Project 019 Development of Aviation Air Quality Tools for Airshed-Specific Impact Assessment: Air Quality Modeling

University of North Carolina at Chapel Hill

Project Lead Investigator

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- PI: Saravanan Arunachalam, Research Professor and Deputy Director
- FAA Award Number: 13-C-AJFE-UNC Amendments 1-9
- Period of Performance: October 1, 2018 to September 30, 2019
- Tasks:
    1. Create Boston Logan airport emission inventories.
    2. Create a weather research forecast (WRF)-sparse matrix operator kernel emissions (SMOKE)-community multiscale air quality (CMAQ) modeling application.
    3. Perform a model-monitoring intercomparison at Logan airport.
    4. Develop a framework for a new dispersion model for aircraft sources.

Project Funding Level

$300,000 from the FAA. Matching cost-share was provided by the Los Angeles World Airports (LAWA).

Investigation Team

Prof. Saravanan Arunachalam (UNC) (Principal Investigator) [Tasks 1, 2, 3]
Dr. Chowdhury Moniruzzaman (UNC) (Co-Investigator) [Task 4]
Mr. Calvin Arter (UNC) (Graduate Research Assistant) [Tasks 1, 4]
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Project Overview

Aviation is predicted to grow steadily in upcoming years;[1] thus, a variety of aviation environmental policies will be required to meet emission reduction goals in aviation-related air quality and health impacts. Tools are needed to rapidly assess the implications of alternative policies for an evolving population and atmosphere. In the context of the International Civil Aviation Organization (ICAO)'s Committee on Aviation Environmental Protection (CAEP), additional approaches are required to determine the implications of global aviation emissions.

The overall objective of this project is to continue the development and implementation of tools, both domestically and internationally, to allow for an assessment of year-to-year changes in significant health outcomes. These tools must be acceptable to the FAA (in the context of Destination 2025) and/or other decision-makers. The developed methods must

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[1] Boeing Commercial Airplane Market Analysis, 2010.

also rapidly provide output in order to support a variety of “what if” analyses and other investigations. While the tools for use within and outside the U.S. need not be identical, a number of goals are desirable for both cases:

- Enable the assessment of premature mortality and morbidity risks due to aviation-attributable particulate matter (PM) having diameter up to 2.5-µm ($PM_{2.5}$), ozone, and other pollutants known to exert significant health impacts;
- Capture airport-specific health impacts at regional and local scales;
- Account for the impact of landing/take-off (LTO) versus non-LTO emissions, including a separation of effects;
- Allow for an assessment of a wide range of aircraft emission scenarios, including differential growth rates and emission indices;
- Account for changes in non-aviation emissions
- Allow for assessments of sensitivity to meteorology;
- Provide domestic and global results;
- Include quantified uncertainties and differences with respect to Environmental Protection Agency (EPA) practices, which are to be minimized when scientifically appropriate;
- Be computationally efficient such that tools can be used in time-sensitive rapid turnaround contexts and for uncertainty quantification.

The overall scope of this work is being conducted at three collaborating universities: Boston University (BU), Massachusetts Institute of Technology (MIT), and the University of North Carolina (UNC) at Chapel Hill. The project is being performed as a coordinated effort with extensive interactions among the three institutions and will be described in reports on three separate projects (ASCENT 18, 19, and 20) by each collaborating university.

The components led by the UNC at Chapel Hill’s Institute for the Environment (UNC-IE) include detailed modeling of air quality using the CMAQ model. UNC-IE is collaborating with BU to develop health risk estimates on a national scale using CMAQ outputs. UNC-IE is also collaborating with MIT to perform an intercomparison against nested Goddard Earth Observing System (GEOS)-Chem model applications within the U.S. and to further compare and contrast forward sensitivity and inverse sensitivity (such as adjoint) techniques for source attribution. This project builds on previous efforts within Project 16 of PARTNER, including detailed air quality modeling and analyses using CMAQ at various scales for multiple current and future scenarios as well as health risk projections that successfully characterize the influence of time-varying emissions, background concentrations, and population patterns on the public health impacts of aviation emissions under a national future emission scenario for 2025. Under Project 16, we initiated the development of a new state-of-the-art base year modeling platform for the U.S., using the latest model versions (CMAQ, WRF, SMOKE), emission datasets (Aviation Environmental Design Tool [AEDT], National Emissions Inventories [NEI]), and tools (Modern-Era Retrospective Analysis for Research and Applications [MERRA]-2-WRF, Community Atmospheric Model CAM-2-CMAQ) to downscale initial and boundary condition data from the general circulation models (GCMs) used in the Aviation Climate Change Research Initiative (ACCRI). We are continuing to adapt and refine the tools developed from this platform as part of the ongoing work in this phase of the project.

During this period of performance, the UNC-IE team was expected to perform research on multiple fronts, as described below. However, the FAA has requested that Tasks 1–3 be placed on hold because the collaborative project ASCENT-18 at BU did not receive funding from the FAA during FY2019. Thus, our report is limited to our progress on Task 4.

1. Create Boston Logan airport emission inventories.
2. Create a WRF-SMOKE-CMAQ modeling application.
3. Perform a model–monitoring intercomparison at Logan airport.
4. Develop a framework for a new dispersion model for aircraft sources.

