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RESEARCH REPORT

Ukraine's Drone Ecosystem and the Defence of Europe: Lessons Lost Can't be Learned

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Contents

2 Acknowledgements
4 Abstract
5 Introduction
7 Speed
12 Scale
17 Urgency
20 Policy Recommendations
20 Conclusion
21 References

Abstract

Ukraine's unique capabilities in drone warfare have significantly contributed to halting the largest land invasion in Europe since 1945. Given the looming threat of escalation on its eastern flank, NATO allies have a problem: falling short in understanding Ukraine's drone ecosystem risks abdicating the strategic momentum in drone warfare to Russia and its allies. Through primary interviews with military, government, and civilian actors, we argue that the core characteristics of this ecosystem represent lessons to be learned themselves. Unfolding across the categories of speed, scale, and urgency, we recommend to NATO allies three policy proposals stemming from our analysis: the establishment of an institutionalised joint venture system for defence technologies, a systematic civil-military liaison structure, and the commitment to binding defence contracts in exchange for soliciting Ukrainian drone expertise. We conclude by pointing towards the sober truth: NATO countries cannot learn the lessons from Ukraine's drone ecosystem if they concede to Russia's strategic goals.

Introduction

Our analysis centres on the first root word of Unmanned Aerial Vehicles (UAVs).[1] The terminological imprecision of this term stimulates a lively literature in scholarship, policy, and journalism.[2] Within the context of the Armed Forces of Ukraine (AFU), the terms 'unmanned' or 'uncrewed' are determined by the battlespaces of land or sea warfare respectively. Whatever one's position, UAVs—colloquially more commonly known as drones—are only tangentially the centre of this review. Beyond the procedural nomenclature, the 'crew' of people behind drones warrant dedicated attention. To maintain deterrence in best case, or to prepare for war in the worst, we argue that the vaunted lessons learned of Russia's invasion of Ukraine encompass more than drones as a weapons system. If one accepts this strategic reality, we argue that the first step in harnessing drone technology for defence is to investigate the people shouldering Ukraine's drone warfare ecosystem. The order of the equation is critical; drones as weapons systems do not inherently manifest a drone ecosystem. Owing to the uniquely iterative nature of drone development, it is the ecosystem comprising the military, volunteers, NGOs, drone schools—in short, 'the crew'—that produces positive results.

> "It is the ecosystem comprising the military, volunteers, NGOs, drone schools—in short, 'the crew'—that produces results."

For this discussion, we consolidate our analysis of Ukraine's drone warfare ecosystem on three themes; speed, scale, and urgency.[3] These three themes encompass underlying aspects of drone warfare that NATO allies must fully register. After laying out our case, we submit three policy recommendations that endeavour to both positively influence Ukraine's war for national survival and to safeguard NATO from potential aggression on its eastern flank by Russian expansionism. Especially with regards to EU Commission President Ursula von der Leyen announcement of 800 billion euros in increased defence spending, in tandem with incoming Chancellor Friedrich Merz' proposed 'drone-army' for Germany, the time to develop European drone ecosystems is now. Moreover, once empirically grounded, it will become evident that the proliferation of *drone ecosystems as such*, rather than merely the weapon system itself, represents its own security challenge to NATO countries.

According to NATO's Joint Analysis and Lessons Learned Centre, this war presents a laboratory of lessons learned for the future of war (North Atlantic Treaty Organization, 2023). In search of the would-be scientists of this laboratory, the three authors conducted interviews on site in Ukraine

1 For pairing our understanding and that of our interviewees, we favour the term 'UAV' in line with the Ukrainian government. See: Schwartz and Reuter (2020, p. 24); See also UAV as the predominant term for the UA MoD (Ministry of Defence of Ukraine, 2025b).

2 Our focus is solely 'aerial' vehicles; see Bondar (2024).

3 We owe the framing of three themes to our interview with KILO.

in Q3 2024. At the authors' discretion and in accordance with best practices of operational security (OpSec), Table 1 sketches the range of interview subjects, their roles, and provides an anonymised name based in the NATO alphabet (North Atlantic Treaty Organization, 2016). For a holistic view, we aimed for key stakeholders in senior military positions, enlisted soldiers, and civilian volunteers, to encompass the battlefield perspective. For a political perspective, we thereafter sought out civilians in advisory roles and members of Ukraine's business community. We relied upon the London School of Economics' networks to make initial contact. There are shortcomings of this approach, but we reiterate the sobering reality compelling the use of anonymous source material: Russia targets these individuals with lethal force in daily air attacks and on the battlefield.

The military landscape in Ukraine is crowded. Private companies, civilian volunteer organisations, NGOs, and the Ground Forces and Unmanned Systems Forces of the AFU comprise the primary actors within this constellation. Working in tandem with the military, our analysis investigates the civilian support of Ukraine's drone ecosystem. Civilians in this table primarily engage as volunteers or under the auspices

Table 1: Overview of interviewees by the authors during field research in Q3 2024 in Kyiv.

Interview Subjects	Role	Status
CHARLIE	Drone school instructor of military personnel; does not undertake combat missions	Civilian
DELTA	Senior policy advisor to the Ukrainian Ministry of Defence	Civilian
ECHO	Senior political consultant	Political
FOXTROT	Senior Army Commander involved with unmanned systems	Military
HOTEL	Senior drone school administrator	Civilian (Veteran)
JULIETT	Volunteer civilian drone pilot; undertakes combat (reconnaissance) missions	Civilian Volunteer
KILO	Senior policy advisor to the Ukrainian government	Political
NOVEMBER	Drone school instructor of military personnel; undertakes combat (FPV) missions	Civilian Volunteer
OSCAR	Non-commissioned officer (NCO) in AFU; combat (FPV) drone pilot	Military
VIPER	Senior FPV drone school instructor	Civilian (Veteran)
UNIFORM	Reserve NCO in AFU; military expert	Civilian (Veteran)
YANKEE	Entrepreneur in the UA defence and drone industry	Civilian

of NGOs. Volunteer groups like the Wild Hornets[4] are staffed predominantly by civilians and produce thousands of drones delivered for use to the military. There are also volunteer organisations that engage directly in frontline activity, like the NGO 'Aerorozvidka', which works in partnership with the Security and Defence Forces of Ukraine.[5] While the Ministry of Defence runs many drone schools, even more are similarly borne out of private initiative. Our interviewees all are orientated within entities such as these. Long-range strategic drones fall beyond our scope. Given our research's emphasis on in-person interviews, the stringent OpSec surrounding strategic drones disallowed in-depth discussion with any relevant stakeholders.

Speed

As far as technologies of war go in the 21st century, the ease of access to constructing drones lends them to individual ingenuity. 'It's basically advanced Lego, I know grandmas who produced hundreds of drones', NOVEMBER recounted. The validity of that notion notwithstanding, normal people are yet unable to jury-rig complex weapons systems, like heavy armour, in makeshift facilities. 'Tinkering and experimenting' in their 'basement workshops', Ukrainians have leveraged the engineering simplicity of drones as tools to stave off a materially superior invader (Fink and Broe, 2025).

UAVs existed prior to the 2022 full-scale invasion—they are neither Wunderwaffe, nor particularly high-tech. The underlying engineering and electronic aspects are well known and understood. Their battlefield use case requires them to be as simple as possible (Bronk and Watling, 2024). Cobbled together largely by civilian parts and components, the engineering triangle favours light, 3-d printable components, and disincentives hardening via additional armour (Perdue, 2024). Owing to the simplicity of manufacturing UAVs as a weapons system, the course of the war privileges the side that best masters mass output and an ability to adapt to Electronic Warfare (EW) and DW countermeasures. In this war of attrition, mass has its own quality in quantity (Vershinin, 2024).

The straightforwardness in drone engineering doesn't preclude deepening layers of complexity. High modularity renders drones exceedingly customisable, allowing practitioners to purpose-fit them to specific operational needs. Diverse factors, such as local enemy countermeasures and environmental considerations, ultimately impact drone design. We primarily focus on FPV drones. Especially amongst this category, the operational scope of capabilities is vast, complex and diverse (Jacoby, 2024b). Generally, FPVs can surveil, disrupt, and attack 'potentially without attribution', simultaneously reducing potential harm to the user and achieve highly favourable exchanges in terms of bang for your buck (United States Department of Defense, (2024). Other types of drones find utility in support roles, like reconnaissance, intelligence gathering, and long-range fire spotting (Newz.AZ, 2024).

