was a saying – 'one flash in your ashes' meaning your survivability is nil. So, drones changed that. (P6)*

The rapid development and deployment of UAV technology requires constant adaptation, innovation and evolution in military doctrine and TTPs. Adaptation is driven by two realities. First, drones are extremely vulnerable to countermeasures that target their particular digital and mechanical characteristics. Related to this, the widespread availability of mechanical and electronic components for building drones renders it easier for designers to swiftly modify drone designs. Given these realities, Western militaries (including Australia's) can learn much from both sides involved in the war in Ukraine. For example, the moment that UAS were used in Ukraine, counter-UAS systems emerged, and then the TTPs had to be adapted. The TTPs that worked for the first six months of the war no longer work today. The increasing use of uncrewed systems across different domains demands that countries stay up to date with technological advancements. Rapid technological evolutions, and their relevance to the way wars are fought, need to shape investment decisions and preparedness for future conflicts. Militaries must have the capacity to adapt to achieve missions and tasks with the resources at hand, despite the obstacles that the adversary may create. This has to be achieved faster than the adversary's capability to respond. The AFU has shown that there is more than one way to achieve military outcomes. Equally, the ADF needs to be sufficiently adaptable to achieve directed missions and tasks with the resources at hand, despite the obstacles that an adversary creates.

The term 'adaptation battle' has been used to refer to the rapid cycle of innovation and adaptation required to operate effectively on the modern battlefield.[98] In his book *War Transformed* Australian Major General (Retd) Mick Ryan notes that:

> *In war, those who plan and lead the fighting must constantly seek to out-think, out-manoeuvre and to out-fight the other side. New technological innovations are introduced into service, the geography or objectives in the war are expanded or evolved, and new tactical and operational concepts are developed to exploit evolving organisational constructs and achieve evolving theories of victory.*[99]

The evolution of robotics and autonomous systems in all domains is a clear example of the adaptation battle. While adaptation is critical on the modern battlefield, as Ryan observes:

> *Not all learning or adaptation in wartime results in battlefield success. This is partly because some institutions are not able to quickly or efficiently absorb new technologies—or ideas. Alternatively, some fail to anticipate the array of future threats or are unable to judge which threats are the most serious. A final cause for adaptive failure is that enemies actively seek to interfere with and degrade their opponent's ability to learn and adapt.*[100]

Lessons in areas such as leadership, multi-domain integration, signature management, closing 'detection to destruction' time against an adversary, massed use of crewed and uncrewed systems, information operations and industrial-scale warfare are likely to drive the institutional adaptation needed to succeed.[101]

> *The ongoing war in Ukraine has accelerated the use of autonomous technology in warfighting, and Australia must ensure that it is not on the wrong side of the asymmetric advantage in any future conflict. To win, we have to be able to adapt to both use robotics and autonomous systems to achieve our desired missions and tasks, at scale, and to defend against them. (P2)*

> *While the need to adapt is self-evident, the challenge remains in determining how to adapt supply chains and UAV designs within the military's strategic industrial base at a pace that matches the rapid battlefield adaptations that may need to occur. For example, FPV drones have needed to be rapidly adapted to respond to the battlefield introduction of counter-drones, with further evolution of TTPs needed to protect the pilot from attack. Measures are needed to offset C2 links in the fact of adaptation cycles that cannot be cancelled. (P1)*
>
> *It is becoming a 'cat and mouse' game. Development of the technologies in Ukraine has been rapid, and it outpaces what other countries have got in this space. In simple terms, it is about distance, power, and noise. The distance that people can employ the systems; the power that they are outputting or using and then the noise that is generated and filtering that out. And that applies across GPS and radio frequencies. Ukrainians are not trying to make something super shiny and expensive, but the challenge is to design and deliver effective use of uncrewed systems that work on the Ukrainian territory. (P2)*

The axiom 'adapt or die' is never more true than in warfare. The AFU's willingness to modify its approach has been integral to its survival. The ability of other nations to learn the importance of adaptation will likely dictate the outcome of future conflicts. Ukraine's transition from Soviet-era weapons and support systems to NATO support systems has been the main driver of this transition. This has involved a rapid induction of different anti-armour, air defence, artillery and armoured vehicles from a variety of donors. It has required an extraordinary level of institutional adaptation by the AFU as it absorbs multiple weapon types in a short period of time while simultaneously reforming its logistic support systems to align with NATO standards. The AFU has been able to adapt in a matter of weeks. Furthermore, Ukraine has been successful in encouraging crowdfunding efforts to support the war. This is important because it provides support in addition to that funded by the government. Support has included the donation not only of drones but also of trucks, medical aid, humanitarian assistance and a satellite. While enhancing Ukraine's military capabilities, this type of support has also allowed the Ukrainian people—as well as citizens from many other nations—to tangibly express their support for Ukraine's resistance against Russia.[102]

Lesson 10: Importance of Training

The USF's Commander, Colonel Sukharevskyi, acknowledged that 'while social media is replete with videos of Ukrainian FPV drone strikes destroying Russian military vehicles, this success isn't replicated across the entire front'.[103] This can be due to differences in access to equipment, levels of training and performance by Ukrainian UAV units. Importantly, the more UAVs the AFU gets, the more pilots it needs with the necessary skills to fly them successfully against Russian forces. The effectiveness of drones' use largely depends on the skills and experience of their operators. Accordingly, ongoing training and education is essential to ensure a high level of competence in drone operation and utilisation (see Figure 15).

Figure 15. Ukrainian soldier operates a drone in winter (Source: Oleksandr Volosyanskyi)

The most important out of lessons learnt is training. That's the key because approximately 60% of drones that we (Ukrainians) were given by the partners were lost due to poor pilot training and a colossal number of Bombers were lost due to pilot training. In Western armies, as well as in Ukrainian army, drone operators were those (not necessarily with the highest IQ), and then there was no time to teach these people, because it was believed that it doesn't take long to learn to operate that drone how to control it—it doesn't matter—it still flies up, down, right, left. However, in fact, the remote controls are different, systems are different, and drones are lost in colossal numbers due to poor training of operators. As such, we are moving to standardisation so that drones are standardised in its operation. We are moving in this direction because we won't have 10 drone kamikaze operators and 2 copter operators, instead a UAS operator should be able to operate any type of drone that should be the same in its operation. (P8)

DJI UAVs are easy to learn and operate. Anyone can fly them. They are also commercially available. This teaches us about the supply chain and the use of commercial technology in military application. Operating a drone can be learnt in less than a day. FPV drone takes 30 days to learn. They can be trained on a laptop. In fact, a drone racing industry was already an industry before the war. Because the sport was well established, there are hundreds of YouTube videos available to teach yourself to build and operate a drone. (P1)

In the first months of Russia's full-scale invasion, many of the 'drone operators' learnt their craft on the job as they had no practical experience. The Magyar Birds was the first squad who operated UAVs at the front line and shared their knowledge and experience with other soldiers. Since 2022, Ukraine has become a significant centre of UAV operators' training, driven by the demands of ongoing conflict and the need for advanced military technology. Training programs across the country are equipping soldiers and civilians with the skills to operate and maintain a variety of drones for surveillance, reconnaissance and combat purposes. These initiatives not only enhance Ukraine's defence capabilities but also foster innovation and expertise in UAV technology.

