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THE $500 DRONE THAT KILLS A $3M TANK: COST-EFFICIENT LETHALITY AND THE RISE OF FPV WARFARE

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Abstract: *The Russo-Ukrainian war has transformed First-Person View (FPV) drones from recreational tools into core tactical assets, significantly impacting ground operations. This study examines their use against armored vehicles, focusing on technical features, engagement tactics, and the rapid innovation cycle since 2022. Using a qualitative methodology and case studies from OSINT and academic sources, the research finds that FPV drones have become a primary driver of tank losses—accounting for an estimated 65% of Russian tank losses as of early 2025. For the T-90M, about 50% of losses were caused by final FPV drone strikes, demonstrating exceptional cost-efficiency. Common tactics include disabling mobility via track attacks, followed by terminal strikes on top armor or optics. Ukraine's production capacity—reportedly 200,000 drones per month and plans to procure 4.5 million units in 2025—further supports the widespread deployment of ~$500 drones capable of neutralizing multimillion-dollar targets. Meanwhile, a fast-paced measure–countermeasure cycle has emerged, including fiber-optic guidance and AI integration. This study contributes to understanding the tactical, operational, and doctrinal impact of FPV drones in modern warfare, offering insights into force restructuring, command adaptation, and the risks posed by technology proliferation to non-state actors.*

Keywords: FPV Drones, Anti-Tank Warfare, Cost-Efficient Lethality, Russo-Ukrainian War, Asymmetric Conflict

1. Introduction

The Russo-Ukrainian war, which erupted in February 2022, marked a defining moment in the evolution of modern warfare, emphasizing the transformative role of unmanned aerial systems (UAS) [1]. In this context, First-Person View (FPV) drones have emerged as a disruptive element of major significance, redefining tactical interactions between ground forces and armored vehicles [2]. Originally designed for recreational use (e.g., racing or aerial filming), these drones were rapidly adapted for military operations due to their low cost, exceptional maneuverability, and capacity to conduct precise strikes against high-value targets [3].

The extensive use of armored vehicles—including main battle tanks (MBTs), infantry fighting vehicles (IFVs), and armored personnel carriers (APCs)—has remained a central feature of military operations in Ukraine. Within this complex operational environment, FPV drones have proven capable of exploiting inherent vulnerabilities in armored platforms, such as relatively thin top armor and limited protection against small, fast, and agile aerial threats [4]. A particularly noteworthy aspect of their rapid adaptation has been the

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critical role played by volunteers and grassroots initiatives in the production and frontline integration of these systems, demonstrating remarkable agility in meeting operational demands [2].

The impact of FPV drones on military operations has been profound, as evidenced by substantial armored losses and the urgent need for tactical and technological adaptations by the affected forces [5]. FPV drones have begun to complement—and in some cases even replace—traditional and more expensive anti-tank systems such as Javelin and NLAW guided missiles, owing to their significant cost-efficiency advantage and broad availability [6]. This shift is directly influencing military doctrine and the organization of operational structures.

Accordingly, this article seeks to address the following core research question: What is the tactical, operational, and doctrinal impact of FPV drones used in an anti-armor role in the Russo-Ukrainian war? The study investigates the practical effectiveness of these drones against different categories of armored vehicles, analyzes the countermeasures implemented, and explores the resulting doctrinal implications. Through this analysis, the article contributes meaningfully to our understanding of the evolution of modern warfare, offering critical insights for contemporary military and security studies and the development of future defense strategies.

2. Relevant Literature and Conceptual Framework

The evolution of unmanned aerial systems (UAS) and their integration into recent military conflicts reflect a growing trend toward asymmetric technology and the innovative use of limited resources in combat operations. Traditional military drones such as the MQ-9 Reaper and the Bayraktar TB2 have set an important precedent in previous conflicts, being deployed for complex missions involving surveillance, reconnaissance, and direct strikes on strategic and tactical targets [7].

By contrast, First-Person View (FPV) drones represent a distinct category of UAS. They stand out due to specific technical characteristics: extremely low cost (often under USD 1,000 per unit), relative ease of operation, and high adaptability. Unlike conventional military drones, FPVs are capable of executing targeted precision strikes against vulnerable targets, exploiting inherent limitations in armored vehicle design. These include relatively weak top armor and the exposure of optical and electronic components [8].

