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FEATURES OF THE COMBAT USE OF LASERS TO COMBAT DRONES

Анотація: *У статті розглянуто аналізує сучасні особливості бойового застосування лазерів для протидії безпілотним авіаційним системам (ПБАС) серед провідних військових держав. Розглядається перехід до високоенергетичних лазерів (ВЕЛ) як стратегічного рішення, що пропонує глибокий боєзапас та вигідне співвідношення вартості за знищення цілі проти зростаючої загрози безпілотників. Представлено сфокусований аналіз програм ПБАС та оперативного досвіду України, Росії, США, Китаю та Ізраїлю, з обов'язковим акцентом на оперативних реаліях, що спостерігаються у російсько-українській та ізраїльсько-палестинській війнах. Ключові висновки підкреслюють різницю між кінетичними засобами з лазерним наведенням та справжньою спрямованою енергетичною зброєю, виявляючи експлуатаційні обмеження, такі як деградація навколишнього середовища (Китай) та стратегічна двозначність щодо можливостей (Росія). Ізраїльська система Iron Beam демонструє значний прогрес на шляху до оперативної готовності проти дронів, тоді як США прагнуть до високопотужної інтеграції на військово-морських і наземних платформах.*

Ключові слова: *Спрямована енергетична зброя (СЕЗ), Протидія БАС (ПБАС), Високоенергетичні лазери (ВЕЛ), Iron Beam, Пєрєсвєт, Silent Hunter, Військові технології, Асиметрична війна.*

Abstract: *The article analyzes the contemporary features of combat laser use for Counter-Unmanned Aircraft Systems (C-UAS) across major military powers. It examines the shift toward High-Energy Lasers (HEL) as a strategic solution offering deep magazines and favorable cost-per-kill ratios against proliferating drone threats. Focused analyses are provided for the C-UAS programs and operational experience of Ukraine, Russia, the United States, China, and Israel, with mandatory emphasis on the operational realities observed in the Russian-Ukrainian and Israeli-Palestinian conflicts. Key findings highlight the distinction between kinetic laser-guided effectors and true directed energy weapons, revealing operational constraints such as environmental degradation (China) and the strategic ambiguity surrounding capabilities (Russia). Israel's Iron Beam demonstrates significant progression toward operational readiness against drones, while the U.S. pursues high-power integration across naval and ground platforms.*

Keywords: *Directed Energy Weapons (DEW), Counter-UAS (C-UAS), High-Energy Lasers (HEL), Iron Beam, Peresvet, Silent Hunter, Military Technology, Asymmetric Warfare.*

I. Introduction:
The Exponential Rise of Directed Energy Weapons in Modern Warfare

The global proliferation of inexpensive, commercially derived, and militarily adapted Uncrewed Aerial Systems (UAS) has fundamentally destabilized the traditional economics of air defense. The contemporary battlefield, exemplified by conflicts in Eastern Europe and the Middle East, is saturated by drone threats – ranging from small reconnaissance platforms to long-range, one-way attack vehicles such as the Iranian-designed Shahed series. This asymmetry compels military forces to seek countermeasures that move beyond traditional kinetic missile systems.

The core problem facing established militaries is the unfavorable cost-exchange ratio. Utilizing expensive surface-to-air missiles (SAMs), which may cost millions of dollars, to intercept drones costing less than 50,000 USD is financially unsustainable. This economic dilemma is the primary strategic catalyst driving the intense global focus on Directed Energy Weapons (DEW), specifically High-Energy Lasers (HEL), for Counter-UAS (C-UAS) applications. Laser systems offer a theoretical "deep magazine," constrained only by power generation and cooling capacity, and a marginal cost-per-kill ratio approaching zero, defined only by the price of electricity. This recognition that DEW development is an economic imperative, rather than merely a capability upgrade, underscores why nations are fast-tracking these programs [1-3].

HEL C-UAS systems defeat threats through several distinct mechanisms. The hard-kill method involves delivering focused energy to the target at the speed of light, resulting in physical destruction.

