Raising HEL: The mirage of laser weapons

Directed Energy Systems (DES) seem perpetually poised to revolutionise warfare, but their adoption on the front line remains elusive, explains Robin Hughes

On the face of it, high energy laser (HEL) weapon systems offer undeniable and potentially revolutionary operational advantages as cost-effective applications that can deliver silent, near-instantaneous precision fluence, with scalable effects, at long range and against multiple/manoeuvring targets; reduced collateral damage and significantly lower cost per shot versus kinetic solutions; and, in the case of fibre lasers with access to a decent electric power source, a deep magazine.

Factor in a reduced logistics and re-supply burden, and the case for the laser weapon system (LWS) appears unassailable.

Internationally, HELs based on commercial technology could form the basis for indigenous defensive systems. Nations that have traditionally imported air defence and point systems are evaluating the extent to which HELs could be fielded without relying on traditional primes.

But the operational uptake of LWSs remains restrained and their promise largely realised - most notably exemplified by the heavily funded US megawatt-class Airborne Laser (ABL) and Space Based Laser Integrated Flight Experiment ballistic missile defence programmes during the 1990s/2000s.

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Enter LaWS

Yet HEL’s coming of age as a technologically mature battlefield engagement capability was heralded for many by the deployment and subsequent operational release of the 33 kW beam-superimposing fibre-based solid-state Laser Weapon System (LaWS): an initial weapon capability integrated on the US Navy (USN) Austin-class Afloat Forward Staging Base testbed USS Ponce in the Gulf in 2014.
LaWS integrates six commercial 5.4 kW fibre lasers with a beam combiner originated by the Naval Research Laboratory. To reduce costs, the programme has re-used hardware developed or procured for other research applications, including an L-3 Brashear KINETO K433 tracking mount, a 500 mm telescope, and high-performance infrared sensors.

"LaWS is an incredibly important development," said Steve Hixson, vice-president, Directed Energy, Northrop Grumman Aerospace Systems. "That is because a lot of the barriers to deployment that we in industry could not solve were solved by the deployment of LaWS into a war zone. There are various policies, predictive avoidance, and other issues which only the government can address and which they've solved on LaWS."

LaWS not only marks the first full deployment of an integrated LWS into an operational environment. It also highlights what is essentially a re-evaluation of the current optimal application of HEL weapons technologies and a move from standalone megawatt-class strategic 'speed-of-light defence' systems for addressing ballistic missile threats, to tactical kilowatt-class force multipliers, complementary to existing kinetic systems, for countering a burgeoning range of low-cost, high-volume threats.

"Laser technologies in the past have always looked at applications that have been the most difficult," Paul Shattuck, director, Lockheed Martin's Directed Energy Systems, told IHS Jane's. 

"What you see today is convergence of two elements: a requirement from the warfighter for tactical, short-range systems and a maturation of HEL technologies, especially fibre lasers and their efficiencies. So if you lay the requirement to defeat rockets, artillery, mortars, small unmanned aerial systems, small maritime attack craft - much easier target sets than previously envisaged for HELs - on top of these current
technology developments, you find that you now have capabilities within the state of laser technology that can engage those particular targets."

This tactical mission application has, in part, been precipitated by a general trend away from chemical laser systems - with their associated limitations in terms of SWaP/footprint, logistics (transportation, storage, and handling of hazardous materials), and their finite magazine capacity - to exploit advances in solid-state systems, including slab, semi-conductor and combined-fibre systems, which output less power but offer greater opportunities in modularity, mobility, and packaging.

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HEL weapons technology development - including in fibre lasers, laser diode fabrication methods, and beam measurement - has benefited from market drivers and significant risk reduction in the commercial sector. For example, the 10 kW fibre lasers used in Lockheed Martin's Aerial Defense Anti Munition (ADAM) system and the HEL effectors used by Rheinmetall and MBDA, among others, are all derived from the IPG Photonics commercial fibre laser.