The context of Ukraine's drone ecosystem demonstrates that FPV drones are evolutionary, and not revolutionary weapons. Regarding the debits in the revolutionary school of thought, cheap drones have proven effective in penetrating expensive air defence systems, and thereby signal a shift in balance towards weaker opponents in asymmetric warfare (Calcara *et al.*, 2022a, p. 131) . On the other hand, other observers contend that drones confer more benefit to the defender than the attacker (Calcara *et al.*, 2022b, p. 822). Moreover, drones' affordability democratises their accessibility, enhancing defenders' ability to scatter concentrated infantry and stymying would-be offensive operations (Pettyjohn, 2024).

4 See the homepage of the Wild Hornets: https://dykishershni.com/en.html
5 See the homepage of Aerorozvidka: https://aerorozvidka.ngo

An emergent layer of the debate hinging upon unmanned systems focuses in part on violent non-state actors' utilisation of drones as commercially viable weapons. A significant strand of this discourse highlights the affordability of drones to replace or supplement more expensive, standardised weapon systems (Chavez and Swed, 2020). Where Ukraine's case substantially differs is how the cheapness of drones as a platform collides with the multiplicity of actors in its ecosystem. Private capital, the military, the government, and a vast array of civilian actors supercharge the iterative development process of drone usage far beyond the capabilities of any non-state context.

Such discussion is not beside the point, given that the AFU mainly acts in defensive operations. Outmatched in terms of conventional war materials, artillery most especially, using drones was born out of necessity for the AFU to guide long range fire power in lieu of adequate artillery ammunition.[6]

The inherent qualities of FPV drones largely bake into the mix the Ukrainians' capacity to utilise them on the battlefield. Here, drone warfare offers the AFU highly flexible, expendable, and cost-effective precision amplifiers (Kirichenko, 2024b). By bringing long range fire to where it is needed, the AFU can compensate for shortfalls in ammunition and other hardened assets (Hunder, 2024).

According to press reports, FPV drones can be produced for 500 USD and fixed-wing reconnaissance drones for 1,500 to 3,000 USD.[7] The variance of these prices, however, fails to encompass the cost of labour. Homegrown experts like NOVEMBER won't produce drones for foreign countries out of altruism. For Ukraine, they proactively refrain from multiplying production costs by not factoring in their labour costs—you get more havoc for your Hryvnia.[8]

As DELTA advised us, such basement-level pricing is hardly reproducible in a western context.[9] This is an important factor, because one of the common things that hinders the production of more drones is limited funding which results in lower-quality components and parts (Snodgrass, 2023). Often the required funds are crowdsourced or supplied by the receiving units themselves, their families, and friends (Kirichenko, 2024e). The fact that labour costs rarely factor into press reporting of FPV drone costs succinctly illustrates our overarching argument: the products of Ukraine's drone ecosystem, and not the people, garner the most attention.

At its core, pragmatism underscores drones' systemic adoption. How each of our interviewees came to engage with drones evidences the role of speed. UNIFORM casually explained how weapons as old as Maxim machine guns weren't unheard of in their unit in February 2022. 'Pick up a rifle and shoot' was OSCAR's first directive at the onset of the full-scale invasion. As a combat veteran, VIPER recognized drones' outsized impact in securing Ukraine and opted instead to join professionalisation efforts of UA's drone school infrastructure.

Backgrounds in finance, software development, and related professions in the private sector were common among the civilians we interviewed, with few-to-no previous military experience. While not initially subject to mobilisation, CHARLIE reasoned that drone school instruction made sense given their skills with technology. JULIETT similarly referred to their familiarity with software in the private sector

6 Authors' interview with OSCAR.
7 Consensus aligns on $500 as a prevailing figure. See: Milasauskas and Jaškūnas (2024).
8 Authors' interview with NOVEMBER.
9 Authors' interview with DELTA.

as a primer to engage with drones. With a background in business also, YANKEE argued how emerging drone and defence-tech startups provide an outlet for investment for a national and international public.

These pathways frequently overlap. Arriving in 2022 as a civilian with a technical skill set, NOVEMBER began the war as a drone instructor but later undertook excursions to the frontline to gain insight into drone warfare. In CHARLIE's perception, while the conflict began as 'a war of two post-Soviet armies', the AFU became receptive in time to intellectual stimulus from civilian actors and organisations. Simultaneously, OSCAR claimed that interpersonal networks between soldiers and civilians accompanied drones' first combat uses. Once it became clear that FPV's evidenced combat utility, OSCAR reports that their commanders supported further experimentation. From a senior perspective, FOXTROT stipulates first that drones found limited purchase in the first phase of the war (2014-2022). However, as soldiers and civilians injected drones into the battlefield in 2022 and into 2023, senior commanders recognised the role FPVs could play in equalizing material imbalances with the enemy. Estimating that 80% of people involved in the war are actually civilians, FOXTROT pointed to the unifying commonality: 'for these people, this is their war.'

All told, drones offered *the* vehicle par excellence for actors from an array of symbiotic backgrounds to achieve impact in the war. Precisely this decentralised dispersion of people amounts to the vertically and horizontally diverse character of Ukraine's drone ecosystem. Alongside the formal structures of the military and government-sponsored defence companies like Ukroboronprom, a fuelling driver of speed derives interpersonal networks between civil-military actors on the one hand, and the enabling of private companies on the other.

"Precisely this decentralised dispersion of people amounts to the vertically and horizontally diverse character of Ukraine's drone ecosystem."

The result of this head-on civil-military collision is what we observe as War DevOps. Terminologically hailing from the private sector, DevOps are an established set of practices and philosophies in the tech industry that aim to streamline and automate processes in software development, fostering collaboration and stimulating efficiency. In traditional tech companies, DevOps strives to continuously iterate, innovate, and integrate. Disambiguating these phrases, DevOps provides a framework for rapidly evolving prototyping (iteration), fixates on delivering tangible outcomes (innovation), and lastly seeks to assimilate rapid feedback from diverse inputs (Gitlab, no date).

High-velocity pressures from war accelerate iterative cycles of drone development to warp speed. In what HOTEL described as 'bringing the start-up spirit into the military', CHARLIE identified 'our garage-band mad scientists' as the 'game changers' facilitating drone testing and

Photo by Iryna Rybakova, press officer of the 93rd separate mechanized brigade "Kholodnyi Yar" of the Armed Forces of Ukraine

development for frontline soldiers. Admittedly, from an observer perspective, it is difficult to ascertain a data-driven judgement on the total number of 'mad scientists' who are active. As the term implies, many civilian volunteers contribute in their spare time, reluctantly returning to their day jobs to maintain an income (Schwennesen, 2024). As per Minister of Digital Transformation Mykhailo Fedorov, Ukraine's 300,000 IT professionals can count on the government to facilitate international investment for an ever up-scaling defence tech sector (Fedorov, 2023). By acting in 'an anti-bureaucratic war', Fedorov demonstrated that the Ukrainian government drastically reduced blockages to private sector involvement to entice talent and involvement from the entire civilian population (Balmforth, 2024a). Because the pace of obsolescence is so quick (Kirichenko, 2024a), owed in large part to Russian countermeasures, the AFU cannot rely solely on state structures for drone innovation. The War DevOps propelled by civilians is indispensable.

Two factors coalesce to compel speed. The first is the sheer size and scale of the battlespace forced upon Ukraine, stretching across a 1,000km frontline (Tobin, 2024). Due to varying environmental factors and differing force concentrations, the battlespace demands of each sector of the frontline effectively force inputs required for further iterations of new drones. Ukraine's drone ecosystem thus far manages to maintain a constant feedback loop from the frontline, accounting for engineering and software needs of drone warfare and is further primed by real-time adjustments driven by operational needs (Borsari, 2024).

Soldering just one FPV drone takes up to 45 minutes (Gebauer and Rosenbach, 2024). As OSCAR tells us, their unit needs hundreds of FPV drones per week. Given the human capital investment in fabricating these systems, committing to one design or the other is not at all trivial; it must fit the bill. Because large factories prove to be tempting targets for Russian drone and missile attacks, NOVEMBER insists that ad hoc, civilian-staffed garage drone factors can be safer, but have the drawback of being slower from manual labour.[10] OSCAR informed us that severe OpSec prevents too many drone experts from assembling at any one location. The realities of war punish centralised committees and reward decentralised meetings

10 Authors' interview with NOVEMBER.

between localised groups.[11] In spite of these conditions, independent analysis confirms that the problem-solution-response cycles for drone development are often measured in weeks.[12] NOVEMBER pointed out that this human-centric approach encourages iterative innovation: 'Everyone knows everyone, we set up a group chat and then find a solution.'

