Integration of AERMOD into EDMS

Abstract No. 355 **Session AS-1c-B**

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ABSTRACT

The Federal Aviation Administration (FAA) requires the use of the Emissions and Dispersion Modeling System (EDMS) for air quality analysis involving aviation sources. Dispersion in EDMS has previously been computed by CALINE3 and PAL2. With the advent of the Environmental Protection Agency's (EPA's) AERMOD dispersion model, the FAA has made a commitment to replacing the older dispersion models in EDMS with AERMOD. AERMOD's dispersion algorithms are state-of-the-art and have been shown through validation efforts to model the physics of the atmosphere more accurately than previous algorithms. In addition to accuracy, the robust features in AERMOD allow a more complete modeling scheme (e.g., such as the use of polygon-area sources and polar coordinates for receptors). This paper discusses the technical aspects of integrating AERMOD into EDMS.

INTRODUCTION

The Emissions and Dispersion Modeling System (EDMS) is required by the Federal Aviation Administration (FAA) for air quality analysis involving aviation sources such as aircraft, auxiliary power units (APU), and ground support equipment (GSE) [1]. As its name implies, EDMS can be used to model both airport-specific emissions as well as atmospheric concentrations resulting from dispersion. The FAA's Office of Environment and Energy (AEE) has recently developed a 5-year research and development plan to continue its improvements of EDMS [2]. A major part of this plan has been to replace the previous dispersion models (CALINE3 and PAL2) within EDMS with an external version of the Environmental Protection Agency's (EPA's) next generation atmospheric dispersion model, AERMOD.

BACKGROUND

EDMS was originally developed in the mid-1980s as a complex source model capable of assessing air quality impacts due to airport development. In 1997, it was completely re-engineered to meet both scientific and policy-related needs. EDMS has been an EPA "Preferred Guideline" model since 1993 and in 1998, FAA elevated the status of EDMS to a required model when conducting air quality analysis for aviation sources. This was done to ensure consistency and quality in aviation-related air quality analyses [1].

The previous version of EDMS (Version 3.23) used CALINE3 and PAL2 for atmospheric dispersion. The source codes from both of these models were integrated into the EDMS code so that external calls to standalone executable versions of the models were not necessary. In the first quarter of 2001, CALINE3 and PAL2 were replaced by AERMOD in Version 4.0 of EDMS.

AERMOD is promulgated by EPA as a next generation dispersion model. It is intended to replace the current EPA de facto standard dispersion model for stationary sources, ISC3. Like its predecessor, AERMOD is based on a steady-state plume model, but has many state-of-the-art improvements. AERMOD has better characterization of the planetary boundary layer (PBL) and allows dispersion to be accomplished using continuous functions rather than with discrete stability classes that do not change with height. Instead of a Gaussian distribution for both the horizontal and vertical directions, AERMOD uses a bi-Gauassian probability density function (PDF) to characterize the dispersion in the vertical direction. AERMOD also incorporates a new, simple method to model flow and dispersion in complex terrain [3].

IMPLEMENTATION OF AERMOD

Control and Execution

Unlike previous versions, EDMS Version 4.0 runs the dispersion model (AERMOD) as a standalone executable through a DOS window. This approach is much simpler to implement than integrating the complex AERMOD code into EDMS. It also allows for easier upgrading when future versions of AERMOD are released. The effect of running AERMOD externally causes no burdens to the user since EDMS creates an input file for AERMOD based on the EDMS input data. Once the dispersion analysis is initiated within EDMS, the execution and control of AERMOD is entirely transparent to the user.

Since AERMOD requires both surface and upper air data, an interface to AERMET was also implemented into EDMS. AERMET is a meteorological pre-processor that prepares “raw” meteorological data for use with AERMOD. Therefore, EDMS (through AERMET) allows the use of several different formats for raw weather data. Similar to AERMOD, AERMET also runs externally to EDMS and places no burdens on the user in terms of execution and control of the pre-processor (i.e., through DOS commands) since a graphical wizard walks the user through the data input process.

