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ADVANCED LIDAR AND SENSOR FUSION TECHNOLOGY DEVELOPMENT FOR REMOTE OPTICAL SENSING

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Final Report

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"This technical report has been reviewed and is approved for publication"

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14. ABSTRACT The objective of this program was to perform a coordinated research effort employing complementary electro-optical techniques to characterize optical and infrared propagation through the atmosphere. This effort included measurements of the parameters that affect propagation, at several wavelengths, under meteorological conditions of interest to DoD. Under this program we performed acquisition, reduction and interpretation of data using lidar techniques (both coherent and incoherent) and visible and infrared transmissometry. This included: Detection, tracking, and discrimination; Measurement of temporal and spatial chemical agents, rocket effluents, and airborne particulates and evolution of release gas and aerosol concentrations for development/verification of dispersion models; Spectral characterization of atmospheric and terrain backscatter for input to performance studies for future airborne DIAL and Doppler lidar systems; Real time ballistic wind measurements for demonstrating and testing Doppler wind sensing lidar tactical applications as well as in support of munitions and delivery system tests; Development of compact eye-safe lidar systems for airborne applications.

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1. PROGRAM OBJECTIVES

The objective of this seven-year program was to perform a coordinated research effort employing complementary electro-optical techniques to characterize optical and infrared propagation through the atmosphere. This effort included measurements of the parameters that affect propagation, at several wavelengths, under meteorological conditions of interest to DOD.

Under this program we performed acquisition, reduction and interpretation of data using lidar techniques (both coherent and incoherent) and visible and infrared transmissometry. This included:

- Detection, tracking, and discrimination of chemical agents, rocket effluents, and airborne particulates;
- Measurement of temporal and spatial evolution of release gas and aerosol concentrations for development/verification of dispersion models;
- Spectral characterization of atmospheric and terrain backscatter for input to performance studies for future airborne DIAL and Doppler lidar systems;
- Real time ballistic wind measurements for demonstrating and testing Doppler wind sensing lidar tactical applications as well as in support of munitions and delivery system tests;
- Remote detection and characterization of localized manmade wind disturbances as signatures of hidden vehicle and installations
- Remote measurement of atmospheric turbulence and detection of wind shear;
- Development of compact eye-safe lidar systems for airborne applications

The research effort was performed over a seven-year period. It consisted of the acquisition and reduction of data using techniques and instruments that were already implemented. In the second and third years we continued data acquisition with all instruments, while beginning to concentrate on developing and improving the analytical techniques used in analyzing the data. The fourth year completed the data acquisition, with concentration upon presentation of coordinated results in a form most useful for development of models to be used in Air Force systems design and evaluation.

2. Chronological Sequence

2.1 First Year

This effort started in the second quarter of 1996, the work consisted of: (1) writing scanner software for the measurement of plumes (2) fielding of the Doppler lidar trailer and (3) modification and testing of the MAPM system. Details were discussed below.

We wrote, debugged, and installed new scanning routines for both the Doppler and MAPM systems. Simple azimuth and elevation scans were quickly commanded by a couple of keystrokes. The data from a scan was displayed in a three dimensional format which uses color or gray shading as the third dimension to show SNR or velocity.

Control of the MAPM scanner by these new routines was sporadic due to a serial communications problem. The program could control the scanner, but there was a short delay after each pointing command because of miscommunication between the scanner controlling computer and the master computer.

The Doppler trailer was deployed to WSMR for a test that was delayed due to problems on the range. The system was made operational at the site and then left unmanned until the test was to take palce.

The first DIAL measurements were made with MAPM during this quarter. Though the system was not yet fully functional, it was able to perform routine measurements. Absolute atmospheric water vapor concentrations were measured along a horizontal path using four different CO_2 lines at wavelengths (10.233, 10.247, 10.260, and 10.303 μm). Each line has a different absorption coefficient for water vapor and by comparing the differences in their returns we quantified the ambient water vapor concentration.

A video camera was installed on the scanner to help direct the lidar's line-of-sight. After a coarse boresighting of the camera, the 'kick' mirror was then adjusted to bring the optical axis of the telescope up through the scanner such that it was parallel with the scanner's two axes of rotation. Pointing accuracy was confirmed by aiming at distant hard targets such as the Raytheon building in Bedford (3 km range).

