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The Use of Light Detection And Ranging (LIDAR) for Determining Plume Characteristics

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Progress Report

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INTRODUCTION

The first study of the Emission and Dispersion Modeling System (EDMS) multi-year validation effort included gathering data on the initial plume characteristics from airplane exhaust. These initial plume characteristics include plume rise, standard plume deviation in the horizontal, and standard plume deviation in the vertical. This data is needed as input to dispersion models for use in complying with air quality requirements. Very little research had been done in this area and input values previously used in the EDMS were primarily based on engineering judgment. With the improvements being made to EDMS Version 4.0 [1] it became apparent that greater detail was needed for these data to continue the improvement in estimating local pollutant concentrations.

It was originally envisioned that these initial dispersion parameters could be measured by using an instrumented tower near an active runway and / or taxiway. It soon became apparent that this would not be feasible because of safety concerns. Alternative measurement schemes were evaluated.

One alternative method seemed promising, the use of LIDAR. Although LIDAR had never been used before in this application, it had been used for studies of wing-tip vortices and for other pollutant evaluations. The opportunity to conduct such a study presented itself when a major airport needed similar data on plume characteristics and were willing to coordinate the effort with the Federal Aviation Administration's (FAA) Office of Environment and Energy (AEE). In support of AEE, the Volpe Center then initiated a search to identify the most qualified organization to provide LIDAR support. After contacting NASA, major universities, and private industry, it became apparent that the most qualified organization was the National Oceanic and Atmospheric Administration (NOAA). NOAA has several LIDAR units and the flexibility to re-engineer the units and associated software on a project-by-project basis.

Contractual arrangements were made between NOAA and the airport with Volpe acting as a technical liaison on behalf of FAA. It was found that this was a very beneficial arrangement because the airport received needed information and data could be collected to support the FAA EDMS effort at the same time.

MEASUREMENT BACKGROUND

Two LIDAR systems were shipped by NOAA to the airport. One system used ultraviolet light as the scan laser and was called the *Ozone Profiling Atmospheric Lidar (OPAL).* The second LIDAR unit used the infrared spectrum and was named the *High Resolution Solid State Doppler Lidar (HRDL).* Each unit was contained in a trailer and set in place

Figure 1. The OPAL System

near the active runway and taxiway. Figure 1 shows a picture of the OPAL system trailer.

The OPAL system proved to be the more effective of the two systems in determining the plume parameters. This was expected since the aerosols and particulate matter emitted by the airplane are what is causing the back scatter of energy from the LIDAR laser and are "seen" as the plume. These components are very small, typically less than 100 nanometers with an average diameter of about 30 nanometers. The OPAL system, using a smaller wavelength, was more easily able to "visualize" the plume. Airplanes on both the taxiway at idle and on a runway during initial take-off roll were measured. Figure 2 shows an example output from the OPAL system.

The HRDL system was brought on line later in the measurements than the OPAL system due to equipment problems that most likely occurred during shipping. Although it was not as effective in scanning the plume, it was useable, mostly allowing air movements to be measured. By measuring the air movements, the wind speed could be determined as a function of height, mixing height, and wind direction. Figure 3 shows a typical output from the HRDL system. This information will provide an important supplement to weather data collected by the airport during the study period. Air turbulence was also measured in the wakes of aircraft, again allowing details of the plume to be measured. In addition, an extra "bonus" was air movements around the blast shield were also measured. This will help determine if a blast shield redirects the plume or breaks up the plume.

