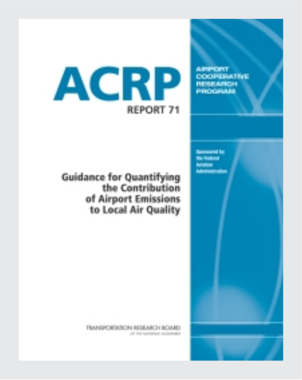

Guidance for Quantifying the Contribution of Airport Emissions to Local Air Quality

DETAILS

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 71

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

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We also would like to thank NOAA's National Center for Environmental Prediction for providing timely access to the NAM and CMAQ model outputs from the national-scale operational modeling that were used as inputs to drive the model applications used in this study.

FOREWORD

By Lawrence D. Goldstein
Staff Officer
Transportation Research Board

ACRP Report 71 is a guide for airport operators on effective procedures for using air quality models in combination with on-site measurement equipment to prepare a comprehensive assessment of air pollutant concentrations in the vicinity of airports. It is designed to help practitioners generate information desired by local communities as they seek to develop more detailed local air quality assessments as well as respond to regulatory needs, including those of the National Environmental Policy Act (NEPA). The guide provides in-depth information on the capabilities and limitations of modeling and measurement tools, adding to an increasing knowledge base concerning preparation of air quality assessments near airports. Starting with the Federal Aviation Administration's (FAA's) regulatory EDMS/AEDT, it describes how best to use available models, in combination with potential on-site monitoring programs, to conduct air quality assessments.

Detailed information on the monitoring campaigns and modeling assessments is included in a set of appendices that accompany the guide. These appendices (available in *CRP-CD-115*) describe the models tested and the various equipment used to collect data, the rationale behind the selection of Washington Dulles International Airport (IAD) as a case study application, and the components and steps involved in the measurement campaigns and include an assessment of the various model outputs. (*CRP-CD-115* is also available on line as an ISO image—search the TRB website for *ACRP Report 71*.)

This research emerged from a desire expressed by local government agencies and community groups for more definitive information about air emissions from aircraft and other airport-related sources. To create this guide, the research team integrated material gleaned from literature reviews with a series of on-site measurement campaigns conducted at IAD outside of Washington, D.C. The research identifies gaps in existing models and shortcomings in availability of required model inputs and suggests possible future research needed to help fill those gaps.

Recently, significant advances have been made with respect to estimating emissions from airport-related sources—advances that have been incorporated into the U.S. airport emissions modeling tool, Emissions and Dispersion Modeling System (EDMS). EDMS is expected to be integrated into the Aviation Environmental Design Tool (AEDT); however, research has been limited on the *relative* contribution of airports to local and regional air quality. Similar to other sources, emissions of air pollutants released from airport activities are chemically reactive. During their atmospheric evolution, these air pollutants undergo complex transport and physical-chemical processes leading to formation of secondary air pollutants. Besides proper representation of these processes, correct estimation of all airport emissions and their contribution to overall air quality are essential components in air quality studies in the vicinity of an airport. As demonstrated in this guide, the combination of ambient air quality measurements and use of modeling tools provides the best available framework to help improve our understanding and measurement of an airport's contribution to local air quality.

The guide will be most useful to those who are asked to measure airport contributions to local air quality in response to increasing public scrutiny. Although the test case application of the models and measurement equipment was specific to IAD, other airports and consultants can build on that information as they apply the methods to their own particular environments. In this way, the guide also serves as a basis for carrying out assessments at other airports.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains color versions if supplied.

SUMMARY

Guidance for Quantifying the Contribution of Airport Emissions to Local Air Quality

The impetus for this project is a limitation with modeling capabilities to comprehensively understand and explain airport contributions to local air quality. Although the FAA's Emissions and Dispersion Modeling System (EDMS) represents the state-of-the-art in emissions and dispersion (through USEPA's AERMOD) modeling capabilities, there are still limitations related to the handling of reactive pollutants and the formation of secondary pollutants. Therefore, the goal of this project was to develop guidance for combining measurements with modeling to fully support airport air quality assessments.

The scope of the project involved conducting various reviews and demonstrations of measurements and modeling through case studies. The resulting assessments involved the use of measured data and various modeling exercises, including sensitivity-type analyses, trend assessments, and modeled-versus-measured comparisons. Although these assessments were extensive in their coverage of various modeling parameters, they did not include formal validation or uncertainty assessments, which were considered outside the scope of this project. The purpose in conducting the assessments was to assess the measurement and modeling techniques for their application to quantifying airport contributions to local air quality.

The review work involved examining all applicable emissions and dispersion models, but mainly focusing on EPA- and FAA-recommended models, as well as some alternatives. In addition to EDMS and AERMOD, others, such as CAL3QHC and CALPUFF, were considered for their potential to either replace or augment the current capabilities in those recommended models. The model selections involving EDMS and CMAQ were largely based on being able to model chemical transformations and to leverage the FAA's previous research in this area. For the field measurements, the equipment was selected based on practical applications at airports (i.e., weighing various issues such as cost of equipment, expertise necessary, fidelity of data, and quantity of data). All equipment/techniques used were USEPA reference, equivalent, or other approved methods.

Field measurements were conducted as part of the case study at Washington-Dulles International Airport. This airport was selected based on consideration of such criteria as airport operations, location of other major sources, and topography. The measurement work involved the collection of both ambient concentration data and source activity information. The equipment included a combination of real-time gaseous analyzers, Summa canisters, draw-tube cartridges, Minivol air samplers with particulate matter (PM) filters, and rotating drum impactors (RDIs). Using the equipment, concentrations of each of the criteria pollutants and various hazardous air pollutants (HAPs) were measured.

The measured data were assessed to identify various trends such as those due to seasonal effects and relationships to airport operations and atmospheric effects (e.g., wind directions). The measured data allowed direct readings of airport contributions (loadings of each pollutant) to the local environment, thereby providing indications of what pollutants to focus on (i.e., resources used for future measurements). The data also served as a comparison for the model evaluation work.

The model evaluations included a comparison of using higher fidelity data versus default data in EDMS/AERMOD. Various modeled-versus-measured comparisons and sensitivity-type analyses were conducted to better understand the accuracy of the models and their behavior.

Further, a novel hybrid modeling approach was developed and applied to combine air quality outputs from CMAQ at a relatively coarser resolution of 4–12 km to provide secondary components of PM2.5 and then use AERMOD to predict concentrations of primary pollutants at a much more spatially resolved network of receptors. The rationale for this was that secondary pollutants tend to be more spatially diffused, while primary pollutants have a much more localized signature, especially when considering airport sources. Airport operators planning to perform air quality impact assessments can adopt this hybrid modeling approach, where a combination of CMAQ and AERMOD are used so as to take advantage of the respective modeling system's features to come up with a comprehensive set of outputs for all pollutants at the finest spatial and temporal scales desirable.

Based on the analyses of the hybrid modeling outputs under this project, for PM2.5, temporal variability dominates. However, for NOx, spatial variability is more important than temporal variability.

In addition to these main assessments, a supplemental PM-focused receptor modeling analysis was conducted to help support the source-oriented modeling work conducted through EDMS and CMAQ. This receptor modeling work served as an investigative tool that helped to confirm some of the findings with the source-oriented models, but, more importantly, helped to identify modeling gaps.

Another minor supplemental assessment conducted for completeness was based on the potential use of noise data to help corroborate aircraft takeoff and landing incidences. If more temporal fidelity is necessary in modeling aircraft operations, noise monitors can be used to identify the specific incidences in time. However, they are limited by their inability to differentiate incidences occurring on nearby runways and other sources.

The outcome from all of the various measurement and modeling reviews, field work, and data and modeling assessments is a set of findings and recommendations that culminated in the guidance materials presented in this report. The overall findings with respect to the goals of this project are that the set of equipment and models demonstrated as part of the case study were adequate (i.e., accomplished their purposes) but there is still significant room for improvement (i.e., to make the models more accurate as well as more robust in their capabilities). As such, a set of suggestions for future research focused on the use of EDMS/AERMOD, is presented in Chapter 6. These suggestions are ranked based on weighing the resources required to conduct the research and the expected impact on the accuracy and/or use of the models.

The scope of the guidance materials presented in this report is based on leveraging existing guidance and standards available in various USEPA and FAA documents. As such, this report's guidance requires a working knowledge of airport and air quality concepts. The guidance materials are, in large part, based on the reviews and findings from the case study assessments conducted under this project. Novices are directed to the USEPA and FAA documents referenced throughout this report.

CHAPTER 1

Introduction

1.1 Project Goal and Overview

This report represents the culmination of an extensive effort to evaluate measurement and modeling techniques to better understand their uses and limitations in quantifying the contribution of airports to local air quality. The main goal of the report is to provide airport operators with guidance to combine the use of measurement equipment with air quality models to allow comprehensive quantifications of pollutant concentrations in the vicinity of airports.

The guidance was developed from a combination of literature reviews and from assessments conducted using data gathered from a test airport. As presented in the appendices, the detailed assessments included evaluations of measured data and modeling capabilities. The guidance presents conclusions and findings from the assessments, recommendations for equipment usage and model applications, discussion of the gaps and limitations of the various techniques, and recommendations for improvements.

All of the information gathered as part of this project is intended to add to the growing knowledge base of airport air quality assessments. The results provide a basis for further airport air quality research and procedures for airport operators.

1.2 Background

There can be many reasons for conducting an airport air quality study, including compliance under NEPA to support the Clean Air Act (CAA); local (e.g., city and state) environmental regulations; and community health concerns (CFR 2008 and USEPA[a] 2007). If a project does not meet an exclusionary condition and an emissions inventory does not suffice, dispersion modeling and/or atmospheric measurements may be required to demonstrate compliance by showing concentration levels are below the limits set by these regulations. The intention of regulatory acts like NEPA is to prevent or eliminate damage to the environment by various activities involving the use of federal funds. NEPA directs federal agencies like the FAA to incorporate environment in decision-making processes.

The current airport air quality handbook promulgated by the FAA is the Air Quality Procedures for Civilian Airports and Air Force Bases, which is consistent with FAA Order 1050 and represents an effort by the FAA to provide an easy-to-understand explanation of the regulatory and decision-making process (FAA 1997). This guidance document provides interpretations for each of the regulations applicable to an airport air quality analysis and provides specific instructions for each step of the assessment process [e.g., emissions inventory development, indirect source review, conformity assessments, and National Ambient Air Quality Standards (NAAQS) assessment]. The decisions made as part of the assessment for NAAQS determine whether or not atmospheric concentrations need to be determined.

These regulatory-type guidance documents assume that the tools from the FAA and the USEPA will be used appropriately based on existing supporting documents (e.g., user guides and technical reports). Although the supporting documents for these tools and the regulatory guidance materials appear to be sufficient, the application of the tools to airports still needs clarification. Compared to emissions inventory development, very few studies have been conducted on airport air quality issues. Due to the costs of conducting such assessments, most airport operators prefer not to conduct such work unless they are absolutely necessary (i.e., no alternatives are available).

Airport air quality assessments can be complex and resource-intensive, especially for larger airports. In the interest of cost-effectiveness and resource efficiency, computer-based models generally provide the primary capability for assessing airport contributions to local air quality. But given the current shortcomings of available emissions and dispersion models, measurement programs may be necessary to compensate for model shortcomings and limitations. However, a significant component of shortcomings in model predictions is related to uncertainties or limitations of emissions inputs to the model. Improving methodologies for emissions factors and having accurate airport activity data will lead to greater confidence in model-based assessments.

Although technological advances are allowing more and more continuous measurements, the equipment and overall resources required to conduct such work is still very expensive, and, in many cases, prohibitively expensive. As such, any use of air quality modeling work to reduce or replace measurements will be attractive to airport operators. However, the use of models (with atmospheric dispersion) can also be resource-intensive and poses greater risk of errors.

In addition to the inherent errors associated with the modeling techniques employed in models such as the USEPA's workhorse dispersion model, AERMOD, myriad other sources of error are associated with the input data: aircraft fleet mix, auxiliary power unit (APU) usage times, ground access vehicle (GAV) speeds, weather data, source locations, and so forth. Any one of these datasets can have significant repercussions on the accuracy of both the resulting emissions inventories and modeled atmospheric concentrations. Although significant improvements have been (and are being) made to improve modeling capabilities by both the USEPA and FAA, much more work needs to be accomplished to make the associated tools more accurate as well as more robust and easier to use.

Currently, the air quality modeling capabilities in the FAA's Emissions and Dispersion Modeling System (EDMS) have some limitations concerning comprehensive analyses of airport contributions to local air quality. This is partly due to some limitations with emissions modeling, but in larger part due to limitations such as the inability to model chemical reactions in AERMOD as implemented within EDMS. As such, the combined use of measurements and modeling are recommended in certain situations to better understand airport contributions.

1.3 Scope of Work

The project involved two sets of work:

1. A comprehensive literature review of airport air quality measurements and modeling techniques.
2. Airport field data collection efforts to assess measurement and modeling techniques.

The literature review involved complete coverage of all applicable USEPA models and measurement techniques (including associated equipment). The reviews and ensuing selections were largely based on following requirements and recommendations provided by both the USEPA and FAA.

Table 1-1. Measurement equipment and data.

Equipment	Pollutant or item	Data type
Real-time gas analyzers	CO, NOx, SOx, and O_3	Second-by-second concentrations
Minivol gas samples	CO, NOx, and SOx	1-hour average concentrations
Minivol PM samples	PM_{10}, $PM_{2.5}$, OC/EC, nitrate, and elemental metals	24-hour average concentrations
RDI	PM and elemental metals	3-hour average concentrations for 8 size categories
Summa Canisters	VOCs	1-hour average concentrations
DNPH Cartridges, TO11	Aldehydes	1-hour average concentrations
HOBO Weather stations	Meteorology	Wind speed, wind direction, temperature, and relative humidity
Noise monitors	Sound level	SEL, Leq, Lmax

The field work started with the selection of a suitable airport (Washington-Dulles International Airport [IAD]) to conduct extensive field measurements. The field work mainly involved the collection of ambient measurements and source (e.g., GAV movements) activity data. The activity data, as well as various other source data obtained from the airport, were used to conduct corresponding modeling of atmospheric concentrations to evaluate the models. Tables 1-1 and 1-2 summarize the overall scope of the measurement and modeling work.

Three measurement campaigns were conducted at IAD:

- April 17–28, 2009
- January 16–24, 2010
- July 9–23, 2010

In order to better understand airport contributions to local air quality and develop guidance for combining measurements with modeling, both the collected data and the corresponding modeled outputs were assessed for their adequacy in being able to explain airport air quality impacts.

The overall objective of conducting the case study was to determine the adequacy of combining the selected modeling and measurement techniques and identify existing gaps in the assessment methods relative to airport contributions to local air quality. The evaluation work involved various considerations:

- Model output assessments involving modeled-versus-measured comparisons and focused sensitivity assessments to understand model behavior and confidence;

Table 1-2. Modeling domain.

Models	Pollutants	Sources	Data Resolution
EDMS/AEDT	CO, THC, NMHC, VOC, TOG, NOx, SOx, PM_{10}, $PM_{2.5}$, various HAPs compounds	Aircraft, APUs, GSEs, GAVs on local roadways, GAVs on parking lots, Stationary boilers, Mobile Lounges	1-hour and 24-hour average concentrations at receptor locations
CMAAQ	CO, NO, NO_2, $PM_{2.5}$ components, PM_{10} components, VOC species, various HAPs	Anthropogenic (major point, area, on-road, nonroad, locomotive, marine) and Natural (agricultural, fire, biogenic, dust) and EDMS sources	1-hour average concentrations at 12 km and 4 km grids with 34 vertical layers

- Evaluation of modeling options and their impacts on modeled concentrations;
- Adequacy of modeled and measured data to explain seasonal, weekly, and diurnal effects;
- Adequacy of modeled and measured data to support regulatory needs and health impact assessments; and
- Source contribution assessments.

These evaluations were used to develop various conclusions and recommendations which highlight significant findings as well as gaps within the resources available under this project. In conducting the measurement and modeling work, the main objective was to assess how the conclusions and recommendations apply to quantifying airport contributions to local air quality. Therefore, while some model evaluations including modeled-versus-measured and sensitivity-type assessments were conducted, this project did not include formal model validation and uncertainty assessments such as those specified by the USEPA (USEPA[c] 2011). Also, while there are some overlaps, the report generally tends to reference information found in existing documents (e.g., model user guides, modeling theories and techniques, equipment usage instructions, and laboratory assessment techniques) rather than repeating them. The purpose of the included guidance is mainly to support the better understanding of the application of the necessary models and equipment to quantify airport contributions to local air quality.

Although some background information is provided, the guidance material was not developed to serve as a primer for novice users. Various resources from the FAA and USEPA can serve as air quality measurement and modeling primers. The guidance requires a working knowledge of air quality measurement equipment and models as well as familiarity with airport air quality issues.

Although an extensive set of IAD-specific data was collected through the field work, the purpose was not to conduct an air quality analysis of the specific airport, but to use the data to assess measurement and modeling techniques with findings that can be generalized to all airports and identify gaps for future research.

In addition to the source-oriented modeling work, a concerted assessment was conducted using the measured PM data with receptor modeling techniques. This work was conducted as a supplemental analysis to demonstrate the "reverse" process of starting with the measured concentrations to predict source contributions to air quality. While receptor modeling is not currently (or for the foreseeable future) considered necessary in meeting regulatory requirements involving air quality assessments, its usefulness has been demonstrated in various studies, and therefore, has been included in this project for completeness in demonstrating different techniques.

1.4 Report Structure

This report has been organized such that the guidance and detailed assessments are clearly separated as indicated below.

1. Main body of the report—focuses on the findings and guidance from the literature reviews and the assessments conducted.
2. Appendices—present details of the assessment work as well as how the research work was conducted, including various decisions made.

Rather than combining the guidance and assessment materials together, they were purposely separated to allow easier use of the report. The main body allows the user to concentrate on the guidance, findings, and recommendations, without being inundated by detail. In contrast, each of the appendices allow the user to focus on a specific topic that provides technical details mostly associated with the assessments conducted as part of the airport case study work.

Chapter 1 provides introductory materials that explain the overall goal and the scope of work—what is and is not included in this report—as well as some background information explaining the impetus for this project. Chapter 2 summarizes the existing state of regulations and the capabilities and limitations of existing measurement and modeling techniques. In addition, a survey of recent airport air quality studies is also presented. These two first sections provide background information mainly for novice users. The measurement and modeling reviews and considerations presented in Chapter 2 help to set the stage to better understand the modeling, measurements, and integration guidance materials found in Chapters 3 through 5. As part of the guidance, important findings from the study are presented and discussed. Chapter 6 summarizes the overall conclusions and recommendations from all of the assessments.

Appendixes A through H are provided on *CRP-CD-ROM-115*, which accompanies this report. Appendix A provides overviews of the various measurement equipment and models as well as the reasoning behind the selections used in this project. Appendix B explains the process used to select the test case airport. Appendix C provides details on how the measurement campaigns were conducted. Appendix D presents the assessments conducted with the measured data. Appendixes E and F provide the modeling evaluations conducted using EDMS and CMAQ, respectively. Appendix G covers the details on the supporting receptor modeling assessments. Appendix H describes the assessments to determine the usability of noise data in conducting airport air quality work.

CHAPTER 2

Current State of Airport Air Quality Assessments and Considerations

2.1 Introduction

This chapter serves as a starting point for better understanding the guidance and findings presented in later chapters of this report. Overviews of the various air quality regulations, guidance, and modeling and measurement capabilities, as well as a survey of recent airport air quality studies, are provided. This background material is intended to summarize the current state of knowledge and capabilities. Although presented in relatively simple terms, this section is not intended to serve as a primer because the reader needs to already have a basic understanding of air quality and airport concepts.

Various USEPA and FAA guidance documents exist related to air quality in general or to the combination of air quality and airports. Although these documents provide a good understanding on how to comply with air quality regulations (e.g., what assessments to conduct), they generally have gaps related to their application to airports and to comprehensively understanding airport contributions to local air quality (e.g., comprehensive coverage of most or all pollutants). These documents are referenced throughout this report, rather than repeating their contents.

The desire to answer the question of when to conduct modeling instead of measurements and vice versa serves as the impetus to better understand the associated capabilities. Although significant advances have been made in recent years to both emissions and atmospheric dispersion modeling capabilities, there are still significant limitations such that measurements are necessary to more comprehensively understand airport air quality contributions. As stated by the USEPA, air quality measurements are generally conducted for one or more of the following purposes (USEPA[j] 2011):

- To judge compliance with and/or progress made toward meeting ambient air quality standards;
- To activate emergency control procedures that prevent or alleviate air pollution episodes;
- To observe pollution trends throughout the region, including non-urban areas; and
- To provide a database for research evaluation of effects: urban, land-use, and transportation planning; development and evaluation of abatement strategies; and development and validation of diffusion models.

