Paper
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Air Power by Small, Low-Cost Drones

Implications for Future Warfare

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Abstract

Militaries have expanded reliance on drones in recent years to deliver air power at low altitudes, evading air defenses and allowing users to amplify the speed, range, lethality, and psychological strain of combat effects. These developments suggest significant opportunities to enhance air power at lower price points; however, the expanding use of drones requires careful assessments of drone and counter-drone capabilities. This paper examines the transformative role of small, low-cost drones in future warfare, drawing on lessons learned from recent theaters of operations and their relevance to force planning. Acquisition programs for drones and counter-drone capabilities must ensure these technologies can be introduced to work inside existing systems effectively and affordably. The use of artificial intelligence and autonomous drones also raises important questions about working within acceptable legal and ethical parameters. Evaluating the operational and tactical utility of drones and the necessity of robust counter-drone capabilities to protect critical assets, this paper analyzes emerging trends and their implications for future warfare by highlighting four lessons to leverage drones as a force multiplier.

Introduction

The Russia-Ukraine and Nagorno-Karabakh wars have proven predictions wrong about how quickly the battle for air supremacy would be decided or how both military conflicts would progress (Deptula, 2024; Gressel, 2020). The effectiveness of tiered air defenses comprising surface-to-air missiles (SAM), anti-aircraft guns, and man-portable air-defense missiles (MANPADS) have been an enduring feature of the air war in Ukraine (Deptula and Bowie, 2024). Absent air superiority, medium- and high-altitude missions have broadly been deemed high-risk for fighter aircraft, constraining their role. In Ukraine, with neither side gaining superiority in the air to allow for the uncontested use of combat aircraft, the resulting air parity shifted the focus of delivering combat effects to missiles and drones (Deptula and Bowie, 2024). However, just as air defense systems have constrained penetrating aircraft, they have also proven largely effective in intercepting the vast majority of missile attacks. The resulting mass diffusion of inexpensive but versatile drones for operational and tactical uses has had a transformative impact, intensifying the speed, range, lethality, and psychological pressure of combat. These "analogs of air power" will almost certainly be a permanent fixture of future warfare, spurring the production and procurement of small, low-cost drones worldwide (Chavéz and Swed, 2024). Although the implications of drones on the changing character of warfare have been widely analyzed, the focus has been primarily limited to large actors and their embrace of advanced drones at the high end of the technology spectrum (Kunertova, 2023a; Murray, 2023). Relatively little attention, in contrast, has been given to the utility of low-cost drones for the air power of smaller states (Kramar et al., 2021).

Small, low-cost drones are driving a "democratization" of air power, making military effects more accessible and at lower price points (Postma, 2021). This paper outlines four lessons drawn from the use of small, low-cost drones in recent conflicts (Renic and Christensen, 2024; Gressel, 2020). Firstly, diverse drone arsenals will be critical for operational and tactical warfighter needs in constrained and contested battlespaces. Their potential to cost-effectively amplify firepower and project combat mass with speed will drive the strategic adoption of these systems at scale. Secondly, drone proliferation in warfare underscores the importance of developing counter-drone technologies. Ensuring acquisition is centered on sustainable affordability will be essential for defending critical military and civilian assets vulnerable to the future drone threat. Local area, short-range air defense, and electronic warfare (EW) will need to be adapted, incorporating new technologies such as counter-drone lasers and guns. Thirdly, international cooperation is imperative to manage the cost of production at scale and for pooling knowledge and resources. Procuring and integrating drones into force structures should be approached as a cooperative endeavor to ensure future requirements can be met effectively and efficiently. Fourthly, not every lesson from recent operational theaters will be applicable elsewhere, and national policy must be tailored to specific threat environments and warfighter requirements. Finally, militaries must ensure a legally and ethically responsible position on the development and use of increasingly autonomous weapons systems.

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Lesson I: The Evolving Use of Drones in Air Power

For decades, American and European interest in armed drones focused primarily on medium-altitude, long-endurance (MALE) models. These expensive, high-tech platforms were utilized extensively in the Global War on Terror, primarily by the U.S. military in Afghanistan, Iraq, and elsewhere. More recently, MALE drones like the Bayraktar TB2 were deployed by Azerbaijan in the Second Nagorno-Karabakh War and by Ukrainian armed forces in their conflict with Russia (Postma, 2020; Danczuk, 2023). Increasingly, however, military attention has shifted to smaller, inexpensive drones at the lower end of the technology spectrum (Cook, 2023). Fast, hard to detect, employable for one-way attack (OWA) or reusable, produced and expendable at scale, these smaller systems are now utilized for a growing and diverse range of missions, including airborne intelligence, surveillance, and reconnaissance (ISR), EW, and targeting (Renic and Christensen, 2024). Table 9.1 provides an overview of the difficulties and limitations in detecting small drones that fly at relatively low altitudes.