Evidencing the complexity of this development cycle, JULIETT offered insight from the perspective of reconnaissance drone flights. Like drone pilots in the AFU's 14th Regiment of Unmanned Aerial Systems, who were civilian students, property developers, and finance workers, JULIETT conducts support missions despite no personal military background (Walker, 2024).Ukraine's expansive frontline is not monolithic in its operational conditions. JULIETT differentiated between 'easy mode' and 'hard mode' for reconnaissance missions. For difficult sectors, AFU units are required to loiter FPV drones to guard reconnaissance crews from responding Russian FPV drones, for instance.[13] But in terms of hardware, JULIETT stipulated that in 'easier' sectors, outdated drone models still maintained utility due to lower intensity resistance.

Commensurate with the demands of war, the speed of this drone ecosystem inherently entails certain drawbacks. Differing challenges across the out-stretched battlefield intensify the total of use-cases needed for drones (Molloy, 2024). While no clear number is presently available to the public, other observers estimate that at least 200 different drone prototypes have found use in the war (Ash, 2024). Immediate needs that facilitate survival take priority over solutions with a prolonged payout. Putting a fine point to it, YANKEE flatly explained that 'if we are not fast, people die'.[14] With speed serving as the undercurrent, the drones designed to respond to dozens of pressure points result in non-standardised products (Jacoby, 2024a). One major advantage of this non-standardisation is, according to NOVEMBER, that normal soldiers can adjust FPV drone schematics in real time as per their battlefield needs. In terms of cons, a standout issue is the reluctant reliance on drone components manufactured in China, as OSCAR shared.

The Ukrainian Government is well aware of this issue. As a tool to coordinate defence tech investment matched with government needs, BRAVE1 serves as a platform to align domestic and international stakeholders (Ministry of Digital Transformation of Ukraine, 2023). Entrepreneurs like YANKEE approved of this sort of instrument, but importantly, policy advisors like DELTA similarly voiced support. Public-private partnerships such as these demonstrate one mechanism to pair capital with capability and to ensure resources are directed to defence tech companies with battlefield knowhow.

Establishing joint ventures with Ukrainian defence tech companies of all sizes is beneficial for all sides. As a constraint of waging a war, the Ukraine Government still prevents exports of defence technologies like drones. Since the primary buyer of UA-made drones is the state itself, profit margins for Ukrainian defence companies are capped at 25% of production costs (Bondar, 2025). Capital injected directly into this ecosystem is not only badly needed but would spur significant innovative development currently only mitigated by financial shortfall. Increasing trade via joint ventures also would reduce Ukraine's reliance on manufactured components from China (Kirichenko, 2024d). Safeguarding Ukraine's supply chains to be dependent instead on Europe is in NATO's best interest. In anticipation of future conflict, by establishing joint ventures with Ukrainian companies, NATO would be securing *its own* supply chain vulnerabilities

11 Authors' interview with OSCAR.

12 Confirmed by two sources, one by BRAVE1, see: BRAVE1, Ukrainian Defense Innovations. https://www.linkedin.com/posts/perryboyle_slaveukraini-ukraine-defensetech-activity-7264269388504006656-tPE0?utm_source=share&utm_medium=member_ios; Kirichenko (2024c).

13 Authors' interview with JULIETT.

14 Authors' interview with YANKEE.

as it pertains to drone production and procurement. Ukrainian President Volodymyr Zelenskyy has further indicated his willingness to allow drone exports to preferred partners, and the potential of this market is no longer theoretical (Plichta, 2024). According to the figures by BRAVE1, the drone ecosystem as of today produces drones at 10x lower prices than EU or US firms, and projects north of $100 million in investment for 2025.[15] In any case, such a system necessitates mutually reinforcing benefits to align local stakeholders.

> “‘At every level of command’, the organisation of UAV forces intends to serve one goal: ‘to preserve the lives of our soldiers.’.”

Scale

Drawing conclusions on this war where ‘mass is making a comeback’ (Horowitz, 2024), one U.S. Department of Defense official contended: ‘We need uncrewed systems, and 155mm artillery rounds. And both are needed at scale’ (Hicks, 2024). In the same vein, former Commander-in-Chief of the AFU Valerii Zaluzhnyi implored NATO allies that over-relying on the efficacy of legacy weapon systems from the mid-20th century ignores ‘the ongoing technological revolution’ of warfare ‘centred on attrition’ (The Baltic Sentinel, 2024).

Discourse concerning the potent problem of mass presented by UAVs represents one inflection of the issue. Implicit in these discussions is the underlying assumption that the problem posed by UAVs are principally the vehicles, and less so the ‘manning’. Our intervention here points to an indispensable quality of Ukraine’s drone ecosystem: systematic education of actors across the spectrum *at scale*. After foregrounding this argument, it becomes clear that NATO countries must expedite efforts to ramp up the necessary degree of aggregate human capital for their own drone ecosystems.

Nevertheless, let’s first prime this discussion with the topline production figures. President Zelenskyy promised in December 2023 that one million drones would be produced in 2024 (Reuters, 2023). Already in October 2024, Zelenskyy announced via his evening address that the Ukrainian domestic drone industry had succeeded in producing one million drones, confirmed as well by the Minister of Strategic Industries, Herman Smetanin, via X (Der Spiegel, 2024). Coinciding these advances in FPV and reconnaissance drone production figures, Deputy Prime Minister Mykhailo Fedorov announced a targeted output of 30,000 deep-strike drones for 2025 (Balmforth, 2024b). Both manufacturing and assigning expert pilots to these latter deep-strike drones represents a significant military challenge (Shukla *et al.*, 2024).

15 BRAVE1, Ukrainian Defense Innovations.

Staggering though these numbers may be, drones lost in conducting combat missions are high enough to necessitate such production (Kirichenko, 2024b). The need to centralise operational deployment of drone forces has also engendered institutional reform within the AFU. As of 16 September 2024, the Unmanned Systems Forces (Сили безпілотних систем) became a separate branch of the AFU, co-equal with the Special Operations Forces and the Territorial Defence Forces (Militarnyi, 2024).Their commander, Colonel Vadym Sukharevskyi, was simultaneously appointed to serve as a deputy to the Commander-in-Chief Oleksandr Syrski, underscoring the centrality of drones to the war effort.

According to FOXTROT, centralising the Ukrainian MoD's resources for UAVs is not just a result of the developing 'war of unmanned systems' on the battlefield. 'At every level of command', the organisation of UAV forces intends to serve one goal: 'to preserve the lives of our soldiers.' Echoing this language, Zelenskyy similarly argued that 'everything must work in practice for the sake of Ukrainian goals and the maximum preservation of the lives of our soldiers' (Office of the President of Ukraine, 2024). This is not just rhetorical flourish; herein lies an impetus for strategy-making. The success of Ukraine's drone ecosystem is owed as much to amassing human capital as material in absolute terms.

In terms of scale, one nucleus of this connection are drone schools. Just like on the battlefield, the drone school landscape is populated by a rich array of civilians, soldiers, and the intelligence services. As of 21 November 2024, the Ukrainian MoD whitelisted over 30 schools for drone operators supporting the Defence Forces (Ministry of Defence of Ukraine, 2024b). The training duration for FPV pilots differs depending on the school in question.

Volunteers from Victory Drones outline 34 working days for FPV instruction, but this presumes a student has previous experience.[16] The school Dronarium offers multiple courses for civilian use and an FPV course for 100 hours.[17] Another school founded by veterans, 'Protection of the Future', offers four-week courses for active service personnel of the AFU.[18] Utilising a longer timeframe, Boryviter mandates three months for initial drone pilot training. Obtaining a certificate from schools like the Boryviter Military School gives a candidate an officially recognised qualification by the Ukrainian Ministry of Defence and qualifies individuals to obtain Military Occupational Specialty (MOS) No. 216 'UAV External Crew Members' (Boryviter, 2024).

In the race against time to fill drone pilot roles within frontline units, these contrasting training times are nontrivial. CHARLIE stipulated that six weeks is sufficient for the basics only, thereafter the student requires specialisation training in line with their future role. Recalling their training, JULIETT shared that two months of training was enough for reconnaissance missions, but reiterated that operators get in-field training before undertaking their own missions. For FPVs, the germination period can be much longer. After several months in a drone school, OSCAR stated unequivocally that six weeks to three months of in-field combat experience was necessary to produce a 'good' pilot. The complicating factor of the pace of innovation further requires drone pilot candidates to be brought up to speed once they arrive in their units. Three months may not be long but, as CHARLIE characterised, quarterly cycles represent 'war in centuries' given the speed of change.