A key factor behind the effectiveness of FPV drones is their use of specialized munitions. These include modified HEAT (High-Explosive Anti-Tank) grenades and shaped charges adapted for drone delivery [3]. Such munitions are designed to channel explosive energy into a high-velocity jet capable of penetrating the top armor of armored vehicles. Secondary effects resulting from such penetration include spalling (the projection of metal fragments inside the crew compartment) and cook-off (the detonation of onboard ammunition or fuel due to heat and pressure), which can significantly contribute to the neutralization or total destruction of an immobilized target [9].Conceptually, the rise of FPV drones can be framed within the broader theoretical contexts of asymmetric warfare and technological innovation in military operations. FPVs exemplify the concept of the democratization of firepower, granting substantial military capabilities even to actors with limited resources, including non-state actors [10,11].

This democratization enables challengers to contest the numerical and technological superiority of adversaries with vastly larger defense budgets. The tactical impact of FPV drones confirms and expands upon theories related to the Revolution in Military Affairs (RMA), illustrating how accessible and versatile technologies can rapidly reshape traditional doctrines and strategies [12]. They also underscore the importance of operational agility and the capacity for rapid adaptation to emerging threats. In summary, this review of the relevant literature and conceptual foundations emphasizes the importance of understanding the complex dynamics between accelerated technological development, continuous doctrinal adaptation, and the operational effectiveness of FPV drones. These elements establish a robust foundation for the in-depth examination of the role and impact of these systems in the context of the Russo-Ukrainian war.

3. Methodology

To examine the tactical, operational, and doctrinal impact of FPV drones in the Russo-Ukrainian war, this study employs a qualitative, multiple case study approach. This enables a contextualized analysis of FPV deployment against armored targets, focusing on battlefield conditions, tactics, and countermeasures. Case studies cover key engagements (e.g., Avdiivka), effects on specific platforms (e.g., T-90M, Western tanks), and broader trends in FPV drone use.

3.1. Data Collection and Source Criteria

Data was gathered through a structured selection of sources meeting three key criteria: direct relevance to FPV drone use against armor in Ukraine, recency (2022–2025), and verifiability through academically or analytically credible evidence. Sources included peer-reviewed journals in security and defense, reports from leading think tanks (e.g., RUSI, CSIS), and OSINT analyses from platforms like Oryx and Conflict Intelligence Team (CIT), recognized for rigorous methods such as geolocation and triangulation. Defense media and official statements were also used, critically assessed and cross-verified. To reduce bias, OSINT was drawn from diverse perspectives. Most data was open-access, supporting transparency and reproducibility.

3.2. Research Limitations

This study recognizes several limitations inherent to analyzing an ongoing conflict: limited access to classified or field data, the imperfect reliability of OSINT, the fast-changing nature of the battlefield, and the context-specific scope of findings. Despite these constraints, the methodological framework offers a balanced and transparent basis for examining the FPV drone phenomenon, yielding insights relevant both to the current war and to future doctrinal development in global security contexts.

4. Findings

This empirical analysis, based on the qualitative methodology and multiple case studies described earlier, reveals several key dimensions of the impact FPV drones have had on armored platforms in the Russo-Ukrainian conflict.

4.1. Technical and Operational Characteristics of FPV Drones

FPV drones deployed in the conflict are typically small in size, with a limited flight endurance of approximately 10–30 minutes and an effective operational range of a few kilometers, depending on line-of-sight and jamming conditions [13]. The average cost of a single FPV attack drone varies widely, typically between $300 and $1,000 depending on components and capabilities [14, 15]. These drones are often equipped with adapted munitions such as modified RPG grenades (e.g.,PG-7VL), grenade launcher rounds (e.g.,VOG-17), or repurposed anti-tank mines (e.g., TM-62), enabling precise strikes on armored targets [16].

Their operational effectiveness stems from high speed (often exceeding 100 km/h), exceptional maneuverability, and the ability to penetrate defenses through pinpoint strikes on vulnerable areas [13]. A frequently used tactic is the multi-stage attack, which involves first immobilizing the vehicle by targeting tracks, wheels, or propulsion, followed by a terminal strike—either with the same drone or a larger one carrying a heavier payload, or with artillery and other coordinated assets. In addition to individual attacks, swarm tactics are used to overwhelm enemy defenses, accepting a planned loss of drones to achieve saturation. According to some estimates, it may take around 5–6 FPV drones to destroy a single armored unit [5].

4.2. Vulnerabilities Exploited by FPV Drones

FPV drones systematically exploit structural weaknesses in armored vehicles [17, 18]:

- Top armor: The turret roof and engine deck are poorly protected and vulnerable to top-attack strikes, even from relatively small but well-aimed explosive charges.
- Sensors, optics, and communications: Drones frequently target external optical devices, antennas, and sighting systems, drastically degrading the vehicle's combat effectiveness.
- Propulsion systems: Strikes on the engine compartment or tracks immobilize the vehicle, leaving it vulnerable to follow-up destruction.

