2010 Airborne Laser Post Test Analysis

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Abstract

The Airborne Laser (ABL) Team led by Boeing announced that they had conducted an airborne COIL laser test earlier this year (2010). These results from a horizontal path laser propagating at altitude and through atmosphere are of great interest to the laser propagation community. In this white paper, we address the questions that the ABL test results pose for the laser propagation physics. We describe in this short analysis, several anomalies that arise from a study of the publicly released video data which represent the ABL COIL test at altitude.

Introduction and Summary

The Airborne Laser (ABL) Team led by Boeing announced that they had conducted an airborne COIL laser test earlier this year (2010). These results from a horizontal path laser propagating at altitude and through atmosphere are of particular interest to the laser propagation community. The atmosphere at aircraft altitudes is multilayered and strong over operational ranges while clear day optical turbulence can also be encountered. Without detail about the actual COIL test, including the actual laser propagation range from aircraft to target, one is left with more serious questions concerning the ABL test results announced. In this white paper, we address the questions that the ABL test results pose for the laser propagation physics. We emphasize, in particular, several anomalies that arise from a study of the publicly released video data which represent the ABL COIL test at altitude.

Although our interest in the actual ABL engagement data stems in large part from a purely scientific interest, we have also been deeply involved with supporting Directed Energy as a viable weapon since 1989. In that capacity, Enguehard and Hatfield analytically solved the physics of the "Thermal Blooming" problem, and continue to contribute to the DOD laser defense community.

Background on ABL Analysis at Applied Mathematical Physics Research

A "flaming wreckage demo" was first planned for an airborne laser by Phillips Lab back in 1991. Using notes from that planned engagement and the video from the 2010 ABL test, our analysis shows that the planned range of that demonstration was short-ranged but still greater than the range used in the early 2010 tests. Phillips Lab scrapped that plan after we derived for them analytic results that showed that a demonstration at short-range had no bearing on whether the ABL will work at longer, operational ranges. Our 1989-2010 analytic results have been supported thus far, by theory and experimental tests.

The main reason that short-range laser tests do not demonstrate ABL capability at operational ranges is atmospheric propagation. The operational range system requires the use of adaptive optics, and that the adaptive optics work exceedingly well. At the engagement ranges of the Jan-Feb 2010 ABL tests, the adaptive optics is not required, and any correction an adaptive optics system might apply would be minor.

As designed, the ABL adaptive optics system cannot work at operational ranges for fundamental physics reasons. The main reasons are:

- At operational ranges, the beam actually points downward to engage SCUD-like targets during boost phase. This means that significant atmospheric turbulence is distributed along the entire propagation path.

- At the size of the Boeing ABL beam director, atmospheric turbulence that must be corrected lies outside of the near field of the adaptive optics. Due to diffraction, this turbulence is undetectable with phase measuring wave-front sensors, thus this turbulence will never be corrected and will cause the beam to break up before reaching the target.

- Furthermore, this residual fluctuating uncorrectable phase error will lead to pointing errors at the microradian level. At operational ranges, a pointing error of a microradian will cause the ABL beam to miss the target.

- The beacon is not cooperative, and the beacon and high power beam do not form a reciprocal propagative pair. This means that the beacon illuminates turbulence that the high power beam should never see, and therefore should not be part of the correction. Adaptive optics applying incorrect compensation is disastrous when beams require deep compensation for the strong turbulence regime as does the ABL at operational ranges.

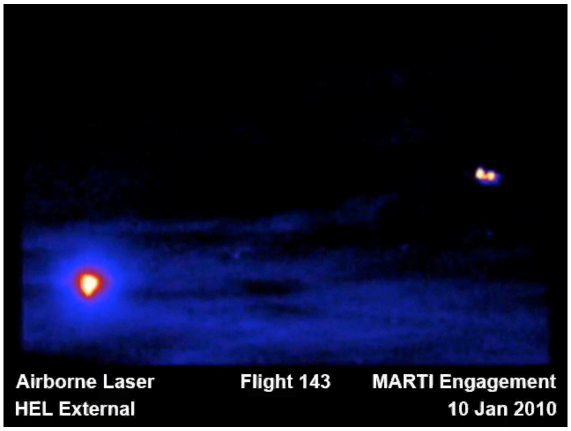
- The “laser guide star” beacon generates a return signal by backscattering or reflection. This process is incoherent and adds an incoherent phase profile to the beacon as it propagates back to the ABL platform. The incoherent contribution to the phase from the backscatter or reflection should not be compensated for as the high power beam does not encounter it, yet there is no way to separate it from the atmospheric turbulence contribution, which does need to be corrected for. Calculations show that, under ideal conditions, over 90 percent of the high beam energy is lost from this effect.

