

## **A Look at the Troubled Development of the Airborne Laser**

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*March 15, 2005*

### **Summary**

The planned U.S. Airborne Laser (ABL) system would be a complex collection of sensors, computers, chemicals and mirrors packed aboard a modified Boeing 747-400F commercial airplane. The system, being developed in tandem by the U.S. Air Force and the Missile Defense Agency (MDA), is being designed to destroy a ballistic missile during the boost phase of flight by heating its skin with a High Energy Laser (HEL). According to the Air Force Research Laboratory, heat from the HEL will cause the missile's skin to crack. Because missiles are pressurized internally, program officials hope the crack will cause an explosion.

This review will provide a basic explanation of lasers; the features of the chemical oxygen iodine laser (COIL) that caused it to be chosen for the ABL weapon system; the shortcomings of the overall project; and the implications of recent events related to the ABL.

The Air Force launched the formal ABL program in Fiscal Year 1994 (FY 94). In 1996, Boeing was awarded the overall design contract for the system. The program has experienced numerous delays and cost overruns since its inception. Test dates for the system have been pushed back repeatedly, and the Government Accountability Office published reports in 1997 and again in 2004 citing the daunting engineering challenges facing the system. Because of these numerous delays, the ABL will cost more than twice what it was projected when it was first undertaken (estimates now range up to \$5.1 billion).

Previously, the design plan for the ABL called for 14 laser modules, but more recently, program officials have been indicating that the ABL is unlikely to end up with that many. The test aircraft for the ABL has only six modules, whose size and weight already tax the aircraft's frame. Instead, ABL officials are working toward squeezing more output from the six existing modules, which may or may not work.

Actually constructing a working COIL that can produce the high levels of energy desired has proven difficult. Its energy source is the reaction of basic hydrogen peroxide (BHP) with chlorine gas. One major problem is that this reaction may not be efficient enough. One proposed solution is to replace the BHP solution with basic deuterium peroxide

(BDP) solution. BDP would theoretically allow the reaction to proceed more efficiently. But if chosen, it would represent a major shift on how the program has been structured and would likely delay it even further.

Another problem has been the optics. These are many mirrors that make up the optical resonator, direct the beam out of the aircraft, and aim the beam at the target. To ensure that they do not become damaged from absorbing high-intensity or high-energy light waves, optical devices used in the ABL system are coated with highly reflective materials. In fact, the mirrors on the ABL have 80 different optical coatings. Ten have been identified as being particularly problematic, but many have general problems.

Often overlooked is the lack of a solid concept of operations for the ABL. Initially, a fleet of seven or eight aircraft was to be fielded. However, as the program dragged on without much progress, that plan was quietly dropped. Currently there is one Boeing 747 jet that has been modified for the ABL: YAL-1. The MDA has held off on purchasing a second aircraft – which would cost \$170 million – until work on its current aircraft advances more.

The recent “first light” test of the six COIL modules working in tandem on Nov. 10, 2004, probably gave the program a political boost even though the test provided no data to support the assertion that the HEL can do what the MDA wants it to do and addressed few of the concerns raised by critics. Particularly disturbing was the presence of “fireflies” (particles of dust and other small objects in the beam’s path which burned and produced flickers of visible light). Setting airborne dust particles in the atmosphere on fire lessens the strength of the outgoing beam. Overall, atmospheric disturbance or jitter is a major problem for the ABL which has not been solved.

On Dec. 3, 2004, the ABL had its first flight, where the reconfigured aircraft flew for the first time. Program officials had planned on taking the aircraft out for a two-hour flight, but after receiving a warning (which later was determined to be false) from on-board instruments that implied there was an air pressure problem, the flight was aborted after only 22 minutes. Despite this shortened flight, ABL officials celebrated the event as a success, since they were under tremendous pressure to achieve the “first light/first flight” by the end of the calendar year.

Based upon these assessments, it is clear that the ABL has a long way to go until it progresses from a very expensive physics experiment to a weapon system that can credibly destroy ballistic missiles. Even MDA’s director admits this. In a March 9, 2005, press briefing, Lt. Gen. Trey Obering said that “it is not out of the woods yet. I can’t declare that as a totally risk free program.”