Frequency jitter was a continuing problem with one of the TEA lasers, and weak output power was a continuing problem with the other. Since the lasers were a 'matched set' it was difficult to understand why only one would jitter. Mechanically, there were some very weak areas to be considered for upgrading in these lasers: the grating mounts had an unreasonable amount of backlash and/or slop in their angle tuning micrometers, and the output coupler mounts had a somewhat coarse and springy tilt adjustment that made alignment difficult. We planned to research what replacements (if any) were available for these parts.

Software for the MAPM system was upgraded from the original Doppler Lidar operating program. Through the use of a digital I/O board, the program can now control the pulse repetition rate of the two TEA lasers. Through the use of a custom built TEA trigger gate controller, the software (also through the digital I/O board) can select which TEA was permitted to trigger the data acquisition. This capability (along with a change in the data handling and display software) now allows the interactive interlacing of shots from the two lasers and allows the data from each laser to be binned separately.

Focusing of the telescope was studied as a means of improving the overlap function and thus the SNR at ranges > 3 km. A wide range of settings for the telescope secondary were used to measure the backscatter return as a function of distance. At all settings of the secondary (focus) the falloff of the return was much faster than theory suggests. We felt it was possible that better beam matching of the local oscillators to the outgoing TEAs was required in order to see any improvement in overlap. As a beginning to an improvement in beam matching, the positions of the two CW local oscillators were adjusted to give the correct size beam at the beam expander. The two oscillators were also relocated relative to one another such that their optical paths to the beam expander were equivalent.

Several improvements were performed along the lines of making the MAPM system road worthy. Clear plexiglass dust covers were put in place over all of the optical elements. Gas cylinders were placed at the back of the trailer next to the TEA power supply racks where they were more convenient and easier to load/unload and ship. The water chiller was placed in the forward room where its heat load was immediately absorbed by the air conditioner and its noise was less annoying.

The following list was compiled of possible measurements that MAPM could attempt:

- Further water vapor measurements, specifically range resolved horizontal and vertical profiles.
- Ozone: ambient levels were on the order of 50 ppb. A very rough estimate puts the MAPM capability at about this ambient level.
- Jet exhaust at Hanscom field.
- Differential backscatter from available hard targets: runways, buildings, trees...
- Low elevation water vapor gradient map (to be compared to a topographic map).
- (Differential) depolarization by targets, dust, water droplets, and ice crystals.
- Atmospheric turbulence by speckle time correlation (CO_2)

During the third quarter, the work consisted of (1) writing scanner software for the measurement of plumes (2) fielding of the Doppler lidar trailer and (3) modification and testing of the MAPM system.

Communications problems continued with the scanner computer in the MAPM system. At the time, the master computer told the scanner control computer where to point and then continually queried the scanner computer to determine when the scanner was pointed in the requested direction. A modification of the software was being discussed which would allow simultaneous scanning and data taking. This technique would be particularly useful for the quick high-resolution scans required for 'helicopter' down-wash measurements.

The Doppler trailer was deployed to WSMR in the previous quarter for a test that was delayed due to problems on the range. The test took place on 20 July 1996. We helped with the preparation of a quick look report on the data as well as the detailed report.

The Doppler trailer was shipped back to Hanscom for several improvements and modifications of its infrastructure. The water chiller and gas cylinder positions were swapped. This change greatly decreased the length of the gas lines (decreasing the number of in-line fittings that were likely sources of leaks.) Moving the chiller allowed the installation of a large Vidmar cabinet that was ideal storage space for the CW lasers during shipment.

The Doppler trailer was shipped to the Starfire Optical Range in New Mexico for wind measurements pertaining to atmospheric turbulence. The tests were scheduled to take place in October 1996.

A new 8-mm video camera was installed on the scanner. The new lens camera included a remote zoom feature that is helpful in pointing at targets.

A weather station was installed on the MAPM trailer. The station records ground conditions at the trailer (various sensors outside the trailer measure the temperature, wind speed and direction, humidity, rainfall, and dew point).

Several more improvements were performed along the lines of making the MAPM system transportable. The most important of these modifications was the installation of a small crane. The purpose of the crane was to expedite the removal and installation of the 300-pound scanner.

We performed preventive maintenance on TEA 1. This entailed the changing of the Brewster windows on both the TEA can and the gain cell. The most difficult part of the process was the realignment of the laser after these changes.

DIAL water vapor measurements were made on 2 July 1996 in concert with a radiosonde launch. The data was analyzed and formed the core of a paper presented at the

Fog meeting in St. Louis. Later that same day, there was a satellite overpass and we recorded coordinated cirrus structure and wind data for about three hours around sunset.