In tests off the California coast, the Lockheed Martin ADAM laser system burned through the hull of a military-grade boat. (Lockheed Martin)
MBDA is exploiting COTS high-power fibre laser technologies. (MBDA)

LWS developers can exploit engineering advances, apply breakthroughs in industrial processes such as welding, cutting and marking, and leverage low-power applications such as sensing and communications. But for next-generation LWS applications that require a higher-power laser than is currently commercially available, developing operationally relevant HELs with the appropriate SWaP and thermal management collateral presents a clear challenge. Implicit in this is the ambition to evolve HEL weapons systems currently under development from principally defensive applications to potentially offensive LWSs.

The impetus in the West for deploying operational LWSs has mainly come from the United States, principally through significant, although increasingly diminishing, allocated funding and a series of jettisoned, ongoing, or future service-specific development programmes.

The US Air Force (USAF) and the Defense Advanced Research Projects Agency (DARPA) are developing a 150 kW High Energy Liquid Laser Area Defense System (HELLADS) for tactical aircraft to defend against and defeat ground threats. The US Army and Marine Corps (USMC) continue their respective efforts to develop High Energy Laser Mobile Demonstrator (HEL MD) and Ground-Based Air Defense directed-energy on-the-move systems.
Screen shot of the Warfighter Machine Interface (WMI) for the HEL MD, showing a laser locked onto a target UAV. (Boeing)

Model of US Navy Maritime Laser Demonstrator. (Northrop Grumman)
HEL in America

In March 2009, under the OSD’s High Energy Laser Joint Technology Office’s (HEL JTO’s) Joint High Power Solid State Laser (JHPSSL) programme, Northrop Grumman demonstrated the world’s first 100 kW (which actually measured 105 kW) slab-based solid-state LWS, using a modular 15 kW ‘building block’ architecture to achieve the required power output. ‘Slab laser’ refers to a class of high-power, solid-state lasers with a gain medium (the source of atoms that emit light) in the form of a slab about the size of a microscope slide.

Northrop Grumman’s JHPSSL solution leveraged earlier solid-state technologies from the late 1990s/early 2000s for its Extreme UltraViolet (EUV) programme (a commercial application to deliver smaller features on micro-electronics). In 2010 the US Army selected JHPSSL to be integrated with the beam control and command-and-control systems from a Northrop Grumman-built chemical laser system, the deuterium fluoride Tactical High Energy Laser (THEL), to provide the US Army with the world’s first high-power Solid State Laser Testbed Experiment (SSLTE). The SSLTE will evaluate the capability of a 100 kW-class solid-state laser and the results will provide the basis for directing future development of solid-state lasers as weapon systems.

The company has since sustained and evolved its slab-based solid-state laser development through fielding the MLD for the ONR in 2011 and through its Gamma company-funded demonstrator. First announced in 2012, Gamma is a single ‘chain’ or building block designed to be combined with other chains to create laser systems of greater power, as demonstrated in the JHPSSL. Northrop Grumman is believed to have bid a comparable system for the LWSD programme: a new ONR initiative, following on from LaWS and the later Solid State Laser Technology Maturation (SSL-TM) programme, to deploy a 100-150 kW solid-state laser weapon demonstrator using the power and cooling of the USS Paul Foster, a decommissioned Spruance-class destroyer that now serves as the USN’s Self Defense Test Ship at Port Hueneme, California.

Hixson confirmed that Northrop Grumman is part of, and "continues to execute" on, the Air Force Research Laboratory (AFRL)/DARPA Aero-Adaptive, Aero-Optic Beam Control (ABC) initiative. Primed by Lockheed Martin, ABC is a new aircraft-integrated beam-control turret being developed to provide 360° coverage for
HEL weapons integrated on next-generation transonic aircraft. Hixson declined to disclose further details on Northrop Grumman's participation in the programme.

Northrop Grumman has also embraced fibre-based solid-state lasers with coherent beam-combining technology (using several high-power laser beams to obtain a single beam with correspondingly higher power and preserved beam quality) for the 2010 Robust Electric Laser Initiative (RELI): a DoD programme to develop a compact operational 100 kW-class LWS for defensive applications in any DoD environment, moving or stationary, in air or on land or sea.