Task 1 - Create Boston Logan Airport Emission Inventories

UNC at Chapel Hill

Objectives

Working with the ASCENT-18 team, identify and obtain (from the FAA) an appropriate aircraft activity data set (e.g., radar data from the Performance Data Analysis and Reporting System [PDARS]) that includes the aircraft type and engine type, along with aircraft space/time coordinates for the chosen modeling period. We will obtain and use the FAA’s AEDT 2d to create an aircraft emission inventory for Boston Logan airport for 2017.

Research Approach
N/A

Milestone
This task was placed on hold during FY2019 due to a delay in funding.

Major Accomplishments
This task was placed on hold during FY2019 due to a delay in the release of FAA funding.

Publications
N/A

Outreach Efforts
N/A

Awards
None.

Student Involvement
Calvin Arter and Praful Dodda, current Ph.D. students, performed a review of the AEDT model and attended the AEDT training offered by the Volpe Center at Cambridge, MA.

Plans for Next Period
Start the task, if authorized by the FAA.

Task 2 - Create a WRF-SMOKE-CMAQ Modeling Application
UNC at Chapel Hill

Objectives
In this task, we will create a 12/4/1-km nested application of the WRF–SMOKE–CMAQ modeling system for two seasons (summer and winter) and will simulate two emission scenarios:

- Background emissions from all sources except the Boston Logan airport
- Background emissions and Boston Logan airport emissions during LTO cycles

Next, we will perform multiple sensitivity simulations with the CMAQ v5.2 base and CMAQ v5.2 augmented with the new nucleation mode described by Murphy et al. (2017). Specifically, this study includes a third mode, in addition to the Aitken and accumulation modes that have been used in all CMAQ applications to date.
The emission inventories for non-aviation sectors for this application will rely on the EPA’s NEI for the year 2017 (if available) or on projections from the NEI-2014.
The meteorological fields will be downscaled from the National Aeronautics and Space Administration (NASA) MERRA v2 (Reinecker et al., 2011).
The base CMAQ model application will be configured as follows:

a) Aircraft emissions from AEDT processed by AEDTProc;
b) Background emissions from NEI processed by SMOKE v3.6;
c) Meteorology from MERRA downscaled with WRF v3.8;
d) Lightning NO_x;
e) Inline photolysis;
f) Latest version of CMAQ (v5.2), enhanced with the new aircraft-specific emission module described by Huang et al. (2017).

The initial and boundary conditions will be downscaled from a global model such as GEOS-Chem or the Model for Ozone and Related Chemical Tracers (MOZART).

Research Approach

N/A

Milestone

This task was placed on hold during FY2019 due to a delay in funding.

Major Accomplishments

This task was placed on hold during FY2019 due to a delay in the release of FAA funding.

Publications

N/A

Outreach Efforts

N/A

Awards

None.

Student Involvement

None.

Plans for Next Period

Start the task, if authorized by the FAA.

Task 3 - Perform a Model–Monitoring Intercomparison at Boston Logan Airport

UNC at Chapel Hill

Objectives

In this task, UNC will obtain 2017–2018 field observations from the ASCENT-18 team at BU and perform model–measurement comparisons. Thus far, BU has acquired measurements at five fixed-site locations on the arrival path of aircraft at Boston Logan airport. We will collaborate with BU on this task and compare regression and dispersion model-based assessments of ultrafine particles (UFPs) from Boston Logan airport.

As described above, this project is a collaborative effort with the ASCENT-18 investigators and will require a constant exchange of information and results throughout the period of performance. This task will lead to an integrated measurement- and modeling-based assessment of UFPs due to aircraft emissions at Boston Logan airport. In the final phase of this project, during the period of 2019–2020, we will upgrade the modeling application to use new fixed and mobile measurement platforms in the integrated assessment. Our intercomparison will rely on the methods described by Penn et al. (2015) and will be enhanced to use CMAQ-based predictions instead of the AMS/EPA Regulatory Model (AERMOD)-based approach used at the Los Angeles international airport (LAX).

Research Approach

N/A

Milestone

This task was placed on hold during FY2019 due to a delay in funding.

Major Accomplishments

This task was placed on hold during FY2019 due to a delay in the release of FAA funding.

Publications

N/A

Outreach Efforts

N/A

Awards

None.

Student Involvement

None.

Plans for Next Period

Start the task, if authorized by the FAA.

Task 4 - Develop a Framework for a New Dispersion Model for Aircraft Sources

UNC at Chapel Hill

Objectives

The FAA's AEDT is currently coupled with the U.S. EPA's AERMOD dispersion model for aircraft sources and is the required regulatory model in the U.S. for modeling airport-level aircraft operations during LTO cycles.

Recent studies have shown several limitations in the use of AERMOD for modeling aircraft sources. The Airport Modeling Advisory Committee (AMAC) developed a series of recommendations in 2011 to improve the modeling of jet exhaust. Subsequently, the Airport Cooperative Research Program (ACRP) project 02-08 developed guidelines for airport operators in conducting measurements and modeling air quality at airports, which were published in ACRP Report 70 (Kim et al., 2012). In this work, a measurement and modeling study was conducted at Washington Dulles international airport (IAD). More recently, ACRP project 02-58 developed a final report, ACRP Report 171 (Arunachalam et al., 2017), providing dispersion modeling guidance for airport operators with regard to local air quality and health. This study applied four dispersion models, i.e., AERMOD, CALPUFF, SCICHEM, and the U.K.'s Atmospheric Dispersion Modeling System (ADMS)-Airport, to LAX and compared model predictions with high-resolution measurements acquired during the Los Angeles Air Quality Source Apportionment Study (AQSAS). This study had some limitations, including a lack of secondary PM formation modeling and a lack of improved NO_x-to-NO_2 prediction models for aircraft sources. These three reports (AMAC, Kim et al, 2012 and Arunachalam et al, 2017) identified several limitations for AERMOD and presented a series of recommendations for improved dispersion modeling of aircraft emissions for airport-level air quality. Similar to other airport dispersion modeling tools such as AERMOD, the Lagrangian simulation of aerosol transport (LASAT) for airports (LASPORT), and ADMS, C-AIRPORT, a line-source-based dispersion model for aircraft sources based on the C-LINE modeling system (Barzyk et al., 2015), is currently being developed by UNC. This tool can potentially be used for airport modeling in the future.