## **ABL System**

The planned U.S. Airborne Laser (ABL) system would be a complex collection of sensors, computers, chemicals and mirrors packed aboard a modified Boeing 747-400F commercial airplane. The system, being developed in tandem by the U.S. Air Force and the Missile Defense Agency (MDA), is being designed to destroy a ballistic missile during the boost phase of flight by heating its skin with a High Energy Laser (HEL). According to the Air Force Research Laboratory, heat from the HEL will cause the missile's skin to crack. Because missiles are pressurized internally, program officials hope the crack will cause an explosion.

This manuscript will provide a basic explanation of lasers; the features of the chemical oxygen iodine laser (COIL) that caused it to be chosen for the ABL weapon system; the shortcomings of the project; and the implications of recent events related to the ABL.

## **Lasers**

The term "LASER" stands for Light Amplification through Stimulated Emission of Radiation. This means that light waves are used to create more light waves from energy stored inside atoms, molecules, crystals or some other material. The simplest way to describe a laser is to call it a concentrated beam of light. Laser light has qualities that make it different from other kinds of light. Laser light is monochromatic, meaning it consists of light waves with the same wavelength, which explains why lasers are a distinguishable color. Other kinds of light, such as sunlight, have light waves of many different wavelengths, making them white.

Another feature that distinguishes laser light from other kinds of light is that it propagates, or moves, primarily in one direction. This occurs because laser light is created in an optical resonator, a device consisting of two or more mirrors that reflect light in a laser system. The open space between the mirrors is called the laser cavity. The light reflected – or bounced back and forth -- in the laser cavity gains in intensity, and eventually, the light is transmitted outside the laser cavity, creating a laser beam. Other kinds of light, such as that produced by light bulbs, are less complex, spreading indiscriminately in all directions.

Materials which produce laser light within the optical resonator are called lasing media. Lasing media come in several forms, but the most common are gases, such as iodine or carbon dioxide, and crystals, such as yttrium aluminum garnet and quartz. The lasing medium is what determines the wavelength of light that a laser produces. Lasers are possible because lasing media can exist in discrete states with different energies. The lowest energy state is called the ground state. States at higher energy levels are called

excited states. When sufficient energy is added to a medium, it will move to an excited state. When the medium returns to its original state, energy is emitted, producing light.

Lasing media – the aforementioned chemicals or crystals - can produce laser light when “excited” by an energy source. When this happens, the medium produces the initial laser light rays, which are then “amplified” in the laser cavity. The energy stored in that excited state is where laser light comes from.

All lasers require an external source of energy to put lasing media in their excited states. This energy can be added in several ways: electricity, a light source, or a chemical reaction. An electrical source can be something as simple as a battery and is used for relatively low-power lasers. Light sources include light bulbs, flashlamps, or other lasers. Lasing media, particularly chemical species, can also be excited through exothermic, or energyliberating, chemical reactions.

In lasing media, there is a point where sufficient energy is added so that there are more molecules in a state of higher energy than a state of lower energy. This is called a population inversion. When this occurs, energy is likely to be released, usually in the form of light waves. Scientists have found that it is easier to describe these emissions as “particles” of light. These particles, called “photons,” are best described as bursts of energy, or packets of light waves, that are released when a medium moves from a state of higher energy to a state of lower energy. Thus, before any laser light can be released in useful quantities from the initial medium, a population inversion needs to occur. The population inversion causes light to be emitted from the lasing medium, and the photon introduction starts the resonator process of bouncing the light back and forth to increase the intensity.

Some of this emission occurs spontaneously; that is, some of the molecules release photons and return to their initial state without any outside interference. In order to produce a laser, however, the bulk of the emissions must be stimulated by a photon that collides with the excited medium. The energy of this photon must be the same as the difference between the higher energy state where a molecule of the medium exists when the photon first collides with it, and a lower state of energy where the molecule can exist. If this criterion is met, a photon with the same wavelength, direction of propagation, phase, and energy as the incident photon is emitted. This production of photons is called gain and is made possible by the optical resonator, which reflects photons back through the lasing medium, also called the gain medium, to stimulate more emissions.

