Lethality at Light Speed: Directed Energy Warfare

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Abstract

This article outlines the strategic imperatives and tactical utility of Directed Energy Weapons (DEWs), with specific emphasis on India's capability development and battlefield employment models. Conventional surface-to-air missile systems and kinetic interceptors are increasingly unsustainable in a threat environment saturated with low-cost, high-density aerial platforms—ranging from swarm drones to hypersonic projectiles. This article assesses the transition from research and development to limited operational deployment of DEWs globally, and evaluates India's indigenous advancements including the Sahastra Shakti Mk-II(A), Directionally Unrestricted Ray-Gun Array *II, and Surya-class platforms. Utilising comparative cost-benefit matrices, real-time engagement capabilities, and magazine-depth analytics, this article illustrates how DEWs offer a high-cycle, energy-efficient solution for next-gen layered air defence. Additionally, this article evaluates the integration of laser platforms with India's existing command, control, communications, computers, intelligence, surveillance, and reconnaissance, mobile armour, naval combatants, and aerial strike platforms. In the context of a limited war or cross-border escalation scenario—particularly with Pakistan—these systems present a paradigm shift in area denial, drone suppression, and critical asset protection, reinforcing India's deterrence posture and*

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operational resilience in both symmetric and asymmetric conflict environments.

Introduction

Since the inception of organised conflict, mankind has continuously pursued technological supremacy to outmatch adversaries—from bronze-tipped spears to mechanised armour. However, since World War II, each passing decade has heralded a quantum leap in battlefield lethality and strategic doctrine. The 1950s saw the rise of jet propulsion and nuclear deterrence, the 1970s introduced precision-guided munitions, and by the 1990s, Network-Centric Warfare (NCW) redefined the tempo of operations. In the current decade, unmanned aerial systems dominate the tactical battlespace. Yet, the emerging disruptor poised to reshape future warfighting is Directed Energy Weapons (DEW)—specifically, laser-based systems capable of engagement at the speed of light.

As military doctrines evolve in the face of emerging aerial threats, DEWs are no longer conceptual edge technologies but critical enablers in multi-domain operations. Their operational relevance is being shaped not just by technological feasibility, but by battlefield necessity. The increasing density and frequency of drone incursions, loitering munitions, and low-observable aerial platforms have rendered conventional missile-based Air Defence (AD) weapon systems cost-ineffective and logistically burdensome in sustained engagements.

India's defence framework, which has traditionally focused on layered kinetic interception systems such as Akash, Surface-to-air PYthon and DERby (SPYDER) Barak-8, and S-400, is now going through a doctrinal recalibration to include high-energy laser-based capabilities. The incorporation of DEWs signifies a move towards high-tempo, cost-effective engagements and precision point-defence solutions. This shift aligns with India's broader transition towards NCW and theatre command structures, where DEWs can be guided by real-time Intelligence, Surveillance, and Reconnaissance (ISR) inputs and seamlessly integrated into the existing kill-chain hierarchy.

Military-Grade Lasers

Military-grade DEWs operate on the principle of lasers, generating a narrow, coherent, high-energy beam of light capable of neutralising aerial or ground threats with pinpoint precision. Since the beam travels at the speed of light—approximately 3,00,000 kms per second—engagement is instantaneous. At their core, laser systems comprise a gain medium such as solid-state crystals like ytterbium-doped yttrium aluminium garnet, fibre lasers, or chemical lasers; a pump source, often electrical or diode-based; and an optical resonator consisting of mirrors that amplify and direct the beam. When photons excite atoms in the gain medium, they stimulate the release of more photons, producing a highly focused beam. Advanced focusing optics then concentrate this beam onto a specific part of the target—causing heating, melting, vapourisation, or structural disruption, depending on intensity and duration.

Lasers are categorised by output power: low-energy lasers (01-10 kW) disrupt sensors and optics; medium-energy lasers (10-50 kW) can destroy Unmanned Aerial Vehicles (UAVs) or disable warheads; high-energy lasers (50-300 kW) can neutralise cruise missiles or swarming boats; and future strategic-class lasers (greater than 300 kW) may one day counter ballistic threats. Tactical effects vary from soft kills such as sensor blinding to hard kills like target destruction, along with non-kinetic disruptions that leave no visible trace. Unlike missiles or bullets, laser systems deliver silent, invisible, speed-of-light engagement, without smoke trails or sound signatures—making them ideal for stealthy AD.