Since 2023, Ukrainian training centres, both private and non-government organisations, have trained 20,000 UAV operators. Training varies depending on the type of UAV; however, on average some training centres provide theoretical and primarily practical training, teaching the students how to build, fix, arm and fly drones through the hatches of vehicles and carry out kamikaze attacks. For example, one and a half days are spent on training for the flight itself, with the remaining time spent on tactics, camouflage, preparatory process, studying maps et cetera.[104]

Training to operate an FPV drone is more difficult than a DJI Mavic drone. Learning to operate an FPV drone requires simulation-based training, and advanced drone operation skills. If a drone is 150kg and over—a proper training is needed (similar to preparing a pilot). An operator will need to know meteorology, aero courses, etc. Learning to operate a drone has become an essential skill for school students. (P7)

My concept is as follows: I direct operators to learn basic skills so that you can learn the equipment controls and know how to operate know how it behaves at the training grounds or professional flight training, and then send to the combat operation/frontline to gain practical skills.

Also, mandatory training when you get a new complex, or a new drone brought by volunteers. An operator has to learn from those the drone manufacturers how to use the controls of a specific type and what the challenges in its operation etc. Time is highly critical. Usually, an average training takes on some types of drones is between several weeks to several months. One can learn to operate a civilian drone within a week on average. More complex systems such as drone-kamikaze or aircraft-type drone require more time to prepare and experience of operating a civilian drone. For example, you can fly a plane, but in order to operate a spaceship you need some time and more experience. You should operate civilian drones for a specific period of time, to gain experience, and then transition to operate more complex systems. I would say 90% of people can operate a civilian drone. They do not need a qualification to operate, apart from basic skills of drone controls. There are significantly a smaller number of those who can operate complex systems. (P14)

Training Centres in Ukraine

The Victory Drones training centre provides online and face-to-face free training to those willing to become a UAV operator. Training includes both theoretical (i.e., lectures) and practical components (i.e., using various technological equipment, including multirotor drones, under the supervision of an experienced instructor). Practical training for military personnel takes place at 12 training grounds. Training also includes tactical medicine, psychological support, and self-regulation for stressful situations. One of the latest updates to training is a separate course on working with ‘Kropyva’ and ‘Delta’105 software. Other topics of training include aspects of micro-class multirotor, aircraft-type UAVs, large multirotor UAVs (bombers), and FPV. Training format is mixed (online and offline) and takes up to one month.[106]

In 2024, Victory Drones has partnered with the Ministry of Defence of Ukraine to provide multi-stage free training for UAV operators. On completion of the course, they may sign contracts to serve as UAV operators in the Ukrainian Armed Forces.[107] Victory Drones provide FPV training for military personnel and servicewomen, with the duration of 34 days. The course includes theoretical and practical modules covering topics including structure, related equipment and combat use of FPV copters, antennas, communications, and software.

Since the beginning of the war, another training centre of UAV operators, Dronarium, has introduced free training for civilians and for military personnel of the Armed Forces, the Ministry of Emergencies, the Security Service of Ukraine, border guards and policeman, as well as for civilians. Dronarium offers a range of course including a basic ‘UAV Operator’ course (42 hours), a weekend course (14 hours), an underwater drone course (24 hours), combat applications of FPV (100 hours), thermal imaging surveillance, mapping and 3D-modelling of the area. Apart from theoretical and practical parts, the curriculum includes in-depth study of aviation law, Ukrainian legislation and international law in the field of UAVs.[108]

Boryviter Centre of Excellence provides free training and professional development for Ukrainian military organisations including the Armed Forces of Ukraine, the National Guard, Intelligence, the Security Service, the State Border Guard Service, and Territorial Defence. Some of the training courses include military leadership and planning, multirotor/

fixed-wing drones, multirotor/fixed-wing FPV drones, topography and land navigation, radio communications, situational awareness systems, psychological support, and lessons learnt. Training duration ranges from one to 10 days.[109]

Other training centres, like Volyn Falcons provide free training including theoretical and practical parts (day and night flights), and simulation flights training for civilians who would like to be UAV operators (see Figures 16 and 17). This course takes up to two weeks. Apart from learning how to build and fix a UAV, students also learn how to avoid detection while operating a UAV, and how to use camouflage traps effectively to protect their positions. Operators also learn how to react if Russian EW units take control of their drones. Some operators are taught 'bombing operations'. They handle practice bomblets specifically constructed to match the weight of those loaded with explosives that are used in combat.

Figure 16. Future UAV pilot training at the drone training centre Volyn Falcons on the Independence Day of Ukraine (Source: Reproduced with the permission of the owner)

Figure 17. Training grounds for FPV operators, drone training centre Volyn Falcons (Source: Reproduced with the permission of the owner)

'Defend Ukraine' School Program

The Ministry of Education and Science of Ukraine has announced integration of learning about drones in the school curriculum as part of vocational education reform. This is because learning how to operate a drone is vital in Ukraine, as drones are used for rescue operations, medical supplies delivery, de-mining, and assessing damage from military actions. This initiative, part of Ukraine's broader strategy to leverage drones in its defence efforts, underscores the country's commitment to preparing the next generation for the technological challenges and opportunities of the future. More than 200 vocational schools in seven regions of Ukraine have expressed interest in upgrading their facilities to offer quality training in this field, indicating strong demand and support. Ukraine's integration of drone technology into its educational curriculum represents a visionary step toward equipping its youth with the skills necessary for the future. Ukraine is not only enhancing its defence capabilities but also paving the way for innovation and technological advancement. This initiative reflects a broader commitment to education as a cornerstone of national resilience and progress, setting an example of how countries can adapt to the rapidly evolving technological landscape.[110]

In September 2024, Dronoznavstvo (drone knowledge, part of the 'Defend Ukraine' course) will be introduced in the educational curriculum for Year 10/11 students. In addition, UAV centres for teachers are planned where they will be able to train for four to five days. Basic knowledge about drones requires one to two hours (one for theory and one for practice) to launch a drone, fly it and land it safely. Expanded courses can be three to four days or sixteen to twenty hours. Obtaining basic skills to fly a UAV does not require much time; however, training and improving skills in its operation are important. 'Drone operations in our time is like at the level of using a computer or an iPad. This is an instrument that will be useful not only in the war time, but beyond as there are so many areas of application.'[111]

Lesson 11: Importance of R&D and Investment in Sovereign Capabilities

Another big lesson learnt from the rapidly evolving nature of modern warfare in Ukraine is the importance of continuous research and development (R&D) and innovations, as well as developing sovereign capabilities. The Ukrainian government has put a stronger emphasis on the importance of localising arms production and investing in domestic capabilities. This includes innovations in key technological sectors and speeding up development and delivery of defence equipment to the front lines.[112] (See Figure 18.)

