An Assessment of the Airborne Laser

Tao B. Schardl

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1 Overview

The Airborne Laser (ABL) is a project under the United States Air Force to design an aircraft that would be capable of destroying theater ballistic missiles (TBMs) during their boost phase. This system would utilize a megawatt class laser to heat and puncture a hole in the side of a ballistic missile, causing the missile to break apart and fall back to the ground. Since this aircraft would be used to destroy TBMs during their boost phase it would have the distinct advantage over other missile defense systems, both because the TBM would be unable to fool the system with decoys or other such techniques, and the warhead would fall back to the ground over enemy rather than friendly territory. Additionally, the use of a laser as the main weapon in this system would potentially enable the development of other laser-based weapons systems, such as the Advanced Tactical Laser.

2 History

The ABL finds its roots in an Air Force project known as the Airborne Laser Laboratory (ALL). This project, conducted in the 1970's and 1980's, involved fitting a CO_2 laser onto a modified KC-135A. The AirForce used this aircraft in an 11-year experiment to prove that a high-energy laser could be operated in an aircraft and employed against airborne targets.[5] At the end of this experiment, between 1983 and 1984 this aircraft demonstrated its ability to disable or destroy five AIM-9 Sidewinder air-to-air missiles and a Navy BQM-34A target drone.[3]

Although the ALL did not target ballistic missiles, the success of the ALL caused the Air Force and Defense Departments to consider and pursue the possibility of using high-powered lasers aboard an aircraft to destroy enemy ballistic missiles during their boost phase.[4] Meanwhile, in 1977 the Air Force Weapons Laboratory invented the COIL, and through the 1980's and 1990's improved its efficiency and power output into the multi-kilowatt range.[1]

Additionally, adaptive optics systems were developed and implemented for use in telescopes to counter the affects of atmospheric distortion.

As a result of these advances in technology and the growing interest for an anti-ballistic missile laser system on an aircraft, The ABL program was begun in November 1996, when the Air Force was awarded a $1.1 billion Program Definition Risk Reduction phase contract.[4] Pentagon officials then proceeded with the conditional development of the Airborne Laser in June, 1998.[4] The original design sought to modify a Boeing 747-400 freighter to carry 14 COIL laser modules and utilize an adaptive optics system to deliver a megawatt infrared laser to a ballistic missile target.[10] The three main contracting companies chosen were Boeing Integrated Defense Systems, for overall program management, system integration, development of the ABL battle management system, modifying the 747 aircraft, and designing and developing ground support subsystems; Lockheed Martin Space Systems, for the design, development, and production of the target acquisition, beam control, and fire control systems; and Northrop Grumman Space Technology, for the design, development, and production of the ABL high-energy laser.[4]

The program has undergone a number of changes since its beginning. In October 2001 the program was moved under the Missile Defense Agency, and in January 2002 dropped their traditional requirements-setting process in favor of a "capabilities-based" approach.[4] The technical challenges involved in the program at this point were significant; in 1997 the GAO issued a report highlighting the program's technical challenges and calling them "significant," while in 2001 the DOT&E called the ABL a "high technical risk" program.[4] The GAO asserts that "problems with maturing technology have consistently been a source of cost and schedule growth throughout the life of the program," however more recent changes to the program have improved its development.

Since the time these assessments were made ABL adopted a new requirements setting process, focusing on developing a less sophisticated system based on currently available technology. In February 2004 the program experienced some adjustments to put it back on budget and schedule, and subsequently GAO found that these changes would result in a knowledge-based approach that should result in a more cost-effective program.[4] Since then ABL has seen a significant increase in the testing of individual systems and their integration,[4] and more recent GAO reports place the key ABL technologies at a nearly mature level.[6]

3 Description of Technologies

3.1 COIL

One major problem with ABLs predecessor aircraft concerned its laser. The CO_2 laser it used required a lot of power to operate and did not yeild enough power to be effective at extended ranges.[3] Unlike it's historical counterpart, the ABL will use an efficient chemical oxygen iodine laser (COIL) as its main weapon. This laser is designed to utilize a chemical reaction to efficiently generate a megawatt infrared laser that is capable of destroying targets at a range of approximately 400 km.[4]