The mirror system in an optical resonator must be designed so that the waves interfere constructively; that is, amplify rather than destroy each other. As a result the light intensifies, or gets brighter, as it bounces back and forth between the mirrors. The external energy source acts as a pump to maintain the population inversion in the gain medium, allowing the laser to function for a significant period of time. Conversely, if light rays are out of sync with each other while in the optical resonator, they will

eventually cancel each other out and substantially reduce the energy output of the laser system.

Eventually, enough new photons accumulate in the optical resonator to form a useful beam. In most lasers, one of the mirrors in the optical resonator does not reflect as much light as the others. When the light reaches a certain intensity, some of it passes through this mirror, forming a beam. This is called a stable resonator configuration. The ABL, however, has an unstable resonator configuration, meaning that the light is switched or reflected out of the laser cavity to form a beam. After it leaves the laser cavity, a series of mirrors and pipes combine the beams from the distinct modules and then focus the beam on the skin of an enemy missile, hopefully producing catastrophic failure.

Photons emitted from the gain medium have wavelengths inversely proportional to the difference in energy between the higher and lower energy states. Mathematically, the relationship is described by the equation:

$$\lambda = hc/(E_2 - E_1)$$

where  $\lambda$  is the wavelength of light emitted,  $h$  is Planck's constant, and  $c$  is the speed of light. The wavelength of light emitted from the COIL is 1.315 micrometers (microns). Light of this wavelength is found in the infrared portion of the electromagnetic spectrum, making it invisible to the naked eye. If the beam is powerful enough, however, particles of dust and other small objects in the beam's path will burn and produce flickers of visible light called "fireflies." One of the problems with the ABL is that setting airborne dust particles in the atmosphere on fire lessens the strength of the beam. Thus, it is unlikely the ABL will be able to engage an enemy missile until near the end of the boost phase, when the number of air molecules and dust particles between the ABL platform and the missile is at a minimum.

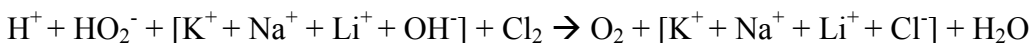
### **The Airborne Laser**

The COIL is, of course, a chemical laser. The energy source for the COIL is the reaction of basic hydrogen peroxide (BHP) with chlorine gas to produce oxygen, water, and alkali salts. While about two-thirds of the energy is released in the form of heat, some is transferred to the products, creating an excited oxygen molecule.

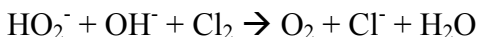
Since we know the COIL emits photons of wavelength 1.315 microns, we can determine the energy of the photon released using the equation in the previous section. The energy of one photon with a wavelength of 1.315 microns is  $1.511 \times 10^{-19}$  joules. The Air Force claimed in a March 2003 Fact Sheet that the prototype COIL with its six modules is a megawatt-class laser; that is, it is capable of producing one million joules per second or more. Applying the value we just calculated to the six modules that will be placed in the prototype ABL aircraft, each module would have to produce approximately 167 kilojoules per second in order to achieve at least one megawatt. For one module to reach 167 kilowatts, 1.83 moles of photons would need to be produced every second. (A mole is the unit that measures the amount of substance that holds the same amount of objects

as atoms in Avogadro's number, which is roughly  $6.02214199 \times 10^{23}$ .) Previously, the design plan for the ABL called for 14 modules, but the Fact Sheet claimed the number of modules was "an outdated issue," and that ABL "is less interested in counting modules than determining how much power can be put on the target." More recently, program officials have been indicating that the ABL is unlikely to end up with 14 modules. The test aircraft for the ABL, YAL-1, has only six modules, whose size and weight already tax the aircraft's frame. Instead, ABL officials are working toward squeezing more output from the six existing modules.

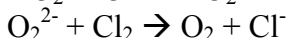
The reaction that fuels the COIL proceeds in several steps. The overall reaction is shown here:  $\text{H}_2\text{O}_2 + [\text{KOH}, \text{NaOH}, \text{LiOH}] + \text{Cl}_2 \rightarrow \text{O}_2 + [\text{KCl}, \text{NaCl}, \text{LiCl}] + \text{H}_2\text{O}$



Some of the atoms in the equation above do not participate in the reaction. After removing these "spectator" atoms, we are left with the reaction:



This reaction has two steps:



