Validation of FAA's Emissions and Dispersion Modeling System (EDMS): Carbon Monoxide Study

Paper # 69607

Roger L. Wayson
University of Central Florida
Working with United States Department of Transportation/Volpe Center
c/o Volpe Center
55 Broadway, DTS-34
Cambridge, MA United States 02142

Gregg G. Fleming
United States Department of Transportation/Volpe Center
55 Broadway, DTS-34
Cambridge, MA United States 02142

Nancy E. Garrity
United States Department of Transportation/Volpe Center
55 Broadway, DTS-34
Cambridge, MA United States 02142

Brian Kim
United States Department of Transportation/Volpe Center
55 Broadway, DTS-34
Cambridge, MA United States 02142

John MacDonald
United States Department of Transportation/Volpe Center
55 Broadway, DTS-34
Cambridge, MA United States 02142

Mike Lau
United States Department of Transportation/Volpe Center
55 Broadway, DTS-34
Cambridge, MA United States 02142

Julie A. Draper
United States Department of Transportation/Federal Aviation Administration
Office of Environment and Energy
800 Independence Ave, SW
Washington, DC United States 20951

ABSTRACT

Air quality at airports has received substantial attention in recent years. In a 2000 report by the U.S. General Accounting Office (GAO), air quality was cited as the number two environmental concern (after noise) by the 50 busiest airports in the United States.[1] Accurate air quality models are needed to properly analyze air pollution in the vicinity of airports, develop appropriate mitigation and policies, and to plan for increased growth.

The FAA's Office of Environment and Energy (FAA/AEE) and the Environmental Measurement and Modeling Division at the United States Department of Transportation's John A. Volpe National Transportation Systems Center (Volpe Center) are engaged in a multi-year validation effort of FAA/AEE's Emissions and Dispersion Modeling System (EDMS). EDMS is the FAA required tool for assessing aviation emissions and concentrations near airports. A systematic validation effort is needed to assess the accuracy of the model and identify any needed refinements.

This study involved the measurement of carbon monoxide (CO) concentrations at 25 locations at a major U.S. international airport. In addition to the CO measurements, a detailed accounting of all related airside and landside activity was also done. This additional data included aircraft types and runways, ground support equipment activity, auxiliary power unit activity, roadway and parking lot traffic activities, stationary sources, and meteorological data.

The airside and landside data are currently being input to EDMS. EDMS-predicted concentration levels will then be compared with measured concentrations, and a detailed statistical assessment of the AERMOD dispersion algorithm within the model will be conducted. As such the information contained in this report is interim, with more detailed results to follow.

INTRODUCTION

Air quality at airports has received substantial attention in recent years and looking towards the future, the GAO report anticipates that air quality will be of equal importance with noise in the coming decade.[1] Accurate air quality models are needed to properly analyze air pollution in the vicinity of airports, develop appropriate mitigation and policies, and to plan for increased growth.

The FAA's Office of Environment and Energy (FAA/AEE) with support from the Environmental Measurement and Modeling Division at the United States Department of Transportation's John A. Volpe National Transportation Systems Center (Volpe Center) is engaged in a multi-year validation effort of FAA/AEE's Emissions and Dispersion Modeling System (EDMS). EDMS, is the FAA required tool for assessing aviation emissions in the vicinity of airports, and a systematic validation effort is needed.

Since the model is often used to predict the stable carbon monoxide (CO) concentrations and inferences made for other pollutants, the study discussed in this report included the measurement of CO concentrations at 25 locations in the vicinity of a major international airport located in the United States. The choice of CO as the comparative gas allowed the study team to focus on dispersion characteristics of the model and reduce physical complications, such as chemical reactions. Detailed accounting of all related aircraft activity, both airside and landside, during the course of the CO measurements was also accomplished. This included aircraft types and runways, ground support equipment activity, auxiliary power unit activity, roadway and parking lot activities, stationary sources and meteorological data.