The lasing action of this laser comes from the transfer of energy from singlet delta oxygen molecules - O_2 molecules excited to a greater energy state than that of a stable O_3 molecule - to iodine, which releases this energy in the form of light at 1.315 microns. The energy transfer from these singlet oxygens to iodine is in nearly resonant, so after some of the oxygen dissociates the molecular iodine, the rest efficiently excites the resultant atomic iodine for this electronic transition.[1] The gas of excited iodine is then accelerated to a supersonic velocity to create a laser gain region, and once the electronic transition occurs in the iodine the light is extracted with a laser cavity positioned transverse to the gas flow, while the residual iodine is released as exhaust and scrubbed.[1]

This lasing action is appealing to the ABL for a couple reasons. First, the generation of photons from this electronic transition in iodine is highly efficient and can yeild very high powers, in the multi-kilowatt to megawatt range. Second, the 1.315 micron wavelength couples highly with most common metals, allowing for efficient energy transfer from such a laser to the metallic casing of a missile. Since a high powered laser that is also highly efficient is necessary for ABL's task, this lasing action is particularly attractive to ABL.[9]

One additional concern that a COIL must address is the source of singlet delta oxygens necessary for lasing. The COIL on the ABL does this through a chemical reaction between chlorine gas and hydrogen peroxide. This reaction generates singlet oxygens with an efficiency of 70%, which is significantly better than other means of singlet oxygen generation, such as through electrical excitation. This reaction does generate additional byproducts which are also removed or scrubbed away, including water vapor and chlorine.[1]

The use of the COIL does pose technical challenges to the ABL. One major concern with the COIL is its extensive use of toxic chemicals. These chemicals will need to be stored on the aircraft during flight, putting the crew and the aircraft at risk. Another concern is the containment of the laser in the plane. The aircraft had to undergo extensive changes to improve its structure to support the laser inside.[2] Additionally, the laser is made up of several modules that work together to generate a single beam. While the original system proposed called for 14 modules, the heavy weight of each module has restricts the use of more than 6 modules in the plane. In fact, 6 modules is over the original weight budget by at least 5000 lbs, but proponents argue that they are still within the weight the aircraft should be able to handle.[4]

3.2 Beam Control, Fire Control, Battle Management

To make the high powered laser on the complete ABL prototype useful, the ABL has a complex system for locating targets, tracking a target, adjusting the optical mirrors for the kill laser, and engaging that target. This system is composed of a series of lasers for fullfilling each task, and a battle management software to direct the actions of these lasers in a proper sequence.

Location and tracking of targets is done with a combination of an infrared sensor and a solid-state laser. The location of targets is done via an infrared targeting sensor, which looks for the hot exhaust from a ballistic missile taking off in order to locate potential targets and "passively tracks" a missile by this exhaust plume. Once this sensor has identified a target, the ABL fires a track illuminator laser (TILL) to track the target, and returns target tracking data to the ABL's battle management system. The TILL "actively tracks" a target by walking the laser from the exhaust plume to the nose of the missile in order to determine where to fire the high-powered laser.[2]

Once this tracking and targeting data has been obtained, the battle management system fires another low-power laser at the target to gather more data. This laser is known as the beacon illuminator laser (BILL) and is used to gather atmospheric data for the adaptive optics system. The battle management software then uses this data to actively adjust any mirrors in the main laser path to maximize the power transferred via the high-power laser. Since high-powered lasers are especially susceptible to scattering and distortion effects from the atmosphere, this data and the adaptive optics system are crucial for maintaining the effectiveness of the high-powered laser.[2]

To complete the testing of these low-powered systems, Boeing installed a surrogate high-energy laser (SHEL) for the system to use as the main firing laser. This allowed the battle management software to actively engage a target once all necessary data had been obtained from the rest of the beam control/fire control system without destroying the target. In the final prototye of the ABL, this laser will be replaced by the COIL, which will have sufficient energy, if all goes well, to destroy a ballistic missile target.[2]

The concurrent operation of all of these lasers posed a significant challange to ABL. The necessity for the TILL to follow the ballistic missile from its exhaust plume to its nose without losing track of the missile was a significant challange. Similarly, obtaining reliable atmospheric condition information from the BILL while in flight proved to be a significant difficult the ABL program has only recently overcome. Finally, the battle management software had to coordinate all of these lasers and sensors to effectively attack a ballistic missile target. These challenges seem to have been overcome, however, since this entire system was effectively tested in flight, as is discussed later in this paper.