It is generally agreed that air quality field measurements are more accurate than modeled results for most cases. As such, notwithstanding errors in measurement techniques including calibration mistakes, measurement data are usually considered the "gold standard." However, current practices at airports in the United States revolve around modeling much more than measurements. The aforementioned FAA guidance documents mainly provide directions on conducting modeling work and virtually no information on conducting measurements. The modeling work is also focused on emissions modeling.

2.2 Existing Regulatory Framework

The applicable regulations begin with the National Environmental Policy Act (NEPA) (Pub. L. 1982 Latest). This 4-page document and its amendments establish a broad national policy to protect the quality of the human environment and provide for the establishment of a Council on Environmental Quality (CEQ) (WH 2011). NEPA requires a detailed statement by all agencies of the Federal Government when conducting a major federal action. This statement is to include descriptions of

- The environmental impacts of the proposed action;
- Any unavoidable adverse environmental impacts;
- Alternatives, including no action;
- The relationship between short-term uses of the environment and maintenance of long-term ecological productivity
- Irreversible and irretrievable commitments of resources; and
- Secondary/cumulative effects of implementing the proposed action.

In 1963, the original Clean Air Act (CAA) was passed but did not have "teeth." The CAA was amended in 1967 and provided authority to establish air quality standards. Subsequent amendments have led to the Clean Air Act Amendments of 1990 (CAAA) which is now in effect (USC Title 42, Chapter 85). The established National Ambient Air Quality Standards (NAAQS) include specified criteria pollutants consisting of ozone, carbon monoxide, particulates, sulfur dioxide, nitrogen dioxide, and lead. Table 2-1 shows the established standards. Some states, as well as local jurisdictions, have additional state requirements pertaining to local air quality concentrations.

Although no ambient standards yet exist for HAPs, HAPs have increasingly become issues of public concern because of the potential for health impacts. As part of this concern, Pb from piston-powered GA aircraft have in recent years gained significant attention because Pb is known for neurological damage among other concerns. Modeling can account for the emissions of most HAPs, but dispersion modeling is limited to assumptions of non-reactivity (i.e., no formation of secondary pollutants).

Table 2-1. National ambient air quality standards.

	Primary Standards		Secondary Standards	
Pollutant	Level	Averaging Time	Level	Averaging Time
Carbon Monoxide (CO)	9 ppm	8-hour	None	
	35 ppm	1-hour		
Lead (Pb)	0.15 μg/m^3	Rolling 3-Month Average	Same as Primary	
Nitrogen Dioxide (NO_2)	100 ppb	1-hour	None	
	53 ppb	Annual (Arithmetic Average)	Same as Primary	
Particulate Matter (PM_{10})	150 ppb	24-hour	Same as Primary	
Particulate Matter ($PM_{2.5}$)	15.0 μg/m^3	Annual (Arithmetic Average)	Same as Primary	
	35 μg/m^3	24-hour	Same as Primary	
Ozone (O_3)	0.075 ppm	8-hour	Same as Primary	
Sulfur Dioxide (SO_2)	75 ppb	1-hour	0.5 ppm	3-hour

Source: USEPA[a] 2010.

UFPs emitted from jet engines have also gained significant attention because their size (<0.1 μm) allows them to penetrate deep into lungs, causing various respiratory problems. Further studies are needed to continue to characterize these emissions and to understand the actual health impacts.

In a larger context, measurements for a defined geographical area are used to determine if the area is in compliance with the NAAQS. If not, these areas are designated as nonattainment areas (NAAs) and the state must develop a State Implementation Plan (SIP) to ensure attainment of the standards in the future. Measurements are then used to determine if the area has come into compliance. Areas previously designated nonattainment pursuant to the Clean Air Act Amendments of 1990 (CAAA90) that come into compliance are subsequently re-designated to attainment and termed "maintenance" areas. A "maintenance" plan, or revision to the applicable SIP is required (USC Title 42, Chapter 85).

Of direct importance to airports in NAAs is the General Conformity Rule. This is a strategy to achieve and maintain (conform) to the NAAQS required in Section 176(c)(1) of the CAAA. Conformity statements are used to ensure that local concentrations are not exacerbated by new government projects. Measurements may be required during major actions at airports to provide baselines and show improvements. Although airports fall under General Conformity, Transportation Conformity may also apply if funding includes any highway or transit project that receives funding assistance and approval through the Federal-Aid Highway program or the Federal mass transit program. These actions could trigger a need for measurements. These conformity determinations can be accomplished through emissions modeling (USC Title 42, Chapter 85, Section 176(c)(4)).

During the preparation of environmental statements, DOT/FAA-Specific DOT Order 5610.1C (Procedures for Considering Environmental Impacts) must be followed. It provides instructions for implementing NEPA, with application to DOT programs, including FAA actions. The order also provides instructions for implementing other environmental laws and executive orders. Again, measurement guidance is not included in these documents.

The amended Airport and Airway Improvement Act of 1982 provides that a grant application for an airport project will not be approved unless the State certifies that there is reasonable assurance that the project will be in compliance with applicable air quality standards (49 USC 2215).

FAA Order 5050.4 (The Airport Environmental Handbook) provides guidance for FAA procedures for processing environmental assessments, findings of no significant impact, and environmental impact statements for airport development proposals and other airport actions as required by various laws and regulations. Unfortunately, measurement of local area concentrations is not included. FAA Order 1050.1, Policies and Procedures for Considering Environmental Impacts, documents procedures in compliance with NEPA requirements, DOT Order 5610.1C, and other environment-related statutes, although air quality is included in this document.

Other documents are available for Department of Defense (DoD) airbases. DoD Directive 6050.1 (Environmental Effects in the United States of DoD Actions), U.S. Air Force Policy Directive (AFPD) 32-70 (Environmental Quality), U.S. Air Force Instruction (AFI) 32-7061 (Environmental Impact Analysis Process or EIAP), and the Environmental Impact Analysis Process (Desk Reference) are available and provide air quality guidance to comply with NEPA and other regulations.

In addition to federal requirements, there often are state and/or local air quality requirements applicable to airports. These requirements differ from location to location and must be addressed on a project-by-project basis.

In summary, many of the environmental laws and regulations apply directly to local air quality and must be considered by airports. Establishment of background concentrations and the existing environment are required. As air quality models are limited, monitoring would provide accurate assessments of these concentrations at points and extrapolation could be used to determine local area concentrations. But, the guidance material is almost devoid of any guidance on local air quality monitoring.

2.3 State of Guidance from FAA and USEPA

The FAA provides considerable guidance on meeting air quality requirements at airports (e.g., Draper 1997). Many airport studies only require an emissions inventory. However, when emissions are found to increase due to some project initiation, it may be necessary to determine local area concentrations either through modeling or measurements (e.g., when additional emissions exceed the General Conformity *de minimis* levels and there are no other alternatives). Although the guidance does provide some information dealing with air quality issues (e.g., background concentrations), there is very little in regard to actual dispersion modeling and no information regarding measurements.

The USEPA provides a dedicated website (USEPA[g] 2011) that provides both regulatory and modeling information for aircraft. The modeling information is largely based on the use of the FAA's EDMS and the USEPA's NONROAD model. Some sources of emissions data and methods for developing and evaluating emissions inventories are also provided. Virtually no direct information on measurements or atmospheric dispersion modeling is provided.

The USEPA's Support Center for Regulatory Atmospheric Modeling (SCRAM) site (USEPA[d] 2011) provides a wealth of information on air quality models and dispersion modeling. In addition to downloadable models, the site provides a comprehensive collection of model user's guides, model formulation documents, and model assessment (e.g., validation reports). Supporting guidance documents on the site include those for permit modeling and SIP attainment demonstrations. Referenced on the site is Appendix W to 40 Code of Federal Regulations (CFR) Part 51 which provides guidance on air quality models, including modeling techniques and data requirements (CFR 2005). Although these resources exist, any air quality modeling work should conform to the protocols set forth by the appropriate agency (e.g., state air resources board).

Although not specific for airports or the vicinity of airports, the USEPA also offers significant information related to ambient monitoring. A good beginning point for this information is the Ambient Monitoring Technology Information Center (AMTIC) site, which is a part of the Technology Transfer Network (TTN) (USEPA[a,e,f,h] 2011). AMTIC is pertinent to the exchange of ambient monitoring-related information and contains all Federal Regulations pertaining to ambient monitoring, as well as ambient monitoring-QA/QC-related information. Information on ambient monitoring-related publications, ambient monitoring news, field and laboratory studies of interest, and available related training is also included.

Although these monitoring and modeling resources are available, an ideal combination of airport guidance with measurements and air quality (concentration) modeling for airports is lacking. That is, although the EPA materials cover both measurements and modeling, they are not specific to airports. As a result, methods used for stationary sources have to be extrapolated to account for the diverse and mobile sources found at an airport.

2.4 Measurement Capabilities and Limitations

The USEPA promulgates various Federal Reference Methods (FRMs) that specify the methods to monitor certain pollutants. Adherence to these standards is crucial for use of the measured data in any regulatory-type study. The FRMs encompass both real-time and sampling methods. For example, continuous analyzers are specified for certain criteria gases (e.g., CO and NOx) while filter-based sampling methods have typically been specified for particulate matter (PM). These methods have been employed as part of the USEPA's various monitoring networks, including the Air Quality System (AQS), Chemical Speciation Network (CSN), and the Interagency Monitoring of Protected Visual Environments (IMPROVE).

Although such methods have been commonly used, new measurement techniques and equipment are being developed to provide continuous measurements of various volatile organic compound (VOC) species and PM, including Tapered Element Oscillating Microbalances (TEOMs), aethalometers, rotating drum impactors (RDIs), and the first Federal Equivalent Method (FEM) for $PM_{2.5}$—Beta Attenuation Monitors (BAM). Continuous measurement equipment is already used in some of the USEPA's monitoring networks and is considered necessary to help improve the assessment of health impacts (USEPA 2008).

Even with these types of improvements, significant limitations still exist (e.g., the inability to practically measure a comprehensive set of individual VOC species in real time). Usually, dedicated monitors can only measure THCs and non-methane HCs or some individual HCs, such as formaldehyde (HCHO). Similarly, dedicated equipment needs to be employed to monitor the various PM components (e.g., black carbon and nitrates). Also, there are no methods to comprehensively monitor individual metals in real time. These have to be measured from samples using techniques such as x-ray fluorescence (XRF).

Although costs of such monitors have decreased, they are still relatively expensive and need infrastructure to support their use. They need reliable sources of power as well as shelter to protect them from the weather (they usually need a climate-controlled shelter to properly operate). Although portable solutions are possible, they are usually employed in a stationary environment in part to help reduce the potential for damages to the equipment. Human resource requirements to use and maintain the equipment also need to be considered, as well as supplemental materials (e.g., calibration gases).

As a result, sampling is performed to overcome the limitations and costs of continuous monitors. VOC and PM samples are usually submitted to USEPA-certified laboratories. Specific protocols for collecting, handling, and shipping of the samples should be followed for each sampling and analysis method specified by the USEPA (e.g., USEPA[e] 2011).

Depending on what monitoring equipment and methods are employed, sometimes a tradeoff is necessary between spatial and temporal coverage. The resources available (e.g., funding, equipment, and personnel) and the requirements of the project will dictate where to place monitors and how to define an appropriate measurement schedule. Given that there are no specific guidance materials for monitoring at airports, existing USEPA protocols for their ambient monitoring networks can be followed (USEPA[f,h] 2011). However, due to resources and depending on the potential use of the collected data, deviations from such protocols have been common with past airport air quality measurement efforts.

2.5 Modeling Capabilities and Limitations

For both airport emissions and dispersion modeling, the FAA promotes the use of the Emissions and Dispersion Modeling System (EDMS) (FAA 2007). Currently at Version 5.1.3 and expected to be incorporated into the FAA's Aviation Emissions Design Tool (AEDT) (FAA[a] 2011), EDMS is the FA-required model for all aviation sources and is listed among the USEPA's "preferred" guideline models. EDMS uses Eurocontrol's Base of Aircraft Data (BADA) for aircraft performance modeling and the Boeing Fuel Flow Method 2 (BFFM2) for emissions modeling (Eurocontrol 2011 and DuBois 2006). Atmospheric dispersion modeling is conducted through the use of the USEPA's American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) which has been integrated into EDMS (USEPA[a,b] 2004).

EDMS development was started in the mid-1980s as a complex source microcomputer model by the FAA and U.S. Air Force as a simpler replacement to the main frame model called the Airport Vicinity Air Pollution (AVAP) model (FAA 2007). Both were designed to assess the air quality impacts of proposed airport development projects, but AVAP was difficult to use and required main frame computer access. EDMS operates in the Windows operating regime and on personal computers, which has led to much more widespread use in the United States as well as abroad.

EDMS provides a graphical user interface (GUI) that allows the user to model various cases within a single study. The user may calculate an emission inventory based on defined emission index/factor databases (EI/EF) using screen input. The EI/EFs in EDMS include a large array of aircraft engines by operational mode, APUs, GSE, motor vehicles using MOBILE6.1 (reference), a partial set of factors, and stationary sources. The informational database for these EI/EFs may be reviewed. After sufficient information has been supplied to allow the successful completion of an emission inventory, the user may, upon entry of additional data such as meteorology, run a dispersion analysis. Earlier versions of EDMS ran the Point/Area/Line (PAL) (reference) model for most sources and CALINE3 (reference) for motor vehicles. Since Version 4.0, EDMS has used the EPA-preferred dispersion model, AERMOD (USEPA[a,b] 2004). Since 1998, the FAA has made it a policy to "require" the use of EDMS to perform air quality analyses for aviation sources instead of just being the "preferred" model.

Given that EDMS is specifically designed for airports, it facilitates the modeling of airport sources. It provides various default operating times for most sources, as well as emission factors for virtually all airport sources. In addition, the representation of sources is already defined in EDMS so that the user does not need to worry about such details. Although this can be limiting to some expert users, it promotes consistency and simplifies the modeling of airports sources. For example, the rectangular shape of taxiways and runways is automatically determined by EDMS for dispersion modeling—the user only needs to specify the locations of the end points. EDMS' GUI also simplifies the use of the USEPA models, MOBILE6.2 and AERMOD. Without the interface, each model would need to be run in the legacy command prompt (character-mode) interfaces such as the Disk Operating System (DOS).

Although most studies (especially relatively simple studies) can be conducted in EDMS without any "special" work, many expert users have used EDMS components and other tools externally to improve the overall modeling work. For example, the use of MOBILE6.2 outside of EDMS has been frequently conducted since it allows more control over the development of GAV-related emissions inventories. Other possibilities include the use of AERMOD outside of EDMS for similar purposes as well as various other emissions (e.g., NONROAD) and dispersion models (e.g., CAL3QHC). This robustness is possible because both emissions and atmospheric concentrations are mathematically additive—component pieces can be added and subtracted as necessary.

In recent years, significant improvements have been implemented in EDMS, including both higher fidelity methods and data. Some of these improvements include, but are not limited to, the incorporation of HAPs speciation, BADA, BFFM2, the First Order Approximation (FOA) for particulate matter (PM) emissions (Wayson 2009), and continued updates to the EPA MOBILE-series [being replaced by the Motor Vehicle Emissions Simulator (MOVES)] and NONROAD models whose data are incorporated into EDMS (USEPA 2005 and 2010[b]). All of these improvements have led to more accurate and more robust emissions modeling and emissions inventory development capabilities.

Since Version 5.1, EDMS has been able to estimate emissions of individual organic gas (OG) species, including 44 known HAPs and 352 non-HAP species (FAA 2008). This is accomplished through the use of a speciation profile applied to the total OG (TOG) (FAA 2009).

With the inclusion of BADA and BFFM2, EDMS' emissions modeling capabilities were noticeably improved, in part because the dynamic aircraft performance modeling allowed more accurate determinations of fuel flow (essentially, power level) and emissions indices (EIs) used to predict emissions for each segment. As shown through the work conducted by the Society of Automotive Engineers (SAE) A21 group, BFFM2 provides less than 5% error for modeling emissions of nitrogen oxides (NOx) per mode (e.g., takeoff and climbout) as compared to 50 to 90% errors using the simpler International Civil Aviation Organization (ICAO) reference methods in older versions of EDMS (SAE 2009). Although the errors in NOx seem to have improved, emissions of carbon monoxide (CO) and total hydrocarbons (total HC or THC) need to be studied further. Errors for CO and THC, especially at the lower power settings (i.e., idle and taxi) can be greater than 200%.

Until recently, there were no recognized viable methods to model PM from aircraft. Hence, EDMS did not provide any results, leaving a gap between regulatory requirements and modeling capabilities. With the implementation of the FOA in EDMS, that gap was filled, but only as a temporary measure. Originally developed by Volpe and FAA, the FOA, which continues to be promulgated through ICAO's Committee on Aviation Environmental Protection (CAEP), is based on the use of the SMOKE Number (SN) data from the ICAO emissions databank. Given that these SNs have large errors, their use is intended to be a temporary, stop-gap measure until mass-based PM EI data become available. The SAE E31 group is developing guidance to help standardize the measurement of aircraft engine exhaust emissions.

In addition to these emissions modeling advancements, various atmospheric dispersion-related improvements have also been made. The basis for these improvements was the implementation of AERMOD in EDMS 4.0. This allowed EDMS to use the latest state-of-the-art dispersion model to assess local air quality impacts. In the last two decades, drastic improvements in the characterization of the atmosphere were made, which led to the improvements represented in the USEPA's workhorse dispersion model, AERMOD. AERMOD represents a significant improvement over its predecessor, the Industrial Source Complex (ISC) model, which was largely intended for industrial sources such as powerplant stacks. Refinements to the use of AERMOD in EDMS involved the incorporation of more accurate jet engine exhaust release heights and more representative initial dispersion coefficients (i.e., initial dispersion sigma values).

Even with all of these enhancements, the overall air quality modeling capabilities of EDMS, and local air quality modeling in general, still have room for improvement. Even though it has been approximately 45 years since air quality modeling was first applied to assess airport air quality, significant uncertainties are still associated with predicting atmospheric behavior and local concentrations. The combination of errors associated with emission factors, source activities, meteorological data, and terrain information can make predicting concentrations difficult. Errors in any one of these input datasets can have significant impacts on the accuracy of predicted concentrations.

A case in point is aircraft CO and THC emissions at lower power settings (e.g., idle and taxi). Errors in estimating fuel burn at low-power settings can cause significant errors in modeling emissions of these pollutants (Kim 2008). This is important because any errors in emissions will propagate to the modeled concentrations. That is, modeled concentrations will only be as accurate as the emissions data allow. Also, speciation of THC needs to be further researched. In addition to data from Spicer (2004), data from various other airport studies and recent measurement campaigns such as those through the TRB Airport Cooperative Research Program (ACRP 2011) and the Aircraft Particle Emissions eXperiments (APEX) (Whitefield 2007) are beginning to provide a better understanding of the types of species emitted and their emissions characteristics (USEPA[b,c] 2009), but more work is required in this area.

Previous studies on errors associated with atmospheric dispersion modeling (at least those involving the use of Gaussian methods) have highlighted the difficulties of accurately predicting atmospheric concentrations (Ellis 1980, API 1980, Bowne 1983, Benarie 1987, Seibert 2000, CEC/CARB 2002, and Stiggins 2002). The inherent uncertainties associated with dispersion components (e.g., initial dispersion values, atmospheric rise, and atmospheric profiles) have resulted in a general understanding that concentrations can be predicted to an accuracy level of within a factor of 2.

Unlike a stationary powerplant stack emitting pollutants at a reasonably constant rate over time, an airport as a whole presents a much more difficult source to model. Although the most visible source at an airport is aircraft, there are various others sources [e.g., ground support equipment (GSE) and ground access vehicles (GAV)], some of which may even exceed aircraft emissions during the Landing and Takeoff (LTO) cycle. Furthermore, much of the airport sources are mobile, meaning that, in addition to fuel-consumption activities, the location of the sources must also be predicted. With such varied sources at an airport, properly modeling their emissions and the associated atmospheric dispersion can be challenging.

In addition to these difficulties, one of the biggest limitations of EDMS and AERMOD in general is the lack of any real capabilities for chemical transformations. The reason for this is that the Gaussian plume framework within AERMOD is not well-suited for modeling chemical transformation. Generally, this type of modeling is handled through grid-based chemistry transport models. The mass conservation techniques and the detailed atmospheric chemical mechanism implementations used with grid models like the Community Multiscale Air Quality (CMAQ) model and the Comprehensive Air quality model with extensions (CAMx) provide a more natural environment suited for the complex reaction modeling necessary to predict concentrations of air pollutants like NO_2, SO_2, O_3, various hydrocarbon species, etc. (Byun 1999, 2006, and ENVIRON 2006).

