MZA 20/20

Program Summary

MZA Associates Corporation

Airborne Laser Test Bed (ALTB) Modeling, Simulation, and Analysis

Since the Airborne Laser Test Bed (ALTB) system was conceived in the early 1990's, MZA has been a leader in modeling and analysis in support of the United States' flagship high energy laser (HEL) weapon. MZA provided risk reduction analysis during the initial conception and procurement of the system and then, starting in 2000, MZA provided the Airborne Laser System Program Office (ABL SPO) simulation, modeling, and analysis expertise in the areas of beam control, weapons performance prediction, and engagement analysis. As a long-time contributor to directed energy programs, MZA has played a crucial role in the Air Force Research Laboratory's ALTB risk reduction and advanced concepts demonstration programs. MZA provides as much experience modeling the key performance aspects of ALTB as any other single organization, including the ALTB prime contractors themselves.

1. The Airborne Laser Test Bed

In response to the need for boost-phase defense against ballistic missiles, the Air Force developed the Airborne Laser Test Bed (ALTB) concept, in which a megawatt class chemical oxygen-iodine laser (COIL) weapon carried aboard a modified Boeing 747 would be used to attack and destroy tactical ballistic missiles shortly after takeoff from hundreds of kilometers away. This concept presented many significant technical challenges, related to the size and power of the laser system required, the requirement to integrate it onto an airborne platform, and the extreme precision required in pointing and tracking and beam control. In February 2010 the ALTB team led by the Missile Defense Agency (MDA) conducted a successful "shoot-down" demonstration, in which the ALTB engaged and destroyed a boosting missile in flight, and then a short time later engaged a second missile. The prime contractor the program, the Boeing Company, was supported by major subcontractors Lockheed Martin for development of the beam control system and Northrop Grumman for the COIL laser device.

2. Concept Development and Risk Reduction Experiments

Early conceptualization and planning for the ALTB in the early 1990's centered around addressing the practicality of performing sufficient atmospheric compensation of a high energy laser at long ranges in order to deliver lethal fluence on boosting targets. Of key interest at the time was whether the then-current understanding of the propagation of coherent light through very long paths through the upper atmosphere was sufficient and whether the models of such propagation were accurate enough to predict the performance of the system. The Air Force Research Laboratory (AFRL) undertook several experiments to characterize upper atmospheric propagation and to anchor wave-optics models that would eventually allow accurate prediction of ALTB's beam on target. MZA was a key contributor to the design, conduct, analysis, and the anchoring of wave-optics models to these landmark experiments.

The Airborne Laser Experiment, ABLEX, completed in January 1993, propagated a laser beam between a transmitter and a receiver aircraft flying at high altitudes. In these experiments, the scintillation patterns resulting from propagation through atmospheric turbulence were recorded. From these patterns, the fundamental performance limits of phase-only adaptive optics systems could be determined. MZA developed algorithms to compute the Strehl ratios that would have been obtained by perfectly compensating the phase of the transmitted beam for atmospherically-induced aberrations. The results established that there were no fundamental physics limits that would prevent a phase-only adaptive optics (AO) system from providing sufficient atmospheric compensation for an effective ALTB system. In other words, an effective ALTB system could be built with current AO technology.

ABLEX did not and was not intended to provide design information for such a system. This was to be the subject of a follow-on program, the Airborne Laser Atmospheric Characterization Experiment, ABLE ACE, flown in 1995. MZA assisted in the design, implementation, and conduct of this experiment, the objectives of which were to anchor laser propagation codes and other propagation models in the regimes of interest for an ALTB and provide direct measures of ALTB performance characteristics over representative ALTB propagation paths. The key simultaneous measurements resulting from aircraft-to-aircraft propagation were 1) the differential phase between beams separated by a known distances at the transmitter plane, 2) resolved pupil plane scintillometry, 3) Shack-Hartmann wave front sensor images, 4) full-aperture focal plane imagery, 5) high-bandwidth scintillometry, and 6) aircraft nose-mounted aero thermal probe. Early in the development, MZA developed data acquisition systems to be flown on the aircraft and devised and implemented a high-speed high-volume digital data recording standard. As the experiment progressed, MZA developed a comprehensive data management and analysis system that was used to compute nearly all the significant results of the experiment. MZA was also responsible for developing most of the data processing algorithms that were used. During the flight test program stress birefringence on the transmitter windows resulted in corruption of the polarization of the dual beams. The most important measurement, that of differential phase necessary to quantify anisoplanatic effects, was dependent on separated polarization of the beams. When the polarization mixing problem arose, MZA devised an experiment-saving calibration scheme which helped ensure the utility of the resultant data. MZA was then key to analyzing and documenting the results of ABLE ACE, the findings of which were used to meet the requirements of Congressionally-mandated knowledge points which allowed the ALTB program to proceed to the next program phase. The ABLE ACE final report to which MZA contributed significantly was given the award of USAF Material Command publication of the year.