Source Modeling

In EDMS Version 3.23, airport sources were each modeled as either a point, line, or area. In Version 4.0, point, area, and volume sources are used. The modeling scheme is shown in Table 1. As indicated in the table, line sources in Version 3.23 were replaced with multiple, contiguous area sources in Version 4.0. A simple reason for this is that AERMOD does not contain an algorithm to model line sources. However, this is likely to improve prediction accuracy since elongated area sources will represent sources more realistically. Sources such as runways and roadways do not emit along a single line (usually coincident with the centerline of a runway or roadway). Rather, the aircraft and vehicles traveling along those runways and roadways, respectively, tend to deviate from a straight line. Even if an aircraft was always perfectly aligned with the centerline as it traveled along a runway, the emissions from the engines (i.e., on the wings) would not be

Table 1. Source Modeling Scheme

Airport Source	EDMS Version 3.23 Source Type	EDMS Version 4.0 Source Type
Runway/Queue/Taxiway/Roadway	Line	Rectangular Area
Approach/Departure Air Space	N/A	Rectangular Area
Parking Lot	Rectangular Area	Polygonal Area
Stationary Source	Point	Point
Training Fire	Point	Point
Gate	Point	Volume

emanating from the centerline. Therefore, the use of area sources is more realistic than line sources. The use of area sources over point or volume sources is due to the “peaks and valleys” effect that occurs when point or volume sources are used to simulate a line. Due to the discrete number of points or volume sources that can be placed on a line, receptors close to a source will experience relatively high concentrations (i.e., peaks) while receptors close to the space between two sources will experience low concentrations (i.e., valleys). Preliminary tests indicate that this effect is much less for contiguous area sources.

Runways, roadways, queues, and taxiways, are each modeled using multiple, contiguous area sources. In keeping with EPA recommendations regarding the use of area sources in AERMOD, the maximum ratio for length to width is 10:1. Because modeled vehicle and aircraft motion along roadways, queues, and taxiways is constant (i.e., no acceleration), the areas used are of maximum length in accordance with the 10:1 ratio (e.g., 10 meters long if the width is set at 1 meter). The use of this maximum length conserves the number of area sources created thereby reducing runtime. The areas used for roadways, queues, and taxiways are set at 200 meter by 20 meter. The 20 meter width is based on approximate geometries of these sources and the results from preliminary sensitivity tests.

Motion along runways, however, tends to have significant acceleration, and therefore, a shorter length of 50 meters has been employed. These shorter segments allow a more realistic modeling of aircraft movements and emissions than maximum lengths which would spread the emissions over larger composite areas. The emissions for each area segment is determined by calculating the time an aircraft would spend in the segment (i.e., based on its speed).

A significant change from Version 3.23 is the ability to model aircraft takeoff and approach. The modeling of these in-flight emissions in Version 4.0 is accomplished by using “stepped” area sources. Figure 1 shows conceptually how aircraft are modeled during these modes. The steps only continue up to a height of 1000 feet because beyond

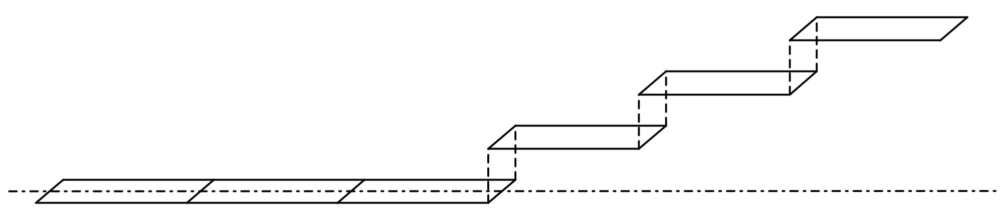

Figure 1. Aircraft Modeling Approach During Takeoff

that, the emissions are not considered to add significantly to the receptors on the ground [4]. However, emissions up to the mixing height are still accounted for as part of the emissions inventory. Aircraft takeoff and approach flight paths are segmented into fifteen steps vertically separated by 20 meters (66 feet). Because in-flight acceleration is significantly lower than on the runway, the area sources used are each 200 meters long and 20 meters wide, which also matches the width of the runway area sources and provides consistency. This minimizes the number of sources used per aircraft while maintaining accuracy (i.e., based on initial sensitivity tests).

In EDMS Version 4.0, parking lots are now modeled as polygonal areas rather than rectangular areas. In keeping with AERMOD's requirements, EDMS allows the user to specify up to 20 vertices for a polygon and a single height. Stationary Sources and Training Fires are still modeled as point sources. From a user's point of view (i.e., involving input data requirements), there are no differences in modeling these two sources in EDMS Version 4.0 and Version 3.23. This is also true for gates, but the underlying modeling scheme for gates is different since they are now modeled as volume sources (instead of point sources) in Version 4.0. Volume sources allow the emissions to be more widely spread thereby more realistically representing GSE usage. In future versions, area sources could be used to represent GSE activity more accurately.

Initial Plume Characterization

As with any dispersion model, the initial properties of a plume are important to properly model its growth and position. Two variables that need to be accurately quantified are the initial release height and the initial sigma (σ) values. EDMS contains default values for both of these variables which have been updated in Version 4.0.