CMAQ is a state-of-the-art, comprehensive, one-atmosphere air quality modeling system that treats gas-phase chemistry, particulate matter (PM), and hazardous air pollutants (HAPs). CMAQ simulates the numerous physical and chemical processes involved in the formation, transport, and destruction of air pollutants. Inputs to the model include emissions estimates (from aircraft as well as all other anthropogenic and biogenic sources), meteorological fields, and initial condition and boundary condition data. CMAQ has been applied to study air pollution from local scales (a few kilometers) to regional (hundreds of kilometers) to hemispheric (several thousands of kilometers). The model has been continually evaluated against both surface observations (Eder 2006 and Boylan 2006) and more recently against remote sensing data from satellite-based observations. CMAQ is an open-source community model (http://www.cmaq-model.org), and, under base funding from the EPA, the Center for Community Modeling and Analyses System (CMAS) (http://www.cmascenter.org) provides support and training of CMAQ to a global user community.

For gas-phase chemistry, CMAQ has the latest version of the Carbon Bond chemical mechanism (Carbon Bond 2005) described by Yarwood (2005). Particulate matter is treated in CMAQ as the sum of three modes—Aitken (diameters up to approximately 0.1 microns for the mass distribution), accumulation (mass distribution in the range of 0.1 to 2.5 microns) and coarse (particles of size 2.5 to 10 microns). Additional details on the treatment of particulate matter in CMAQ are described elsewhere (Binkowski 2003). CMAQ's treatment of HAPs is described by Luecken (2006). The last version of CMAQ that was released during the performance of this project was 4.7.1. This version has several updates to the algorithms for the formation of the Secondary Organic Aerosol (SOA), a key component of $PM_{2.5}$ in several areas of the country (Carlton 2010). Foley (2010) presents an evaluation of this CMAQ version focused on O_3 and $PM_{2.5}$. The treatment of coarse sea-salt particles is described by Kelly (2010), and a comprehensive multi-year evaluation of CMAQ's wet deposition is described by Appel (2011). The USEPA has been preparing CMAQ v5.0 for release in early 2012, and it is expected to have additional updates to the treatment of particulate matter and several other new features.

To be able to use a gridded model like CMAQ, one has to prepare emissions inputs from various anthropogenic as well as natural sources at the same gridded resolution and prepare meteorological inputs from a prognostic model, also at the same gridded resolution. The emissions processing is accomplished through the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system (Houyoux 2000), which is also an open-source community model, continuously developed and also supported by CMAS (http://www.smoke-model.org). SMOKE takes state- or county-level emissions inventories developed by USEPA or other agencies and performs chemical speciation, temporal allocation, and spatial allocation in a format that can be used by CMAQ.

The meteorological inputs for CMAQ are prepared from either the Pennsylvania State University/NCAR mesoscale v3.7 model (MM5) (Grell 1994) or more recently from the Weather Research Forecast Model with its Advanced Research WRF core (WRF-ARW). The WRF-ARW is typically used in research settings such as this and based off the MM5 model. It uses a terrain following sigma vertical coordinate and the Arakawa-C grid in the horizontal. Additionally, it contains additional surface physics packages developed at the USEPA to help process meteorological parameters required by the CMAQ air quality model. More information about the WRF-ARW model can be found at http://www.mmm.ucar.edu/wrf/users/model.html. The MM5 or WRF outputs are processed through the Meteorology-Chemistry Interface Processors (MCIP) (Otte 2010) to prepare the meteorological inputs in a form that can be directly used by CMAQ. MCIP is also available via, and supported, by CMAS.

2.6 Survey of Recent Airport Air Quality Studies

In order to better understand airport contributions to local air quality and atmospheric dispersion modeling processes, there have been various recent studies. These have included, but are not limited to, projects and measurement programs conducted at (or being conducted at) the following airports:

- Los Angeles International Airport (LAX) (LAWA 2011)
  - The ongoing LAX source apportionment study is considered the most comprehensive air quality measurement and modeling project conducted by the Los Angeles World Airports (LAWA) and possibly any airport authority nationwide.
  - The work involves the collection of criteria and hazardous air pollutants (HAPs), and the purpose is to associate (apportion) pollutants to their sources.
- Teterboro Airport (TEB) (ENVIRON 2008)
  - The TEB study involved measurements of various pollutants, including volatile organic compounds (VOCs) and PM, to investigate health risks associated with airport operations.
  - The study generally found that the risks associated with the measurement locations were higher than at other New Jersey Department of Environmental Protection (NJDEP) monitoring locations.

- T. F. Green Airport (PVD) (KBE 2007)
  - The ongoing PVD monitoring work is conducted as part of a long-term plan to measure and better understand air quality near the airport.
  - Pollutants included in the measurement program include PM components and various VOCs.
- Van Nuys Airport (VNY) and Santa Monica Municipal Airport (SMO) (SCAQMD 2010 and ICF 2010)
  - Under a grant from the USEPA, a community-scale air toxics monitoring study was conducted in the communities surrounding VNY and SMO.
  - Except for measurements conducted near runways, most concentrations of PM and VOCs were similar to those in other urban areas. The air toxics study also found that while relatively high concentrations of ultrafine particles (UFP) were noticed in the surrounding neighborhoods, further studies would be necessary to determine airport contributions.
  - Based on public concerns over lead (Pb) emissions from General Aviation (GA) aircraft, the USEPA commissioned a study to develop a method to evaluate lead concentrations near airports operating piston-powered aircraft.
  - The SMO Pb modeling work was conducted using EDMS with dispersion handled with AERMOD. The modeled results showed relatively good agreement with measured concentrations which generally tended to be higher than the regional background concentrations.
- Boston Logan International Airport (BOS) (Massport 2011 and CDM 2010)
  - As the longest running airport air quality measurement program in the United States (begun in 1982), the Massachusetts Port Authority (Massport) NO2 program collects data to track air quality changes in and around the airport.
  - A 2-year Massport-commissioned set of ambient measurements was started in 2007 in the vicinity of the airport as part of the requirements for a Massachusetts Environmental Policy Act (MEPA) study related to the Logan Airside Improvements Project (LAIP). With a focus on air toxics, the first year's baseline data has been established.
- Chicago O'Hare International Airport (ORD) (IEPA 2002)
  - The purpose of the ORD study was to better understand airport air quality impacts on large urban areas by specifically focusing on HAPs or air toxics.
  - The study found that, in general, the concentrations measured near ORD were similar or lower than those found in other large U.S. cities.
- Washington-Dulles International Airport (IAD) (Wayson 2003)
  - An intensive measurement campaign was conducted during the winter of 2002 to collect ambient CO data to help validate the dispersion modeling capabilities implemented into EDMS.
  - Real-time gas analyzers and Minivol bag samplers were used to collect CO samples from various locations in and around the airport.
  - Although the results from the project were not published, the study provided useful insights on typical concentration levels at the airport.
- London-Heathrow International Airport (LHR) (UKDOT 2006)
  - A recent study was undertaken by the United Kingdom Department for Transport (UKDOT) to strengthen the understanding of air quality and assessment capabilities around the airport.
  - A combination of criteria pollutants and HAPs were measured using various types of equipment.
  - The resulting recommendations involved approvals to use the Atmospheric Dispersion Modeling System (ADMS) (CERC 2011) with limited use allowed for LASPORT. EDMS was not chosen as an acceptable model for the airport.

- Zurich International Airport (ZRH) (Duchene 2007)
    - A 2004 study involving the use of ALAQS showed that, based on improper modeling of thrust settings and times in mode (TIM), errors in NOx emissions can be up to about 25%. The results also indicated the important impacts that heat flux, plume dynamics, and terrain have on modeled concentrations.
    - Depending on the location of monitors, 8 of the 21 sites showed predominant NOx contributions by the airport.

In addition, there have been various FAA efforts to study and further the science involved in assessing air quality models, including through the FAA's Center of Excellence (CoE) Partnership for Air Transport Noise and Emissions Reduction (PARTNER) projects. For example, the ongoing work under FAA's PARTNER Project 16 have shown that a 108 by 108 km domain centered on the airport captured most of the population exposure to primary components of $PM_{2.5}$, but total public health risks were dominated by populations at greater distances from the airport—based on the impact of secondary PM (Arunachalam 2011).

The purpose of all of these airport air quality projects/programs is to better understand local air quality contributions and health impacts posed by the airports. These studies have advanced and continue to advance the understanding of airport air quality impacts by contributing to the existing knowledge base. Given that measurements and modeling studies are resource-intensive, it is expected that, although the overall understanding will increase, it will be a long-term process to expand beyond the current state of infancy.

The importance of continuing this process is clear when considering future impacts of airports on local air quality. Even with the advent of Next Generation Air Transportation (NextGen) technologies, the demand for air travel will ensure that airport emissions loadings will increase beyond present conditions (Woody 2011). As such, this ACRP project is intended to further advance the understanding of airport contributions to local air quality by providing guidance to better understanding and use of the combination of measurement with modeling techniques.

CHAPTER 3

Modeling Guidance and Findings

3.1 Overview

The modeling guidance provided in this chapter is a mixture of findings from the literature review and the airport modeling assessments that were conducted during this project. Although there may be some overlap, the guidance does not seek to duplicate existing guidance materials, including the measurement and modeling protocols mentioned in the previous sections. As a result, the guidance is intended for experienced modelers.

The guidance mainly focuses on air quality (as opposed to emissions) modeling capabilities of EDMS and CMAQ with supplemental discussions on the potential use of receptor models as well. (These models were selected based on the reviews presented in Appendix A. The assessments conducted using the models are presented in Appendixes E through G.)

In addition to some of the modeling protocol-type issues, the guidance helps to better understand the accuracy and impacts of using different datasets and options in the models. In this way, the guidance helps to better allocate resources so that, for example, 95% of the effort is not wasted on 5% of the work. These guidance points as well as other conclusions are summarized in Chapter 6.

Although guidance is provided, the information also adds to the growing knowledge base on airport air quality contributions. As such, it is expected that the guidance and the results presented in the various appendices should be used as a basis for further studies.

3.2 EDMS and AERMOD

3.2.1 Modeling Accuracy and Applications

Based on the modeled-versus-measured results presented in Appendix E, there appears to be much room for improvement with the models themselves (EDMS and AERMOD) but perhaps more importantly with the input data. This includes not only correctly representing the sources and their activity information, but using representative meteorological data, especially wind data. When modeling ambient concentration contributions from airports, the level of accuracy for receptor locations that are relatively far away from sources, especially runways, may not be very high. For example, under this project, the accuracy at the first and second base stations which were about 1,500 ft and 2,600 ft away, respectively, from the closest runway was low. However, for those receptor locations that were only a few hundred feet from a runway, the accuracy was generally higher. This appears to support the understanding that at closer distances, the potential for influence by erroneous input data decreases. That is, the closer the receptors are to sources, the greater the influence of each source's emissions on the concentrations.

For regulatory-based modeling, receptor locations may be placed at relatively far locations (e.g., locations accessible by the public) in the vicinity of the airport. As such, concentration-prediction errors may be up to a magnitude (i.e., a factor of 10) for each pollutant based on the maximum and minimum errors witnessed as part of the assessments. However, using CO concentrations as an example, the average error as represented by the modeled-versus-measured comparisons conducted for the base station is approximately 120%. In contrast, the average error at Sites K and M (very close to a runway) was about 23%.

In addition to these accuracy issues, the differences between the application of AERMOD for generally well-defined stationary sources and airports need to be understood. AERMOD was developed with a focus on meeting regulatory requirements. Although its ability to model line, area, and volume sources may imply the potential to model mobile sources, some source characteristics may be difficult to capture with these sources types. More importantly, the input data necessary to accurately represent the sources may be difficult to implement. For example, the release heights of the exhaust from aircraft main engines, APUs, and GSEs may not be accurate. Also, the movements of these sources may not be accurately represented by the area sources currently used in EDMS. That is, the user may not be able to correctly identify the size of the GSE activity area around a gate and may just be guessing at which taxiways are used in EDMS by specific aircraft types. More detailed protocols need to be developed to improve and make consistent the development of source characterization data. Therefore, the errors in the modeled concentrations is partly based on the underlying modeling methodologies (e.g., dispersion methods in AERMOD), but is likely based in large part on the application of the models to the varied sources found at an airport. This perspective is necessary; otherwise, both EDMS and AERMOD could be wrongly criticized as performing poorly.

3.2.2 Pollutants and Chemical Transformations

AERMOD allows the modeling of CO, NOx, sulfur dioxide (SO_2), particulate matter with an aerodynamic diameter of 10 um or less (PM_{10}), and total suspended particulate matter (TSP). Each of these pollutants can be modeled using the assumption that no chemical transformations occur, even for NOx and SO_2. The optional ozone-limiting methods used for NOx and the SO_2 half-life decay parameter allow some semblance of modeling first-order chemical transformation effects.

Although these options exist, AERMOD is mainly considered a steady-state dispersion model with sophisticated characterizations of the atmosphere's dispersive potential. This is indicative of the "OTHER" keyword that can be used in AERMOD to specify other nonreactive pollutants. The non-chemistry aspects of AERMOD are relatively common among most other Gaussian plume models.

This does not mean that reactive pollutants cannot completely be modeled in AERMOD. Three categories of chemical transformation can be defined: (1) pollutants such as ozone which are formed from other "input" pollutants (e.g., NOx and VOCs); (2) relatively fast reacting pollutants (e.g., nitric oxide [NO]); and (3) relatively slower reacting pollutants (i.e., those with lower reaction rate constants). Except for NOx, the first two categories of pollutants cannot be modeled in AERMOD. However, if a pollutant's reaction rates are low enough, they can be assumed to be nonreactive and modeled in AERMOD. The potential to do this will depend largely on the location of the receptor with respect to the source(s), wind speed, and wind direction. In simple terms, if the dispersing pollutant can reach a receptor before the pollutant experiences any significant transformations, then AERMOD can be used to predict its concentrations.

3.2.3 Modeling Options

Fortunately, EDMS already includes data and methods for representing certain plume characteristics and behavior such as the initial dispersion parameters (initial s values) and plume rise (e.g., through thermal buoyancy). Although the specifications for these effects can be modified in the AERMOD input file(s) created by EDMS, it is not recommended, unless the new data can be justified technically and the responsible agency consents to the changes. This is also true for most of the other modeling options, including those visible through the EDMS interface used to both create and run the AERMOD input file.

The default SO_2 decay option in AERMOD (and as presented in the EDMS interface) is based on a nominal 4-hour half-life. In EDMS, the default setting is not to use this option. Similar to the previous discussions on chemical transformations, the use of this option should mainly be based on a combination of receptor location in relation to the source(s), wind speed, and wind direction. For the receptor locations modeled within the airport under this study, the decay option produced virtually no difference in concentrations. For regulatory purposes, such decay options are normally not used.

Similarly, the non-regulatory options for modeling NO to NO_2 conversion were also exercised. Given that the EDMS interface does not provide access to these options, they were exercised directly through the AERMOD input file. Based on the understanding (see Appendix E) that the Plume Volume Molar Ratio Method (PVMRM) is more accurate than the Ozone-Limiting Method (OLM), the PVMRM option was used with a field-measured NO_2/NOx ratio of 0.7 (derived from the IAD measurements). As this value was specific to the measurement conditions and location of receptors at IAD, it should not be considered to be representative of other airports and is only presented here to add to the existing knowledge base. The modeling results showed little difference between using and not using the PVMRM option.

The option to use terrain data was also exercised. The flat terrain-modeled data were compared to those from using 1-degree Digital Elevation Model (DEM) data covering the region surrounding IAD. The resulting comparisons showed virtually no difference in modeled concentrations. It is suspected that because most of the receptors were placed within the boundary of the airport which is relatively flat, the additional fidelity provided by the DEM data made little difference. As such, if receptors are placed outside, but still relatively close to the airport, the assumption of flat terrain may be justified.

To gain a better understanding of the impact of elevated plumes, a sensitivity assessment was conducted to determine the impact of using different receptor locations, including flag pole receptor heights. In order to account for thermal buoyancy, EDMS elevates the taxiway and runway area sources to a height above the average aircraft engine exhaust height. A potential concern here is that any errors associated with the estimated plume rise can cause errors in the modeled concentrations, which are usually conducted at 1.8 m, which approximates human breathing height. Based on the assessment conducted under this project, the impacts caused by an elevated plume may have noticeable effects for distances within about 10 m from a runway source. However, for receptor locations about 60 m away from the runway (and probably closer), the impact of the elevated plume appears to be minimal (i.e., concentration at 1.8 m height is similar to the concentration at the centerline). Although these assessments were specific to the runway at IAD, the overall conclusions are likely to be similar at other airports.

3.2.4 Spatial and Temporal Protocols

In developing a modeling plan, the modeling protocols from EPA should be followed as much as possible (USEPA^{d} 2011 and CFR 2005). These protocols are intended to help guide the user in making technically sound and consistent decisions that focus on meeting regulatory requirements, including criteria for placement of receptors and modeling periods used to identify the appropriate concentrations for use in addressing regulations. The decisions for receptor placement should not be based on the number of receptors, but on other criteria such as public access, topography, and weather. Modeling periods should be based on justifying adequate coverage of variability (e.g., 5-years' worth of meteorological data).

In general, these protocols should be applicable to most airport studies, but the local responsible regulatory agency should be consulted to ensure that all local or regional practices are followed and requirements met. These requirements include the use of state-specific emissions and air quality standards.

3.2.5 Input Data Fidelity

Although some of the modeling options may not have significant impacts under the situations discussed, the overall fidelity of the input data can have significant impacts. To illustrate this, two different fidelity levels were modeled (as discussed in Appendix E). While both cases used the same aircraft flight schedule to provide fleet mix and operating information, the lower fidelity case involved the use of default EDMS data for other sources such as GSEs, APUs, and GAVs.

Although not all pollutants showed noticeable differences, the accuracy level for CO concentrations showed noticeable improvements in modeled-to-measured comparisons. Part of this is likely because most receptors were relatively far away from the impacted sources (i.e., GSEs, APUs, and GAVs). But more importantly, the fact that the aircraft fleet mix and operations were the same for both cases seems to corroborate the significant influence aircraft can have on airport air quality.

3.2.6 Source Contributions

While it is common knowledge that aircraft are generally the largest source (or one of the largest sources) of emissions at an airport, the study also demonstrated that aircraft generally appear to be the biggest contributors to ambient concentrations as well. The magnitude of aircraft emissions appears to override any effects of plume rise and other dispersion-related factors. While this appears to be true for receptor locations that are relatively far or in-between the various sources, it will depend on location of receptors with respect to the sources. For example, a receptor located very close to a nearby highway will likely be heavily influenced by on-road vehicle emissions—possibly more than aircraft emissions.

Depending on how the boundaries are specified, passenger vehicles (GAVs) entering and exiting the airport may provide a significant amount of emissions, perhaps even more than aircraft. Therefore, it is important that roadways and portions thereof are properly identified in an airport air quality assessment. In general, roadways should be included to the point where the destination of the associated traffic is clearly the airport.

Because aircraft and GAVs tend to be the biggest airport contributors to local ambient concentrations, resources should be appropriately applied to focus on these sources first. It should also be recognized that airport contributions to air quality in locations that the public typically has access will tend to be small. In addition to sources, meteorological data should also receive significant attention as the use of wrong or non-representative meteorological data could result in erroneous concentrations, no matter how accurate the source fleet mix and activity data are. Therefore, the "significant" emissions from airport sources need to be tempered with the realistic locations of the public and the dispersive characteristics of the local atmosphere when planning the assessment of airport contributions.

If source contribution modeling assessments are to be conducted using EDMS, it is recommended that a complete study first be developed that includes all sources. Using this study, EDMS allows the specification of individual or a group of sources when creating an AERMOD input file. Also, multiple copies of the study can be made, and then each study can be dedicated to a single or group of sources by deleting the unwanted sources (e.g., if various sensitivity-type studies are to be conducted with a subset of the sources). These approaches are recommended rather than starting with individual studies for each source. The reason is that aggregation of separate studies is difficult. Other than inputting the data for one source into the study of another source through the EDMS interface, the only other way would be to copy the appropriate dataset from one study's system data tables to the other. Neither of these approaches is recommended as they are tedious and error prone.

In addition to modeling ambient concentration contributions from airport sources, proper background concentrations should also be developed to ensure proper reporting of total concentrations. USEPA protocols specify the use of nearby monitor data to determine background concentrations. Consistent with this protocol, more specific guidance is provided in the next section using IAD as an example.

Developing accurate background concentrations is very important because airport contributions for most pollutants are likely to be smaller than those from surrounding sources unless a receptor is located very close to an airport source. As such, the accuracy of the total concentration may depend in large part on the accuracy of the estimated background concentration. The modeled-versus-measured comparisons conducted under this project showed that varying the fidelity of background concentrations can have noticeable impacts on overall accuracy.