The Strategic Rationale for Laser Weapon Development

India's investment in high-energy laser-based DEWs is underpinned by the need to correct battlefield asymmetries that favour saturation attacks using low-cost aerial threats. These asymmetries manifest in four interrelated tactical and logistical deficiencies in conventional AD doctrine:

- **Cost Asymmetry and Tactical Economics**. A quadcopter drone used for surveillance or improvised explosive device delivery can cost as little as INR 40,000 to INR 4,00,000 (approximately USD 500–USD 5,000). In contrast, intercepting it with a Surface-to-Air Missile (SAM) such as Akash, SPYDER, or S-400 results in an economically disproportionate exchange ratio.[1] This imbalance allows state and non-state actors to field low-cost drone swarms that drain India's high-value interceptor stocks. This creates an economically asymmetric warfare model that favours the attacker unless neutralised by near-zero cost intercepts, such as lasers.

- **Magazine Depth and Sustainment Fragility**. Legacy AD systems are limited by fixed magazine capacities and time-consuming reload cycles. For example, a typical quick reaction SAM battery may carry only six to eight interceptors as first line scale of ammunition, creating a finite engagement window before logistical support is required. In contrast, laser-based DEWs operate on electrical input, offering deep-fire endurance—hundreds of engagements per power cycle—making them ideal for protracted or swarm-style saturation attacks.[2] DEWs, operating on stored electrical energy, can theoretically fire hundreds of times without reloading, provided continuous power and cooling.

- **Engagement Velocity for Hypersonic and Saturation Threats.** Directed energy systems operate at speed-of-light (approximately $3x10^8$ m/s), enabling real-time kill-chain execution against supersonic or hypersonic threats (greater than Mach 5) where milliseconds determine intercept viability by offering zero delay from detection to impact. This is critical in Indo-Pak theatre where tactical ballistic missiles and short-range rocket artillery may offer greater than 60-second time-to-target.

- **Surgical Precision and Collateral Minimisation**. Unlike explosive-based SAM intercepts, DEWs use thermal kill mechanisms (melting, cracking, overheating), enabling surgical elimination of drone optics, motors, or warheads without kinetic debris or collateral blast damage. This feature is vital in urban counterinsurgency/counterterrorism environments like Kashmir or border settlements in Punjab and Jammu, where civilian spillover is unacceptable, thereby, aligning with Rules-of-Engagement (ROE)[3] protocols.

Together, these factors represent a confluence of doctrinal necessity and technological inevitability—where DEWs emerge not just as adjunct systems but as indispensable components of India's future integrated air and missile defence matrix.

Global Operational Developments. Global operational developments in laser warfare are accelerating across major military powers, such as High Energy Lasers (HELs) transition from experimental labs to operational battlefields. The operational tempo is shifting from test beds to real-time deployment, and nations are racing to incorporate lasers into multi-domain combat architectures—from space denial and naval warfare to urban counter-drone grids, as under:

- **Israel: Iron Beam (100 kW Class)**. The Israeli Defence Forces, in collaboration with Rafael Advanced Defence Systems, operationally deployed the Iron Beam system in Oct 2024 during the Hezbollah-Israel skirmishes. The laser weapon successfully neutralised loitering munitions and UAVs within a 10 km engagement envelope. Cost-per-shot estimates remain around INR 900-INR 1,200 (USD 10-USD 13) due to its electric power base. Plans are underway to upscale it to a 150 kW configuration, potentially increasing effective range to approximately 15 kms and enabling it to tackle faster UAVs and rockets, artillery, and mortars targets.[4]

- **United States (US): High Energy Laser with Integrated Optical-dazzler and Surveillance (HELIOS), Directed Energy Maneuver-Short-Range Air Defence (DE M-SHORAD), and Airborne Lasers**. The US Navy's HELIOS system, fielded aboard Arleigh Burke-class destroyers, operates in the 60 plus kW power class and has demonstrated target acquisition and neutralisation of drones and ISR platforms at sea.[5] The US Army's DE M-SHORAD (50 kW)[6] mounted on Stryker vehicles entered early deployment in 2024 to counter drones, rockets, and mortars. A landmark milestone occurred in Apr 2025 when General Atomics test-fired a 300 kW high-energy laser from an MQ-9B Reaper drone, allowing stand-off engagement of aerial threats from an airborne ISR platform.