Figure 18. Magyar Birds preparation for the mission (Source: Reproduced with the permission of the owner)

According to the Project Lead of Brave1, 'Two years of war has shown us that we are competing with technology—we are working with various solutions including drones, robotics, electronic warfare, cybersecurity and command-and-control management systems.'[113] Indeed, new systems are developed so fast that some systems fielded only a few months ago are now considered outdated. R&D is key in addressing new challenges to continuously 'out-innovate' the enemy.

> *We cannot afford to take a long time to develop these things. What we must do is develop them fast and that means embracing new approaches to development, such as synthetic development simulation. For instance, testing out drones in simulated environments and altering the design because of that evaluation. And then when you're ready, you produce the piece of hardware, using 3D printing technologies, to mass produce them very quickly. (P12)*

> *The ongoing war in Ukraine has accelerated the use of autonomous technology in warfighting, and Australia must ensure that it is not on the wrong side of the asymmetric advantage in any future conflict. To win, we have to be able to adapt to both use robotics and autonomous systems to achieve our desired missions and tasks, at scale, and to defend against them. (P2)*

Since 2022, Ukraine has been expanding its defence industrial capacity to develop the ability to satisfy its military requirements with reduced foreign military assistance. In 2023, Ukraine produced three times as much equipment and weapons as it did in 2022, and defence industry companies increased their production by 62 per cent in 2023 compared to 2022.[114] Ukraine's drone production increased more than one-hundredfold between the start of Russia's full-scale invasion and November 2023,[115] reaching monthly production of 83,000 FPV drones per month.

> *We (Australians) have a very limited range of drones; our production is very small. We need to seriously invest. We have to roll out the infrastructure, we have to hire more people, and we have to emulate a similar innovation loop and the best way forward because we have an ally that is doing it quite successfully. Ukraine is our ally, and Ukrainians need help. So, the best thing you can do is to team up with them, to learn from and with them.*

> *There is a need for research and investment in new technologies. For example, if we are talking about artificial intelligence about machine learning as innovations, indeed this solution is very simple but pricey. In order to make it less expensive, there is a need to do research how to utilise a device that costs $300 instead of $2000 in the same way. It requires research and development, as well as testing and evaluation. Same for the distance of drone's operation. Why do we have FPV drones with a range of 13–20km on average? Because we are working with repeaters. Same with the battery for drones—they should be designed and tested on a high level. Each supplier should meet the quality requirements of the mandatory technical control. And the main thing is to learn and to lead (to be ahead). Hence, there is a need to invest in R&D, and act on it step-by-step. (P20)*

> *In 2014, Ukraine did not have good drone capability, Russians had better one. Ukrainians invested in their own drone capability from 2015 and hence had the advantage from 2022. One of the lessons about the future of the autonomous systems in the future battlefields that is an opportunity that is right to be tapped by Australia, because you will never have the mass in our Defence Force to defend Australia and everything we need to defend. Now when you do it, you can do it with robotic systems, you will not buy $10,000 helicopters from Norway. You need to buy $500.00 drones, $1000 drones that are manufactured by your own company in your own country. And if our government chose to do this, if we did the equivalent of the British $7 billion investment, if we invested that into our own companies in our own country, that would make them competitive on the global stage. And there is a good chance that we would just be selling it to the Brits. (P1)*

The lessons learnt from Ukraine have direct application to ADF policies, future strategies, and future budget allocations. The Ukrainian experience offers valuable lessons for the ADF regarding key challenges and themes in defence innovation. This includes the need for active engagement of civil society and the commercial sector, and the adaptation of commercial technologies for defence purposes. The desirability of effective collaboration with partner armed forces has also been highlighted, as has the value of networked, non-hierarchical communication and implementation structures.

Additionally, the Ukraine war has generated a rich body of data concerning specific technological benefits of UAS technology. To fully capitalise on the R&D lessons generated from the Ukraine war will require effort, commitment, and trust between Ukraine and the international community more broadly. Nonetheless, the time is ripe to initiate structured cooperation between Ukraine and its allies in pursuit of defence innovation to 'outsmart' potential adversaries today and in the future (Figure 19).

> *Ukraine has demonstrated investments in sovereign capabilities and manufacturing components in Ukraine. While the US and Europe make efforts in investing to build up own sovereign capability, in Australia more support from the government is needed.*
>
> *Ukraine started off that way. But necessity is the mother of invention, and you know they rapidly realise if they do not all work together, the future is bleak. And because they have no choice, and that there is no room when the wars at your front door, and the buildings are on fire and your families in danger, it is not about profit anymore. It is not about who can do what and who is better. It is about how do I deliver capability to the frontline troops to keep the devil away from the door? Australia doesn't see that strategic peril and therefore is not operating under that pretext, and I am sad to say it will not be until it is too late.*
>
> *Most of core technology comes from overseas, Australia does not manufacture enough explosives, warheads that go on a drone. How many armed drones are currently in Australian Defence Force? Australia may consider investing in company that has got economies of scale and expertise to deliver whatever capability they find that they need in the next conflict and act on it. (P6)*
>
> *We must learn the lessons from the use of robotics and autonomous systems in Ukraine, because we will need them for the next conflict, we are called on to fight. We need to win the adaptation battle. We need to use robotics and autonomous systems at scale; to generate the combat mass we need to defeat our potential adversaries. We must consider how to defeat adversary use of robotics and autonomous platforms against us. We must support a sovereign robotics and autonomous systems industry to allow us to generate and re-generate combat power. (P18)*

The development and deployment of autonomous technology in warfare is an inevitable reality, and Australia must ensure that it is prepared to take advantage of it. We must adapt the way we think about them so that we can fight, and win, at sea. The drone army you go to war with is not going to be the drone army you win with. It's going to constantly evolve based on interaction with the enemy and the environment over the course of a conflict, and we need to be postured to do that learning and rapidly respond to that learning and roll out different and evolved products. (P18)

Figure 19. Research and development of UAV (Source: Atlas Aerospace)

Lesson 12: Future Capabilities and Technologies

Emerging technologies are undoubtedly changing the modern battlefield and will continue to play a larger role in future conflict. The war in Ukraine shows that uncrewed systems—of various levels of sophistication, autonomy, and types of functions—are now an essential element of modern warfare. When successfully integrated into battlefield tactics and as part of mature concepts of operations, it is clear that drones can confer asymmetric advantages to outgunned armies and provide cost-effective and sophisticated intelligence, reconnaissance, and strike capabilities.

Ukrainians are also starting to use 'mass effect' drone operations: where several drones, sometimes with diverse capabilities like electro-optical, infrared, communications links, and kinetic capabilities, are flown in concert. Each drone is controlled by a single pilot with the intention of confusing, if not overwhelming, the enemy and their counter-drone systems. The effectiveness of these operations has not been rigorously tested but participants generally agreed this could be highly effective, perhaps for no other reason than the fact that operators on the ground in Ukraine—from both sides—are traumatised by the sounds made by drones and tend to take cover whenever they hear a drone's high-pitched buzz.[116]

In addition to current drone missions, future uses may include landmine detection, tripwire detection by quadruped drones, and sensor fusion for better targeting. Additionally, when tens of thousands of UAS are used on the battlefield, they can be used to generate multiple different effects. The systems are hard to detect and are dispersed, so they are resilient to enemy action. Importantly, many can be lost without compromising the mission. Ukraine is estimated to lose 10,000 drones per month.

