High energy laser air defence weapons

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The reality of warfare is that it is evolutionary, for better or for worse. Periodically technological and tactical breakthroughs are achieved, and rapid changes ensue as operators scramble to match potential opponents' new capabilities. High Energy Lasers are now emerging as such a breakthrough, and as a result there is significant investment in developing deployable weapon systems based on this technology.

Laser weapons are attractive, as the potential 'cost per shot' is very low compared to the creeping costs of guided projectile munitions. The downside of laser weapons is that they cannot penetrate dense cloud or aerosols, and achieving long range presents serious technological complexities in penetrating the lower atmosphere.

Why Point Defence Lasers?

While the allure of laser weapons derives from the popular appeal of beam weapons, having been a feature of science fiction since the early 1900s, the pragmatic realities of speed-of-light effect and potentially cheap 'cost per shot' have proven a sufficient incentive for billions to be invested in weaponising this technology. The most prominent development programs are in the United States and China, with the Russian effort muted after the significant progress made during the last years of the Cold War.

The current focus in laser weapons development is twofold: the first category being very large multi-MegaWatt weapons intended to attack ballistic missiles during the boost phase or low orbiting satellites, and the second being short range point air defence weapons with output ratings of up to hundreds of kilowatts.

In operational terms, the focus in much of the current effort has been on weapons designed to provide terminal defence against projectiles such as artillery rockets, artillery and mortar rounds, termed a "Counter-RAM" or C-RAM weapon, smart bombs and cruise missiles.

The principal limitations of all laser weapons is a need for a clear line of sight to the incoming target, which makes such weapons problematic under conditions where the target is obscured by cloud, fog, haze, sandstorms or other impairments. This limitation will never be overcome due to basic physics, and no matter how effective the laser weapon might be in clear air, it can never be a panacea air defence solution.

All laser weapons comprise several key functional components. The first of the chain is the optical beam director, which in point defence weapons mostly resembles a searchlight in appearance. Its purpose is to focus and point the beam at the target. It is aimed using typically a combination of a radar cueing sensor, and an optical and/or infrared precision tracking system. Much of the cost in a laser weapon is in these three components. Where long range or very high power output are important, the weapon may have to employ adaptive optics to compensate for atmospheric turbulence, thermally dissimilar air pockets, and beam induced blooming via air heating. Adaptive optics add much cost via a multisegmented flexible mirror in the main optical path, a Hartmann-Shack wavefront sensor, and a highly stable and coherent low power illuminator laser coupled into the main optical path.

The US Army THEL demonstrator proved the viability of the C-RAM role.

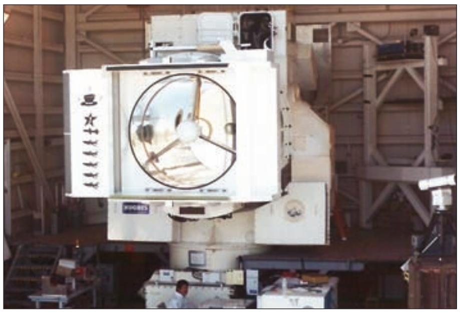
While the optical subsystem is major cost component, the laser and its power supply can also be expensive.

Two technologies are dominant today in demonstrators and prototypes. Chemical and gasdynamic lasers are fuelled by a mix of gaseous chemicals, which generate the laser power when expanded rapidly in a supersonic nozzle, the power being extracted from the beam using an optical resonator. The principal limitation in such designs is the volume and weight of the laser, and potentially expensive and toxic or corrosive fuels and exhaust products. The most popular technologies are the Carbon Dioxide Gas Dynamic Laser (CO2 GDL), the Chemical Oxygen Iodine Laser (COIL) and the Deuterium Floride Laser (DF).

More recent arrivals are forms of laser 'diode pumped' laser, where the laser medium is pumped (excited) by using large arrays of electrically powered solid state semiconductor diodes. These arrays may employ up to hundreds of thousands of laser diodes. The latter are the same category of mass production technology components used in CD-ROM drives, DVD players, and communications equipment, but optimized for much higher power output and efficiency. This is essentially a scaled up equivalent to the laser dioded pumped 1.55 micron eyesafe rangefinding lasers now in use.