3.3 Other Technologies

In order to support all of the major hardware components for ABL, a number of additional technologies had to be developed extensive modifications had to be made to the 747-400 freighter used. First of all, support structures had to be installed into the aircraft in order to support all of the optical equipment, especially the heavy COIL modules. A ball turret for firing the laser also had to be designed to be mounted on the nose of the plane. This turret required some careful design work, since it had to have a wide range of motion and survive at very high altitudes without damage that would degrade the main laser's performance. Special window designs and optical coatings had to be developed for this system as a result.[10] A stable optical bench and some "benchless" optical systems also had to be designed for ABL, since ABL would use a large number of lasers that would need to be stable during a turbulent flight.[2] The stabilization technologies are referred to by GAO analysts as "jitter control," technology to ensure that vibrations unique to the aircraft do not degrade the high-powered laser's aim point.[6] Although these technologies are not the most heavily advertised of ABL's technologies, they are critical to its effectiveness nonetheless.

4 Current Status

ABL is currently assembling and testing a prototype design that will contain a six-module COIL and all of the necessary systems to let ABL find a ballistic missile target, track it, adjust for atmospheric disturbances, and fire upon it with the COIL. Difficulties with integrating the COIL laser with the beam control/fire control system, as well as technical difficulties with the COIL itself, have postponed ABL's lethality test until at least 2009.[6]

The GAO's 2007 assessment of ABL assessed seven critical technologies: the six-module COIL, missile tracking, atmospheric compensation, transmissive optics, optical coatings, jitter control, and managing the high-power beam. GAO assessed all of these technologies as "nearly mature," with all of them having been demonstrated in a relevant (although not necessarily realistic) environment. As a change from their 2006 report on the project, the GAO reduced the rating of the technology of managing the high-power beam to nearly mature, citing that it had not yet been tested in a realistic environment.[6] This latest report from GAO, however, does not take into account more recent systems testing, which if accurate were significant.

4.1 Aircraft and Low Power Systems

The ABL has seen some notable milestones in its development recently, with the successful testing of its beam control/fire control and engagement mechanisms in flight. Between March and September of 2007, Boeing reported a series of three successful test sequences that, on August 31, culminated in a successful test of all of the low power components of the system on the aircraft in flight.

In this test, first the plane used its infrared sensors to locate an instrumented target board on a U.S. Air Force NC-135E "Big Crow" test aircraft, then the ABL's battle management system issued engagement and target instructions to the beam control/fire control system.

This system then used the ABL's TILL and BILL lasers to track the acquired test target and compensate for atmospheric distortions respectively. Finally the ABL fired its SHEL at the target, completing the simulated target engagement.[2]

The successful completion of this test thus demonstrates the functionality of all of ABL's major components in a simulated engagement except for the COIL. Assuming that these test results are accurate, the next step is to integrate a working version of the COIL into the aircraft and the existing ABL systems.

4.2 COIL Status

The 2007 GAO report on ABL noted a number of quality-related issues concerning the COIL's performance. According to their 2006 report, ground tests of the laser in December 2005 had the six modules of the laser working together to successfully produce a beam for more than 10 seconds. However the laser only produced 83% of its design power, which program officials claimed corresponded to 95% of its lethal range against all classes of ballistic missiles.[7] In their latest assessment they mentioned that program officials believe that a number of failed or deficient laser subcomponents, found during FY2006, may have contributed to the laser achieving this unexpectedly low power. These failed and deficient subcomponents were attributed to poor quality control by program officials, who further claimed that the laser power would be tested again once all of these deficiencies were resolved.

In a news release in October 2007, Northrop Grumman reported reassembly of their 6-module COIL onto the aircraft had begun, in preparation for high-power system testing. In this release officials mentioned that most components within the COIL showed very little degredation after over 70 laser firings in ground tests. They also discussed refurbishing work done on the laser, and said, "Due to the enhancements made during refurbishment, we expect the megawatt-class laser to perform even better than demonstrated in the system integration lab."[8] The reassembly of the laser into the aircraft will be followed by ground and flight tests of the COIL, culminating in ABL's lethality test.