3.3 CMAQ

3.3.1 Overview

As discussed in Appendix F, the application of CMAQ for the IAD region was demonstrated at a horizontal resolution of 12 and 4 km to model both primary and secondary pollutants. CMAQ, being a one-atmosphere model, was used to model various gas-phase pollutants–CO, NO, NO_2, O_3, SO_2, particulate matter of size 2.5 ($PM_{2.5}$) and 10 (PM_{10}) microns and their various chemical constituents, as well as various hazardous air pollutants or air toxic species such as formaldehyde, acetaldehyde, acrolein, 1,3-butadiene, benzene, toluene and xylene. These HAPs were chosen based on a health risk prioritization study of aircraft emissions related air pollutants (Levy 2008).

3.3.2 Modeling Domains

For modeling air quality contributions from a single airport, it is recommended that a nested model application of 12 and 4 km be developed. While the 12-km modeling domain is intended to capture the broad regional background, the 4-km domain will provide adequate spatial resolution to model the impacts of airport sources. Furthermore, based on results from this work as well as previous airport air quality studies, the secondary components of $PM_{2.5}$ due to airport emissions change at distances of up to 300 km away from the airport. Thus, the spatial extent of the modeling domain should be at least 500 km at the coarse resolution (12 km), and at least 200 to 300 km at the fine resolution (4 km). However, if multiple airports are being modeled in a single study, and these airports are at least 200 to 300 km apart, a single 12-km model application can be developed. The vertical resolution of the model should be comparable to what was used in this study, i.e. 22 layers from the surface to 50 millibars (about 18 km), with about 15 layers spanning the lowest 10,000 feet, where aircraft emissions are modeled during the Landing and Takeoff (LTO) cycle.

3.3.3 Input Requirements

CMAQ requires the following types of major inputs:

- Emissions (from non-airport sources): A complete inventory of all anthropogenic and natural sources in the modeling domain needs to be created for use in CMAQ. Such datasets can be obtained from the USEPA's National Emissions Inventories (NEI) from http://www.epa.gov/ttnchie1/eiinformation.html. Appendix F provides a complete list of source sectors from which emissions were estimated. Given that the USEPA develops and publishes the NEI on a 3-year cycle (e.g., NEI-2005 and NEI-2008), usually, the emissions need to be adjusted for the modeling period using control factors that take into account both emissions increases due to increases in economic activity and emissions decreases due to the effects of various regulatory control programs. These control factors are available as part of projection year inventories created by EPA for various regulatory needs. After acquiring all the emissions inventories from the EPA or any other state/local agency that has jurisdiction over the airport region, one should use the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system to create CMAQ-ready emissions. SMOKE performs three main functions—chemical speciation, temporal allocation and spatial allocation, and the outputs are usually hourly estimates for each hour of the modeling period for each grid-cell in the modeling domain. In processing the NEI emissions, care must be taken to identify emissions from the study airport and remove them, to avoid double counting of these sources.
- Emissions from airport sources: These can be based on the EDMS modeling. The user can use the EDMS2Inv utility (Baek 2007) to process the emissions in a format that SMOKE can use and then use SMOKE to prepare them for CMAQ. Care must be taken to use the appropriate chemical speciation profiles for airport sources in SMOKE. EDMS estimates $PM_{2.5}$ emissions from aircraft engines based on the First Order Approximation (FOA) and provides non-volatile PM (PEC) and volatile PM broken down into primary organic carbon (POA) and primary sulfate emissions (PSO4). EDMS provides total volatile organic compounds (VOCs) from aircraft engine as a single number. The FAA and EPA have jointly developed a speciation profile for total organic gases (TOG) (USEPA[b,c] 2009), and this profile varies depending on whether the aircraft engine is piston-driven or turbine-driven. The user must choose the appropriate TOG speciation profile depending on the engine type in the fleet mix. SMOKE uses default chemical speciation and temporal profiles for all other airport sources (based on previous studies) which are built into the modeling system.
- Meteorology: CMAQ needs meteorological inputs from a prognostic model such as MM5 or WRF. Sample WRF model configuration with preferred physics options are provided in the Technical Memorandum. The outputs from MM5 or WRF are processed through the MCIP utility, and the outputs are hourly for each hour of the modeling period for each grid-cell in the modeling domain. As a mesoscale model, WRF relies on data from a model run on a larger domain for boundary conditions. To create meteorological inputs that coincide with a measurement period, it is beneficial to take advantage of the real-time forecasted meteorological model outputs from the National Center for Environmental Prediction's (NCEP) 40-km North American Model (NAM). This model is run over the entire North American continent four times daily at 0, 6, 12, and 18 Z. Each of these model runs has an analysis field created by blending the results for that time from the previous model run with observations to create an updated set of initial conditions. These fields can be considered as the best representation of the atmosphere at a given point in time. For the demonstration under this study, an automated download of outputs from the NCEP ftp site (ftp://ftp.ncep.noaa.gov) was set up and created tools to downscale from NAM to drive WRF at 12-km resolution. In the WRF simulations, these NAM data were also used for initial conditions and for grid-based nudging.
- Initial and Boundary Conditions (IC/BC): To obtain regionally representative initial and background air quality conditions, one can use either outputs from another regional-scale

air quality model application or from climatological data. Under this study, real-time experimental CMAQ forecasts from NCEP for the nation were relied on. An automated download of outputs from the NCEP ftp site was set up and tools were developed to create CMAQ-ready IC/BC files for each hour of the modeling period for the 12-km resolution. The 4-km resolution IC/BCs are created using outputs from the 12-km CMAQ outputs using CMAQ's *icon* and *bcon* utilities.

- Ocean-mask File: This is a file that defines whether each grid-cell in the domain is on land or on the ocean. All grid-cells that either border or completely span the ocean are needed to create surf-zone information necessary to predict coarse mode (particulate matter of size between 2.5 and 10 microns) aerosols from sea surf. This file is created using the Spatial Allocator tool developed and supported by CMAS.
- Photolysis Rates: CMAQ also needs a photolysis lookup table for modeling certain species that undergo photolytic reactions. This table is developed through a standard CMAQ preprocessor called *phot.*

3.3.4 CMAQ Model Configuration

Given that the CMAQ code is modular, the user has flexibility in configuring the model by choosing various modules and science process algorithms as necessary. For example, for each science process listed in Table 3-1, multiple module choices are available. Some combination of modules makes the overall model configuration incorrect and leads to unexpected or even erroneous results in the model application that are not easily trackable. As with any model, it is recommended that the user review the documentation thoroughly, understand the pros and cons of each module, and adopt recommended configurations for urban-scale studies by consulting with the EPA or other expert model users. A sample CMAQ model configuration based on this study is provided in Table 3-1. The same configuration was used for both the 12-km and 4-km resolutions.

3.3.5 Resource Requirements

Unlike the use of "simpler" plume-based models, it is worthwhile to discuss resources and runtimes necessary to conduct grid model runs. In the tables below, the computational resource requirements for the CMAQ modeling are provided. Table 3-2 presents the daily input and output file sizes for each of the two modeled grid resolutions and the totals for the month-long datasets. Recent versions of CMAQ provide an option to perform inline processing of both biogenic and major elevated point sources. Using this option will reduce the size of emissions input files, but will increase the computational time modestly. In Table 3-3, the CPU-hours taken for each

Table 3-1. CMAQ Science configuration.

Science Process	Module Name
ModDriver	Ctm_yamo
ModInit	Init_yamo
ModHadv	Hyamo
ModVadv	Vyamo
ModHdiff	multiscale
ModVdiff	Acm2_inline_txhg
ModPhot	Phot_table
ModChem	Ebi_cb05cltx_ae5
ModAero	Aero5_txhg
ModAdepv	Aero_depv2
ModCloud	Cloud_acm_ae5_txhg
Mechanism	Cb05cltx_ae5_aq
PAOpt	Pa_noop

Table 3-2. Data requirements (in Gigabytes) for CMAQ inputs and outputs.

	12-km	4-km	Both Grids	Per Month
Inputs - Meteorological	4.7	0.6	5.3	186.3
Inputs - Emissions (Base Case)	3.4	1.4	4.8	169.4
Inputs - Emissions (Sens Case)	0.3	0.1	0.4	13.7
Inputs - Other	0.5	0.3	0.8	26.4
Outputs (Base Case)	17.4	7.3	24.7	863.2
Outputs (Sens Case)	17.4	7.3	24.7	863.2
Total	43.6	17.1	60.6	2122.2

modeled grid resolution for each modeled scenario are presented. These numbers are based on model simulations performed on a Linux cluster with Xeon 2.0 or 2.8 or 3.0 GHz quad-core processors and with each execution using eight CPUs in parallel. More information about the Linux cluster and the technical specifications can be found at: http://help.unc.edu/6020. The estimates in both Tables 3-2 and 3-3 need to be scaled for additional months/seasons that will be modeled.

3.3.6 Evaluation and Accuracy

Evaluation of WRF and CMAQ is performed through the use of the Atmospheric Model Evaluation Tool (AMET). WRF is evaluated against observations from the Meteorological Assimilation Data Ingest System (MADIS) observational data, available from http://madis.noaa.gov/. The MADIS data includes NWS surface and Rawindsonde Observations (RAOBs), MESONET surface monitors, and the wind profiler networks. The AMET toolkit allows for comparisons of wind speed and direction, temperature, and specific humidity. Since this study was conducted in a near real-time forecast mode, WRF outputs for both a 24-hour (D1) and a 48-hour (D2) forecast were developed and evaluated independently, and no significant differences in the model outputs between the D1 and D2 forecast outputs were found. Furthermore, for all three seasons modeled, the 4-km model application was found to consistently give better performance than the 12-km outputs, emphasizing the need for finer grid resolution to capture local-scale features at the urban scale.

CMAQ is evaluated against observations from several routine monitoring networks in the United States [e.g., the Air Quality System (AQS), Speciated Trends Network (STN), Clean Air Status and Trends Network (CASTNet), and the Interagency Monitoring of Protected Visual Environments (IMPROVE) network]. Most of these data are available for download from http://epa.gov/ttn/airs/airsaqs/detaildata/downloadaqsdata.htm. However, it usually takes a few months because the measurements are taken for EPA to make these data available on this website. During the near real-time modeling, the model was evaluated on a daily basis using data from EPA's AIRNOW system (http://airnow.gov/) which is used for providing air quality guidance for the nation. This includes only O_3 and total $PM_{2.5}$ from the AQS monitors. Data for the previous day are usually available within 24 hours on this website, and a system was created to acquire and ingest these data in near real-time for the CMAQ model evaluation. However, although the availability of these data from AIRNOW are timely and assist in obtaining an initial evaluation of the model performance and help identify weaknesses, they are subject to further screening and QA before they are made final and posted to the first link mentioned earlier; hence, the data quality is not as robust as the former.

Table 3-3. CPU requirements for CMAQ simulations.

	Total CPU-hours / model month		Average CPU-hours / model day	
	12-km	4-km	12-km	4-km
Each scenario	148.4	132.6	3.9	3.5

Besides evaluating against routine monitoring, this study also gave an opportunity for an integrated measurement and modeling-based assessment of air quality impacts due to airport emissions. Specifically, CMAQ was evaluated against additional sets of on-site measurements of both gas-phase and aerosol species. In addition to total $PM_{2.5}$ mass, speciated measurements of sulfate, EC and OC, and size-segregated measurements from the rotating drum impactor (RDI) were performed. Although evaluations of CMAQ against RDI measurements are not routine, this gave an opportunity to evaluate the relevant size fraction of $PM_{2.5}$ that is more critical from the perspective of AQ impacts of aviation emissions. However, given CMAQ's modal treatment of the formation of particulate matter, it takes additional effort to convert CMAQ's predictions of PM to sectional values so they can be compared. (The details of this additional effort along with the results of the model evaluation are presented in Appendix F.)

The overall goal of the model evaluation was to ensure that CMAQ model performance is within the goals and criteria recommended by Boylan (2006) and by the USEPA for such urban-to-regional scale applications (USEPA[b] 2007). Although this application for assessing air quality impacts from an airport is not a regulatory application for SIP purposes, the USEPA's modeling guidance presents a good overview of considerations necessary to develop a CMAQ application, and procedures for model evaluation.

3.3.7 Limitations

Given that CMAQ is an urban-to-regional scale model, the 4–12 km resolution used above does not capture the fine scales of spatial variability that may be observed in and around an airport. Although a preferred option would be to develop an even finer resolution model application (e.g., 1-km or less), it is usually computationally intensive, and developing meteorological inputs using a prognostic model at that resolution is even more challenging. Thus, depending on the layout of the airport, the use of three or four grid-cells that span the airport property at the 4-km grid resolution is typically used. This limitation is further addressed in the next section.

3.4 CMAQ and AERMOD Hybrid Modeling

The overall goal of hybrid modeling is to use CMAQ outputs at a relatively coarser resolution of 4–12 km to provide secondary components of $PM_{2.5}$ and then use AERMOD to predict concentrations of primary pollutants at a much more spatially resolved network of receptors. The rationale for this is that secondary pollutants tend to be more spatially diffused, while primary pollutants have a much more localized signature, especially when considering airport sources. While details of the algorithm for performing hybrid calculations are provided in Appendix F, the key point is that there are two different options—one meant for evaluating model outputs against observations, and the other for performing source attributions. Airport operators planning to perform air quality impact assessments can adopt a hybrid modeling approach, where a combination of CMAQ and AERMOD are used so as to take advantage of the respective modeling system's features to come up with a comprehensive set of outputs for all pollutants at the finest spatial and temporal scales that are desirable.

For this study, a nested grid of AERMOD receptors was used. The outer coarse grid had receptors spaced uniformly every 1 km in a 15- by 15-km area, while the inner finer grid had receptors spaced uniformly every 500 m in a 5- by 5-km area—both centered on the airport. This nested approach gave the ability to obtain air quality impacts at a highly resolved scale in the immediate vicinity of the airport and a relatively coarser scale at downwind distances.

The inputs for AERMOD are exactly the same as those used if AERMOD was used alone (or as part of EDMS), except for the network of receptors at a finer resolution. The outputs of the hybrid model provide an estimate of pollutant concentrations at a very highly resolved spatial scale (compared to what CMAQ alone can provide at the 4–12-km resolution). Based on the analyses of the hybrid modeling outputs under this project, for $PM_{2.5}$, temporal variability dominates. However, for NO_x, spatial variability is more important than temporal variability.

3.5 Receptor Modeling

3.5.1 Overview

Receptor modeling is the application of data analysis methods to elicit information on the sources of air pollutants. Receptor-oriented or receptor models are focused on the behavior of the ambient environment at the point of impact as opposed to the source-oriented dispersion models that focus on the transport, dilution, and transformations that occur beginning at the source and following the pollutants to the sampling or receptor site. The fundamental principle of receptor modeling is that mass conservation can be assumed and a mass balance analysis can be used to identify and apportion sources of airborne particulate matter in the atmosphere. This methodology has generally been referred to within the air pollution research community as receptor modeling (Hopke 1985). The approach to obtaining a data set for receptor modeling is to determine a large number of chemical constituents such as elemental concentrations in a number of samples. Alternatively, automated electron microscopy can be used to characterize the composition and shape of particles in a series of particle samples. In either case, a mass balance equation can be written to account for all m chemical species in the n samples as contributions from p independent sources.

$$x_{ij} = \sum_{p=1}^{P} g_{ip} f_{pj} + e_{ij} \qquad \text{Eq. 3-1}$$

where x_{ij} is the measured concentration of the jth species in the ith sample, f_{pj} is the concentration of the jth species in material emitted by source p, g_{ip} is the contribution of the pth source to the ith sample, and e_{ij} is the portion of the measurement that cannot be fit by the model.

When the source profiles are not known, factor analysis methods that are quite different from traditional Principal Components Analysis and related techniques have been developed over the past decade. An explicit least-squares approach, Positive Matrix Factorization (PMF) (Paatero 1997 and 1999), has been found to be very useful when applied to particulate matter (e.g., Zhao 2006, Lee 2006, and Kim 2007) and volatile organic compound (VOC) (Kim 2005) compositional data. In these factor analysis methods, the problem is expanded to the solution of the source profiles and contributions over a set of samples.

An advantage of the PMF approach is that it can be expanded to the analysis of more complex data that require advanced data models such as the size-composition data produced by the University of California at Davis RDI sampler coupled with synchrotron x-ray fluorescence. Pere-Trepat et al. (2007) demonstrated such a model that takes into account that sources produce particles whose composition vary by size and require a model different from that presented in Equation 3-1. Thus, the methodology can provide a mechanism to fit conceptual models of the nature of the sources for the particular type of data available.

3.5.2 Data Requirements and Usage

Factor analysis methods like PMF can be applied to a variety of data. The critical issue is having sufficient variability in the contributions of the various sources (Henry 2003). This variability can be obtained through short-duration samples like those obtained using the rotating drum

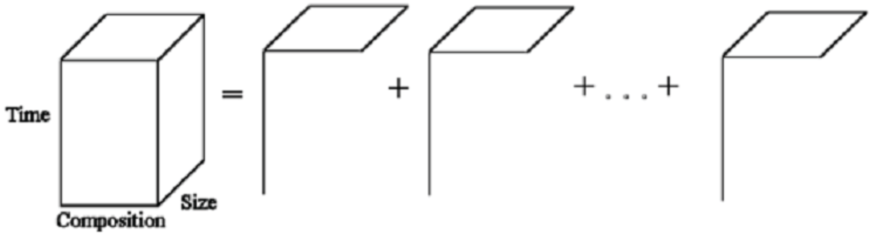

Figure 3-1. Schematic view of the new three-way model proposed for the analysis of the DRUM data. It is possible to fit these more complex models such as is shown in Appendix G.

impactor (RDI) or other semi-continuous sampling methods (Chow 2008). Variation can also be obtained through the spatial arrangement of the samplers relative to the source areas (e.g., runways) knowing the prevailing wind directions. The combination of spatial and temporal variation can provide a very effective sampling strategy that provides data with specific source contributions that will be zero or close to it.

The data need to include species that have relative concentrations that are sufficiently different from one another so that there is limited colinearity among the source profiles. These species can include elements, ions, or organic compounds. A critical issue is that the species have to have sufficient stability in the atmosphere that the pattern of relative concentrations for a given source does not change substantially over the spatial and temporal scales of the measured region.

The methodology can handle data with a substantial number of below-detection-limit values and a wide range of measurement uncertainties. However, there needs to be sufficiently high signal-to-noise ratio variables that will permit the analysis to succeed. A careful sampling and analysis design based on the understanding of this data analysis method can provide the data required to assess the major source types arising from multiple sources around an airport.

PMF as provided by the USEPA only permits the solution of the simple mass balance equation shown in Equation 3-1. However, sampling systems like the RDI provide more complex data with samples segregated by time and particle size. It is then necessary to build conceptual models of the source emissions to ambient concentration processes. For example, for the RDI data, the data should be considered as a three-dimensional array of size by elements by time. The sources emit particles whose compositions vary with size. Thus, the source profile is a matrix of elements by size. The model can be expressed as shown in Figure 3-1.

3.5.3 Model Application and Results

It is necessary to explore a range of solutions. The choice of the number of factors is generally difficult. A number of possible diagnostics are available, but the primary criterion for selecting solutions is the examination of the distribution of the scaled residuals. A residual is the difference between the measured and modeled values.

$$e_{ij} = x_{ij} - \sum_{p=1}^{P} g_{ip} f_{pj} \qquad \text{Eq. 3-2}$$

These residuals are then weighted by the estimated data point uncertainty.

$$\frac{e_{ij}}{s_{ij}} = \frac{x_{ij} - \sum_{p=1}^{P} g_{ip} f_{pj}}{s_{ij}} \qquad \text{Eq. 3-3}$$

The distributions for each variable should be symmetric and generally the values should lie in the range of –3 to +3. Such results suggest that the data has been adequately fit by the model.

The model produces estimates of the source profiles that have to be interpreted as to what sources that they represent. The interpretation of the results can be difficult if new or unexpected sources are derived. The assignment of a source name to each profile depends on an understanding of the physical and chemical processes that result in the release of particles into the air. Different mechanisms produce particles of different size and composition. Prior examples of measured source profiles are available from the USEPA in its SPECIATE database (USEPA[c] 2010) and the scientific literature reporting source profiles.

There should be consistent results in the pattern of the time-series of source contributions. For example, the RDI analysis provided in Appendix G identified a profile with high Na and Cl in particle sizes greater than 1 μm that only was observed during the winter sampling campaign. This profile can be assigned to salt applied on icy surfaces that is then suspended by the movement of vehicles over the salt-laden surface.

The PM-focused receptor modeling and assessments presented in Appendix G demonstrate the difficulties in identifying the exact sources for each pollutant, but also serve to illustrate the usefulness in categorizing airport versus non-airport sources. Also, the assessments showed the potential to help identify “gaps” in the source modeling work (e.g., emissions from brake and tire abrasion). Although these gaps were demonstrated, the assessments also showed the need for detailed data such as those from an XRF analysis in the context of relatively higher temporal resolutions and longer time spans. In general, the more spatially and temporally itemized sets of data are available, the higher the fidelity in predicting source speciation.