- **United Kingdom (UK): Dragon Fire**. The UK Ministry of Defence, in partnership with Leonardo, Matra BAE Dynamics Alenia, and QinetiQ, validated its DragonFire laser system in early 2025 by striking a coin-sized moving target at one km, with a cost-per-shot of approximately INR 1,000.[7] Dragon Fire demonstrates significant potential for Close-In Weapon Systems (CIWS) roles aboard Royal Navy vessels and static asset protection. Full deployment is projected by 2027.

- **China: Silent Hunter and Anti-satellite (ASAT) Lasers**. China has made rapid advancements in DEW technology, including the deployment of Silent Hunter—a vehicle-mounted fibre laser system claimed to deliver up to 30-100 kW of power. It has been showcased at international defence expos and is reportedly capable of disabling UAVs at distances of 04 kms. Open-source intelligence suggests deployment of higher-powered space-oriented ASAT DEWs and ship-mounted prototypes focused on anti-drone and anti-missile applications.[8] These developments reinforce China's strategy of leveraging DEWs in asymmetric and grey-zone scenarios.

India's Progress in Directed Energy Weapons

Sahastra Shakti Mk-II(A). The Defence Research and Development Organisation (DRDO) tested the Sahastra Shakti Mk-II(A) system on 13 Apr 2025 at the Kurnool test range.[9] The system employs a 30 kW fibre laser mounted on a high-mobility tactical vehicle chassis for rapid deployment. It demonstrated a 100 per cent kill probability during trials against fixed-wing UAVs, quadcopter swarms, and passive optical surveillance arrays at engagement ranges of up to 05 kms. The laser achieves destructive effects via localised thermal energy delivery, leading to immediate structural failure or warhead detonation. Its integrated Electro Optical/Infra-Red (EO/IR) targeting suite enables autonomous threat tracking and beam stabilisation under mobile combat conditions. The Mk-II(A) is slated for tri-service induction into frontline counter-UAS and perimeter denial roles by 2027.

Future Systems[10]:

- **Directionally Unrestricted Ray-Gun Array (DURGA) II**. DURGA II is a next-generation platform under classified development, envisioned as a modular 100 kW system for deployment on air-superiority fighters, naval destroyers, and armoured ground vehicles. It incorporates adaptive optics for countering atmospheric degradation and is expected to provide 360 degrees engagement against UAVs, loiter munitions, and cruise missile targets across domains.

- **Surya**. DRDO's Surya-class is an ultra-high-energy 300 kW laser weapon under concept validation. Designed for extended airspace interdiction, it aims for an operational range of 15-20 kms and can intercept high-speed missiles including short-range ballistic missiles, manned aircraft, and large UAVs. Integration with long-range radar systems and strategic platforms such as the Airborne Warning and Control System (AWACS) and INS Vishal (future aircraft carrier) is under feasibility evaluation.

- **The Kilo Ampere Linear Injector (KALI) System**. An indigenous high-powered accelerator-based pulsed power source, the KALI-5000, developed by the Bhabha Atomic Research Centre, is being considered for integration into India's DEW test infrastructure. Capable of delivering ultra-short bursts of kilo-ampere electric pulses, KALI can simulate electromagnetic pulse-like disruptions and may provide the foundation for next-generation non-lethal electronic kill DEWs and ASAT applications. Reports suggest that modified KALI-based emitters are under evaluation for electro-thermal blinding of UAV guidance packages and disabling enemy ISR satellites in low Earth orbit.