It means that we need to get away from traditional approaches to capability acquisition, and I suppose that traditional approach is epitomized by something like the F35 Joint Strike Fighter, where you have this sophisticated, really capable platform that's taken 20 or 30 years to develop at huge cost, but can only afford a small number of F-35s, and we have to spend an ordinate amount of money to sustain them. We have to switch from that to mass production at a rapid rate of knots of large numbers of drones that are low cost and can be produced in high volume and generate effect through mass and overwhelm an enemies' ability to defend by essentially flooding the battle space. The two types of capability go together, yes, we are always going to have that need for high-end fighter jets, but if they are complemented with these large numbers of low-cost drones (i.e., 1 F35 = 75,000 UAS) that we can mass produce at speed and scale, then you get new ways of generating military force. So, it's about getting the defence industry to recognize the advantage of high volume, low cost. If we lose 10,000 UAS, we will still generate the effect.

We're still sort of getting to the point whereby we're experimenting with the grunt on the ground with the drone in his backpack until we can get to utilising where you've got an infantry squad that has an integrated drone capability that you can give them eyes in the sky, give them the ability to link into long-range fires from HIMARS.

We're still not at that point yet, and there is a slow pace in Australia's development, I think because we are still thinking in terms of that 'silver bullet solution', which is what the Ghost Bat is all about. We are still thinking in terms of developing a high-end capability—a fighter jet without a pilot, or a warship without a crew, and that is slowing us down. (P12)

AI-Enabled Drone Warfare

The potential for mature AI capabilities to dominate the global arena is becoming evident to military strategists and leaders. The decision-making power currently seen through the prism of the OODA (observe-orient-decide-act) loop will evolve with the integration of AI into the entire cycle. The machines and human teaming enabled with AI will act more quickly than an adversary to gain operational and tactical advantage on the battlefield.[117] In the context of UAS warfare, AI-enabled drones may allow for faster OODA loops and hence facilitate a faster decision-making process for UAS operators. Further technological advances in computing power that supports AI will allow more capability to be installed onto smaller, cheaper drones. Using AI, drones may react autonomously to changing circumstances and communicate with each other to orchestrate a sortie.

> *AI-powered drones can do in seconds what would take a human several hours, simply because human performance is limited to a slow process of large volume of information; while the swarm is effective because one experienced drone pilot can work effectively with dozens of drones at the same time (P11)*

> *If your OODA loop is faster than mine, then you can act quicker than me, which means you will win because you can see that an accident and do something else and I am slower. So, I am always 2 steps behind when you come to AI, it's speed of decision making is instantaneous. So, unless we can have instantaneous responses, we will lose, and the cost of AI will be low. Indeed, if you look at an FPV drone, and Ukraine just started doing this, so you have got an FPV drone that is seeing a live video feed, keep it on board, process the video image, and do the targeting. So now that drone is basically saying everything north of this line is the enemy. If I see something, I will engage in it. A million drones will overwhelm every defensive system that Russia has if they all hit at once. The problem is at the moment they're coming out [piecemeal] 100 drones, and they are responding to it … (P.6)*

In Ukraine, AI is already assisting decision-makers to act and to better integrate warfighting systems on the battlefield. Specifically, AI's most widespread use in the war in Ukraine is in geospatial intelligence for object recognition to detect the identity of invading Russian troops (Clearview), real-time analysis of Russian unencrypted radio transmissions (Primer), and the imagery of Ukraine (Scale AI).[118] In fact, 12,000 enemy targets (i.e., units of enemy vehicles/equipment) are detected by the Ukrainian military weekly with the help of AI, via the Avengers platform. This platform enables operators to make decisions more quickly and more efficiently, reducing the risk of fatigue-related errors. Future work remains to enhance the platform's cloud capabilities and integrate AI solutions with drone systems.[119]

An increasing number of Ukrainian UAS companies are developing AI technologies for UAS, one of several innovative leaps taking place in the country's domestic UAV market. For example, Ukraine's new Saker Scout drones, trained on machine learning, are able to independently identify up to 64 different types of Russian targets while also carrying explosives.[120] In addition, due to AI data analytics, the time from detection of a target to its destruction has, in some cases, been reduced to just over 30 seconds. However, the accelerated targeting and strike cycles are likely to come with inherent biases for speed—an action that may pose a challenge, since the battlefield is still human-centric.[121] AI has been used in some of Ukraine's long-range drone strikes that target military facilities and oil refineries hundreds of kilometres inside Russia. In these operations, a core drone flies to the target while others distract air defences along the way. AI with human oversight is used to assist in target or threat spotting and possible route planning.[122]

The need for AI-enabled drones is becoming more pressing as both Ukraine and Russia roll out EW systems that disrupt signals between pilots and drones. According to Max Makarchuk, the AI lead for Brave1, some current projects are focusing on developing a defence technical accelerator to remove the connection between the pilot and UAS. As jamming increasing, the hit rate by the FPV drones decreases. According to Makarchuk, the percentage of FPVs that hit their target is around 30 per cent to 50 per cent, while for novice pilots this could be as low as 10 per cent. AI-enabled drones can increase hit rates to around 80 per cent. The key enabler is the capacity to 'lock onto a target' to counter EW threats. This is because automating the final part of a drone's flight to its target means that it no longer needs the pilot, nullifying the effect of EW jamming. In theory an AI-enabled drone could fly without a live link to a human operator using preset instructions before launch, fly itself around the designated area, use object-recognition software to recognise potential targets, and send back brief, compressed and encrypted reports instead of live video. The challenge is to generate inexpensive, small AI-enabled systems that could be deployed en masse along the entire 1,000 km front line, where thousands of FPV drones are used each week.

The estimate of a simple targeting system able to lock onto a shape visible to the drone's camera is around US$150 per UAV.[123] Some of DJI's drones already can track designated targets, but high-end AI currently runs on large, powerful computers that are expensive, and would not fit on a 'quadcopter-sized digital brain'. Hence, any sophisticated AI processing would require significant computational power that is not currently available on any small drone. In addition, AI computer vision models are not at a level of performance to operate without a constant link to an operator.[124]

A risk with AI-enabled drones is that they may be more vulnerable to EW-delivered malicious software those that are remotely controlled. While all commercial-off-the-shelf drones are vulnerable to EW, platforms that rely on the electromagnetic spectrum for their operation are especially vulnerable to EW. The risk exists that so-called 'self-learning' capabilities that are being explored by scientists would enable drones to quickly and effectively analyse large amounts of incoming information, while working out possible response scenarios. AI could enable drones to identify important data contained in intercepted signals, conduct appropriate analysis, and distribute the results. Scientists are already working on creating a technology that will radically improve the ability to geolocate and assess the characteristics of devices that emit electromagnetic signals. It is expected that next-generation systems will be able to accurately identify signals with different approach angles and polarisation states, improve the signal-to-noise ratio, detect signals and source geolocation with multivariate adaptive signal processing, and provide accurate ionospheric state determination. Of course, the generation of effective counter-EW is technologically demanding and expensive. The question therefore remains as to whether the benefits outweigh the costs.[125]

Limited range remains a significant drawback of all UAVs that slows down the development of uncrewed technologies. Remote control implies that the drone and the operator must be in electronic line of sight of each other. In some instances, UAVs use repeaters (which can be aircraft or other drones) to build a chain of communication, but this chain is vulnerable.