5 Budget

Congress has traditionally favored the ABL program through appropriations matching or on occasion exceeding the Defense Departments requests. In FY2001, for example, the President requested $148.64 million and Congress appropriated $233.64 million. More recently, in FY2007 the Bush Administration requested $631.6 million for ABL, which Congressed approved. The total appropriations to ABL from FY1994 through FY2007 is over $4.3 billion,[4] while the known program cost through FY2011 is $6.4 billion.[6] In FY2008, however, the Bush Administration requested $548.8 million for the ABL program, yet House version of the defense authorization bill decreased this request to $298 million. Meanwhile, the Senate decreased the ABL request to $348 million in its version of the defense authorization bill.[4]

A number of issues with the ABL program concern Congress and may address this drop in financial support. First of all, ABL continues to face technical challenges, and it is highly questionable whether or not they will make the planned 2009 date for their lethality test. Meanwhile MDA is exploring alternatives to ABL in the form of kinetic kill vehicles, thus reinforcing the uncertainty of the ABL program.[4] In addition, ABL faces serious CONOP questions that may never be answered, as will be discussed in the following section. These issues may account for the diminished support in Congress for ABL.

6 Future Developments

6.1 Future Tests

The next major test for the ABL is its lethality test, scheduled for 2009. This test would differ from its final engagement test in two major ways. First, the SHEL would be replaced by the COIL laser, which as mentioned before is the laser that will be used in the final weapons system. Second, in this test ABL would fire upon a ballistic missile, performing all of the necessary tasks for identifying, tracking, and engaging the target. This lethality test will test all of the ABL prototye's system in a realistic environment, and if these lethality tests go well then ABL may be able to move out of its prototyping phase.

After the installation of the COIL into the aircraft is complete, tests will be conducted on the ground to assess the lasers functionality in the plane. The plane must then be assessed for flight readiness before it can be flown again and before any in-flight weapons testing may occur. After these tests are complete, ABL will have a lethal demonstration of their prototype aircraft. This test is currently scheduled for August 2009, but technical issues may further postpone this date.[2] The overall plan for Block 2008 (2008-2009) is therefore further ground and flight testing of the prototype ABL weapon and studies for ABL weapon systems to come.[4]

6.2 Post-Prototyping Design and Development

Once the prototype design is complete the ABL program will move on to designing a second aircraft.[4] This design process will be the primary focus of Block 2010 (2010-2011) and will utilize the lessons learned from the construction of the first one to better assess the design of the components in the second one. Design activities and initial fabrication of weapon components will take place during this block, and the initial capability of the aircraft will also be decided upon at this point, after which assessments can be made concerning the

ABL's design stability.[4] At this time, although the ABL program office has released all of their engineering drawings to GAO, they are unable to make any design stability assessment because they do not know whether the prototype designs can be relied upon as an indicator for the design stability of the second aircraft.[6] Design changes in the second aircraft will need to be determined from the flight testing of the first.

Another major assessment that the GAO was unable to make concerning ABL was its production maturity. The reason for this is because no production decision has been made concerning ABL.[6] While proponents of ABL see it as a near-term ballistic missile defense system, there are several factors concerning ABL that must be considered before a design decision can be made. Many of these factors reside in the concept of operations for the aircraft.

6.3 CONOPS

The concept of operations for ABL are a significant concern for the program. Three CONOP issues in particular concern Congress: how many aircraft must be procured, where they may be deployed, and for what functions they may be used. These operational concerns make ABL a potentially very expensive means of missile defense, potentially too expensive for its capability.

First, there are sizeable concerns with respect to the number of ABLs necessary to defend U.S. interests. To maintain on-station time for the ABL, forward basing would be required, and such bases would probably lack the chemical replenishment capabilities ABL would need to refuel its laser, should it ever be used. Therefore, return trips to the U.S. would be necessary for ABL, thus potentially leaving extensive periods of time when theaters are undefended, during which an enemy could launch an attack. To counter this problem a large number of these aircraft may be necessary to cover just one theater, which would come at a great expense. Of course U.S. interests could be threatened in multiple theaters simultaneously, thus further increasing the number of such aircraft required to provide adequate defense. As a result of these issues, a very large number of these aircraft may be necessary to provide effective defense of U.S. interests.[4]