This is achieved through thermal effects, such as direct ablation (vaporizing material), burning through the airframe or wings, or igniting critical flammable components like the fuel tank, batteries, or onboard warhead. For instance, certain Chinese systems claim the ability to penetrate 5 millimeters of steel at a range of 1,000 meters through ablation. Conversely, systems can operate in a lower-power, non-lethal mode. This dazzling mechanism targets and overwhelms the drone's sensitive electro-optical and infrared (EO/IR) sensors and navigational apparatus, effectively blinding the UAV and disrupting its mission without physically destroying the airframe [3-5].

Despite the profound economic and strategic advantages, the maturity of HEL technology is hampered by inherent physical constraints. The most significant technical challenge is mitigating atmospheric interference, particularly thermal blooming. Thermal blooming occurs when the laser beam heats the air immediately surrounding it, causing the beam’s energy density to decrease and the focal point to spread. This phenomenon, along with general atmospheric turbulence and refractive index fluctuations, severely degrades the laser's effectiveness and limits its maximum effective range, especially in adverse weather conditions. This theoretical constraint finds empirical validation in operational deployment, where environmental factors become a critical inhibitor of performance. Furthermore, high-power HEL systems require highly efficient, powerful cooling mechanisms and reliable, continuous electrical power generation. Integrating these large, complex subsystems – power, cooling, and the beam director – onto mobile platforms without resulting in excessive size, weight, and power (SWaP) demands or high operational downtime remains a crucial engineering hurdle for fielding rugged, combat-ready C-UAS systems [6-8].

II. The Crucible of Conflict: Laser Applications in the Russian-Ukrainian War

The ongoing Russian-Ukrainian War provides an invaluable, high-intensity operational laboratory for C-UAS technologies, revealing a tactical necessity for solutions that prioritize cost-effectiveness. Crucially, the deployment of laser technology in this conflict must be categorized into two distinct types: true Directed Energy Weapons (DEW) and Laser-Guided Kinetic Solutions (LGKS).

Laser-Guided Kinetic Solutions as a Cost-Effective Bridge

Faced with massive, continuous attacks by low-cost Russian drones, Ukraine has rapidly adopted LGKS systems supplied by Western partners. These systems employ a laser not for energy projection, but for terminal guidance of a kinetic projectile. A prime example is the US-supplied L3Harris VAMPIRE (Vehicle-Agnostic Modular Palletized ISR Rocket Equipment). Mounted on tactical vehicles such as Humvees, VAMPIRE utilizes laser-guided 70-millimeter rockets, typically the Advanced Precision Kill Weapon System II (APKWS II), as its effector. The VAMPIRE system has been highly successful, reportedly shooting down hundreds of enemy drones and, significantly, achieving a substantial reduction in the "cost per effect" compared to traditional surface-to-air missile systems [1].

Similarly, Ukraine utilizes European-made LGKS, such as the Thales 70-millimeter laser-guided rocket. This system employs a specialized FZ123 airburst warhead. Upon proximity detonation, this warhead disperses thousands of steel pellets, creating an 80-foot diameter lethal cloud. This specialized kinetic design is optimized for countering high-volume, low-cost threats like the Shahed drone series (NATO Class II and Class III threats) and is particularly effective against drone swarms or tightly grouped formations. The widespread reliance on VAMPIRE and Thales LGKS systems confirms that, under the pressure of high-intensity, asymmetric conflict, military procurement immediately prioritizes reducing the interception cost, often settling on hybrid solutions as a necessary bridge until mature HEL systems become deployable [9].

The importance of these laser-guided solutions as an economic intervention on the battlefield is summarized below in table 1 [1; 9].

Table 1 – Laser-Assisted Kinetic Countermeasures in the Russia-Ukraine Conflict

System	Origin	Role in Ukraine	Effector Type	Laser Function	Cost-Effectiveness Insight
VAMPIRE	U.S. (L3Harris)	Mobile C-UAS against enemy drones (Shahed) and cruise missiles	70mm APKWS II (Laser-Guided Rocket)	Terminal Guidance (Illumination)	Greatly reduces cost per effect compared to traditional missile systems.
Thales FZ123	Europe (Thales)	Countering Shahed/Class II/III drones	70mm Laser-Guided Rocket (Airburst Warhead)	Terminal Guidance (Illumination)	Airburst warhead increases lethality against swarms, compensating for targeting imperfections.