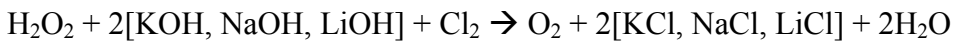
$\text{H}_2\text{O}_2$	hydrogen peroxide
$\text{KOH}$	potassium hydroxide
$\text{NaOH}$	sodium hydroxide
$\text{LiOH}$	lithium hydroxide
$\text{Cl}_2$	chlorine gas
$\text{O}_2$	oxygen gas
$\text{KCl}$	potassium chloride
$\text{NaCl}$	sodium chloride
$\text{LiCl}$	lithium chloride
$\text{H}_2\text{O}$	water
$\text{HO}_2^-$	hydroperoxy ion
$\text{OH}^-$	hydroxide ion
$\text{Cl}^-$	chloride ion
$\text{O}_2^{2-}$	peroxide ion

The hydrogen peroxide reacts first with alkali hydroxides to produce BHP solution. BHP solution is highly unstable and must be stored at close to  $-19^\circ\text{C}$  in order to prevent  $\text{H}_2\text{O}_2$  from decomposing to oxygen and water vapor. Temperatures well below the freezing point of water ensure that the BHP solution remains stable and that water vapor does not interact in the reaction vessel. If the temperature of the BHP solution goes above  $29^\circ\text{C}$ , it

will degrade rapidly to water vapor, which would interact with excited oxygen, robbing it of the energy needed to make the laser work.

In the second reaction, chlorine gas takes electrons from the peroxide ion, producing oxygen gas and chloride ions.

The balanced chemical reaction is:

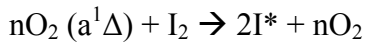


Some of the oxygen produced during this reaction is in the singlet-delta excited state, abbreviated  $\text{O}_2(a^1\Delta)$ . This state of oxygen has 95 kJ/mole more energy than ground-state oxygen and is used as the fuel source for lasing. Because oxygen can remain in the excited state for over an hour before releasing its excess energy and returning to the ground state, it is not a suitable lasing medium. A material this stable would not produce enough emissions for an efficient laser. That is why iodine is an essential ingredient of the COIL. It has an excited electronic state that is nearly the same energy as singlet-delta oxygen, but excited iodine decays much faster, making it a better lasing medium. The oxygen is used as a metastable energy reservoir that stores energy until it is transferred to the more laser friendly iodine species.

Several processes can sap energy from the singlet-delta oxygen reservoir, but the most prominent is a "pooling reaction," where two  $\text{O}_2(a^1\Delta)$  molecules collide and one transfers its energy to the other, producing a ground-state oxygen molecule and an oxygen molecule in an even higher excited state than singlet-delta oxygen. This new excited oxygen molecule is then quenched to the singlet-delta oxygen excited state through interaction with water. The new ground-state oxygen molecule is no longer useful for transferring energy to iodine. The result is the loss of one molecule of  $\text{O}_2(a^1\Delta)$  every time this process occurs. The greater the density of  $\text{O}_2(a^1\Delta)$  in the laser cavity and the faster the  $\text{O}_2(a^1\Delta)$  moves through the laser cavity, the more  $\text{O}_2(a^1\Delta)$  will be lost to pooling. However, iodine and excited oxygen must flow through the laser cavity quickly in order to maintain a population inversion. To minimize the speed that  $\text{O}_2(a^1\Delta)$  moves through the cavity and to lessen the chance of the  $\text{O}_2(a^1\Delta)$  molecules colliding, helium is added to the gas flow. In addition to ensuring that only a small amount of singlet-delta oxygen is wasted, helium also absorbs any excess heat that might adversely affect the reaction.

Helium, excited-state and ground-state oxygen, residual chlorine, and water vapor leave the reaction chamber at 17°C and 106 torr. (A torr is a unit of pressure equal to 0.0013 atmospheres or 0.018 pounds per square inch.) Iodine vapor is injected and the gases are expanded using a supersonic flow nozzle, cooling everything to -145°C, lowering the pressure to 5 torr, and distributing the gases throughout the gain medium. Lower temperatures improve power extraction and condense the water vapor so that its quenching effect is minimal.