Differential backscatter from various targets (i.e., runways, buildings, trees...) was imaged using two different CO_2 wavelengths. The laser lines chosen were at the low and high ends of the operational wavelength range: 10P(28) and 9P(14) that were at 10.675 μm and 9.501 μm respectively. The ratio of backscatter returns from these two lines showed a distinct trend that was dependent on the type of target.

During the forth quarter, the work consisted of: operation of the Doppler lidar trailer at the Starfire Optical Range (SOR) in New Mexico and analysis of the data obtained, software modifications of the data acquisition system for both the Doppler and MAPM systems, MAPM scanner software modification, and testing of the MAPM lidar system. In addition, we performed further analysis of data taken at PHETS in July 1996.

The Doppler lidar system was operated in October at Kirtland AFB in concert with SOR optical turbulence experiments. Software modifications were done in the field to provide the SOR personnel with both wind and relative backscatter data files at the end of each measurement period. A number of instrumental problems were encountered during this measurement period. In particular, the preionizer assembly on the TEA laser was replaced to solve a laser misfire condition that had been worsening since the summer operations of the system at PHETS. Another intermittent problem with the laser stabilization pulse frequency counter was traced to a power supply. This supply was temporarily replaced in the field, with permanent correction planned to be performed when the system was returned to Hanscom AFB.

Given the large increase in speed of x86 host improvements in the last several years, tests were made to determine the merit of host FFT processing with a Pentium 200 MHz based machine relative to the parallel ATT DSP32c processing we had used since early to mid 1992. The host FFT processing sections of code were written in hand optimized assembler language. The result was that single serial Pentium 200 MHz processing significantly outperformed the dual parallel DSP32c processing. Given this result, work began on modifying the Doppler/MAPM software to enable either processing technique to be used.

Completely abandoning the parallel DSP32c based system was not considered prudent until both systems had updated computers installed and the software was fully checked out on both systems. This new software feature was expected to be completed by the end of the next quarter.

The causes of occasional MAPM scanner driver time out errors were located and corrected. The data acquisition code was modified to allow for capture and storage of large volumes of raw shot data during preprogrammed scanning. In addition software modifications were done to allow for acquisition of data from short time-delayed pulse pairs. Also, much work was done towards converging the lidar system code used in both the Doppler and MAPM trailers. The goal of this work was to have only one code base that operated both lidar systems. Required device differences, e.g., the very different scanner interfaces required, will be handled with conditional compilation. This will greatly simplify maintenance of the code.

Additional testing and water vapor measurements were made with the MAPM system. This data has not been fully analyzed as yet.

2.2 Second Year

During the first quarter of 1997, the work consisted of modifications of the lidar control and acquisition system for both the Doppler and MAPM systems. Also, testing and installation of a new signal digitizer, system layout modifications of the MAPM trailer in preparation for shipment and consultation with the program office on the measurement plan for upcoming MAPM lidar deployments.

The assembler encoding and optimization of the FFT processing was completed. In addition, the acquisition code was modified so that it could use for signal digitization either the CAMAC based DSP2012F's (as previously employed) or the Signatec DA60 card. This modification allowed conditional compilation for either device. Full tests of the DA60 card were planned for the next quarter. Initial assessments indicated that use of the DA60 and the optimized assembler with a Pentium 200 host, would at least double achievable data acquisition rates. In addition, we had neared completion of the work on unifying the codes employed by the Doppler and MAPM systems. Although tests had proceeded using the updated code on the MAPM system, full installation and testing on the Doppler trailer had to wait until it returned from SOR. We had also assisted in evaluating the operation of the lidar control and acquisition code under Windows 95. Although this was still in a test phase, no significant slowdown (e.g., due to time slicing) has been found. A DMA bus data transfer bug did become apparent in Win32 that was not a problem under DOS (in both real and protected mode). The source of this error was found and corrected. The near-term motivation for operating under Windows 95 was to be able to use standard and well supported network software to rapidly transfer data to other computers for backup as well as "off-line" analysis in parallel with continuing data acquisition. Towards this end, we had also assisted in networking the system control computer with another computer in the trailer. Tests of this system were proceeding.