Budgetary Support. India's Union Defence Budget for Financial Year 2025-26 earmarked INR 26,816 cr for the Department of Defence Research and Development. Of this, INR 14,924 cr (approximately USD 1.8 bn) is specifically allocated to projects focused on high-impact next-generation warfare technologies—including DEWs, Artificial Intelligence (AI), swarm drones, and hypersonics. DRDO has further received multi-year capital support through the Technology Development Fund for DEW-specific labs under the Laser Science and Technology Centre and the Centre for High Energy Systems and Sciences.

Integration of Directed Energy Weapons with Existing Weapon Systems

To ensure seamless battlefield utility, DEW systems must be embedded within India's Integrated AD Control and Reporting System and Battlefield Management System grids. Real-time sensor fusion from AWACS like Netra, ground-based fire control radars like Swathi Weapon Locating Radar, and passive EO/IR systems must feed targeting data to DEW operators. Laser systems on naval platforms should be networked with CMS-17 and BrahMos fire control suites, enabling integrated threat engagement. Armoured formations deploying laser-mountable Infantry Combat Vehicles (ICVs) or Main Battle Tanks (MBTs) will benefit from Helina or Nag missile guidance architecture, ensuring redundancy and dual-mode engagements (laser plus kinetic). As India operationalises Project Akashteer, a new-generation digital AD control network, DEWs will serve as both autonomous kill assets and precision effector nodes, accelerating India's shift toward distributed lethality and sensor-to-shooter loop optimisation.

- **SAM-Complementary Deployment**. Laser systems like Sahastra Shakti can be co-located with Akash and S-400 SAM batteries to form layered defences.
- **Armoured and Infantry Formations**. Future iterations of DURGA II could be mounted on MBTs and BMP-2 ICVs, providing mobile units with autonomous anti-drone and short-range aerial defence.
- **Naval Platforms**. Surya-class lasers could be integrated with INS Visakhapatnam-class destroyers, adding another line of defence to the Barak-8 and CIWS layers already in place.
- **Airborne Integration**. Lightweight DEWs could be integrated into fighter aircraft such as Su-30MKIs and Tejas Mk2 via external pods to provide airborne anti-UAV and sensor-disruption capability.
- **UAV and Drone Carriers**. Integrating compact laser modules into medium-altitude long-endurance UAVs and future high-altitude long-endurance platforms like Tactical Airborne Platform for Aerial Surveillance-Beyond Horizon-201 will enhance independent neutralisation capability against aerial threats.

- **Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) Systems**. DEWs must be linked with integrated battle management systems, radar feeds, and electro-optical fire control for automated cueing and rapid targeting.

Enhancing the lethality of DEWs require a synergistic evolution across power delivery, beam quality, target tracking, and operational integration. Scaling output from current 30–100 kW systems to 300 kW and beyond exponentially increases destructive capacity—enabling hard-kill effects against high-speed cruise missiles, low-observable UAVs, and potentially manned platforms. Beam coherence and focus must be optimised using advanced adaptive optics and turbulence compensation technologies to ensure precision engagement across varying atmospheric conditions. Tactical effectiveness further hinges on real-time target acquisition through AI-integrated fire control systems, fused with EO/IR sensors and radar arrays for seamless multi-target tracking and rapid kill-chain execution. Sustained lethality demands sophisticated thermal management—leveraging liquid or cryogenic cooling loops to maintain beam integrity during extended firing cycles. Power supply remains a critical enabler; advances in pulsed power modules, compact turbine generators, and supercapacitor-based energy banks are vital for mobility across land, naval, and airborne platforms. Integration of DEWs with kinetic systems in hybrid defence architectures enhances overall mission survivability during saturation or layered attacks. Expanding functional lethality to soft-kill roles—via high-power microwave pulses or sensor blinding—adds a spectrum of non-kinetic disruption options in electronic warfare-contested environments. Future innovations may see DEWs coupled with electromagnetic pulse emitters for area denial, infrastructure paralysis, or strategic system degradation. DEW lethality will be defined not just by wattage, but by its integration into dynamic multi-domain operations, resilience under load, and capacity for precision at tactical, operational, and strategic tiers.