Although receptor modeling can provide useful results, its use should generally be considered supplementary. Considering the resources available at an airport, source-oriented modeling should be considered first along with any necessary measurements. If receptor modeling is to be conducted, airport operators will need to carefully consider whether the work can be conducted using ambient data that is already expected to be collected (i.e., as part of the overall air quality project) or whether resources are available to develop a concerted monitoring-and-receptor modeling program. In addition, consideration will need to be given to the expertise necessary to conduct such assessments. In general, there are far fewer individuals at airports as well as consultants (including universities) who have the expertise necessary to both conduct and understand the results from receptor modeling assessments.

CHAPTER 4

Measurement Guidance and Findings

4.1 Overview

In general, USEPA protocols should be followed when developing an airport measurement plan (e.g., USEPA[f,h] 2011). However, different airports may require different strategies by airport officials in developing air quality monitoring programs—one size does not fit all when it comes to measurement programs. The development of such programs requires the following types of considerations:

- The size and layout of the airport;
- The types of sources present;
- The operations associated with the airport (both air side and land side);
- Purpose of monitoring; and
- Resources available (e.g., monetary, locations, and personnel).

The physical size of the airport is important in many ways and directly linked with operations and resources. As such, one of the first considerations is physical coverage of the airport. Smaller airports, especially those away from other air pollutant sources require fewer locations to characterize the air quality at the airport. Very small airports with only minor operations may only employ a single location to allow characterization of the area. Additionally, resources are directly related to airport size and operations. A smaller airport with very limited resources, especially personnel, may not be able to support continual monitoring even at a single location and may have to depend on measurements from local air quality monitoring stations to characterize air quality in the area.

A very large airport is like a small city where concentrations vary significantly according to location. There are also the upwind/downwind considerations which are integral to determining the actual contribution of the airport versus background concentrations. Therefore, a large airport should consider two measurement locations as a minimum. This number of locations could increase according to purpose and resources as discussed later. Of course, the greater the coverage (number of locations), the more flexibility in what can be accomplished using the measured data.

The purpose determines not only the type of pollutant measured, but the number and location of monitors and/or samplers. If the purpose is long-term monitoring to establish general trends, then the minimum is required and this could range from zero for a small airport using non-airport-specific data from local monitoring systems to two for the larger airports to allow for upwind/downwind analysis. If the purpose is to establish the airport contribution, then the minimum for a small airport generally becomes two (upwind and downwind) (realizing that resources may be limited). For larger airports, the number will depend on the airport layout. If there are multiple runways at different angles, then background quadrants must be established

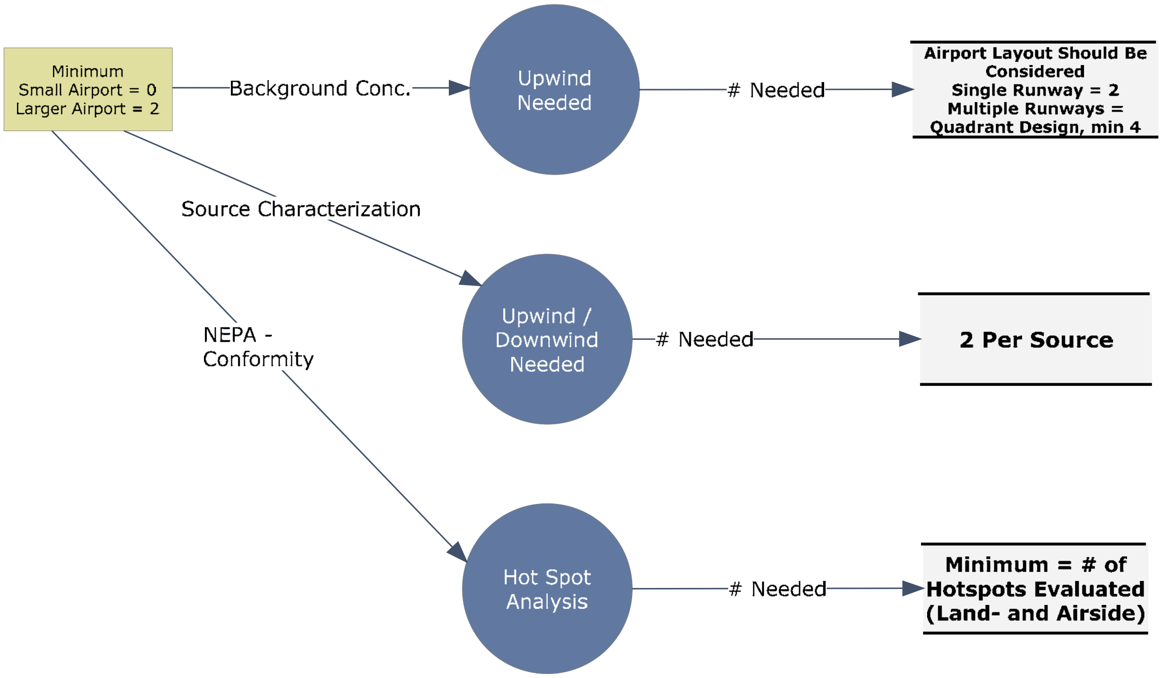

Figure 4-1. Number of monitoring locations.

to allow the upwind concentration to be determined regardless of wind direction. This most likely results in a minimum of four locations and, if resources are available, even more measurement locations may be needed to further define the airport contribution.

Two common purposes of monitoring that occur at airports are the regulatory requirements of NEPA and Conformity. Regarding NEPA, monitoring can play an important role in the following three things: establishing the background concentration, establishing if the NAAQS are approached or exceeded, and trend analysis. When monitoring is used to evaluate against the NAAQS or in the cases where it is needed for conformity analysis, then the number of locations is determined by the "hot spots" on the airport, where a hot spot is a location where elevated concentrations occur. Hot spots often occur on the land side, primarily from motor vehicle activity. To determine the number of monitors on the land side, the analyst should evaluate intersections, the terminal area, parking areas, and maintenance/storage facilities using the EPA protocol for determining the top locations. This could result in multiple monitoring locations. On the air side, possible monitoring areas include heavily used gate areas and, to a lesser degree, locations where aircraft queues occur. Again, multiple monitoring locations could be needed. Figure 4-1 summarizes the number of monitoring locations needed.

4.2 Pollutants Measured

Two basic categories of pollutants to measure can be defined: criteria pollutants and non-criteria pollutants. Criteria pollutants (i.e., those pollutants with defined ambient standards as determined and implemented by the NAAQS) include carbon monoxide (CO), oxides of nitrogen (NOx), sulfur oxides (SOx), ozone (O_3), particulate matter ($PM_{2.5}$ and PM_{10}), and lead (Pb). Non-criteria pollutants include greenhouse gases (GHG), hazardous air pollutants (HAPs), and pollutants of specific concern (e.g., ultrafine PM). The primary GHG to consider is carbon dioxide (CO_2). Each of these pollutants is discussed in the following paragraphs and summarized in Table 4-1.

Table 4-1. Measurement recommendations for pollutants of concern at airports.

Pollutant	Typical Sources	When Measurements Recommended
CO	Aircraft, motor vehicles, support equipment, combustion sources, construction equipment	Only for special use
NOx	Aircraft, motor vehicles, support equipment, combustion sources, construction equipment	General trends, NEPA/conformity analysis, special use
SOx	Aircraft	General trends, special use
O_3	Secondary pollutant, not generated by sources directly; primary precursors are NOx and hydrocarbons	Not recommended
PM	Aircraft, motor vehicles, support equipment, combustion sources, construction equipment, brake/tire wear, stationary sources depending on fuel use, ambient entrainment	General trends, NEPA/conformity analysis, special use
Pb	Piston aircraft and leaded fuel operations	Only for airports with substantial piston aircraft operations
CO_2	Aircraft, motor vehicles, support equipment, combustion sources, construction equipment	For special studies and combustion source tracing
HAP	Aircraft, motor vehicles, support equipment, combustion sources, construction equipment	For special studies

On the air side, the measurement data has shown that CO is not significantly increased along the taxiways and runways and measurements provide little benefits. This is also shown by other studies (e.g., Wayson 2003). As such, the only place to consider is the gate area. But even here the public is not significantly exposed (i.e., the public is exposed for very short durations) so measurements would mainly be conducted for worker considerations and not necessarily NEPA. On the land side, areas that could require CO measurements are enclosed areas where motor vehicle activity occurs such as in parking garages or the terminal drop-off area if covered. As such, CO measurements are recommended only in certain defined areas and not on the airfield except to develop background concentrations.

NOx is an important consideration at airports. Aircraft have become more efficient in fuel burn, thereby reducing pollutants such as CO and hydrocarbons, but NOx continues to be important. Motor vehicles and ground support equipment, especially diesel vehicles, also emit significant amounts of NOx. As such, NOx measurements are recommended on both the air side and land side. An important point to measuring near aircraft movements is to do so where high power modes, such as takeoff, occur.

SOx is a function of the sulfur in the fuel, which is still significant in Jet A, but future legislation could reduce fuel sulfur content. As sulfur levels change, so does the SOx impact. SOx emissions are interdependent with PM emissions. For these reasons, SOx measurements on the air side could still be important for specific needs, but are not recommended as highly as NOx. Of note is that PM measurements may often supply surrogate information on SOx. On the land side, the need for monitoring is even less since low-sulfur fuels have been mandated for motor vehicles.

O_3 is a secondary pollutant, formed primarily from the precursors of NOx and hydrocarbons, and elevated concentrations occur hours downwind of the source. Near airports, O_3 depression (reduced concentrations) actually occurs as it reacts with the NOx emissions. As such, ozone is not recommended for measurements at airports—instead the precursors are more important and provide more meaningful results.

PM is an important pollutant at airports. This is because the PM emitted from aircraft is predominantly below 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$) and emitted in sufficient quantities to be significant. Indeed, most PM emissions from aircraft tend to be in the ultrafine category (<0.1 μm) which can cause serious human respiratory damage. PM concentrations can be significant on both the land side and air side, and as such, it is recommended that measurements be taken separately to account for motor vehicle activity and airfield activity. Additionally, point sources such as heating plants could also be significant contributors, depending on the fuel used and source controls in place.

Pb becomes a concern if operation of piston-powered aircraft is substantial. Pb is used in aviation fuel (Avgas) and is known to have neurological impacts on humans. As such, Pb is a listed HAP. Pb is not a concern from most other sources at an airport, and measurements are only recommended for airports with substantial piston aircraft operations with the runway ends being the most significant location according to recent EPA documents. However, fueling operations for the piston aircraft could also be a significant source.

Ambient hydrocarbon and HAP species are not currently regulated, with the exception of Pb, but remain a concern to the public and generated by multiple airport sources. Measurements of HAPs is only recommended for special uses (e.g., health risk assessments) and then only a subset of the total. For example, measurement of formaldehyde has been shown to be proportionally related to other HAPs (USEPA[b] 2009). It should also be stated that mass-wise, carbonyls such as formaldehyde comprise the majority of HAP emissions (Wood 2008). Therefore, using simple measurement techniques for formaldehyde could be used as a surrogate for other HAPs occurring at airports. The USEPA has established an extensive list of HAPs, but the following appear to be detectable in aircraft engine exhausts (USEPA[c] 2009):

- 1,3-Butadiene;
- Acetaldehyde;
- Acrolein;
- Benzene;
- Ethylbenzene;
- Formaldehyde;
- Isopropylbenzene;
- Methanol;
- N-xylene and P-xylene;
- Naphthalene;
- O-xylene;
- Phenol;
- Proprionaldehyde;
- Styrene; and
- Toluene.

4.3 Upwind and Downwind Concentration Assessments

An upwind/downwind analysis is needed to compare results from EDMS/AERMOD to measured results without assuming a background concentration. The basic assumption is that pollutants migrate to the airport from other area sources and contribute to the overall measured concentration. It follows that measurement locations upwind of airport sources would only include those from background sources. Subtracting these concentrations from the measurement locations downwind of airport sources should lead to concentration values only due to airport sources. Figure 4-2 demonstrates this idea for one position, Position B, using the measurement campaign at IAD as an example. Of course, the analysis method repeats for other positions but with different results.

In Figure 4-2, the IAD area has been divided into four defined angle quadrants based on the runway orientation which is usually based on the predominant wind directions. Each quadrant, named for the wind angles it includes, represents a grouping of wind angles that would cause the

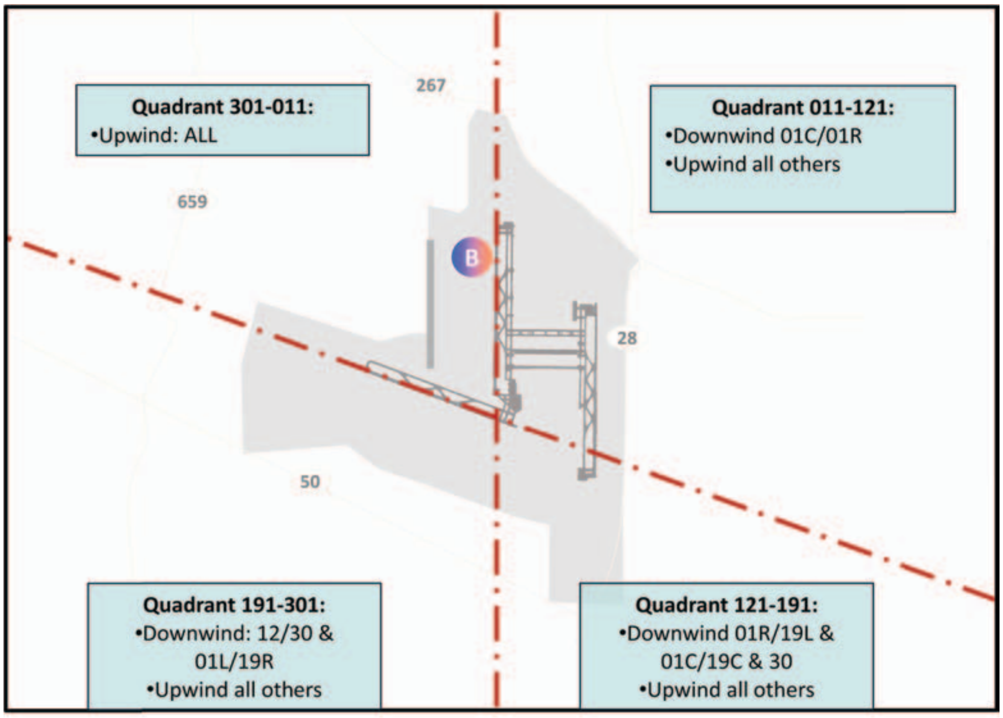

Figure 4-2. Wind analysis for Position B.

local concentrations at different positions to be influenced by various runway activities. Other airports would require specialized assessment based on the characteristic wind angles.

Multiple scenarios were investigated to derive the background levels from the measurement data by combining the consideration of wind flow and runway operations during collection times. For each quadrant, background measurement positions were identified to allow the evaluation of the concentrations due to aircraft activity as indicated below:

$$C_A = C_{dnwind} - (K)C_{upwind} \qquad \text{Eq. 4-1}$$

where

C_A = Concentration due to airport activity
C_{dnwind} = Downwind concentration
C_{upwind} = Upwind concentration (assumed background)
K = Conservatism factor

Of note is the conservatism factor K. This has been included for two reasons: (1) to provide a measure of conservatism and (2) the realization that some airport sources may still have an effect on the concentrations in low wind conditions or from other mobile sources such as motor vehicles or construction equipment in the area. Because the K value is intended to help account for some of the uncertainties surrounding the derivation of the airport's air quality contributions, the value may be estimated using measured data (either a current dataset or historical data). The differences in the measured concentrations from receptors that are relatively close would provide an indication of the K value. This value would provide some conservatism to account for the transient influences of distance (e.g., location of receptors), weather (e.g., wind direction) and sources that are either near or cross the upwind/downwind boundaries. Concentrations based on shorter averaging periods may experience greater variations than those based on longer averaging periods. A nominal K value of 0.9 may be reasonable for most cases, indicating about 10% conservatism. However, based on the strength of the transient influences, other more conservative values, such as 0.8 (20% conservative), may be justified.

Again considering Figure 4-2, if the wind is flowing from Quadrant 301-011, and there is no activity on Runway 01L/19R, then Position B is upwind of all (or most) airport sources. Although some contribution from airport activity other than aircraft may occur, the location still represents a good estimate of background concentration for the airport. This is thought to be much better than trying to estimate the background concentration from permanent monitoring stations many miles away influenced by completely different sources.

Using the measured concentrations at Position B as background and subtracting from the measured concentrations at other positions then results in a concentration that represents the increase due to airport activity (see Equation 4-1). This allows a direct comparison to the results predicted by EDMS/AERMOD that only includes the airport sources. Additionally, depending on wind direction and runway activity, Position B could be a downwind position and the analysis would be completed using another position as background.

Using this approach, the wind conditions have been reviewed and all positions designated as upwind or downwind positions for the various runway activity. The background receptor locations are

- Quadrant 011–121: Location M
- Quadrant 301–011: Locations C and X (X only measured PM)
- Quadrant 191–301: Location K
- Quadrant 121–191: Location M

Operations have been reviewed to closely determine the important source locations for each analysis hour. Background concentrations have been determined and the simple method as shown in Equation 4-1 has allowed the contribution from the airport activity to be determined.

For simplicity, it would be desirable to have a single value for a background level. Of course, the weather is unpredictable and nearby sources are not often constant emitters. There is considerable variance day to day and hour to hour. Additionally, it is not possible to separate longer term aggregate measurements (1-hour, 3-hour, 24-hour) into shorter time periods with certainty. This is particularly true of the 24-hour particulate matter sampling. This causes the analysis complexity to increase. In these cases, a statistical averaging approach is needed to determine the background and concentration contribution due to airport activity. Various methods are being used to analyze the data in these conditions. All follow the same basic format of

$$C_A = C_{dnwind} - KC_{upwind}\left(f\left(time\right) * f\left(operations\right)\right) \qquad \text{Eq. 4-2}$$

where

f(time) = a statistical function of the upwind/downwind time at a position
f(operations) = a function of operations during the upwind and downwind times

Methods vary with both uncertainty and resource commitment. The research team reviewed different methods and the relative merits of each. It was decided that the best time function, f(time), in Equation 4-2 (based on airport resources) was to use a weighted average of the upwind locations based on the time fraction of wind direction. Stability was not included because it was thought that this was already a function of the measured concentration. As such, the f(time) is equivalent to the time each upwind site exists. Or

$$C_A = C_{dnwind} - K\left(t_1 * C_{1upwind} - t_2 * C_{2upwind}\right)\left(f\left(operations\right)\right) \qquad \text{Eq. 4-3}$$

where

$C_{1upwind}$, $C_{2upwind}$ = concentration for two primary upwind locations due to wind direction
t_1, t_2 = fraction of time during defined time period where each location is upwind

Additionally, the operations function, f(operations), was determined to not be a consideration for IAD. If measurement locations for other airports were located such that no location was truly upwind of all major sources, this could be implemented and could be as simple as considering the times when aircraft are present during different wind flows. This resulted in the following equation to determine C_A and allow a direct comparison to EDMS results:

$$C_A = C_{dnwind} - K\left(t_1 * C_{1upwind} - t_2 * C_{2upwind}\right) \qquad \text{Eq. 4-4}$$

4.4 Measurement Locations

Each airport is unique. As such, measurement locations will vary by airport. Some general guidance is provided, but the final locations should be determined after a careful review of airport sources, local sources, and resources available. The determining factor in monitor placement is the purpose of the measurement(s) which determines final use of the data. The previous section presented a methodology that greatly increases the use of background information and helps to improve modeling results. If data are to be used for background, then locations should be situated so as to define the upwind component for the wind flow as related to sources. Related to this is the ability to determine the airport contribution by use of downwind locations. This requires consideration of the runway, terminal, and other facility layout details as indicated in Figure 4-3.