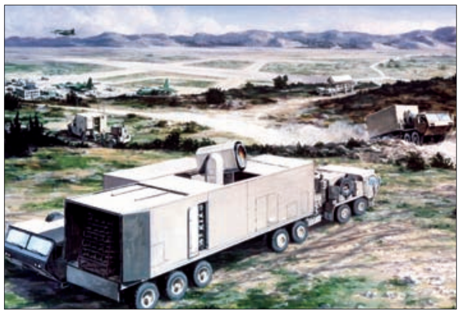
The attraction of diode pumped lasers is that they are electrically powered, which means a diesel or kerosene driven generator can sustain them as long as the fuel tank is not empty, and the cost per shot in terms of fuel burn is trivial.

The downside of diode pumped lasers is that cooling of the array and the laser medium remains itself a problem which is not yet adequately solved. A truly effective cooling system will allow such a laser to run continuously, a not so effective system will permit a shot lasting some seconds, followed by many seconds of "cool down" time during which heat is dumped from the laser until it is ready for another shot. A less obvious drawback of the latter compromise is that the laser will be exposed to repeated thermal cycling (heating and cooling),



The THEL made extensive use of technology developed in the US Bavy Sealite beam director program.

Elta acquisition and tracking radar for the THEL. The radar is used to cue the precision optical tracker on the beam director.



Northrop-Grumman's proposed Mobile THEL (MTHEL). It is unlikely to be funded given recent progress on electrically powered lasers.

which impairs the reliability of all electronic hardware, especially hardware with possibly hundreds of thousands of electrical connections. Conversion efficiency from electrical power to optical output for these systems is typically of the order of 10 per cent, which means that 90 per cent of the electrical power put into the laser is converted into waste heat, which needs to be removed. The individual laser diodes are also not very powerful, typically emitting around one Watt each. A laser rated at 25 kW with a 10 per cent conversion efficiency would require 250,000 diodes. At $10 per diode, this results in a multimillion dollar investment in lasers alone.

The Tactical High Energy Laser (THEL)

The THEL is a laser weapon jointly developed by the US and Israel, with the program initiated in 1996. The THEL was to be built in two configurations, the static baseline THEL and relocatable Mobile THEL (MTHEL).

The design aim of the THEL systems was to provide a point defence weapon which is capable of engaging and destroying artillery rockets (Katyushas), artillery shells, mortar rounds and low flying aircraft.

The THEL demonstrator was trialled repeatedly between 2000 and 2004, destroying 28 122 mm and 160 mm Katyusha rockets, multiple artillery shells, and mortar rounds, including a salvo attack by mortar.

The demonstrator THEL system was built around a DF chemical laser operating at 3.8 microns wavelength. A complex exhaust diffusion and pressure equalisation system must be used, including a neutralisation stage to soak up the highly corrosive and toxic DF exhaust efflux gas. The THEL exploited earlier US Navy effort on the MIRACL DF laser and Sealite beam director.

The THEL program yielded excellent trial results, using an Israeli phased array radar to track incoming targets and direct the beam. The sheer bulk of the demonstrator made it impractical for operational deployment, leading to the proposed second generation MTHEL system. MTHEL was to initially have been in three semi-trailers, but more recently appears to have been repackaged into a single container sized semi-trailer. A prototype was intended to be deployed by 2007, but more recent reports indicate funding difficulties and thus uncertainties in timelines. The THEL/MTHEL system was developed by a team including TRW/Northrop-Grumman, Ball Aerospace, Elbit/El-Op, IAI/Elta who developed the radar and fire control system, RAFAEL and Tadiran.

In operational terms, a key limitation of this design lies in the expensive and toxic exotic fuel mix. At several thousand dollars per shot in fuel expenditure, the Deuterium Fluoride laser is problematic for a system to be deployed en masse with a land force. At the time of writing funding had been stopped for this effort, the focus shifting to electrically pumped solid state laser technology. The program remains an important technology benchmark as it was the first demonstration in this application, and performed well, proving the viability of laser weapons for air defence.

High Energy Laser Technology Demonstrator

The High Energy Laser Technology Demonstrator (HEL TD) is a follow on effort to the THEL by the US Army, to demonstrate a mobile multi-hundred kiloWatt class laser using solid state laser technology. The budget justification for the effort, running until 2013, is thus:

"The major effort under this program element is the development of a multi-hundred kilowatt (kW) Solid State Laser (SSL) laboratory demonstrator that can be integrated into a HEL weapon system to provide increased ground platform-based lethality. HEL systems have the potential to address the following identified Army capability gaps: 1) Defeat In-Flight Projectiles such as rockets, artillery, mortars, anti-tank guided missiles, and man-portable surface-to-air missiles; 2) Ultra-Precision Strike with little to no collateral damage; 3) Disruption of Electro-Optical (EO) and Infra-Red (IR) sensors; and 4) Neutralizing mines and other ordnance from a stand-off distance."