Tactical Applications in Indo-Pak Conflict Scenarios

Border Drone Incursions. The increasing frequency of drone-based incursions sponsored by Pakistan across Punjab, Rajasthan, and Jammu sectors—including reconnaissance platforms and payload-dropping UAVs—necessitates a rapid, scalable countermeasure. Conventional SAMs such as Akash or SPYDER are logistically unsustainable for such low-cost threats. Deployment of mobile Mk-II(A) laser DEWs along forward posts, Border Security Force (BSF) compounds, and sensor-rich checkpoints offers a zero-munition, high-endurance intercept solution. These systems can autonomously track and disable UAVs via thermal kill or optical disruption modes, neutralising the asymmetric cost advantage that favours the adversary.

Defence of High-Value Assets. Strategic installations such as frontline Indian Air Force airbases (e.g., Pathankot, Ambala), oil depots, and forward ammunition stockpiles remain high-priority targets for cross-border stand-off attacks via cruise missiles, suicide drones, or artillery rockets. Integrating DURGA II and Surya-class DEWs as the terminal hard-kill layer within existing AD perimeters enables faster, cost-effective interdiction of incoming threats. These laser platforms preserve high-cost SAM inventories (S-400, Akash Next Generation) for layered engagement of stealth aircraft or long-range munitions while reducing radar cross-section exposure through silent operation.

Naval Deployment in the Arabian Sea. The Indian Navy assets in the Arabian Sea operate under increased risk of saturation missile attacks, anti-ship drones, and swarming fast attack craft, particularly from adversaries using asymmetric littoral strategies. Integration of HEL systems aboard frontline vessels (Visakhapatnam-class, Nilgiri-class) provides non-depletable, omnidirectional defence capable of 360 degrees engagement without the thermal signature or reload downtime of conventional CIWS systems. HELs offer precision neutralisation of EO-guided threats and low-radar cross section drones without compromising stealth posture or radar bandwidth.

Non-Kinetic Roles. DEWs can serve in soft-kill configurations by blinding EO/IR sensors on ISR drones, disrupting laser designators, or degrading optical surveillance pods mounted on loitering munitions and aerial platforms. These silent, instantaneous energy strikes create tactical disorientation and impede targeting accuracy. Furthermore, their psychological impact—via invisible, noiseless kills—adds to the deterrence factor in hybrid warfare and irregular border conflicts.

Strategic Cost Benefit. During prolonged border skirmishes or limited wars, the financial burden of intercepting hundreds of drones with missiles costing in the range of INR 03-INR 10 cr becomes strategically unsustainable. DEWs capable of 80 to 90 per cent intercept rates at INR 1,000 per shot present a revolutionary cost-to-kill inversion. Their unlimited magazine, powered by electric grids or mobile energy cells, ensures long-duration deployment. With minimised collateral damage due to non-explosive neutralisation and a near-zero logistic footprint, DEWs represent a disruptive leap in India's defence doctrine against Pakistan's evolving threat vectors.

Operational Challenges along the Pakistan and Bangladesh Borders

Power Generation and Thermal Management Bottlenecks. Laser weapon systems require consistent, high-density power generation to sustain operational beam output. For tactical-grade systems like Sahastra Shakti Mk-II(A), mobile power packs suffice. However, upscaling to 100–300 kW class platforms (e.g., DURGA II, Surya) along extended border sectors pose a logistical and engineering challenge:

- Pakistan border (3,323 km) and Bangladesh border (4,096 km) span multiple terrains—deserts, marshes, riverine belts—where continuous energy supply and effective cooling systems are a challenge to deploy.

- High-output laser platforms demand closed-loop thermal dissipation units and reliable fuel-based generators or supercapacitor systems, which impair mobility in forward areas.

Atmospheric Propagation and Beam Attenuation. Operational environments along India's borders, from the icy heights of Ladakh to the humid riverine belts of Bengal, impose unique constraints on sustained DEW employment as under:

- Dust storms, fog, and snow affect beam coherence and accuracy.

- High humidity and rainfall introduce optical scattering, reducing effective range by up to 40–60 per cent, requiring beam shaping and adaptive optics, which are still under development along the Bangladesh Border (Assam, Meghalaya, Tripura).