As part of the proposed ASCENT research under Task 4, we propose the following subtasks:

- Subtask 4a: Perform a comprehensive review of the AEDT/AERMOD approach for modeling aircraft sources. This review will include current known applications of the AEDT/AERMOD modeling system, with a specific focus on how the emission inventories are built to capture aircraft activity and how AEDT/AERMOD treats aircraft sources during various modes of aircraft operation.
- Subtask 4b: Perform a comprehensive review of various approaches for modeling aircraft sources. These approaches will include, but are not limited to, various air quality models within and outside the U.S., including CALPUFF, SCICHEM, C-AIRPORT, ADMS-Airport, LASPORT, etc., and Gaussian, Lagrangian, or other hybrid approaches.
- Subtask 4c: Develop a comprehensive plan or modeling framework that addresses the limitations identified in the above tasks and propose the most suitable and viable approach for modeling pollutants from aircraft sources. The primary objective of this plan is to demonstrate that a robust, improved pollutant dispersion model for aircraft can be developed for U.S. regulatory compliance purposes. The proposed model shall model the dispersion of

pollutants from aircraft sources in a more technically and scientifically advanced manner (compared with current AERMOD capabilities), with the ultimate goal of becoming a potential U.S. regulatory compliance tool, based on future discussions between the FAA and EPA. This plan will include an itemized list of known limitations and a corresponding proposed developmental approach to address these limitations. We will then share the proposed plan with the FAA for the next phase of this task.

Research Approach

In this research, we plan to conduct a comprehensive review of dispersion models for airports and will then formulate a plan to develop an improved model that overcomes some of the shortcomings identified in the review discussed herein.

1. Introduction and Objectives

1.1 Approaches to dispersion modeling

Steady-state plume models are often applied beyond the appropriate range of applicability, with the justification that the concentration at the receptor is representative of the plume that eventually reaches the receptor. In principle, dispersion under unsteady and spatially varying conditions can be treated by puff or particle models, which attempt to model the dispersion of puffs or particles as an unsteady wind field carries them along their trajectories.

1.2 Aircraft emissions

Figure 1 shows an idealized movement pattern for aircraft at a typical airport, separated into four modes. These modes include the approach, taxiing (including idling), takeoff, and climb-out. The greatest potential impact on ground-level concentrations arises during taxiing and takeoff, when emissions occur close to the ground.

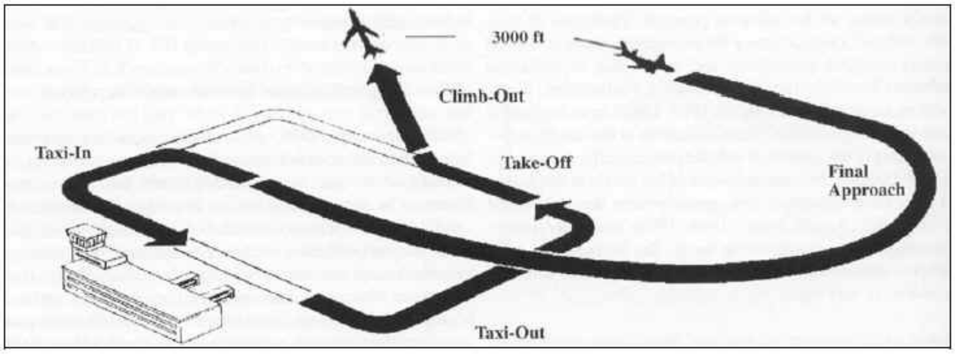

Figure 1. Aircraft modes at an airport (source: ICAO).

2 Literature Review of Dispersion Modeling Studies for Airports

A summary count of the different dispersion models applied in published papers, reports, and conference presentations focused on dispersion modeling for airport-level studies is shown in Figure 2. Dispersion modeling papers for airports, Air Force (AF) bases, and Navy bases have been compiled and reviewed, as shown in chronological order in Table A1 in Appendix A. Based on a review of simulations of pollutant dispersion at airports since the early 1970s utilizing different dispersion models, the most widely used model is found to be AERMOD (Cimorelli et al., 2004), as shown in in Figure 2 and Table A1 in Appendix A. The most widely studied airports are LAX and the London Heathrow (LHR) airport. The most widely simulated pollutant is NO_x, as shown in Table A1 in Appendix A. Several studies have shown that NO_x has been overpredicted at airports.