Second, although ABL has a fairly well-defined purpose, the nature of the aircraft currently under development brings this purpose into question. An operational ABL would be a highly visible asset; it would be easily distinguishable from other wide-body aircraft, typically escorted by fighter aircraft, and lingering near or over enemy territory for long periods of time. Current estimates indicate that ABL's range (400 km) is too short for it to engage ICBMs from outside of Russian or Chinese airspace, leading to questions of how such threats would be dealt with; ABL may have to risk flying into enemy airspace during times of crisis, or an alternative defense solution would have to be employed for such scenarios.[4]

Furthermore, given the distances between U.S. bases and potential theaters of interest, ABL would require aerial refueling to reach its theater of interest, linger there for an extended time to counter any threats, and to return home from this theater, further straining the Air Force's current aerial refueling fleet. Additionally, with the current ABL design already overweight, this could reduce the amount of fuel the aircraft is able to carry, thus mandating more frequent refuelings and further straining the Air Force's existing capability.[4]

In light of these issues of ABL's engagement of ballistic missiles, some have suggested, in light of recent events with the Chinese destroying a satellite from the ground, that ABL could serve a similar anti-satellite capability. One major problem with this proposal is the current design of the aircraft. ABL currently utilizes an infrared sensor to identify targets, utilizing the hot exhaust from a ballistic missile launching. Satellites have no such heat signature for ABL to readily identify, thus complicating its use as an anti-satellite weapon.[4]

In addition to these issues, because of its use of specialized technologies, each ABL aircraft may be very expensive to manufacture and to maintain. In light of these CONOP issues, and because each aircraft would be expensive to obtain, to maintain, and to fly, such an aircraft may be deemed too expensive for its TBM defense capability. Thus these issues potentially pose a major problem for the future of ABL.

7 Overall Program Assessment

There is a lot of work remaining to be done on ABL. While significant tests are being made and significant progress is being achieved, ABL is still in its prototying stage after more than a decade of work, and has already seen sizeable cost overruns and schedule delays. A lot of new technology had to be developed for this system, resulting in significant advances in laser technology, but at a steep price in time and government dollars. Furthermore the complex operational considerations pose serious problems to the usability of an operational ABL, ignoring how effective it may be at destroying ballistic missiles.

The ABL has resulted in some amazing advances in laser technology during its development. Systems for precisely operating lasers in mobile and potentially turbulent environments had to be developed designed and developed for this system. The desired use of a COIL as the aircraft's kill laser has led to significant work in improving COIL efficiencies and generating singlet delta oxygens for more general oxygen-iodine lasers. ABL has thus made great contributions to the field of laser development.

In addition, recent developments with the ABL project make the prospect of a working prototype in the near future quite vivid. This year alone a set of in flight tests demonstrated most of the key systems for ABL's operation, sans the arguable most important if not simply most advertised system, the COIL. With the remaining task for the ABL prototype to integrate the COIL into the ABL aircraft, though complications could easily arise to further postpone the lethality test date, the possibility of an operational ABL prototype does not seem far off.

However, I still do not believe this system will be effective or ever used in a military application. The complications with the aircraft's CONOPS simply do not make it look like a cost-effective means of missile defense. Flying such an expensive and visible asset close to enemy territory for extended periods of time exposes each ABL aircraft to a host of threats, many of which it would be unable to cope with, such as extensive enemy anti-air missiles. At this time the burden each plane would place on the existing industrial base, military funds, and existing Air Force capabilities (i.e. for refueling the aircraft in flight) would make each ABL plane lost to enemy anti-air defenses a significant loss to the Air Force and United States, and this loss simply seems too likely if the ABL is deployed anywhere where it would truly be an effective missile defense system. Therefore, although the ABL project has made significant strides towards a functional prototype and has advanced laser research in significant ways, I do not see this program yeilding a useful military system.

One investigation that I did not perform in this analysis is the application of some of ABL's technologies to other laser-based systems, such as the Advanced Tactical Laser. Such systems would be designed with different operational considerations and with the knowledge of what the current high-power technology is capable. Therefore such systems could develop into more effective and useful weapons systems. In this way, even if the ABL never produces a useful military system, the vast amount of research and development that has gone into this system will not be at a complete loss.

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