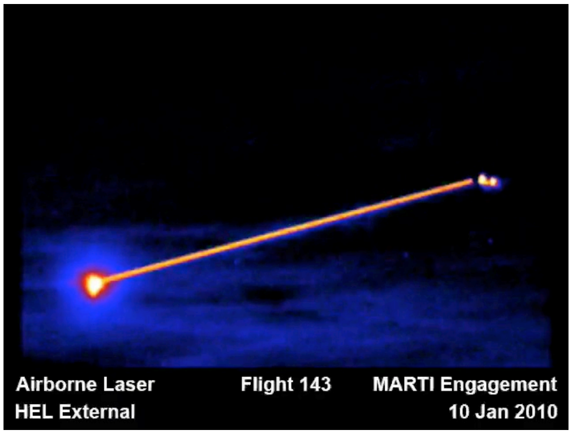
A short range test cannot measure or demonstrate the system performance of the ABL at operational ranges due to the effects of atmospheric turbulence and the lack of the ability to compensate far-field turbulence through adaptive optics. (For detail, please see References 2 and 3 and other basic propagation physics papers from the authors.)

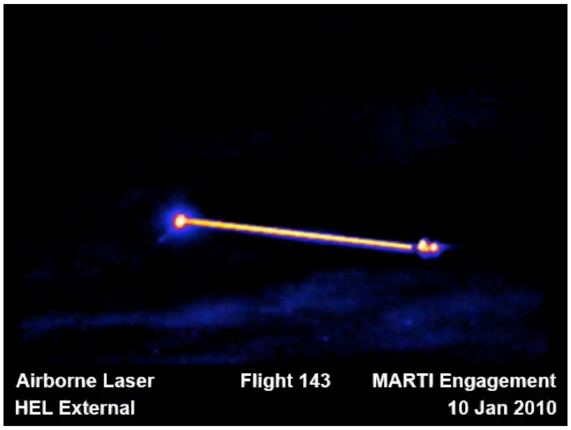
Early 2010 Tests

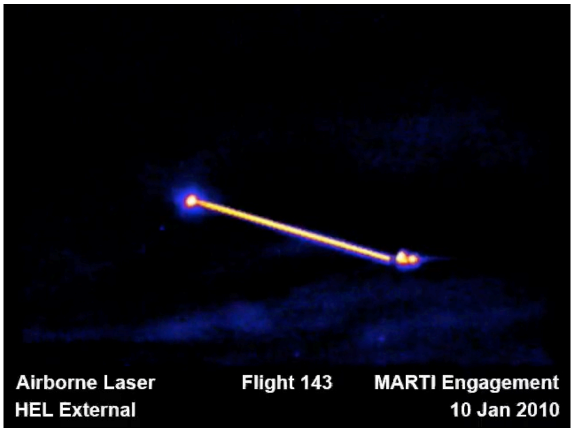
Details of the tests are kept from experts (even cleared experts) if they are perceived as critics of the ABL. However, from the material released to the public (mainly two videos), there are some interesting questions.

The four frames below were taken from a publicly released video from the test in Jan 2010. The first frame occurs just prior to the beginning of the engagement, the second immediately after the start of the engagement, the third about 12 seconds later, and last near the end of the engagement at about 15 seconds (although the video may be stretched or compressed in time for release).