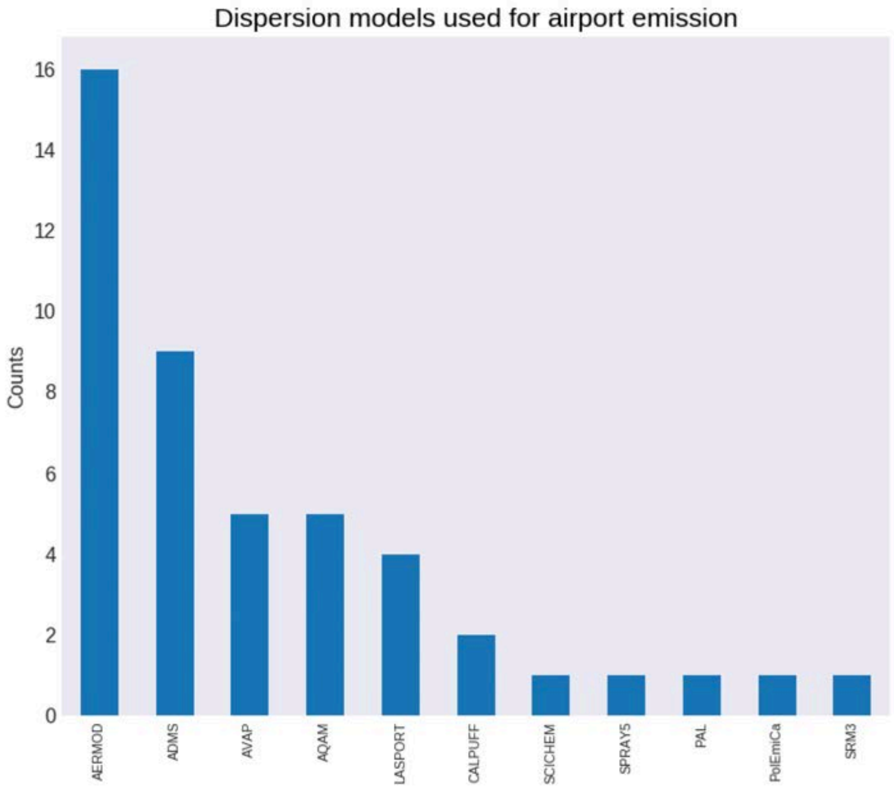

Figure 2. The frequency of papers and reports presenting dispersion modeling results of pollutant dispersion from airports since 1977.

3 Fundamentals of Micrometeorology

We developed a primer that presents the physics of atmospheric boundary layers, which is required to understand the transport and dispersion of pollutants associated with airport emissions. This primer is included in the draft report submitted to the FAA (Arunachalam et al., 2019a).

4 Source Characterization and Emission Model for Airport Dispersion Modeling

In this section, the characterization of aircraft emission sources is discussed for three recent, widely used emission models of airport dispersion (shown in Table A1 in Appendix A): AEDT (Ahearn et al., 2017), ADMS-Airport (CERC, 2017a), and LASPORT (Janicke et al., 2011).

4.1 Source characterization by the AEDT

The AEDT distributes each aircraft's segment emissions into the spatially fixed emission sources required by AERMOD through its built-in emission dispersion module (EDM). For each modeling hour, all flights whose segments cross a given rectangular AERMOD area source (spatially defined by the user for a given domain) are summed for that individual area source. The area sources, composed of all emissions from individual flight segments crossing each area, are used as hourly emission rates in the AERMOD dispersion model.

4.2 Source characterization by ADMS-Airport

A single ADMS-Airport run can simultaneously model a full range of explicit source types, including a single grid source containing up to 3,000 cells, 500 aircraft jet sources, 3,000 road sources, and 1,500 industrial point, line, area, and volume sources (CERC, 2017a). Accelerating jet sources for individual aircraft source are modeled to simulate the near-field plume rise. The jet source has the same aircraft speed, thrust, and emission rate of a moving aircraft following a line segment. An aircraft jet source in this line segment includes the aircraft speed at the start and end of the line segment, the emission rates in g/m^3-s, and the number of interpolation points.

4.3 Source characterization by LASPORT

LASPORT (Janicke et al., 2011) is a Lagrangian dispersion modeling system for airport emissions, with LASAT (LASAT, 2017) as the primary dispersion model. The aircraft emission treatment consists of aircraft traffic (LTO cycles), which is treated as a stationary line source (in "scenario calculations") and a moving line source (in "monitor calculations"), followed by auxiliary power units (APUs), ground power units (GPUs), ground support equipment (GSE), motor traffic (airside and landside), and other sources, which are treated as point, line, and volume sources. These sources are treated as a Lagrangian particle model, which calculates the trajectories of a representative sample of particles using stochastic processes, in contrast to the deterministic approach used by the other reviewed models. The characterized emissions from aircraft sources can be specified according to individual aircraft performance model calculations, designated as monitor calculations in LASPORT, or according to assumptions regarding general fleet makeup and movement, designated as scenario assessments.

5 Review of Dispersion Models Used in Airport Dispersion Modeling Studies

The major components of the 11 dispersion models used in airport dispersion modeling studies since 1970, shown in Figure 2 and listed in Table A2 in Appendix A, are described in the draft report (Arunachalam et al., 2019a) submitted to the FAA. These 11 models are listed below:

1) Airport Vicinity Air Pollution (AVAP) model (Wang et al., 1975),
2) Air Quality Assessment Model (AQAM) (Rote & Wangen, 1975; R. J. Yamartino et al., 1980),
3) Point, Area, and Line (PAL) model (Peterson, 1978),
4) AERMOD model (Cimorelli et al., 2018, 2004),
5) Atmospheric Dispersion Modeling System (ADMS) (Carruthers et al., 1994; CERC, 2016), the ADMS-Urban model (CERC, 2017b), a customized sub-version of the ADMS model, and the ADMS-Airport model (CERC, 2017a), a customized sub-version of the ADMS model for airport dispersion modeling,
6) LASPORT model (Janicke et al., 2011),
7) CALPUFF (California Puff) model (Scire et al., 2000),
8) SCICHEM (SCIPUFF with CHEMistry) model (Chowdhury et al., 2015; Knipping, 2019),
9) Pollution and Emission Calculation (PolEmiCa) model (Synylo & Zaporozhets, 2017; Zaporozhets & Synylo, 2019),
10) SRM3 model (InfoMil, 1998), and
11) SPRAY5 model (Tinarelli et al., 1994)