While debates remain about the current effectiveness, and future potential, of AI-enabled drones, there are several key areas where AI promises to make a significant impact. These include terminal guidance, visual navigation, target detection and swarming. Specifically, AI drone development is broadly split between visual systems helping to identify targets into which drones can be flown, terrain mapping for navigation, and more complex programs enabling UAVs to operate in interconnected 'swarms'. Regardless of the purpose, it remains the case that AI drone control systems will always need a human in the loop to prevent the system making errors in target selection and to address the ethics of weapons use.

Drone Swarming

A drone swarm is a group of drones that work together to achieve a common goal.[126] Instead of operating a single UAV, drone swarms could involve thousands of UAVs operating in the battlespace at any one time in a coherent, coordinated formation. In a swarm, the individual drones work in unison to complete tasks using distributed coordination, with each communication sent out by one drone providing the others with up-to-date information about their environment and roles in the mission.[127] As their commands are based on real-time data, these swarms react quickly and precisely to changes in their surroundings. Although defences might attempt countermeasures, such as physical barriers, swarms possess adaptive capabilities to overcome these.

Swarming drones can perform multiple roles simultaneously, such as surveillance, reconnaissance, and direct attack. This multi-role capability adds to the complexity of defending against them, as different defensive measures might be required for different drones. As their commands are based on real-time data, these swarms react quickly and precisely to changes in the operational environment. The sheer number of drones can saturate defence systems, making it difficult to target and neutralise each individual drone effectively. Even if several drones in the swarm are destroyed, the remaining drones can continue their mission, ensuring that the overall objective is still achievable. It becomes difficult to disrupt the entire swarm since there is no single point of failure.[128]

Swarms use various communication methods, including mesh networks, which can adapt to interference. Jamming such networks requires targeting multiple frequencies and communication links simultaneously, which is complex and resource intensive. Many drones within a swarm have autonomous capabilities allowing them to continue their tasks independently if they lose communication with the central controller or other drones. This autonomy reduces the effectiveness of jamming or spoofing. Swarms can be equipped with sensors to detect jamming signals and employ anti-jamming measures, such as switching to backup communication channels or modes.

Swarms offer sheer combat mass, able to overwhelm defences and exploit design vulnerabilities that cannot be easily countered. Swarm drones work together to complete tasks that would be much harder for a single drone to undertake. For example, unarmed drones may collect information from the field to inform armed drones on where best to strike. Drones armed with guns, bombs and missiles would allow the drone swarm to use a combination of weapons to carry out an attack. Militaries might add drones equipped for EW if needed, or maybe add drones with anti-tank missiles. Ideally, drone swarms would operate somewhat akin to Lego bricks where capabilities can be mixed and matched to build the drone swarm the battle commander requires.[129]

Swarming allows for an individual operator to direct many drones, multiplying the potential effect for both offence and defence. It would be logistically and technically impractical to have 600 drone operators controlling 600 drones, due to the complexity and expense of coordinating numerous radio transmissions and commands. Instead of directing each drone separately, the pilot or programmer assigns a task to the group and lets the operating algorithms take over. To simplify the process, drones are separated into ‘queens’ and ‘workers’. The queens use complex on-board algorithms to analyse data from the environment, respond quickly to unexpected variables, and assign tasks to the worker drones depending on the circumstances. The workers will then efficiently carry out orders the queen provides, maximising speed and safety. Drone swarms can incorporate different types of collective functions, with specialised roles as sensors, attackers, decoys or communicators.

> *We are not yet there, but I think in a small country like Australia, the use of massed, uncrewed systems that are either swarming or orchestrated by a single operator will be a really important part of our concepts of operations and future. (P2)*

Battlefield swarming is in its infancy, despite its widespread use in civil industry, especially for light shows and replacing fireworks. Nevertheless, swarms of drones developed in Ukraine have already passed their first tests of combat effectiveness.[130] Ukraine is emerging as a testing ground for cutting-edge warfare, including drones (and other capabilities) capable of carrying out parts of their mission on their own. Swarming drones may be deployed in 2024. By allowing a single pilot to control multiple drones, swarming aims to alleviate the personnel shortages that have put Ukraine's armed forces on the back foot. The war in Ukraine is bringing future trends for drone use into view. Drones are not only uncrewed long-range persistent eyes in the sky and robotic missile launchers, but also a new generation of small, stealthy drone scouts across most domains of operation.[131]

> *It's exactly like we read and see in movies, in science fiction where robots are fighting robots. This is not the future anymore. This is the present. (P21)*

While the drones of the future will have different capabilities and functions—and will operate in the air, on land and at sea—they will inevitably need to work in cooperation with other battlefield systems. While a single drone is unlikely to kill 100 people, it can effectively and efficiently direct the infantry officer who will achieve this effect with the joint forces.

> *In order for the swarm to pass, you need to knock out EW. First, we use systems that knocks out the electronic warfare and air defence, and then swarms anti-personnel and anti-armour, these are swarms that is, they are the last to go and knock out everything that moves and everything that breathes. Russians are using this strategy, and Ukrainians are using this strategy. It's like mirrored. However, Russians also have land drones—people—resource that they rely on to take on some territory (i.e., in Avdiivka, in Bakhmut) (P14)*

The modern landscape of warfare is characterised by attrition, where the ability to deploy overwhelming force is crucial. In this context, achieving superiority involves deploying large numbers of assets, such as swarms of drones, to incapacitate frontline defences. Once these defences are overwhelmed, traditional military forces—tanks, infantry, and other ground units—can advance and secure territory. This method of warfare leverages sheer numbers and technological prowess to achieve strategic objectives. However, as this tactic becomes more prevalent, countermeasures will inevitably develop. The nature of these countermeasures remains an open question, but they will likely involve advancements in defensive technologies and strategies designed to neutralise or mitigate the impact of swarm attacks.

> *In a small country like Australia, the use of massed, uncrewed systems that are either swarming or orchestrated by a single operator will be a really important part of our concepts of operations and future. We really need to think about that. (P24)*

Every conflict is different. Australia is geographically different to Ukraine and the rest of the world. The Australian population is small compared to many other countries, with limited human resources in the ADF. Autonomous and uncrewed systems offer real potential to enhance military capabilities with existing personnel constraints. Once battlefield swarming becomes commonplace in all domains there will be a shift in the density of drones and humans in military operations. As the cost of individual drones continues to fall, operational demands will likely drive the need for more and more drones to join the swarm.[132]

What Is Next?