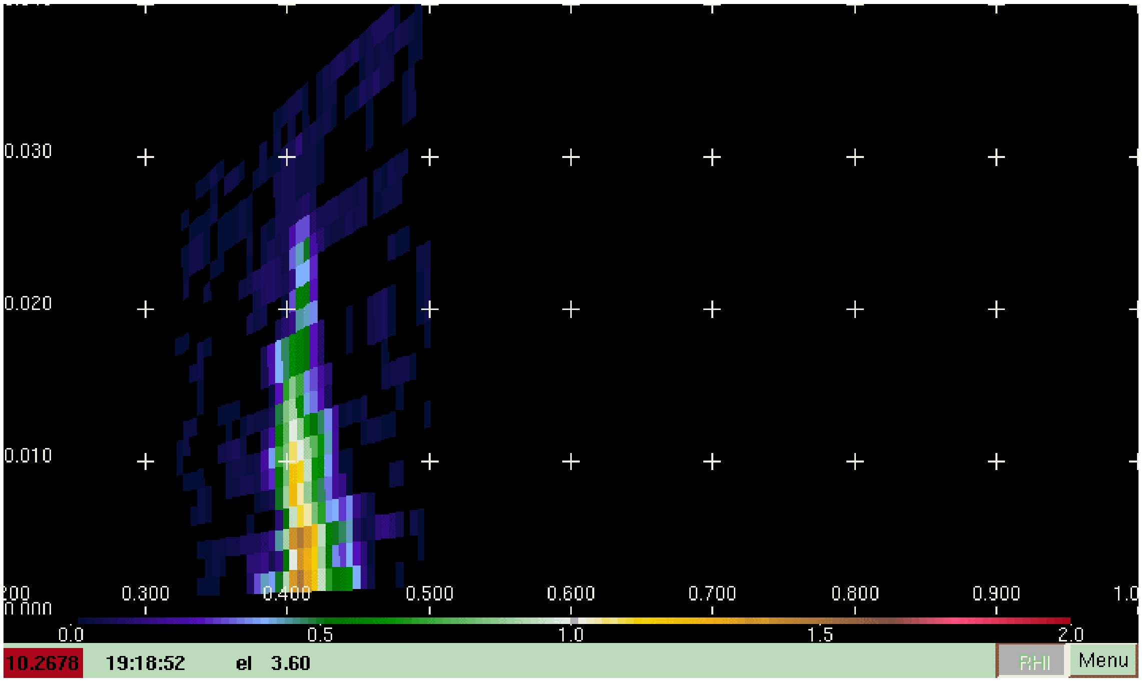

Figure 2. Example Output from the OPAL System

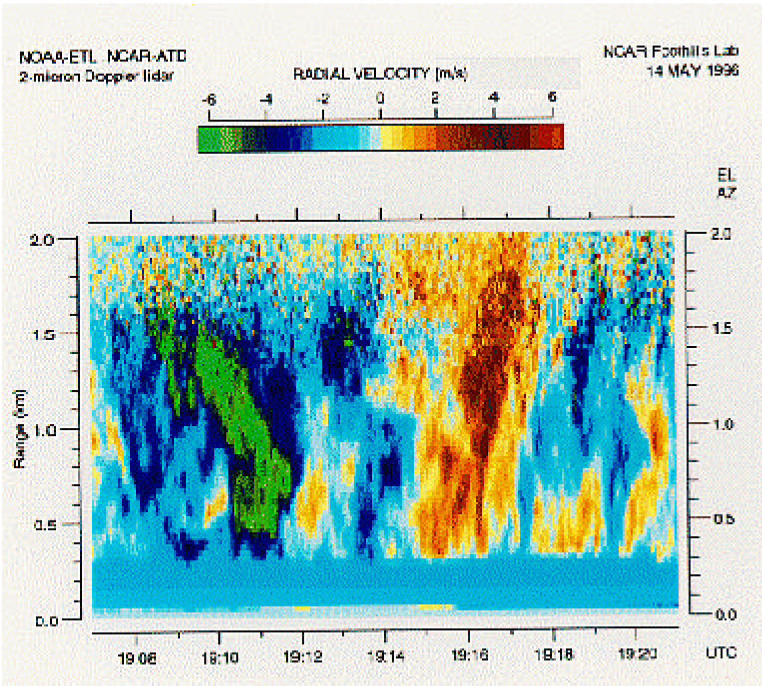

Figure 3. Example Output from the HRDL System (A range-time display of vertical profiles of the vertical wind)

Concurrent to the sampling by the LIDAR units, a spotter was used to identify aircraft. This included the airplane type, airline, and the tail number during the daylight hours. At night it was not possible to read the tail numbers. Multiple still pictures and filming of events were also performed. Requests were also made for tower operational data and weather data collected at the airport. These data will be integrated into the final database.