As background information, EDMS was developed in the mid-1980s as a complex source microcomputer model (i.e., multiple air pollution sources at an airport) to assess the air quality impacts of proposed airport development projects. EDMS is designed to assess the air quality impacts of aircraft, auxiliary power units, ground support equipment, stationary sources, fueling operations, motor vehicles, and training fires. The model uses the latest aircraft engine emission factors from the International Civil Aviation Organization (ICAO) Engine Exhaust Emissions Data Bank[2], vehicle emission factors from the Environmental Protection Agency's (EPA) MOBILE5a[3], and stationary source/fueling emission factors from AP-42.[4] Since 1993, EDMS has been an EPA "Preferred Guideline" model for use in civil airports and military air bases. In 1998, the FAA revised its policy on air quality modeling procedures to identify EDMS as the required model to perform air quality analyses for aviation sources. This revised policy ensures the consistency and quality of aviation analyses performed for the FAA.

In response to the need for increased accuracy and flexibility by the air quality analysis community, the FAA, in cooperation with the United States Air Force (USAF), re-engineered and enhanced EDMS in 1997 and released Version 3.0.[5] The FAA has continued to improve EDMS. To take advantage of new data and algorithm developments, Version 4.0 was released by FAA in May 2001. EDMS 4.0 was developed under the guidance of a government/industry advisory board composed of experts from the scientific, environmental policy, and analysis fields.

A primary enhancement of the Version 4.0 release of EDMS was the incorporation of the EPA's next-generation dispersion model, AERMOD[6,7]. The manner in which AERMOD is used in EDMS is based on guidance from the American Meteorological Society/EPA Regulatory Model Improvement Committee (AERMIC), which is responsible for developing AERMOD and introducing state-of-the-art modeling concepts into the EPA's local-scale air quality models. In theory, the incorporation of AERMOD should result in substantial improvements in EDMS accuracy, but validation using appropriate field measured data is desirable to substantiate this assumption and refine the manner in which airport emission sources are characterized using AERMOD. Although AERMOD has been validated for stationary sources, the dispersion algorithms of AERMOD have not been validated with regard to the many and varied sources found at an airport, particularly aircraft. Complete sets of data, including measured concentrations and associated operational data are lacking.

Because AERMOD, the emission calculation procedures, and the emission factors used in EDMS are well established and EPA developed and/or recommended, the purpose of this study is not to evaluate these parts of the analysis process. Rather, the manner in which AERMOD is being used to characterize dispersion from airport sources is being evaluated and quantified so that FAA can refine how AERMOD is applied in EDMS to model airport sources. This evaluation is needed because there is no official EPA guidance on how AERMOD should be used to model airport sources, e.g., should aircraft be modeled as an area or a volume source. EPA has given FAA guidance on applying AERMOD in EDMS, but in an effort to maximize model accuracy FAA is evaluating EPA's guidance and will refine the source characterization where possible.

The EDMS version used for this study is EDMS 4.1, which reflects several enhancements to Version 4.0. Complete information on all enhancements can be found at www.faa.gov.

The objective of this study, as previously mentioned, was to measure CO concentrations and collect related airport activity data to allow direct comparison to EDMS Version 4 results. For the purposes of this study, validation includes the quantification and assessment of model uncertainty for direct application in the vicinity of an airport. To the degree practicable, the measurement study followed the applicable portions of the EPA's four volume, Quality Assurance Handbook.[8,9,10] Comparisons of the CO concentrations were measured and then modeled at predetermined locations. This direct comparison facilitated statistical assessment of the uncertainty associated with how AERMOD is applied in the model. Meteorology, motor vehicle activity in the nearby area, and airport operations were logged concurrently for later use during the modeling effort.

MEASUREMENT AND SITE SELECTION

In 2001, the FAA and Volpe Center initiated the process of identifying a suitable airport at which to conduct CO measurements for the purpose of validating how AERMOD dispersion algorithms are performing in EDMS. Specific considerations in identifying a potential airport were as follows:

- Located away from urban areas and other major sources of CO to minimize the influence of non-airport sources, not explicitly included in EDMS.
- Seasonal data are not a requirement since sampling will not be used for compliance issues. However, weather was still a major consideration. Winter conditions were picked when lower mixing heights may occur. It was desirable to measure both stable and unstable cases. Additionally, cases with low wind speeds, regardless of stability were deemed important to allow higher concentrations to be measured. Also, the sampling was performed when no precipitation was present since the effects of precipitation cannot be accounted for in AERMOD.
- Measurements were performed during peak aircraft activities at the study airport to increase the "CO-to-background" ratio.

