MZA 20/20

Program Summary

MZA Associates Corporation

Airborne Laser Extended Atmospheric Characterization Experiment (ABLE ACE)

Early planning and development of the Airborne Laser (ABL) concept in the early 1990's addressed 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 the ABL's beam on target. ABLE ACE, the Airborne Laser Extended Atmospheric Characterization Experiment, was the second of the major atmospheric characterization efforts undertaken to answer these questions. MZA was a key contributor to the design, implementation, and conduct of the experiment and lead the data analysis and anchoring of wave-optics models to this landmark experiment.

1. ABL, ABLEX, and ABLE ACE

In response to the need for boost-phase defense against ballistic missiles, the Air Force developed the ABL 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[1]. AFRL conducted the ABLEX and ABLE ACE experiments to characterize the effect of scintillation on the propagation of coherent light, establish an upper-bound on the efficacy of phase-only compensation, characterize the effects of anisoplanatism, and to anchor the wave-optics modeling algorithms to be used in the design the ABL.

During the ABLEX flights of January 1993, a pulsed laser beam was propagated between a transmitter and a receiver aircraft flying at high altitudes[2,3]. 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 were determined. The results established that there were no fundamental physics limits that

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[1] In February 2010 the ABL team led by the Missile Defense Agency (MDA) conducted a successful "shoot-down" demonstration, in which the ABL 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. The acronym for the ABL has since been changed to ALTB for Airborne Laser Test Bed. (http://en.wikipedia.org/wiki/Airborne_laser)

[2] L. D. Weaver and R. R. Butts, "ABLEX high-altitude laser propagation experiment", Proc. SPIE 2120, 30 (1994). (http://dx.doi.org/10.1117/12.177697)

[3] R. R. Butts and L. D. Weaver, "Airborne laser experiment (ABLEX): theory and simulations", Proc. SPIE 2120, 10 (1994). (http://dx.doi.org/10.1117/12.177690)

would prevent a phase-only adaptive optics (AO) system from providing sufficient atmospheric compensation for an effective ABL system. In other words, an effective ABL system could be built with then-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 which became known as ABLE ACE.

The ABLE ACE Argus Aircraft Over Japan's Mount Fuji[4]

Following ABLEX there remained significant questions concerning the applicability of wave-optics codes in the prediction of phase-only adaptive optics correction through extended turbulent paths, the effects of anisoplanatism, and the tracking and adaptive optics bandwidths necessary to sufficiently point and compensate an airborne high energy laser. ABLE ACE was commissioned with the task of providing additional high-resolution measurements which would serve to anchor laser propagation codes in regimes of interest for ABL and provide direct measures of ABL performance characteristics over representative ABL propagation paths.

ABLE ACE was a high-altitude, laser-propagation experiment in which a series of measurements were made of laser propagation between two aircraft flying at 13 to 14 km altitude and at up to 200 km separation[5,6]. Under the AMASS contract with the Phillips Laboratory, MZA supported the initial analysis and design of ABLE ACE and was tasked with the development of data acquisition and data analysis systems for the experiment. During the conduct of the experiment, MZA supported calibration and data acquisition operations. Finally, following the experiment MZA gathered, collated, managed, and analyzed nearly all of the data from the primary measurements.

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4 Photo by Dr. Mark Kramer, Phillips Laboratory, ABLE ACE Transmitter Aircraft Lead Engineer.

5 D. C. Washburn, "ABLE ACE, A High Altitude Propagation Experiment," Proc. SPIE 3065, 296 (1997). (http://dx.doi.org/10.1117/12.281021)

6 D. C. Washburn, et. al., "ABLE ACE Final Report", Phillips Laboratory, PL-TR- 96-1084, Volumes I-III, Limited Distribution, 1996.

2. Experiment Design

MZA assisted in the specification of the measurements to be made on ABLE ACE. MZA conducted numerous simulations and analysis efforts which identified the fundamental requirements and limitations of the measurements. MZA also simulated the measurements using wave-optics codes and verified the ability of post-analysis routines to extract meaningful information from data corrupted by anticipated measurement artifacts. Under subcontract to MZA, Russ Vernon and Dr. Don Link of SAIC and Dr. Wilbur (Bill) Brown performed significant wave-optics analysis in support of the pre- and post-analyses of the experiment[7].

In the end, there were more than a dozen distinct complex science measurements taken on ABLE ACE. The most significant were the Differential Phase Experiment (DPE)[8,9], the Pupil Plane Imager (PPI)[10], the Far-Field Imager (FFI), the Shack-Hartmann Wavefront Sensor (WFS)[11], the High Bandwidth Scintillometer (HBWS)[12], Thermal probes or anemometers, and the Global Tilt Measurement (GTM).

3. Data Analysis System

MZA developed the ABLE ACE Data Analysis System (DAS) which comprised a suite of computer hardware and software designed to assist in the organization, management, and analysis of data recorded during the ABLE ACE experiment. The main goal of the DAS was to provide analysts convenient access to sophisticated data analysis capabilities that allow them to investigate the statistics of the data as well as correlations between the individual measurements and environmental conditions. The functional requirements of the DAS were quite formidable since it had to provide mechanisms for recording, managing, and analyzing data from more than a dozen data recorders, each with differing requirements related to data type, bandwidth, and volume. In addition, the DAS was required to provide quick-look analysis capabilities that would allow analysts to identify, diagnose, and fix experimental problems between sorties.

To support the effort, MZA developed the Tagged Acquisition File Format (TAFF)[13] to provide a mechanism to record both high rate and low rate data in an efficient form and in a manner that would work for multiple platforms and media. MZA also specified the data acquisition media (primarily magnetic DAT tapes) to ensure it was sufficient for all purposes.