Ukraine's Emergent Directed Energy Weapon: Tryzub

Beyond relying on kinetic laser-guided systems, Ukraine has reportedly moved toward fielding its own laser weapon system, dubbed 'Tryzub' (Trident). Colonel Vadym Sukharevskyi, Commander of the Ukrainian Unmanned Systems Forces, confirmed the deployment of Tryzub, claiming it can neutralize aerial targets, including drones, flying at altitudes over 6,500 feet (more than 2 kilometers) [10-11].

The development and deployment of Tryzub reflect Ukraine's urgent need to establish a true, low-marginal-cost C-UAS capability. The system's design emphasizes energy efficiency and operational flexibility, allowing for deployment in both stationary and mobile configurations. Colonel Sukharevskyi emphasized that the laser system "really works, it really exists," suggesting that the intense operational demands of the war have accelerated either rapid indigenous innovation or the critical acquisition and integration of foreign DEW technology. If operational, Tryzub moves Ukraine into a select group of nations possessing dedicated DEW capabilities, reflecting the profound strategic importance of rapidly acquiring a sustainable method to defeat the Russian drone threat [12].

III. Strategic Deployment and Capability Gaps: Russia's Directed Energy Arsenal

Russia has made highly publicized claims regarding its development and deployment of advanced laser systems, notably Peresvet and Zadira, though operational substantiation of the hard-kill capability remains highly contested, particularly in the context of the Ukrainian conflict.

Peresvet and Zadira: Propaganda vs. Performance

The Russian state narrative, advanced by officials such as Deputy Prime Minister Yury Borisov, divides their laser efforts into two categories based on function. The Peresvet system is described primarily as a non-lethal dazzling weapon, intended to blind or incapacitate enemy sensors, with Borisov claiming it can dazzle satellites in orbits up to 1,500 km. The Zadira system, however, represents the claimed leap to thermal destruction, with Borisov describing it as the "new generation" capable of physically destroying targets by burning them up. Specific, high-profile claims include Zadira successfully shooting down a Ukrainian drone in just five seconds at a distance of 5 kilometers [13-14].

Despite these bold claims and assertions of wide deployment, evidence confirming the operational effectiveness of Zadira as a thermal hard-kill system remains critically absent. Skepticism from military experts is widespread, and Ukrainian President Volodymyr Zelensky publicly dismissed the claims as propaganda, drawing comparisons to the German *Wunderwaffen* (wonder weapon) myths of World War II. Simultaneously, the Pentagon has stated that it has seen no evidence to corroborate Borisov's statements regarding the system's lethal capabilities [14].

Technological Immaturity and Foreign Dependence

The strategic ambiguity surrounding Russian domestic laser programs is further complicated by reports of reliance on foreign systems. Sources indicate that Chinese low-altitude laser defense systems (LASS), potentially related to the Silent Hunter model, have been deployed by Russian forces in Ukraine as recently as May 2025 [8].

This reported use of exported Chinese laser systems, which themselves have documented limitations in environmental resilience and operational readiness (as detailed in Section V), strongly suggests that Russia's indigenous hard-kill HEL technology is either operationally immature, confined to low-power dazzling roles, or suffering from crippling deficiencies. If the Zadira system were truly capable of incinerating drones in five seconds, there would be no apparent military necessity to rely on a Chinese export system with known performance flaws. This dependency suggests that while Russia recognizes the critical need for a DEW C-UAS solution to address the volume of Ukrainian drone attacks, its domestic technology is currently unable to fill the gap effectively. The public claims, therefore, primarily serve a psychological and strategic posturing function rather than demonstrating a deployable technological reality.

IV. Technological Maturity and Naval Integration: The United States' High-Energy Laser Programs

The United States has adopted a robust, methodical, and multi-domain approach to DEW development, prioritizing high-power outputs and deep integration into existing military command and control architectures to ensure systemic combat effectiveness.