On the left is a simple single runway where aircraft are taking off into the wind and a minimum of two measurement locations are needed. On the right, for a more complex airport, the quadrant approach applies because of changes in runway usage for operations and wind. (This methodology is described more in Appendix B.) Additionally, local sources may also cause

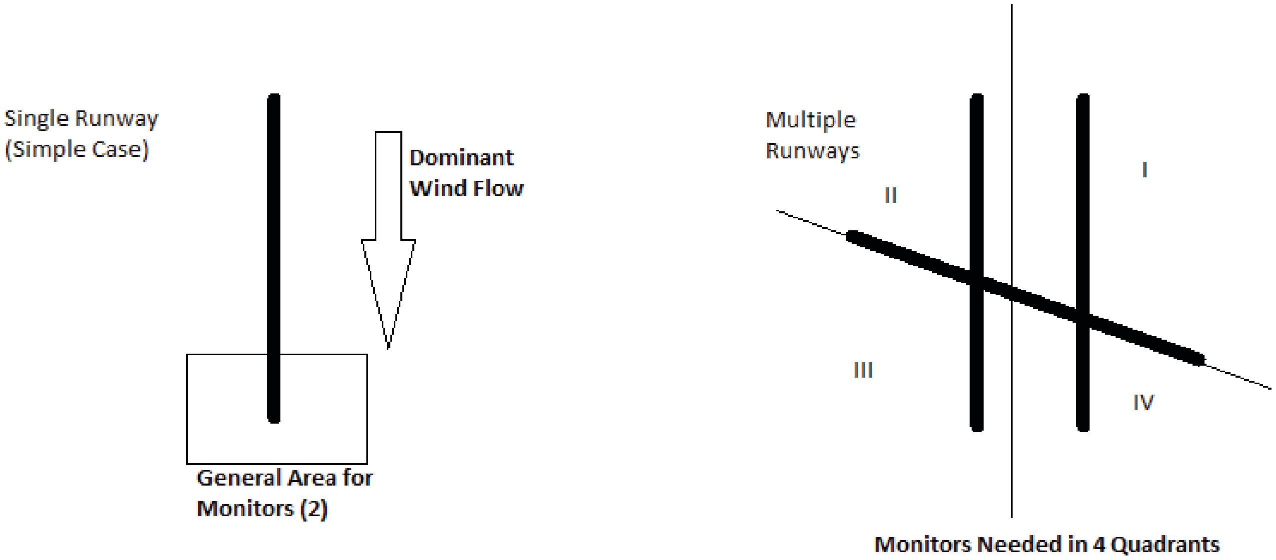

Figure 4-3. Examples of areas for monitor placement for background and airport contribution considerations.

changes in locating monitors. For example, a large freeway or a manufacturing source near the airport should be considered because background from this facility could be substantial.

Other guidelines for placement include the following:

- Locate away from major sources unless characterization of that source is a reason for placement.
- When locating on the airfield, locate as close to the apron, taxiway, and/or runway as safely possible (and permitted) to determine the impact of the aircraft. With distance the concentrations decrease and, for aircraft, individual movements are difficult to record. In addition, consideration should be given to measurements at multiple heights given that the initial release is somewhat elevated and plume rise may also cause the plume to be elevated.
- Locate away from structures and buildings to the degree possible to avoid wake influence (see EPA guidance).
- In the case of long-term measurements and/or real-time instrumentation, both shelter and line power will be required.
- Evaluate whether the location will meet the data need.
- Safety is always a consideration.
- Security is always a consideration.

4.5 Equipment

Equipment used for air pollutant measurements and meteorology are primarily established by data needs, the intended measurement period(s) (e.g., 1 month, 1 year, continual), power availability, enclosure availability, safety, and security. The USEPA has defined equipment that is acceptable for use in state or local air quality surveillance systems in accordance with Title 40 CFR Part 53 (CFR 2006) which is referred to as reference or equivalent methods and listed by the USEPA (USEPA[f,i] 2011).

This equipment requires a shelter for climate control and line power and, if applied properly, should follow all Ambient Air Monitoring Regulations (CFR 2006). For the gaseous components, this equipment is often referred to as real-time analyzers because a continuous sampling process occurs. For PM, filters have been used, and, as such, a 24-hour period occurs for each sample. The research team has found that short-term PM measurements may not supply sufficient filter loading to allow a quality sample. If an airport is considering very high fidelity sampling or sampling on a continuous basis, other equipment types, such as BAM equipment which has been approved as an FEM for $PM^{2.5}$, should be used.

Measurements at airports often require monitoring at locations away from available power. In these situations, equipment that requires no line power (e.g., uses battery power), is weather resistant, and easy to handle must be used. Some gases and PM can be monitored through sampling (i.e., rather than through continuous monitoring). Although such sampling often results in less fidelity, it is still an important option to collect necessary data and needs to be balanced with the resources available. Table 4-2 provides suggestions on monitoring methods for the important airport pollutants.

4.6 Measurement Schedule

Measurement schedules, including total duration, will be based on a balance of the purpose of the measurements and resources available. With a lack of airport-specific information on this subject, applicable USEPA guidance should be followed (USEPA[f,h] 2011).

Table 4-2. Suggested air pollutant monitors for use at airports.

Pollutant	Sampling Description	Equipment
CO	continuous sampling compliance with CFR Part53 desired	reference or equivalent method (i.e., non-dispersive infrared)
CO	short-term or hot spot sampling	battery powered bag sample units with the reference or equivalent method used to test captured air
NOx	continuous sampling compliance with CFR Part53 desired	reference or equivalent method (i.e., chemiluminescence)
NOx	short-term or hot spot sampling	battery powered bag sample units with the reference or equivalent method used to test captured air (note: reactivity of gases must be considered)
SOx	continuous sampling compliance with CFR Part53 desired	reference or equivalent method (i.e., spectrophotochemical)(note: not generally recommended at airports)
PM	continuous sampling compliance with CFR Part53 desired	reference or equivalent method (i.e., filter with impaction specific for PM_{10} and/or $PM_{2.5}$)
PM	short-term or hot spot sampling	battery powered filter unit specific for PM_{10} and/or $PM_{2.5}$
Pb	continuous sampling compliance with CFR Part53 desired	reference or equivalent method (i.e., filter in hi-volume sampler)
Pb	short-term or hot spot sampling	battery powered filter unit
CO_2	continuous sampling	non-dispersive infrared
CO_2	short-term or hot spot sampling	battery powered bag sample units with the reference or equivalent method used to test captured air
HAP	continuous sampling	flame ionization detector (note: not generally recommended)
HAP	short-term or hot spot sampling	evacuated canisters or sample cartridges. formaldehyde may be used with proportionality factors to determine other HAP concentrations
Meteorological	continuous sampling	u,v,w sonic anemometers and aspirated thermometers at two heights with appropriate data logger system. Relative humidity and barometric pressure area also possibilities but not as important
Meteorological	short-term or hot spot sampling	Battery operated u,v,w sonic anemometers with appropriate data logger

The overall schedule for a monitoring campaign can range from just a few days for a specific need to years for continuous measurements if used in trend analyses. Considerations for short-term sampling for specific needs include seasonal variations, unusual weather conditions, atypical operations, and precipitation events. There is no strict guidance on the length needed for short-term sampling, but the analyst should review the USEPA guidelines and the necessary data to ensure the data will be sufficient.

In long-term or continuous sampling, it is important to represent all seasons over multiple years for a high confidence level. Therefore, reviews of climate data for the area of interest are necessary to obtain a good understanding of how the measurement schedule should be developed.

4.7 Planning

Although the previously discussed issues and items (e.g., measurement locations and equipment) can be considered separately to a certain extent, eventually they need to be pulled together into a cohesive monitoring plan. Careful planning is crucial to the success of any monitoring campaign. Resources such as those offered by USEPA should be reviewed to increase the likelihood of success (USEPA[f] 2011). At a minimum, an airport measurement plan should include the following elements:

- Determination of the final use of data,
- Selection of locations,

- Selection of equipment,
- Determination of time required to meet final data needs,
- Equipment calibration protocols,
- Analysis methods to be employed,
- Quality assurance during collection and data analysis, and
- Consideration of safety and security.

The final use of the data is the key consideration. The first part of the plan should include the key goals followed by a critique of how the data will be used. This includes consideration of regulatory requirements (e.g., are the data to determine compliance with a NAAQS), which pollutants are of concern, previous or ongoing measurements in the area, total duration of sampling needed to meet goals, and level of variability acceptable to meet goals.

Once the needs of the data and the goals of the monitoring plan have been established, the pollutants to be monitored will have been determined. This then allows the sample locations to be determined. If enclosures and/or line power are required, the first consideration is where these would be available (or set up). The first step in this process should involve the use of a good map of the area. Contour maps are also very helpful in identifying possible disturbances to local air movements. Initial locations can then be selected, followed by field reconnaissance (which is always needed for reasons including the ability to take into account recent changes to the area, security fences/walls that do not appear on a map, and drainage conditions). The previous discussions on site locations should be considered to evaluate and determine the best locations to monitor. The last step should involve consultation with field operations and safety officers to confirm that these locations are valid, in no way hinder the field operations, and meet all requirements set for safety, especially if some of the monitoring work is to be conducted on airport property.

Appropriate measurement equipment will need to be selected and the previous discussions should be considered—decisions regarding the use of real-time samplers or remote samplers (e.g., battery powered) will need to be made. If real-time sampling is used, not only must the specific equipment type be decided, but considerations for the enclosure and line power must be made as well. This will also require a sample manifold system. Best systems use a non-reacting manifold with a downstream pump. Calibration gases and procedures must also be considered.

Meteorological data are usually available near most airports from existing weather stations, but may not be very “close” to the measurement locations. Therefore, if resources allow, additional meteorological data (more representative data) should be obtained using meteorological equipment. Multiple locations are desirable, especially if topography is a concern, but resources or available locations away from obstacles may not always be available. For hot spot analysis or at smaller airports, one location may be sufficient. However, for more in-depth projects, a minimum of one location at two heights (e.g., temperature, wind speed, and wind direction at two heights) is advised to help better characterize local temperature and wind vertical profiles.

As previously indicated, the sampling schedule needs to be balanced with available resources. However, even in planned short-term measurements, additional time should be included to account for set up, shut-down, and days with precipitation. Erroneous data may occur on days with precipitation. Time for calibration of data must also be scheduled. One common error for remote sampling is not allowing sufficient time to collect samples to bring back to be analyzed. Navigating in and around a large airport can easily take hours. Where sufficient resources exist, allowing more time to collect more data (more than the minimum) is advised. For NAAQS or conformity determination, the aforementioned USEPA requirements should be followed closely.

Data are without merit if proper calibrations do not occur. This may be as simple as having a calibration curve developed for a sample pump used for cartridge sampling or as complex as using multiple gas mixtures to determine dilution times and flame ionization detector response when using a gas chromatograph. Regardless, a rigorous calibration routine must be included in any complete sample plan.

Analysis methods are also important considerations. This is not only related to how collected samples will be measured but also how the data will be analyzed. In the case of real-time analyzers, there is no additional analysis to determine the concentration of the sample. In the case of impaction on filters or absorption on media, it is best to send to a standard laboratory for analysis. This will not only greatly reduce the cost for the airport but provide a measure of traceability that might not occur with establishment of a field lab. For capture of gases using bag samples, analysis should occur at the airport using the reference or equivalent method real-time analyzer. As always, analyzers should be calibrated using National Bureau of Standards (NBS) traceable calibration gases.

In addition to calibration, an overall quality assurance plan is needed. As previously cited, the USEPA has established guidelines which are included in a large 5-volume compendium of topics related to ambient air measurements. These topics include, but not restricted to, test methods, sampling, analysis, and QA (USEPA^{h} 2011).

Safety and security must be considered as well. All rules at an airport (especially those involving the air side) should be carefully followed to prevent injuries and violations of any airport rules. The airport should be well-apprised of all measurement activities and schedules. Sampling outside of the airport in areas with public access may require additional considerations (e.g., enclosures) to ensure the equipment and samples are uncontaminated. Whenever possible, it is advisable to have more than one person check equipment and/or gather samples because this usually increases the likelihood of following safety precautions.

In terms of expectations, it should be recognized that an optimal sampling plan is difficult to develop—there are always items that will be difficult to foresee. Even when the same set of measurements are planned to be conducted by the same individuals at the same airport, a measurement plan will never be truly perfect. The hope is that the individuals developing the plan will be able to account for most potential issues that could arise and have appropriate contingencies set up. Many past monitoring efforts have not been completely successful because the plans were too ambitious with given resources, including time, personnel, and budgets.

CHAPTER 5

Integrated Modeling and Measurement Recommendations

5.1 Introduction

Although from a resource standpoint, modeling is usually preferred over measurements, the need for integration of both may be required largely because of modeling limitations. Even with all of the advances that have been made in developing and improving models to support airport air quality assessments, there still remain significant modeling gaps (e.g., using AERMOD) that are either difficult or impossible to fill at this time. Measurements are partly necessary because chemically reactive species and secondary pollutants such as ozone cannot be easily and robustly modeled. Although CMAQ helps to fill several of these modeling gaps, there are issues associated with fidelity and spatial resolution that need to be addressed. Also, measurements generally provide more accurate and more defensible results than modeling, but lack adequate characterization of spatial and temporal variability and can be resource-intensive (expensive).

The next two subsections provide a general, decision-making framework that can be applied to most airport scenarios. However, this framework needs to be integrated with the specific needs of each airport as well as the regulatory context of the air quality assessments. For example, the goals under a NEPA project may be different than those under a local (e.g., city) requirement.

5.2 General Decision Process

The decision on what models to use and measurements to conduct needs to be based on the specific needs of each project. No single combination of modeling and measurements will suit all airport projects (i.e., one size does not fit all). However, Figure 5-1 presents a general flow chart that can help to methodically determine the modeling and measurement combination to use, including which models. Once the combination is determined, the guidance from Chapters 3 and 4 should be followed to implement any modeling or measurement programs.

Figure 5-1 represents one decision-making order. Others are possible by ordering the decision points differently, but the outcome would be the same for each scenario. Therefore, the order is not as important as the need to make sure each of the decision points (as reiterated below) is considered:

- Assess stable pollutants (e.g., CO, $PM_{2.5}$, PM_{10}, NO_2 and SO_2)?
- Need to support detailed assessments, including troublesome hot spots?
- Need to establish accurate baselines and/or meet local (e.g., state) requirements for measurements?
- Regional concentrations necessary?

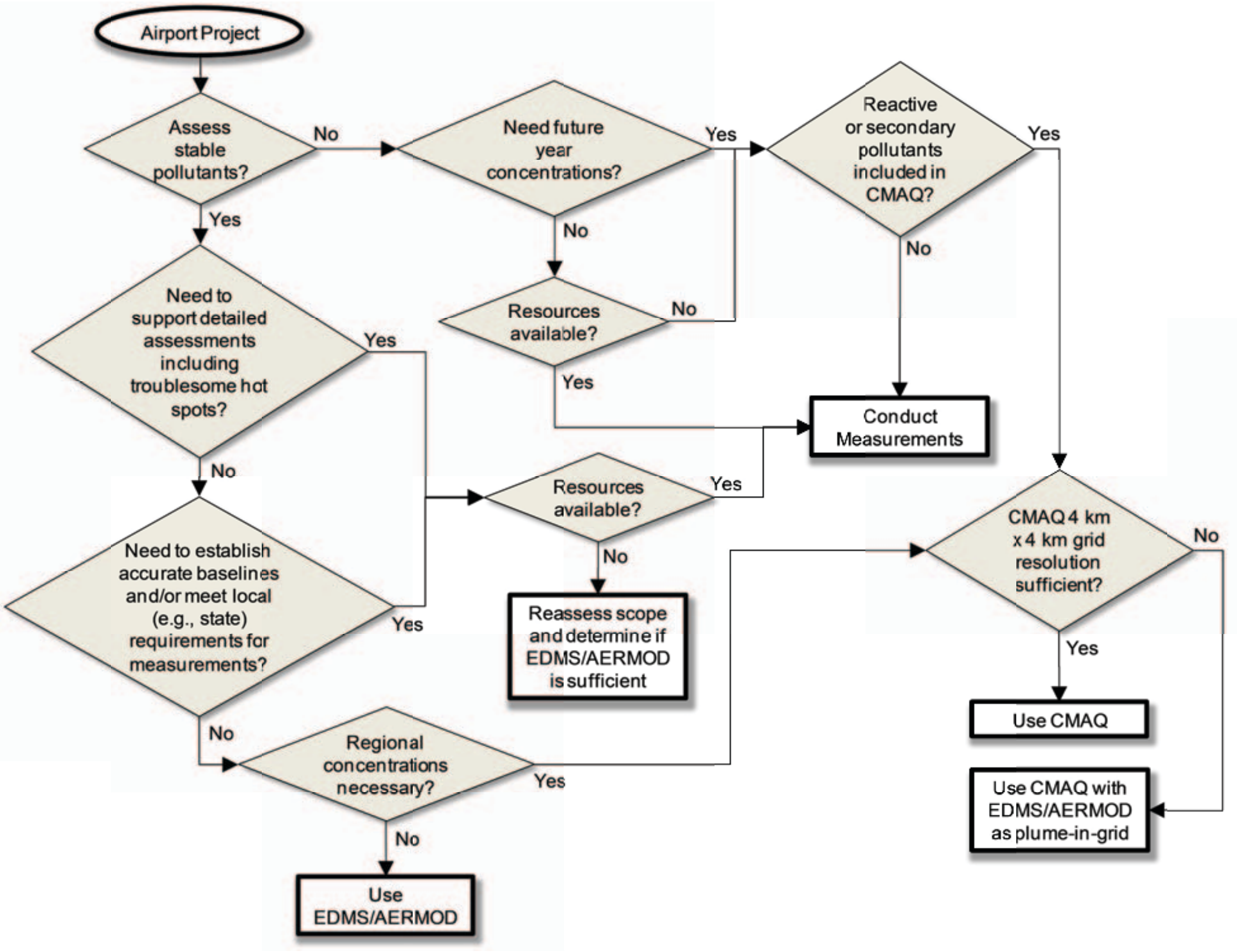

Figure 5-1. Modeling and measurements decision support diagram.

- Need future year concentrations?
- Resources available?
- Reactive or secondary included in CMAQ?
- CMAQ 4 km by 4 km resolution sufficient?

The starting point for the decision-making process in Figure 5-1 is the determination of which pollutants to assess. In general, EDMS/AERMOD is used to model relatively stable pollutants (e.g., CO, PM_{10}, $PM_{2.5}$, NO_2, and SO_2) while CMAQ and measurements can be conducted to assess reactive pollutants. As previously indicated, some reactive pollutants can be modeled in EDMS/AERMOD, if the reaction rate is relatively low (i.e., lower than the duration required for the pollutant to travel from the source to the farthest modeled receptor location). Although this decision point results in the first set of major decision branches, they should not be considered mutually exclusive. Indeed, the ensuing sub-branches merge as necessary. If both stable and unstable (relatively reactive) pollutants are to be assessed, then the flow chart can still be used, especially to help determine the use of measurements versus CMAQ.

If the pollutants are relatively stable, then the next decision point concerns the potential need to support detailed and troublesome assessments. Although models can be used to conduct such work including hot spot assessments, there may be some specific reasons (e.g., features at an airport) that may make it difficult to model certain locations and/or the locations may have significant community health concerns. In such cases, measurements may be necessary to either help confirm the modeled results or provide more accurate concentrations.

Another reason for measurements may be due to either an airport initiative to better understand its impacts on the local community or in response to local government requirements. In any case, a set of baseline measurements (e.g., a years' or multiple years' worth of concentration measurements) may be necessary to determine average levels as well as impacts from meteorology.

In addition to the local-scale impacts for relatively stable pollutants that can be assessed using EDMS/AERMOD, the larger scale modeling capabilities of CMAQ may be used to help determine regional impacts. As such, the need for larger scale results needs to be weighed with the resource requirements needed to use CMAQ.

In assessing both reactive and secondary pollutants, one of the decision points that will need to be addressed is whether future year concentrations will need to be predicted. Associated with this is whether or not air quality for varying scenarios (e.g., "what-if"-type modifications to aircraft operations and taxi movements) will need to be determined. Although measurements may provide accurate concentration levels (assuming sufficient samplings), they generally do not allow assessment of different scenarios.

Another decision point regarding reactive pollutants is to make sure CMAQ can adequately model their concentrations. A thorough model evaluation needs to be conducted (as demonstrated in this project), and the evaluation needs to be compared with similar studies to see if the measures of model performance are comparable or within the criteria and goals recommended by the EPA. As such, expert decisions will need to be made whether CMAQ predictions will suffice or if measurements will need to be conducted either in support of or as a replacement to the use of CMAQ.

The other decision regarding the use of CMAQ to model reactive pollutants involves the resolution of the grids used. Although smaller grids may be possible, the smallest that has been used to produce acceptable results is 4-km grids (16 km^2 areas). This means that concentrations within each 4 km by 4 km grid are homogenous (i.e., one average concentration for each grid). If higher resolution concentrations are necessary, then either higher resolution grids will need to be investigated and/or measurements will be necessary.

A common decision point when considering measurements is whether adequate resources (e.g., personnel, equipment, and time) are available to conduct the work. Depending on the scope of the work, it can often be difficult to determine the overall resources necessary to conduct measurements. Hence, underestimating resources is not uncommon when conducting measurements, and this may be compounded by unforeseen (or at least difficult to foresee) events such as inclement weather. Although resources are only highlighted for measurement work in Figure 5-1, it should be obvious that the various modeling work require resources as well. Measurements and modeling each require personnel expertise (e.g., airport personnel and consultants) to conduct both types of work and should not be overlooked. Therefore, the issue of resources should actually be considered throughout the decision-making process.