Northrop-Grumman and Boeing were contracted for Phase I of this effort. Boeing were contracted August, 2008, to integrate a beam control subsystem on a Heavy Expanded Mobility Tactical Truck (HEMTT) under Phase II.

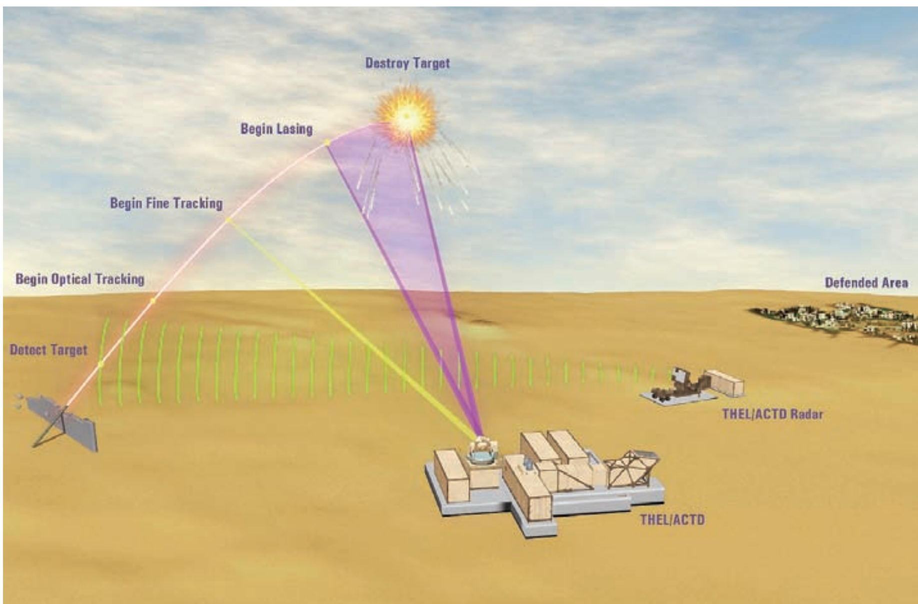
Army Joint High Power Solid State Laser

The JHPSSL effort is intended to develop a family of electrically powered high power solid state lasers suitable for 100 kiloWatt class weapons applications, primarily for land and sea based point defence systems, but also airborne applications.

The program was defined in multiple phases. Phase I involved demonstration of laser power modules, Phase II the ability to scale the design beyond 25 kiloWatts, and Phase III the ability to scale the design beyond 100 kiloWatts. The aim is to produce power modules which can be ganged together to produce a combined 100 kiloWatt class weapon.

Northrop Grumman demonstrated early 2008 a 15.3 kiloWatt laser module for this program. Textron systems were contracted to produce a competing JHPSSL design, using proprietary ThinZag laser ceramic Neodymium doped Yttrium-Aluminum-Garnet (Nd:YAG) slab technology.

US industry sources cite targets including 200 seconds of continuous operation, 15 per cent total power conversion efficiency, thus requiring 700 – 800 kiloWatts (~ 1000 SHP) of electrical power to drive a 100 kiloWatt weapon, and the whole 100 kiloWatt weapon fitting into a cubic metre volume.



Concept of operations for the THEL demonstrator.

DARPA High Energy Liquid Laser Area Defense System

The High Energy Liquid Laser Area Defense System (HELLADS) effort was launched following a research breakthrough by DARPA in 2003, with a budget of around US$75M. Running in parallel with the Army led JHPSSL effort, its aims were described by the US DoD thus:

'The goal of the High Energy Liquid Laser Area Defense System (HELLADS) program is to develop a high-energy laser weapon system (~150 kW) with an order of magnitude reduction in weight compared to existing laser systems. With a weight goal of less than 5 kg/kW, HELLADS will enable high-energy lasers (HELs) to be integrated onto tactical aircraft."

"An objective system laser module with integrated power and thermal management will be fabricated and demonstrated at an output power of 15 kW. Based on the results of this demonstration, additional laser modules will be developed and integrated with a beam control subsystem to produce a 150 kW laser weapon system demonstrator."