Singlet-delta oxygen transfers the energy to iodine in the following process:



A general rule of thumb is that 5.5 moles of singlet-delta oxygen produce two moles of excited monatomic iodine. A 2:1 ratio of excited iodine to ground-state iodine is needed to maintain lasing; this ratio is maintained as long as 10 percent of the oxygen flowing into the gain region is in the  $\text{O}_2 (a^1\Delta)$  excited state. Approximately 3.3 kJ/mole is lost when iodine absorbs energy from singlet-delta oxygen.

While in the gain region, excited iodine atoms can release their energy in three ways: through collisional quenching, spontaneous emission, or stimulated emission.

Quenching occurs when excited iodine atoms interact with water vapor and the energy stored in the iodine is transferred to water molecules. As a result, the temperature of the water increases, and photons are not produced. Keeping the temperature of the system low condenses the water molecules, preventing them from interacting extensively with iodine atoms.

Spontaneous emissions are essential to initiate lasing. Photons with a wavelength of 1.315 microns are released whenever the excited iodine atom returns to the ground state. Far more prevalent than spontaneous emission, however, and the key feature of laser operation, is stimulated emission.

Stimulated emission occurs when photons interact with iodine atoms in the excited state. The interaction induces the iodine atom to emit its stored energy and return to the ground state. This energy is emitted in the form of a photon with the same phase (or manner of up-and-down movement), wavelength, and direction of propagation as the incident photon. Thus, the optical resonator produces a multiplier effect, increasing the intensity of the light until it can no longer contain it. As light escapes from the gain region, it propagates in one direction, forming a laser beam.

### **Why is the COIL used for the HEL?**

The COIL in particular, and chemical lasers in general, has properties that make it more useful in this application than other types of lasers. Some of these reasons are discussed here.

The major advantage of chemical lasers is that they can produce a large amount of energy without needing a large battery or other power supply to help them along. The reactions used in chemical lasers are spontaneous and do not need to be sustained through outside heating. Using another kind of laser might require a power source even bulkier than the SUV-sized modules that make up the COIL.

The other lasers used in the ABL system are not chemical lasers. The Track Illuminator Laser (TILL) and the Beacon Illuminator Laser (BILL) are low-power solid-state lasers, and the Active Ranging System (ARS) uses a carbon dioxide laser. The gain medium for

the TILL is an ytterbium: yttrium aluminum garnet crystal. The laser is pumped with electrical current to produce a wavelength of 1.030 microns. The TILL passes through the turret on the nose of the airplane and determines the altitude, speed, and flight path of the target.

The BILL uses a neodymium: yttrium aluminum garnet crystal pumped with an electrical current to produce a 1.064-micron beam. It also passes through the nose turret and is used to lock-on to the target, with the goal of correcting for atmospheric distortions that could disrupt the beam.

The ARS uses carbon dioxide as its gain medium and is powered electrically. It is mounted on top of the plane, providing information on the range to the target.

### **Technical Challenges**

All of what has been presented above is a theoretical design concept for the ABL. Actually constructing a working COIL that can produce the high levels of energy desired has proven difficult. The ABL program has been delayed numerous times because of engineering problems and will cost more than twice what it was projected when it was first undertaken (estimates now range up to \$5.1 billion). In this section some of the ABL's problems are discussed.

One major problem is that the BHP reaction with chlorine may not be efficient enough to produce the required amount of singlet-delta oxygen. The main problem has been the quenching of singlet-delta oxygen to ground-state oxygen because of interaction with water. Several years ago, there were explosions reported at the factories used to make and mix BHP. This problem has reportedly been resolved, presumably by lowering the storage temperature of the BHP. Problems remain, however, with the efficiency of the reaction. One proposed solution, discussed by program director Col. Ellen Pawlikowski at a press teleconference on Nov. 19, 2004, is to replace the BHP solution with basic deuterium peroxide (BDP) solution. Deuterium is a hydrogen atom with a neutron in the nucleus: most hydrogen has only a proton in the nucleus. BDP would theoretically allow the reaction to proceed efficiently at higher temperatures than those discussed above and delay salt precipitation. Most importantly, however, it would reduce the effect of parasitic quenching on singlet-delta oxygen. If the ABL manager opted to shift to a deuterium peroxide solution, this would represent a significant change to the program and would likely delay it even further.