UAS are prevalent on the battlefields in Ukraine today and will increasingly feature on the global battlefields of the future. Uncrewed systems can save and have saved human lives, and they also serve as a force and combat multiplier. Soon they will be everywhere: on the ground, in the air, on the water, under the water. According to the Chief of Defence Intelligence of Ukraine:

> *The robotic and autonomous systems are being modernised. Technologies are being mastered. New technologies are emerging. Over time, we will probably see the complete dominance of uncrewed vessels over conventional warships. At least in closed or semi-closed waters, such as the Black Sea, the Mediterranean, etc. This is definitely the way forward.*[133]

Ukraine's effective utilisation of drones in combat operations has prompted military organisations across the world to reassess their strategic priorities and defence investments. The establishment of an 'Uncrewed Systems Force' within the AFU marks a crucial advance in military strategy that has global implications. Drones, which were once primarily utilised for reconnaissance and minor tactical gains, have now seen widespread use on the battlefield in a number of different roles. Uncrewed systems have demonstrated their value in surveillance, in direct assaults, and in disrupting enemy operations across various domains including land, sea and air. The strategic employment of UAS has significantly bolstered Ukraine's defensive capabilities and provided a template for asymmetric warfare. The innovative use of drones highlights their transformative potential in modern military conflicts, illustrating how technology can be leveraged to counteract traditionally superior forces.

Employing UAS competitively on the battlefield will necessitate sustainment from the defence industry as a critical enabler. Mass still matters. The war in Ukraine has called into question Western military-industrial capacities.[134] According to the Fortune Business Insight report 'The Global Unmanned Aerial Vehicle', market size is projected to grow from $31.70 billion in 2023 to 91.23 billion by 2030.[135] In response to this requirement, NATO has introduced recent initiatives such as the NATO Innovation Fund. It aims to bring allied nations and their industries and research communities into a closer partnership to fund, develop, and deploy dual use of emerging and disruptive technologies and offer prospects of commercialisation at scale.[136]

Several nations are already revising their strategies and testing new approaches to drone innovations. The UK has already taken measures to revise its strategy in response to the events in Ukraine. In February 2024, the United Kingdom Ministry of Defence launched a new drone strategy, aiming to enhance its capabilities in UAS. The investment includes at least $5.7 billion over the next decade.[137] This substantial commitment demonstrates the UK's commitment to staying ahead in the rapidly evolving field of drone technology, maintaining a technological edge and ensuring the readiness of its armed forces in an ever-changing security landscape. The UK's primary goal is to ensure the UK remains 'one step ahead' of adversaries in future drone warfare, with the focus on logistics (enhancing supply chain and transportation capabilities), one-way attack (developing offensive drone systems), naval mine clearance (improving maritime security), and ISR (enhancing situational awareness and information gathering).
The UK drone strategy aims to accelerate access to UAS across air, land, and sea. Importantly, this strategy underscores lessons learnt from Ukraine: the UK draws lessons from the ongoing conflict in Ukraine, where both sides have extensively used drones for combat and ISR purposes.
The UK remains committed to its ongoing Ukraine–UK uncrewed systems initiative—supplying Ukraine with uncrewed systems, collaborating with Ukrainian industry, and scaling up the UK domestic drone industry across manufacturing and software development. The war has served as an incubator for new ways of winning battles, and the UK aims to implement those hard-fought lessons.[138]

In the US, lessons from Ukraine are informing the Pentagon's Replicator Program. This initiative is aimed at fielding small drones in high numbers and on a rapid timeline via engaging with new partners, keeping the cost of drones low, and scaling up commercial solutions.[139] To date, considerable investment has been made in the production of small, cheap and disposable drones. The US is more confident that wars will be fast, lethal and fought with a blizzard of small drones in the future.[140] France is changing its acquisition processes for small drones.

In Australia, the 2024 National Defence Strategy and the 2024 Integrated Investment Program recognise the importance of enhancing the nation's drone and counter-drone capabilities, given the rise of drone warfare globally. Overall, $300 million over the next four years and AU$1.1 billion over the decade has been committed to the investment in Australian drone and counter-drone capabilities (this compares to an estimated 2024 expenditure by Ukraine of $2 billion in drone production technology[141]). The 2023 Defence Strategic Review made no mention of the lessons learnt from the war in Ukraine, but those lessons need to be heeded. Opportunities exist for Australia to observe and learn, as well as to support industry through collaborative work that enhances Ukraine's capabilities while making data available that can help accelerate Australia's own production efforts.

Australia has already taken an important step in enhancing its drone capabilities and supporting Ukraine by joining the 'Drone Coalition' together with the UK, Latvia and 13 other countries. This coalition, established in February 2024, represents a collaborative effort to provide advanced drone technology and capabilities to support Ukraine's defence. The Joint Statement by the Drone Coalition's Ministers of Defence highlighted the joint effort in supporting Ukraine by delivering different types of drones, supporting Ukrainian manufacturing, and providing drone testing training.[142] According to the Deputy Defence Minister of Ukraine for Digital Development, Digital Transformations, and Digitalization:

> *Technology, not people, should be fighting. The drone coalition will be another step towards implementing this idea. It will save many lives. Strengthening and developing the production of uncrewed systems will make it possible to transform the military and make the latest technologies a reality today. I would like to invite nations to develop software solutions that will create the future of this sector.*[143]

The drone coalition adheres to a '50, 30, 20' financial principle under which 50 per cent of the funds are allocated for Ukrainian drones, 30 per cent for drones from partner nations, and the remaining 20 per cent for joint venture projects. This coalition aims to provide FPV drones to Ukraine, which will be produced at scale and at more affordable prices by leveraging the industrial strength of signatory countries.[144]

> *UAS and more broadly multi- and cross-domain Uncrewed Systems (UxS) offer a suite of novel opportunities not available with existing technologies. While a range of effects are available to generate mass and scalable effects, there is also substantial opportunity to protect our soldiers and remove them from the dull, dirty and dangerous tasks of the battlefield. In the future, we envisage first contact with the enemy to be robotic. This enables our humans to transform their role from transactional to more analytical and meaningful roles. (P26)*

> *The future is here. What is going on in Ukraine right now is even crazier thing, and not many people realize that war phase completely has changed. We are already in this futuristic scenario where it just war of robots, land drones, sea drones, air drones that are dominating everything. The only thing they're not dominating are jets, but there are even jet-propelled drones now, so we are not far off from even combating F-16s with drones or F-16 type operated drones are not far away. Every aspect of a battlefield is now being dominated by drones. When you merge those two revolutions together—AI and drones—it is a big lesson. Except for Ukrainians, Russians, and maybe the Chinese, not many people realize that it's happening right now. And what people do realize, but people are not acting on it, not preparing for it by a lot of the equipment we have, a lot of the equipment we're investing in—is no longer useful—if we don't have the drones. This is what will be the big focus of the future. It's already part of any warfare. It's part of the present. (P16)*