4.3. Case Studies and Field Examples

- Avdiivka: In this area, FPV drones were used to halt the advance of Russian armored columns, targeting T-72s, T-80s, and BMPs. The result was a significant disruption in maneuver operations [3].
- T-90M Proryv (Breakthrough): Out of 33 visually confirmed destroyed T-90Ms as of early 2024, 16 (roughly 50%) were directly neutralized by FPV drones, according to a Forbes analysis—often following immobilization or requiring multiple hits [19].
- Western-supplied tanks: Russian FPV drones systematically targeted modern Western armored platforms supplied to Ukraine, focusing on optical systems and engine compartments. The absence of dedicated anti-drone defenses such as "cope cages" significantly increased their vulnerability. Even vehicles considered highly protected proved susceptible to these inexpensive but effective threats [5].

4.4. Operational and Economic Efficiency

FPV drones have become a primary method of anti-armor engagement. Their cost-efficiency exemplifies the concept of cost-effective lethality. With individual drone prices typically ranging from $300 to $1,000 [14], [20], the contrast with armored vehicles worth millions is striking. By comparison, a single Javelin missile costs approximately $80,000, and a 155mm artillery shell around $3,000 [21].

Estimates of the share of Russian armored losses attributed to FPV drones vary by source and timeframe. One report indicates that 45% of irreversible Russian vehicle losses were caused directly by FPV drones, compared to 35% by artillery and 3% by mines [3]. Other reports from early 2025 suggest that drones are now responsible for up to 65% of all Russian tank losses [22], and a February 2025 Forbes report claims drones now destroy two-thirds (~66.7%) of Russian targets [4]. Regardless of the exact percentage, all sources converge on the view that FPV drones have become a predominant cause of armored losses.

Ukraine’s large-scale industrial production reinforces this dynamic. Reports indicate output of up to 200,000 FPV drones per month by early 2025 [23], with procurement plans for 4.5 million units over the course of 2025 [24, 25]. This industrial scalability overwhelms enemy defenses and supports the sustainability of FPV tactics on the battlefield.

4.5. Countermeasures and Tactical Adaptation

The rapid innovation cycle of FPV drones has triggered an equally fast evolution in countermeasures:

- Electronic Warfare (EW): A range of solutions—from man-portable anti-drone weapons to vehicle-mounted jamming systems—have been used to disrupt FPV control links [3]. However, their effectiveness is increasingly contested as drone technology evolves.
- Improvised and reactive armor: Widely used "cope cages" and explosive reactive

armor offer partial protection, but remain vulnerable to repeated attacks, tandem warheads, or precision strikes on exposed areas [26, 27].

- Adaptive tactics: Vehicle dispersal, camouflage, and night-time operations reduce drone exposure [28]. A clear shift away from troop and equipment concentration is observable due to the "drone wall" patrolling wide areas [23, 29].
- Unit-level active defense: Dedicated "drone hunter" teams, acoustic sensors [30], and early-warning drones are increasingly integrated into operations [5].
- Counter-countermeasures: In response to EW, both sides have begun deploying FPV drones using fiber-optic guidance, which are immune to conventional jamming [23, 24]. Additionally, techniques to trace drone control signals and target operators as high-value individuals are under development [31].

5. Discussion

The findings reveal a major shift in tactics and doctrine, as FPV drones redefine ground warfare and challenge the relevance of armored vehicles in asymmetric conflicts.

5.1. Redefining Cost-Effectiveness in Modern Warfare

FPV drones fundamentally alter the economic calculus of modern conflict, showcasing extraordinary cost-effectiveness. This cost-efficient lethality paradigm allows for the destruction or neutralization of multimillion-dollar military assets through minimal investments in individual equipment [19, 22]. This economic shift favors actors with limited resources by granting them asymmetric capabilities that can challenge the technological and numerical superiority of more powerful adversaries.

This trend validates the concept of the democratization of firepower [10], where relatively simple technologies—often based on commercial off-the-shelf (COTS) components—can level the strategic playing field. It also raises the risk of proliferation to non-state actors and violent extremist organizations [11]. This is not merely a tactical shift, but a potential restructuring of the global defense ecosystem, forcing a reorientation toward more numerous, cheaper, and potentially expendable systems.