6 Dispersion Model for Airport Emissions

An airport is a small urban area with a wide range of source types and road and building configurations that can affect the dispersion of pollutants. In principle, any of the commonly used dispersion models, such as AERMOD, CALPUFF, SCICHEM, or ADMS, can be used to model the impact of most emission sources at an airport.

6.1 Modeling dispersion of LTO emissions

It is important to note that the major emission source at an airport, the aircraft, is a moving source that emits pollutants in short bursts during LTO operations. Dispersion from this transient source differs substantially from that associated with continuous sources, which have been well-characterized by field studies and modeling over the past 50 years. Plume dispersion parameters for continuous sources have also been characterized relatively well and have been incorporated in models such as AERMOD. In contrast, empirical knowledge on the dispersion of short releases is limited. Carslaw et al. (2006, 2008) demonstrated that hourly averaged NO_x concentrations at a position 180 m north of a northern runway showed little variation with wind speed at LHR, indicating the significant role of the jet plume buoyancy in governing ground-level concentrations.

6.2 Modeling key physical dispersion processes for airports

Airport dispersion models must account for the following: 1) the impact of structures, such as near-road sound barriers and buildings, on dispersion, 2) chemical reactions, and 3) non-buoyant airport sources near the ground under low wind speeds, which give rise to the highest concentrations. While most models reproduce non-buoyant behavior, they tend to overestimate concentrations under low wind speeds, especially under stable conditions (Arunachalam et al., 2017a).

7 Key Challenges in Dispersion Modeling for Airports

We identified several challenges that arise in modeling the dispersion of pollutants at an airport, as discussed below.

7.1 Source characterization

7.1.1 Area sources

Aircraft operation sources (idling, taxiing, take-off, climbing, and landing) are modeled as area sources in the AEDT/AERMOD. Modeling an aircraft source as an area source is advantageous because no stack parameter data are required for the AEDT area segment; however, area source modeling for aircraft also has some disadvantages, particularly the plume rise and downwash, caused by building obstacles, cannot be modeled in the area source treatment in AERMOD.

7.1.2 Point sources

One of the greatest challenges in modeling an aircraft source as a point source is the assumption of stack parameters (stack diameter, stack temperature, and stack velocity). If aircraft emission sources can be modeled as point sources, some of the existing limitations, such as the plume rise and building downwash, for airport pollutant dispersion in the AERMOD area source model can be solved, as AERMOD has a plume rise and building downwash modeling option for point source modeling.

7.1.3 Line sources

Aircraft emission sources can be modeled as stationary or moving line sources in a dispersion model. The current AERMOD version has a line source option for onroad sources as a beta (non-regulatory) option. A recent study presented an aircraft emission model in which an individual aircraft is modeled as a line source based on multiple data sources, such as AEDT data, airport flight data, and ICAO engine emission data. Dispersion modeling using this line source model is currently in progress (Arunachalam et al., 2019b).

7.1.4 Jet sources

Aircraft emission sources can be well modeled as jet sources. Aircraft sources can be modeled in two ways: 1) stationary aircraft sources are modeled as an area, volume, line, or point source and 2) moving aircraft sources are modeled as a jet source by tracking an individual jet. The aircraft emission sources are modeled as jet sources in pollutant dispersion modeling for airports by the ADMS-Airport model (Carruthers, 2006; Carruthers et al., 2007; Elie et al., 2008; Sarrat et al., 2012) and PolEmiCa model (Synylo and Zaporozhets, 2017). Jet source modeling has been found to be particularly important for modeling take-off emissions (Elie et al., 2008). However, jet source modeling also has challenges, as high-time-resolution aircraft flight data, including flight trajectories, are required.

7.2 Plume rise

Modeling the plume rise from aircraft exhaust in a dispersion model has remained a challenge in airport dispersion modeling studies over the past four decades (Arunachalam et al., 2017; Daley & Naugle, 1979). In the AEDT modeling system, the primary challenge is associated with the typical assumption of an aircraft emission source as an area source. The plume rise can be easily modeled as either a point source or a jet source in the dispersion model. A detailed proposal for modeling the plume rise of aircraft emissions is given in the ACRP report (Arunachalam et al., 2017).

7.3 Downwash low-height emission source such as aircraft at the gate or terminal

At an airport, a wake vortex can occur around the tarmac, and the Plume RIse Model Enhancements (PRIME) algorithm (Schulman et al., 2000) for downwash in AERMOD may not be feasible, as the emission height for aircrafts at the surface is lower than the building height. The concentration at the wake vortex area near the building, created by the 2 L-shaped walls of the terminal building, may be higher than that at the non-vortex area of the terminal. For a point or area emission whose height is smaller than the building height, a new model may be required.

7.4 Number of air sources

The AEDT generates too many emission segments as individual emission sources as LTO path spans a long distance (>10 km). This higher number of emission sources (a significant fraction of which are in the atmosphere in the LTO path, which has little effect on the surface air quality) increases the computational cost of the Lagrangian SCICHEM model (Arunachalam et al., 2017), an open-source model and the only dispersion model that includes detailed gas-phase and aerosol chemistry.