Recommendations for the Australian Army and the Australian Defence Force

The conflict in Ukraine has demonstrated the transformative impact of drones on modern warfare, highlighting their strategic, operational, and tactical advantages. Based on these lessons, the following recommendations are made for the Australian Army and the ADF:

1. UAS Are Changing the Character of War:

- Continue to evaluate UAS/C-UAS capability based on the lessons learnt, benefits and effects they have demonstrated on the battlefield in Ukraine. The biggest lesson learnt is that drone technology is showing us that it remains a contributor to modern warfare by generating mass and precision strike effects, and, when facing existential threats, it can save and has saved lives. Although UAS cannot reduce the importance of legacy systems such as artillery, armoured vehicles and tanks, their unique characteristics may enable the ADF to fight differently and generate the asymmetric advantage articulated within the 2023 Defence Strategic Review and the 2024 National Defence Strategy.
- Integrate UAS further into TTPs (i.e., artillery, intelligence, surveillance and reconnaissance) to enhance teams' tactical and operational effectiveness. For example, UAS have shown improved pace and precision of artillery and provided information and situational awareness to all fighting formations, down to individual soldiers. The information provided by drones and shared on new digital battle command networks greatly increases the speed of decision and action.

- Develop the ADF strategy for the use of UAS/C-UAS. Integrate UAS into the military doctrine, ensuring that all levels of command understand how to effectively employ UAS/C-UAS in joint and combined arms operations. Lessons learnt from Ukraine, including procurement at pace, rapid delivery and iterative capability development highlights the need to adopt a more adaptable and agile acquisition process.

2. Prevalence of Small UAS:

- Acquire UAS of different types and purposes of use. Small UAS (sUAS) are currently dominating the battlefield in Ukraine.
- Equip ADF personnel with sUAS for ISR purposes. This capability may allow for threat detection and mitigation.
- Develop a training program for better awareness of the UAS threats and the ways to counteract current and emerging threats.

3. Counter-Drone Systems:

- Develop and deploy C-UAS capabilities that can evolve as UAS threat develops.
- Be ready to counter UAS threats and to install C-UAS in various means/levels of operation.
- Advance C-UAS capability investments and operations technology that can counteract different types of UAS. Technology to counter UAS is continuously developing, and hence various types of C-UAS should be taken into consideration that can be effective in operation.

4. Multidomain Use of Uncrewed Systems:

- Develop a diverse fleet of uncrewed systems that can be used for various purposes, including small tactical drones for reconnaissance, larger UAS for long-range surveillance, and armed drones for precision strikes. These systems should vary in range, endurance and payload capacity to meet different operational needs and environments.
- Develop capabilities for multidomain operations where UAVs can support air, land and sea operations, enhancing overall mission effectiveness and saving lives.
- Strengthen uncrewed systems capabilities in the air, at sea, and on the ground. Develop new ways how these systems may interact (i.e., employing UAV and USV for a mission).

5. Financial Imperative of UAS:

- UAS are a cheaper alternative to traditional military systems, allowing adversaries to leverage limited resources to achieve disproportionate effect.
- UAS serve as an asymmetric response to the adversary's cost imposition strategy. This cost imposition strategy is critical in modern warfare, where financial constraints play a significant role in the longer term.
- In a long and large conflict, cost is key: the fewer resources used to destroy a target, the better.
- Focus on further developing sustainable UAS production, supply chain and maintenance.
- Invest in collaborative programs, working with defence industry and academia to accelerate and scale up sovereign capabilities.

6. Rapid Innovation and Adaptation:

- The TTPs that worked for the first six months of the war no longer work today. Forces need to maintain adaptation in battle.
- The rapidly evolving nature of modern warfare in Ukraine necessitates an accelerated cycle of innovation, which currently ranges from a week to approximately three months. New solutions or significant modifications to existing technologies are continuously required to maintain a competitive edge over the adversary.
- The rapid development and deployment of UAV technology requires constant adaptation, innovation and evolution in military doctrines.
- Foster a culture of rapid innovation and continuous learning to adapt to evolving threats and technological advancements.
- Develop and invest in industrial base – both defence industry suppliers new to small and medium sized enterprises. Communicate specific requirements and standards, while allowing for providing innovative solutions, and the opportunity to deliver at scale. Ensure supply chain resilience for key components and platforms in line with the ADF's needs.
- Engage with industry and academia through regular events to share knowledge, expertise and capability requirements.

7. Importance of Training:

- The rapid development and deployment of UAV technology requires constant adaptation, innovation and evolution in military doctrines. It is essential to learn from both sides in conflicts like Ukraine and integrate those lessons into tactics, techniques and procedures.
- Enhance training programs for drone operators, focusing on both manual control and autonomous operations.
- Ensure high levels of training for UAV operators and maintain robust maintenance programs to keep the technology operationally effective. Training should cover various scenarios, including urban warfare, counterinsurgency, and high-intensity conflicts.

- Train all ADF staff to operate UAS, based on the nature of their operations.
- Develop and seek advanced training for instructors and operators for various conditions of operation and with various teams.
- Update TTPs based on the lessons learnt from Ukraine.

8. Importance of R&D and Investment in Sovereign Capabilities:

- Strengthen partnerships with allied nations and Ukraine to share knowledge, technology, and best practices related to UAS operations and TTPs. To be achieved via government initiatives and knowledge exchange sessions, in order to foster innovations and cutting-edge UAS/C-UAS technologies.
- Establish an R&D hub for UAS/C-UAS capabilities to continuously research lessons learnt, and the latest innovations, to develop low-cost, high-value technology that can provide an asymmetric advantage in any future conflict.
- Continuously learn from the fast-evolving innovations, harnessing data from Ukraine and other theatres to refine capabilities, adapt and improve uncrewed systems in response to real-world challenges.
- Invest in R&D projects to stay at the forefront of UAS/C-UAS technology.
- Collaborate with civil and military regulators to navigate regulatory challenges and to support industry's test and evaluation capabilities.
- Facilitate the creation of controlled test areas ('sandboxes') in Australia and overseas for research and development, as well as test and evaluation of industry's capabilities in uncrewed systems.

9. The Future of Robotics and Autonomous Systems Has Arrived:

- Robotics and autonomous systems have been shown to be effective at providing lethality at range, at low cost, and with economy of effort.

- Develop the ecosystem in which robotics and autonomous systems, artificial intelligence, and swarm technology can enable a single operator to control multiple drones.
- Invest in the development of future UAV capabilities, including AI-driven autonomous operations, advanced sensors, and improved endurance and stealth features.

10. UAS Displace Rather Than Replace a Human:

- UAS, whether ground-based, aerial, or maritime, are still controlled by humans but displace their roles in the surveillance chain, removing them from frontline exposure and risk.
- Recognise UAS as a force multiplier that enhances combat effectiveness by providing superior situational awareness and precision strike capabilities.