With these considerations in mind, a major international airport in the United States was targeted as a suitable site. Coordination with the airport was important and the study could have not been done without the support provided by the airport.

Site Layout

The actual placement of the 25 sample positions around the airport was based on three broad categories. The categories included: anticipated upwind locations (based on historical data for the month of January), near aircraft in various modes of operation, and locations typical of those where human activity occurs (e.g., terminal area). The upwind positions were used to determine the background CO concentrations during the measurement periods. The average concentrations from these positions, during each sample period, were subtracted from the measured CO concentrations during data reduction and analysis. As a general rule-of-thumb, the distance from the sampler to any large obstacle, such as a building, was at least twice the height of the obstacle.

Some sources required more detailed data collection, such as the aircraft and roadways, since they were the main focus of the study (i.e., these sources are typically large emission contributors). In these cases both upwind and downwind sample positions at multiple distances from the runway were employed. The downwind sample positions at multiple distances allowed for a determination of pollutant changes with distance from the source. This was expected to provide valuable insight to the performance of AERMOD dispersion algorithms as applied in EDMS.

Instrumentation

Airmetrics Minivol bag sample units, using 5-liter Tedlar bags, were used because of the compact design, battery operation, and weather resistance. Although the MiniVol is not an EPA reference method, the flow control units were designed and developed jointly with the EPA and the samplers have been successfully used in numerous studies.[12] In the current study, the unit was prepared such that one bag was filled each hour, with both bags being filled over a consecutive two-hour time period. This provided one-hour averages allowing direct comparison to modeled concentrations using the EDMS.

Two Monitor Labs Model 9830 non-dispersive infrared (NDIR) photometers were utilized to measure CO concentrations. One unit was used to measure the CO concentration in each Tedlar bag. As an added level of quality assurance, the other unit was co-located with one of the Minivol samplers, and setup to measure CO concentrations continuously in real time. These continuous samples were converted to one-hour averages for comparison with the concentrations measured in the co-located Tedlar bags. The inlet of the NDIR and the co-located air sampler were within 6 inches of one another.

Also located at the reference site was the base operational station used for the study. It consisted of a 30-ft storage trailer, which provided system power and charging capability, as well as equipment and data storage. The deployment of a co-located reference system provided an extra measure of quality control that was specifically suggested by EPA as a result of the study test plan review. Calibration consisted of a zero and 5-point upscale testing at the beginning and end of the three-day sample period and zero and single point upscale calibration conducted multiple times during each sample day.

In addition to the airport's own meteorological data collection, meteorological stations were co-located with air sampler units at two sites. Landside traffic logging was conducted at the entrance/exit to the airport. Airside traffic logging was conducted at the ramp tower. A more detailed discussion of instrumentation is presented later.

Various types of support instrumentation and supplies were integral to the success of the study. Such instrumentation included calibration equipment to measure the intake flow of the bag samplers, gas regulators for connection to ultra-pure zero air and calibration gas, a laptop computer for communication with the instrumentation, certified gases, Teflon tubing, and associated miscellaneous instrumentation. In addition, for both technical and safety reasons, Motorola i700plus cell phones with Nextel's Group Calling Mode were utilized. Also, a single digital watch served as the master clock for time synchronization of all instrumentation. Several sets of binoculars were utilized for logging aircraft activity.

Installation of Air Samplers

The MiniVol air sampling units were installed in one of four configurations: pole-mounted, tripod-mounted, fence-mounted, or light-post-mounted. Where applicable, a marker was driven into the ground at each position to allow for easy location of the specific sampler, and to facilitate later site surveying. Each sample bag canister was labeled with the particular site number it was designated, as well as an L (left) or R (right) designator. The right Tedlar bag was always the first one filled during each two-hour sampling period.[11]

Airside and Landside Activity Logs

Manual logging was utilized to record airside and landside activity on the airport. Observers were positioned in the airport ramp tower at locations that allowed for a 360-degree view of airside activity at the airport. These observers used a log sheet to record aircraft/flight parameters such as left- or right-side runway, arrival taxiway, arrival taxi time, gate number, gate in time, aircraft tail number, aircraft type, airline, related GSE and APU activity, gate out time, departure taxi time, and departure taxiway designator. Landside activity entering and leaving the airport was also manually recorded. One observer was positioned to log traffic exiting the airport and a second observer was positioned to log traffic entering the airport. These observers used the log sheets to record vehicle types over consecutive fifteen-minute start/stop times. In addition, vehicle speed was periodically sampled using a Doppler Radar Gun.