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Lockheed Martin has demonstrated the ability of its ATHENA laser weapon system to disable a small truck from a distance of more than a mile. The company intends to test ATHENA against a moving target in 2015. (Lockheed Martin)

Shattuck noted that funding from the US Army/HEL JTO to develop laser technologies for the RELI programme was instrumental to Lockheed Martin in the development of its spectral beam-combining technology. "We'd been working on that technology for about 12 years and RELI was helping to mature that. The reason they wanted to develop them is that it represents the next generation of lasers that roughly have twice the efficiency of the old slab solid-state lasers," he said.

"If you think about that for a second, if your laser device is twice as efficient, it means you only need half as much electrical power to put the same optical power out, and it also means that you are going to have half the amount of waste heat that you need to dissipate. What that allows you to do is package the system with a smaller electrical and thermal management system because that's really what starts to drive the size..."
of the overall laser weapon system. So that’s why the army and the HEL JTO wanted to invest in that technology; we chose to develop a 30 kW variant on our own funding so that we could continue to mature the technologies."

ATHENA successfully disabled the engine of a small truck at a range of more than a mile in an initial field test in March 2015.

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Shattuck said the next variant of the spectral beam combining laser to be integrated in ATHENA will be a 60 kW version to be delivered to the US Army for the joint Boeing/army HEL MD programme. Lockheed Martin was awarded a sole-source in February 2014 to design, test, and deliver a ruggedised 60 kW high-power fibre laser module for integration with the HEL MD platform by the end of 2016, ahead of an integrated demonstration and field testing planned by the army in 2017.

*The US Army’s High Energy Laser Mobile Demonstrator set up for demonstration in fog at Eglin Air Force Base, Florida. (Boeing)*

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*IHS Jane’s* understands that the contracting authority, Space and Missile Defence Command, is seeking to demonstrate a 100 kW HEL MD variant in the 2022 timeframe. Shattuck added that elements of the beam-control technology present in ATHENA will benefit the Aero-Adaptive ABC turret being tested by Lockheed Martin for AFRL/DARPA, "so the technologies we are developing are not just technologies designed for ground vehicles and ships, but also for airborne applications".

Boeing Defense, while not developing any laser or laser subsystem, specialises in integrating beam control fire-control laser weapon systems. As prime for the US Army’s HEL MD - a mobile solid-state LWS to counter rockets, artillery shells, mortars, and UAVs - Boeing has designed, tested, and integrated on an Oshkosh Heavy Expanded Mobility Tactical Truck a ruggedised beam control fire-control system, along with
other key HEL TD (Technology Demonstrator) components including, as an intermediate step ahead of Lockheed Martin's 60 kW spectral beam-combining laser, a 10 kW commercial fibre laser.

Although still classed as a prototype, during 2013 testing at White Sands Missile Range, New Mexico, HEL MD destroyed more than 70 mortars and an Outlaw UAV using the 10 kW laser. In testing at Eglin Air Force Base in 2014, HEL MD acquired, tracked, and targeted mortars and UAVs in a maritime environment.

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Gen 3 includes upgrades for improved beam quality - given as above the 50 kW level - increased electrical-to-optical efficiency, and further reduced size and weight. Powered by a compact Lithium-ion battery supply designed to demonstrate a deployable architecture for tactical platforms, Gen 3 is also a unit cell for GA-ASI's Tactical Laser Weapon Module (TLWM), currently under development. TLWM is designed for use on land, surface, maritime, and airborne platforms and will be available in four versions at the 50 kW, 75 kW, 150 kW, and 300 kW laser output levels. In the interim, GA-ASI is reportedly positioning Gen 3 as a future contender for a 120 kW HEL MD LWS requirement, testing for which is earmarked to begin in the early 2020s.

