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Directed Energy Weapons part 2

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Airborne Laser

The AL-1A Airborne Laser (ABL) is without doubt the flagship of the US High Energy Laser weapons effort. The aim of the ABL program is to produce an operational weapon system capable of engaging and destroying ballistic missiles during the boost phase of their trajectory when they are most easily detected and most vulnerable to attack.

During the boost phase, ballistic missiles are heavily stressed with structural loads, and full of highly combustible propellants under pressure. Even modest damage to the skin of the vehicle results in a catastrophic breakup akin to the many explosive booster failures observed over the years.

In a crisis the ABL systems would be deployed to the borders of a nation that is threatening a ballistic missile attack, candidates now being Iran and the DPRK. Orbiting at the tropopause, the ABL would detect, track, and attack ballistic missiles once they clear the cloudbase, with the debris falling back on the nation that launched the weapon, the latter a critical consideration for WMD payloads. A design objective for the ABL is to carry enough fuel to destroy 20-40 missiles during a 12 to 18 hour sortie. Other roles canvassed for the ABL include attacks on low orbit reconnaissance satellites.

The airframe used to carry the ABL system is the YAL-1A, which is a modified Boeing 747-400F freighter. This is a robust and mature 100 tonne payload class airframe, with a main deck which is comparable to the C-5 Galaxy in payload and capacity.

In an operational environment the AL-1A would be positioned into an orbit near enough to cover the territory of interest and loiter awaiting target tracks. Surveillance systems such as orbital early warning satellites, AEW&C equipped with suitable radar, and UAVs would detect the initial launch of the missiles, relaying this data via Link-16 to the AL-1A. Once the ABL system is cued, if required, the aircraft would turn to face the threat sector to afford the best possible field of regard for the laser weapon.

As the ballistic missiles break through the overcast their enormous heat signatures would be detected by the LANTIRN sensor and coarse tracking initiated. The BMS would attempt to establish missile trajectories as early as possible to determine priority for engagement. While the US Air Force has not disclosed how they intend to do this, it is reasonable to speculate that the value of the target and the distance of the missile would both be factors in the beam scheduling algorithm. Not unlike phased array radars used for missile defence, there is a finite time window to attack each target and a finite amount of laser time available within this window. Therefore, judicious scheduling of laser use is essential to provide opportunities for reattack if needed. More distant targets will require that the laser 'dwell' on the target much longer to achieve effect, compared to nearer targets.

Once a coarse track for a specific missile has been established and the laser scheduled to shoot, the turret is slewed to point at the target and the TIL illuminator is lit up to initiate fine tracking. Once the fine track is established, the BIL beacon is lit up to generate continuous data on atmospheric distortion along the beam path. With the BIL operating, the COIL laser is engaged and a multi-MegaWatt beam of 1.315 micron infrared radiation is put on to the target. In a viable engagement scenario, this would lead within seconds to the breakup of the target missile. Once this has happened, the system is cued to the second highest priority target and a similar engagement sequence initiated. This would continue until laser fuel is exhausted or the remaining targets either killed or out of reach.

AL-1A Airborne Laser in flight.

Defences against the ABL

Given the signature size of a ballistic missile, detection and tracking is unavoidable once the missile clears any cloud. At that point the only defence lies in improving the missile's resistance to laser attack.

Years ago a physicist remarked to this author that this was 'simple, you cover the missile with a mirror coating to reflect the laser'. This is of course is easier said than done since any dirt, dust, moisture droplets, ice particles or other material on the surface of even a perfect mirror will vaporise and the superheated plasma will eat into the surface, destroying its reflectivity. At best mirror surfaces increase required laser dwell time to destroy the target.

Another strategy proposed has been to impart a rotation to the missile, effectively causing it to spin around its longitudinal axis to minimise local exposure time to the laser, the idea being that through the remainder of each rotation the skin would cool. But this strategy also at best delays the inevitable, and could at best increase required dwell time.

A third strategy proposed has been the use of ablative surface coatings, which would evaporate and so both cool the surface and block the beam in a layer of superheated vapour. A variation on this theme is the use of highly heat resistant skin materials. Both these strategies would significantly add to the cost and weight of a missile, impacting deployable numbers and useful warhead size.