Meteorological Instrumentation

In addition to the air sampling instrumentation, two Qualimetrics Transportable Automated Meteorological Stations (TAMS) were deployed adjacent to one site. The sensors of the two units were positioned at a height of 5 feet and 15 feet. Ambient temperature, relative humidity, wind speed and direction, and ambient atmospheric pressure were measured in one-second time intervals. The data is captured in an HP 200 LX palmtop computer. At the end of a measurement day, the files were transferred to a laptop computer. Co-located with the air samplers at the Reference Site were two additional meteorological stations, with sensors positioned at a height of 5 feet and 15 feet. These units consisted of RM Young U-V-W anemometers connected to a Campbell Scientific datalogger. NOAA also operated several sites on the airport property and this information was also used, since the AERMOD meteorological processing program AERMET, requires files in the NOAA format.

Site Survey Instrumentation

A site survey was conducted using a differential Global Positioning System (dGPS) which was designed around two single-frequency (commonly referred to as L1) NovAtel® Model RT20E GPS receivers and two GLB® Model SNTR 150 transceivers which facilitate remote communication between the two GPS receivers.[12] As deployed, one of the NovAtel/GLB combinations acts as a base station and the other combination as the roving unit, the two working together providing a relative, three-dimensional, position accuracy of 20 cm.

The dGPS system also contained a Graphical User Interface (GUI) and supporting software that was tailored for use during aircraft noise certification tests. The dGPS system was used to determine a coordinate system for the measurement instrumentation and the airfield. This coordinate system was also used in data processing and analysis. The coordinate system used was defined with the positive X axis running under the departure centerline from one runway, the positive Y axis to the north, and the positive Z axis in the vertical. All measurement and modeled sites used this coordinate system.

Measurement Procedures

The initial team members arrived at the airport on January 3, 2002 and began calibrations of the equipment and initial equipment setup. Other team members arrived on the January 6th and setup was completed. Measurements were then conducted on the 8th, 9th and 10th of January. Of note is that these days could not be changed due to approvals, the team member involvement from FAA, Volpe, the airport, and the University of Central Florida. It would have been preferred to have very long sampling for select weather conditions but this was not possible. Equipment removal and shipping occurred on January 10th and 11th.

During a typical field measurement day the bag sample units were programmed to initiate sampling at 0800 and continue for one hour, until 0900. Each unit was equipped with two independent sampler canisters containing the Tedlar bags, so immediately following the 0800 to 0900 sampling period (right canister) the units were programmed to switch to the second sampler canister (left canister) and initiate sampling (0901 to 1001). Similarly, two, sequential one-hour sample periods were programmed to occur between 1200 and 1401 and between 1600 and 1801. Bags were collected, new bags installed and measurements conducted after each two hour measurement period. Consequently, the entire framework for a typical measurement day was structured around these three two-hour sequential sampling periods, purposely selected to capture peak periods of airside operations.

The study team was organized into three groups, each with unique responsibilities: (1) the air sampling and meteorological group; (2) the airside activity group; and (3) the landside activity group. The test director oversaw all groups during measurements. The air sampling and meteorological group were responsible for checking air sampler and meteorological system functionality, as well as replacing the filled sampler canisters after each two-hour measurement period. The sampling team consisted of three, two-person teams, which were each responsible for between 6 and 10 units. An additional individual was always on site at the trailer and was responsible for the two NDIRs, and the co-located air sampler and meteorological stations. The airside activity group, which consisted of four individuals, was responsible for logging all airside activity. Similarly, the landside activity group, which consisted of two individuals, was responsible for logging all landside activity.