Satisfied with its understanding of the propagation of light between high-altitude targets, AFRL directed risk reduction experiments to the demonstration of the fundamental beam control concepts to be used on the ALTB. A key aspect of the design of ALTB involved the use of active illumination systems to perform non-cooperative tracking, aim point maintenance, and atmospheric compensation. To prove the fundamental technologies, AFRL undertook the development of the Airborne Laser Atmospheric Compensation Testbed (ABL-ACT) facility on North Oscura Peak (NOP) and Salinas Peak at White Sands Missile Range (WSMR). MZA helped to design the facility and was involved in the development of numerous atmospheric characterization devices including scintillometers, an differential image motion (DIM) r_0 meter, a scintillation-based anemometer, weather monitors, and atmospheric profilers. MZA also developed a low-cost high speed image capture system and designed and implemented the facility-wide personnel safety system which prevented inadvertent human exposure to non-eye safe lasers. MZA refurbished and installed the ABLE ACE telescope at the site and later designed and built the Coude path for the NOP 1-meter telescope and the illuminator laser insertion optics. At Salinas Peak MZA helped to instrument the surrogate target.

Throughout the life of ABL-ACT, MZA provided modeling support and analysis of experimental data. MZA helped plan data acquisition efforts and conduct the experiment operations, manning optical and control stations. ABL-ACT activities resulted in several successful campaigns including numerous peak-to-peak emulated weapons engagements and the peak-to-aircraft Dynamic Compensation Experiment (DyCE) and Non-cooperative Dynamic

Compensation Experiment (NoDyCE). MZA played key roles in understanding the data and in making recommendations concerning the performance of the system. The results of these AFRL experiments provided confidence in the fundamental approach underlying the design of the ALTB and served as milestones for the Undersecretary of Defense and Congress to approve the ALTB's continued funding and development.

3. High-Fidelity Beam Control System Modeling

As the ALTB program matured, the government required a high-fidelity model of the ALTB beam control system (BCS) in order to accurately predict the performance of ALTB against its target set. Having developed the reconfigurable wave-optics modeling tool called WaveTrain which had been anchored to the ALTB atmospheric characterization and compensation tests, MZA was chosen to develop ABLWOPM, a model which would be used to understand and predict the end-game performance of the ALTB from early system development, through laboratory tests, low- and high-power flight tests culminating in the first-ever HEL shoot-down of a ballistic missile from an aircraft in flight.

Early development of the ABLWOPM model centered around isomorphic modeling of the ALTB BCS taking into account all of the optics and control systems involved in the alignment, tracking, and adaptive optics compensation systems. The model was developed in such a way that each of the aircraft's optical components and control processing systems were represented to have a one-to-one correspondence between items in the design and components within the model. This allowed the model to be maintained as a true engineering model, changing the characteristics of model components as information concerning the performance of actual subsystem components became available. Eventually, every major aspect of the BCS was represented in ABLWOPM, taking into account all manner of calibration and measurement data. As the model matured, its ability to accurately predict the performance of the ALTB and to diagnose the effect of system design aberrations and modifications was used heavily by government and ALTB prime contractor alike.

The earliest concrete test of ABLWOPM was the BEE test conducted in a laboratory ALTB mock-up at Lockheed’s facilities in Sunnyvale, CA. During the combined tracking and adaptive optics experiment, the performance of the BEE system was evaluated. MZA’s WaveTrain-based models were used to reconstruct the experiment and a determination was made that the model matched the performance of the BEE system very well. In fact, there were a couple of alignment problems with the laboratory setup that resulted in less-than-anticipated performance. However, the laboratory misalignments were understood. Because MZA’s model was deemed to be reliable, the results of the model allowed analysts to conclude that, had the laboratory misalignments not been present, the BCS would have performed as expected. This finding allowed the ALTB program to proceed to the next phase without having to conduct additional laboratory tests which would have adversely impacted the program’s cost and schedule.

ABLWOPM was used to model ALTB’s Low Power System Integration (LPSI) and High Power System Integration (HPSI) ground and flight tests. MZA added test configuration items such as Surrogate High Energy Laser (SHEL) and instrumented mock targets. MZA analyzed the Tracker Illuminator Laser (TILL) and Beacon Illuminator Laser (BILL) systems to accurately model the delivered near- and far-field characteristics of the beam. A broad series of experiments were conducted which tested all of ALTB’s systems in preparation for the eventual boost-phase shoot-down of two ballistic missile targets in flight which occurred in February of 2010. These tests represent the first time in history when a military system was used to successfully destroy a ballistic missile in boost phase. ABLWOPM continues to be used to plan ALTB experiments and diagnose system performance.