We had also assisted with the many modifications of the electronic, optical, and mechanical layout of the trailer required to ensure that no damage was incurred on road shipment of the trailer and also to lessen the work and time involved in the system breakdown and setup. This included: construction of assemblies for securing the scanner, gas cylinders, and racks; addition of signal wire conduits for routing; merging the control components of the two TEA lasers into one rack; and reorganization of the signal and triggering electronics.

During the second quarter, we made three field trips to operate the PL/GPO Doppler lidar system at Kirtland AFB in support of Starfire Optical Range measurement programs. These trips were on 5/24 to 5/31, 6/8 to 6/15, and 6/30 to 7/3. Wind and relative backscatter measurements were made with the data delivered to Starfire Range personnel. The operation was mostly routine with some minor repairs of frequency locking electronics needed. We had also acquired a Pentium II computer and ordered a PCI bus digitizer card for upgrading the Doppler data acquisition system. We planned to write the necessary device driver code to support the new digitizer in the next quarter and install the upgraded system whenever the Doppler trailer was returned to Hanscom AFB.

Additional software modifications of the MAPM data acquisition system were made to provide for higher spatial resolution measurements of high SNR data, accumulation of a mean laser PSD, and more accurate zero velocity bias. Some system electronic modifications were made to improve system performance: notably, the high gain signal amplification stages were repackaged and relocated to reduce RFI pickup.

MAPM trailer layout modifications continued and the packing was begun for shipment of the system to Cape Canaveral for the upcoming launch support measurements. We consulted with the program office on the basing and support required for the upcoming mission and helped prepare documents on trailer safety procedures and exterior system eye safety.

We prepared and delivered a 20-30 page report on error sources in the unguided parachute delivery of payloads. This report included the effects of release algorithm inaccuracy, wind error, mechanical turbulence, convective wind structures, payload weight and parachute performance variations.

The major effort in the third quarter was a collaboration with Lt Col John Roadcap in writing a paper for the August SPIE meeting covering the MAPM system design, construction, and operational performance. In particular, this paper documented MAPM's ability to make DIAL, Doppler wind profile, as well as aerosol and cloud MAPM measurements. We also attended this conference and delivered the paper. In addition, we began writing the driver software required for use of the newly acquired PDA12 signal acquisition card and consulted on technical issues related to the precison air delivery (PADS) program.

During the final quarter of 1997 we (1) continued adapting the Doppler and MAPM acquisition software for use of the PCI PDA12 digitizer.(2) assisted with preparing the Doppler trailer for shipment back from Kirtland AFB to Hanscom. (3) Consulted on technical issues related to the precision air delivery (PADS) program as well as attending the PADS conference at Hanscom in December.

2.3 Third Year

Most of the work in the first quarter of 1998 was involved with packing, shipping, and installing the MAPM system at Kennedy Space Center, Florida. In addition, we operated this system during an experimental burn test on February 19. The data obtained--wind field maps, vertical wind profiles, and burn plume images--were further analyzed post-mission and delivered to the program office and Air Force CCAS personnel. An additional trip was made to KSC in March to prepare the system for a required move. We also consulted on the plans for future measurements at Kennedy and assisted with modifications and upgrades to the Doppler trailer at Hanscom. In March, we also began an effort to calibrate and upgrade the PEELS lidar. The early tests of this system were of the bandwidth and noise performance of the detectors/preamplifiers. In the next quarter, we planned to study and implement detector, transmit and receive optics, software, and scanning improvements as well as to characterize the required geometry for the end-to-end calibration of this system.

A number of tasks were performed during the second quarter to refurbish and improve the systems on line. We repaired the MAPM laser HV power supply and the DA60 digitizer, both of which malfunctioned during the February 19 Kennedy test burn data trials. In addition, we performed more data reduction/display of the February 19 test burn results. In planning for coverage of the STS-90 launch, we made data acquisition code modifications, wrote Excel Visual Basic Macros for display of real time data, and tested out telephone networking for the real time transmission of wind fields to the Canaveral Range Safety Office. We traveled to Canaveral on April 9-12 for coverage of this launch; however, launch coverage clearance was not forthcoming so we left after installing the repaired components.

A number of PEELS system improvements were made: impedance matching of the amplifier output to reduce noise; an evaluation of the transmitted beam shape and divergence was made followed by realignment and adjustment of the beam expander; new PEELS data acquisition software was written and tested. We also evaluated various options for improving the detector technology including near-IR PMT's and InGaAs APD's. A calibration target was made with a sample of the material sent to Surface Optics Inc. for absolute measurement of its backscattering coefficient.