While all of these decision points provide a general framework that can be applied to each airport, they need to be tailored to meet the needs of each specific airport. Some of the needs and specific issues at airports may include but are not limited to

- Community and political pressures to use certain types of resources;
- Pressures to conduct measurements rather than modeling;
- Availability of appropriate background concentrations (e.g., from USEPA monitoring stations);

- Local regulatory requirements;
- Desire to conduct the modeling work only using airport personnel; and
- Little confidence in the models.

Each of these types of issues will need to be considered as the aforementioned decision points are addressed. A specific issue may help to confirm the decisions made, contradict and override the decisions, or, depending on the scope of the issue, may not impact certain decisions.

5.3 Modeling Versus Measurements

To better understand the decision points, it is also important to review the advantages and disadvantages of using models and conducting measurements. Although some of these points were covered in the previous section, they are expanded and elaborated on in this section to provide a better understanding of the issues involved. In general, the reasons for modeling tend to be disadvantages for conducting measurements and vice versa. Some of the advantages of modeling include but are not limited to

- Generally more cost-effective than measurements,
- More flexibility in spatial and temporal coverage,
- Can predict future concentrations, and
- Allows "what-if"-type scenario modeling.

In general, modeling is less costly than measurements. However, this will depend on the overall scope of the assessments as it is conceivable that some modeling work could be comparable or even more expensive. The overall modeling work includes all of the tedious work required to gather the various input data. There are various degrees of fidelity that can be achieved in the resulting concentrations based on the quality of the input data. Therefore, it is important that the model users understand the impacts of each set of input data. By understanding these impacts (sensitivities to the input data including the meteorology and locations of receptors), modelers can optimize their use of resources by focusing their efforts on data that have the most impact. But even with all of these efforts and considerations that go into modeling, measurements are usually much more expensive. All of the planning, scoping, sample collections, and so forth associated with measurements can easily dwarf the costs of modeling.

With regard to spatial and temporal coverage, models usually have a significant advantage in providing the ability to model various receptor locations and, depending on the availability of appropriate source activity and fleet data, different times can be modeled. Even if resources were available to set up a wide array of field sampling locations, the logistics including safety and other airport restrictions may not allow such setups. And unless real-time analyzers are used, sampling at fine resolutions (e.g., every hour of a day) may not be possible. As such, modeling allows for the flexibility to predict concentrations at fine spatial and temporal resolutions that could be valuable in conducting detailed assessments to better understand trends and airport impacts. However, it should be pointed out that while this is true for Gaussian models such as AERMOD, it is not wholly true for models such as CMAQ. Although CMAQ provides the ability to model chemical transformations of various pollutants, including secondary species, the spatial resolution is typically limited to the grid sizes (e.g., 4 km by 4 km) used for modeling.

Most NEPA projects that require air quality dispersion modeling will need the ability to predict concentrations corresponding to future scenarios, including both build and no-build cases. While this is related to the flexibility issue, it illustrates the inherent limitation of measurements, which can only be conducted for current conditions. Of course, predictions of future concentrations need to be carefully considered as their accuracy is dependent on the quality of the projected input data and any assumptions thereof.

Similar to predicting future concentrations, the ability to play "what-if" games also provides models with a significant and powerful advantage over measurements. While some scenario modeling is certainly possible, they are usually dependent on either the opportunities that present themselves through the natural operation (differences from hour to hour or day to day) of an airport or through staged operations (scenarios created by the airport) provided by the airport. In either case, the opportunities to analyze different scenarios would be limited by what is possible at an airport (e.g., use of different aircraft and GSEs). In contrast, various policy scenarios can be modeled and this is only limited by the quality of the available input data.

As these discussions point out, modeling can provide many advantages related to costs and robustness with regards to scenario modeling. While these are all disadvantages to conducting measurements, there are various advantages as well that can be pointed out including but not limited to

- Develop more accurate yearly concentrations;
- Spatial resolution of chemical transformation models (but can be limited depending on resources);
- Clarify difficult modeling assessments;
- Develop more accurate background concentrations; and
- Obtain more local meteorological data.

Either due to community pressures or local government requirements, an airport may want to develop a measurement program that monitors air quality in and around the airport. This may be a continuous program that monitors air quality yearly or for a finite period. In any case, the measured results represent a level of accuracy results that can be used to assess airport contributions to local air quality. Notwithstanding any limitations from the amount of pollutants covered or spatial and temporal resolutions, a long-term measurement program could provide valuable data that could serve as accurate baselines for comparison purposes and allow trend assessments. The main point is that measured data are considered more accurate and more defensible—such data constitute the "gold standard." Furthermore, the usefulness of measured data increases when continuous monitoring equipment is used to obtain highly time-resolved data as opposed to sampling equipment that requires laboratory analysis.

As previously indicated, the current grid models such as CMAQ that can be used to predict concentrations of reactive species are limited by the resolution of their grids. A single grid could include an entire airport and its surrounding community. While CMAQ could provide relatively accurate concentrations within a region containing an airport, it could be difficult to obtain differences in concentrations within the region. Depending on the size of the region, placement and different sized grids could be used. Although the 4 km by 4 km grid size is currently the smallest size that has been used and tested with CMAQ, smaller sizes may be possible and are being explored in ongoing research using adaptive or variable-grid resolution approaches. However, hybrid modeling approaches such as that used in this study using CMAQ and AERMOD provide a powerful alternative to developing explicit very fine-scale model applications using CMAQ alone.

Although models can be robust in providing a wide variety of capabilities that measurements cannot, measurements can still ultimately provide the "real" or "actual" information that can help address uncertainties in modeled results. Notwithstanding the representativeness (spatially and temporally) of the measured results, they can be used to fill modeling deficiencies. Such deficiencies may range from difficult-to-model chemical transformations to unusual geographical features.

Because of the relatively low airport contributions of some pollutants (e.g., CO), it would be advantageous to develop better background concentrations through measurements. Obviously, such efforts would need to be weighed based on the need for increased fidelity versus availability of resources to conduct the measurement work.

In addition to data obtained from various existing meteorological stations (e.g., NOAA Automated Surface Observing Systems [ASOS]), measured weather data from equipment located strategically in and around the airport could provide a better understanding of the wind fields that affect the movement and dispersion of pollutants. Such data would be beneficial to any assessments involving the use of measured concentrations but could also be used to improve modeling—e.g., better modeling of future scenarios.

CHAPTER 6

Findings, Recommendations, and Suggested Future Research

This chapter provides findings and recommendations resulting from both the reviews of the various measurement and modeling techniques and the airport case study assessments presented in the appendices. Based on those findings and recommendations, this chapter suggests areas for future research that might be considered.

6.1 Summary of Findings Regarding Measurement Equipment and Data

The following list summarizes the findings from the measurement campaigns and analysis of the measured data:

- In general, all of the equipment used during the measurement campaigns was demonstrated to provide adequate measurement capabilities for either typical airport use (e.g., regulatory purposes) or for research projects. Appendixes A and D provide details on measurement issues and associated guidance. All of the proposed equipment worked adequately (i.e., met expectations) in collecting data. One of the lessons learned from the first campaign was to use on-site line power whenever possible. The use of battery power for short-term measurements is recommended when possible, since portable power may not be reliable and can be disruptive when it needs to be refuelled. Also, enclosures to protect the equipment are necessary.
- All of the criteria pollutants were adequately measured and assessed. While NOx can be relatively high, it should be expected from the makeup of modern jet engine technology and the relatively low content of sulfur in jet fuel that CO and SOx concentrations at airports will be low (i.e., much lower than the NAAQS).
- The concentrations of a few VOCs (including HAPs) were quantified, but most VOCs were largely undetectable using the current standard sampling methods from USEPA. Therefore, more complex equipment with greater sensitivity could be used to measure these pollutants but would require support such as line power and a shelter/enclosure. Due to the relatively small concentrations for VOC, the sampling equipment (Summa canisters and DNPH cartridges) should be strategically placed to obtain the highest concentrations possible. Smaller concentrations may also be an indication of health impacts but this will need to be further studied with receptors appropriately placed closer to typical human activity areas.
- Similar to emissions, the concentration correlations between formaldehyde and other VOCs appear to suggest that some general relationships could be established (perhaps with error bars) to relate formaldehyde concentrations to those of other VOCs. This assumes uniform mixing in the atmosphere among the various VOC species.
- The concentrations of $PM_{2.5}$ and PM_{10} were more prevalent compared with the other pollutants in relation to the NAAQS. However, the concentration levels of these pollutants were

similar, indicating that, due to the much smaller size of PM from aircraft exhaust, virtually all of the mass is due to PM with an aerodynamic diameter smaller than 2.5 μm.

- While Minivols allow cost-effect spatial coverage, their lower flow rates restrict their use to longer sample periods. It should be noted that even the USEPA reference methods must impact sufficient mass on the filters to be quantified accurately. This is not a serious issue for comparisons to the NAAQS given that 24-hour standards are available. The 24-hour sampling by the Minivols revealed adequate mass collection.
- Based on the methodology developed under this project for determining background concentrations, there appears to be significant variations in background concentrations on an hourly and daily basis. Comparisons with the USEPA AQS data also revealed that airport levels are lower than some background sites far away that may or may not be located next to a major traffic road or power plant. This seems to indicate the relatively low contribution of airport sources to local air quality. However, this may be specific to the airport and region studied under this project and will need to be corroborated with other airports. Overall, the important finding is that background concentrations need to be as specific in time and location as possible.
- While a sufficient amount of background concentrations for some receptor locations was developed, the base site in particular was limited. As such, future projects should make more concerted efforts to strategically place receptors to obtain adequate upwind concentrations. This will depend on the resources available to a project and will involve juggling the needs to obtain higher concentrations (close to sources) and the availability of equipment and personnel to cover multiple locations.
- As with the determination of background concentrations, it would be helpful to co-locate more sampling equipment whenever resources permit so that comparisons can be made to better understand uncertainties in the data. Again, this will depend on resources available to each project.
- As expected, the trend assessments showed that there appear to be correlations between concentrations and seasons. For example, CO concentrations appeared to be higher in the winter and spring, while O_3 concentrations were higher in the summer. This type of information can be helpful in better understanding air quality trends, possibly providing information for air quality mitigation strategies.
- NO_2/NOx concentration ratios were developed to better understand the conversion capabilities of the atmosphere. The assessments showed that these ratios can vary significantly by location, distance from source, and by time of day. Therefore, assessments to calculate these ratios should include the location and relatively large sets to obtain representative averages. More work will be necessary to further understand this ratio.
- The overall findings seem to show some impacts of aircraft operations, and wind directions on concentrations showed some correlations that confirm our understanding that these factors affect airport air quality. Although this is intuitive, further assessments can potentially be conducted to show better correlations.
- To further evaluate atmospheric impacts, time-series comparisons were made to the Monin-Obukhov Length (L) and the Sensible Heat Flux (H), two indicators of atmospheric stability. While there did not seem to be a correlation with CO and NOx, the other pollutants (SOx, O_3, PM_{10}, and $PM_{2.5}$) appeared to generally show an increase in concentrations under an unstable atmosphere, possibly indicating that the spread of the plume is increased, thus making more of the plume visible to receptors that are close to the ground.
- Comparisons with background concentrations generally showed that CO concentrations generated by the airport were very low and may not even be worth measuring in future projects (i.e., can just be modeled).
- The assessments in Appendix D show that, although noise event data can be useful in identifying events, the data are limited by the fact that such data cannot be feasibly used to identify

specific aircraft types. As such, these data can only be used to help corroborate incidences of flights in a flight plan or schedule. The placement of sound level meters is critical since, ideally, only aircraft noise should be measured. The use of more than one meter (e.g., on opposite ends of a runway) would be helpful in corroborating aircraft operations. Also, it is recommended that, if possible, either videocameras alone or in combination with sound level meters be used to both record incidences and identify aircraft types. In any case, it is further recommended that a computer program be used to automate the processing of the data because the research team's assessments have shown that it can be very tedious to process the data.

6.2 Summary of Findings Regarding EDMS/AERMOD Modeling Capabilities

The following summarizes findings, including limitations/gaps from the various EDMS/AERMOD assessments and improvements/recommendations that can either address the limitations/gaps or help to improve the modeling work:

- The overall findings from the modeled-versus-measured assessments is that although there appears to be much room for improvement in accuracy, the combination of EDMS and AERMOD seems to be appropriate or adequate for modeling emissions and concentrations of the various criteria pollutants studied. It should be noted that although these assessments may have similar elements, the purpose (and the scope of this project) was not to conduct a formal validation study, but to evaluate the models' outputs and capabilities to determine their appropriateness for assessing airport air quality contributions. With that understanding, our assessments have generally shown that while overall (for all receptor locations as a whole) the modeled and measured concentrations showed moderate to little agreement (e.g., low R^2 values), the correlations were generally all positive (positive slope of the regressed lines) or could be explained due to deficiencies in the comparison data (e.g., background concentrations and potential outliers). Also, the y-intercepts were generally all positive, providing a level of desired conservatism for smaller values. Overall, our evaluations showed that there do not appear to be significant gaps that would prevent improvements to these models and/or improvements to the application thereof. As previously indicated, the research team leveraged its understanding of concentration levels and source locations from the previous FAA study (Wayson 2003). Our modeled-to-measured comparisons generally show an improvement over the previous study's findings. It should be noted that the results from the previous study have not been made public.
- Since aircraft were indeed confirmed to be the biggest contributor to both emissions and concentrations (based on the chosen receptor locations) and wind and atmospheric stability are the most significant meteorological factors influencing dispersion, the general agreement between these components and concentrations provided good evidence of proper responses by the model.
- Although both modeled emissions and concentrations can be improved through the use of better quality source activity data, the potential for improvement with modeled concentrations appears to be greater because the location of moving sources can have a significant impact on concentrations.
- The assessments revealed the importance of developing accurate background concentrations. If at all possible, hourly background concentrations that are specific to each receptor location should be developed. Our results showed that using approximations like daily averages or interpolations between long periods (several hours) could result in significant errors in the prediction of absolute concentration values. This is especially important because background concentrations can be significantly greater than the modeled values and, therefore, can have a significant influence as they did in our evaluations.

- As exemplified in our study, EDMS/AERMOD can be used to apportion the concentrations at each receptor location by source. Unfortunately, this can only be conducted by manually choosing one source at a time in the EDMS interface. Although the current version of EDMS allows selecting one source type (e.g., aircrafts) at a time to run in AERMOD, there is no batch mode to automatically generate source-apportioned concentrations. Each source type must be selected one at a time. Implementation of a batching method in AEDT might be considered as a possible enhancement.
- Although it should be determined on a case-by-case basis, most airports can probably be considered to have flat terrain. Our assessments seemed to indicate little difference in concentrations for receptors placed within the relatively flat terrain of an airport environment when assuming a flat terrain versus using DEM data. However, since the process of obtaining and implementing the freely available DEM data from USGS data is not difficult or time consuming, it should be included to help reduce any uncertainties in a study. Ultimately, it will depend on the terrain surrounding an airport and where receptors are located.
- While EDMS/AERMOD currently allows the emissions and concentration modeling of various aggregated hydrocarbon pollutants (e.g., VOC and NMHC), the concentrations of individual VOC and HAPs species (e.g., formaldehyde and benzene) cannot be modeled using the publicly available version of EDMS. The EDMS interface for creating AERMOD interface provides no provisions for modeling individual species. The modeling also cannot be performed directly within AERMOD because there is no feasible way to edit the HRE files. To do so would require a developer's knowledge of EDMS to determine how the hydrocarbon pollutants were allocated to each source listing in the HRE file, and a processing tool or method would need to be developed to modify the HRE file accordingly to reflect the emissions of each species. It is possible that this capability can be implemented within AEDT. A post-processing method could be applied to proportionally modify concentrations according to emissions ratios, but it would need to be accomplished using one source (e.g., aircraft) at a time since it would be difficult (or impossible) to do so with multiple sources resulting in a mixture of different source pollutant profiles.
- Based on our limited comparisons of modeled-versus-measured NO_2 concentrations, it appears that the PVMRM option in AERMOD may be adequate for predicting NO_2 (i.e., as good as predicting NOx concentrations) but further studies will be necessary. Further sensitivity assessments modifying the input values for background ozone concentrations, ambient NO_2/NOx equilibrium ratio, and the in-stack NO_2/NOx ratio should be conducted. The PVMRM option must be specified directly through the AERMOD input file since the EDMS interface does not provide this option. Similarly, various other options in AERMOD can be used as long as they do not require modifications to the HRE files (which are difficult or impossible to do without an EDMS developer's knowledge of how the HRE files were constructed).
- Exercising the SO_2 decay option using the nominal 4-hour half-life value showed very little difference in concentrations. Only a few higher level concentration points were affected. There was very little difference in R^2 values.
- The default regulatory modeling option in AERMOD was also exercised as part of the sensitivity assessments. The resulting concentrations showed virtually no change, producing similar or identical R^2 values.
- As our assessments have shown, the emissions and air quality contributions from GAVs on roadways surrounding the airport can be significant. The inclusion of these sources and how much of them (how much of the roadways) to include will depend on the purpose of the study (e.g., NEPA project-level assessment or air quality health study).
- For model evaluations, and for better application of the models, choosing receptor locations that are closest to airport sources is advantageous for characterizing the sources. As our comparisons of results between the base station and the other receptor sites have shown, the agreement between modeled and measured concentrations is better when closer to the sources

(e.g., near runways). Although this is intuitive, it should be one of the most important considerations when planning an air quality study because smaller concentrations can be much harder to work with, especially since airport concentration contributions generally appear to be either comparable to or less than background concentrations.

6.3 Summary of Findings Regarding CMAQ Modeling Capabilities

The following summarizes the conclusions, including limitations/gaps, from the various CMAQ assessments and insights for improving the modeling work:

- The model performance for the WRF model was better at 4 km than at 12 km, especially in simulating the temperature and humidity fields, while the 12-km simulated the wind fields better. The differences in model performance between the 24-hour and 48-hour forecasts were negligible. Initializing the meteorological fields using NCEP's North American Model (NAM) was crucial in obtaining such favorable model performance, when the models are run in near real-time.
- The WRF model performance was better for the April 2009 and January 2010 periods than for the July 2010 period. This is in large part due to the poor temperature performance, which was observed in previous studies and is especially magnified during the summer months due to the higher average temperatures.
- A methodology to process EPA's National Emissions Inventories (NEI-2005) was implemented to create emissions for the 2009–2010 time period. Incorporating growth and controls for this period for the various anthropogenic source sectors was critical to obtain good model performance for the CMAQ model for the period modeled for this study.
- Using the EDMS2Inv tool was critical for smooth transfer of information of EDMS outputs to the SMOKE-CMAQ modeling system and to model aircraft sources in a more realistic representation with 4-D variability. Aircraft sources at Dulles contribute from 45 to 80% of total airport-level emissions for the various pollutants.
- Even though the release version of EDMS does not provide explicit estimates of HAPs from aircraft sources for use in dispersion modeling, the FAA-EPA chemical speciation profile for TOG was used to estimate HAPs, which were modeled with CMAQ to further estimate incremental ambient concentrations.
- Using initial and boundary conditions from NCEP's Eta-CMAQ forecast system was critical in obtaining realistic flow of upwind concentrations to the Dulles region and to further obtain desirable model performance in the study region, when compared with various surface networks in the region.
- Airport operators desiring to set up CMAQ model applications are recommended to use the NAM and CMAQ model outputs from NOAA's NCEP to drive their local-scale model applications. In the near future, the model resolution from NOAA will likely be a high resolution of 4 km, which may be a valuable resource for local-scale studies.
- When compared to routine EPA monitors, the CMAQ model performance was statistically insignificant between the 12-km and 4-km modeling outputs. For $PM_{2.5}$, the model underestimated high concentrations (warm season in July 2010) and overestimated lower concentrations (cool seasons, April 2009 and January 2010). In general, the predictions over the 12-km domain are higher than the predictions over the 4-km domain. Model performance was best in predicting daily maximum 1-h and 8-h O_3 concentrations and reasonable for the other gas-phase species and within the ranges of performance metrics found in other comparable modeling studies to date.
- In the evaluation of CMAQ against the Dulles study measurements, the model reproduced the observations very well for April 2009, overestimated for January 2010, and underestimated

for July 2010. Overall, predictions in the 12-km domain are higher than those in the 4-km domain. The daily variability observed by the field study measurements is captured well by CMAQ at both resolutions, which is a key indicator of model performance to be used for performing subsequent sensitivity studies for policy assessments.