5.2. Technical Limitations and Tactical Constraints

While FPV drones offer clear advantages in precision and affordability, they also present notable technical limitations that impose tactical constraints on their effective deployment. Their short operational range—generally under 10 km, though some variants exceed this [22]—and limited performance under adverse weather or at night necessitate careful integration into coordinated operations, with dependence on supporting assets like reconnaissance teams and artillery [13].

Efforts to mitigate these constraints include the use of relay drones to extend range, more accessible thermal imaging systems for night operations, and the deployment of fiber-optic-guided drones that are more resilient to jamming and offer more stable data links [23]. These limitations show that FPV drones, though disruptive, are no silver bullet—they serve best as part of an integrated combat system.

5.3. Accelerated Measure–Countermeasure Cycle and Doctrinal Agility

The conflict in Ukraine has generated a rapid innovation and adaptation cycle between FPV drone use and countermeasure development, effectively turning the theater into a real-time “innovation lab” [11]. Each tactical advantage gained by one side is quickly analyzed and countered by the other, underscoring the importance of organizational and technological agility [28].

Current countermeasures—from electronic jamming to improvised armor—highlight the urgent need for advanced systems such as active protection systems (APS), integrated electronic warfare (EW), and tactical-level drone detection and interdiction solutions [32].

The speed of this cycle exerts intense pressure on traditional military structures, often constrained by slow procurement and doctrinal inertia. It rewards organizations capable of decentralized innovation and rapid fielding of new solutions [33].

5.4. Doctrinal and Strategic Implications

The rise of FPV drones necessitates a comprehensive rethinking of both offensive and defensive strategies. Armed forces must adapt not only their hardware, but also their organizational structures, training protocols, and operational concepts. Key areas of transformation include:

- Decentralization of firepower: Recognizing the ability of small units to wield significant anti-armor capability [27]. This shift may lead to revised command-and-control structures granting lower echelons greater autonomy [34].
- Enhanced situational awareness: There is an urgent need for early warning systems against low-altitude, small, and fast aerial threats. The integration of ISR drones, satellite feeds, and acoustic sensors is becoming increasingly essential [35].
- Multi-layered defense: Developing integrated anti-drone strategies at the individual, unit, and formation levels, combining passive, active, and electronic warfare measures.
- Psychological impact: Beyond physical damage, the constant presence and threat of FPV drones degrades troop morale and alters behavior, forcing more cautious, dispersed movement patterns. Chronic stress from drone exposure can undermine combat effectiveness.
- Future of armored platforms: The demonstrated vulnerability of expensive tanks to cheap drones raises questions about the long-term viability of heavy armor. Rather than obsolescence, this implies an urgent need to rethink design—focusing on top armor protection, sensor shielding, and integration of effective APS. It also suggests combining tanks with robotic and aerial protective systems.
- AI integration: The implementation of artificial intelligence in FPV drones for functions such as automatic target recognition (ATR), GPS-denied navigation, and swarm coordination is increasingly relevant [11, 35]. AI could reduce cognitive load on operators while improving decision speed and precision.

6. Conclusions

This study has highlighted the transformative impact of FPV drones on ground combat in the Russo-Ukrainian war, directly addressing the core research question regarding their tactical, operational, and doctrinal implications. The analysis demonstrates that these systems—originally developed for recreational use but adapted to become inexpensive and highly effective—have fundamentally reshaped anti-armor tactics. FPV drones, due to their low cost, high precision, and operational flexibility, have emerged as a major threat to armored vehicles (tactical impact), compelled adjustments in operational deployments and force composition (operational impact), and created an urgent need to adapt military doctrines and combat strategies (doctrinal impact).

The findings indicate a paradigm shift in modern land warfare, where the traditional dominance of heavy armor is being eroded by accessible, asymmetric, and versatile means.

The integration of FPV drones into a coherent and effective combat system—along with the development of agile countermeasures and new protection concepts for armored vehicles—represents a crucial lesson for the future of military planning.

A deep understanding of this phenomenon is essential not only for military analysts and security strategists, but also for policymakers tasked with designing armed forces prepared for next-generation technological confrontations.

This study contributes to the existing body of literature by providing a holistic analysis of the tactical, operational, and doctrinal impact of FPV drones, emphasizing both their demonstrated effectiveness and the evolving dynamics of the measure–countermeasure cycle in the war in Ukraine. Through detailed case studies and a rigorous methodology grounded in OSINT, this research offers a nuanced perspective on how a disruptive, low-cost technology can rapidly redefine the battlefield.

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