In June, we began consulting with the Project Office on the deployment of the Doppler lidar to Holloman AFB in support of the SMV trial releases.

The effort in the third quarter was two fold, with the major effort being the improvements in the PEELS system. The other effort was a field trip to Holloman AFB, NM. .

We completed the evaluation study of detector technology with the choice clearly being an InGaAs APD that, by specification, should improve range resolution by a factor of ten to about 30 m while lowering the NEP per root bandwidth by a factor of from 3 to

6. We ordered such a detector/amplifier and planned to install and test it in the next quarter. We also performed calibration target measurements and reported the preliminary results. Some discrepancies were seen between the nominal and observed attenuation of the neutral density filters used in the calibration measurements. These filters were re-calibrated. Additionally, there was a discrepancy between the observed relative depolarization in the lidar calibration target data and the target material calibrations made for us by Surface Optics.

We assisted in equipping, packing, shipping, and installing the Doppler trailer system near the flight line at Holloman AFB, NM. From 7/30 to 8/14, we operated this system for early morning real time wind profile measurements for the SMV team.

In the final quarter of 1998 the new InGaAs APD detectors were installed and tested. Additionally the re-calibrated measurements for the neutral density filters were inspected and found to provide more realistic interpretations of the PEELS calibration measurements. We had to locate the source of the discrepancy of the polarization calibration as discussed previously.

We assisted in the re-siting of the Doppler trailer at Hanscom AFB and with the analysis of the SMV data.

2.4 Fourth Year

Wwe began the design of an Excel application for viewing MAPM wind data delivered in real–time to a remote site via a network. In addition we assisted with the design and constraints on such a network connection as it was currently planned for use at KSC and CCAS during shuttle launch coverage. Relative to the technical mission issues, we traveled to a toxic hazard meeting at Kennedy Space Center where we presented a briefing on the capabilities of the MAPM system and a review of the data types provided during the 02/19/98 test burn. We consulted after this meeting on the safety, modeling, and other technical issues raised at the meeting.

In the second quarter we covered the June, 1999 shuttle launch with the MAPM system. On the days prior to launch, we realigned the lidar system and tested the lidar as well as the network communication system for providing real time wind profiles. For six hours prior to launch we performed Doppler lidar wind profiles with input of this data to ROCC personnel.

The third quarter mainly dealt with discussions concerning plans for future shuttle launch coverage.

The main effort of the fourth quarter was the coverage of the STS103 shuttle launch. Real time wind profiles were provided to the ROCC for six hours prior to launch. For approximately 30 minutes after launch we tracked the low altitude plumes. Image product of the initial processing of this later tracking data was delivered within two weeks after the launch.

2.5 Fifth Year

During the first quarter of 2000, Visidyne finished analysis of the MAPM data collected on the shuttle launch covered in December of the previous year. In addition, we arranged for shipment of the MAPM trailer back to Hanscom AFB. In March we began assisting in planning, software, and hardware modifications of the MLT and MAPM lidar systems for the TREX Phase I program.

During the second quarter of 2000 Visidyne:

- Assisted in planning and system modifications of the MLT and MAPM lidars for use in the TREX Phase I program.
- Participated in the operation of the MAPM system at Hanscom AFB and in data analysis in support of a joint NASA/AF program to compare GPS based sonde to Doppler lidar results.
- Arranged for shipment to Dugway Proving Ground of the MAPM, MLT, and AFCPR systems for TREX I.
- Assisted in setting up the MAPM and MLT systems at Dugway Proving Ground for TREX I.
- Was involved in operation of MAPM and MLT systems during the first TREX Phase I tests.

The third quarter of 2000 covered the end of the Phase I TREX field tests and the beginning of the Phase II tests. During this time Visidyne:

- Was involved in operation of the MAPM and MLT lidars at Dugway Proving Grounds during the final test releases of the TREX I program.
- Assisted in packing the MAPM and MLT systems.
- Arranged for shipment of the MAPM, MLT, and AFCPR systems back to Hanscom AFB.
- Analyzed the MAPM TREX I field data and supplied final calibrated to M. Egan.
- Assisted in planning and system software and hardware modifications for the TREX Phase II tests.
- Assisted in MLT planning and modification required for an LLLTV field test.
- Arranged for or assisted in packing, shipment, and installation of the MAPM, MLT, AFCPR, and WYDAH systems to WSMR for both LLLTV test coverage and TREX Phase II tests.
- Assisted in MLT operation during the LLLTV tests at WSMR.
- Assisted in operation of the MAPM and MLT systems during the initial TREX Phase II tests.