4. System Performance Modeling

For ALTB, it is necessary to evaluate system performance over the entire timeline of an HEL weapons engagement including the possibility of consecutive multiple target engagements. Such analysis using wave-optics models like ABLWOPM is difficult because of the significant computer run-time required to execute even a fraction of a real-time second. Beginning in about 2000, the ALTB undertook the effort to upgrade its capabilities for engagement analysis and performance prediction with scaling codes. Scaling codes are HEL propagation representations that are compute average performance of the laser on target as opposed to the instantaneous performance considered by wave-optics codes.

Developing a scaling code that can make accurate performance predictions across a broad parameter space is itself a significant challenge, because the approximations that may accurately describe one part of the space, such as the low turbulence regime, often break down when one pushes the limits of the operational regime, and that is precisely where it is most important to be able to make accurate predictions. As a result, early attempts at scaling codes often required large “fudge factors” to ensure that their predictions matched those of wave optics codes at specific well-anchored design points, but they were not able to make similarly accurate predictions in between the chosen design points. The first HEL scaling codes of which we are aware to achieve accurate predictions across the system parameter space without the use of such fudge factors are SHARE and SCALE, codes now maintained by MZA personnel. SHARE can be used to model a wide variety of HEL weapons systems and engagements, including engagements involving Relay Mirrors, whereas SCALE is essentially a specialized version of SHARE, developed specifically for modeling ALTB engagements.

Using scaling codes in place of wave optics codes to speed up the simulation of the closed loop portion of the engagement makes it feasible to model longer engagements, multiple engagements (1-on-n & m-on-n), and to model and evaluate the many other aspects of the system that also need to work correctly if the system is to fulfill its mission, such as target acquisition, coarse track, the hand-off from coarse track to fine-track, and variations in the closed loop system performance throughout the course of the engagement. MZA has developed detailed models of the entire BMC4I system for the ALTB, including all the finite state machines used to implement the system and the messages exchanged between them. This kind of modeling can be useful in system design, troubleshooting, maintenance, mission planning, training, and for integration into larger systems-of-systems models.

5. Advanced Concepts Development and Assessment

Throughout the 1990’s and into the early 2000’s, MZA supported the development and evaluation of advanced concepts intended to improve the performance of the ALTB. MZA investigated new adaptive optics concepts, performed illuminator trade studies, and did analysis on alternate missions for the ALTB. MZA’s modeling and analysis expertise were heavily utilized to determine which concepts were better and eventually resulted in recommendations for upgrades as the ALTB program matures.

6. Test Support

MZA has provided support for ALTB mission test planning and post-test analysis throughout the various phases of the ALTB test program. ALTB conducted several high energy laser engagements against boosting targets. For all these tests, results from ABLWOPM and SCALE were used to plan the engagement geometry and predict the performance of the ALTB against the target. After the tests, both models were used to analyze the results and develop inferences regarding the performance of ALTB components that cannot be directly measured. MZA was a regular participant in test planning meetings and in test results data reviews.

7. Summary

MZA has provided modeling, simulation, and analysis support to the Airborne Laser (ALTB) program from its conception since the early 1990's through man's first successful demonstration of an airborne laser weapon shoot-down of a boosting ballistic missile in flight. As a long-time contributor to directed energy programs, MZA played a crucial role in the Air Force Research Laboratory's ALTB risk reduction and advanced concepts demonstration programs and later MZA provided direct support to the Missile Defense Agency's (MDA) Airborne Laser System Program Office (ABL SPO) simulation, modeling, and analysis in the areas of beam control, fire control, battle management, weapons performance prediction, and engagement analysis. MZA continues to support the Missile Defense Agency in extended experimentation and test of the ALTB including performing research and analysis for future MDA directed energy systems.

MZA 20/20: Celebrating 20 years of technical excellence and service to the United States Armed Forces and looking forward with clear 20/20 vision.

MZA is commemorating its 20th anniversary through the MZA 20/20 initiative, part of which includes publishing a series of articles that provide an on-going retrospective of twenty significant accomplishments that MZA has made to the industry throughout the company's history. This document was written by the staff of MZA to recognize one of those accomplishments. For more information about MZA Associates Corporation and its 20/20 initiative, visit the MZA website at www.mza.com.

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Written by the staff of MZA Associates Corporation with various information taken from publicly-available summaries.

Current as of November 2011.