16 See homepage: https://en.victory-drones.com/home#program
17 See homepage: https://dronarium.academy/en/kurs-zastosuvannia-fpv
18 See homepage: https://maibutniefund.org/en/projects/fpv-drone-pilots-school-en

Lines between drone schools, frontline units, and civilian volunteer drone units blur considerably. Tracing the interactions of prominent drone activists illustrates this liminality. Civilian volunteers like Serhii Sternenko engross online audiences with videos of prototype drones, implicitly calling upon viewers for donations to ensure the drone's wider battlefield use (Hambling, 2024). When asked where NATO countries should invest capital, JULIETT pointed to Sternenko. Other civilians go one step further and periodically interface with frontline units, which NOVEMBER referred to 'joining the hunt'. One prominent public example of this is typified by Serhii 'Flash' Beskrestnov, who avidly shares his lessons for survival and best practices in electronic warfare and drones freely online (Metcalfe, 2024).

Volunteers like Maria Berlinska channel their expertise into drone school education, who supported founding the aforementioned volunteer-run Victory Drones project (Ukrainian Institute London, 2024). Owing to the emergence of decentralised drone schools as meeting spaces, military and civilian actors are able to engage with one another at scale across the country. In the judgement of the Kraken Regiment's commander, callsign Chili, frontline units recruiting drone pilots are looking for 'an 18–19-year-old kid, who grew up playing *Counter-Strike* and *Need for Speed* (Бомбардир, 2024).' Drone schools facilitate a porous boundary between civilians interested in drone training and military units, which otherwise would not exist. Some drone battalions, such as one followed by the *Wall Street Journal*, even started out as 'unpaid civilian enthusiasts', only to later be subsumed into the AFU during the course of the war (Marson, 2024).

In part due to civilian-military interfacing, many AFU brigades have embraced War DevOps by employing start-up-style practices. This observation is not new (Spirlet, 2024). Recognising the deeply decentralised, interpersonal networks of people that bring in new recruits, the Ukrainian MoD formally codified as of 1 October 2024 structures enabling frontline brigade commanders to recruit for their specific units (Ministry of Defence of Ukraine, 2024a). Strikingly, when travelling in and around Kyiv, we observed a proverbial deluge of military recruitment of specific battalions and brigades, accompanied by as many advertisements for defence tech start-ups and volunteer drone units.

Expanding on this dynamic, ECHO commented that units such as the 53rd Mechanized Brigade, and especially the 93rd Mechanized Brigade, had distinguished public profiles as leading pioneers and practitioners in drone warfare.[19] Elite units like the 3rd Assault Brigade, bucking the trend of diminished recruitment quotas, employ their own in-house drone school and distribute convincing advertisements to entice hundreds of monthly applications to their ranks (Jacoby, 2025). Drone schools therefore serve as a vital pipeline between not just the military and society in the broadest sense, but also between units and individuals.

This civil-military interconnectivity influences policy. On 21 January 2025, the Ministry of Defence announced the allocation of 2.5 billion UAH (approximately $60 million) to 'be distributed among brigades' of the AFU, granting 'flexibility to use these funds to acquire drones that are the most effective for carrying out mission requirements (Ministry of Defence of Ukraine, 2025a). In partnership with the Ministry of Digital Transformation, the MoD also seeks to support private defence tech innovation via tax breaks, grants, and technical advice from sponsored experts (Jacoby, 2024a). Put together, soldiers with cash in hand, paired with emerging confidence in the Ukrainian private market, compound into a mutually reinforcing dynamic where drone development is decentralised to grassroots actors. As others have observed, the decentralised approach accelerates delivery significantly (Bondar, 2025).

19 Authors' interview with ECHO.

So far, there's a recency bias in referring to these interlocking structures. Alongside programmatic strategies undertaken by the government in Kyiv, our interviewees confirm the central role of individual initiative in this ecosystem. As it pertains to FPVs, OSCAR maintained that in the winter of 2023, their company had one drone pilot. Once FPV drones gained immediate acceptance as a tool to compensate for decreased artillery capabilities, the deficit in available drone pilots was critical. On a self-organised basis, by the fall of 2024, OSCAR reported across five battalions, they now employ 300 drone pilots. If it were their decision, OSCAR argued that fully half of their battalion would be comprised of drone pilots. From a commander's perspective, FOXTROT agreed that UAV units needed to be systematically attached to all brigades, not just the AFU, but all armies of the future. Because unmanned systems can positively contribute to lessening combatants' exposure to direct enemy fire, we find proof of the strategy of preserving soldiers' lives (Bendett and Kirichenko, 2025).

The know-how touted by Ukrainian defence tech companies heavily relies upon civilian volunteers and veterans who participated in frontline missions. Both NOVEMBER and VIPER discussed the commonplace practice of retrieving Russian drones to private workshops to develop potential countermeasures. Through their reconnaissance missions, JULIETT's familiarly with the precise technical aspects of Russian electronic warfare further hammered home the wide accessibility of combat lessons learned at the level of a civilian volunteer. Through personal networks such as these, drone prototyping that once took three to five years now is shortened to two to three months (Jacoby, 2024a). KILO interjected that, despite best efforts, the Russians often can catch up with Ukrainian drone innovations within three to four months.

Scale in combat prowess therefore owes its roots to these individual actions. When asked about recruitment for drone schools or soliciting funds for drone development, NOVEMBER attributed their localised success with self-cultivated networks seeking online 'drone-ations' (Daily Mail World, 2024) that support affiliate drone workshops. Put differently, OSCAR stated that 'we are all like Zelenskyy, we all do our part to get money and recruit manpower'.

In connection with his affiliation with BRAVE1, Rear Admiral Michael Hewitt (U.S. Navy, ret.) stipulated that this drone ecosystem's 'connection between the warfighter and the technology' is 'really unprecedented, and it's an outcome of fighting for survival' (Januta, 2024). Intermingling between warfighter and technology, however, are the manifold groups of civilian volunteers who breathe significant life into this system. Precisely this expanded constellation is what U.S. Army Major General David F. Steward referred to as a 'whole-of-nation approach, not just a whole government' initiative (Tucker, 2024).

> "Drone schools therefore serve as a vital pipeline between not just the military and society in the broadest sense, but also between units and individuals."

In this holistic spirit, our second policy recommendation aims to supply NATO countries with an informational exchange framework. A core challenge of Ukraine's drone ecosystem is the multiple points of entry owing to the complex array of actors. We propose sending official liaisons on a *bilateral* basis to all nodular points of this drone ecosystem. Such personnel as military officers, civilian defence employees, and diplomats; effectively, the nucleus of a domestic drone ecosystem. Connecting with our first policy recommendation to upscale bilateral joint ventures with Ukrainian companies, a state-directed liaison structure would formulate the information tip of the spear to interface with Ukrainian government and companies.

Liaisons delivered across the spectrum, such as military educators to drone schools and civilian engineers to volunteer drone units, would provide governments the necessary mass of data to make more informed decisions on where to send financial support. Strategically chosen, such liaisons would consequently facilitate expertise in NATO domestic countries for their own defence initiatives. Most importantly, a government-sponsored liaison structure centralises stakeholder alignment and streamlines the process with the Ukrainian Government.

Photo by the press service of the 77th separate airmobile brigade of the Armed Forces of Ukraine

Urgency

This 'WW1 with robots' will have a winner.[20] Across the wire, Russia's own drone warfare capabilities amass with alacrity. Concomitant with political platitudes, on a practical level, Russia securing victory places a million-man army at NATO's eastern flank, hardened and experienced in drone warfare. For NATO countries, manifesting a robust drone industrial base with combat-ready countermeasures is as much a strategy for deterrence as it is for warfighting.

Integration and not replication of Ukraine's drone ecosystem is in the strategic interest of NATO countries. Bluntly put, the only sure way to duplicate this ecosystem would be to pay the same blood price as Ukraine has in wartime. We operate on the baseline assumption that NATO countries principally endorse deterrence. One future pillar to dissuading aggression will be matching Russian drone capabilities in kind. As the previous sections have argued, generating a drone ecosystem is unique to specific characteristics of drones as a weapons system.

Urgency, this third aspect, is the one quality of Ukraine's drone ecosystem that is shared with NATO countries. The system's speed and scale are contingent on the conditions of a full-scale invasion, but the urgency for a lasting security arrangement is shared by all. The challenge presented by urgency is learning the lessons of drone warfare from an ecosystem attritting every day and risking dismantling by a Russian victory.

With this in mind, we seek to add a final layer to how NATO countries can operationalise the lessons learned of this war. To start, it's clear that many NATO countries fully grasp the imperative of drones in future war. As part of a landmark security agreement between Germany and the United Kingdom, drones are ascribed importance in supporting roles alongside air, naval, and land forces (Ministry of Defence [MoD, United Kingdom], 2024c). Similarly, in a fact sheet co-signed by former US Secretary of Defense Lloyd Austin, the 'low cost, widely available nature' of UAVs to bring 'democratized precision strike' capabilities is acknowledged (United States Department of Defense, 2024).