Naval Dominance: The HELIOS Program

The High Energy Laser with Integrated Optical-dazzler and Surveillance (HELIOS), developed by Lockheed Martin, is the centerpiece of the U.S. Navy's Surface Navy Laser Weapon System (SNLWS) Increment 1. HELIOS is designed to be fully integrated with ship combat systems, such as the Aegis architecture, providing a multi-mission capability that extends far beyond simple drone interception [3].

During factory testing, HELIOS consistently demonstrated full power operation above 60 kilowatts (kW). The system's scalable design architecture is intended to accommodate increased power levels in the future, positioning it as a long-term solution against evolving threats. A critical element of the HELIOS program is its dual functionality. It operates both as a lethal hard-kill weapon and as a non-lethal optical dazzling system (C-ISR Dazzler) and long-range Intelligence, Surveillance, and Reconnaissance (ISR) tool. This integrated, layered approach confirms that the U.S. DEW strategy does not see lasers merely as destructive weapons, but as tools capable of offering a graduated response. Blinding an enemy's reconnaissance drone, for example, degrades their targeting chain and provides a tactically valuable, non-lethal disruption that satisfies stringent rules of engagement. Furthermore, the system is guided by the fundamental principle of achieving a "low cost per kill" and a "favorable cost exchange ratio," highlighting the priority placed on economic sustainability in conflict planning [3].

Ground Force Capability: IFPC-HEL and HPM Integration

For ground forces, the U.S. Army is pursuing the Indirect Fire Protection Capability (IFPC) program, which includes both High Energy Laser (HEL) and High Power Microwave (HPM) components. The IFPC HEL, developed by Dynetics, is designed to protect fixed and semi-fixed critical assets against a wide range of aerial threats, including Cruise Missiles (CMs), UASs, and Rockets, Artillery, and Mortars (RAMs) [15].

The Army has set ambitious goals for power and mobility, planning to mount four operational prototypes of the 300 kW-class IFPC HEL onto tactical vehicles by Fiscal Year 2024. Successful testing has been reported, demonstrating the program's ability to proceed toward a transition to a Program of Record in FY2025. This pursuit of high-power mobile systems (300 kW class) signifies an effort to achieve lethal effects at tactically useful ranges against more complex, hardened threats [16].

In a key strategic decision emphasizing layered defense, the Army is developing the IFPC High Power Microwave (HPM) system in parallel. HPM systems, such as the Epirus Leonidas prototypes being delivered for testing , are specifically designed to provide short-range protection against small UAS swarm attacks. This dual development pathway demonstrates a crucial doctrinal understanding: the limitations of the HEL against saturation swarm attacks, where sequential targeting is highly inefficient, are compensated for by the broad-area effect and high efficiency of the HPM against multiple targets simultaneously. This integration of HEL (precision, deep magazine) and HPM (area denial, anti-swarm) ensures that the US C-UAS architecture is robust against various threat vectors [15-16].

V. Export and Environmental Challenges: China's Silent Hunter and Low-Altitude Laser Systems

China has emerged as a significant global developer and exporter of fiber-optic laser technology for counter-drone applications, with systems like the Silent Hunter demonstrating initial capabilities but facing severe operational constraints upon deployment in challenging environments.

System Design and Mechanisms of Destruction

The Silent Hunter system, developed by Poly Technologies, uses an electrically powered fiber optic laser. Publicly reported specifications indicate that the power output falls within the range of 30 kW to less than 100 kW. The system is technically capable of achieving kinetic effects through thermal destruction, with claims that it can penetrate 5 millimeters of steel at 1,000 meters through ablation. Chinese academic literature further details the precise damage mechanisms employed by laser C-UAS, which include the deliberate irradiation of electro-optical reconnaissance sensors, burning the UAV's airframe structure (wings or fuselage), and critically, igniting flammable internal components such as fuel tanks or battery packs [4-5].

Operational Failure in Harsh Environments

The practical operational viability of China's exported C-UAS laser technology has been significantly challenged by documented failures in real-world deployment. A major case study involved the SkyShield integrated counter-drone system, which incorporates the Silent Hunter laser module, deployed in Saudi Arabia [7].