Another problem has been the optics. These are the many mirrors (and perhaps lenses) that make up the optical resonator, direct the beam out of the aircraft, and aim the beam at the target. To ensure that they do not become damaged from absorbing high-intensity or high-energy light waves, optical devices used in the ABL system are coated with highly reflective materials. These coatings are especially important in the HEL, because the optics are so susceptible to damage from the intense heat of the laser. The mirrors are finely-tuned and must maintain a high level of sensitivity in order to carry out their mission. Otherwise, the laser may lose its intensity and be rendered useless.

The mirrors and lenses in the ABL system have to be extremely durable in order to withstand the intense heat generated from the COIL. In fact, the mirrors on the ABL have 80 different optical coatings. Ten have been identified as being particularly problematic, but many have general problems, due to the amount of energy that the HEL creates. Since the HEL is to rely on an unstable resonator to produce the requisite power output, the mirrors must completely reflect all photons in the optical resonator. Optical coatings and devices can be easily damaged with high-power lasers, however. It is extremely important that optics remain clean and that their coatings be uniformly distributed. Any non-uniformity or impurities will cause the light to scatter, forming “hot spots” on the optics, where heat becomes overly concentrated and damages the optical device.

The amount of heat associated with the HEL requires very durable, and thus, very expensive optical instruments and coatings. Maintenance for the laser’s optics will also be very expensive until cheaper and more durable materials are developed.

Maintenance of the system in general has been criticized because of its projected expense. Furthermore, forward operating bases to produce the chemicals to fuel the laser, provide maintenance for the aircraft and its many systems, and supply the support aircraft needed to defend and refuel the ABL in flight would be required in the theatres of operation. Also, storage of these highly flammable chemicals is tricky, as evidenced by explosions in their processing plants a few years ago.

The MDA released in the fall of 2004 its draft Programmatic Environmental Impact Statement for the overall ballistic missile defense system. While the ABL was discussed in it, any environmental impact concerns were dismissed out of hand. For example, the document says that if the ABL could not land at “an appropriate location,” its fuel and laser chemicals could be jettisoned, but this would be at a minimum altitude of 15,000 feet and thus “would be diluted in the atmosphere.” And if there were a fire on the ABL, “the liquid and solid laser chemicals would be consumed or contained.” The possibility of the ABL jettisoning its chemicals at a lower altitude than 15,000 feet or failing to contain all its chemicals is not considered.

Often overlooked is the lack of a solid concept of operations for the ABL. Initially, a fleet of seven or eight aircraft was to be fielded. However, as the program dragged on without much progress, that plan was quietly dropped. Currently there is one Boeing 747 jet that has been modified for the ABL: YAL-1. The MDA has held off on purchasing a second aircraft –which would cost \$170 million – until work on its current aircraft advances more. With one aircraft, or even two, the ABL would have to be kept fairly near anticipated hot spots to ensure it could arrive over an enemy’s airspace in a timely manner. As well, this very slow aircraft would not be able to defend itself as it lumbers across the sky, so it would require fighter escorts. This entourage would degrade what little stealth the ABL would have, thus aiding enemy efforts to hide and/or redeploy mobile missile assets while the ABL was in range of their launch.

Research on this type of laser weapon goes back more than 30 years. In the early 1980s, the Air Force Research Laboratory operated the Airborne Laser Laboratory to conduct research on high power airborne lasers. The Air Force launched the formal ABL program in Fiscal Year 1994 (FY 94) when two competing design contracts were awarded. In 1996, Boeing was awarded the overall design contract for the system. The program has experienced numerous delays and cost overruns since its inception. Test dates for the system have been pushed back repeatedly, and the Government Accountability Office published reports in 1997 and again in 2004 citing the daunting engineering challenges facing the system. These include ensuring that the reaction vessel and optics do not overheat, that turbulence does not throw the beam off target, and that the reaction is efficient enough to produce sufficient power to actually destroy enemy missiles.

Presently, MDA officials hope that they can have a test of the ABL against a target in FY 07 and attempt a shoot-down in FY 08, but those dates represent highly unrealistic expectations that the ABL will have unimpeded and consistent progress in its development. Given how far the system has fallen behind its schedule, it is improbable that it will meet this test schedule. Meeting the final milestone of achieving a shoot-down is estimated to cost nearly \$1.4 billion.