7.5 Aircraft engine exhaust dynamics

Exhaust dynamics, such as high-speed exhaust during take-off, wing-tip vortices, and plume rises, can be better modeled if individual aircraft engines are modeled as point or jet sources. Because high-speed exhaust and wing-tip vortices arise for individual aircraft (or aircraft engines) and because individual aircraft engines can be easily modeled as a horizontal point source rather than an area or volume source, point source modeling of individual aircraft enables the modeling of these two dynamic exhaust phenomena. As the existing plume rise models, such as the PRIME algorithm (Schulman et al., 2000), are designed for point sources, treating individual aircraft engines as horizontal point sources will also be helpful for modeling plume rises.

8. Framework for an Airport Dispersion Model

The AEDT framework should allow for alternate treatment of sources and corresponding model formulations of governing processes, as in CMAQ (Byun & Schere, 2006). We present a brief summary of the desired framework here.

8.1 Dispersion and plume rise during the LTO cycle

A line thermal model, as shown in Figure 3, assumes a continuous release from an infinitely long line source along the runway, but can be readily adapted for a finite-length line puff whose length is approximately the length of the runway, using an approximation suggested by Venkatram and Horst (2006).

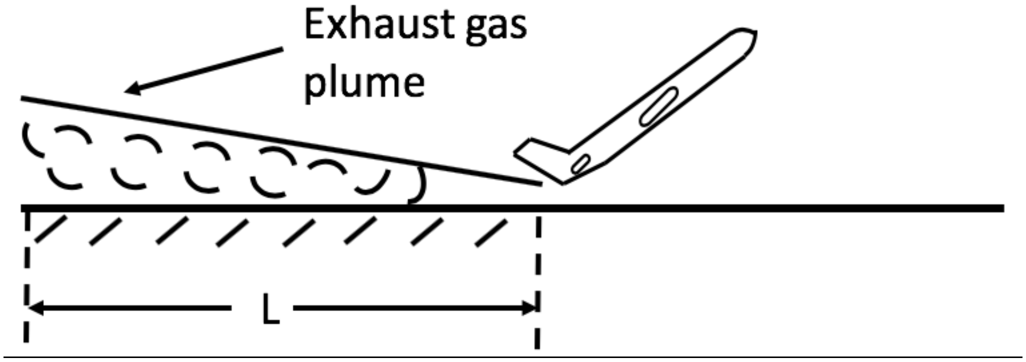

Figure 3. Exhaust gas plume created along the runway during take-off.

8.2 Building effects

The dimensions of the volume sources are governed by buildings adjacent to the sources, where the initial vertical spread corresponds to the building height. Schulte et al. (2015), Amini et al. (2016), and Heist et al. (2013) suggested methods for incorporating building effects in line source models. Omitting the building effects is likely to result in overestimated impacts of airport emissions close to the airport.

8.3 Modeling chemical transformation

NO_x emissions from aircraft and vehicles are converted into NO_2, which is a regulated pollutant. The AEDT framework should include options for different methods of treating NO_x. The new AEDT should also include options for treating the formation of secondary sulfate, nitrate, and organic aerosols from aircraft emissions. One option is a computationally efficient method that separates the transport and chemistry to model the formation of these aerosols, as described by Venkatram et al. (1998).

8.4 Accounting for shoreline meteorology in AERMET

Several of the largest airports in the U.S. are located on a coastline. AERMET, AERMOD's meteorological processor, is based on a one-dimensional boundary layer model that, in principle, cannot be applied to shorelines, where surface properties vary sharply across the water–land interface. Thus, AERMET need to be modified to account for the thermal internal boundary layer (TIBL) that develops during onshore flows, when cold stable air flows from water onto warmer land.

8.5 Effects of aircraft wing-induced flows

The pressure difference across an aircraft wind can drive flow from under the wing to above the wing at the tips, resulting in wing-tip vortices. These relatively long-lived structures can affect the dispersion of aircraft engine emissions. The wing also pushes the air downward to generate lift of the aircraft. In principle, this "downwash" can push emissions down, partially counteracting the effects of the plume rise, particularly when the aircraft is climbing. These effects needs to be incorporated in the proposed model.

8.6. Dispersion at low wind speeds

An evaluation of several dispersion models using data collected at LAX (Arunachalam et al, 2017) showed that the concentrations are overestimated when wind speeds are low. Furthermore, the highest concentrations occurred under light winds (1–2 m/s at 10 m) for both stable and unstable conditions, suggesting the need for better treatment of dispersion under low wind speeds.

9 Evaluation with Data from Field Studies

A diagnostic evaluation of the AEDT will require a new field study with the following elements:

1. Stationary monitors at several locations within an airport, including near runways, to measure the concentrations of relevant pollutants.
2. Mobile monitors to identify hotspots that might be missed by stationary monitors.
3. Stationary monitors downwind of the airport to collect the data required to evaluate model components that are sensitive to boundary layer variables rather than source characteristics.

4. Lidar measurements of exhaust plumes to evaluate model estimates of plumes that rise and spread along the runway during the takeoff roll.
5. Tracer release from an aircraft engine to evaluate the accuracy of the line source approximation. The release could be sampled by several monitors downwind of the runway.
6. Sonic anemometers at several locations to provide micrometeorological inputs for the dispersion model.
7. Sonic Detection and Ranging (Sodar) measurements to provide vertical profiles of horizontal velocity and turbulent velocity, which are needed to evaluate the model with respect to emission dispersion during climb-out in the boundary layer and downwind of the airport.
8. Details of aircraft types and activity during the field study to evaluate the emission model component of the AEDT.