Reports from former Saudi military personnel revealed that the laser module struggled severely under the kingdom's harsh desert conditions. Environmental factors proved to be a practical operational kill switch. High ambient temperatures necessitated diverting substantial system power toward cooling rather than firing, reducing effective lethality. Furthermore, dust and sand disrupted the precision optical tracking required for continuous energy delivery. This environmental degradation translated directly into combat ineffectiveness, with operational experience showing that the Silent Hunter sometimes required between 15 and 30 minutes of continuous targeting to guarantee a drone kill – a timeframe that renders the system obsolete against modern, fast-moving, or swarm threats. This empirical data converts the theoretical atmospheric and cooling challenges into concrete operational limitations, confirming that current DEW technology is highly constrained by the environment and is not yet an all-weather solution [7].

Doctrinal Implications of Swarm Defense

The performance challenges of the Silent Hunter laser contrast sharply with the reliability of the overall SkyShield package's electronic jamming components, which proved more effective at neutralizing threats. This operational data aligns with Chinese military thought on countering large-scale threats. Chinese writings indicate a doctrinal preference for High Power Microwave (HPM) weapons over HEL systems for anti-UAV swarm operations. This preference is rooted in the HPM system's capacity for wide damage range, allowing it to target multiple drones simultaneously, thereby mitigating the HEL's limitation of requiring sequential, precise targeting against saturation attacks. Despite these limitations, Chinese LASS variants have been exported and reportedly deployed by Russian special forces in Ukraine and by the Iranian military in Tehran, highlighting the global spread of this technology even in its nascent stage [7-8].

VI. The Operational Imperative: Israel's Iron Beam and Counter-UAS Defense in the Gaza War Context

Israel has achieved the most significant and verified progress globally in transitioning a high-power laser C-UAS system from development to operational readiness, confirming the system's utility within a highly kinetic conflict environment.

Development and Integration into Layered Defense

The Iron Beam system, developed jointly by Rafael Advanced Defense Systems and Elbit Systems, is conceived as a high-power laser interceptor designed to work in conjunction with the existing kinetic Iron Dome system. Iron Beam is intended to address the persistent cost challenge posed by small threats, such as short-range rockets, mortars, and cheap drones, which would otherwise consume expensive kinetic Iron Dome interceptors (costing 100,000 to 150,000 USD per shot) [2].

Following an advanced series of operational tests conducted by the Directorate of Defense Research & Development (DDR&D), the Israeli Air Force, and Rafael, Iron Beam successfully intercepted a range of targets, including rockets, mortars, aircraft, and UAVs. These tests concluded the developmental process, and the system has been officially declared operational, with Rafael preparing to deliver the first full operational systems to the Israel Defense Forces (IDF) before the end of 2025. The system, renamed Or Eitan (Eitan's Light) in a symbolic gesture, is configured as a relocatable, self-supported module, housed in an ISO container with an adjacent generator [17-19].

Confirmed Combat Use in the Israeli-Palestinian Conflict

The most critical data point confirming the combat utility of laser C-UAS technology is Israel’s validated deployment during the current conflict. During fighting on the northern front of the Israeli-Palestinian conflict, a *lower-powered version* of the Iron Beam system was utilized by the IDF and successfully shot down drones launched by Hezbollah from Lebanon [19].

This confirmed operational kill represents the highest degree of real-world validation available for a DEW C-UAS system globally, moving Iron Beam beyond the realm of prototypes and unverified claims. The tactic employed by the IDF – deploying a lower-powered version first – is a strategy of graduated fielding. It allows the military to rapidly integrate the system, refine tactical protocols, and gather crucial performance data against live threats, mitigating the risk associated with fielding complex, high-power systems immediately. This pragmatic approach has successfully demonstrated the laser's tactical viability against drone threats in a high-threat, active engagement environment.

VII. Conclusion:
Future Trajectories and the Tactical Reality of Battlefield Lasers

The features of combat use of lasers to combat drones are defined primarily by the urgent need to solve the cost-exchange ratio crisis triggered by drone proliferation. While directed energy weapons are heralded as the future solution, current deployments reveal a complex tapestry of confirmed operational success, strategic ambiguity, and severe environmental limitations.