Raytheon is exploiting scalable planar waveguide laser technology to deliver a 30 kW LWS solution for the ONR's Ground Based Air Defense (GBAD) Directed Energy On-the-Move Future Naval Capabilities programme for the USMC. The programme calls for a field demonstration of a HMMWV-mounted short-range LWS with a minimum power output of 25 kW. Raytheon, along with BAE Systems and Northrop Grumman, was also selected to lead industry teams to develop the ONR’s SSL-TM designs, exploiting data gathered from the LaWS at-sea demonstration. SSL-TM currently appears to have been superseded by the ONR’s LWSD solicitation.

European HEL

In Europe, the most significant progress in LWS development has been in Germany, where Rheinmetall and MBDA Germany are pursuing separate HEL effector development paths, principally in land- and ship-based air-defence applications, although both are exploiting COTS high-power fibre laser technologies. Both efforts rely principally on IRAD funding, with access to some German government R&T funding. But the German government has yet to make public any end goal for this technology. There are no programmes of record, although industry insiders note the government is "very very interested in this technology".
MBDA Germany is pursuing HEL effector development paths, principally in land- and ship-based air-defence applications. (MBDA)

Rheinmetall has opted for a dual-track approach to LWS development, both based on modular laser technologies. In the near term it has focused its developmental efforts on beam-superimposing technology (BST), while evaluating spectral coupling technology as a longer term option.

Beginning in 2010, the company tested a 5 kW HEL demonstrator integrated with a MANTIS counter-rocket, artillery, mortar, and missile (C-Ramm) platform. By 2012 "we had demonstrated the integration of our fibre laser weapon system into different stationary air-defence platforms, where our modular concept of beam superimposition of several identical laser weapon modules [LWMs], each consisting of a 10 kW fibre laser coupled to a beam forming unit [BFU], proved to be reliable and effective against generic mortar targets, UAVs, and stationary structures; we demonstrated 50 kW power on the target with two laser weapon stages [3x10 kW, 2x10 kW] using our standard 10 kW laser weapon module in combination with our BST. With this modular approach we validated the scalability of our concept," Dr Marcus Jung, vice-president Directed Energy at Rheinmetall, told IHS Jane’s.

Rheinmetall has since focused its efforts on mobile and maritime applications of its BST LWM technology. In 2013 the company added three additional 10 kW LWS concepts to complement its existing 8x8 GTK Boxer armoured fighting vehicle (AFV0 - mobile LWS demonstrator; integrated with a remote weapon station coupled to a Rheinmetall RMG.50 heavy machine gun; integrated with an unmanned protected turret, and integrated with a fully automated MANTIS turret). Jung said that in 2014 the company increased the power output of its BFU from 10 kW to 20 kW, and subsequently conducted successful sea trials with a 20 kW BFU integrated with a Rheinmetall MLG 27 Naval Gun.

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MBDA conducted a series of proof-of-concept trials with the technology at its plant in Schrobenhausen between 2008 and 2010. In 2010, in the first of a series of trials at the Bundeswehr facilities at Oberjettenberg, the company tested its HEL system, using a single 10 kW laser source over a distance of 2.5 km; in 2011, it demonstrated the coupling of two 10 kW laser sources at distances "of more than 2 km",
and 2012, coupling 4x10 kW lasers, the company proved the full functional chain, from target acquisition to engagement of several airborne targets.

"In 2013 we conducted a series of successful trials in Schrobenhausen to prove our advanced tracking algorithms and the harmonisation of the aim point and the [4x10 kW] coupled laser beams against highly dynamic, fast-accelerating targets. The tracking system was evaluated by using a UAV model flying at 500 m to 1 km, and a rocket model launched 500 m from our LWS technology demonstrator. In both cases, we had fully automated target acquisition and fully automated re-acquisition of the target when the target was lost, for example due to obstacles in the line of sight," said Martinsetter.

He said that MBDA is "close to developing a deployable demonstrator. While there is currently no dedicated German government LWS programme, in 2013-14 we evaluated different concepts for our operational systems and we now are in ongoing discussions with the customer, which we hope will result in that demonstrator." In terms of an initial operating capability (IOC), Martinsetter said, "From a technical point of view, it is possible to get an IOC with a size of laser up to 50 kW within this decade. This might be possible from a technical point of view, but it depends on the funding."

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