Milestone

We submitted a draft of the framework to the FAA, and a revised version incorporating feedback from the FAA will be submitted.

Major Accomplishments

- Extensive literature review of both dispersion models and local air quality studies at airports across the world.
- Identification of limitations in existing models.
- Initial conceptual approach for modeling aircraft sources to assess local air quality at airports.

Publications

N/A

Outreach Efforts

Presentation at semi-annual ASCENT stakeholder meetings in the spring (Atlanta, GA) and fall of 2019 at Alexandria, VA. Presentation and collaborative discussion during monthly meetings with the ASCENT-18 team at BU.

Awards

None.

Student Involvement

Calvin Arter, a current graduate student, assisted in reviewing the characterization of aircraft sources for the AEDT and ADMS-Airport.

Plans for Next Period

Finalize the framework document for the FAA and begin developing the model.

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Appendix A

Table A1. Dispersion modeling studies on airport/aircraft emissions performed since 1977.

Year	Airport	Model	Emission Model	Meteorology	Species	Ref.
1977	Washington Dulles (IAD), USA	AVAP			CO, NO_2, THC	(Smith et al., 1977)
1978	Washington Dulles (IAD), USA	AQAM			CO	(Shellar, 1978)
1978	Van Nuys (VNY), USA	PAL			CO	(Schewe et al., 1978)
1978	Miramar Naval Air Station	AQAM			CO	(Netzer, 1978)
1978	10 USAF Bases	AQAM			CO, RHC, NO_2, TSP, SO_2	(Naugle et al., 1978)
1978	Los Angeles International (LAX), USA	AVAP			CO	(Yamartino and Rote, 1978)
1979	Los Angeles International (LAX), USA	AVAP			CO, THC, NO_x	(Yamartino and Rote, 1979)
1979	Nellis AF Base	AQAM			NO_x	(Daley and Naugle, 1979)
1980	William AF Base	AQAM			CO, NMHC, NO_x	(Yamartino et al., 1980)
1980	Los Angeles International (LAX), John F. Kennedy International (JFK), Chicago O'Hare International (ORD), USA	AVAP				(Yamartino et al., 1980)
1981	Los Angeles International (LAX), Chicago O'Hare International (ORD), John F. Kennedy International (JFK), USA	AVAP			CO, NO_x, THC	(Segal and Yamartino, 1981)
2003	Washington Dulles (IAD), USA	AERMOD-EDMS	EDMS		CO	(Wayson et al., 2003)
2005	Zurich (ZRH), Switzerland	LASPORT	LASPORT-LASAT		NO_2	(Fleuti and Hofman, 2005)

Year	Airport	Model	Emission Model	Meteorology	Species	Ref.
2006	Manchester (MAN), UK	ADMS-Urban	Manual, ICAO		NO_x	(Peace et al., 2006)
2006	London Heathrow (LHR), UK	ADMS-Urban	Manual, ICAO	U.K. Met Office	NO_x	(Farias and ApSimon, 2006)
2006	London Heathrow (LHR), UK	ADMS-Airport			NO_x, NO_2, O_3	(Carruthers, 2006)
2007	Zurich (ZRH), Switzerland	AERMOD, LASAT	ALAQS-AV	AIRMET	NO_x	(Duchene and Peeters, 2007)
2007	London Heathrow (LHR), UK	ADMS-Airport			NO_x, NO_2	(McHugh et al., 2007)
2007	London Heathrow (LHR), UK	ADMS-Airport	Arbitrary		NO_x, NO_2	(Carruthers et al., 2007)
2007	Brisbane (BNE), Australia	CALPUFF		CALMET	CO, NO_x (NO_2), SO_2, TSP, HC	(BAC, 2007)
2008	London Heathrow (LHR), UK	AERMOD			NO_x	(Barrett and Britter, 2008)
2008	Budapest (BUD), Hungary	AERMOD-EDMS	EDMS		NO_x, CO	(Steib et al., 2008)
2008	London Heathrow (LHR), UK, CAEPort (mock airport)	ADMS-Airport			NO_x	(Carruthers et al., 2008)
2009	32 U.S. airports	AERMOD	EDMS		Benzene, 1,3-butadiene, and benzo[a]pyrene (BaP)	(Zhou and Levy, 2009)
2009	London Heathrow (LHR), UK	AERMOD			NO_x	(Barrett and Britter, 2009)
2010	SMO), USA	AERMOD			Pb	(Den, 2010)
2010	Budapest (BUD) Hungary, Zurich (ZRH), Switzerland, Frankfurt (FRA) Germany	AERMOD, LASPORT	EDMS		NO_2, NO_x	(ACI, 2010)
2011	Santa Monica (SMO), USA	AERMOD			Pb	(Carr et al., 2011)
2011	London Heathrow (LHR), UK	ADMS-Airport	Arbitrary		NO_x, NO_2	(Carruthers et al., 2011)
2011	London Heathrow (LHR), UK	AERMOD	EDMS		NO_x, NO_2	(Sabatino et al., 2011)
2012	Pittsburgh International	AERMOD	Manual, ICAO		$PM_{2.5}$	(Lee, 2012)