On the level of NATO countries' investment in Ukraine's drone ecosystem, there are significant initiatives. A leader both in supporting Ukraine generally, and the drone ecosystem specifically, the UK as of February 2024 co-leads the Drone Coalition (MoD, 2024a), which directs capital and bids for drone production to the industry of Ukraine Defence Contact Group (UDCG) countries (MoD, 2024b). This coalition boasts co-leadership with Latvia, and as of January 2025, has already successfully directed 54 million euros to support Ukraine (Ministry of Defence of the Republic of Latvia, 2025). Mutual ties between British and Ukrainian industry are receiving additional inter-governmental support, as announced in October 2024 (MoD and Luke Pollard MP, 2024). International partnerships like the Drone Coalition are 'beneficial to Ukraine now', but scaling up production that 'should also be used to equip British forces at the same unit price as Ukrainian forces are equipped,' when in the future the British government is permitted to import drones from Ukraine (Watling and Bronk, 2024). Ukraine's Defence Minister Rustem Umerov additionally announced Denmark's intention to increase its investment in 2025 in Ukraine's defence sector (Ministry of Defence of Ukraine, 2025d). In 2023, Ukrainian defence start-ups reportedly received $5 million in investment, and in 2024, that figure increased to $50 million (Bilousova *et al.*, 2024). These initiatives demonstrate the best examples of recognition of the growing importance of UAVs in future war.

20 Authors' interview with CHARLIE.

> “But when posing the quandary of Lessons Learned, we stipulate that the people of Ukraine’s drone ecosystem should be regarded as a strategic reserve in their own right.”

Systematic recognition of the deficiencies in the *human* investment needed for fostering a domestic drone ecosystem are less obvious. For the UK, the British Army’s own drone program currently foresees three weeks training for FPV forces (British Army, 2024). And while this is a promising start, the reform is not wide-spread. Ukrainian soldiers sent to the UK, for instance, expressed discontent about the British Army’s inability to adapt their training environments to drone warfare, citing civil aviation rules constricting British airspace (Rathbone, 2024).For the U.S. Army, units as localised as the platoon level are reportedly experimenting with so-called Lethal Unmanned Systems for reconnaissance in training (Skove, 2024a). At the same time, according to one journalist, the US Joint Chiefs of Staff Lessons Learned Division has no working groups ‘who focus solely on Ukraine’ (Skove, 2024b), preventing more systematic review. Instead, ecosystem-centric approaches go in the right direction. The MoD of Lithuania, for example, plans to offer FPV drone pilot schools additional funds for explicit recruitment of future pilots (Saballa, 2024). A 2025 study conducted by the American Enterprise Institute examined the impact of a Ukrainian defeat on the US defence budget. Given an insufficient total of companies’ capability of upscaled UAV production, the cost of required investment would total $28.9 billion through to Fiscal Year 2029 (McCusker, Kagan and Sims, 2025). The point being, attempts to rigidly replicate Ukraine’s drone ecosystem are disadvantageous to NATO member states’ own security.

According to a German Ministry of Defence official, it is undesirable to pre-produce and store drones in advance in anticipation of quick obsolescence (Müller, 2024). Nevertheless, Polish Deputy Prime Minister Władysław Kosiniak-Kamysz similarly underscores that ‘drones cannot be purchased in advance’, even as he calls for an increased role of drone units in the Polish military (Zak, 2024). This approach assumes that either the Polish or the German industries are currently capable of massively upscaling production of drones in an Article 5 situation. At least for Germany, this is highly suspect. The fledgling drone ecosystem that does exist, embodied by German defence-tech company Donaustahl GmbH, has battle-proven drones—like the MAUS—that have found success in Ukraine (Shcherbak, 2024). Inexplicably, drones manufactured by Donaustahl as of today cannot legally be procured by the German Armed Forces due to arcane legal constraints (Frank, 2024). In a time when German auto manufacturing companies have open capability due to lagging sales, this capacity could be harnessed to enliven *Zeitenwende* to build defence technologies (Bartels, 2024). In any case, evidence is lacking that lynchpin states like Germany take the notion of nurturing a domestic drone ecosystem seriously. This aspect of peacetime thinking has run its course.

Where these inter-governmental initiatives can substantially improve is by elevating the centrality of human capital with that of technology. Current approaches that promote investment and support drone procurement for the AFU serve the needs of today. But when posing the quandary of Lessons Learned, we stipulate that the *people* of Ukraine's drone ecosystem should be regarded as a strategic reserve in their own right. Lessons in this sense do not restrain themselves to weapons systems and processes. The sections of speed and scale make clear: the utility of operational lessons from this war will have a limited shelf-life. But by investing in and preserving the lives of those engaged in the drone ecosystem, their expertise can accompany security debates into the wider future.

In practice, this investment demands binding weapons orders. Followed logically, if joint ventures with Ukrainian defence tech companies (R1) are formed—and fed data and expert input—by bilateral liaisons (R2), this proposed system will only take physical form if NATO governments and private industry immediately inject capital on a predictable basis. According to DELTA, pricing in the human labour of Ukraine's drone experts across the spectrum is central to focusing their attention. Because the country is at war, overhead in all sectors must be contained. Binding defence orders promote systemic stakeholder alignment on precise outcomes. As per YANKEE, private capital paired with targeted companies is one immediate instrument that is mutually beneficial for Ukraine and NATO economies. R2's foreseen liaison structure would engender an expert-class of people to help advise NATO countries on where to invest. R3's contention of promising compulsory orders to established joint ventures assures Ukrainian stakeholders of intended outcomes.

Strategy in NATO has since its inception centred on the dichotomy of technology and people. In the Cold War, the greatest political sensitivity lied in calibrating the correct deployment of conventional forces in conjunction with nuclear deterrence. Neither nuclear nor conventional options exclusively carried the day. The alliance opted for both.

For Europe, the question remains: Will FPV drones be as relevant for NATO militaries as they are for the AFU in the short to medium term? We do not know. With Europe's security architecture currently in flux, to put it mildly, defence capabilities are needed now. As of Q1 2025, few of Europe's leading military powers have wartime levels of ammunition storage and production, to say nothing of current uniformed manpower. As scalable, comparatively cheap weapon systems, drones offer European militaries a force multiplier today with only modest investment. Our policy recommendations have these dynamics in mind in propelling domestic drone ecosystems.

Learning lessons from Ukraine should not solely restrict their scope to technology. Even as Ukraine nears sharing partial lessons with NATO (Ministry of Defence of Ukraine, 2025d), Kyiv's official policy is to share full operational lessons after the war.[21] This framing is overly programmatic. The decentralised character of Ukraine's drone ecosystem presents more data points than Ukraine's government is able to single-handedly market. Their ultimate strength is the mass human capital itself. Our proposed recommendations singularly aim to multiply the points of contact across NATO's spectrum of industrial and military capacity. As FOXTROT appealed, the eventual goal should be to establish a 'common European security space from Portugal to Ukraine'.

21 According to authors' interviews with KILO and HOTEL.

The good news is that unlike nuclear weapons, drone ecosystems are relatively inexpensive; CHARLIEs drone school took years to develop and OSCARs frontline drone school attrites every day. Failing to invest in a national drone ecosystem effectively forfeits advantage in the initial exchanges in war, getting your own OSCAR's and CHARLIE's killed before they can develop their own capabilities.

Policy Recommendations

To meet the future challenges of the European security space, we submit three policy recommendations.

1. **Surging support of bilateral joint ventures** between NATO member states and Ukrainian defence tech companies and start-ups.

2. **Negotiating bilateral civil-military liaisons** to interface with the full spectrum of Ukraine's drone ecosystem

3. **Committing to binding defence tech orders** to vest capital and political trust into NATO-Ukrainian joint ventures.

Conclusion

Uncertainty is a prevailing sentiment. In February 2022, an acute source of uncertainty revolved around Ukraine's ability to resist full-scale invasion. In the days and years following, predictions continuously fell short in adequately approximating how the war would progress and what technologies would emerge as decisive. In 2025, there is no shortage of speculation whirling around the implications of AI, the weapon systems of the future, and what role unmanned systems will play as instruments of force.

Innovation always accompanies warfare. NATO countries cannot allow themselves to build an equivalent drone ecosystem ad hoc in wartime against a prepared adversary. To do so would be to incur unacceptable losses. We do not believe that NATO, hand-in-hand with Ukraine, can predict the future and account for all eventualities. But we are certain that however future challenges to Europe's security unfold, NATO countries cannot afford to learn these lessons twice. Supporting Ukraine's drone ecosystem today is in everyone's best interest—except Russia's.