A fourth strategy proposed has been the use of higher rocket thrust per payload so the missile climbs out of the atmosphere in a much shorter time, thus reducing firing opportunities for the laser. If the missile can complete its boost phase in half the time, the time available for attack is halved, which during a massed launch would allow some fraction of missiles to get past the laser. As with the preceding strategy, cost/numbers become a major issue since a much bigger missile first and second stage is required for the same payload.

Assuming a player develops a fast burn, spinning ballistic missile with an ablative coating, covered by a mirror coating, what it means is that more ABL platforms will need to patrol a given area to ensure that the increased dwell time does not allow any missiles to escape. The attacker would have to spend a lot more on missiles. As is the case with all missile defence technologies, the ABL drives up the cost of mounting a successful missile attack, to the point where it may not be economically viable. Suffice to say the intensive interest of China and Iran in cruise missiles indicates that the ABL, and ground based interceptor missiles, are already having impact well before they have even achieved full operational capability.

The ABL program has been controversial, to say the least. As it is directly competing for funds with capabilities such as interceptor missiles – be they silo, warship or air launched – there is an added element to the controversy, as all players attempt to maximise their slice of the budgetary pie.

The COIL laser achieved 'First Light' in November 2004, with an initial test run. Significant integration and testing remains before the system will be viable for operational use. This February, the buy of five production airframes was put on hold until such time as the capabilities of the prototype could be proven. Current planning envisages a trial shot against a target ballistic missile in late 2008.

Recent US reports indicate that many problems remain to be resolved. One is that of atmospheric dust particles in the main beam, termed 'fireflies'. Given the intensity of the beam, dust particles vaporise and the plasma exacerbates local turbulence and soaks up energy from the beam, reducing effective range, but also potentially interfering with the fine tracking function, which relies on infrared reflections off the target.

There has been considerable speculation on the use of the ABL for other roles, excluding the previously mentioned ASAT role. One idea has been to use the ABL to attack cruise missiles. If these are high-flying supersonic weapons like the Kh-22 Burya/Kitchen fly a relatively flat trajectory then the ABL will be highly effective. If they are low flying cruise missiles in the class of the Tomahawk or ALCM then effectiveness is apt to be poor. The same is true of low flying aircraft targets or surface targets. The reality is that the troposphere, below 36,000 ft, is a poor propagation environment with a lot of water vapour and dust particles, or water droplets in cloud. The tropospheric 'soup' absorbs and dissipates the energy in the laser beam a lot faster than the dry/cold/thin stratosphere does. Physics are physics and cannot be easily beaten. The result will be very poor effective range, and an unusuable weapon if any cloud gets between the laser and the target. Much the same constraints apply if the target is an aircraft. A high-flying UAV, reconnaissance aircraft or even hypersonic vehicle is vulnerable to the ABL. A low flying aircraft is not.

In perspective, the AL-1A ABL is a revolutionary weapon which once mature will render ineffective arsenals of short, intermediate and intercontinental ballistic missiles, and high flying aircraft and cruise missiles, where conditions permit the ABL to operate within lethal range of the target. How soon the ABL matures to operationally viable system remains to be seen.

A laser fires from space toward Earth in this artistic rendering. The Air Force Research Laboratory's Directed Energy Directorate is conducting research in a wide variety of laser technologies for ground-, air- and space-based applications. (AFRL)

Speed-of-light weapons on the battlefield. Conceptual look at putting a solid-state laser on an armored ground combat vehicle for potential use in the U.S. military's Future Combat Systems program. (Northrop Grumman)

tech ops

YAL-1A ABL Tech Specs

The YAL-1A ABL will be the first large laser weapon to become operational. Its purpose is to destroy ballistic missiles during the boost phase (Boeing).

The most notable external feature of the AL-1A is the nose mounted optical turret for the laser's primary mirror. The turret has a +/- 120 degree field of regard in azimuth and is used to point the 1.6 metre primary laser mirror, produced by Corning Glass and Contraves. The roll shell is constructed from composite materials. When the laser is not in use, the 1.8 metre 150 kg window, built by Heraeus/Corning/Contraves, is rotated into a stowed position to protect the optical surface from abrasion by atmospheric dust particles, and birdstrike damage.

The main deck forward of the wing is separated from the aft main deck, which houses the laser system, by a full height bulkhead. The forward fuselage section houses the Battle Management system and the Beam Control Subsystem.