Year	Airport	Model	Emission Model	Meteorology	Species	Ref.
	(PIT), Asheville Regional (AVL), USA					
2012	A regional French airport	ADMS-Airport	IESTA		NO_x	(Sarrat et al., 2012)
2012	Zurich (ZRH), Switzerland	LASPORT-LASAT			NO_2	(Fleuti and Maraini, 2012)
2012	Washington Dulles (IAD), USA	AERMOD	EDMS		CO, THC, NMHC, VOC, TOG, NO_x, SO_x, PM_{10}, $PM_{2.5}$, various HAP compounds	(Kim et al., 2012)
2013	Los Angeles International (LAX), USA	AERMOD	EDMS		CO, NO_x, $PM_{2.5}$, SO_2	(Arunachalam et al., 2013)
2015	Amsterdam Schiphol (AMS), Netherlands	SRM3		Stations	EC, PNC	(Keuken et al., 2015)
2015	Florence (FLR), Italy	AERMOD-EDMS	EDMS	Stations	CO, NO_x, SO_x, PM_{10}	(Simonetti et al., 2015)
2015	Los Angeles International (LAX), USA	AERMOD-EDMS	EDMS	Stations	EC, NO_x	(Penn et al., 2015)
2015	Western Sydney (SWZ), Australia	AERMOD-EDMS	EDMS		NO_2, $PM_{2.5}$, PM_{10}, CO, SO_2, benzene, toluene, xylene, formaldehyde	(DOIRD, 2015)
2016	Venice Marco Polo (VCE), Italy	SPRAY5	Manual, ICAO	SWIFT model	NO_x, CO, HC	(Pecorari et al., 2016)
2017	Los Angeles International (LAX), USA	AERMOD-EDMS, CALPUFF, SCICHEM, ADMS-Airport		AIRMET, NWS, CALMET, MMIF,	CO_2, H_2O, CO, VOC, NO_2, NO_x, SO_x, PM_{10}, $PM_{2.5}$	(Arunachalam et al., 2017)
2017	CAEPport (mock airport)	PolEmiCa			NO_x	(Synylo and Zaporozhets, 2017) CMAS
2018	Istanbul Ataturk (ISL), Turkey	AERMOD	Manual, ICAO	AIRMET	HC, CO, NO_x	(Kuzu, 2018)

Table A2. Major components of eight dispersion models used in airport dispersion modeling studies.

Model	AERMOD	ADMS-Airport	LASPORT	SCICHEM	CALPUFF	AQAM	AVAP	PolEmiCa
Reference	(Cimorelli et al., 2004)	(Carruthers et al., 1994; CERC, 2016)	(Janicke et al., 2011)	(Chowdhury et al., 2015)	(Scire et al., 2000)	(Rote and Wangen, 1975)	(Wang et al., 1975)	(Synylo and Zaporozhets, 2017; Zaporozhets and Synylo, 2019)
Sponsor	U.S. EPA	EA and HSE of U.K.	German Airport Association	EPRI	CARB	USAF	FAA	
Developed by	AERMIC	CERC, U.K.	Janicke Consulting	Ramboll	Sigma Research Corporation	ANL	ANL	NAU, Kyiv, Ukraine
Is designed for airports	No	Yes	Yes	No	No	Yes, for military bases and airports	Yes, for civil airports	Yes
Type	Gaussian plume	Gaussian plume	Lagrangian particle	Lagrangian puff	Lagrangian puff, non-steady-state puff	Gaussian plume	Gaussian plume	Gaussian plume
Components	Meteorology, emission, terrain, dispersion	Emission, GIS, dispersion	Dispersion	Meteorology, terrain, dispersion, GUI		Source inventory, short term, long term, and		Engine emissions, jet transport, dispersion

Model	AERMOD	ADMS-Airport	LASPORT	SCICHEM	CALPUFF	AQAM	AVAP	PolEmiCa
						meteorological data		
Is emission processor included	No	Yes	Yes	No	No	Yes	Yes	Yes
Emission source type	Point, area, volume	Road traffic, point, area, volume, grid, jet	Point, line, volume, area, grid	Point, area, volume	Point, line, area, volume	Point, area, line	Point, area, line	Jet
Chemistry	NO-NO$_2$ (OLM, PVMRM)	NO, NO$_2$, O$_3$, sulfate from SO$_2$	NO, NO$_2$	Detailed, cb05, cb06	Multi-species			
Plume rise	Yes	Yes	Yes	Yes	Yes	No		Yes
Moving jet model	No	Yes	Yes					Yes
Wake vortex surface effects	No	Yes						Yes
Effects of exhaust speed and exhaust dynamics		Yes	Yes					Yes
Downwash	Yes	Yes	Yes	Yes	Yes			
Wet and dry deposition	Yes	Yes	Yes	Yes	Yes			
Time step used	No	No	Yes	Yes, adaptive time				

Model	AERMOD	ADMS-Airport	LASPORT	SCICHEM	CALPUFF	AQAM	AVAP	PolEmiCa
				steps				
GUI soft visualization	No	Yes, ADMS mapper	Yes	Yes, SCIPUFgui				
Purpose for development	Dispersion for point, area, and volume source	Dispersion for airport	Dispersion for airport			Dispersion for military base and airport	Dispersion for civil airport	Exhaust dynamics
Proprietary	No, free	Yes	Yes	No, free	No, free	NA	NA	NA
Operating system	Windows, Linux	Windows	Windows, Linux for LASAT	Windows, Linux	Windows, Linux			NA
Computation time	Low	Medium		High	Low			