Congress cut the ABL budget for fiscal year 2005, which in the past has been a sign that a project is on the verge of cancellation, but it is unlikely that Pentagon and White House officials will let the program die. Pentagon analysts tried from 1998 to 2001 to cancel the ABL but could not. This program apparently has some powerful backers. Interestingly, the ABL in the FY 06 budget request only lost \$60 million from what program managers had projected for this year. This contrasts to the massive cuts its rival boost phase intercept program, the Kinetic Energy Intercept (KEI), suffered (\$800 million in the FY 06 budget request). The ABL was authorized to receive \$474.3 million in FY 05. Missile defense is one of the cornerstones of President George W. Bush's defense policy. There have even been efforts to sell an ABL aircraft to the Japanese, a bold move since a fully operational prototype has not yet been completed and tested.

The recent "first light" test of the six COIL modules working in tandem on Nov. 10, 2004, probably gave the program a political boost even though the test provided no data to support the assertion that the HEL can do what the MDA wants it to do and addresses few of the concerns raised by critics. The laser was fired for only a very small fraction of a second. According to Pawlikowski, this was not enough time to gauge the power output of the beam or the effect of the beam on the laser's optics. Pawlikowski cited the presence of "fireflies" and an unspecified increase in temperature on a heat sensor in the beam's path as evidence that the laser worked. While this demonstrated that the laser works, it did not show that it could crack the skin of a ballistic missile. Furthermore, it has not been stated publicly how hot the missile skin must be for it to crack.

The first light test was more a qualitative demonstration that the six modules can fire in tandem than a preliminary assessment of the HEL's destructive power. Pawlikowski indicated as much in the press conference following the event. She said that the chlorine flow-rate would eventually be raised to 100 percent or more, which should increase the

power output. Also, the time that the beam would be on would gradually increase in further tests conducted in 2005.

Also indicated by program officials is a shift in the ABL's target. It used to be promoted by supporters as a weapon that could intercept short-range tactical missiles and therefore provide a theater missile defense. However, due to problems with fireflies and jitter breaking up the laser's beam, now the ABL is being pushed as a system that could intercept ICBMs when they are exoatmospheric – when there is much less atmospheric interference. This implies that the ABL is not trusted to work that effectively at lower altitudes. When this is coupled by scripted testing where the ABL is run at an unrealistically thin air pressure (allowing its beam to flow easier than it would normally), it seems to be an exaggeration to call the ABL's "first light" a success.

On Dec. 3, 2004, the ABL had its first flight, where the reconfigured aircraft flew for the first time. Program officials had planned on taking the aircraft out for a two-hour flight, but after receiving a warning (which later was determined to be false) from on-board instruments that implied there was an air pressure problem, the flight was aborted after only 22 minutes. Despite this shortened flight, ABL officials celebrated the event as a success, since they were under tremendous pressure to achieve the "first light/first flight" by the end of the calendar year.

Based upon these assessments, it is clear that the ABL has a long way to go until it progresses from a very expensive physics experiment to a weapon system that can credibly destroy ballistic missiles in the boost phase.

The ABL must overcome several high technological hurdles before it is able to demonstrate an effective defensive capability. These include problems with airframe vibrations, atmospheric turbulence between the target and the weapon, and turbulence encountered during flight, all of which contribute to jitter and impede the laser beam. Developing sufficiently robust and cost-effective adaptive optics is one of the most significant challenges. Even MDA's director admits this. In a March 9, 2005, press briefing, Lt. Gen. Trey Obering said that "it is not out of the woods yet. I can't declare that as a totally risk free program."

It is not yet known whether six COIL modules will be able to produce the power required to damage a boosting missile now that the original number of modules, 14, seems to be an unfeasible alternative. Even now, the Air Force is working on ways to make the modules lighter or to reinforce the floor panels on the aircraft where the modules are supposed to sit, a sign that there is concern that even six modules may be too heavy. Also, the effectiveness of the weapon against simple countermeasures is unknown. There may be certain materials that can be used to coat the skins of missiles that would render the ABL ineffective against them by reflecting the laser light or acting as a heat shield. It is imperative that more tests be conducted on the prototype laser to determine whether the design will be effective against actual enemy missiles.

## **Sources**

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