By far, the most complex bulk processing performed was on the DPE, PPI, and FFI data. Because processing of these sensors involved a significant amount of computation, MZA devised time-saving methods by which each frame of data could be preprocessed and intermediate results stored. This allowed analysts to retrieve the intermediate results and

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[7] W. P. Brown, "Simulation of laser propagation on long stratospheric paths", Proc. SPIE 3065, 313 (1997). (http://dx.doi.org/10.1117/12.281024)

[8] G. A. Tyler, et al., "The Differential Phase Experiment: experimental concept, design analysis, and data reduction analysis", Proc. SPIE 3065, 367 (1997). (http://dx.doi.org/10.1117/12.281028)

[9] L. D. Weaver, "Robust phase-measuring interferometer for airborne applications", Proc. SPIE 3065, 307 (1997). (http://dx.doi.org/10.1117/12.281022)

[10] S. C. Coy and R. W. Praus II, "The ABLE ACE Pupil Plane Imaging Experiment", Proc. SPIE 3065, 394 (1997). (http://dx.doi.org/10.1117/12.281029)

[11] R. R. Butts, "The ABLE ACE wavefront sensor", Proc. SPIE 3065, 339 (1997). (http://dx.doi.org/10.1117/12.281026)

[12] B. P. Venet, "High-altitude optical scintillometry", Proc. SPIE 3127, 332 (1997). (http://dx.doi.org/10.1117/12.283914)

[13] R. W. Praus II, et al., Tagged Acquisition File Format (TAFF) Specification, Version 1.0, MZA Associates Corporation, MZA-AMASS-94-003-TR, 1996.

compute interval statistics based on arbitrarily chosen intervals. Without storage of the intermediate results, analysts would have to choose the intervals over which they average before the properties of the data were known. In addition, storage of the intermediate results avoided having to repeat the same computations on data simply because an analyst's choice of intervals had changed. The method of storing intermediate results is conceptually simple, but was actually very complex to implement.

The ABLE ACE Flight Patch

The analysis routines for DPE, PPI, and FFI using one or both of the two 532 nm science laser beams shared similar architectures. For each, the automated processing took place in three distinct stages: (1) frame preprocessing, (2) frame processing, and (3) interval processing. In frame preprocessing we computed our best estimate of the physical quantity we are trying to measure from the raw data. In frame processing we computed and recorded quantities for each frame that we later needed when we have selected an interval of frames over which to compute statistics. The point of frame processing is that it was possible to choose the intermediate quantities to be recorded so that the great majority of the necessary computation can be done before deciding what intervals to average over; this makes it inexpensive to pick new intervals, or to use techniques such as sliding-window averaging. It also turns out to be possible to greatly compress the data at this stage; two-dimensional quantities such as correlation functions can be replaced by x-, y-, and azimuthally-averaged slices. In interval processing we used the quantities recorded in frame processing to compute statistics over a chosen interval. Intervals are generally chosen such that the atmospheric statistics are thought to remain relatively stationary throughout the interval. Often, we simply used a sliding-window of a length shorter than the typical time-scale of the variations in C_n^2.

4. Experiment Challenges

Once gaining access to early flight data, MZA discovered a serious source of corruption of the marquee measurement, the Differential Phase Experiment (DPE). The interferometric nature of DPE required that the two beams used in the experiment be transmitted in a manner which was orthogonally polarized so that they could be separated and measured individually at the receiver. Unfortunately, stress birefringence in the transmitter windows caused polarization mixing between the beams and corrupted the measurements. MZA principal Steve Coy devised a technique by which the amount of polarization mixing could be established and removed by providing transmitting interleaved calibration shots, one beam at a time. This allowed the conduct of several additional flights which did not suffer from the polarization mixing. MZA's Phillips Laboratory customer wrote of MZA's contributions[14],

> *"Their untiring efforts were key in the ultimate success of the ABLE ACE project, a project which was awarded the AFMC Scientific Achievement Award for 1995. Through careful examination of the data, MZA discovered problems with the Differential Phase Experiment, the highest priority experiment on ABLE ACE, and devised strategies for solving those problems. Without their crucial contributions, ABLE ACE would have failed."*

The primary MZA contributors to the ABLE ACE program were Bob Praus, the MZA program manager who designed the ABLE ACE Data Analysis System and spent nearly two years combing through and processing the data, Steve Coy, who devised the data processing scheme and the DPE calibration process, Greg Cochran, who did some of the earliest wave-optics modeling of DPE, Zane Dodson, who developed the data acquisition and on-the-fly processing software, and Michele Praus, who provided administrative support and helped to format and edit the final report.

5. Conclusion

With MZA's help, the Phillips Laboratory continued to analyze this rich set of data for more than two years. The primary scientific result of the effort was to establish the validity of wave-optics models in accurately predicting optical propagation phenomena in the regime applicable to the Airborne Laser. The practical result of the effort was to allow the Airborne Laser program to pass a congressionally-mandated knowledge point that resulted in its continued funding. Dr. Don Washburn, the ABLE ACE program manager, Dr. Russell Butts and Dr. Boris Venet, key ABLE ACE scientists and significant contributors to the field of adaptive optics compensation, eventually became MZA employees themselves after they left government service many years later. For that matter, Russ Vernon and Dr. Don Link also later joined MZA as employees. For their efforts, the Phillips Laboratory ABLE ACE team won the Air Force Material Command's Scientific Achievement Award for 1995 and the Phillips Laboratory Lasers and Imaging Directorate Outstanding Publication Annual Award in 1997.

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 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 Bob Praus with various information taken from publicly-available summaries. Current as of April 2012.

[14] Dr. R. Butts and Dr. D. Washburn, Phillips Laboratory, open correspondence with MZA principals Steve Coy and Bob Praus, circa 1995.