Method	**Description**				
Type	**Range**	**Characteristics**	**Accuracy**	**Advantages**	**Limitations**
Audio-based	25–30 ft	Multi-directional microphone array	Variable	Detects drones, buzzing sound waves	Short range, noise interference
Video-based	350 ft	High-distance image capture	Moderate-Low	Good-resolution image capture	High detection failure
Motion-based	50–150 ft	Motion and speed detection	Acceptable	Detects drones among flying objects	Short range
Thermal-based	350 ft	Heat detection	High-Low	Accurate at detecting fixed-wing drones	Inaccurate at detecting smaller quad-copters
Radar-based	150–1500+ ft	Heat, motion, and noise detection	High-Moderate	Highly accurate at detecting large and medium drones	Inaccurate at detecting small and miniaturized drones
RF-based	200–1400 ft	Radiofrequency signal detection, interception	High-Moderate	Successful at detecting and intercepting signals	Prone to signal interference, unable to detect higher and lower frequencies

Table 9.1: Methods for Detecting Drones (adapted from Yaacoub et al., 2020)

At the tactical level of warfare, the integration of First Person View-drones has radically increased the availability of low-altitude air power; providing capabilities to support ISR and targeting previously assigned to support aircraft (Bronk and Watling, 2024). Integrated with artillery units, drones have also enhanced the pace and precision of frontline strikes, compressing the kill chain to less than 5 minutes (Cranny-Evans, 2023; Renic and Christensen, 2024). Small, low-cost drones have expanded the scope of operational capabilities for military users, cost-effectively providing a means to strike quickly at high-value and expensive targets (Renic and Christensen, 2024, p. 58). For example, so-called kamikaze drones have been used by Ukrainian units to target and destroy ships at sea, disrupting vital sea lines of communication (Eckel, 2024; Williams, 2024). More advanced models like the Bayraktar TB2 have proven highly effective in striking at or behind enemy lines to hit ground units, vehicles, critical infrastructure, and logistics nodes. Smaller OWA drones have also been effective in degrading supply lines and logistics centers.

Drones in Ukraine have been deployed in their thousands, scouting the battlespace to gather intelligence, track opposing force movements, and geolocate positions, contributing to a more ‘transparent’ battlespace. With enemy maneuver becoming more detectable and high-value platforms like armored tanks and tactical command more vulnerable to targeting by drones, ground forces have placed a premium on speed, dispersion, and detection avoidance. As a highly valuable but also expendable resource that can be deployed and expended at scale, small, low-cost drones are increasingly dominating the military thinking around Europe and elsewhere, for large and small militaries alike. There is a realization that small, low-cost drones can enable high-intensity warfare by making possible long-range strikes at significantly lower costs. Ukrainian drones, for example, have operated more than 1,000km (620 miles) inside Russia and have been shot down over Moscow (BBC News, 2024). Additionally, the persistent threat from drone systems on and beyond the frontline can amplify psychological stress against opponents and support information operations to influence adversarial decision-making.

In the future, even small military actors will gain from the increased strategic depth and operational flexibility enabled by the deployment of diverse drone arsenals. However, assessing where and how drones can be integrated within existing force structures to enable operational gains cohesively is no straightforward task. Embracing a mix of high-end, advanced drone platforms for strategic ISR to “see deep” and “strike deep” with small, low-cost drones that can be produced and deployed at speed and scale for tactical effects, will be essential. Finally, success in drone warfare will depend on more than drone access; beyond mere production and procurement, the effectiveness of projecting air power using drones will depend on institutional factors, including doctrine, integration, and warfighter training. In turn, these highlight other enabling factors, such as the role of adaptive mindsets and military innovation. Militaries must plan for a future in which every adversary, even non-state actors, can be expected to possess a versatile drone arsenal to deploy at scale. Owing to this, militaries must think not just about *their* potential use of drones but also address how they will counter drone threats.