Synthesis of Global Status and Doctrine

A comparative analysis of leading national programs reveals distinct developmental philosophies and operational statuses:

- **Israel** has achieved verified operational deployment (albeit with a lower-powered variant) against real drone threats in the Israeli-Palestinian conflict, leading the world in demonstrated maturity and tactical integration (Iron Beam) [19].
- **The United States** pursues high-power (300 kW class) systems integrated deeply into existing command architectures (HELIOS, IFPC-HEL). The U.S. strategy is characterized by a layered approach, utilizing both precision HEL and area-effect HPM to counter swarms and individual threats effectively [2; 16].
- **China** acts as a major DEW exporter, but the documented failures of the Silent Hunter in severe desert conditions provide irrefutable evidence that current commercial off-the-shelf (COTS) laser technology is highly susceptible to atmospheric and thermal degradation. Furthermore, Chinese doctrine indicates HPM may be preferred over HEL for effective anti-swarm operations [4; 7].
- **Russia** maintains an outward posture of advanced capability (Zadira, Peresvet), but the claims of hard-kill performance remain unverified and are contradicted by reported reliance on foreign Chinese laser systems in the Ukrainian theater [8; 14].
- **Ukraine** has rapidly adopted laser-guided kinetic effectors (LGKS) like VAMPIRE and Thales FZ123, systems that function as an essential, cost-effective bridge, confirming the immediate operational priority of drone interception economics [1; 9].

Table 2 – Comparative Analysis of Global High-Energy Laser C-UAS Systems

Country	**Designation**	**Reported Power Class (kW)**	**Primary Role**	**Current Status**	**Salient Insight**
United States	HELIOS	>60 kW (Scalable)	Naval Anti-Air/ C-UAS/ ISR Dazzler	Factory tested; nearing naval delivery (SNLWS Inc 1)	Integration into Aegis; focus on graduated response and scalability.
United States	IFPC HEL	300 kW (Class)	Mobile Ground C-RAM/ C-UAS	Prototype development; planned transition to Program of Record FY2025	Focus on high power (300kW) for kinetic effects against CMs and swarms.
Israel	Iron Beam (Or Eitan)	High-Power Laser	C-RAM/ C-UAS	Operational; lower-powered version successfully deployed against drones; full IDF delivery planned by late 2025	Verified combat kill confirmation in active conflict (Hezbollah drones).
China	Silent Hunter (SkyShield/LASS)	30 kW – 100 kW	Low-Altitude C-UAS	Exported/deployed (Russia, Iran, Saudi Arabia)	Fiber optic design; poor operational performance documented in harsh environments (dust, cooling issues).
Russia	Zadira	Undisclosed	Physical Destruction C-UAS	Claimed operational deployment in Ukraine	Claims of 5-second kill time at 5km remain highly disputed and uncorroborated.
Ukraine	Tryzub (Trident)	Undisclosed	C-UAS	Acquired/Fielded; reportedly shoots down targets >2km altitude	Represents an urgent operational integration/indigenous development.

Key Technological and Operational Barriers

The trajectory of battlefield laser use is still constrained by two significant physical hurdles. First is the power/cooling paradox. The requirement for high power output (e.g., 300 kW) necessitates vast electrical power generation and corresponding high-efficiency cooling systems, which dramatically increases the size, weight, and power (SWaP) demands of the system. This engineering compromise directly inhibits the system's mobility and limits operational runtime, forcing power to be diverted for cooling in high-temperature environments [7-8].

Second, atmospheric resilience remains paramount. The continued viability of lasers depends on overcoming environmental challenges like thermal blooming and distortion. Future progression requires highly advanced adaptive optics and beam conditioning technology capable of compensating for atmospheric fluctuations to maintain lethal energy density over extended ranges and under degraded visibility conditions. Until these fundamental engineering challenges are resolved, laser systems will continue to suffer from constrained engagement windows and reduced range capabilities [6].

Ultimately, the future of C-UAS combat use lies not in lasers replacing missile defense entirely, but in establishing HEL and HPM systems as the essential, low-cost, high-volume layer within a tiered air defense architecture. The strategic and economic pressures exerted by widespread drone use ensure that the global focus on miniaturization, power efficiency, and atmospheric robustness will continue to drive DEW technology toward inevitable battlefield maturity.

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