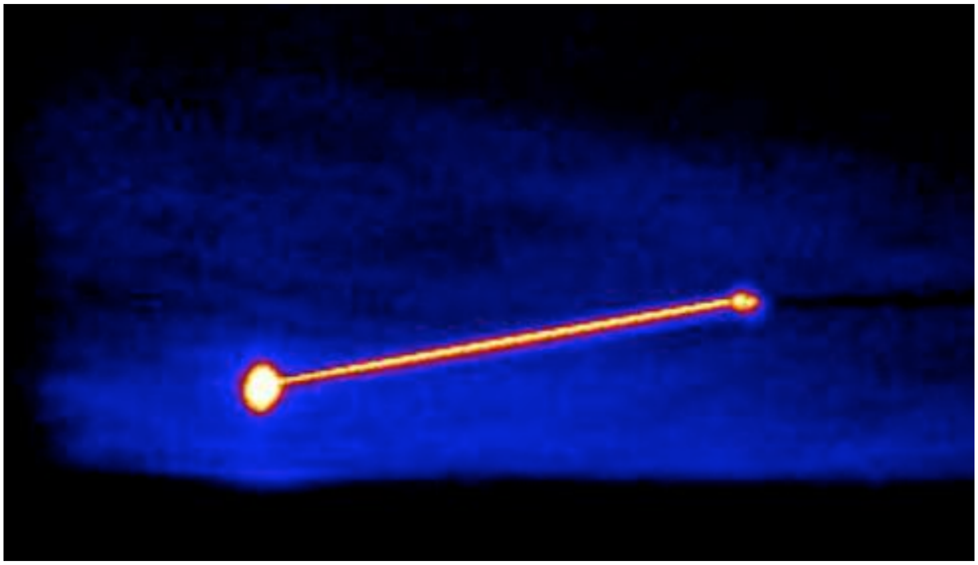




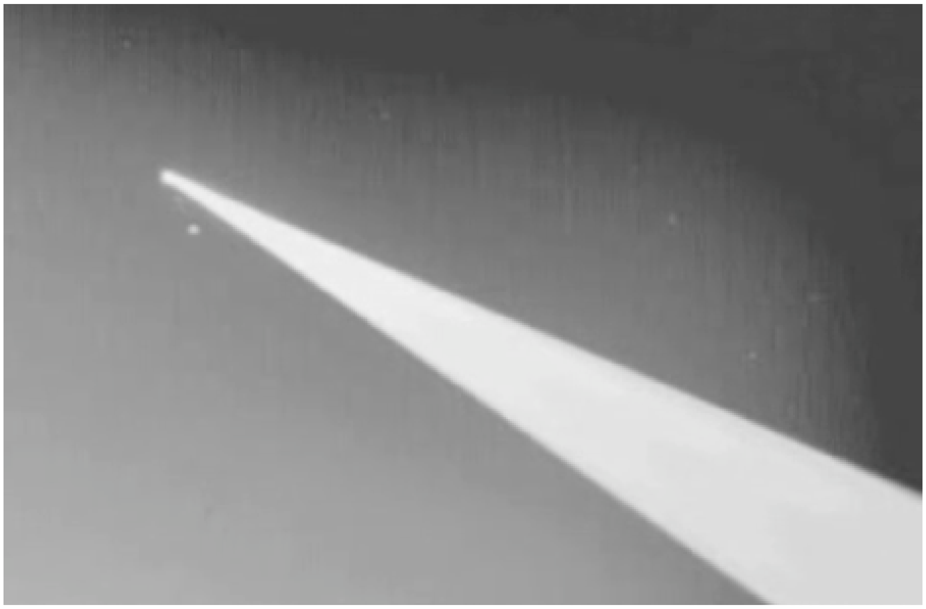
Given the size of the signature of the ABL and target, it is apparent that the engagement range is very short, a few percent of the operational range. The COIL beam is at 1.38 microns. At this wavelength the sensitivity of CCD and CMOS sensors is virtually nil, and it is too short of wavelength for mid IR FLIR sensors. Assuming we are looking at this wavelength directly (that is, it falls within the sensitivity range of the sensor used), then it is amazing that the ABL and target radiate so significantly at this wavelength. More amazing is that the laser beam is visible and bright. Its clear that the beam is not pointed at the camera but rather transverse. A laser beam will not be visible from that angle unless there is a tremendous amount of atmospheric scattering. That amount of visibility and scattering means a large power loss that increases with range. This much scattering is not what is observed at ordinary visible wavelengths and is not part of common experience. If this is a FLIR video instead, then the only way the laser beam would be visible would be from absorption and re-radiation of the heated air. This too would be bad news since this would cause energy loss and thermal blooming.

The video images also have the curious feature of a gap between the ABL and where the laser beam becomes visible. This gap is hard to understand unless the engagement range is extremely small (the ABL takes up a large number of pixels).

The image below is from a frame from a video released of the 10-11 Feb 2010 tests. The arrangement is very similar to the mid January video. Note again that the highly directional, coherent laser beam appears to be as bright as the ABL platform and the target, even though it is viewed transversely. This is truly unusual. In addition, there is a black horizontal streak to the right of the ABL platform. It is visible in the frame below but is more obvious in the full video. This must be an artifact of some kind, but is a mystery.