11. Other:

- Integrate UAS with advanced battle management systems to enhance coordination and efficiency during operations.
- Move towards the standardisation of UAS systems and develop a comprehensive UAS ecosystem that supports maintenance, supply chain management, and operational readiness.
- Utilise UAS in information warfare to gather intelligence, conduct psychological operations, and influence enemy decision-making.
- Exploit social media platforms for real-time intelligence gathering and dissemination, leveraging the broad reach and immediacy of these tools.
- Develop programs/mechanisms to mobilise civilian drone operators for support roles in defence operations, expanding the pool of skilled personnel available for UAV missions.

The final and most important recommendation is to continuously draw on the lessons learnt from the war in Ukraine.

Conclusion

This paper has highlighted the role of UAS/C-UAS in modern warfare in the war in Ukraine. UAS will soon be everywhere: on the ground, in the air, on the water, under the water. The establishment of an 'Uncrewed Systems Force' within the AFU marks a crucial advancement in military strategy globally. Drones, which were once primarily utilised for reconnaissance and minor tactical gains, have now become a cornerstone of Ukraine's defence mechanism against adversaries. New drones strategies are written and rewritten to stay ahead in an ever-changing security landscape.

The role of UAVs in the Ukraine war is unlike anything previously seen in warfare. First, the scale of use has been extraordinary. Previously drones were used on a small scale—compare the small number of MQ-9 Reapers that have been built to the thousands of drones that Ukraine expends and loses in a single month. Second, drones have assisted a demonstrably weaker military force to prevail against a stronger adversary.

Ukraine's innovative deployment of drones in its conflict has not only reshaped its military strategy but also set a new standard for other nations. The global trend towards incorporating uncrewed systems into warfare marks a substantial shift in military doctrine, with profound implications for future conflicts. As nations adapt to this new paradigm, the strategic, ethical, and legal dimensions of warfare will continue to evolve, heralding a new era of modern warfare.

As military forces worldwide continue to integrate drones into their arsenals, the nature of warfare is set to undergo further significant transformations. The growing reliance on uncrewed systems is expected to drive rapid advancements in counter-drone technologies and strategies, fostering a continuous innovation cycle in military tactics and defence mechanisms.

This evolving landscape indicates that future military strategies will increasingly hinge on technological superiority, with drones playing a pivotal role in determining conflict outcomes.

Overall, the UAV phenomenon in the Ukraine war has implications across time, space and domains that are likely to be longstanding, far-reaching and multidimensional.[145] The conflict has seen the deployment of the widest array of drone types, from military-grade medium-altitude long-endurance drones, such as Turkish TB2, to loitering munitions such as the US Switchblade, to commercial DJI quadcopters and homemade FPV drones. Ukraine has been both quicker and more effective in their understanding of this reality and in the development and deployment of various drone capabilities than has Russia.[146]

The war in Ukraine has shown the promise of smaller, relatively cheap, abundant, and expendable UASs and drones. Small, expendable systems, deployed en masse, have a tactical advantage on the battlefield—identifying, disrupting, and even destroying large, armoured columns; interdicting resupply convoys; and destroying critical or high-value targets. Large formations of UASs and/or drones will be extremely difficult to defend against in the future, requiring the use of sophisticated EW tools, the expenditure of large numbers of expensive air-to-air or surface-to-air missiles, the deployment of directed energy or high-powered microwave weapons, or some combination of all three categories of weapons. Future air-superiority fights may be defined by the more advanced military struggling to effectively and efficiently allocate resources to the counter-UAS mission.

As systems and technologies continuously evolve and improve, this evolution necessitates an organised system to enhance and support future warfare. This includes methods to ensure that the drone technology is appropriately certified, thoroughly tested and equipped with comprehensive instructions. Soon, it is anticipated, almost every battalion will include units equipped with attack UAVs, so training schools will become increasingly important. While strategies and tactics inevitably evolve, the cost of conflict is measured in human lives—the lives of military personnel, including UAV operators. It is therefore paramount to ensure that systems that support the use of drones in warfare are robust, reliable, and effectively integrated into military operations in order to safeguard forces while enhancing operational effectiveness.

Each conflict is unique, characterised by different participants, military capabilities, organisations, and strategic objectives. Rapid technological adaptation and continuous innovation in uncrewed systems will be critical in future warfare. By maintaining an accelerated cycle of innovations and learning from Ukraine, nations such as Australia have the opportunity to stay ahead of their adversaries, ensuring that they are prepared to meet contemporary and future conflict strategic challenges.

Acknowledgements

I would like to acknowledge the Australian Army Research Centre, Department of Defence, for their invaluable support throughout the course of this research. In addition, I would like to extend my sincere gratitude to all participants in Ukraine and Australia, advisers and reviewers whose contributions were essential to this research. I would like to express my heartfelt appreciation to Robert Brovdi (the Commander of the 414th Marine Strike UAV Regiment, known also as the 'Magyar Birds'), Dmytro Frolov (Head of Gnizdo Ltd of the Magyar Birds division), Oleksandr Volosyanskyi (Platoon Commander of unmanned aerial systems, 68th Territorial Defence Battalion of Ukraine), Pavlo Tsapiuk (CEO of the training centre 'Volyn Falcons'), Ivan Tolchinsky (CEO of Atlas Aerospace), Mykhailo Liuksikov (Editor-in-Chief at Militarnyi), Vadym Kushnikov (Head of International Edition at Militarnyi) and Brave 1 (Ukrainian Defense Tech cluster co-founded by the Ministry of Digital Transformation of Ukraine, the Ministry of Defence of Ukraine, the General Staff of the Armed Forces of Ukraine, the National Security and Defence Council of Ukraine, the Ministry of Strategic Industries of Ukraine, and the Ministry of Economy of Ukraine) for supporting this research and for the opportunity to share the photography in this paper.

Importantly, I would like to express my deepest gratitude to all the brave men and women who courageously defend Ukraine. Your unwavering dedication, sacrifice, and resilience in the face of adversity inspires hope and strength in the hearts of millions.

Thank you for your extraordinary courage!

Слава Україні! (Glory to Ukraine!)

About the Author

Dr Oleksandra Molloy is a Senior Lecturer in Aviation and Aviation Program Lead at the School of Science, the University of New South Wales (UNSW) Canberra, Australia. She has a PhD in Aviation from UNSW, Australia; a MSc in Human Factors from the University of Nottingham, UK; a Master of Education and Linguistics from the Central Ukrainian State Pedagogical University, Ukraine; a Graduate Research Certificate from Kirovograd Flight Academy of National Aviation University (Ukraine); and a Diploma in Aviation Safety from International Air Transport Association (IATA; Canada). Dr Molloy also serves as a Vice President of Education at the Advanced Air Mobility Institute (USA), Chair of the Human Factors Ergonomics Society Training Technical Group (USA), and a Chair of the Women in Road Safety Network (Australia). Dr Molloy is a research trailblazer and award-winning leader who conducts multi-disciplinary and collaborative research in human factors, transport safety, and training. Some of the recent research in uncrewed systems led by Dr Molloy include investigating lessons learnt from the use of UAV/C-UAV in the war in Ukraine and developing AI-assisted approach to support situation awareness and cognitive load for Mission Aircrew.

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