All groups were synchronized to a single universal time base, which would facilitate later data reduction and analysis. Collection of both landside and airside activity data began

15 minutes prior to each sample period and continued for 15 minutes beyond each period to ensure that any time lag associated with vehicle movement could be taken into account.

DATA REDUCTION AND ANALYSIS

After field data collection, the data set was extensively reviewed for errors, omissions, and reasonableness with respect to expected accuracy ranges. Once quality control was complete, the data was organized in a commercial spreadsheet to permit easy review, graphing of results, and to facilitate input into EDMS. The master study spreadsheet contained information such as: Minivol numerical designator, reference NDIR, sampler NDIR, bag log, aircraft log, traffic speed, traffic count, parking lot count, parking lot map, information from both weather stations, dGPS summary tables, and dGPS summary plots.

Site Geometry

The local airport authority supplied one-foot pixel resolution digital orthophotos of the study airport. This was translated to a format similar to the one used in the study. With all geographically referenced data in a common coordinate system, geographic features such as points, lines, and polygons were added based on the image, and geographic relationships were established with previously-collected data such as the air sampler locations. Precise relative X-Y coordinates of all pertinent features were supplied as input to the EDMS model. These features included elements such as runways, taxiways, terminals and gates, airside roadways, power generators, landside access roads, parking lots and air sampler locations.

Source Data

In preparing source input data for EDMS, care was taken to draw on the best available information.

Aircraft and GSE

Pertinent data from aircraft logs maintained by study personnel located in the ramp tower and the southern most concourse were entered into a commercial spreadsheet. Where available, these data included aircraft/flight parameters such as: arrival runway side, arrival taxiway, arrival taxi time, gate number, gate in time, aircraft tail number, aircraft type, airline, related GSE and APU activity, gate out time, departure taxi time, departure taxiway designator and departure runway.

The primary area in which these data were lacking was for arrival and departure runway use of each aircraft. Reduced data received by the research team included departures and arrivals, but in an aggregate form for the entire airport configuration. This meant that during times of multiple runway use for departures and/or arrivals, specific aircraft events could not be assigned to each runway. Obviously, when only a single runway was used during a particular time period for takeoff or approach operations, all flights were assigned to the specific runway. However, when a configuration called for multiple runway operations, then judgments had to be made. Data reported by the tower did not list individual flights. Several alternatives for determining exact runway allocation of the aircraft events have been explored. One method, the use of FAA's Enhanced Traffic Management System (ETMS) data, would seem to allow much more detailed allocation. Refinements, allowing for more detailed results will be accomplished as the research progresses.

Needed aircraft information included landing/take-off (LTO) cycles, times in mode (taxi and queue), gate assignment, taxiway assignment, and runway assignment. The Department of Transportation's Bureau of Transportation Statistic's Airline Service Quality Performance (ASQP) database was used to supplement missing operational data such as the specific aircraft/engine configurations. ASQP includes aircraft flight id, aircraft tail number, and aircraft taxi times, as well as other information. In fact, ASQP average annual (50th percentile) taxi-in and taxi-out times of 5 and 13 minutes, respectively, were used for all aircraft events input to EDMS. Most importantly, since ASQP provided the precise tail number for a flight, the specific model engine could be determined using the BACK aircraft registration database. This allowed for more precise modeling of the specific aircraft/engine combination within the model.

Default EDMS values were utilized for GSE input. GSE defaults were based on the particular aircraft/engine combination specified. Aircraft weight was assumed to be the maximum based on the particular aircraft/engine combination specified.

Parking Lots

Airport personnel provided vehicle counts by hour for each of the parking facilities on airport property. Personnel also provided estimates of vehicle speeds and routes while in each lot. This actual lot usage information was utilized for all approaches. Actual parking lot activity data provided by airport personnel were used as input.

Roadways

As previously discussed, field personnel collected detailed data related to roadway activity in the vicinity of the airport. These data included a count of vehicle types in fifteen-minute blocks, along with a random sampling of vehicle speeds. Actual roadway counts and speeds collected by field personnel were used at input.