PROGRESS TO DATE

Preliminary coordination for the LIDAR measurements occurred between Volpe, NOAA, FAA and the airport from December, 2000, until May of 2001. Multiple conference calls and correspondence (primarily emails) occurred during this time period. The initial discussion with the airport occurred at FAA headquarters on January 30, 2001. A field visit to finalize plans occurred on March 28, 2001. This coordination allowed each organization to understand the goals of the project and how these goals would be accomplished.

Measurements and setup occurred from May 14 through 24, 2001. Equipment and data were then shipped to the NOAA labs. All sample runs (called sweeps) have been transferred from tapes used in the field to the computer for analysis. A total of 928 total runs were measured by the OPAL system. More data was also collected by the HRDL system. Since the measurements in May, NOAA has performed initial data processing and formatting. The files have been sorted and obvious good events determined. Also during this process, each sweeps was numbered and header data were added.

EXPECTED PROGRESS IN THIS FISCAL YEAR

The next step in data processing is underway. Each sweep must be reviewed to decide if it is good, bad, or marginal data. All sweeps will be categorized as such. This same process will occur for both the runway and taxiway events. Header information will be revised during this process to list the data included and the condition of the data. NOAA has estimated that this process will be completed by June 21, 2001.

The next step will be visualization. A Volpe representative will visit NOAA and provide input on what the final data format and graphics should be. This is best done in real time with the NOAA analyst and the Volpe representative. This is estimated to be a one-day event and will take place in early July. The process will be completed by formatting all good and perhaps some of the marginal sweeps. Statistics will be generated as well at this time. This process is estimated to take approximately one week.

The formatted data, along with the associated NOAA processing programs to allow visualization of the data will then be provided to Volpe. Volpe will complete the analysis by determining plume rise and the standard deviations of the plume spread (both horizontal and vertical). Analysis of the blast fence data will be performed next. This will take approximately two weeks to complete.

Once the data analysis is complete, a final report will be prepared. This report will include recommendations for an interim procedure that may be used by EDMS users to properly account for plume characteristics in the model. The report will also include recommendations for adaptation of EDMS inputs to better take into account the true plume characteristics. Finally, the report will include recommendations for future aircraft plume studies to supplement the data collected at this one, initial airport. It is estimated that the draft version of the final report will be available in the August time frame and a final report will published soon thereafter.

In summary, this study has resulted in significant insights into the initial plume characteristics from airplane exhaust, and can be used to greatly increase the accuracy of current airplane exhaust dispersion modeling. This testing is considered to have produced the best information gathered for the purpose of inputs to dispersion models for airplanes to date. Initial field data reviews show that plume rise does occur and that the initial standard deviations of the plume are different than previously assumed. These two findings may result in lower predicted concentrations from airplane sources for nearby ground level receptor locations. Quantification of these two effects cannot be reported upon until data analysis is complete. A complete description and quantification will be included in the final report.

Generalization of the plume characteristics will allow the EDMS model inputs to be altered to more accurately predict local concentrations of pollutants. However, the airport in this study represents a warmer climate at a lower elevation, two key geographical factors that may influence airplane plume behavior.[1] Site bias may be present. Therefore, further evaluation and supplementation of this data would be extremely beneficial to help insure the results were not unique to the airport where testing was conducted. Additional investigations at airports with different temperature and elevation characteristics should be conducted. These further investigations would likely consist of similar studies performed at two additional airports: one in a cold weather climate and one at a higher elevation.

SCHEDULE

The Gantt chart shown in Figure 4 lists the project time line for this initial study on aircraft plume behavior.

REFERENCES

1. U.S. Department of Transportation, *Emissions and Dispersion Modeling System (EDMS) Reference Manual*, Federal Aviation Administration, Report No. FAA-AEE-01-01, Washington, D.C., May, 2001.

[1] Buoyancy, the prime force in the plume rise, is directly related to the temperature differential between the exhaust gas and the ambient air. Elevation has a direct effect on air density.

Figure 4. Gantt Chart of LIDAR Project

ID	Task Name	Start	End	Duration
1	Initial Coordination	12/4/00	5/14/01	23.20w
2	Measurements	5/14/01	5/24/01	1.80w
3	NOAA Data Reduction	5/24/01	7/6/01	6.40w
4	Volpe Analysis	7/6/01	7/20/01	2.20w
5	Determination of EDMS Inputs	7/16/01	7/27/01	2w
6	Final Draft Reporting	7/2/01	8/10/01	6w