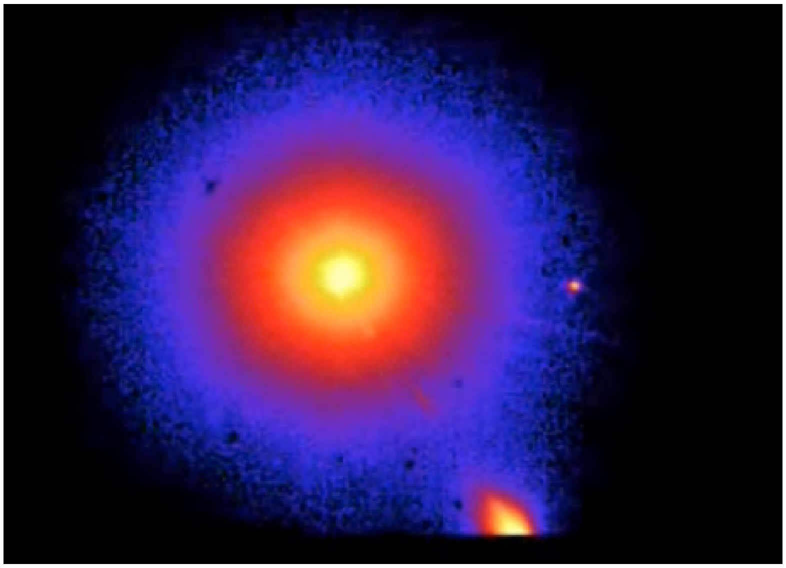


The following frame is from a video labeled as taken from the "cockpit." It is an unusual sensor that operates well at this wavelength. The remarkable feature of the beam in this image is how uniform it is. Lasers in general do not put out "top hat" beams, because such a profile is not a mode of a cavity. One would expect some kind of Gaussian beam that should be brighter towards the center. Another truly amazing feature of the beam is how well you can see it, even though one appears to be viewing it from a 50 - 60 degree backscatter angle. Additionally the backscatter is uniform along the entire beam, making the frame look artificial. This much scattering represents a significant power loss and would severely limit the range of operation.



The beam near the ABL (at the lower right corner) we know is about 1.5 meters in diameter. The image of the beam near the target is still resolved (that is, wider than a pixel, and wider than the piece that has been ejected from the target that is just below and to the right of the target). By estimate, the beam near the target is 1/10 in diameter that near the ABL. If the beam were collimated, then the range to the target would be approximately 150 meters. Of course, we expect the beam to be focused. Even with a spot size reduction of 50 (a level one would expect from the range of the whole beam Fresnel number at the COIL wavelength), then the range to the target is less than 10 km. This was a very short range test. Even with this level of focusing, one would expect the beam in the image to appear to be narrower at the target.

Finally there is a video sequence, presumably of a zoomed-in version on the target, in the same false color as the first video above. The geometry is of course unknown, as well as the sensor sensitivity range. The reflected beam appears to be circular which is a little curious, given that the target is basically a cylinder. It is possible that the image of the target is small enough to be unresolved, resulting in a circular image, but the ejected blobs, which should be smaller than the target, are elongated, and therefore somewhat resolved. In the frame below, taken from the 10-11 Feb 2010 released video, an elongated larger blob can seen on the bottom to the right of center.



Also curious, the ejected blobs seemed to fly straight out from the centroid of the image, at varying speeds. None of these blobs shows any path curvature, despite the fact that the target is rapidly moving. Interestingly, the blobs all appear to drop, that is, all appear on one side of the target. Nothing flies off upwards.

In summary, the test appears to be very short ranged. A highly directional, coherent laser beam is very uniformly visible along its entire path at angles that it should be nearly invisible. Such isotropic scattering is puzzling and unusual.

Relevant fundamental atmospheric laser propagation physics with adaptive optics discussed in:

1. S. Enguehard and B. Hatfield, "Compensated Atmospheric Optics," *Prog. Quant. Electron.* **19**, 239-301 (1995).

2. S. Enguehard and B. Hatfield, "Incoherency and Multiple Laser Guide Stars." NOAO Workshop on the Reduction of Gemini AO Data, February 2001. www.noao.edu/usgp/aow_pdf/enguehard.pdf

3. Redacted

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