On-Airport Shuttles

On-airport shuttles are used to transport passengers to/from the main terminal. Based on conversations with airport personnel, it was determined that these vehicles run on a fairly rigid schedule from day to day. Hence it was deemed most appropriate to model their movements in EDMS based on their nominal daily schedule. The emission factors for the vehicles were obtained from as airport source. In EDMS, the on-airport shuttle routes were modeled as roadways and subsequently populated with the information provided by airport personnel.

Stationary Sources

Data in this category includes any type of stationary source on the airport property, such as power plants, incinerators, fuel tanks, solvent degreasers, or surface coating operations. The study airport has four natural gas fired boilers located in the Utility Building. In addition, the airport maintains several diesel-powered electric generators, but they were not operated during the study period. EDMS input for the boilers was based on the specific data provided by airport personnel. This information included source diameter, gas velocity, temperature, and peak usage data.

Training Fires

Airport personnel verified that no training fires were conducted during the time period of the study, January 7 through 11, 2002.

Meteorological Data

EPA's AERMET is the meteorological preprocessor to EPA's AERMOD, the dispersion algorithms used in EDMS. AERMET requires data to be in NOAA's TD-6201 format, which is commonly available. Fortunately for this purposes of this study, NOAA maintains a surface and upper air meteorological station in the immediate vicinity of the airport. Meteorological data was obtained directly from the NOAA station at the airport for the study period. Further work, using the multiple weather station data will continue to define the wind field as the project proceeds.

COMPARISON OF MEASURED VERSUS MODELED RESULTS

Comparison of the measured and EDMS modeled CO values is in its initial stages. It is anticipated that a paired graphical comparison of measured versus modeled concentrations will be utilized in the final uncertainty assessment for EDMS. A conceptual representation of the type of graphical comparison that will be used is presented in Figure 1. The example data is shown along with a trend line drawn through the data, and a line of perfect agreement. These types of graphics will be developed separately for all of the data included in the eighteen, one-hour modeling periods from January 8th to January 10th. Similar graphics will also be developed to allow for more focused assessment. For example, separate comparisons will be made for receptors near roadways and parking lots to assess the ground-based portions of EDMS. Additional comparisons will be performed for receptors more heavily influenced by aircraft, e.g., runways, aircraft gates, and taxiways.