The final quarter of 2000 covered the end of the Phase II TREX field tests and the data analysis of the tests. During this time Visidyne:

- Was involved in operation of the MAPM and MLT lidars at White Sands Missile Range during the final test releases of the TREX II program.
- Assisted in packing and deployment of the MAPM and MLT systems.
- Arranged for shipment of the MAPM, MLT, and AFCPR systems back to Hanscom AFB.
- Analyzed the MAPM TREX II field data and deliverd final calibrated data.
- Assisted in MLT planning and modification required after the LLLTV field test.
- arranged for or assisted in packing, shipment, and installation of the MAPM, MLT, AFCPR, and WYDAH systems from WSMR after the LLLTV test coverage and TREX Phase II tests;

- assisted in operation of the MAPM and MLT systems during the intial TREX Phase II tests.

2.6 Sixth Year

During the first quarter of 2001 we used the time to plan the move of the MLT system to a new trailer. Many things had to be prepared and manufactured to allow for a smooth move.

The MAPM trailer underwent refurbishment of the laser and scanner systems after the TREX field trips. A more reliable method for cable take-up for the scanner was also addressed.

The second quarter of 2001 was comprised of several efforts:

- The trailer to receive the MLT system was refurbished.
- The MLT system was moved into the new trailer. This new trailer system will be referred to as the MWLT (Explained further).
- The system was set up and preliminarily aligned optically using the hemispherical scanner as the point of reference.
- The Peels system was set up and aligned to perform cloud measurements.
- Design issues were addressed for the MAPM scanner.

Development of a Win32 version of the MAPM data acquisition software was commenced during this time period. The emphasis early on in this effort was design of the user interface and writing/testing drivers for the legacy hardware for which there were no available win32 drivers. The software architecture for this win32 version was of necessity quite different (e.g., multi-threaded) than the DPMI code used at the time.

Other software issues were addressed, such as tracking, co-pointing, and displays.

During the third quarter there were several meetings concerning the upcoming AFRL/Hanscom parking lot tests. The MWLT system work consisted of continuing to install and develop new alignment procedures for the new configuration. Work was also done on readying the system for a rapid deployment configuration. The MAPM system was aligned and new software and hardware configurations were employed. Procedures were developed for the co-alignment issues of the three sensors. There were three weeks of data acquisition in the month of August. After the test, software was written for near real time image display. Preliminary LAN software was tested. The parking lot data was analyzed and the results were presented at a meeting at AFRL.

No work was performed on this contract during forth quarter. This was due principally to staff realignment, holiday and vacation days taken

2.7 Seventh Year

There was no work performed on this contract during the first quarter of 2002. This was due principally to staff realignment, holiday and vacation days taken, and other commitments.

During the second quarter of 2002, work continued on the preparation for a mobile water vapor lidar system to support the JTO High Energy Laser project.

On the detection and calibration side, we improved the photoacoustic (PA) cell that we designed and had built to assist us in tuning our Nd:YAG/dye laser system to wavelengths corresponding to water vapor resonance's. The new design uses a double-barreled, "figure-8" shaped beam tunnel whose two chambers were isolated from each other. Signal from the chamber that receives the laser radiation consists of resonant signal and acoustic noise; the vacant chamber signal was only acoustic noise. The noise was separated from the signal by a different lowpass filter. This resulted in improved signal-to-noise. Our results were written up and prepared for submission to Review of Scientific Instruments.

Two detector boxes were designed One of the detector boxes mounts to our present system in the Multiple Wavelength Lidar Trailer (MWLT) for testing. This box gathers returns using the optical chain up to the end of our 12" telescope and sends it via fiber optics to the second box that re-expands the beam and feeds the return to a Fabry-Perot etalon and photomultiplier tube. The telescope-side box will be easily retrofit to adapt to any other optical system, particularly the one planned for what was the Mobile Lidar Trailer (MLT).

Refurbishment of the MLT and its bogey was being done to transform it into a mobile water vapor system. The bogey was modified in order to provide an air ride system on which to transport the trailer

The third quarter started with preparation for AFRL parking lot tests in support of the NAOPEX and the Long EZ programs. We performed seven nights of low altitude aerosol studies from the last week of July through the first two weeks of August. Over this period, some 5000 files were recorded of low-altitude lidar return in the 355, 532 and 1064 nm channels. The preparation for these sessions involved bringing the Multiple Wavelength Lidar Trailer (MWLT) back up to operational condition

Work continued on the water vapor lidar. Among the tasks were procurement and design of the various parts of the experiment. Various sprockets, belts, servomotors, were procured and the scanner was assembled.