For future research: The authors emphasise the importance of conducting field research in Ukraine both for qualitative refinement of a given inquiry, but to also increase collaboration. Urgent future research should address: the applicable uses of artificial intelligence for autonomous systems in contested airspaces, air defence resilience against unmanned systems, and Ukraine's adaptation of civil-military defence cooperation. ■

References

Ash, T. G. (2024) 'Zelensky has a game-changing plan to win peace. For it to work, Biden must back it—fast', *European Council on Foreign Relations,* 23 September. Available at: https://ecfr.eu/article/zelensky-has-a-game-changing-plan-to-win-peace-for-it-to-work-biden-must-back-it-fast/ (Accessed: 27 January 2025).

Balmforth, T. (2024a) 'Ukraine to produce thousands of long-range drones in 2024, minister says', *Reuters,* 12 February. Available at: https://www.reuters.com/business/aerospace-defense/ukraine-produce-thousands-long-range-drones-2024-minister-says-2024-02-12/ (Accessed: 31 January 2025).

(2024b) 'Ukraine sees use of uncrewed ground vehicles, AI-targeting drones surging next year', *Reuters*, 2 December. Available at: https://www.reuters.com/world/europe/ukraine-sees-use-uncrewed-ground-vehicles-ai-targeting-drones-surging-next-year-2024-12-02/ (Accessed: 10 February 2025).

Bartels, H. (2024) 'Wir brauchen ein "Konjunkturprogramm Rüstung Die Welt"', 27 September. Available at: https://www.welt.de/debatte/kommentare/article253721458/Gastbeitrag-Wir-brauchen-ein-Konjunkturprogramm-Ruestung.html (Accessed: 10 February 2025).

Bendett, S., and Kirichenko, D. (2025) 'Battlefield Drones and the Accelerating Autonomous Arms Race in Ukraine', *Modern War Institute*, 1 January. Available at: https://mwi.westpoint.edu/battlefield-drones-and-the-accelerating-autonomous-arms-race-in-ukraine/ (Accessed: 10 February 2025).

Bilousova, O. *et al.* (2024) 'Ukraine's Drones Industry: Investments and Product Innovations,' Kyiv School of Economics', *Brave1*, 04 October. Available at: https://kse.ua/wp-content/uploads/2024/10/241004-Brave1-report-v.1.pdf (Accessed: 27 January 2025).

Бомбардир [Bombadier] (2024) КРАКЕН: КОСМІЧНІ СПЕЦОПЕРАЦІЇ, ВЕРБУВАННЯ РОСІЯНАМИ, ЗАГРОЗА ХАРКОВУ, ЕВОЛЮЦІЯ В1ЙНИ ['Kraken Commander Chili: Incredible Special Operations, Stupid Prisoners, the Evolution of War'], *YouTube*, 26 September. Available at: https://www.youtube.com/watch?v=t06F2FB_IMo&ab_channel=%D0%91%D0%BE%D0%BC%D0%B1%D0%B0%D1%80%D0%B4%D0%B8%D1%80 (Accessed: 27 January 2025).

Bondar, K. (2024) 'Why Ukraine is Establishing Unmanned Forces across its Defense Sector and What the United States can learn from it', *Center for Strategic & International Studies*, 19 November. Available at: https://www.csis.org/analysis/why-ukraine-establishing-unmanned-forces (Accessed: 10 February 2025).

(2025) 'How Ukraine Rebuilt its Military Acquisition System Around Commercial Technology', *Center for Strategic & International Studies*, January. Available at: https://www.csis.org/analysis/how-ukraine-rebuilt-its-military-acquisition-system-around-commercial-technology (Accessed: 10 February 2025).

Borsari, F. (2024) 'Ukrainian Lessons for the Age of Automated Warfare', *Center for European Policy Analysis,* 1 October. Available at: https://cepa.org/article/ukrainian-lessons-for-the-age-of-automated-warfare/ (Accessed: 27 January 2025)

Boryviter (2024) *Summarizing our work in October*, 15 November. Available at: https://boryviter.org.ua/en/articles/summarizing-our-work-in-october/ (Accessed: 21 February 2025).

British Army (2024) *Soldiers' drone flying skills tested*, 30 August. Available at: https://www.army.mod.uk/news/soldiers-drone-flying-skills-tested/ (Accessed: 10 February 2025).

Bronk, J., and Watling, J. (2024) 'Mass Precision Strike: Designing UAV Complexes for Land Forces', *Royal United Services Institute*, 11 April. Available at: https://www.rusi.org/explore-our-research/publications/occasional-papers/mass-precision-strike-designing-uav-complexes-land-forces (Accessed: 21 February 2025).

Calcara, A. *et al*. (2022a) 'Why Drones Have Not Revolutionized War: The Enduring Hider-Finder Competition in Air Warfare', *International Security* 46(4), pp. 130-171.

(2022b) 'Will the Drone Always Get Through? Offensive Myths and Defensive Realities.', *Security Studies* 31(5), pp. 791-825.

Chavez, K. and Swed, O. (2020) 'Off the Shelf: The Violent Nonstate Actor Drone Treat', *Air & Space Power Journal*, 34(3), pp. 29-43. Available at: https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-34_Issue-3/F-Chavez_Swed.pdf (Accessed: 27 January 2025).

Daily Mail World (2024) 'Why Ukraine's FPV Drones are a Russian Soldier's Nightmare | War On Tape', *YouTube*, 20 December. Available at: https://www.youtube.com/watch?v=hWxUt41DlB4 (Accessed: 27 January 2025).

Der Spiegel (2024) *Ukraine verkündet Bau von einer Million Drohnen für Streitkräfte*, 15 October. Available at: https://www.spiegel.de/ausland/ukraine-verkuendet-bau-von-einer-million-drohnen-fuer-streitkraefte-a-2bee284c-58e1-44a7-8186-9e684d849198?sara_ref=re-so-app-sh (Accessed: 21 February 2025).

Fedorov, M. (2023) 'Ukraine's vibrant tech ecosystem is a secret weapon in the war with Russia,' *Atlantic Council*, 17 August. Available at: https://www.atlanticcouncil.org/blogs/ukrainealert/ukraines-vibrant-tech-ecosystem-is-a-secret-weapon-in-the-war-with-russia/ (Accessed: 10 February 2025).

Fink J., and Broe, J. (2025) 'Putin is Finished in Long Term as Systemic Damage to Russian Economy Rises Dramatically', *Silicon Curtain*. [Podcast]. 20 January. Available at: https://podcasts.apple.com/de/podcast/silicon-curtain/id1661722315 (Accessed: 21 February 2025).

Frank, D. (2024) 'Der Tod der deutschen wehrtechnischen Industrie', *Defence Network*, 5 September. Available at: https://defence-network.com/der-tod-der-deutschen-wehrtechnischen-industrie/

Gebauer, M., and Rosenbach, M. (2024) 'Fliegen, sprengen, töten', *Der Spiegel*, 22 November. Available at: https://www.spiegel.de/wirtschaft/ukraine-krieg-niederbayerisches-start-up-liefert-kamikazedrohnen-fliegen-sprengen-toeten-a-e81a99c6-5075-4a12-a664-a84af7508c74 (Accessed: 10 February 2025).

Gitlab (no date) *What is DevOps?* Available at: https://about.gitlab.com/topics/devops/ (Accessed: 10 February 2025).

Hambling, D. (2024) 'Ukraine roles out target-seeking terminator drones', 22 March. Available at: https://www.forbes.com/sites/davidhambling/2024/03/21/ukraine-rolls-out-target-seeking-terminator-drones/ (Accessed: 21 February 2025).

Hicks, K. H. (2024) '"The Future Character of War": Keynote Address by deputy Secretary of Defense Kathleen H. Hicks', *United States Department of Defense*, 10 December. Available at: https://www.defense.gov/News/Speeches/Speech/Article/3992669/the-future-character-of-war-keynote-address-by-deputy-secretary-of-defense-kath/ (Accessed: 21 February 2025).

Horowitz, M. C. (2024) 'Battles of Precise Mass: Technology is Remaking War—and America Must Adapt', *Foreign Affairs*, November/December. Available at: https://www.foreignaffairs.com/world/battles-precise-mass-technology-war-horowitz#author-info (Accessed: 10 February 2025).

Hunder, M. (2024) '"War of robots": How 1,000 days of Russia's invasion of Ukraine spurred an automation boom', *Reuters*, 18 November. Available at: https://www.reuters.com/world/europe/how-1000-days-conflict-fuelled-robot-wars-between-russia-ukraine-2024-11-18/ (Accessed: 27 January 2025).