The Battle Management System (BMS) comprises computers, which manage the weapon system, the operator consoles for the weapon system, and supporting communications. Built around open systems COTS hardware and software, the system is the nerve centre of the ABL. It performs the identification, tracking, prioritisation and nomination of targets, and controls the engagement.

To do this, the battle management system relies on offboard sensors and an onboard infrared tracking and rangefinding sensor. The latter is a derivative of the legacy LANTIRN targeting pod, using the existing longwave FLIR sensor to track the missile and a new carbon dioxide 10.6 micron band rangefinding laser and sensor to supplement angle track data with accurate range. The intent is to produce an accurate trajectory projection for the target missile to facilitate prioritising targets for attack. The sensor is mounted in a dorsal pod carried on a short pylon.

The third subsystem in the forward fuselage is the Beam Control System (BCS). This is the critical component that ensures that the laser's power can be effectively delivered to the target. The BCS comprises: the wavefront sensor and control system for beam distortion control, the systems for beam jitter control, beam alignment and beam 'walk' control, calibration hardware, and target acquisition and tracking equipment. The deformable mirror has 341 actuators that update the shape of the mirror at 1,000 Hz frequency, which means only 1/1000 sec is required not only to measure the distortion but also to calculate and control the mirror actuator.

The lower forward cargo hold is retained to carry equipment required to support deployments.

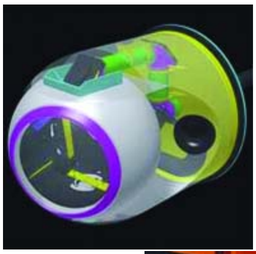
The aft main deck area carries the HEL subsystem and supporting hardware. Immediately aft of the wing are the two supporting lasers, built by Raytheon and Northrop-Grumman. These are the Tracking Illuminator Laser (TIL) and Beacon Illuminator Laser (BIL), both diode pumped solid-state devices. The TIL is used to illuminate the target to facilitate fine tracking, while the BIL is used to measure atmospheric distortion to compensate beam wavefront shape, via the wavefront sensor.

Aft of these are the main laser power stages, using 1.315 micron band COIL technology. Plastics, composites and titanium are used extensively to save structural weight. Despite this, each of the six laser modules weigh around 1.5 tonnes. Each of the modules vents exhaust efflux via six ventral exhaust ducts and ports (see photo).

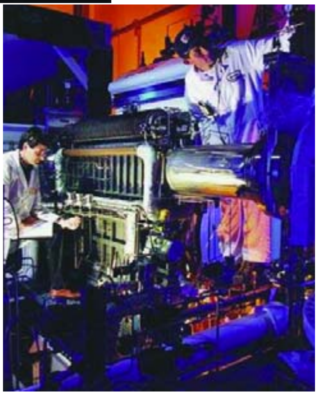
The laser stages are complex. The gaseous atomic oxygen fuel for the COIL is produced in a reactor which mixes Helium, He, hydrogen peroxide liquid, H_2O_2, and potassium hydroxide, KOH, producing waste heat and potassium chloride (KCl). The hydrogen peroxide is recycled in a closed loop system until it has been exhausted. US sources claim that 1,200 USG of propellant is to be carried. The atomic oxygen produced is then mixed with gaseous iodine, to produce the excited iodine required for laser operation. The gaseous mix is then flowed through a supersonic expansion nozzle, which also acts as the laser cavity.

The high power beam is flowed through all six laser stages gaining power with each stage, for an aggregate output of the order of a Megawatt of continuous wave power. The full power beam is directed via a system of mirrors to the beam control subsystem and then the optical turret in the nose.

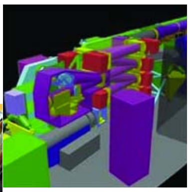
ABL Cutaway.



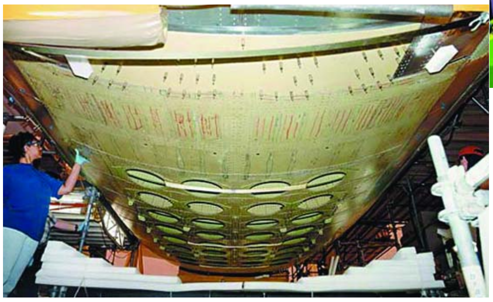
COIL Turret Assembly.



A single stage of the COIL laser.



Beam Control Subsystem.



Ventral aft fuselage exhaust ports for the COIL laser.