A new optical table was designed and built.

A flatbed that would be suitable for safely transporting the trailer over long distances was obtained.

Testing that couldn't be accomplished in the trailer was carried out in the penthouse laboratory at AFRL. All components that were to be present in the mobile version were used for testing purposes. The testing employed the 12" telescope that had been stored in the penthouse and will be used in what will be the mobile water vapor lidar trailer. A new detection chain was designed and implemented. We went with a modular system that employs a fiber optical link between a detector box that mounts to any telescope we choose and a second detector box which houses a Fabry-Perot etalon, an interference filter and a PMT. In this way, the detection chain can be used with any of a number of telescopes.

The fourth quarter was spent working on the different facets of the water vapor lidar system. A continuing project was the design and fabrication of a replica of the scanner currently used in the Multiple Wavelength Lidar Trailer (MWLT). Most of the original drawings were available; however, many of these drawings were first drafts and required, in some cases, extensive modifications or clarification. In addition to the uncertain nature of the drawings, we intended to replace the ¾" thick mirrors of the MWLT system with 2" thick mirrors. This required further modifications to the scanner parts.

The old Mobile Lidar Trailer (MLT) was emptied to prepare for its refurbishment. Plans for electrical and structural changes were developed. In addition, work was done to secure a flatbed to which the trailer would be permanently mounted. This trailer would be used to house the water vapor lidar experiment.

Preparations were made in the penthouse laboratory of AFRL to test the various components of the water vapor lidar experiment. The 12" telescope was modified to transmit the lidar return to a variety of detectors. Modifications were made to the detector boxes to allow flexibility in data collection techniques. Primarily, the ability of the system to collect light and transmit it through a fiber optic cable-Fabry/Perot detection chain was tested.

Several weeks were spent preparing for the arrival, set-up and operation of the custom alexandrite laser built by Light Age. Not knowing exactly how much cooling the laser would need, we set up and prepared for several options to provide external water to the laser heat exchanger. Once the alexandrite laser arrived, was plumbed and power supplied to it, two representatives from Light Age came to instruct us on its operation. We tested the laser, its seeding capabilities and our ability to get the diode seeder to tune in and out of a chosen water vapor resonance.

Work was also done on the revision of a manuscript that entails our experimenting with our "home-built" photoacoustic (PA) cell.

In addition to the water vapor lidar preparation, we took the opportunity to use a gated socket/PMT combination, acquired for the water vapor experiment, to re-take and improve the quality of aerosol data that was first taken this past summer for the NAOPEX effort. This was set up in the MWLT with modifications to the existing optical chain. The gated socket allowed us to make the opening of the shutter function much sharper, and thereby decrease saturation from low altitude return.

3. SUMMARY

This research effort employed complementary electro-optical techniques to characterize optical and infrared propagation through the atmosphere. This effort included measurements of the parameters that affect propagation, at several wavelengths, under meteorological conditions of interest to DOD. Detection and tracking of airborne particulates was done and the results were characterized and analyzed. Many new approaches were tested to optimize the operation of a sensor suite, such as those employed during the TREX campaigns. Measurements were made of temporal and spatial evolution of release gas and aerosol concentrations for development and verification of dispersion models. Real time wind measurements were made for demonstration and testing of the Doppler wind sensing lidar's tactical and safety applications as well as in support of munitions and delivery system tests. The Doppler trailer was shipped to the Starfire Optical Range in New Mexico for wind measurements pertaining to atmospheric turbulence. DIAL water vapor measurements were made by the MAPM system on 2 July 1996 in concert with a radiosonde launch. Additional software modifications of the MAPM data acquisition system were made to provide for higher spatial resolution measurements of high SNR data, accumulation of a mean laser PSD, and more accurate zero velocity bias. A mobile water vapor lidar system to support the JTO High Energy Laser project was under development at the close of the program.

4. Publications

The following article, referenced in the text, was published concerning research performed under this contractual effort.

"Heterodyne CO_2 DIAL and its measurements" published in the Proceedings of the SPIE, Vol. 3127, pages 201-211 (1997)