Lesson II: The Imperative of Counter-Drone Capability

While drones are effective and versatile weapons, they are not without limits. Firstly, drone technology cannot offset deficiencies in force design, quality, or employment. Secondly, drones do not herald an end to attritional warfare – in some circumstances, they actually reinforce it. Finally, a range of countermeasures are available, with new ones under development to neutralize or mitigate the potential impact of drone use by adversaries. This is not a static and short-loop process, however; the continuous need to maintain and upgrade defenses and countermeasures against the persistent risk of swarming tactics and saturation attacks will be challenged by the cost and complexity of countering 'cheap' drones. As JAPCC warned in a report on countering drones: "...the field of counter-UAS needs to be on the cutting edge of current developments ...otherwise, NATO will have a clear and decisive disadvantage in upcoming missions" (JAPCC, 2020).

Air defense is guided by hard economics; the systems necessary to neutralize incoming drone threats are often vastly more expensive than the target. For example, drones costing a few thousand dollars are being shot down by interceptors costing over US$1 million. With dozens of small drones routinely launched toward the same target in coordinated strikes, if even 10 percent reach their target, the impact on an opponent's war economy can be immense (BBC News, 2024). Ukraine is producing drones at a massive scale, taking less than a couple of hours to build the fuselage and fit electronics, motor, and explosives – and as much as 30 percent of these highly expendable systems are utilized purely for deception (BBC News, 2024; CNN, 2024). On the Russian side, Iranian sourced ***Shahed*** drones cost as little as US$20,000; in contrast, high-end air defense systems like the ***Patriot*** – developed to counter more advanced threats in smaller numbers – can cost as much as US$1 billion to deploy (Terajima, 2024; BBC News, 2023). In general, air defenses operated today are designed to detect, identify, and provide target-indicator tracking against high-speed fighter aircraft, and are therefore mostly ineffective against small and slow drones (Gressel, 2020). As the size of the target decreases and as drone swarms are introduced to overwhelm enemy air defenses, these defenses are becoming increasingly challenged (Postma, 2021).

In short, using drones manufactured cheaply and operated at scale can both evade and exhaust air defenses (Postma, 2021). Active defense against drones has become a wicked problem, driving attention toward layering low-tier air defense with more effective and sustainable counter-drones capabilities, including, but not limited to, anti-aircraft platforms like the German Gepard vehicle and SKYNEX platforms, jamming devices like the Lithuanian Skywiper systems, and vehicle-mounted weapons like the Slinger C-UAS (Newsweek, 2023; Forbes, 2023; C4ISRNET, 2023). This highlights a second lesson: Air defenses that prioritize sustainable affordability are vital to defend effectively against enemy drones. Table 9.2 illustrates the major countermeasures for drone threats and their limitations.

Countermeasure	Effect on Target	Limitations
Direct fire	Destruction	Size of targets Number of targets Visibility
Hunting drones	Destruction	Number of targets Visibility Inherent drone weaknesses Deployment time
Missiles	Destruction	Costs
Laser weapons	Destruction	Atmospheric conditions Smokescreens Target's coating
Microwave weapons	Disabling	Sealing of electronics
Electronic jamming	Disabling Control taking	Sealing of electronics
Defending drone swarm	Individual destructions Swarm disruption	Lack of accurate response Deployment time

Table 9.2: Countermeasures against Drones

Lesson III: International Cooperation on Drone Technology

Cooperative approaches for maximizing the potential gains from the expanded use of small, low-cost drones and minimizing the costs of counter-drone capabilities will be vital going forward. With an average attrition rate as high as 10,000 units per month by Ukrainian forces, drones are better conceptualized, in procurement terms, as a type of ammunition (Watling and Reynolds, 2023). This underscores the industrial levels of production and supply availability needed to meet warfighter requirements with drones in sustained operations. With military requirements to procure small, low-cost drones now in millions of units per year, companies worldwide have stepped in to meet these rapidly growing military needs (Zelenskyy, 2023; Euroactive and Reuters, 2024; Martin, 2024; Clark, 2024). Manufacturers from the U.S., Turkey, the United Kingdom, and Canada, among others, are supplying a vast range of drone and counter-drone technologies, such as the Phoenix Ghost loitering munition drone, Bayraktar TB2, and Terrahawk Paladin air defense systems (Zelenskyy, 2023; Renic and Christensen, 2024). Russia, too, has expanded its industrial connections, using the Iranian-made *Shahed* kamikaze drone and now manufacturing its own EW-hardened variant, known as the Geran-2 (Geranium) locally, in Siberia (Bennet and Ilushyhina, 2023; Euroactive and Reuters, 2024).