EDMS models all aircraft in a fleet mix as part of runway sources. In previous versions, emission heights for these runways were set to a fixed value of 2 meters which was considered to be a conservative average release height value. In Version 4.0, the effective emission height used for runways, taxiways, and queues is a weighted average of emission heights from an airport's fleet mix and their usage (i.e., LTO cycles). An aircraft's emission height (where aircraft-specific geometric data is available) is also a weighted average based on the number of engines at each height on an aircraft.

The length and width of the area sources determine the initial shape and size of the plume, and therefore, no initial sigma-y values are required when using area sources in AERMOD. This applies to runways, queues, taxiways, and roadways. The initial sigma-z values used for all of these area sources is set at 3 meters. This is also true for polygonal area sources used to model parking lots. Emissions from GSE and APU activities are aggregated into a single volume source at each gate location. The initial sigma-y and sigma-z values for these volume sources are 16 meters and 3 meters, respectively. These values provide an elliptical shape for the cross-section of the initial part of the plume.

In addition to characterizing dispersion, initial properties (e.g., temperature) of sources are also important because they can affect plume rise. Traditionally, plume rise has been applied to point sources that emit vertically upwards with an initial velocity resulting in a vertical momentum. Aircraft have inherently different characteristics than these traditional point sources (i.e., power plant stacks) including the fact that aircraft emit horizontally which impacts vertical momentum. Therefore, plume rise for aircraft may be primarily due to thermal buoyancy. A further complicating issue is that due to the mixing and velocity of the exhaust, the temperature decreases rapidly with distance away from the engine outlet. These issues are currently being studied for further clarity.

EDMS IMPROVEMENTS DUE TO AERMOD

The most important improvements afforded by AERMOD are the state-of-the-art dispersion algorithms. As previously mentioned, some of AERMOD's strengths include a better characterization of the PBL and the use of a bi-Gaussian PDF for the dispersion in the vertical direction. These and other features not only make AERMOD an improvement over its predecessor (ISC3), but also inherently better than CALINE3 and PAL2.

In addition to superior dispersion algorithms, AERMOD provides the ability to model building downwash and terrain effects. These features are currently not implemented in EDMS, but they are being considered for future versions. The incorporation of building downwash is dependent on EPA's incorporation of PRIME into AERMOD. PRIME is a building downwash algorithm developed by the Electric Power Research Institute (EPRI) and most notably used in the ISC models (i.e., "ISC-PRIME") [5]. The use of downwash algorithms in PRIME would be preferred since they have been shown to be more accurate than the Schulman-Scire algorithms currently in AERMOD [6].

The incorporation of terrain effects in future versions of EDMS will involve the use of AERMOD's terrain pre-processor, AERMAP. The implementation of AERMAP would be similar in scope to how AERMET is currently incorporated in EDMS Version 4.0. Although AERMAP is currently not implemented into EDMS, the user can still run AERMAP externally. The use of AERMAP will require significantly more data and analysis. However, the incorporation of these features within EDMS will not necessarily place additional burdens on the user since the features will be optional.

AERMOD also provides several modeling and output advantages. First, unlike CALINE3 or PAL2, AERMOD allows the use of polar coordinates for receptor locations. This feature adds versatility and can simplify the modeling effort. Second, area sources do not have to be limited to rectangular shapes since AERMOD allows polygons with up to 20 vertices. By using irregularly shaped area sources, compromises do not have to be made in terms of size and location of the source. This feature is currently used for parking lots, and could be extended to GSE and training fires in future versions. Third, the output reporting capabilities of AERMOD are comprehensive. Therefore, AERMOD's outputs can be used directly to represent EDMS dispersion results. Lastly, the use of a single dispersion model (AERMOD) allows for easier maintenance and upgrading which correspond to reductions in development time.

CONCLUSION

In 2001, the FAA replaced the older dispersion models, CALINE3 and PAL2, in EDMS with AERMOD. AERMOD is not only a superior dispersion model, but it also provides a more robust modeling environment including the ability to use polar coordinates and polygonal area sources. The sources (i.e., runways, queues, taxiways, and roadways) that had been modeled as lines in EDMS Version 3.23 are now modeled as elongated contiguous areas in Version 4.0. Unlike CALINE3 and PAL2 which were integrated into EDMS at the source code level, AERMOD is controlled through a shell (DOS) window. In effect, AERMOD is implemented as an external module. This modular nature will allow easier upgrades to newer versions of AERMOD.

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