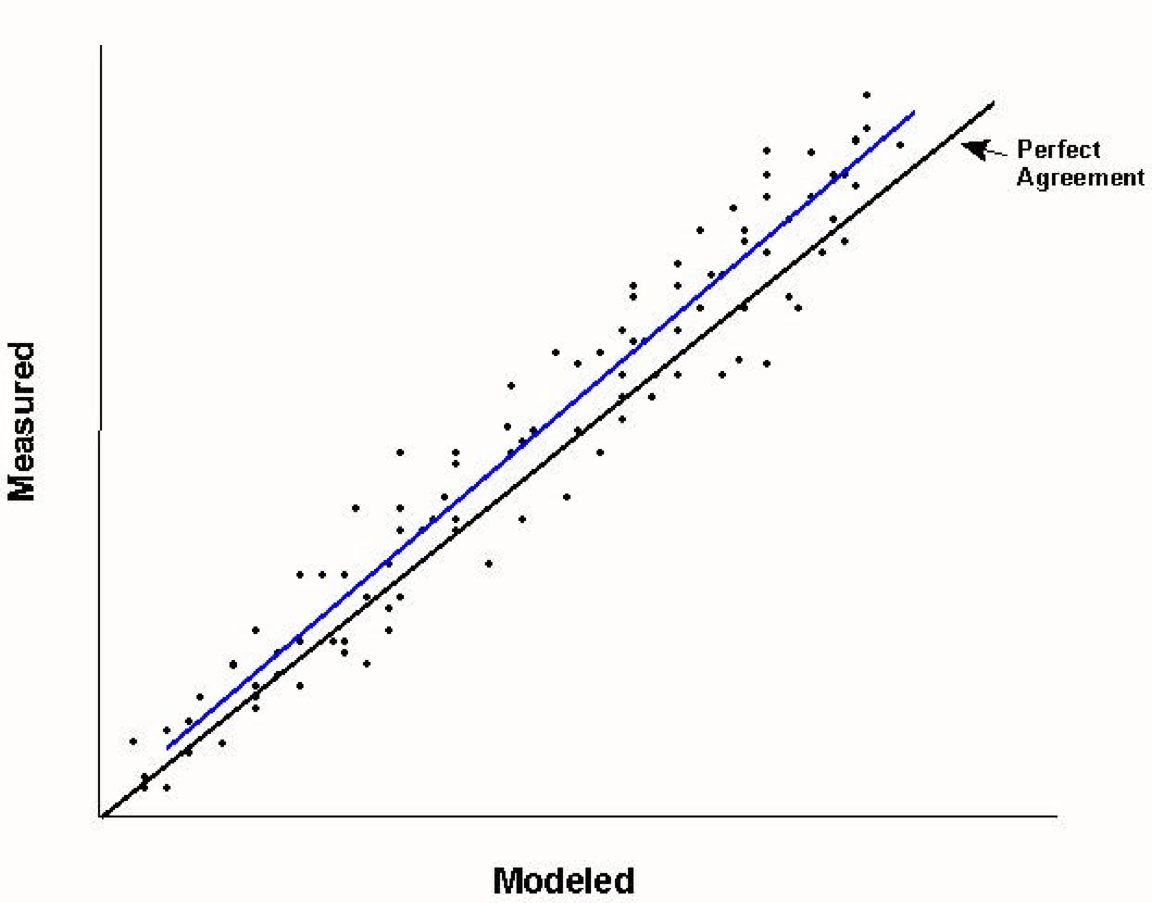

Figure 1. Example Comparison of Measured Versus Modeled Data (Note: This figure does not depict actual data from the study.)

CONCLUSIONS

A substantial database has been assembled. It includes CO concentrations for eighteen, one-hour periods from January 8th to January 10th, 2003. The database also includes a detailed quantification of both airside and landside activity at the airport during the entire measurement period. Over the coming months, these data will be utilized to assess the performance of the AERMOD dispersion algorithm recently incorporated into FAA's EDMS. As deemed necessary, enhancement to AERMOD and/or recommendations on its use within the context of EDMS will be documented in a final comprehensive report, which will be made available to the modeling community. Final results of the study will be available on the FAA website at www.faa.gov.

REFERENCES

1. U.S. General Accounting Office, *Aviation and the Environment; Results from a Survey of the Nation's 50 Busiest Commercial Service Airports*, GAO/RCED-00-222, Washington, D.C., August, 2000.

2. International Civil Aviation Organization, *Aircraft Engine Exhaust Emissions Databank*, maintained by the QinetiQ, available at http://www.qinetiq.com/aircraft.html, July 2002.

3. EPA, *MOBILE5a*, Office of Mobile Sources, Ann Arbor, Michigan, February, 1995.

4. EPA, *Compilation of Air Pollutant Emission Factors,* EPA AP-42, Fifth Edition, Washington, D.C., January 1995.

5. Anderson, C., S. Augustine, Embt, and T. Thrasher, *Emission and Dispersion Modeling System (EDMS) Reference Manual*, U.S. Dept. of Trans., Federal Aviation Administration, Report No. FAA-AEE-97-01, Washington, D.C., April 1997.

6. EPA 7th Modeling Conference in Washington, D.C., June 28-29, 2000.

7. Cimorelli, A.J., S.G. Perry, A. Venkatram, J.C. Weil, R.J. Paine, R.B. Wilson, R.F. Lee, and W.D. Peters, *AERMOD - Description of Model Formulation, Draft*, EPA, Office of Air Quality Planning and Standards, Research Triangle Park, NC, December, 1998.

8. EPA, *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II: Part 1, Ambient Air Quality Monitoring Program Quality System Development,* EPA-454/R-98-004, August 1998.

9. EPA, *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume I, Principals,* EPA 600/9-76-005, Washington, D.C., December, 1984.

10. EPA, *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume I, A Field Guide to Environmental Quality Assurance,* EPA 600/R-94/038a, Washington, D.C., April, 1994.

11. Airmetrics, Airmetrics Home Page, http://www.airmetrics.com/company.html, last accessed April 26, 2001.

12. Fleming, G.G., et al., "A differential global positioning system for determining time space position information in support of aircraft noise certification," Proc.2001 National Technical Mtg., Inst. of Navigation, 2001.