International cooperation is key for military users to meet rapidly growing warfighter requirements through increased industrial capacity. To exploit the maximum potential of drones in future warfare, international cooperation in procurement, technology development, and integration will be essential. Governments and militaries need to strengthen cooperative mechanisms with allies and partners to develop joint programs for the procurement, development, training, and integration of drone technology into force structures. In relative terms, drone technologies are highly affordable and only getting more so, though future drone warfare itself will not be cheap. Establishing an adequate industrial base, training and re-training operators, sourcing foreign investment, and purchasing platforms at scale are key elements of capability development for low-cost drones. All of this will require time and resources.

Lesson IV: The Need for Tailored Approaches

While recent armed conflicts provide critical lessons on future warfare, especially in relation to the transformative role of drone power, a final lesson relates to what *not* to learn. The specific characteristics of the Russia-Ukraine war, for example, including its scale, cost, and strategic backdrop, are not perfectly replicated elsewhere (Renic and Christensen, 2024). For Ukraine, the conflict represents an existential threat with extremely high stakes which were a key driver in its acquisition and fielding of drones at break-neck speed. Ukrainian military officers, technicians, and civilians have collaborated with innovative and experimental approaches to the use and development of drones, along with a range of other technologies. Once it had grasped the utility of small, low-cost drones to project air power at reduced cost and operational risk, the Ukrainian government supported the rapid development of industrial capacity and created a network combining 'commercial satellite services, open-source intelligence, and drones,' gathering and transmitting through systems like DELTA (Devaraux, 2023).

DELTA is a battle management system integrating NATO ISTAR standards to provide cross-domain situational awareness to users. Later enhanced with AI and machine learning capabilities, exploiting big data analytics, DELTA has been vital for improving the use and effects of drones (CSIS, 2024). For example, British engineers from Palantir, a data analysis software provider, have supported Ukrainian counterparts in developing solutions for mapping the best routes for drones to reach targets while skirting around air defenses, radar, and electronic jammers, using data from signals intelligence and satellite imagery (BBC News, 2024). Supported by AI, some drones are now programmed with more than 1,000 waypoints to evade countermeasures (CNN, 2024). As Retired Major General Robin Fontes of the US Cyber Command stated, operational data and analysis from recent operational theaters feed into AI laboratories, allowing companies to "fine-tune, adapt, and improve their AI systems on the go." The applied lessons and knowledge from recent operations push forward incremental improvements in military AI, facilitating movement toward the "networked battlefield" of the future (National Defense Magazine, 2023).

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Militaries must also maintain caution in the adoption of AI more broadly, identifying specific applications where AI can improve operational efficiency while maintaining meaningful human control and judgment over critical decision-making.

With its growing reliance on drones, Ukraine has formed a separate branch to accelerate innovation in ground, maritime, and aerial uninhabited system development (Bieliesko, 2024). With this openness to experimentation and quick adoption of new systems and technologies, the Ukrainian military, like others, has become more open to the use of more autonomous weapons systems. However, the movement toward greater autonomy is not without strategic, ethical, and legal trade-offs, especially in relation to the reduction of meaningful human control in the exercise of lethal force (Renic and Christensen, 2024). Governments must strategically evaluate the benefits and risks of loosening regulatory frameworks relating to autonomous drone technology.

While there are clear military incentives for these technologies, ethical and legal considerations need to be urgently addressed. Militaries must also maintain caution in the adoption of AI more broadly, identifying specific applications where AI can improve operational efficiency while maintaining meaningful human control and judgment over critical decision-making. Expanding the use of drones to solve operational challenges and maximize military effectiveness may help militaries seize the advantage, but they must remain cognizant of the practical limits of these tools and their ethical use. Although states cannot decisively impact international regulation as individual actors, a common recognition of the need to avoid an global autonomous arms race would critically help promote ethical and legal development approaches.

Conclusion

Recent conflicts have underscored the transformative impact of small drones and offer critical insights for other militaries to build the capacity to project air power at lower price points in highly constrained and contested spaces. By taking four key lessons, the militaries can position themselves to effectively prepare for drone warfare. Firstly, military actors can be empowered at the operational and tactical levels with better clarity, precision, and reach in contested battlespaces by small, highly affordable drones. Secondly, effectively countering drone threats will require new approaches to low-tier air defense, which must be reinforced with newer, more cost-effective solutions. Thirdly, the role of international cooperation will be crucial in pooling resources and expertise to ensure the cost-competitive industrial-scale production capacity necessary to support future drone requirements. Finally, militaries must build tailored approaches for embracing low-cost drones at scale to reflect their unique threat environment and warfighter requirements, ensuring that ethical and legal standards to guide the expanded use of drones and AI are maintained.

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