Jacoby, T. (2024a) 'How Ukraine's Drone Industry Took Flight', *Foreign Policy*, 6 July. Available at: https://foreignpolicy.com/2024/07/06/ukraine-drone-industry-russia-war-regulation/ (Accessed: 10 February 2025).

(2024b) 'AI is reshaping drone warfare in Russia and Ukraine', *The New York Post*, 29 September. Available at: https://nypost.com/2024/09/29/world-news/ai-is-reshaping-drone-warfare-in-russian-and-ukraine/ (Accessed: 10 February 2025).

(2025) Amid a National Conscription Crisis, One Ukrainian Unit Takes a Different Approach', *Forbes*, 28 January. Available at: https://www.forbes.com/sites/tamarjacoby/2025/01/28/amid-a-national-conscription-crisis-one-ukrainian-unit-takes-a-different-approach/ (Accessed: 10 February 2025).

Januta, A. (2024) '"We believe that in 5 years, Ukraine's defense sector will attract half a billion dollars": Q&A with foreign defense investors', *The Kyiv Independent*, 9 October. Available at: https://kyivindependent.com/we-believe-that-in-5-years-ukraines-defense-sector-will-attract-half-a-billion-dollars-q-a-with-foreign-defense-investors/ (Accessed 27 January 2025)

Kirichenko, D. (2024a) 'Ukraine's Drone Front,' *Center for European Policy Analysis,* 6 June. Available at: https://cepa.org/article/ukraines-drone-front/ (Accessed: 27 January 2025).

(2024b) 'Ukraine's innovative drone industry helps counter Putin's war machine', *Atlantic Council*, 26 June. Available at: https://www.atlanticcouncil.org/blogs/ukrainealert/ukraines-innovative-drone-industry-helps-counter-putins-war-machine/ (Accessed: 27 January 2025).

(2024c) 'Ukraine's Nerds Join Rambos to Repel Russia', *Center for European Policy Analysis*, 4 September. Available at: https://cepa.org/article/ukraines-nerds-join-rambos-to-repel-russia/ (Accessed: 27 January 2025).

(2024d) 'Affordable Drones and Civilian Supply Chains are Transforming Warfare,' *Small Wars Journal*, 11 November. Available at: https://smallwarsjournal.com/2024/11/26/affordable-drones-and-civilian-supply-chains-are-transforming-warfare/ (Accessed: 27 January 2025).

(2024e) 'The Rush for AI-Enabled Drones on Ukrainian Battlefields,' *Lawfare*, 5 December. Available at: https://www.lawfaremedia.org/article/the-rush-for-ai-enabled-drones-on-ukrainian-battlefields (Accessed: 27 January 2025).

Marson, J. (2024) 'The Nerdy Gamers who became Ukraine's deadliest drone pilots', *Wall Street Journal*, 3 November. Available at: https://www.wsj.com/world/europe/ukraine-gamers-drone-pilots-russia-85a1af3b?mod=hp_lead_pos82&mod=hp_lead_pos8 (Accessed: 27 January 2025).

McCusker, E., Kagan, F. W., and Sims, R. (2025) 'Dollars and Sense: America's Interest in a Ukrainian Victory', *American Enterprise Institute*, 9 January. Available at: https://www.aei.org/research-products/report/dollars-and-sense-americas-interest-in-a-ukrainian-victory/ (Accessed: 27 January 2025).

Metcalfe, C. (2024) 'Meet the radio-obsessed civilian shaping Ukraine's drone defense', *MIT Technology Review*, 12 September. Available at: https://www.technologyreview.com/2024/09/12/1103833/ukraine-russia-drone-war-flash-radio-serhii-beskrestnov-social-media/ (Accessed: 10 February 2025).

Milasauskas, T., and Jaškūnas, L. (2024) 'FPV drones in Ukraine are changing modern warfare', *Atlantic Council*, 20 June. Available at: https://www.atlanticcouncil.org/blogs/ukrainealert/fpv-drones-in-ukraine-are-changing-modern-warfare/ (Accessed: 27 January 2025).

Militarnyi (2024) *Unmanned Systems Forces have become a separate branch of the Armed Forces of Ukraine*, 16 September. Available at: https://mil.in.ua/en/news/unmanned-systems-forces-have-become-a-separate-branch-of-the-armed-forces-of-ukraine/ (Accessed: 10 February 2025).

Ministry of Defence of the Republic of Latvia (2025) *Latvian-UK led Drone Coalition to deliver 30 000 drones to Ukraine*, 14 January. Available at: https://www.mod.gov.lv/en/news/latvian-uk-led-drone-coalition-deliver-30-000-drones-ukraine-12-000-which-are-latvian-made (Accessed: 27 January 2025).

Ministry of Defence [MoD, United Kingdom] (2024a) *UK to supply thousands of drones as co-leader of major international capability coalition for Ukraine*, 15 February. Available at: https://www.gov.uk/government/news/uk-to-supply-thousands-of-drones-as-co-leader-of-major-international-capability-coalition-for-ukraine (Accessed: 10 February 2025).

(2024b) *Joint Statement by Defence Ministers of the Drone Coalition*, 10 July. Available at: https://www.gov.uk/government/news/joint-statement-by-defence-ministers-of-the-drone-coalition (Accessed: 27 January 2025).

(2024c) *Landmark UK-Germany defence agreement to strengthen our security and prosperity*, 22 October. Available at: https://www.gov.uk/government/news/landmark-uk-germany-defence-agreement-to-strengthen-our-security-and-prosperity (Accessed: 10 February 2025).

Ministry of Defence [MoD, United Kingdom] and Pollard, L. (2024) *UK trade mission visits Kyiv to deepen industry ties*, 6 October. Available at: https://www.gov.uk/government/news/uk-trade-mission-visits-kyiv-to-deepen-industry-ties (Accessed: 27 January 2025).

Ministry of Defence of Ukraine (2024a) *Without the involvement of enlistment offices: The Government permitted military units to recruit volunteers directly*, 1 October: Available at: https://mod.gov.ua/en/news/without-the-involvement-of-enlistment-offices-the-government-permitted-military-units-to-recruit-volunteers-directly-2 (Accessed: 10 February 2025).

(2024b) *The Ministry of Defence has certified over 30 schools for drone operators*, 21 November. Available at: https://mod.gov.ua/en/news/the-ministry-of-defence-has-certified-over-30-schools-for-drone-operators (Accessed: 10 February 2025).

(2025a) *The estimated combat losses of Russians over the last day: 1 690 persons, 153 UAVs and 19 artillery systems*, 20 January. Available at: https://mod.gov.ua/en/news/the-estimated-combat-losses-of-russians-over-the-last-day-1-690-persons-153-ua-vs-and-19-artillery-systems (Accessed 20 January 2025).

(2025b) *The Ministry of Defence will allocate UAH 2.5 billion each month to combat brigades of the Armed Forces of Ukraine for the procurement of UAVs*, 21 January. Available at: https://mod.gov.ua/en/news/the-ministry-of-defence-will-allocate-uah-2-5-billion-each-month-to-combat-brigades-of-the-armed-forces-of-ukraine-for-the-procurement-of-ua-vs (Accessed: 27 January 2025).

(2025c) *Ukraine is Ready to share Combat experience with NATO*, 29 January. Available at: https://mod.gov.ua/en/news/ukraine-is-ready-to-share-combat-experience-with-nato-deputy-minister-of-defence-serhii-melnyk-at-nrfc-and-cior-meeting (Accessed: 10 February 2025).

(2025d) *In 2025, Denmark will increase its financial commitment to Ukraine's defence industry*, 1 February. Available at: https://mod.gov.ua/en/news/in-2025-denmark-will-increase-its-financial-commitment-to-ukraine-s-defense-industry (Accessed: 10 February 2025).

Ministry of Digital Transformation of Ukraine (2023) 'Ukraine launches BRAVE1 defence tech cluster to stimulate development of military innovations and defence technologies', 26 April. Available at: https://www.kmu.gov.ua/en/news/v-ukraini-zapustyly-defense-tech-cluster-brave1-iakyi-stymuliuvatyme-rozvytok-viiskovykh-innovatsii-ta-oboronnykh-tekhnolohii (Accessed: 27 January 2025).

Molloy, O. (2024) 'Drones in Modern Warfare: Lessons Learnt from the War in Ukraine', *Australian Army Research Centre*, Australian Army Occasional Paper No. 29. Available at: https://researchcentre.army.gov.au/sites/default/files/241022-Occasional-Paper-29-Lessons-Learnt-from-Ukraine_2.pdf (Accessed: 10 February 2025).