In practical terms, HELLADS is to produce a 750 kg laser capable of producing 150 kiloWatts of power, compact enough to be carried by aircraft, ground vehicles and UAVs. The technology is a liquid laser, where the lasing medium is a fluid containing the active chemical species pumped for laser action. No details of the design concept have been released so far, but it is reasonable to speculate that the liquid is actively cooled thus avoiding the problems inherent in solid state lasers. The pump mechanism has not been disclosed. If pumping is performed using laser diodes, it is reasonable to speculate that the liquid also cools the pump lasers. General Atomics is the prime contractor, with Lockheed-Martin providing integration. HELLADS will like the ABL use a wavefront sensor and active mirror technology for beam wavefront correction.

High Power Fibre Laser (HPFL) - Optical Fibre Lasers

Doped optical fibre lasers are a recent technological development, devised to provide low noise amplification for long haul submarine optical fibre communications systems, replacing conventional electronic repeaters. The technology is currently being developed for weapons applications by Raytheon, following a demonstration conducted with the AFRL and Sandia in June, 2006.

The technology is based on the idea of doping a span of optical fibre with suitable material, and then pumping this length with an external laser of a suitable shorter wavelength than the lasing mode of dopant material. Photons entering one end of the fibre are multiplied by laser action as they travel along the fibre.

DARPA funded experiments performed post 2000 demonstrated that the technology was feasible and in 2003 a single fibre single mode fibre laser delivered an output power of 1 kiloWatt, putting the technology into the domain of viable weapons. Pump efficiency in such lasers has been as high as 80%, as a result of which only 20 per cent of optical power fed into the fibre needs to be removed as waste heat.

US research aims to produce power outputs of the order of 100 kiloWatts or more. To achieve this, power per fibre must be increased, and optical hardware to combine the ouput of multiple HPFLs is required. Effective cooling of pump lasers and the HPFL spools is also required.

Raytheon's LADS demonstrator uses technology from the Phalanx CIWS and an electrically powered high power optical fibre laser.

Raytheon's Laser Area Defense System (LADS) is intended to provide a short range point defence weapon as a replacement for the Phalanx CIWS, utilising existing Phalanx hardware and systems. Cite: "The LADS unit consisted of an Air Force Research Laboratory (AFRL) 20-kilowatt IPG Photonics fiber laser and a bench-mounted beam director secured to the top of a Phalanx mount. AFRL testing verified the ability to propagate the laser beam and achieve the desired effect for a 60 mm mortar in a real-world environment. This series of tests was analyzed by AFRLs Directed Energy Directorate, which substantiated predictions that a mortar could be destroyed at ranges greater than 550 meters."

China's Laser Weapons Program

There is an abundance of material in various publications, especially web based, claiming a well developed and advanced High Energy Laser Directed Weapons program funded by the PLA. Unfortunately, much of this material lacks supporting evidence, and there are to date no unclassified images of PLA HEL DEW components, such as beam directors and laser power stages.

What can be tracked readily in the unclassified domain is research effort, via publications in Chinese language academic research journals. These publications provide some insight into the level of advancement in Chinese indigenous research into the basic physics and technology required to construct laser weapons.

A survey of unclassified journal publications in relevant technologies is revealing, and shows that China does indeed have a major research program under way.

What is evident from such a survey is that the PLA has the basic technology and research capabilities to design and build credible laser weapons. What cannot be assessed so easily is progress on the integration of these technologies to produce operationally viable weapons. However, a viable end product is only a matter of time and effort.

A 1999 paper authored by US Army researcher Mark Stokes is cited with a claim that over "10,000 personnel -- including 3,000 engineers in 300 scientific research organizations -- with nearly 40 per cent of China's laser research and development (R & D) devoted to military applications".

US Army concept illustration for a deployed JHPSSL laser weapon.

Boeing CONOPS illustration for the HEL TD system, used in the "C-RAM" role against rockets, artillery and mortars.

Other public claims include the development of Deuterium Fluoride and Free Electron lasers (THEL/MIRACL), and a cruise missile defence capability based on laser weapons.

The 2006 US DoD annual report to Congress on PLA modernisation also details a major effort in laser and RF directed energy weapons. In evidence to Congress last year, the US DoD also detailed the use of a laser weapon to blind a low orbit US reconnaissance satellite. US sources have claimed that China made use of Russian expertise to advance their laser weapons effort, Russia's program being stalled since the end of the Cold War due to funding starvation.

In summary, until the PLA unveils its first generation of weapons to global scrutiny, detailed assessments of capability will continue to be at best speculative. However, the PLA will be a major player and we can expect point defence applications such as counter-PGM and counter-cruise missile systems to be the first to emerge, as the power, beam quality and pointing requirements are the least challenging.