Terrain-Based Deployment Constraints.

- In hilly regions like Kashmir and Nagaland, line-of-sight engagements are obstructed by undulating topography. DEWs rely on direct path exposure, therefore, deployment is confined to elevated terrain or ISR-assisted cueing from UAVs.

- Floodplains and riverine borders (e.g., West Bengal, Assam) have unstable soil and seasonal waterlogging, restricting platform mobility and static emplacement.

Command and Control Integration Over Diverse Theatres. Seamless laser integration demands high-bandwidth, real-time data fusion across multiple ISR and fire control systems. Current limitations include:

- Incomplete Akashteer network coverage in northeast sectors.

- Interoperability gaps between BSF, army, and air force surveillance platforms.

- Need for multi-domain fusion centres capable of synchronising satellite, UAV, and human intelligence inputs for laser cueing.

Manpower, Training, and Doctrine Gaps. Laser weapons require the development of new doctrinal frameworks, fundamentally distinct from those used for kinetic munitions. Unlike traditional missile-based systems that rely on flight-time intercepts, blast fragmentation, and magazine logistics, DEWs demand real-time C4ISR integration, adaptive energy management, and instantaneous fire control logic. This shift entails drafting theatre-specific ROE, environmental propagation protocols, prioritising power grid allocation in battlefield planning, and developing a multi-domain convergence doctrine to align with existing kinetic strike chains. Moreover, DEWs blur the lines between non-lethal deterrence and high-precision lethality, necessitating doctrinal evolution within India's operational art and joint service command structures. Current limitations include:

- Absence of standing operating procedures for ROE under DEW usage.
- Shortage of laser-trained technicians and command staff across regular army formations and Central Armed Paramilitary Forces.
- Need to establish a Tri-Service DEW Command and Training School to develop joint tactics, techniques, and procedures.

Vulnerability to Countermeasures. Adversaries may adopt reflective coatings, ablative surfaces, rotating modules, or smoke generators to reduce laser efficiency. Without robust real-time power modulation and beam tracking, DEWs risk reduced lethality under dynamic battlefield conditions.

Logistics and Maintenance Tail.

- Laser systems, especially mobile platforms, require delicate optics, beam directors, and thermal components that are sensitive to vibration, shock, and dust.
- Establishing forward repair depots and modular component replacement protocols across border command sectors is essential but still nascent.

Policy and Legal Ambiguities.

- There is currently no formal doctrine or legal framework governing use-of-force thresholds with DEWs.
- The Geneva Convention restricts the use of lasers for anti-personnel roles, necessitating a clear distinction between anti-material versus human target engagement.

Conclusion

India's DEW programs are no longer aspirational research and development efforts; they represent a foundational shift in the country's long-term strategic deterrence matrix. Unlike traditional weapon systems that rely on kinetic saturation or attrition warfare principles, DEWs signal the arrival of a 'Light-speed kill-chain doctrine' where rapid neutralisation, multi-target engagement, and minimal logistical dependency redefine the tempo of conflict response.

As adversaries recalibrate their threat models using low-cost drone swarms, standoff loiter munitions, and hybrid infiltration tactics, India's DEW deployment, if synchronised across services, will tilt the escalation ladder in its favour. The capacity to project precision lethality without ammunition fatigue, backed by indigenous production and reduced foreign dependency, allows India to shape the battlefield not just defensively, but psychologically and doctrinally.

Moreover, DEWs offer a dual utility—combat superiority and symbolic escalation control. Their silent, surgical, and near-invisible nature enables India to exert hard power without inviting disproportionate retaliation, making them ideal tools in a sub-conventional warfare environment where escalation management is as critical as target elimination.

Finally, the real success of India's laser programs will lie not merely in fielding hardware but in integrating them as cognitive nodes within a real-time ISR matrix—where AI, satellite feeds, and predictive threat analytics converge to trigger engagement. The weaponisation of light, thus, becomes not just a technological leap but a doctrinal inflection points in India's journey from reactive defence to pre-emptive area denial.

Endnotes

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