Müller, B. (2024) 'Die drohnenarme Armee', *Magazin Loyal*, 4 October. Available at: https://www.reservistenverband.de/magazin-loyal/die-drohnenarme-armee/ (Accessed: 10 February 2025).

News.AZ (2024) *Future of military robotics: Russia, NATO, and China's impact—INTERVIEW*, 25 November. Available at: https://news.az/news/-future-of-military-robotics-russia-nato-and-china-s-impact-interview (Accessed: 10 February 2025).

North Atlantic Treaty Organization (2016) *The NATO Phonetic Alphabet*. Available at: https://www.nato.int/cps/en/natohq/declassified_136216.htm

(2023) 'JALLC publishes Factsheet on its Observations from Russia's war against Ukraine', *Joint Analysis and Lessons Learned Centre*, 12 December. Available at: https://www.jallc.nato.int/articles/jallc-publishes-factsheet-its-observations-russias-war-against-ukraine (Accessed: 27 January 2025).

Office of the President of Ukraine (2024) *Combat commanders, brigades' real-life experience must be implemented for the Armed Forces' success*, 10 February. Available at: https://www.president.gov.ua/en/news/uves-realnij-dosvid-bojovih-komandiriv-i-brigad-maye-buti-re-88897 (Accessed: 10 February 2025).

Perdue, M. (2024) 'Inside Ukraine's Drone High Command,' *Center for European Policy Analysis*, 27 September. Available at: https://cepa.org/article/inside-ukraines-drone-high-command/ (Accessed: 10 February 2025).

Pettyjohn, S. L., (2024) 'Drones are Transforming the Battlefield in Ukraine but in an Evolutionary Fashion', *War on the Rocks*, 5 June. Available at: https://warontherocks.com/2024/03/drones-are-transforming-the-battlefield-in-ukraine-but-in-an-evolutionary-fashion/ (Accessed: 27 January 2025).

Plichta, M. (2024) 'Ukraine may allow drone exports in bid to support domestic producers', *Atlantic Council*, 15 October. Available at: https://www.atlanticcouncil.org/blogs/ukrainealert/ukraine-may-allow-drone-exports-in-bid-to-support-domestic-producers/ (Accessed: 10 February 2025).

Rathbone, J. P. (2024) 'UK sent Kyiv large supplies of old military equipment, watchdog finds', *Financial Times*, 11 September. Available at: https://www.ft.com/content/f44bf7d0-0895-4f63-9fce-d3de8e686b57?accessToken=zwAGJAnmShQAkdP0S_fQCJVPY9OfztPejmhrVw.MEQCIGRd-dAYWYQqB_eTJikm2cWxm5BGGFmbiQsPv9g_wc1E5AiAmnfhBVXI77MGRpIci0g1bSQQszRijrUCBXGCwAMxdHA&sharetype=gift&token=6210ee89-bb6b-4c1e-9adb-1d0a3e1fea4f (Accessed 10 February 2025).

Reuters (2023), *Ukraine to produce one million drones next year, Zelenskiy says,* 19 December. Available at: https://www.reuters.com/world/europe/ukraine-produce-one-million-drones-next-year-zelenskiy-says-2023-12-19 (Accessed: 10 February 2025).

Saballa, J. (2024) 'Lithuania to Develop Drone Ecosystem Amid Growing Regional Threats', *The Defense Post*, 21 May. Available at: https://thedefensepost.com/2024/05/21/lithuania-drone-ecosystem-threats/ (Accessed: 10 February 2025).

Schwartz, S. and Reuter, C. (2020) '90.000 Tonnen Diplomatie 2.0: Die Integration von unbemannten Systemen in den operativen Flugzeugträgerbetrieb am Beispiel der X-47B', *Zeitschrift für Außen- und Sicherheitspolitik*, 13, pp. 23-45.

Schwennesen, P. (2024) 'Eyewitness to war: Drones and implications for America', *GIS*, 13 December. Available at: https://www.gisreportsonline.com/r/drones-ukraine-implications/ (Accessed: 27 January 2025).

Shcherbak, S. (2024) 'Germany Develops FPV Drone for Various Munitions, Now Striking Russian Forces in Ukraine', *Defense Express*, 15 June. Available at: https://en.defence-ua.com/industries/germany_develops_fpv_drone_for_various_munitions_now_striking_russian_forces_in_ukraine-10849.html (Accessed: 27 January 2025).

Shukla, S. *et al*. (2024) 'Inside a secretive Ukrainian drone unit targeting Russian territory', *CNN*, 16 October. Available at: https://edition.cnn.com/2024/10/16/europe/elite-ukrainian-drone-unit-russia-intl-cmd/index.html (Accessed: 10 February 2025).

Skove, S. (2024a) 'Army embraces Ukraine-style warfare with new all-drone unit', *Defense One*, 19 September. Available at: https://www.defenseone.com/threats/2024/09/army-embraces-ukraine-style-warfare-new-all-drone-unit/399679/ (Accessed: 27 January 2025).

(2024b) 'Is the US military learning enough from Ukraine?', *Defense One*, 24 September. Available at: https://www.defenseone.com/policy/2024/09/us-military-learning-enough-ukraine/399893/ (Accessed: 27 January 2025).

Snodgrass, E. (2023) 'Russia and Ukraine are filling the sky with drones. There are so many buzzing around over eastern Ukraine, they're actually crashing into on another,' *Business Insider*, 17 August. Available at: https://www.businessinsider.com/russian-ukrainian-drones-cause-traffic-jams-in-donetsk-region-report-2023-8?r=US&IR=T (Accessed: 10 February 2025).

Spirlet, T. (2024) 'Ukraine's drone teams are operating more like startups than military units', *Business Insider*, 4 November. Available at: https://www.businessinsider.com/ukraine-drone-units-operate-like-edgy-tech-startups-military-russia-2024-11 (Accessed: 27 January 2025).

The Baltic Sentinel (2024) *Automated Attrition: Valerii Zaluzhnyi: The Future of Warfare is Here, and NATO is Falling Behind*, 11 November. Available at: https://balticsentinel.eu/8132828/automated-attrition-valerii-zaluzhnyi-the-future-of-warfare-is-here-and-nato-is-falling-behind (Accessed: 27 January 2025).

Tobin, J. (2024) 'War in Ukraine: Update October 2024', *House of Lords Library*, 16 October. Available at: https://lordslibrary.parliament.uk/war-in-ukraine-update-october-2024/#fn-1 (Accessed: 10 February 2025).

Tucker, P. (2024) 'US Army rushes to boost defenses as Russia ups strike-drone autonomy', *Defense One*, 15 October. Available at: https://www.defenseone.com/technology/2024/10/us-army-rushes-boost-defenses-russia-ups-strike-drone-autonomy/400291/?oref=d1-homepage-top-story (Accessed: 10 February 2025).

United States Department of Defense (2024) *DoD Announces Strategy for Countering Unmanned Systems,* 5 December. Available at: https://www.defense.gov/News/Releases/Release/Article/3986597/dod-announces-strategy-for-countering-unmanned-systems/ (Accessed: 10 February 2025).

Ukrainian Institute London (2024) *War and activism: a conversation with Maria Berlinska*, 14 May. Available at: https://ukrainianinstitute.org.uk/events/war-and-activism-a-conversation-with-maria-berlinska/ (Accessed: 27 January 2025).

Vershinin, A. (2024) 'The Attritional Art of War: Lessons from the Russian War on Ukraine', *Royal United Services Institute*, 18 March. Available at: https://rusi.org/explore-our-research/publications/commentary/attritional-art-war-lessons-russian-war-ukraine (Accessed: 27 January 2025).

Walker, S. (2024) '"The game continues": evacuating casualties and bombing bridges in Kursk', *The Guardian*, 13 September. Available at: https://www.theguardian.com/world/2024/sep/13/the-game-continues-evacuating-casualties-and-bombing-bridges-in-kursk (Accessed: 19 March 2025).

Watling, J., and Bronk, J. (2024) 'Protecting the Force from Uncrewed Aerial Systems', *Royal United Services Institute*, 15 October. Available at: https://www.rusi.org/explore-our-research/publications/occasional-papers/protecting-force-uncrewed-aerial-systems (Accessed: 27 January 2025).

Zak, K. (2024) 'Polska będzie miała wojska dronowe. Jest zapowiedź szefa MON', *RMF24*, 28 November. Available at: https://www.rmf24.pl/fakty/polska/news-polska-bedzie-miala-wojska-dronowe-jest-zapowiedz-szefa-mon,nId,7865525#crp_state=1 (Accessed: 27 January 2025).

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