- Across the three seasons, the incremental airport contributions varied from 0.30 (April 2009) to 0.41 μg/m^3 (January 2010) to ambient $PM_{2.5}$ in the Dulles airport grid-cell. On a percent basis, the range was from 4.8% (April 2009) to 7.8% (July 2010).
- In all three seasons, AEC (non-volatile soot PM) was the highest contributor, ranging from 49% (July 2010) to 96% (April 2009). Organic Carbonaceous Aerosol ranged from 10% (July 2010) to 20% (January 2010). Of the inorganic $PM_{2.5}$ components, nitrate aerosol (ANO3) was the key contributor, ranging from 27.6% in April 2009 to 154.5% in July 2010. This large change in ANO3 is explained by a large change in a very low value of ANO3 in the background scenario. However, locally, ANO3 was reduced in the vicinity of the airport. Notably, the inorganic $PM_{2.5}$ contributions were higher at downwind distances and varied for each season depending on the meteorology. These results are consistent with prior airport modeling studies, which showed that secondary inorganic aerosols from airport emissions have larger effects at downwind distances of 200 to 300 km from an airport. Similar trends of local decreases and downwind increases are also seen for the two other inorganic $PM_{2.5}$ components (sulfate and ammonium). However, these increases and decreases are both less than 1%.
- Dulles airport contributes from up to 13.3% (January 2010) to 110% (July 2010) increase in NO_2 concentrations. However, due to high incremental emissions of NO_x from airport aircraft activity, decreases in ozone levels in all three seasons can be seen. These decreases range from –6.0% (July 2010) to –30.1% (April 2009). During the summer campaign alone, Dulles airport contributes about 0.98 ppm or 1.8% increase in daily maximum 8-h O_3 slightly northeast of the airport.
- An approach to evaluate CMAQ's modal treatment of $PM_{2.5}$ against the 8-section distribution from the RDI measurements was developed. The measurements show a much more pronounced bimodal distribution than the model. The RDI data are point measurements, each better able to identify near-source concentrations than otherwise allowed by the 4-km model resolution. This is especially true of the smallest size ranges, which are not represented adequately in the emissions inputs to the model (due to lack of information in emissions inventories). However, this evaluation could provide a basis for improving size fraction assumptions in aircraft emissions used in models.
- The total PM (TM) is uniformly under-predicted across the size distribution at all sites in warmer months, except in the size range representing accumulation mode aerosol. This indicates that the model is more representative of aged aerosol and of mixing within the grid of locally produced PM with that transported long range.
- Total PM is generally under-predicted in the smallest size bins, indicative of the inability of the model to capture near-source primarily emitted (or nucleating) particles, both due to the coarse resolution compared to point measurements and due to not using a plume-in-grid model.
- Soil is generally under-predicted in the largest size ranges and over-predicted in the fine size cuts, pointing to the need to re-examine the soil emissions magnitudes and mean diameters in which emitted.
- The main contributor to the under-bias is components other than SO_4 and soil, as these are present in much smaller magnitudes relative to TM; however, the contributing sources of these other PM constituents are not obvious in the data provided because the breakdown into other PM components is not available in the RDI measurements. This makes it difficult to conclude where the model representation of PM-Other needs to be improved.
- The winter-time measurements also show a significant over-prediction of TM, due to over-predictions in every constituent. This indicates that secondary species are a more significant component of the modeled size distributions relative to the measured.

- The impact of aircraft emissions is seen to decrease with increasing particle size on an event-average basis, with the largest size cut showing little or no impact, and in some cases a very slight increase in concentrations when the aircraft emissions are removed.
- The evaluation of the hybrid model for each of $PM_{2.5}$, CO, NO_x, and SO_x showed good model performance for $PM_{2.5}$ when compared with observations for all three periods. It had a slight positive bias during the April and January periods and a slight under-bias during the July period. In both the April and July periods, the hybrid model using the 12-km CMAQ simulation performed better than the 4-km simulation as seen in the scatter plots. This, when combined with the results from the model evaluation of both WRF and CMAQ earlier, indicates that 12-km resolution is adequate for regional-scale model application.
- Airport operators desiring to develop hybrid applications for performing airport air quality assessments are recommended to use WRF-SMOKE-CMAQ at a resolution of 12 km, and instrument AERMOD with a finely resolved grid of receptors uniformly spaced at 500 m within the area of interest, and perform hybrid calculations using the methodologies discussed in Appendix F.2.
- Use of a hybrid model allows blending of regional contributions from background sources with highly resolved local-scale impacts to obtain variability at local scales and provides a powerful technique for estimating local-scale air quality impacts of airport emissions.
- The hybrid model performance was not as good for CO, not showing much correlation with observed values during the April period, while dramatically over-predicting concentrations during both the January and July periods. The modeling data also showed some extreme outlier values which have been seen in previous hybrid models, and has been introduced through high concentrations in AERMOD. Additional investigation is needed to look at specific conditions under which AERMOD predicts these high concentrations while modeling aircraft sources.
- The model performance is fairly good for NO_x in that the model picks up the changes in distribution across the seasons and fairly closely matches in all three seasons. However the scatter plot shows that, when paired in time and space, the model does not tend to agree with the observations all the time. This is similar to other AERMOD results in other studies. As with CO, the model contains some extraneous outliers, and this further reinforces the need for additional investigation of AERMOD behavior.
- The SO_x model performance is the poorest that has been seen, especially for January and July where the model dramatically overestimates the observed values. The model performed relatively well during the April campaign, but both the January and July campaigns showed much lower observed SO_x values and consequently poorer model performance. Further study is recommended.
- From analyses of the spatial distribution of $PM_{2.5}$, the primary airport impact was near the gates, and secondly, the January period had much higher concentrations than either the April or July period. It was also found that the impact of the airport did not extend much beyond the airport property. In the 4-km CMAQ modeling, the secondary impact was found to be isolated to the western edge of the airport, while the 12-km modeling resulted in secondary impacts which were more widespread but of lower magnitude.
- The spatial distribution of SO_x is similar to that of NO_x with peaks near the gates and secondary maximum values near the runways; however, the concentrations are much smaller compared to the background values for SO_x. As with CO and $PM_{2.5}$, the impact of the airport on SO_x concentrations does not extend much beyond the airport itself.
- Using CMAQ, it was possible to estimate incremental contributions of aircraft emissions to various air toxics. Based on the analyses of differences in primary versus secondary constituents of key air toxics, up to 96% of formaldehyde and 95% of acetaldehyde (maximum value in a single 4-km grid-cell) are from secondary production, rather than primarily emitted by airport sources. On a monthly average basis, the average secondary to total formaldehyde and acetaldehyde for the 3 months range from 92.4 – 95.6% and 86.4 – 88.4%, respectively. On a daily

average basis, the corresponding numbers are 87.5 – 99.2% (formaldehyde) and 72.1 – 93.6% (acetaldehyde), showing the importance of secondary production due to atmospheric chemistry, rather than primary emissions of these two HAPs. The emissions analyses further show that formaldehyde and acetaldehyde contribute 8.7% and 2.8% to the total VOCs from IAD. When compared to all emissions sources in Loudoun county (where Dulles airport is mostly located), formaldehyde and acetaldehyde from Dulles airport contribute 9.7% and 4.0% to the total countywide emissions.

6.4 Summary of Findings Regarding Receptor Modeling

The major conclusions of the PM-focused receptor modeling work conducted under this study are

- Based on the use of the elemental data from the RDI, the receptor modeling work showed that useful insights on overall contributions from different sources can be accounted for. This includes the potential for identification of sources/processes through signature-type species identified in the measurements as well as comparisons to source-modeled, apportioned ambient concentrations.
- A source not included in the EDMS emissions modeling work—aircraft landings—was identified as a potential source of PM emissions. The higher concentrations of Zn appeared to support this conclusion as well as an analysis involving a conditional probability function (CPF) using wind direction data that pointed to the runways as significant sources.
- Landings appeared to produce significant amounts of airborne particulate matter, with most of the mass being $PM_{2.5}$ as would be expected from the ablation of tires and brake parts. Landing emissions are characterized by tire and brake wear particles as well as vaporization/condensation of lubricating grease. Similar impacts of this source were observed during the three sampling campaigns.
- High concentrations of transported secondary sulfate were observed, with highest concentrations observed during the July campaign. High concentrations of deicing salt were observed during January. Suspended soil impacts were highest in the April campaign and lowest during the winter. These findings are consistent with expectations by seasons and provide indications of receptor modeling methods to help support the identification and relative amounts of certain species by season.
- Soil and salt contributed mostly to particle sizes greater than 1 μm.
- The component concentration comparisons against the source-oriented models showed that significant PM mass from the EDMS/AERMOD-predicted concentrations appeared to be missing. This appeared to corroborate the understanding that there are various missing PM components within the modeled aircraft emissions inventory, including gaps in the EDMS emission factors database as well as certain processes that are currently not included, such as emissions from landings (tire and brake wear).
- While currently not considered a main technique for analyzing air quality near airports, the receptor modeling work has demonstrated potential in serving as a supplemental tool for corroborating and investigating gaps in the overall source-oriented modeling work.

6.5 Suggestions for Improving EDMS/AERMOD Modeling Capabilities

Suggestions for future research based on the reviews and assessments conducted under this project are presented below. These suggestions are loosely ranked based on a combination of their expected impact and ease of investigation. That is, the top-ranked suggestions would tend to have the most significant impact on air quality modeling and would tend to be easier to implement. As such, the higher ranked suggestions are expected to provide a better return on resource investment.

1. Aircraft emissions under idling and taxiing conditions are modeled assuming a power setting with corresponding fuel flow at the ICAO standard 7% level. It is widely understood that aircraft under idling conditions (and possibly under taxiing/queuing conditions) experience power settings that are generally lower than the ICAO standard (Kim 2008). As such, emissions for CO and hydrocarbon species may be significantly higher than predicted, since these emissions increase exponentially below the 7% power setting. There is some dispute by the engine manufacturers as to whether this increase in emissions actually occurs because there are other operational changes in the engine below 7% that tend to result in a capping effect of the emissions at the 7% level. Measured data from ACRP Project 02-03A (TRB 2012); however, appear to confirm that there is significant increase in emissions below 7%. Therefore, a new power setting for idle/taxi to more accurately model emissions should be considered for incorporation into AEDT.
2. It is suggested that both GSE and APU operating times as well as the default fleet mix for GSEs be further investigated to determine if more accurate (more current) data are available. It is further recommended that videocameras be used to facilitate the data collection work.
3. For aircraft sources, EDMS currently elevates the area sources to account for the height of the aircraft engine exhaust as well as plume rise due to thermal buoyancy. An average height is used for all aircraft types. If it is found that an average height is not representative, then it is suggested that different heights be developed by either aircraft type or by aircraft size categories. This would help to improve the overall air quality modeling work, since some airports may only service certain types/categories of aircraft that may not correlate well with the average height of the elevated area sources.
4. Along with improving taxi emissions, the accuracy of modeled aircraft engine start-up emissions should also be investigated to determine their impacts on the overall ambient concentration modeling process. For most jet engine aircraft, the start-up emissions for THC, NMHC, VOC, and TOG are the largest aircraft modal emissions for those pollutants (larger than the other modes).
5. Further studies should be conducted to verify the aircraft PM-related emissions from EDMS. Most of these emissions are apparently based on the use of the FOA methodology. Until measurement-based emissions indices can be made available, this methodology will likely be used for the foreseeable future. Therefore, the accuracy of the FOA should be further assessed.
6. While some sensitivity assessments were conducted to help gauge the behavior and responses by EDMS/AERMOD, the assessments are by no means comprehensive. Therefore, it is suggested that a formal sensitivity assessment be conducted to exercise most or all of the pertinent options in both EDMS and AERMOD. While numerous studies regarding airport emissions have been conducted, very few studies have been performed regarding air quality (concentration) modeling. Therefore, such a study could help to better understand the behavior and accuracy of the models.
7. EDMS has no method to predict PM emissions from aircraft tire and brake wear during landing events. As such, a methodology should be developed and implemented into EDMS to account for these emissions. Such emissions could contribute significantly to PM concentrations near an airport, especially near runways.
8. OG-speciation profiles for non-aircraft sources (e.g., GSEs) are not considered to be as accurate as those for aircraft. Therefore, the improvement of these non-aircraft, ground-level source profiles for OG-speciation may provide more confidence in the speciated emissions inventories. Exhaust emissions would need to be measured to develop new profiles.

9. With limited understanding of the evolution of plumes, especially involving chemically reactive pollutants, it would be beneficial to conduct a study to evaluate and/or confirm the conversion, decay, settling, and so forth of various pollutants, including VOC/HAPs species in the airport environment which represents different reaction conditions than other environments, including those that may have been simulated previously in a laboratory. Potentially, monitors could be located at varying locations away from a runway to record the concentration fall-off characteristics.
10. While EDMS allows the use of volume sources for stationary sources and gate-related sources (i.e., parked aircraft and GSEs), GAVs and aircraft are modeled as part of area sources representing roadways, taxiways, and runways. Because of the three-dimensional nature of plumes and the elevated aircraft exhausts, the use of volume sources should be investigated for aircraft and possibly GAVs as well. The current source specifications in HRE files cannot be modified without a developer's knowledge of how the files are constructed.
11. Although the use of AERMOD has unified the modeling work in EDMS (i.e., only one dispersion model), it is suggested that the use of a model such as CAL3QHC be revisited to allow for the possibility of more accurately modeling the impacts of vehicle queues. CAL3QHC may provide better micro-scale modeling of atmospheric dispersion from interrupted roadway vehicle activities.
12. With the increasing availability of specific aircraft operational information and finer resolution (time-wise) weather data at airports, it is suggested that time-varying models (e.g., Gaussian puff models) be investigated to determine their utility in providing finer resolution (e.g., per second and per minute) concentrations and the potential for more accurate results. Using a flight schedule, the dispersion of aircraft emissions can be modeled more accurately since each aircraft's movements can be simulated and, therefore, treated as a discrete moving source (i.e., rather than as part of a stationary homogenous area source).
13. Whether it involves the use of static plumes or time-varying Gaussian puffs, it is suggested that the impacts of an aircraft's wake be investigated. Unlike stationary sources, the wake of moving sources such as an aircraft can both drag and disperse pollutants. Although some of the dispersive impacts of an aircraft's wake may be accounted for in the initial dispersion parameters of the area sources representing taxiways and runways, the effects of the wake on plumes/puffs generated by other sources (including other aircraft) are not clear.

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Acronyms and Abbreviations

ACRP	Airport Cooperative Research Program
ADMS	Atmospheric Dispersion Modeling System
AEDT	Aviation Environmental Design Tool
AERMOD	American Meteorological Society/EPA Regulatory Model
AFI	Air Force Instruction
AFPD	Air Force Policy Directive
ALAQS	Airport Local Air Quality Studies
AMET	Atmospheric Model Evaluation Tool
AMTIC	Ambient Monitoring Technology Information Center
ANO3	Nitrate Aerosol
APEX	Aircraft Particle Emissions eXperiments
APU	Auxiliary Power Unit
AQS	Air Quality System
ARW	Advanced Research WRF
ASOS	Automated Surface Observing Systems
ATOFMS	Aerosol Time-of-Flight Mass Spectrometer
AVAP	Airport Vicinity Air Pollution
BADA	Base of Aircraft Data
BAM	Beta Attenuation Monitor
BC	Boundary Condition
BFFM2	Boeing Fuel Flow Method 2
BOS	Boston Logan International Airport
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAEP	Committee on Aviation Environmental Protection
CAL3QHC	CALINE3 Queue Highway Capacity Intersection Air Quality Model
CALINE3	CALTRANS Link Roadway Air Quality Model
CALPOST	CALPUFF post-processing package
CALPUFF	California Puff Model
CAMx	Comprehensive Air Quality Model with Extensions
CARB	California Air Resources Board
CASTNet	Clean Air Status and Trends Network
CB	Carbon Bond chemical mechanism
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CMAS	Community Modeling and Analysis System
CMAQ	Community Multiscale Air Quality

CMB	Chemical Mass Balance
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CoE	Center of Excellence
CPC	Condensation Particle Counter
CSN	Chemical Speciation Network
DEM	Digital Elevation Model
DLR	Deutsche Forschungsanstalt fur Luft- and Raumfahrt
DNPH	2,4-dinitrophenylhydrazine
DoD	Department of Defense
DOT	Department of Transportation
EC	Elemental Carbon
EDMS	Emissions and Dispersion Modeling System
EF	Emission Factor
EI	Emissions Index
EIAP	Environmental Impact Analysis Process
EMFAC	Emission Factor model
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FID	Flame Ionization Detector
FOA	First Order Approximation
FEM	Federal Equivalent Method
FRM	Federal Reference Method
GA	General Aviation
GAV	Ground Access Vehicle
GC	Gas Chromatography
Ghz	Gigahertz
GIS	Geographical Information System
GSE	Ground Support Equipment
GUI	Graphical User Interface
H	Sensible Heat Flux
HAP	Hazardous Air Pollutant
HC	Hydrocarbon
HCHO	Formaldehyde
HPLC	High Performance Liquid Chromatography
HRE	AERMOD hourly emission rate file
HYROAD	Hybrid Roadway Air Quality Model
IAD	Dulles International Airport
IC	Initial Condition
ICAO	International Civil Aviation Organization
IMPROVE	Interagency Monitoring of Protected Visual Environment
ISC	Industrial Source Complex Dispersion Model
L	Monin-Obukhov Length
LASAT	Lagrangian Simulation of Aerosol Transport
LASPORT	LASAT for Airports
LAWA	Los Angeles World Airports
LAX	Los Angeles International Airport
Leq	Equivalent Sound Level
LHR	London-Heathrow International Airport
LIDAR	Light Detection and Ranging

Lmax	Maximum Sound Level
LRT	Long Range Transport
LTO	Landing and Takeoff
MADIS	Meteorological Assimilation Data Ingest System
Massport	Massachusetts Port Authority
MAN	Manchester International Airport
MCIP	Meteorology-Chemistry Interface Processor
MM5	Mesoscale Model
MMU	Manchester Metropolitan University
MOBILE	Mobile Source Emissions Model
MOUDI	Micro Orifice Uniform Deposit Impactor
MOVES	Motor Vehicle Emissions Simulator
MS	Mass Spectroscopy
NAA	Nonattainment Area
NAAQS	National Ambient Air Quality Standards
NAM	North American Model
NBS	National Bureau of Standards
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NCHRP	National Cooperative Highway Research Program
NDIR	Non-dispersive infrared (NDIR) spectrometry
NEI	National Emission Inventory
NEPA	National Environmental Policy Act
NextGen	Next Generation Air Transportation
NJDEP	New Jersey Department of Environmental Protection
NMHC	Non-methane hydrocarbon
NO	Nitrogen Oxide
NO_2	Nitrogen Dioxide
NOAA	National Oceanographic and Atmospheric Administration
NONROAD	Nonroad emissions model
NOx	Nitrogen Oxides
O_3	Ozone
OC	Organic Carbon
OG	Organic Gases
OLM	Ozone-Limiting Method
ORD	Chicago O'Hare International Airport
PAL	Point Area Line source model
PARTNER	Partnership for Air Transportation Noise & Emissions Reduction
Pb	Lead
PBL	Planetary Boundary Layer
PM	Particulate Matter
PM_{10}	Particulate Matter with aerodynamic diameter of 10 μm or less
$PM_{2.5}$	Particulate Matter with aerodynamic diameter of 2.5 μm or less
PMF	Positive Matrix Factorization
ppb	Parts per billion
ppm	Parts per million
PUF	Polyurethane Foam
PVD	T. F. Green Airport
PVMRM	Plume Volume Molar Ratio Method
QA	Quality Assurance

QC	Quality Control
RAOB	Rawinsonde Observation
RDI	Rotating Drum Impactor
SAE	Society of Automotive Engineers
SCAQMD	South Coast Air Quality Management District
SCRAM	Support Center for Regulatory Atmospheric Modeling
SEL	Sound Exposure Level
SIP	State Implementation Plan
SMPS	Scanning Mobility Particle Sizer
SMO	Santa Monica Municipal Airport
SMOKE	Sparse Matrix Operator Kernel Emissions
SN	Smoke Number
SO_2	Sulfur Dioxide
SOx	Sulfur Oxides
STN	Speciated Trends Network
TEB	Teterboro Airport
TEOM	Tapered Element Oscillating Microbalance
THC	Total Hydrocarbons
TOG	Total Organic Gases
TRAQSIM	Traffic Air Quality Simulation Model
TSP	Total Suspended Particulate Matter
TRB	Transportation Research Board
TSA	Transportation Security Administration
TTN	Technology Transfer Network
UAM	Urban Airshed Model
UFP	Ultrafine Particle
UK	United Kingdom
USC	United States Code
USGS	United States Geological Survey
USEPA	United States Environmental Protection Agency
VNY	Van Nuys Airport
VOC	Volatile Organic Compound
WG3	Working Group 3
WHO	World Health Organization
WRF	Weather Research Forecast Model
XRF	X-Ray Fluorescence
ZRH	Zurich International Airport

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation