Understanding Airport Air Quality and Public Health Studies Related to Airports

DETAILS

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 135

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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.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). The ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. It is modeled after the successful National Cooperative Highway Research Program and Transit Cooperative Research Program. The ACRP undertakes research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration. The ACRP provides a forum where airport operators can cooperatively address common operational problems.

The ACRP was authorized in December 2003 as part of the Vision 100-Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), Airlines for America (A4A), and the Airport Consultants Council (ACC) as vital links to the airport community; (2) the TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academies formally initiating the program.

The ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

Research problem statements for the ACRP are solicited periodically but may be submitted to the TRB by anyone at any time. It is the responsibility of the AOC to formulate the research program by identifying the highest priority projects and defining funding levels and expected products.

Once selected, each ACRP project is assigned to an expert panel, appointed by the TRB. Panels include experienced practitioners and research specialists; heavy emphasis is placed on including airport professionals, the intended users of the research products. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, ACRP project panels serve voluntarily without compensation.

Primary emphasis is placed on disseminating ACRP results to the intended end-users of the research: airport operating agencies, service providers, and suppliers. The ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties, and industry associations may arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by airport-industry practitioners.

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FOREWORD

By Joseph D. Navarrete
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ACRP Report 135: Understanding Airport Air Quality and Public Health Studies Related to Airports provides airport industry stakeholders with an overview of what is known and not known regarding the impact of airport activity on air quality and public health. The report effectively communicates key information about this technically challenging and frequently sensitive topic through the use of frequently asked questions, a topic overview, critiques of recent studies, and recommendations for further research. The report will help practitioners address air quality and public health issues that may arise at their airport.

The communities surrounding airports have become increasingly aware of potential impacts to air quality and public health from airport operations. A number of airport air quality and health studies have been completed or are underway in North America and Europe; most of these studies have been required by regulatory agencies or legislated in response to airport improvement projects or to the public health concerns from local government or citizen groups. These studies vary in method, scope, and duration, and include air sampling, modeling, and health assessment. There is a need to compile and assess relevant information on airport air quality and public health studies to provide an understanding of how these studies can be useful for airport operators.

The research, led by Wyle, was focused on an extensive and thorough critique of air quality and public health literature. This review included not only airport-centric studies but also studies that address pollutants related to airport emissions even if the study's focus was not on airports. The sources of these studies included universities, state air agencies, the FAA, and airport monitoring studies. Both domestic and a limited number of international sources were included.

The report begins with a review of air quality standards and regulations. It then focuses on airport air quality issues, including source characteristics and emissions contributions, airport operations, geography, meteorology, mitigation measures, airport emissions and dispersion modeling, air quality measurement capabilities, and aircraft landing/takeoff emissions impacts vs. impacts at cruising altitude. The report then provides an overview of air quality health impacts and risk, followed by a discussion of the industry's current understanding of airport air quality health impacts. The report concludes with recommendations for future research. Key features of the report include a summary of findings in the form of frequently asked questions and an extensive table summarizing the literature review.

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 the color versions.

Summary of Findings

This section provides a summary of the basic findings presented for a broad readership. Technical information is provided in the body of the report. To support airport operators, the purpose of this study was to evaluate the existing body of knowledge on airport air quality and public health to help better understand and respond to concerns over airport-related air quality health concerns. The work was accomplished through a review of past studies and a critical synthesis where conclusions were drawn from a preponderance of the evidence. This involved summarizing, corroborating, and refuting findings from the existing literature to extract general conclusions applicable to most airports. Since it is difficult to generalize to all airports, the conclusions were qualified to indicate that findings at specific airports may differ.

To assist airport novice users, this report provides primer-type information in Chapters 2 through 4. These sections provide background information necessary to understand the conclusions drawn from the synthesis. In addition, Appendix B, Frequently Asked Questions (FAQs), provides direct answers to popular questions—those that are likely to be asked by novices. Chapter 5 presents the synthesis work shaped in the form of two basic questions: (1) What pollutants are of most concern at an airport? (2) What are the airport's contributions to local air quality and health impacts? The key findings for airports are as follows:

- **Factors that affect airport contributions to local air quality and public health**—In addition to pollutant type, there are many factors that can affect airport contributions to local air quality and public health. These include pollutant emissions (largely affected by source characteristics and operations), pollutant toxicity, and exposure. In addition, a person's background and condition also can play a significant role in affecting his/her health. Factors such as age, gender, pre-existing disease status, and co-exposures to other risk factors can all affect susceptibility to air pollutants. See Section 4.2 and the FAQs.
- **Ability to state conclusions for specific airports**—Since all airports are different, it is very difficult to make general statements about airport air quality contributions and health impacts. Airport contributions to air quality can depend on many different factors including, but not limited to, airport source types (e.g., aircraft fleet mixes), source operations, airport layout and location, surrounding geography, and meteorology. See Sections 3.1–3.5.
- **Pollutant(s) that pose the biggest health risk at airports**—Airport risk assessment studies have shown that fine particulate matter ($PM_{2.5}$) dominates the overall health risks posed by airport emissions. The risk for fine particles is orders of magnitude higher than that for the closest hazardous air pollutant (HAP), formaldehyde, although the ability to quantify the non-cancer health effects of HAPs is limited. $PM_{2.5}$ levels have been found to vary significantly at different airports. Although PM_{10} is a health concern, the fact that much of the coarser portion is filtered out by the upper respiratory tract in human beings makes it less of a concern than are the finer particles. See Chapter 4 and Section 5.1.

- **Secondary PM (PM not directly emitted from a source but formed in the atmosphere) at airports**—Studies indicate that secondary PM may form at significant distances downstream from an airport (many miles) adding to health impacts, and thus, requiring large-scale (e.g., regional) modeling to determine overall PM health impacts. In addition, the impacts of different PM components including black carbon, nitrates, and sulfates need to be taken into account as well as PM size distributions. See Chapter 4 and Section 5.2.
- **Airport contributions of ultrafine PM (PM sized below 0.1 μm diameter)**—In addition to the suspected health concerns of ultrafine PM from airport sources (along the lines of the current understanding of $PM_{2.5}$), measurement studies have shown that ultrafine concentrations tend to be highly elevated near an airport (near runways) with persistence above background levels at distances of 600 m downwind of an airport. As such, ultrafine PM generated by airports is suspected of having a broader impact than that generated by roadway vehicles. See Chapter 4 and Section 5.2.
- **Consistency of airport contributions of HAPs**—Concentrations of HAPs at airports seem to vary without clear, consistent levels of contributions. While some studies suggest that HAP concentrations near airports may be similar to background levels, there appears to be enough evidence suggesting otherwise—keeping in mind there are noticeable uncertainties with measured concentration levels. See Section 5.2.
- **Airport contribution levels of most criteria gases**—Airport studies appear to indicate that most criteria gases (e.g., CO, NO_2, and SO_2) generated from airports generally tend to result in similar concentrations to background (or urban) levels in surrounding communities, although with appreciable contributions closer to the emission sources and variable conclusions depending on background levels. Although health effects of criteria gases are well defined, quantitative health risk assessments for these gases are relatively limited in comparison to ozone and PM. See Chapter 4 and Section 5.2.
- **Airport contributions to ozone**—Because of the nature of ozone chemistry, ozone levels around airports tend to be lower than background levels (i.e., airports tend to be a sink for ozone). Although ozone levels in the vicinity of an airport may be depressed, airports can contribute to the formation of ozone on a larger regional level, thus resulting in increased health impacts. See Section 5.2.
- **Lead as a concern at airports**—Lead is a health concern at general aviation (GA) airports and will continue to be an issue as long as AvGas is used. Current studies indicate that lead emissions can noticeably persist at distances close to 1,000 meters downwind of an airport. As such, studies indicate that lead contributions near GA airports may not be negligible. See Section 5.2.
- **Airport air quality and public health research**—The state of airport air quality and health research is currently not mature enough to allow definitive conclusions in most cases. As such, all conclusions should be considered snapshots in time since future research may provide further details. However, the current research efforts appear to be aligned with the prioritization of pollutant health risks. Based on the relative number of studies and the recent focus, available resources appear to be correctly being applied to PM and HAPs research, with consideration of ozone for regional-scale analyses. See Sections 5.1–5.2 and Appendix A at the back of the report.
- **Correlating airport contributions to local air quality**—Regarding airport contributions to local air quality, studies have shown that airport emissions and resulting concentration contributions can be well correlated to airport operations (e.g., aircraft usage) as part of source identification and apportionment work. The more pertinent issue is in quantifying the contributions. The current research efforts appear to be aligned with the need for further measurements and understanding of health impacts. See Sections 5.1–5.2.

CHAPTER 1

Introduction

The communities surrounding airports have become increasingly aware of airport emissions and how they contribute to local air quality that may affect public health. The growth in airport operations as well as increased public awareness of health impacts, has spurred the need for airport operators to more fully understand the potential for health impacts and to develop better information and methods to share with the public. Understanding airport contributions to air quality is challenging because it involves many factors including, but not limited to, the following:

- Airport source characteristics (including pollutant emission rates),
- Type of pollutants,
- Location of sources and population,
- Meteorology,
- Seasonality, and
- Geography.

Understanding airport contributions to local air quality can be complex because any of these factors can significantly impact airport contributions. They also can contribute in different ways and interfere dramatically with each other (i.e., one factor can interfere with the efficacy of another). For example, one airport may generate lower emissions of certain pollutants, such as nitrogen oxides (NO_x), but because the surrounding region experiences weather conditions and a geography that is more conducive to the formation of ozone (O_3), the airport may be seen as contributing more to the detriment of local air quality than another airport that may produce higher emissions of NO_x. The story becomes more complicated when health effects are being considered, as this depends on the location of the population as well as their vulnerability characteristics. Two different airports may have similar sources (e.g., similar aircraft fleet mixes) resulting in similar concentrations for each pollutant, but if the population surrounding one of the airports is directly downwind of the airport while the population for the other airport is predominantly upwind, the former airport may be seen as contributing more to public health impacts than the latter airport.

These examples illustrate the interactive nature of various factors but they also show that airports can vary significantly for each factor. As such, definitive generalizations cannot be made when considering the air quality and corresponding health impacts from airports. Each airport needs to be considered separately when assessing specific air quality contributions and potential public health impacts. With these qualifiers in mind, some conclusions can be drawn from the existing literature of airport studies to help better understand the state of research and its findings.

Common Terms

Emission—The release of a pollutant from a source (e.g., aircraft engine) and quantified in mass units such as kilograms and pounds.

Emission Factor—The rate of release of a pollutant from a source, typically quantified as mass per activity (e.g., grams/hour).

Concentration—The amount (mass) of pollutant(s) within a volume of air with units such as parts per million (ppm) and micrograms per cubic meter ($\mu g/m^3$). A concentration value represents the quality of the air to which human beings can potentially be exposed.

Receptor—A location of interest where an air quality concentration is experienced (e.g., a location representing public exposure).

Dispersion—The scattering or diffusion of a pollutant in the air after release from a source.

Health Risk—The chance of harm due to exposure to a pollutant.

Toxicity—The degree to which a pollutant can harm a human being.

Exposure—Refers to the "contact" a human being may experience with a pollutant (i.e., breathing in a pollutant).

1.1 Goal and Scope

Many studies have used different methods and data to characterize airport contributions to local air quality and potential health impacts. As such, the scope and approaches utilized in airport-related air quality and public health studies vary widely, resulting in conclusions that can vary widely as well. This variability and insufficient information can make it difficult for airports to properly respond to proximate communities that are concerned about health impacts and look to the airports for answers.

Because of the lack of specific guidance regarding the understanding of airport impacts on public health, the Transportation Research Board (TRB) funded this project under the Airport Cooperative Research Program (ACRP). The goal of the project was to develop a guidebook to help inform airport operators and allow them to better respond to public concerns over air quality and health impacts in the vicinity of airports.

Overall, the project involved a formal literature review and a critical synthesis of the existing knowledge base. This included reviews of each of the aforementioned factors affecting airport contributions to local air quality and of health impact assessments involving risk estimations to provide an understanding of the current state of knowledge of airport contributions to air quality and health impacts. It should be noted that while pertinent (airport-centric) health-related studies were reviewed in the development of this report, it is not an exhaustive summary, as there are thousands of health studies that address pollutants related to airport emissions but are not specific to airport settings.

The composition of the literature materials reviewed for this section includes reports, documents, and articles from various sources including universities, state air agencies, FAA, airport monitoring studies, etc. Most of the reviewed literature is focused on the United States,

Pollutants of Interest at Airports

Criteria Pollutants

- Carbon monoxide (CO)
- Lead (Pb)
- Nitrogen dioxide (NO_2)
- Particulate matter with an aerodynamic diameter 10 μm (PM_{10}) or less—coarse particles
- Particulate matter with an aerodynamic diameter 2.5 μm ($PM_{2.5}$) or less—fine particles
- Ozone (O_3)
- Sulfur dioxide (SO_2)

Hydrocarbons (HCs)
Volatile Organic Compounds (VOCs)
Hazardous Air Pollutants (HAPs)

- Volatile organic compounds
- Aldehydes and ketones
- Dioxins and furans
- Polycyclic aromatic hydrocarbons (PAHs)
- Metal compounds

Ultrafine PM

- Particulate matter with an aerodynamic diameter less than 0.1 μm

Other PM Types and Components

- Black carbon (BC or elemental carbon)
- Nitrates
- Sulfates

but some non-U.S. studies also were included. Since there were many potential studies to review, the focus was first placed on those that directly covered airport air quality contributions and health impacts. After this, the reviews were expanded to include documents related to airport ambient measurements and airport air quality modeling. Then more general health impact documents were included. Appendix A provides a list of the documents reviewed under this project in the form of a matrix, look-up table where each document has been assigned categorization factors for easier grouping and identification.

The overall scope of this project involved answering key questions related to airport health impacts. As such, it included the development of concise summaries of findings from the literature and appropriately interpreting and critiquing the materials. Although not all of the literature materials listed in Appendix A were cited, they were all reviewed for this project.

1.2 Organization

Chapters 2 through 4 present concise background materials to help better understand airport air quality issues and concepts. Chapter 2 provides a review of air quality regulations. Chapter 3 provides descriptions of airport sources and factors affecting airport air quality. Chapter 4 provides a concise primer on pollutant health effects and risk assessments.

Chapter 5 presents the findings of the researchers' critical reviews. This chapter is comprised of two sections dealing with pollutant prioritizations and quantifying the contribution of airports to local air quality and health impacts. Chapters 6 and 7 provide the conclusions and recommendations for future research. The recommendations also serve to point out any knowledge gaps.

The last three sections provide a list of acronyms; Appendix A, the matrix of references; and Appendix B, Frequently Asked Questions (FAQs). The FAQs section was added to help readers obtain quick answers to commonly asked questions.

CHAPTER 2

Ambient Air Quality Standards and Regulations

The following sections provide overviews of the predominant air quality standards and regulations as they apply to airports.

2.1 Clean Air Act (CAA) and the National Environmental Policy Act (NEPA)

For decades following the establishment of commercial-service airports in the United States, the common complaint from neighboring communities was aircraft noise, which was considered more of an annoyance as opposed to a health concern. This focus on noise continued through the introduction of the large commercial turboprop-engine aircraft in the 1950s and the turbofan engines in the 1960s. However, with the initial enactment of the Air Pollution Control Act in 1955, and then the Clean Air Act (CAA) in 1970, and the Clean Air Act Amendments (CAAA) in 1990, emissions and air quality were given increasingly greater scrutiny. The 1990 CAAA brought sweeping changes that included various measures to further control and regulate emissions.

Along with the CAA in 1970, the National Environmental Policy Act (NEPA) was enacted to serve as a national policy on protecting the environment—requiring environmental evaluations for federal actions with significant impacts on the environment. In compliance with this, the FAA is required to provide an accounting of emissions projected to occur from aircraft and other sources of harmful emissions at airports when seeking to expand or improve operations. As part of the NEPA process, FAA is required to evaluate all potential environmental impacts caused by an action at an airport by comparing build and alternative cases with those of the corresponding

Standards Versus Pollutants

Primary and Secondary Standards refer to the ambient standards established as the National Ambient Air Quality Standards (NAAQS) for criteria pollutants for the protection of public health (primary standards) and protection of the environment (secondary standards).

Primary and Secondary Pollutants refer to whether pollutants are emitted directly from a source (primary pollutants—e.g., NO_x, CO, VOCs, $PM_{2.5}$, etc.) or formed in the atmosphere through chemical reactions and/or physical processes (secondary pollutants—e.g., O_3, PM nitrates, PM sulfates, etc.).

no-build (baseline) case. The amendments also established the General Conformity Rule that sets thresholds above which an air quality assessment would be required in areas of the country already experiencing poor air quality (i.e., within maintenance and nonattainment areas).

2.2 National Ambient Air Quality Standards (NAAQS)

Under the CAA, ambient air concentration limits of six (6) criteria pollutants having adverse human health and environmental effects were established by the EPA as the National Ambient Air Quality Standards (NAAQS) summarized in Table 2-1.

The NAAQS reflect concentration values (e.g., $\mu g/m^3$) that have been developed through various scientific and health studies. The EPA defines the NAAQS on two levels: primary and secondary. Primary standards protect public health, particularly for sensitive populations such as asthmatics, children, and the elderly. Secondary standards address public welfare by protecting against the reduction of visibility and damage to animals, crops, vegetation, and buildings. The NAAQS have been updated frequently during the past two decades and the current standards can be found on the EPA website at http://epa.gov/air/criteria.html.

The EPA uses the NAAQS values for each criteria pollutant to signify the health status of each county within the United States. The following designations are used to signify the status of each county:

- Nonattainment—Any area that does not meet (or that contributes to ambient air quality in a nearby area that does not meet) the national primary or secondary ambient air quality standard for the pollutant.
- Attainment—Any area . . . that meets the national primary or secondary air quality standard for the pollutant.
- Unclassifiable—Any area that cannot be classified on the basis of available information as meeting or not meeting the national primary or secondary air quality standards for the pollutant.

Nonattainment areas are also further designated as being marginal, moderate, serious, severe, or extreme depending on how much the area's concentrations are above the ambient standards. Based on the county(ies) in which an airport is located, it must abide by the attainment status of the county for all NEPA and General Conformity evaluations.

Table 2-1. National Ambient Air Quality Standards.

Pollutant	Averaging Period	Primary Standards	Secondary Standards
Carbon Monoxide (CO)	8 hours	9 ppm	None
	1 hour	35 ppm	
Lead (Pb)	Rolling 3-month average	0.15 $\mu g/m^3$	Same as Primary
Nitrogen Dioxide (NO_2)	Annual	53 ppb	Same as Primary
	1 hour	100 ppb	None
Particulate Matter (PM_{10})	24 hours	150 $\mu g/m^3$	Same as Primary
Particulate Matter ($PM_{2.5}$)	Annual	12 $\mu g/m^3$	15.0 $\mu g/m^3$
	24 hours	35 $\mu g/m^3$	Same as Primary
Ozone (O_3)	8 hours	0.075 ppm	Same as Primary
Sulfur Dioxide (SO_2)	1 hour	75 ppb	3-hour 0.5 ppm

Source: http://epa.gov/air/criteria.html

While the NAAQS include PM_{10} and $PM_{2.5}$, currently there are no standards for much smaller PM size ranges such as the ultrafine range (i.e., PM with an aerodynamic diameter smaller than 0.1 µm). Similarly, there are no general, ambient standards for hazardous air pollutants (HAPs) also known as air toxics (see Section 2.5). However, it should be noted that the Occupational Safety & Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) have concentration standards for workplaces in the form of permissible exposure limits (PELs) and recommended exposure limits (RELs). These standards would apply to airport employees.

2.3 State Implementation Plan

The 1970 CAA required states to develop a legislative plan to implement the NAAQS and ensure the standards are met and maintained. The plan referred to is the State Implementation Plan (SIP), and includes many other provisions related to control of emissions from industry. A SIP is intended to serve two purposes, to demonstrate how a state's air quality management program will implement additional or revised NAAQS, and identify the emission control strategies relied on to meet and/or maintain the NAAQS. An inventory of estimated emissions from airports located within each state, and the emissions projected to occur in the future from those airports, are included in the states' SIP budgets and are considered in the states' plans to reduce further emissions of harmful pollutants and maintain pollutant concentrations at an acceptable level.

2.4 General Conformity

To assess the impact of new projects on a SIP, either General Conformity or Transportation Conformity evaluations need to be performed. Most airport projects require General Conformity evaluations that include the quantification of the expected net emissions from a project (i.e., emissions beyond the status quo or no-build case). These are compared to established *de minimis* levels to determine if they will have a significant impact on the overall state's emissions inventory. Depending on the magnitude of the project emissions levels, an evaluation of its compliance with the SIP may need to be made (i.e., whether the regional emissions budget can absorb the project emissions). In addition, atmospheric dispersion modeling may need to be conducted to better assess the impact of the project emissions.

2.5 Emissions Standards and Permits

To control emissions, the New Source Performance Standards (NSPS) serve as federal emissions standards that apply to new and modified sources on a category basis. The standards are typically specified in terms of emissions per amount of fuel/feedstock or the product (e.g., 0.60 pounds of NO_x per million BTU of coal for steam electric power plants). Similar to the NSPS, the National Emission Standards for Hazardous Air Pollutants (NESHAP) were established to control mass emissions of HAPs (air toxics) through the promotion of technology-based standards for each facility type. These standards apply to equipment used at airports such as power generators, boilers, etc. Section 112 of Title I of the CAA includes provisions for implementing NESHAP and lists each of the close to 200 HAP species, some of which are exemplified below:

- Acetaldehyde,
- Benzene,
- 1,3-Butadiene,
- Formaldehyde,
- Toluene,
- Trichloroethylene, and
- Lead compounds.

The full list can be found at the EPA air toxics website, http://www.epa.gov/ttn/atw/. Emissions and concentrations of each HAP species will vary at airports, with many below the detection limits of ambient monitoring and sampling equipment. It should be noted that lead is both a criteria pollutant and a HAP.

In addition to the NSPS and NESHAPs, there are various rules to limit and control the release of air emissions. The New Source Review (NSR) permitting program was established as part of the 1977 Clean Air Act Amendments, and is intended to protect air quality degradations, especially in pristine areas such as National Parks. Under the NSR, there are three preconstruction permits that control the source construction, emissions limits, and source operations: prevention of significant deterioration (PSD), nonattainment NSR, and minor NSR. These permits are required based on the equipment size and air quality status of the region, and airports must apply for permits accordingly for new equipment.

The CAA Title V permits are named after Title V of the 1990 CAAA, and they generally apply to all major sources including those operated at airports. These operating permits provide permission on a facilitywide basis and cover emissions limits and monitoring requirements, recordkeeping, and reporting. Title V permits are usually issued by state agencies and are legally enforceable documents. Airports must maintain these permits for their equipment and follow the reporting requirements.

2.6 Indoor Air Pollution

Human health concerns typically focus on the quality of outdoor air with the corresponding NAAQS set to protect and promote human health and welfare from ambient air quality impacts. In contrast, the EPA currently does not regulate indoor air quality although guidance from the EPA's Indoor Environments Division (IED) is offered on educating and helping the public reduce exposures to indoor pollutants. Both gaseous and PM pollutants can be generated from various indoor sources including, but not limited to, combustion sources (e.g., using oil, gas, etc.), smoking (e.g., tobacco use), cleaning solutions, building materials, and furniture (e.g., formaldehyde released from pressed-wood products). In addition to these sources, indoor air pollution can escalate if inadequate ventilation exists and not enough outdoor air is allowed to mix with the indoor air, thus diluting indoor air pollutant concentrations.

While not the main focus for airports, indoor air still needs to be considered to allow for a comprehensive understanding of potential public health impacts from air pollution. Indoor air pollution at airports can occur for both airport personnel (e.g., within maintenance facilities, boiler room, offices, etc.) and the public/passengers (e.g., within terminal buildings, aircraft, etc.). In general, indoor air pollution is not a concern at airports as there no significant indoor sources and, typically, buildings are well ventilated.

CHAPTER 3

Airport Air Quality Background

This chapter provides an overview of the issues and components related to understanding airport air quality contributions.

3.1 Airport Source Characteristics

Airport emissions sources include those involving the combustion of fossil fuels and various fugitive sources. Emissions from mobile combustion equipment (e.g., aircraft) are generally considered the main sources at airports, but other sources also can contribute significant emissions as well. Emission characteristics depend on several factors that include, but are not limited to, the type of source (i.e., mobile, stationary, or fugitive), equipment power setting, fuel type, and pollution control technologies implemented.

3.1.1 Source Types and Pollutants

Although other sources of emissions exist at airports, mobile sources are often the largest sources of emissions. Aircraft, as well as their auxiliary power units (APUs), ground access vehicles (GAVs), and ground support equipment (GSE) make up the bulk of emissions from mobile sources, although GSE can be both mobile and stationary. Stationary equipment sources include waste incinerators, boilers for producing heat and hot water, and power plants. When airports propose projects that require construction work (e.g., runway modifications, new terminal buildings, etc.), the emissions from construction equipment and associated activities must be accounted for as part of the project even though the emissions are temporary in nature.

Like combustion-related sources (i.e., emissions from equipment exhaust), fugitive sources also must be considered. These include activities other than combustion such as maintenance activities, fuel storage operations, painting, and other activities that can result in the release of volatilized compounds. The re-entrainment of PM from the operation of mobile equipment (e.g., airport GAVs, construction equipment, etc.) and construction activities also needs to be considered.

Table 3-1 provides a summary of the types of pollutants that potentially can be generated by the different sources at an airport. Although aircraft have been grouped separately, the types of pollutants emitted from combustion sources are similar even though the quantities emitted per pollutant may be different. As such, the main difference is between combustion activities and those involving fugitive emissions. Table 3-1 also provides a subset of pollutants that tend to be of primary interest with regard to health concerns. This is an indication of the pollutants that are receiving the most focus based on health concerns and continuing research. Although the criteria pollutants continue to be a concern (including the secondary formation of ozone), the current focus is largely on HAP and PM (including ultrafine) emissions.

Table 3-1. Airport sources and associated pollutant emissions.

Source Types	Pollutants That Can Potentially Be Emitted	Main Pollutants of Interest for Health Concerns and Research
• Aircraft main engines (jet, turboprop, and piston/GA) • APU	• Criteria: CO, HC/VOC, NO_x, PM_{10}, $PM_{2.5}$, SO_x • Criteria: Pb (only GA aircraft using AvGas) • HAPs: VOCs, aldehydes and ketones, PAHs, dioxins and furans • Ultrafine PM • Other PM species: black carbon, nitrates, sulfates	• Criteria: HC/VOC, NO_x, $PM_{2.5}$ • Criteria: Pb (only GA aircraft using AvGas) • HAPs: VOCs, aldehydes and ketones, PAHs • Ultrafine PM • Other PM species: black carbon, nitrates, sulfates
• GSE (baggage tractor, belt loader, service truck, etc.) • GAV (passenger vehicles, airport-owned vehicles, shuttle buses, etc.) • Construction—combustion (on-road and off-road equipment)	• Criteria: CO, HC/VOC, NO_x, PM_{10}, $PM_{2.5}$, SO_x • HAPs: VOCs, aldehydes and ketones, PAHs, dioxins and furans • Ultrafine PM • Other PM species: black carbon, nitrates, sulfates	• Criteria: CO, HC/VOC, NO_x, $PM_{2.5}$, SO_x • HAPs: VOCs, aldehydes and ketones, PAHs
• Stationary sources—combustion (boiler/heater, incinerator, power generator, etc.) • Training fires	• Criteria: CO, HC/VOC, NO_x, PM_{10}, $PM_{2.5}$, SO_x • HAPs: VOCs, aldehydes and ketones, PAHs, dioxins and furans, metals, acids (metals and acids generally not associated with training fires) • Ultrafine PM • Other PM species: black carbon, nitrates, sulfates	• Criteria: CO, HC/VOC, NO_x, $PM_{2.5}$, SO_x • HAPs: VOCs, aldehydes and ketones, PAHs, dioxins and furans
• Stationary sources—fugitive (maintenance, painting/coating, etc.) • Construction—fugitive (demolition, asphalt paving, wind erosion, dust re-entrainment from roadways, etc.)	• Criteria: PM_{10}, $PM_{2.5}$ • HAPs: VOCs • Other PM species: black carbon, nitrates, sulfates	• Criteria: $PM_{2.5}$ • HAPs: VOCs

3.1.2 Equipment Power Settings

Equipment power settings refer to the mode of operation of equipment such as an aircraft, GAV, or GSE. The settings are important since both the emission factors and types of pollutants emitted can vary significantly from one mode to another. For example, the following modes are typically used to describe the different power settings aircraft engines experience during normal operations at an airport:

- Takeoff,
- Climb out,
- Approach, and
- Idle/taxi.

The standard power settings range from 7 percent at idle/taxi to 100 percent during takeoff. Emission factors for pollutants such as CO and hydrocarbons including HAPs tend to be higher at low power conditions while NO_x emission factors tend to be higher at higher power settings (i.e., using fuel-based emission factors such as gram of pollutant per kg of fuel burned). For GSE, modes are typically not associated with the equipment. Rather, power settings in horsepower are generally used with time and power-based emission factors (e.g., gram of pollutant per horse-power per hour of equipment usage). In addition to mobile equipment, it should be noted that stationary source equipment such as power plants, incinerators, etc., also have different modes of operation even though emissions from such sources are typically assessed assuming constant, average emission factors.

3.1.3 Fuel Types

Several types of fuels are used at airports. Jet A is used by jet and turboprop engines while AvGas is used by piston-engine aircraft. Diesel has typically been used for GSE but electric equipment, as well as gasoline and alternative fuels, has increasingly been used for ground equipment.

Jet A is denser and has a higher energy content than gasoline, but also results in greater carbon (e.g., CO_2) output on a per energy basis. This does not, however, provide any implications for air pollutant emissions (especially involving CO and hydrocarbons/VOCs) as it depends on many factors including the specific combustion technologies and pollution controls used. But based on fuel content of certain chemicals such as sulfur (which is higher in Jet A as opposed to motor vehicle gasoline, for example), it can be expected that aircraft emissions may have higher SO_x emissions on an energy output basis than do motor vehicles.

Due to the continued use of lead in AvGas, general aviation (GA) airports have come under scrutiny for their lead contributions to local air quality. Historically, human exposures to lead have occurred through the use of lead in paints and automobile fuels (i.e., the use of tetraethyl lead in fuels to reduce engine "knocking"). Although these uses have largely been phased out, lead continues to be actively used in aviation gasoline (AvGas or 100LL). Most GA aircraft with piston engines use AvGas.

Diesel fuel is typically used to power many GSE types while unleaded gasoline has generally been used for GAVs (although some GSE can use gasoline and GAVs can use diesel as well). These fuels have different characteristics that contribute to different pollutant emissions. For example, diesel has been associated with increased PM emissions. Some airports have installed charging stations that support using electric GSE. Airport buses and shuttles as well as GSE and GAVs also may use alternative fuels such as compressed natural gas (CNG).

3.1.4 Pollution Control Technologies

Pollution control technologies (or pollution controls, for short) typically refer to some device or equipment that helps to reduce pollutant emissions. Aircraft engines do not have a separate piece of equipment used to control emissions. Emissions reductions are generally achieved through new combustor designs. In contrast, ground mobile equipment such as GSE and GAVs typically use catalytic material (i.e., as part of a catalytic converter) located in the exhaust system to convert pollutants such as CO and unburned hydrocarbons (including HAPs) to CO_2 and water. Stationary sources (e.g., incinerators, power plants, etc.) also may use catalysts but they typically employ controls such as scrubbers and baghouses to convert or filter out pollutants depending on the size and design of the equipment/systems.

3.2 Source Emissions Contributions

With all of the differences among airports, the mix of emissions contributions from sources at each airport may be different as well. There may be differences in source activities, geography, and infrastructure (e.g., airports with excellent transport infrastructure and/or a large proportion of freight operations may be expected to have a reduced contribution from the landside road network). Nevertheless, it is generally accepted that emissions source contributions may

Table 3-2. On- and off-airport inventory of emissions at Airport XYZ (unit-less example values).

Source Group	CO	VOC	NO_x	SO_x	PM_{10}	$PM_{2.5}$
Aircraft	446	188	837	76	16	13
GSE	551	21	322	10	8	5
APU	37	2	32	5	-	-
Parking facilities	31	5	5	0.01	0.2	0.2
On-airport roadways	141	12	58	0.4	5	4
Off-airport roadways	3542	374	590	6	171	33
On-airport, airport-owned stationary sources	9	0.3	31	0.3	1.4	1.1
On-airport, not airport-owned stationary sources	15	5	7	0.3	5	4
Off-airport stationary sources	230	155	69	6	22	21
Off-road sources	932	122	341	6	21	18
Total	**5934**	**884**	**2292**	**110**	**250**	**99**

be described through the following approximate rank where the first source—aircraft—are generally the highest emitters:

- Aircraft in the landing and take-off (LTO) phase;
- Road vehicles on airport landside roads and on the road network around the airport;
- Ground support equipment (GSE);
- Airport ground access vehicles (GAVs);
- Aircraft auxiliary power units (APUs);
- Airport heating and boiler plants;
- Evaporative losses (e.g., fuel storage, maintenance, etc.); and
- Airport fire training exercises.

It should be noted that this is a general rank and that it is dependent on pollutant type as well and will vary by airport. For example, depending on how much of the roadways may be included in an airport air quality study, road vehicle emissions could be significantly greater than emission levels from aircraft.

The variation in these source contributions may be illustrated by considering the emissions generated by Airport XYZ (a fictitious airport) presented in Table 3-2. In this example, it is clear that there are many different sources that may contribute to local air quality, and that the relative magnitude of these contributions is dependent upon the pollutant of interest. This example illustrates how aircraft are generally the most significant source of emissions, but they can produce fewer emissions than GSE (e.g., CO emissions) and roadway vehicles. In fact, the off-airport roadway emissions can be significantly higher than aircraft emissions depending on roadway coverage. Depending on the layout, equipment types, and operations at each airport, the emissions inventories can be very different than this example inventory. However, in general, aircraft, GSE, and roadway vehicles tend to be the largest sources of emissions at an airport.

3.3 Airport Operations

Airport operations essentially mean the activities (e.g., usage) of a source such as aircraft, GSE, boiler, etc., such that the greater the usage, the greater the magnitude of emissions. But more than that, airport operations refer to the complexities associated with analyzing source operations and the temporal impacts of the associated emissions on air quality. For example, the distribution and transport of pollutants at an airport are determined by the airport layout and the operations schedule. Airports usually have a schedule that reflects a "peak day" and "peak hour" of operations (e.g., Thursdays between 5:00 p.m. and 6:00 p.m.). Even the choice of runway will influence pollutant transport, as runway use is determined by prevailing winds. Emissions from other mobile sources and GSE also would likely peak (i.e., maximized usage occurs) around the same time.

Airport emission trends follow a familiar pattern with decreased emissions from the individual sources due to improved design and/or efficiency, and increased emissions within source categories due to airport growth. This is the challenge for airport operators (and more broadly the aviation industry): that the growth of the airport and overall emissions will tend to exceed any operational or technological improvements for emissions reduction. An emissions inventory, usually completed on an annual basis, is used to track the amount of emissions from each source category over time including operational improvements. In contrast, air quality assessments must be performed with more detailed information taking into account appropriate temporal conditions (e.g., time of day, concentration averaging periods, etc.) to properly determine pollutant concentrations that can be compared to health benchmarks (e.g., NAAQS). This is in addition to all of the other factors including meteorology and spatial information (i.e., source and receptor locations and geography). All of the factors must be taken into account accurately when assessing air quality trends.

3.4 Geography

Physical geography can play a significant role in both airport operations and local air pollutant dispersion. Ranges of mountains not only require a specific aircraft approach procedure but can define their own weather and channel air sheds to form distinct wind patterns. The emissions from airports in valleys would not tend to disperse as rapidly in comparison to emissions at airports in open terrain that experiences no major geographical hindrance to dispersion.

For example, Los Angeles and LAX sit in a bowl ringed by mountains to the north and east that trap pollutants in an urban basin such that in warm weather, a cool sea breeze is drawn onshore at ground level creating a temperature inversion that prevents pollutants from dispersing and can result in photochemical smog. Similarly, Mexico City's MEX Airport is situated at over 7,000 feet above mean sea level in a basin constrained by mountains with intense solar radiation; these characteristics combine to cause air quality problems involving both primary and secondary pollutants. Even with relatively flat terrain, changes in land use (e.g., urban sprawl) also may appreciably affect the surrounding meteorology through changes in the local surface energy budget (e.g., urban heat island effect) impacting diurnal air temperatures and wind patterns, thereby affecting the dispersion of pollutants.

3.5 Meteorology

Wind direction and the prevailing meteorological conditions are particularly important to the way emitted air pollutants disperse. Below the mixing height (nominally about 3,000 feet above ground level), dispersion occurs based on the turbulent strength of the atmosphere (largely defined by the diurnal heating and cooling cycle) and mean wind characteristics. Overall, the daily and seasonal meteorological components that affect local concentrations of pollutants include wind direction, wind speed, mixing depth, ambient temperature, relative humidity, and solar insolation (i.e., solar energy received on a surface).

Winds are of particular significance in that they determine the direction in which airport emissions will move and the area over which they will disperse. Wind patterns often demonstrate correlations with seasonality—for example, wind may flow predominately northwest in the winter to predominantly southwest in the summer as is the case at New York's John F. Kennedy International Airport (JFK). Similarly, predominant wind speeds may show seasonal trends. Periods of very low or nil wind may lead to stagnation near the point of emission leading to localized pollution episodes (increased concentrations).

Varying wind patterns arise on a small scale as a result of the interaction of air flows with local topography, and on a larger scale from synoptic wind patterns that may be modified by differential heating effects such as the sea–land breeze cycle (which is strongest in early summer but also can occur later in the year) and complex, typically nocturnal, local drainage flows. It should be noted that sea breezes may be observed even tens of miles inland. Different wind patterns at different locations are therefore to be expected, and this is reflected in the choice of runway orientations at any given airport.

3.6 Mitigation Measures for Airport Source Emissions

Typically, it is the airport operator that leads the preparation and delivery of an airport air quality management plan, comprising a measurement program, air quality assessments, and various mitigation activities. However, many emission sources at an airport, and the two most significant—aircraft and access road traffic (as well as GSE in many cases)—are not within the direct control of the airport operator. Therefore, any airport mitigation plan needs to be developed in collaboration with airport tenants in order to properly account for all potential sources of emissions and reductions.

A range of mitigation options is available at airports to reduce local air quality pollutants. Mitigation options are typically described against each emissions source, as is the case in this section. However, mitigation options also can be considered according to the type of measure that is being implemented (see Table 3-3).

In the United States, the FAA runs the Voluntary Airport Low Emission (VALE) Program. As the program title suggests, it is voluntary, and any airport in a nonattainment area is eligible to take part in the program. It provides airport operators with a legal mechanism to raise funds through their Passenger Facility Charge (PFC), and provides funding for the financing of certain air quality pollutant mitigation initiatives (Airport Improvement Program funds) such as low emission vehicles, refueling and recharging facilities, and gate electrification. The FAA also created the Zero-Emissions Airport Vehicles and Infrastructure Pilot Program in 2012, which provides funds for the purchasing of zero-emissions vehicles at airports and the supporting infrastructure.

In addition to the nonattainment status of an area, airport emissions reduction programs may be triggered from findings of significant impacts of non-criteria pollutants (e.g., HAPs). Like these largely voluntary measures rooted in sustainability-type programs, airports may be incentivized from increasing public pressure associated with the need to better understand airport contributions to local air quality and scrutiny from the public on health concerns.

3.7 Airport Emissions and Dispersion Modeling Capabilities

To assess potential health impacts from airports, pollutant loading into the local and regional atmosphere, and concentrations, need to be quantified. Since measurements can be costly and may not be representative (e.g., for certain locations or time periods), modeling is necessary—for both emissions and atmospheric dispersion. The following sections provide overviews of the current state-of-the-art capabilities in these areas, as well as their limitations.

Table 3-3. Categorization of air pollutant emissions mitigation measures.

Options	Notes
Technology	Technological options can be further categorized as those relating to • Fuel efficiency, • Electric equipment, • Design of engines/combustors, and • Control devices. For aircraft, technology changes are applied to the airframe or aircraft engines. Electric GSE with charging stations have been used commonly at airports to reduce fossil fuel use. The use of ground power and preconditioned air at gates is also a common practice that helps to reduce APU usage. Emissions abatement technologies are applied to road vehicles, such as catalytic convertors and particulate traps to vehicle exhaust systems. Centralized de-icing facilities can help reduce aircraft queuing near gate areas and reduce idling emissions.
Fuels	Alternative fuels can offer a reduction in some pollutants. Examples of alternative fuels for GSE and GAVs include compressed natural gas (CNG) and liquefied natural gas (LNG). Airport operators can consider alternative fuels (e.g., biofuels) for their vehicles. Biofuels used in aircraft also will have implications for air quality at airports.
Operational	Certain operational changes can reduce emissions. These include finding alternatives to travel, minimizing route distances, avoiding or reducing delays (reducing queues), minimizing weight, and using optimal power and speed. Such measures are applicable to aircraft and road vehicles. Examples may include the implementation of single-engine taxiing, towing aircraft using alternative power, and use of high-speed taxiways.
Policy	Policy options can be subdivided as follows: Regulatory—includes regulations that set limits on particular sources of emissions (e.g., International Civil Aviation Organization [ICAO] aircraft certification standards, road vehicle exhaust standards) or ambient pollutant concentrations (e.g., National Ambient Air Quality Standards [NAAQS]). Economic—Utilizing economic incentives and disincentives for promoting a particular course of action that is environmentally beneficial. An example is aircraft emissions charging at some airports. Voluntary—When an airport decides to mitigate the emissions of pollutants in the absence of regulatory requirements or economic incentives to do so.

3.7.1 Emissions Modeling

The first steps in any air quality modeling work are those related to quantifying emissions. Modeling emissions for airport sources is similar to those for other industries since many of the sources are the same (e.g., GAVs are the same sources as those found on highways and boilers/incinerators are similar to those found in industrial applications). For modeling emissions, there are two key categories of data:

- Emission factors and
- Activity information.

Emission factors are generally in the form of mass amount of a pollutant per some unit activity. For example, grams per mile and grams per second are common units for an emission factor. These factors are specific to each pollutant and can encompass many different characteristics of a source including but not limited to the following:

- Type of equipment,
- Emissions control technology,
- Fuel type, and
- Power setting.

Although some emission factors may be static (e.g., available in a data table), others may need to be modeled based on these characteristics. Once an emission factor is available, it can be applied (e.g., multiplied) with activity data to calculate emissions. The activity data represents some measure of use or operation of the source (e.g., hours of usage). Both the emission factors and activity data can be complicated—for example, they are typically dependent on power settings for many equipment types. Emission factors for aircraft, GSE, and GAVs are dependent on power settings (or modes of operation).

Currently, the state-of-the-art emissions modeling capability for airports is represented by the FAA's Emissions and Dispersion Modeling System (EDMS, see http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/edms_model/), which is to be replaced by the Aviation Environmental Design Tool (AEDT, see http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/aedt/). FAA's long-term goal is to have AEDT encompass the full capabilities of EDMS (both emissions and dispersion modeling), and therefore, AEDT can be considered as a newer version of EDMS, as well as other FAA models. In keeping with this long-term view of the models, herein they are simply referred together as "EDMS/AEDT." The sources modeled in EDMS/AEDT are categorized as follows:

- Aircraft,
- Auxiliary power units (APUs),
- Ground support equipment (GSE),
- Ground access vehicles (GAV),
- Stationary sources, and
- Training fires.

The underlying datasets in EDMS/AEDT were obtained from various sources and are generally considered the best publicly available emission factors and activity information on a national level (i.e., for general use at all U.S. airports). However, it is recommended that specific equipment and activity information be obtained for each airport whenever possible to improve the accuracy of emissions inventories. Although EDMS models emission factors for GAVs, AEDT will not do so. When using AEDT to study airports, emission factors for GAVs will need to be modeled separately using the EPA's Motor Vehicle Emissions Simulator (MOVES).

Although EDMS/AEDT is considered state of the art, there are still various areas for improvement, some of which are currently under research (e.g., through ACRP, FAA, etc.). Users need to be mindful that uncertainties exist with the underlying modeling data and methods. To a certain extent, these uncertainties can be decreased by collecting airport-specific activity information (e.g., aircraft operations, GSE hours of usage, etc.). With the conservative nature of the model, a common tactic has been to model worst (or near-worst) cases and compare the resulting emissions inventories to regulatory limits such as the General Conformity *de minimis* levels. As such, if the worst case produces lower results than regulatory limits, then a more accurately modeled scenario would also be below the limits. This tactic can serve as both a screening approach as well as (in some cases) a means of allaying concerns over worst-case scenarios.

3.7.2 Dispersion Modeling

As the name implies, dispersion modeling refers to the process of predicting the dispersion of pollutants in the atmosphere once they have been released from a source. There are different scales of assessments—for airports, local-scale (e.g., within a local community) and larger, regional scales may apply. The larger the scale (and, generally, the more time involved for dispersion), the greater the dispersion generally resulting in lower concentrations experienced by the public for directly released pollutants. However, in each scale, secondarily formed pollutants (e.g., through atmospheric chemistry) also can impact local populations. Ozone and PM species are examples of such secondary pollutants.

Much of the local-scale modeling is conducted through the use of Gaussian models. The EPA's AERMOD modeling system (see http://www.epa.gov/ttn/scram/dispersion_prefrec.htm) is based on a Gaussian methodology and is the regulatory workhorse model used for most local air quality assessments. AERMOD represents the state of the art in the current scientific understanding of the dispersive nature of the atmosphere. In contrast, regional-scale modeling requires the use of grid-based models such as the EPA's Community Multiscale Air Quality (CMAQ) modeling system. Grid models are necessary since they can appropriately model atmospheric chemistry and the influence of background concentrations, whereas Gaussian models are limited in that regard. Some chemistry such as that involving NO_2 can be modeled through simplified methods in Gaussian models, but ozone and secondary particulate matter formation require grid models.

Although this airport dispersion modeling capability exists, relatively little dispersion modeling work has been conducted in comparison to emissions inventory development. Most regulatory studies (e.g., NEPA-related studies) have only required the development of emissions inventories. However, dispersion modeling is necessary to better understand potential health impacts since emissions inventories do not provide a direct correlation with pollutant concentrations experienced by the public.

Because of the additional factors affecting dispersion, predicted concentrations can have significantly greater uncertainties than emissions inventories. Concentrations are highly dependent on meteorology and the spatial relationship between sources (e.g., aircraft) and receptors (i.e., population). Any uncertainties in these factors—as well as various others such as the surrounding geography, seasonality, source activities, etc.—can drastically affect modeled concentrations. Also, it should be noted that dispersion modeling is only as accurate as the modeled emissions will allow. That is, any uncertainties in the emissions will carry through to the concentrations.

Airport air quality studies including those demonstrated in *ACRP Report 71: Guidance for Quantifying the Contribution of Airport Emissions to Local Air Quality* (Kim et al. 2012) illustrate the challenges of accurately predicting pollutant concentrations arising from airport emissions. As such, model users need to understand the potential limitations and uncertainties of these dispersion modeling processes. Considering all of the potential sources of uncertainty, the EPA has indicated that air quality models with predictions within a factor of two (compared to actual values) may be considered acceptable—and that it is difficult to be more accurate.

It also should be noted that although alternative models exist, AERMOD is a static model generally used to predict concentrations by hour (i.e., average concentration for each hour). So although AERMOD can provide hour-by-hour concentrations, it is considered a static model due to its Gaussian plume methodology. As the need for health impact assessments increase, finer time-varying models such as those employing Gaussian puffs rather than plumes may be necessary. Such time-varying models may allow better correlations of source activities with population exposures, although the importance of this modeling refinement would depend on pollutant and health outcomes (i.e., whether short-term or long-term exposure is under consideration).

3.8 Air Quality Measurement Capabilities

From the literature review conducted for this reporting, even though dispersion modeling has been conducted less than emissions inventory development, dispersion modeling has been used more to characterize air quality contributions from airports than measurements (monitoring). This is in large part due to the costs and resources required to conduct measurements often resulting in limitations on the number of measurement sites and samples that can be supported. Although measurements have further drawbacks of not being source-specific (difficult to assess contributions from specific sources) and have uncertainties in the monitoring equipment/methods and influences from various other factors (e.g., meteorology) that may cause difficulties in obtaining good samples, measurements are generally considered to provide the best information because they represent real-world values.

Uncertainties in measurements can vary depending on the types of equipment employed. For example, readings from continuous gas analyzers tend to be more accurate than air samples (gaseous or particulate matter) collected and analyzed over an averaging period (e.g., 1 hour, 24 hours, etc.). Although uncertainties exist, if proper measurement protocols are followed, measured concentrations will tend to be more accurate than modeled results, which can involve greater degrees of errors. An indication of the level of errors that can be expected through dispersion modeling can be found in 40 CFR Part 51, Appendix W, which indicates that modeling is considered "reasonably reliable" if the results are within a factor of two of actual values. Appendix W also states, "Measurements are particularly useful in assessing the accuracy of model estimates. The use of air quality measurements alone however could be preferable . . . when models are found to be unacceptable and monitoring data with sufficient spatial and temporal coverage are available." However, as previously indicated, the costs and resource requirements associated with measurements frequently make modeling more attractive.

A compromise that includes both measurements and modeling is possible. For example, limited monitoring can be used to help establish background concentrations and measured data can be used to help validate modeled values. Also, measured meteorological data could be used to support more accurate modeling. Modeling can be used to provide greater spatial coverage and cover greater time periods to establish temporal trends.

Generally, methods and equipment are related either to regulatory needs or research at airports. In terms of regulatory needs, the criteria pollutants as defined in the NAAQS dominate at U.S. airports. The promulgation of reference and equivalent measurement methods for specific pollutants also results in the type of equipment used. Table 3-4 provides a high-level overview of the most common types of measurement equipment by pollutant.

3.9 Aircraft LTO Versus Cruise Emissions Impacts

For completeness, a brief overview of cruise emissions versus LTO emissions is provided in this section. The long used ICAO LTO cycle at airports includes takeoff, climb out, approach, and idle/taxi modes. These modes are defined as occurring below 3,000 feet altitude above ground level, which is nominally considered an average mixing height where an inversion layer occurs that tends to prevent the lower air (including pollutants) from mixing into the upper layers. Therefore, only the emissions occurring below this mixing height are included in an airport air quality study.

Although aircraft generally continue climbing well above 3,000 feet, their flight segments above this height are defined as part of the overall cruise mode. Cruise emissions are typically excluded in airport air quality studies because they occur above the mixing height and are considered to have negligible effects on local air quality. In addition, there is no defined, standard power setting for cruise but there are power settings for the LTO modes; and there are no defined emission factors for cruise. However, cruise emissions have the potential for secondary effects on larger scales (e.g., regional, national, and global). These effects may include acid deposition, ozone formation, secondary PM, etc., and may have detrimental effects to human populations at significant distances from the airport.

Table 3-4. Air pollutant measurement equipment by pollutant.

Pollutant	Sampling Description	Equipment
CO	Continuous sampling	Reference or equivalent method (i.e., non-dispersive infrared)
CO	Short-term or hot-spot sampling	Air sampling units with the reference or equivalent method used to test captured air
NO_x	Continuous sampling	Reference or equivalent method (i.e., chemiluminescence)
NO_x	Short-term or hot-spot sampling	Air sampling units with the reference or equivalent method used to test captured air (note: reactivity of gases must be considered)
SO_x	Continuous sampling	Reference or equivalent method (i.e., spectrophotochemical); note: not generally recommended at airports
O_3	Continuous sampling	Reference or equivalent method (i.e., ultraviolet absorption)
Pb	Continuous sampling	Reference or equivalent method (i.e., filter in high-volume sampler)
Pb	Short-term or hot-spot sampling	Air sampling filter units
PM_{10} and/or $PM_{2.5}$	Continuous sampling	Reference or equivalent method (i.e., filter with impaction specific for PM_{10} and/or $PM_{2.5}$)
PM_{10} and/or $PM_{2.5}$	Short-term or hot-spot sampling	Air sampling filter units specific for PM_{10} and/or $PM_{2.5}$
Ultrafine PM	Continuous sampling	Scanning Mobility Particle Sizer (SMPS), Aerosol Time-of-Flight Mass Spectrometer (AFOTMS), or Micro-Orifice Uniform Deposit Impactor (MOUDI)
Black Carbon	Continuous sampling	Aethalometer
Black Carbon	Short-term or hot-spot sampling	Air sampling filter units specific for black carbon (i.e., quartz fiber filters) with elemental carbon (EC)/organic carbon (OC) analysis
PM Nitrates and Sulfates	Short-term or hot-spot sampling	Air sampling filter units specific for black carbon (i.e., quartz fiber filters) and ion chromatography
CO_2	Continuous sampling	Non-dispersive infrared
CO_2	Short-term or hot-spot sampling	Air sampling units with the reference or equivalent method used to test captured air
VOCs/HAPs	Continuous sampling	Flame ionization detector (note: not generally recommended)
VOCs/HAPs	Short-term or hot-spot sampling	Evacuated canisters or sample cartridges; formaldehyde may be used with proportionality factors to determine other HAP concentrations
PAHs	Continuous sampling	Photo-electric Aerosol Sensor (PAS) for particle-bound PAHs
PAHs	Short-term or hot-spot sampling	Air sampling filter and adsorbent unit specific for PAHs and high-speed liquid chromatography (HPLC)
Meteorology	Continuous sampling	u,v,w sonic anemometers and aspirated thermometers at two heights with appropriate data logger system; relative humidity and barometric pressure also can be measured
Meteorology	Short-term or hot-spot sampling	u,v,w sonic anemometers with appropriate data logger

CHAPTER 4

Air Quality Health Impacts and Risks

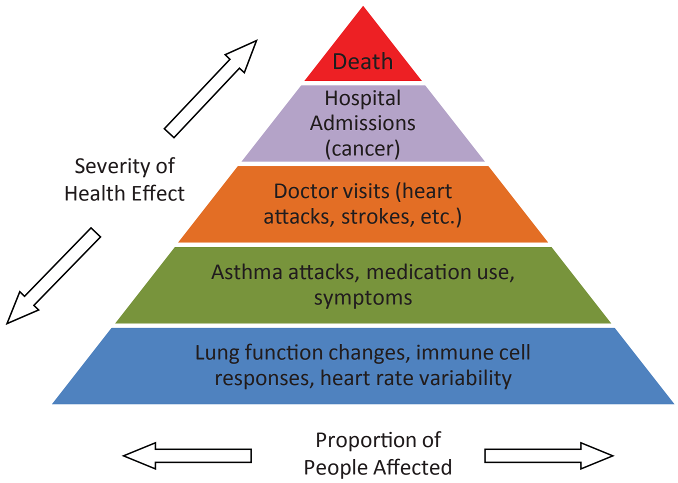
This chapter serves as a primer on understanding potential air pollutant health impacts and health risks.

4.1 Pollutant Health Impacts Overview

Each of the pollutants targeted in this report can be categorized as either a criteria pollutant or a hazardous air pollutant (HAP). HAPs are also referred to as air toxics or as both criteria pollutants and HAPs (e.g., Lead, Pb, is regulated as a criteria pollutant but Pb-based compounds are on the EPA's HAPs list). Each of these pollutants has health effects that range from mild to severe chronic and acute health effects, as well as premature death. Figure 4-1 provides an overview of the population proportions associated with the severity of health effects—in general, the more severe the effect, the smaller the proportion of the population affected. The figure describes different degrees of health effects, and it should be understood that different pollutants will have different health impacts and levels of severity. The following sections describe the potential health effects of each pollutant.

There are six (6) criteria pollutants. A discussion of concerns over their public health impacts follow:

- **Carbon monoxide (CO)** is a colorless and odorless gas that can cause various physiological damages by displacing oxygen in the bloodstream. At high concentrations, CO has known health effects including dizziness, unconsciousness, and death. At lower concentrations more typical of ambient settings in the United States, individuals with cardiovascular disease are at risk of myocardial infarctions (heart attacks) or other exacerbations.
- **Lead (Pb)** is a soft, malleable metal in the "heavy metal" category. Pb is a concern for its ability to cause a range of neurological damage from all exposure pathways (inhalation, ingestion, and dermal contact).
- **Nitrogen dioxide (NO_2)** is one of the nitrogen oxides (NO_x) that is part a family of gases, mainly represented by NO and NO_2, that can contribute to respiratory disease exacerbations. In addition to its direct health impacts, NO_x is well known as a precursor to ozone (O_3) formation. Furthermore, NO_x also contributes to the formation of nitrate aerosols that can have respiratory and cardiovascular health effects.
- **Ozone (O_3)** is a pollutant that generally is not directly emitted from most sources. Within the troposphere, it is formed through a complex interaction (chemical reaction) mainly involving NO_x, and volatile organic compounds (VOCs) in the presence of sunlight. O_3 can contribute to respiratory health effects through inflammation of airways and decrements in lung function, with evidence of increased respiratory symptoms among sensitive individuals such as asthmatics and those with chronic obstructive pulmonary disease, as well as evidence of increased



Source: Adapted from Environmental Health & Engineering, Inc. (EH&E) (2011). "Emissions of Hazardous Air Pollutants from Coal-Fired Power Plants." EH&E Report 17505. Prepared for the American Lung Association, Washington, D.C., March 7.

Figure 4-1. Severity of health effects versus proportion of people affected.

hospitalizations and premature deaths. Because of the formation of O_3 from directly emitted pollutants (from many different sources) within a relatively large area, O_3 is characterized as a regional issue even though it is a local air quality concern.

- **Particulate matter (PM)** is tiny solid, liquid, or mixed solid and liquid particles suspended in the air. These are of concern since ambient concentrations of PM have been shown to be correlated with serious respiratory and cardiovascular illnesses and premature mortality. PM sizes (aerodynamic diameters) range from greater than 100 µm to the ultrafine range of below 0.1 µm. The smaller the size, the deeper they are able to penetrate into the respiratory system, possibly even resulting in blockages of the gas–blood interfaces within the lungs. Figure 4-2 provides an overview of the portions of the respiratory system affected by the different PM size ranges. While the discrete PM size ranges shown generally correspond to different degrees of respiratory penetration, it should be understood that different size ranges can be deposited

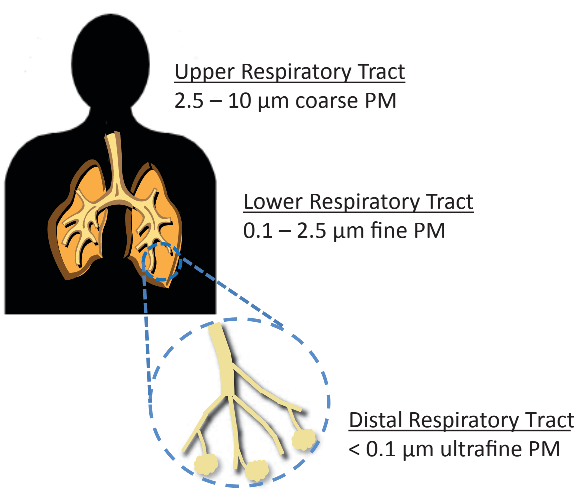


Figure 4-2. PM penetration into the human respiratory system.

throughout the respiratory system. PM with a size range of 10 μm or less are referred to as PM_{10} and those with a size range of 2.5 μm or less are referred to as $PM_{2.5}$. NAAQS concentrations are currently only specified for these two size ranges. In addition to these regulated size ranges, PM in the ultrafine range (less than 0.1 μm in diameter) is thought to contribute to health effects. Ultrafine particles are of particular concern at airports because of relatively higher concentrations (higher than background) found near aircraft operations. Other PM types and components include nitrates, sulfates, and black carbon (BC). Also known as elemental carbon (EC), BC is composed of pure carbon clusters and is differentiated from organic carbon (OC), which is composed of organic compounds. BC is a significant contributor to the health effects caused by $PM_{2.5}$ and ultrafines. Nitrates and sulfates can penetrate deep in the respiratory system and can also react with other chemicals to form harmful compounds (e.g., acids).

- **Sulfur dioxide (SO_2)** is a sulfur oxide (SO_x). So_x refers to a family of gases mainly represented by SO_2 that can act as irritants to the respiratory system and can contribute to asthma attacks and other health outcomes. As with NO_x, concerns about SO_x often relate to its ability to form sulfate aerosols in the atmosphere, with the corresponding health effects seen for fine particulate matter.

HAPs are generally defined as those pollutants that are known or suspected of being able to cause serious health effects such as cancer, birth defects, etc. The EPA maintains a list of close to 200 HAPs comprised of VOCs, aldehydes, polycyclic aromatic hydrocarbons (PAHs), dioxins, furans, metals, acids, etc. A discussion of the formation and concerns over these pollutants follows:

- **Volatile organic compounds (VOCs)** are comprised of a large group of carbon-based compounds with relatively high vapor pressures. The EPA further defines these as chemicals that participate in atmospheric photochemical reactions. They are emitted through evaporation from certain operations (e.g., painting, dry cleaning, etc.) and through incomplete combustion of fossil fuels. Indoor concentrations of VOCs are usually higher than outdoor concentrations—up to 10 times higher. Health effects depend on the specific species as well as exposure duration, but some short-term effects may include headaches, nausea, sore throat/eyes/nose, etc. Long-term effects may include cancer. Examples of VOCs include benzene, toluene, xylene, 1,3-butadiene, etc.
- **Aldehydes and ketones** are subsets of VOCs. Sometimes they are treated separately, which is in part due to the different methods required to measure these compounds. Both groups of compounds are made up of a double-bonded carbon-oxygen core (C=O). An aldehyde has at least one hydrogen bonded to the carbon atom while a ketone has two hydrocarbon groups attached to the carbon atom. Aldehydes are used in production of commercial applications including the production of alcohols, resins, detergents, perfumes, etc. Ketones have industrial uses as solvents, polymer precursors, and pharmaceuticals, etc. As VOCs, both groups have relatively high vapor pressures, and their health effects are similar: irritation of the eyes and air passages under short-term exposure and lower concentrations. Long-term exposures and/or high concentrations can cause depressions of the central nervous system and cancer. Examples of aldehydes are formaldehyde, acrolein, and acetaldehyde. Examples of ketones are acetone and acetophenone. Methyl ethyl ketone (MEK) is also a ketone but not a HAP—EPA removed this from their official list.
- **Polycyclic aromatic hydrocarbons (PAHs)** are comprised of a group of compounds that generally have more than two benzene rings (a ring of six carbon atoms). They tend to stick to solid particles (e.g., soot) and are formed from incomplete combustion processes such as those from coal burning, automobile gasoline combustion, forest fires, coke and coal tar processing, etc. Animal testing has indicated that it is reasonable to expect PAHs to cause birth defects and cancer. Examples of PAHs include anthracene, benzo-a-pyrene, naphthalene, chrysene, etc. Of these, only naphthalene is currently listed on the EPA HAPs list.

- **Dioxins and furans** are comprised of a family of toxic substances that are similar in chemical structure and more formally referred to as polychlorinated dibenzo-para-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). In addition to exposures through ingestion of food containing these compounds, exposures through inhalation of emissions from incineration (e.g., of municipal solid waste), copper smelters, cement kilns, coal-fired power plants, etc., are common. Potential health effects include birth defects, suppressed immune system, changes in hormone levels, and cancer. On the EPA HAPs list, these pollutants are listed as 2,3,7,8-Tetracholordibenzo-p-dioxin and dibenzofurans.
- **Metals** make up a small but important portion of the EPA HAPs list. Either in elemental form or as part of a compound, they can typically be emitted as PM from combustion sources including power plants, industrial operations, ore refining, etc. Three of the common metals are mercury (Hg), lead (Pb), and chromium (Cr). Exposure to air emissions of Hg can result in various disorders including tremors, emotional changes, neuromuscular changes, changes in nervous response, reductions in cognitive function, etc. As previously indicated, exposures to Pb can result in neurological damage. Air exposure to Cr (III), the most common form of chromium in the air, can result in damage to the respiratory system. Exposure to Cr (VI) can result in more serious respiratory damage, as well as lung cancer.
- **Acids** make up a small subset of the EPA HAPs list, and hydrochloric acid (HCl) and hydrogen fluoride (HF) are two of the more well-known HAPs. In addition to being used in various industrial activities such as refining ore, metals processing, glass etching, aluminum production, etc., they also can be generated through combustion of coal and other fuels containing chlorine (Cl) and fluorine (F). Acute health effects of these acids are similar in that they are corrosive and can cause serious damage to the respiratory system. Chronic effects for HCl include gastritis, bronchitis, and dermatitis as well as hyperplasia of the nasal mucosa, larynx, and trachea. HF chronic effects include increased bone density and damage to the liver, kidneys, and lungs.

To ensure no misunderstandings regarding these health effects, it should be noted that while the descriptions provide a comprehensive view of the current understanding of health impacts by pollutant type (or category), they do not directly indicate the risks associated with airport air quality impacts. Other details such as emissions and exposure need to be taken into account and are discussed in the next section.

4.2 Health Risk Factors

As defined by the EPA (see http://www.epa.gov/risk_assessment/basicinformation.htm), health risk is "the chance of harmful effects to human health or to ecological systems resulting from exposure to an environmental stressor" where stressors are described as "any physical, chemical, or biological entity that can induce an adverse response." Characterizations of risk are accomplished by conducting both exposure pathway assessments (how the pollutant interacts with the population) and dose-response assessments (how much of the pollutant is required to cause harm). These are general definitions used to describe risk for environmental impacts.

For air quality, health risk can be described as being influenced by three components: emissions, exposure, and toxicity. As indicated in Figure 4-3, each of these components encompasses details regarding the source, pollutants, and the exposed public. The emissions of each pollutant depend on source characteristics. Source characteristics include emission factors (or rates) that are dependent on type of source, equipment age, emissions control, etc. Toxicity is the degree to which a pollutant can harm a human being. Toxicity is characterized differently for criteria air pollutants versus HAPs. For criteria air pollutants, concentration–response relationships are generally constructed from epidemiological literature. These epidemiological studies typically contain concentrations representative of the current range of concentrations in the United States, and the concentration–response functions are applied as continuous functions to quantify

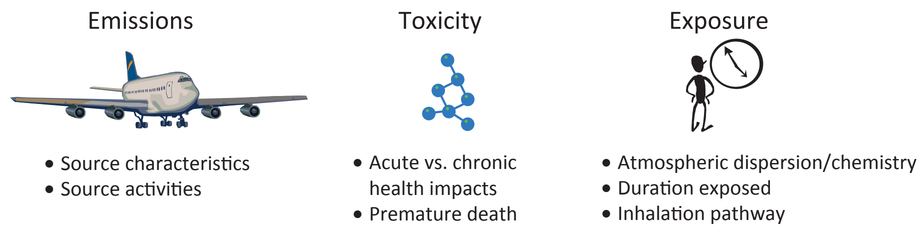


Figure 4-3. Air quality health risk components.

incremental health effects of concentration changes. For HAPs, conventional risk assessment differentiates between carcinogenic effects and non-cancer effects, with the presumption that most carcinogens demonstrate low-dose linearity and that most non-cancer health effects display a putative population threshold. There are an increasing number of counterexamples that contradict this model, but most health risk assessments to date maintain this structure. Within the structure, for non-cancer health effects, inhalation reference concentrations (RfCs) are used. For carcinogenic effects, unit risk factors are used. The EPA defines these terms as follows:

- RfC: An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure of a chemical to the human population through inhalation (including sensitive subpopulations), that is likely to be without risk of deleterious noncancer effects during a lifetime. (See http://www.epa.gov/ttn/atw/hlthef/hapglossaryrev.html.)
- Unit Risk: A unit risk is an upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 µg/L in water or 1 $\mu g/m^3$ in air. (See http://www.epa.gov/iris/help_ques.htm.)

Exposure encompasses both the pathway leading to the interaction between pollutants and the exposed population (i.e., concentrations experienced by the population) as well as the duration of the interaction. This is partly dependent on how pollutants disperse in the atmosphere and undergo chemical conversions to form other pollutants. It also is dependent on the size and activities of the local population and their locations.

In general, the health impacts from specific sources can be evaluated from either an individual perspective or a population perspective, and this holds for airport emissions as well. In the former case, the influential factors will be those that cause an individual to have greater risk from airport emissions than other individuals. In the latter case, the influential factors will be those that cause the public health burden from airport emissions to be greater. The factors will overlap but will not be identical.

From an individual perspective, proximity to the airport is clearly the dominant factor, although not necessarily in a simple distance-dependent fashion. Multiple studies indicate that being immediately downwind of a primary departure runway significantly increases exposures to multiple combustion pollutants, including ultrafine particulate matter, NO_x, and black carbon. However, some studies indicate the potential for exposure over a fairly broad geographic area, especially related to arrivals—appreciable impacts can be observed more than 1 km from the airport, in a manner that is not strictly distance-dependent. The common influence of wind direction on aircraft movement patterns and plume dynamics creates challenges in interpreting monitoring data, but location relative to prevailing winds is clearly an important factor for individual risk. When spatiotemporal patterns differ across pollutants, which locations are most important from an individual health perspective are more difficult to ascertain, but evidence shows similar patterns across most pollutants with major public health implications. The one major exception is ozone, which has a large public health burden but is generally reduced in close proximity to airports given the significant local contribution of NO_x emissions.

From a population perspective, proximity and prevailing winds clearly influence the population health burden from airport emissions as well, but population density and spatial patterns of at-risk populations also must be considered. For example, pollutants such as fine particulate matter (with significant contributions from secondary formation) may have public health impacts that can span hundreds (or thousands) of kilometers. Thus, even if individual health impacts may be greatest at relatively close proximity to an airport, the public health impacts will be spread over a very large geographic area where the characteristics of the exposed population needs to be taken into account. That is, health impacts will be influenced not only by exposures, but also health status and other factors that make individuals or subpopulations more susceptible to the effects of air pollution. Elderly individuals and young children, as well as those with pre-existing respiratory or cardiovascular disease, are generally considered to be at greatest risk. That main point is that population-based health assessments that take into account the exposed area and population characteristics may show differing results from an individual perspective where distance is the major factor.

Two general approaches can be used to estimate the public health burden associated with either an individual source (such as an airport) or a source category (such as LTO emissions). Epidemiological investigations involve developing new associations between exposures and health outcomes for a defined population, which can be interpreted as causal given supporting evidence from other epidemiological and toxicological studies. There have been numerous epidemiological studies evaluating ambient air pollution and its effects on respiratory and cardiovascular health, and the methods for conducting these studies are well established in the literature. However, epidemiological studies rarely associate air pollution specific to aviation with health outcomes. This is both because the contribution from aviation to ambient air pollution is generally small and because the pollutants associated with aviation are similar to those from traffic and other local combustion sources. There have been a limited number of occupational epidemiological studies of airport workers, which can better capture exposures specific to the airport environment but may not generalize to the public given differences in exposure levels and health status.

Because direct epidemiological studies of air pollution specific to airports are generally impractical, it is far more common to use health risk assessment methods to quantify the health impacts of airport emissions. These methods typically involve bottom-up analyses linking airport emissions inventories with atmospheric fate-and-transport models, yielding estimates of the marginal contribution of airport emissions to ambient air quality across a region. These contributions are then linked with concentration–response functions for mortality and morbidity, derived from the general air pollution epidemiological literature. In other words, air pollution epidemiology provides the association between specific pollutants and health outcomes, and this evidence is assumed to be applicable to airport-related air pollution. For pollutants that do not differ by source, this approach has fewer uncertainties, beyond exposure assessment uncertainties and general concerns about whether the epidemiological evidence can be interpreted as causal. For fine particulate matter, where the composition from aviation may differ from the ambient composition in a manner that influences health effects, there are additional uncertainties. However, the application of ambient air pollution epidemiology to determine contributions from specific source categories is a well-established approach in the health risk assessment literature, and constituent-specific epidemiology could be used when available and based on statistical models appropriate for health risk assessment.

CHAPTER 5

Current Understanding of Airport Air Quality Health Impacts

This chapter provides the current state of research related to potential health impacts from airport pollutant emissions. It has been organized to respond to the following basic, key questions:

- What pollutants are of most concern at an airport?
- What are the airport contributions to local air quality and health impacts?

The answers to these questions were obtained through a preponderance of the existing research studies conducted in this area. The latter question is a combination of airport contributions to ambient pollutant concentration levels as well as potential health impacts (risks). Because these issues typically accompany each other, they were integrated into one overall question. With on-going research in all of these areas, it should be noted that the answers are representative of a snapshot in time, and they may change with future research. Although there are some overlaps in the answers, they are kept to a minimum but are necessary to properly answer each question.

To promote the understanding of airport health impacts, this section tackles two basic questions dealing with the pollutants of most concern (highest risk) and the airport contributions to local air quality and potential health impacts.

The purpose of answering these questions is to better understand the current health implications of air pollutants generated by airports as a whole. The overall results and conclusions are not intended for scrutinizing individual airports because each airport presents unique characteristics.

5.1 What Pollutants Are of Most Concern at an Airport?

5.1.1 Evaluations

At first glance, the answer to the question of which pollutants are of most concern may simply be based on what pollutants are emitted by the airport and their toxicities. But in order to answer this question, one must consider the risks associated with each pollutant. As previously explained, risk involves taking into account emissions and exposure in addition to toxicity. Just considering toxicity may cause undue attention to be paid to a pollutant that may be emitted in small quantities at an airport such that it may pose minimal risks to the public. In contrast, just focusing on pollutants with high emission rates overall (for the whole airport) may cause undue attention to pollutants with relatively low toxicity that may have little or no impact on the public. In addition, the exposure pathway needs to be considered. If an airport is located in a region where the geography and meteorological patterns are such that most of the emitted pollutants tend to move away from populated areas, the risks associated with that airport may be less than with an airport with lower levels of emissions but with dispersion and atmospheric chemistry conditions that are conducive to exposing larger portions of the public.

As a result, it can be very difficult to determine risks in a general sense across all airports (or even a group of airports) since each has distinctly different characteristics (e.g., mixes of sources, airport layout, operations, etc.). Therefore, each airport needs to be assessed separately for each pollutant, and all of the aforementioned factors need to be taken into account.

That said, researchers still attempt to define risks in a general sense to provide helpful information that may be used as a screening-type starting point to help the aviation community make better decisions regarding airport planning efforts and emissions mitigation measures. That is, the research results could help identify which pollutants to target for such efforts so airports could make efficient use of resources, and also serve as a basis for future research work.

In developing *ACRP Report 7—Aircraft and Airport-Related Hazardous Air Pollutants: Research Needs and Analysis* (Wood et al. 2008), researchers focused on prioritizing HAP compounds. The prioritization was conducted based on combining emissions rates and toxicity, but without consideration of possible variability in the emissions-to-exposure relationship. Although both exposure pathway and the characteristics of the exposed groups were described as a necessary component in risk assessments, they were not included because they were outside the scope of the project. As such, the resulting prioritized list and research was intended to serve as an initial assessment to help identify information gaps.

The study involved reviewing emissions inventories from several major airports (e.g., BOS, PHL, ORD) for emissions contributions from each of the airport sources (aircraft, GSE, GAV, etc.), and the development of risk-based concentrations (RBCs) to serve as measures of toxicity for each pollutant. The resulting prioritized list is provided in Table 5-1.

Table 5-1 compares the prioritized list of pollutants developed from *ACRP Report 7* to those from an FAA 2003 analysis (URS 2003) and the ORD 2005 airport modernization environmental impact statement (EIS) (FAA 2005). The FAA-developed list was based just on emission rates while the ORD study used both emission rates and toxicity. The different results between the ACRP and ORD studies are largely attributed to different toxicity weighting schemes. These lists show similarities such as formaldehyde being included within the top three in all lists, but significant differences such as the fifth-place location of acrolein on the FAA list while it is first on the other two lists.

A study conducted under the FAA's Partnership for AiR Transportation Noise & Emissions Reduction (PARTNER) Program also involved the development of a prioritized list of pollutants

Table 5-1. Prioritized list of pollutants from *ACRP Report 7*.

This ACRP Review	FAA 2003	ORD 2005
Acrolein	Formaldehyde	Acrolein
Formaldehyde	Acetaldehyde	1,3-Butadiene
1,3-Butadiene	Benzene	Formaldehyde
Naphthalene	Toluene	Benzene
Benzene	Acrolein	Acetaldehyde
Acetaldehyde	1,3-Butadiene	Naphthalene
Ethylbenzene	Xylene	Toluene
	Lead	
	Naphthalene	
	Propanal (Propionaldehyde)	

Source: Wood et al. 2008

emitted from airport sources (Levy 2008). The study included assessments of emissions of criteria pollutants and HAPs but focused on fine particles ($PM_{2.5}$), ozone, and a selected group of HAPs (formaldehyde, acetaldehyde, benzene, toluene, acrolein, etc.). This reduced pollutant focus was based on a screening analysis that determined that the excluded compounds pose significantly less risk. Also, for pollutants such as NO_2, the literature was considered inadequate to develop the required concentration-response functions for the required risk assessments, and preliminary evidence indicated a greater criteria pollutant health impact from $PM_{2.5}$ and ozone (EPA 2004 and 2005).

The study included emissions from three airports: Chicago O'Hare International Airport (ORD), Hartsfield-Atlanta International Airport (ATL), and T.F. Green Airport (PVD). These airports were selected based on size, likely magnitude of impact, and location. Emissions inventories for each airport were prepared with the FAA's EDMS/AEDT, and dispersion modeling was performed using AERMOD and CMAQ, the latter of which was used with different grid cell sizes.

For the main comparison work, an intake fraction was defined as a "unitless measure characterizing the total population exposure to a compound per unit emissions of that compound or its precursor." This metric was used to represent population-based exposures, which correspond directly with health risks for pollutants with linear concentration-response functions, and it allowed for rapid comparisons among pollutants and airports. The intake fraction also allowed for rapid estimation of health risks, as it was beyond the scope of this screening-level analysis to conduct more detailed health risk modeling.

Tables 5-2 and 5-3 provide comparisons of the risks by pollutant for each airport studied. The risk values (deaths/year) indicate that fine particles ($PM_{2.5}$) clearly dominate the overall risk and their impacts are magnitudes higher than the other pollutants. For example, the risks for ORD are as follows:

- Total fine particles: 15 deaths/year,
- Total HAPs (air toxics): 0.09 deaths/year, and
- Highest ranking HAP (Formaldehyde): 0.043 deaths/year.

These results are consistent with general EPA risk statistics that also show significantly higher risks posed by fine particles (see http://www.epa.gov/ttn/atw/nata1999/tables.html). Furthermore, the study was simplified (for comparison purposes) such that the HAPs risks are actually cancer risks with only a fraction of that corresponding to death. As such, the relative contribution of fine particles would be even higher in comparison. Non-cancer effects such as those from acrolein and various other pollutants were not considered as part of the prioritizations, because the data available were not amenable to quantification, although the researchers noted that ambient acrolein in the grid cells surrounding the three airports exceeded its RfC, implying potential health effects. This would imply that other HAPs with respiratory effects also could contribute health effects following the non-cancer risk assessment approach used by EPA and others; this would potentially include acetaldehyde, formaldehyde, naphthalene, styrene, and toluene. The negative values for ozone risk in Table 5-3 are indicative of the nuances of ozone chemistry where increasing NO_x emissions can reduce ozone concentrations over an area.

As part of the study, the prioritized list of HAPs by risk was compared to rankings based on just emissions and emissions with toxicity (potency). As indicated in Table 5-4, formaldehyde is at the top of each list, but there are significant differences. For example, without taking into account toxicity or exposure, the emissions-based list shows acetaldehyde as second while the others have the pollutant in sixth place. This comparison helps to exemplify the need to include all aspects of risk so that the relative impacts of such pollutants are properly understood.

Table 5-2. Population risk (deaths/year) for three airports using AERMOD (50-km radius).

Pollutant	ORD	% of air toxics risk	ATL	% of air toxics risk	PVD	% of air toxics risk
Formaldehyde	4.3E-02	48%	3.4E-02	48%	2.7E-03	48%
Acetaldehyde	3.7E-03	4%	2.9E-03	4%	2.3E-04	4%
Benzene	6.4E-03	7%	4.9E-03	7%	4.0E-04	7%
1,3-butadiene	1.9E-02	22%	1.5E-02	21%	1.2E-03	22%
Naphthalene	6.9E-03	8%	5.4E-03	8%	4.4E-04	8%
Styrene	9.7E-03	11%	7.5E-03	11%	6.1E-04	11%
Phenanthrene	1.7E-06	0%	1.3E-06	0%	9.4E-08	0%
Fluoranthene	4.8E-05	0%	3.9E-05	0%	2.1E-06	0%
Pyrene	1.3E-06	0%	1.0E-06	0%	6.0E-08	0%
Anthracene	2.5E-07	0%	2.3E-07	0%	1.3E-08	0%
Benzo[b]fluoranthene	1.1E-04	0%	9.1E-05	0%	4.9E-06	0%
Benzo[k]fluoranthene	1.1E-04	0%	9.1E-05	0%	4.9E-06	0%
Benz[a]anthracene	1.6E-05	0%	1.6E-05	0%	8.8E-07	0%
Benzo[a]pyrene	1.5E-04	0%	1.6E-04	0%	8.7E-06	0%
Chrysene	2.0E-06	0%	2.0E-06	0%	8.8E-08	0%
Indeno[1,2,3-c,d]pyrene	1.1E-04	0%	9.1E-05	0%	4.9E-06	0%
Total air toxics	9.0E-02		7.0E-02		5.7E-03	
Total fine particulate matter	15.0		7.2		0.65	

Source: Levy et al. 2008

Table 5-3. Population risk (deaths/year) for three airports using CMAQ (12- and 36-km grids).

	ORD		ATL		PVD	
Pollutant	12 km	36 km	12 km	36 km	12 km	36 km
Formaldehyde	5.9E-02	4.2E-02	4.3E-02	3.5E-02	2.8E-03	2.2E-03
Acetaldehyde	4.0E-03	2.8E-03	3.0E-03	2.3E-03	1.9E-04	1.5E-04
Benzene	4.5E-03	3.5E-03	3.7E-03	2.9E-03	2.4E-04	1.9E-04
1,3-butadiene	1.4E-02	9.2E-03	9.9E-03	7.2E-03	6.4E-04	4.9E-04
Naphthalene	4.9E-03	3.4E-03	3.7E-03	2.9E-03	2.3E-04	1.9E-04
Total air toxics	8.6E-02	6.0E-02	6.3E-02	5.0E-02	4.1E-03	3.2E-03
Total fine particulate matter	12	7.9	4.5	4.2	0.57	0.48
% Sulfate	49%	52%	59%	64%	41%	37%
% Nitrate	-2%	-5%	-12%	-8%	13%	21%
% EC	15%	16%	19%	16%	13%	12%
% OC	21%	20%	18%	12%	18%	15%
% Ammonium	17%	17%	15%	16%	15%	16%
% Other	1%	0%	0%	0%	0%	-1%
Ozone	-1.9	-2.3	-2.1	-1.9	-0.2	-0.1

Source: Levy et al. 2008

Table 5-4. HAPs rankings based on different prioritization schemes.

Pollutant	Ranking, emissions only	Ranking, emissions*potency	Ranking, risk
Formaldehyde	1	1	1
Acetaldehyde	2	6	6
Benzene	3	5	5
1,3-butadiene	4	2	2
Naphthalene	6	4	4
Styrene	5	3	3
Phenanthrene	7	14	14
Fluoranthene	9	11	11
Pyrene	8	15	15
Anthracene	13	16	16
Benzo[b]fluoranthene	10	8	9
Benzo[k]fluoranthene	10	8	9
Benz[a]anthracene	15	12	12
Benzo[a]pyrene	16	7	7
Chrysene	14	13	13
Indeno[1,2,3-c,d]pyrene	12	10	8

Source: Levy et al. 2008

The pollutants selected for this project represent those that have the greatest risks based on airport emission levels and toxicity.

Another study conducted under the PARTNER Program (Project 15) used a combination of CMAQ and the Environmental Benefits Mapping and Analysis Program (BenMAP) to study airport air quality impacts from 325 U.S. airports, focusing on the nonattainment areas (Ratliff et al. 2009). BenMAP uses health impact functions for criteria air pollutants to relate changes in air concentrations to a change in the incidence of a health endpoint. Only the impacts from PM and ozone were included in the study. Similar to the previous studies, the modeled results indicated that almost all of the health impacts were due to fine particles with about 160 cases of PM-related premature mortality per year. Health impacts such as chronic bronchitis, non-fatal heart attacks, respiratory and cardiovascular illness, also were associated with aircraft emissions.

Although health concerns are associated with each of the criteria pollutants, the greatest risks (i.e., cancer and morbidity) seem to be posed by PM and HAPs. Specifically, fine PM ($PM_{2.5}$) appears to pose the greatest risk to human health—magnitudes higher than HAP species. Formaldehyde was ranked as the HAP species having the greatest risk. Although ultrafines are inherently included as part of $PM_{2.5}$, further research is necessary to better understand potential health impacts from ultrafines.

5.1.2 Summaries and Conclusions

Studies such as these illustrate the need to conduct further research on more pollutants and other airports, but they indicate that, with regard to the potential for health impacts (risk), fine particulate matter appears to pose the greatest risk. As such, much of the current research in airport air quality has focused on fine particles. Among criteria air pollutants, ozone also can contribute significantly to public health impacts, although it would have a lesser impact in the near field and has been excluded from some previous analyses given methodological limitations. For HAPs, formaldehyde was ranked as having the highest risk followed by others such as 1,3-butadiene, styrene, naphthalene, benzene, acetaldehyde, etc. Although fine particles may pose much greater risk, it does not negate the need to further investigate other pollutants. In addition, although many previous analyses have focused on fine particulate matter mortality given its large contribution to monetized health impacts, additional health outcomes from $PM_{2.5}$ and other pollutants merit inclusion.

5.2 What Are the Airport Contributions to Local Air Quality and Health Impacts?

5.2.1 Evaluations

The health effects of each pollutant are summarized in Chapter 4. Although there are uncertainties associated with the toxicities, exposures, etc., the effects are well documented. Organizations such as the EPA and the World Health Organization (WHO) provide extensive information on pollutant health effects.

- EPA Risk: http://www.epa.gov/oia/air/pollution.htm
- WHO Risk: http://www.who.int/mediacentre/factsheets/fs313/en/

Although the overall airport emissions characteristics (mix of pollutants, chemical characteristics, sizes ranges for PM, etc.) may not be the same as other sources, the health effects of each pollutant are the same. That is, all other things being equal, a mass of a pollutant emitted from an airport will produce the same health effects as the same amount from other sources (or another airport)—if the pollutants are identical (no differences in characteristics).

> This section presents summaries of selected studies to illustrate the air pollutant concentration levels (and their variability) that can be found at different airports and implications for their contributions to local air quality.

As such, most studies that have addressed the question of airport impacts on local air quality and health impacts have used data from measurements or modeling results to provide indications of exposure (either with emissions or ambient pollutant concentrations) and have linked these data with literature-based concentration-response functions within human health risk assessments. These encompass correlating aircraft activities (e.g., aircraft operations) with emissions, modeling how those emissions influence concentrations, and comparing airport concentration contributions to background levels. Since no two airports are the same, it is difficult to make general statements regarding airport contributions to local air quality because this depends on many factors including emissions strength (emission factors), airport layout, local meteorology, etc. Although further studies are needed, the available findings from the literature can be used to provide some general understandings of airport contributions. As such, each of the studies cited in the references was reviewed, and the following abridged summaries of selected references provide an indication of the wide range of different types of studies and results available for consideration for further details:

- *ACRP Report 71: Guidance for Quantifying the Contribution of Airport Emissions to Local Air Quality* (Kim et al. 2012). The goal of the project was to better understand the use of modeling and measurement capabilities to determine airport contributions to air quality. This included measurements of ambient concentrations for both criteria pollutants and HAPs.
- *The Impact of NOx, CO and VOC Emissions on the Air Quality of Zurich Airport* (Schurmann 2007). Ambient measurements of criteria pollutants were performed to assess the impact of airport emissions on local air quality.
- *T.F. Green Airport Air Monitoring Study* (RIDEM 2008). A monitoring study was conducted by the Rhode Island Department of Environmental Management (RIDEM) to assess air quality levels and health risks to surrounding neighborhoods. Measurement sites were located around the airport with some near runways. The goal of the study was to characterize HAP concentrations in communities near the airport, assess contributions from different sources (e.g., aircraft, GSE, motor vehicles), verify modeling outputs, and develop a baseline that can be used to assess impacts of future airport changes.
- *Preliminary Study and Analysis of Toxic Air Pollutants from O'Hare International Airport and the Resulting Health Risks Created by These Toxic Emissions in Surrounding Residential Communities* (ENVIRON 2000). The study used emissions data collected in 1999 to conduct a health risk assessment for the airport.
- *General Aviation Airport Air Monitoring Study* (SCAQMD 2010). The goal of the study was to characterize the ambient levels of several important air toxics and ultrafines in communities adjacent to Van Nuys Airport (VNY) and Santa Monica Municipal Airport (SMO).
- *Teterboro Airport Detailed Air Quality Evaluation* (ENVIRON 2008). The study involved measurements of various pollutants including volatile organic compounds (VOCs) and PM to investigate health risks associated with airport operations.
- *ACRP Report 7: Aircraft and Airport-Related Hazardous Air Pollutants* (Wood 2008). San Leandro Measurements: After JETS-APEX2, the Aerodyne Mobile Laboratory spent 2 days at the San Leandro Marina, which is about 2 km downwind of the OAK runway.
- *Aircraft Emissions' Contributions to Organic Aerosols in a Regional Air Quality Model Using the Volatility Basis Set* (Woody 2012). The focus of this work was to estimate contributions of aircraft emissions from ATL to $PM_{2.5}$, focusing on organic aerosols, using a research version of CMAQ v4.7.
- *Relationships between Emissions-Related Aviation Regulations and Human Health* (Sequeira 2008). The study was conducted under the Energy Policy Act of 2005 to assess aircraft impacts on air quality in the United States.
- *Risk Factors of Jet Fuel Combustion Products* (Tesseraux 2004). Using available monitoring data, the possibilities and limitations for a risk assessment approach were determined for the population living around large airports. Measurement data from German airports at Frankfurt and Hamburg, as well as from ORD, were presented (Spicer 1994, Eickhoff 1998, and EPA 2002).
- *Detecting and Quantifying Aircraft and Other On-Airport Contributions to Ambient Nitrogen Oxides in the Vicinity of a Large International Airport* (Carslaw 2006). Based on concerns over the building of a third runway at London-Heathrow International Airport (LHR), data from NO_x monitoring sites near the airport were used to assess contributions by the airport.
- *LAX Air Quality and Source Apportionment Study* (Tetra Tech 2013). The Los Angeles International Airport (LAX) Air Quality Source Apportionment Study (AQSAS) was conducted to measure criteria pollutant HAP concentrations in the vicinity of LAX and to assess the potential impacts of airport-related emissions on ambient air quality of communities adjacent to the airport.

- *Current and Future Particulate-Matter-Related Mortality Risks in the United States from Aviation Emissions during Landing and Takeoff* (Levy 2012). A study was conducted to systematically quantify aviation contributions to air quality concentrations and corresponding public health effects using 99 airports.
- *Development and Evaluation of an Air Quality Modeling Approach to Assess Near-Field Impacts of Lead Emissions from Piston-Engine Aircraft Operating on Leaded Aviation Gasoline* (Carr 2011). A new methodology is presented on modeling the dispersion of lead emissions from general aviation aircraft.

These example studies illustrate the fact that recent and current research tends to follow the pollutant prioritization scheme previously discussed (i.e., significant focus on PM). Although more research is necessary, the information gathered from existing studies allows for a snapshot-in-time summary of airport impacts. This is a temporary summary since further research is expected, including both measurement and modeling efforts. In particular, measurements will be necessary to help assess actual conditions at an airport, as well as to validate modeling efforts. Based on the research work conducted thus far, it is expected that as the research work continues, some of the details may become clarified and corrected, but many of the more general understandings will likely remain intact.

Along those lines, one of the first general issues is whether airports have a discernible influence on local air quality. Some studies have indicated that pollutant concentration levels near an airport are similar to urban levels (e.g., Tesseraux 2004, McGulley 1995, and KM Chng 1999), which can result in a misunderstanding that airports overall contribute little or no pollutants to local air quality. Contrary to this, there have been several measurement studies that indicate that concentrations around airports are elevated (e.g., Wood 2008, RIDEM 2008, Zhu 2011). Depending on the pollutant, the contributions may range from a small or negligible contribution (e.g., some criteria pollutants and HAPs species) to significant contributions (e.g., ultrafine particles). Also, background concentrations may affect pollutants through chemical conversions. In addition, various modeling studies have quantified the concentration contributions and associated health risks (e.g., Levy 2008, Sequeira 2008, and Barrett 2012, etc.)

> Although there have been differing conclusions from past studies, the preponderance of the evidence appears to indicate the concentrations of pollutants (depending on the pollutant) are generally elevated in the vicinity of airports.

Modeled estimates and measured findings for the specific contributions to local air quality and health impacts are varied and depend on pollutants. The focus of each study—which pollutants and heath assessments were included and which were left out—also is important. The following summaries provide examples of quantified airport contributions to ambient concentrations as well as health-related statistics.

- On a national level, the modeling study conducted under PARTNER Project 15 (Ratliff 2009 and Sequeira 2008) found aircraft emissions contributing to the following criteria pollutant concentrations:
  - Annual $PM_{2.5}$: 0.01 μg/m^3 (0.08 percent) and
  - 8-hour ozone: 0.10 ppb (0.12 percent).

  These contributions represent averages across the U.S. airports selected for this study. As such, individual airports may experience significantly different outcomes.

The airport concentrations (largely monitored data) presented herein were obtained from publicly available documents for illustration purposes to summarize and help expand the understanding of airport contributions to local air quality. Since most of the cited studies were research efforts, the concentrations should not be taken out of context and used for regulatory purposes. For further details and to understand the context of each dataset, it is recommended that the cited sources be reviewed accordingly.

- Measurements were conducted at Dulles International Airport (IAD) on the airside adjacent to an apron area (Kim et al. 2012). The measured 1-hour concentrations for criteria pollutants were all much lower than the NAAQS, and in most cases, *much* lower:
  - NO_2: Typically below 30 ppb,
  - CO: Typically below 1 ppm,
  - SO_2: Typically below 3 ppb,
  - O_3: Typically below 20 ppb in the winter and below 50 in the summer, and
  - $PM_{2.5}$: Typically below 25 μg/m^3 (24-hour samples).

  These measured levels seem to suggest that the airport's contributions to local air quality tend to be small.
- The measurements and modeling conducted under the LAX Source Apportionment Study provided a lot of detailed information. A summary follows (Tetra Tech 2013):
  - CO, NO_2, SO_2, and Pb ambient concentrations within the communities next to LAX were below threshold levels for state and national standards.
  - $PM_{2.5}$ concentrations were near air quality standard levels and had compositions of
    - 50–75 percent ammonium nitrate, ammonium sulfate, and unapportioned organic matter;
    - 20–30 percent sea salt aerosol, soil-derived fugitive dust, and wood smoke;
    - 1–2 percent jet exhaust; and
    - 8–17 percent diesel plus gasoline vehicle exhaust.
  - Airport $PM_{2.5}$ concentration contributions were estimated to be 5–20 percent.
  - CMAQ modeling showed most of the nitrates, sulfates, and most of the residual organic matter were formed outside of the study area.
  - Winter: airport accounted for 15–22 percent of CO and NO_x concentrations.
  - Summer: airport accounted for 40–50 percent CO and 50–74 percent NO_x concentrations at some measurement sites.
  - Airport SO_2 contributions ranged from 10–80 percent depending on season.
  - HAP concentrations were consistently lower than the levels found elsewhere in the basin area.
  - The generally low concentration levels can be attributed to the coastal location of LAX.
  - Ultrafine composition was found to be largely composed of sulfuric acid aerosols from jet exhaust and their number concentrations east of LAX were found to be higher than typical values in the region.
- Using measured data near LHR, Carslaw et al. (2006) found that aircraft NO_x concentrations could be detected at least 2.6 km from the airport. At the airport boundary, approximately 27 percent of the annual mean NO_x and NO_2 concentrations were found to be due to aircraft. At distances of 2 to 3 km downwind of the airport, an upper limit of 15 percent contribution from the airport was estimated.
- Ellerman et al. (2010) used measurement data from Copenhagen Airport to show that the number of ultrafine particles (43,000 particles/cm^3) in an apron area was approximately

Particles/cm^3 is a measure of the number of particles over a unit volume (particle concentration) and should not be confused with PM mass concentrations such as μg/m^3.

Particles/cm^3 cannot be converted to mass concentrations without the use of (or assumptions involving) the density of the particles.

It also should be noted that particle counting equipment does not typically differentiate between primary and secondarily formed particles (i.e., particles formed in the atmosphere). As such, studies that do not explicitly account for the effects of secondary particles may overestimate the number of particles.

4.4 times greater than the levels found at a background site (near a major roadway). In contrast, a site located on the east side of the airport (closer to the airport boundary) experienced 12,000 particles/cm^3 or 22 percent higher than the same background concentration. The study also found that 90 percent of the particles were in the lower end of the ultrafine size range of 6–40 nm.

- From measurements downwind of Santa Monica Municipal Airport (SMO), Hu et al. (2009) found elevated concentrations of ultrafine particles beyond 660 m downwind of SMO. At distances of 100 and 660 m downwind, respectively, ultrafine concentrations were found to be 10 and 2.5 times greater than background levels.
- Using measured data near runways at LAX, Hsu et al. (2013) observed median ultrafine particle concentrations of 150,000 particles/cm^3. In some cases, concentrations exceeded 1,000,000 particles/cm^3, which is far in excess of levels seen near roadway sources. However, the concentrations were observed to drop rapidly with distance—by an order of magnitude before reaching the airport boundaries.
- Based on data collected at the LAX blast fence (downwind sites up to 600 m from a runway and upwind of a major runway), Zhu et al. (2011) found high spikes in ultrafine particle concentrations. Time-averaged concentrations of $PM_{2.5}$, two carbonyl compounds, formaldehyde, and acrolein, were found to be elevated compared to background levels. As ultrafine particle and black carbon levels have previously shown to return to background levels at 300 m downwind for roadway sources, the persistence of airport ultrafine concentrations up to 600 m seem to indicate that airport emissions may have a broader spatial impact than roadway sources.
- Using data from a monitoring study in the vicinity of LAX, Westerdahl et al. (2008) found the following:
  - Upwind site:
    - Ultrafine particles ranged from 58 to 3,800 particles/cm^3 at below 90 nm size,
    - NO_x ranged from 4–22 ppb,
    - BC ranged from 0.2–0.6 μg/m^3, and
    - PM-PAH ranged from 18–36 ng/m^3.
  - Downwind site:
    - Ultrafine particles—50,000 particles/cm^3, 500 m downwind at 10–15 nm size and
    - Black carbon, PM-PAH, and NO_x levels were "elevated to a lesser extent."
- A monitoring study near PVD showed the following results (Rhode Island 2007):
  - None of the HAP species measured exceeded the acute health and non-cancer benchmarks.
  - Concentrations of benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acetone, chloroform, carbon tetrachloride, and perchloroethylene exceeded the cancer benchmark levels.
  - Formaldehyde concentrations at all sites were greater than 10 times the cancer risk benchmark.

- Acetaldehyde and acetone were 2.5–3 times higher than the cancer risk benchmark.
- Black carbon concentrations in communities were higher in areas near roadways.
- Although a non-reference method (with a bias towards higher readings) was used to measure $PM_{2.5}$, the levels were still below the NAAQS in the communities near the airport. Airport contributions could be identified based on the fidelity of the monitors.

- Based on data collected during a monitoring study around VNY and SMO, the following were found (SCAQMD 2010):
  - The daily average TSP lead concentrations at airport sites were 2–9 times higher than corresponding South Coast Basin levels and mostly below the NAAQS. But 24-hour concentrations at SMO near the tarmac were found to be above the NAAQS on more than one occasion.
  - The highest VOC concentrations at the airport sites were comparable to levels found at urban monitoring sites.
  - $PM_{2.5}$ concentration levels, as well as those of organic carbon (OC) and elemental carbon (EC), were found to be similar or below the corresponding South Coast Basin averages.
  - Ultrafine particle numbers measured near a runway were found to be up to 600 times that of background air.
  - Diurnal profiles suggest that CO concentrations may be mostly due to motor vehicles from surrounding roadways rather than the airport.
- From ambient measurements taken at the San Leandro Marina (Wood 2008), the average HCHO concentration in a time series is 1.3 ppb while the interpolated background value is approximately 0.8 (similar to the background value observed on the OAK airport grounds).
- On a national level, a system-level health risk assessment study (Levy 2012) using CMAQ and appropriate concentration response functions (CRF) to model baseline and future scenarios determined that national population health impacts would increase by a factor of 6.1 from 2005 to 2025. This was based on a notional "what if" aviation growth scenario and corresponding emissions assumptions. The factor of 6.1 increase was decomposed into the following contributing factors:
  - Emissions: 2.1;
  - Population factors (growth and aging): 1.3; and
  - Changing non-aviation concentrations, enhancing $PM_{2.5}$ formation: 2.3.
- A study analyzing HAP emissions from ORD and related health risks (ENVIRON 2000) showed that HAPs concentrations measured at the airport fence area may result in about 5 times higher cancer risks than those associated with background air. The most significant contributing HAPs such as aldehydes, benzene, and naphthalene are included in aircraft emissions.
- Based on a health impact study of U.K. airport expansions, especially LHR (i.e., third runway), the following results were estimated (Barrett et al. 2012 and Yim 2013):
  - Approximately 110 people in the United Kingdom die early each year due to airport emissions today. Of these deaths, approximately 50 are due to emissions from London Heathrow.
  - By 2030, without airport capacity expansion, the number of early deaths per year caused by U.K. airport emissions is projected to increase to 250.
- For an airport occupational exposure study (Tunnicliffe et al. 1999) conducted at Birmingham International Airport, U.K., it was found that the results appear to support an association between high occupational exposures to aviation fuel or jet stream exhaust and excess upper and lower respiratory tract symptoms for airport male workers. However, it is acknowledged that there could have been some bias effects such as residual confounding due to smoking.

These example findings illustrate the types of quantitative and investigative studies that have been conducted on airport air quality health impacts. They also illustrate that airport concentration contributions and health impact statistics are closely related. Although the types and scope of these studies vary, they help to form a picture of the current understanding of airport health impacts.

5.2.2 Summaries and Conclusions

In summary, it should be noted that all pollutants emitted from airports have some level of toxicity with the potential to cause health effects. Again, each airport is different and can have significantly different emissions, weather patterns, geography, etc., from each other, resulting in different air quality contributions. With that in mind, the existing body of research appears to suggest the following for each pollutant (or category of pollutants):

- Most criteria gases (CO, NO_2, and SO_2)—In most situations, airport contributions of these pollutants appear to be such that resulting ambient community or urban concentrations are generally below the NAAQS. Depending on the pollutant and distances to the affected communities, airport contributions of these pollutants may be relatively small. However, as studies have pointed out, the contributions can still be apportioned at relatively far distances (a few miles).

  While much of the health impact focus has been placed on PM and HAPs, it is worth remembering that gaseous criteria pollutants can cause damage to the respiratory system. But the evidence supporting quantitative health risk assessment is more limited for CO, NO_2, and SO_2, relative to ozone and fine particulate matter.

Although variability exists among airports, past studies seem to indicate that airport contributions of criteria gases generally tend to be small (or at least in most cases, not contributing to the point where the vicinity of an airport exceeds the NAAQS).

- In general, most studies suggest that ozone levels in the vicinity of airports will tend to be lower than background levels due to the chemistry with NO_x. Because airports emit large quantities of NO_x emissions, health assessments indicate the risks associated with airport indirect ozone contributions to *local* air quality are relatively small. However, the airport contributions to *regional* ozone can be greater and can contribute significantly to the overall health impacts of airport emissions.
- Lead has been an emerging source of concern due to its toxicity and use at GA airports. Modeling and measurement efforts have shown that lead emissions from GA airports can persist up to 900 m downwind and may be above the background and the NAAQS.

Unlike criteria gases, $PM_{2.5}$ concentrations in and around airports seem to vary significantly.

Although health impacts of $PM_{2.5}$ have been found to be higher than others, further research is necessary on the influence of PM chemical composition and size distribution.

- $PM_{2.5}$ or fine particles are a serious concern for health impacts as they dominate air quality health risks (e.g., by orders of magnitude over HAPs). The levels found in airport measurement studies vary, ranging from relatively low levels to those that are close to the NAAQS, and in some cases exceeding the standards.

  In addition to the variability of $PM_{2.5}$ contributions, the various components and types of PM including black carbon, nitrates, sulfates, volatiles, etc., need to be recognized as well.

Modeling studies suggest that some of the PM (secondary PM) may form much farther downstream (many miles). As such, the total health impacts from airport-emitted PM and PM precursors requires regional-scale atmospheric modeling. Also, although the general health effects of PM regarding both morbidity and mortality are established, there is greater uncertainty regarding the influence of chemical composition and size distribution of PM on health outcomes.

PM_{10} is also a health concern, but because coarse particles ($PM_{10-2.5}$) are filtered to a greater extent by the upper respiratory tract in humans, there is less focus on its impacts.

- Ultrafine PM is a suspected major health concern but there is little data available on both particle concentrations and resulting health effects. However, existing studies indicate that ultrafine particle concentrations are highly elevated at an airport (i.e., near a runway) with particle counts that may be orders of magnitude higher than background with some persistence many meters downstream (e.g., 600 m).

Although ultrafine PM is a suspected major health concern, there is little data currently—more research is necessary. But from existing studies, ultrafine levels have been found to be elevated (above background levels) in the vicinity of airports.

- While HAPs or air toxics have less risk than $PM_{2.5}$, they still pose a health concern, in part due to the potential for cancer and premature death endpoints. Measurement studies indicate that concentration levels can vary significantly from one airport to another. Although some studies suggest monitored concentrations may be comparable to background levels (depending on where the measurements were conducted), there is also enough evidence to suggest that airport contributions are not negligible.

As with other pollutants, more studies are necessary to measure concentration levels of HAPs near airports. Although some studies indicate that HAP emissions from airports may be negligible (i.e., resulting in concentrations comparable to background levels), there appears to be enough evidence that suggests otherwise.

CHAPTER 6

Conclusions

Since all airports are different, it is very difficult to make general statements about airport air quality contributions and health impacts. Airport contributions to air quality can depend on many different factors including, but not limited to, airport source types (e.g., aircraft fleet mixes), airport layout and location, geography, and meteorology. Contributions to population health impacts depend on these factors as well as population patterns and vulnerability attributes.

Although there have been increasing amounts of research on airport contributions to local air quality health impacts, more research is necessary. Although the current state of research allows one to "paint a picture" of current understanding in this area, it should be considered as a snapshot in time since future research may provide further details. The current research efforts appear to be aligned with the prioritization of pollutant health risks. Based on the relative number of studies and the recent focus, available resources appear to be correctly being applied to PM and HAPs research, with consideration of ozone for regional-scale analyses.

Regarding airport contributions to local air quality, studies have shown that airport emissions and resulting concentration contributions can be well correlated to airport operations (e.g., aircraft usage) as part of source identification and apportionment work. The more pertinent issue is in quantifying the contributions. The current research efforts appear to be aligned with the need for further measurements and an understanding of health impacts.

Risk assessments have shown that fine PM ($PM_{2.5}$) dominates the overall health risks posed by airport emissions. The risk for fine particles is orders of magnitude higher than that for the closest HAP, formaldehyde, although the ability to quantify the non-cancer health effects of HAPs is limited. $PM_{2.5}$ levels have been found to vary significantly at different airports. Although PM_{10} is a health concern, the fact that much of the coarser portion is filtered out by the upper respiratory tract in human beings makes it of less concern than the finer particles.

Studies appear to indicate that most criteria gases (e.g., CO, NO_2, and SO_2) generated from airports generally tend to result in similar concentrations to background (or urban) levels in surrounding communities, although with appreciable contributions closer to the emission sources and variable conclusions depending on background levels. Although health effects of criteria gases are well defined, quantitative health risk assessments for these gases are relatively limited in comparison to ozone and PM.

Because of the nature of ozone chemistry, ozone levels around airports tend to be lower than background levels (i.e., airports tend to be a sink for ozone). Although ozone levels in the vicinity of an airport may be depressed, airports can contribute to the formation of ozone on a larger regional level, thus resulting in increased health impacts.

Lead is a concern at GA airports and will continue to be an issue as AvGas continues to be used. Current studies indicate that lead emissions can noticeably persist at distances close to

1,000 meters downwind of an airport. As such, studies indicate that lead contributions near GA airports may not be negligible.

Studies indicate that secondary PM may form at significant distances downstream from an airport (many miles), adding to health impacts thus, requiring large-scale (e.g., regional) modeling to determine overall PM health impacts. In addition, the impacts of different PM components including black carbon, nitrates, and sulfates need to be taken into account as well as PM size distributions.

In addition to the suspected health concerns of ultrafine PM (along the lines of the current understanding of $PM_{2.5}$), measurement studies have shown that ultrafine concentrations tend to be highly elevated near an airport (near runways) with persistence above background levels at distances of 600 meters downwind of an airport. As such, ultrafine PM generated by airports is suspected of having a broader impact than that generated by roadway vehicles.

Concentrations of HAPs at airports seem to vary. Although some studies suggest that HAP concentrations near airports may be similar to background levels, there appears to be enough evidence suggesting otherwise, however, there are noticeable uncertainties concerning the actual concentration levels.

Health assessments involving a system-level scope (i.e., involving many airports) appear to provide useful statistics on both total and average airport risks with the understanding that individual airport studies also need to be conducted, the results of which may differ significantly.

CHAPTER 7

Recommendations for Future Research

The following provides a summary of the existing knowledge gaps and recommended future research to help advance the understanding of airport air quality contributions and public health impacts.

- In general, more health-related research is necessary to gain a better understanding of airport air quality contributions and health impacts. This includes more airport air quality monitoring programs and additional health risk assessments that should involve both airport and system levels. Understanding the health risks attributable to an individual airport requires atmospheric modeling and health risk assessment specific to the individual airport, and these efforts should be prioritized to provide insight to individual airport operators.
- Since, from recent risk assessments, PM seems to pose the greatest risk to human health, more specific characterization studies of fine particles ($PM_{2.5}$), ultrafines, PM components, and size distributions are necessary. Health effects and risks of ultrafines and PM components (e.g., nitrates, sulfates, etc.) are not well understood. More characterizations are necessary to determine what further differences may exist between primary PM directly emitted from aircraft versus secondary PM formed in the atmosphere, as well as emitted from other sources (e.g., roadway vehicles).
- Although PM and HAPs are the priority, gaseous criteria pollutants need further research to better understand their health risks (i.e., in addition to current understanding of their health effects).
- More research on the overall risks posed by lead emissions from GA aircraft is necessary. This should include more measurements as well.
- Modeling uncertainties need to be better understood so that health risk assessments can be made more reliable with clearer (or smaller) error bands. This includes uncertainties in emissions inventories, atmospheric dispersion models, and in the underlying health evidence.
- With the importance of $PM_{2.5}$ health impacts, the PM emissions data, as well as emissions of particle precursors (VOCs, NO_x, SO_2), need to be as accurate as possible. More mass and size-based PM measurements of aircraft engines should be conducted to develop a more accurate set of emission factors (emissions indices).
- Research needs to be conducted on interactions with the following other health impacts:
  - Multi-pollutant epidemiological investigations should be conducted to assess potential synergies and interactions of different pollutants on health effects.
  - Similarly, risks associated with air pollution and noise combined should be assessed to determine what interactions may exist.
- Although some source apportionment methods such as the Chemical Mass Balance (CMB) have been used, some guidance or clarification of the methods would be helpful.
- In addition to risks placed on the public, more assessments should be conducted on airport workers (e.g., GSE operators) since they are much closer to the sources. Also, more studies should be conducted (with measurements) on the risks to passengers.

- Further research is needed to determine aircraft power setting (and operations) influences on emitted PM characteristics, including size and chemical characteristics.
- Research should be conducted to improve aircraft taxiing/idle and engine start emissions modeling. These transient conditions tend to have different emissions characteristics than steady-state conditions.
- In addition to dispersion modeling, local atmospheric chemistry modeling should be further investigated/improved since AERMOD generally does not have chemistry modeling capabilities (beyond the use of decay rates and simplified NO_x chemistry). Although CMAQ has a large set of chemistry mechanisms, it uses larger grid sizes that make finer spatial resolution assessments difficult. Nested modeling capabilities can be applied, but require greater resources, and there remains the need to use ambient monitoring to validate dispersion modeling outputs.
- Rather than using the typical 1-hour or coarser concentrations from models like AERMOD, time-varying models should be investigated to provide more robust modeling environments to conduct health risk assessments.

Acronyms

AEDT	Aviation Environmental Design Tool
AMTIC	Ambient Monitoring Technology Information Center
APEX	Aircraft Particle Emissions eXperiments
AQSAS	Air Quality Source Apportionment Study
ATL	Atlanta Hartsfield-Jackson International Airport
ATOFMS	Aerosol Time-of-Flight Mass Spectrometer
AvGas	aviation gasoline
BC	black carbon
BOS	Boston Logan International Airport
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAEP	Committee on Aviation Environmental Protection
CFR	Code of Federal Regulations
CMAQ	Community Multiscale Air Quality
CNG	compressed natural gas
CO	carbon monoxide
EC	elemental carbon
EDMS	Emissions and Dispersion Modeling System
EF	emission factor
EI	Emissions Index
EIS	Environmental Impact Statement
GA	general aviation
GAV	ground access vehicle
GSE	ground support equipment
HAP	hazardous air pollutant
HC	hydrocarbon
HCHO	formaldehyde
ICAO	International Civil Aviation Organization
LAX	Los Angeles International Airport
LHR	London-Heathrow International Airport
LNG	liquefied natural gas
MOUDI	Micro-Orifice Uniform Deposit Impactor
NAA	nonattainment area
NAAQS	National Ambient Air Quality Standards
NEI	National Emission Inventory
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NIOSH	National Institute for Occupational Safety and Health

NO	nitrogen oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NSR	New Source Review
OC	organic carbon
OG	organic gases
ORD	Chicago O'Hare International Airport
OSHA	Occupational Safety & Health Administration
PAH	polycyclic aromatic hydrocarbon
PARTNER	Partnership for AiR Transportation Noise & Emissions Reduction
Pb	lead
PEL	permissible exposure limit
PFC	Passenger Facility Charge
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
ppb	parts per billion
ppm	parts per million
PSD	prevention of significant deterioration
PVD	T. F. Green Airport
REL	recommended exposure limit
RfC	reference concentration
SIP	State Implementation Plan
SMO	Santa Monica Municipal Airport
SMPS	Scanning Mobility Particle Sizer
SO_2	sulfur dioxide
SO_x	sulfur oxides
TEB	Teterboro Airport
TIM	time in mode
TOG	total organic gases
TSP	total suspended particulate matter
UFP	ultrafine particle
VALE	Voluntary Airport Low Emission
VNY	Van Nuys Airport
VOC	volatile organic compound

APPENDIX A

Literature Review Summary and References

		General and Overviews			Modeling		Measurements		Health Impacts					Pollutants					Sources							Airport Size			Miscellaneous		
Citation	**Summary**	**Overviews and Policies**	**Standards and Guidance**	**Methodology and/or Reviews**	**General Emissions and Dispersion**	**Fate and Transport**	**Emissions**	**Ambient**	**Epidemiological Studies**	**Risk Assessment/Health Impact Assessment**	**Pollutant Contributions and Toxicities**	**Monetization**	**Correlations to Airport Activity, Meteorology, etc.**	**Criteria Gases (e.g., NO_2)**	**Lead (Pb)**	**Particulate Matter (PM)**	**VOCs and HAPs**	**Secondary Pollutants**	**All Airport Sources**	**Aircraft Main Engines Only**	**APU and Ground Power**	**GSE and/or GAVs**	**Stationary Sources**	**Other Airport Sources**	**Non-Airport Sources (e.g., Surrounding Highways)**	**Large/International**	**Medium/Regional**	**Small/GA**	**Airport Surrounding Geography**	**Airport Seasonality**	**Yearly Trends**
ACI EUROPE (2010) "Effects of Air Traffic on Air Quality in the Vicinity of European Airports, Local Air Quality Assessments at and around European Airports Based on the Airspace Closure in Europe during the Volcano Eruption in Iceland in April 2010," ACI EUROPE Environmental Strategy Committee, Brussels, Belgium.	During the Icelandic volcano eruption in April 2010, European airspace was closed for a number of consecutive days. The report produces graphs for 13 major European airports showing aircraft movements before, during, and after the closure, alongside air pollutant concentrations at monitoring stations close to the airports. The report highlights the limitations of the approach taken but concludes, "reduction of flight activity did not significantly affect air quality concentrations of NO_2, confirming that the contribution of air traffic to local air quality in the vicinity of airports is very small."							X						X																	
Adamkiewicz G., Hsu H.H., Vallarino J., Melly S.J., Spengler J.D., Levy J.I. "Nitrogen Dioxide Concentrations in Neighborhoods Adjacent to a Commercial Airport: A Land Use Regression Modeling Study," *Environ Health* 9:73 (2010).	Saturation sampling for nitrogen dioxide was conducted in neighborhoods surrounding TF Green Airport (PVD) in 2007–2008. Land-use regression techniques were used to determine predictors associated with airport and traffic.				x			x						x					x						x		x			x	

Advanced Decision Systems (2005) "Evaluatie Schipholbeleid: Schonere Lucht, Schonere Vliegtuigen, Meer Uitstoot Luchtverkeer," Dutch Ministry of Transport and Works, ed. J. Lammers, Phoenixstraat 49c, 2611 AL Delft.	This was a report prepared for the ministry of public works. Air quality around Schiphol is improving, but not fast enough to meet Dutch norms. Most of the pollution comes from the generality of sources—industry, road transport, etc., and in particular from the motorway. The small contribution of air transport to NO_2 will double between 2004 and 2008. Aircraft may individually be cleaner; but there are more of them. The document reports detailed modeling of NO_2, PM_{10}, CO, and benzene in the Schiphol area for 2004 and for a business-as-usual 2008. This permits the contributions from the motorways and airport to be estimated.	X			X									X		X	X			X	X				X	X					X
Aeroporti di Roma (2006) "Environmental Report 2005," Aeroporti di Roma, Via del'Aeroporto di Fiumicino 320–00050 Fiumicino, Italy.	A general environmental report published by the airport for public consumption. From p 67 it outlines air quality measurements at the two airports (Fiumincino and Ciampino). A mobile laboratory was used, being placed airside for periods of 1–3 years at what were deemed to be the most critical locations within the airports. Species measured were O_3, CO, NO_2, SO_2, and PM_{10}, with annual means for 2001–2005 and monthly means for 2005 being shown. Concentrations were generally moderate, in large part because of the frequent sea breeze.	X						X						X		X							X			X				X	X
Aeroporti di Roma (2007) "Environmental Report 2006," Aeroporti di Roma, Via del'Aeroporto di Fiumicino 320–00050 Fiumicino, Italy.	A general environmental report published by the airport for public consumption. From p 39 and p 80 it lists air quality measurements at Fiumincino. Mean NO_2 concentrations in 2005 and 2006 were 25.8 and 14.5 µg m-3 respectively. (It is not clear that the measurements are strictly comparable, since the mobile laboratory may have been moved—PM_{10} concentrations also dropped very sharply over the few years of measurements.) Benzene and other hydrocarbons were now being measured in addition to the species measured previously—though their values were not reported.							X						X		X							X			X				X	
Aeroporti di Roma (2008) "Environmental Report 2007," Aeroporti di Roma, Via del'Aeroporto di Fiumicino 320–00050 Fiumicino, Italy.	A general environmental report published by the airport for public consumption. Ambient concentrations at Fiumincino for the year are quoted on p 44. There are many missing data, but it appears that concentrations are generally modest. ADR had commissioned an external body (Istituto sull'Inquinamento Atmosferico del CNR) to make air quality measurements at a fixed site at Ciampino from 2006. The results seemed similar to those for the city of Rome, characterized by the large number of motor vehicles. The contribution of aviation activities thus seems to be rather modest.							X						X		X							X			X				X	

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Aeroporti di Roma (2009) "Environmental Report 2008," Aeroporti di Roma, Via del'Aeroporto di Fiumicino 320–00050 Fiumicino, Italy.	A general environmental report published by the airport for public consumption. Monthly concentrations at Fiumincino for the year are quoted on p 43; values for NO_2 are quoted for 10 months—the highest value was 40.1 µg m-3in October.						X	X						X		X	X						X			X				X	
Aeroporti di Roma (2010) "Environmental Report 2009," Aeroporti di Roma, Via del'Aeroporto di Fiumicino 320–00050 Fiumicino, Italy.	A general environmental report published by the airport for public consumption. Monthly concentrations at Fiumincino for the year are quoted on p 45; the annual mean for NO_2 was 25.8 µg m-3. Additional measurements were also made by the IIA-CNR in the second half of the year at 8 sites around Fiumicino and 6 sites around Ciampino. Species measured were benzene, toluene, ethyl benzene, xylene, NO, NO_2, O_3, SO_2 and NH_3. Some of the hydrocarbon concentrations seemed quite high—at Fiumicino the average toluene concentration was 64.2 µg m-3 airside and 185.2 µg m-3 landside, while that for benzene was 1.2 µg m-3 airside and 1.1 µg m-3. Apparently these values are within regulatory limits (albeit that they only cover summer and autumn).						X	X						X		X	X						X			X				X	
Aeroports de Paris (2007) "Emission Assessment and Air Quality Monitoring at Paris Airports."	Powerpoint presentation describing monitoring activities being carried out at the three Paris airports: two routine sites at CDG, one at Orly. There was also some specialized emissions testing for particulates and VOCs carried out in October 2005 and June/July 2005.						X	X						X		X	X			X					X	X					
Aeroports de Paris (2012) "Paris-Orly et Paris-Charles de Gaulle. Blian Mensuel de la Surveillance de la Qualité de l'air sur les Platformes Aéroportuaires. Octobre 2012." Paris-Orly and Paris-CDG, "Monthly Summary of Airside Air Quality Monitoring," Oct 2012.	This is a monthly report of monitored air pollution concentrations around the two main Paris airports. Monitoring takes places at two stations at each airport and also at several nearby landside sites operated by Airparif. Pollutants monitored are NO, NO_2, PM_{10}, $PM_{2.5}$ and O_3.							X						X		X										X					
Air Force Civil Engineer Center (AFCEC) (2009) *Air Emissions Factor Guide to Air Force Stationary Sources, Methods for Estimating Emissions of Air Pollutants for Stationary Sources at U.S. Air Force Installations.* AFCEC Environmental Consulting Division. Dec.	Standard Air Force guidance that provides methods and emission factors for various stationary sources and aircraft. Information for criteria pollutants including Pb and PM as well as HAPs species.	X	X				X							X	X	X	X						X								
Air Force Civil Engineer Center (AFCEC) (2013) *Air Emissions Guide for Air Force Mobile Sources, Methods for Estimating Emissions of Air Pollutants for Mobile Sources at U.S. Air Force Installations.* AFCEC Compliance Technical Support Branch. Jan.	Standard Air Force guidance that provides methods and emission factors for mobile sources including on-road vehicles, non-road equipment, and aircraft. Criteria pollutants including Pb and PM as well as HAPs. Includes APUs, GSEs, and GAVs. Also, covers aircraft operations and mixing heights.	X	X				X							X	X	X	X			X		X									

AIRPARIF (2009) "Campagne de Mesure Autour de L'Aéroport de Paris Charles de Gaulle," Airparif, Pôle Etudes 7, rue Crillon, 75004 Paris, France.	Study of air quality around Paris CDG airport. In the course of an 8-week survey between December 2007 and February 2008, diffusion tubes were used to monitor NO_2 concentrations at 120 sites around Paris-CDG airport. These measurements were supplemented by three mobile laboratories, which reported concentrations of NOx, PM_{10} and $PM_{2.5}$ on an hourly basis. Concentrations of NO_2 were dominated by the generality of urban emissions, in particular near major roads. The mobile laboratories could detect the impact of the airport (with an unfavorable wind direction, NO_2 concentrations near the airport could be up to 40% greater than those in central Paris), but not of individual ATMs. The limit value of 40 µg NO_2 m-3 is exceeded within the conurbation, close to major roads, and close to the airport (perhaps within a few hundred m of the perimeter); but the influence of the airport is not detectable beyond a range of 3.5 km. Such long-term exceedences would cover 28% of the population living within the study zone. Baseline concentrations of $PM_{2.5}$ are marginal in respect of international norms, but are dominated by road traffic.							X						X		X			X						X	X					X
AIRPARIF (2012) "Rapport D'Activité & Bilan de La Qualité de L'Air, Année 2011," Airparif, Pôle Etudes 7, rue Crillon, 75004 Paris, France.	AIRPARIF is an organization responsible for monitoring the air quality in the Paris agglomeration. AIRPARIF monitors the air quality and contributes to the assessment of health risks and environmental impacts. This is their (very substantial) annual report for monitoring in 2011.	X		X	X			X						X	X	X	X								X						X
Arunachalam S., Wang B., Davis N., Baek B.H., Levy J.I. "Effect of Chemistry-Transport Model Scale and Resolution on Population Exposure to $PM_{2.5}$ from Aircraft Emissions during Landing and Takeoff," *Atmos Environ* 45:3294–3300 (2011).	LTO concentration contributions from three airports (Atlanta, Chicago O'Hare, and T.F. Green) were predicted with CMAQ. As expected, populations nearest the airport captured most of the effects of $PM_{2.5}$, but populations farther away resulted in most of the health risks due to secondary pollutants (e.g., ammonium sulfate and nitrates).				X					X						X		X	X							X	X				
Arunachalam, S., A. Valencia, D. Yang, N. Davis, B.H. Baek, R. Dodson, E.A. Houseman, and J.I. Levy (2011). "Comparing Monitoring-Based and Modeling-Based Approaches for Evaluating Black Carbon Contributions from a U.S. Airport," D.G. Steyn and S.T. Castelli (eds.), *Air Pollution Modeling and its Application XXI,* NATO Science for Peace and Security Series C: Environmental Security 4, DOI 10.1007/978-94-007-1359-8-102, Springer, The Netherlands, 2011.	Three methods/models were compared to estimate aviation contributions to BC concentrations: (1) a statistical method, (2) AERMOD, and (3) CMAQ. The statistical method seems to imply much higher contributions from aviation than AERMOD or CMAQ.			X	X											X											X				

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Arunachalam, S., B.H. Baek, H.-H. Hsu, B. Wang, N. Davis, and J.I. Levy (2010). "The Influence of Chemistry Transport Model Scale and Resolution on Population Exposure due to Aircraft Emissions from Three Airports in the United States," *Air Pollution Modeling and Its Application XX*, D.G. Steyn; Rao, S.T. (eds.) 2010, XLVII, 592 pp, ISBN 978-90-481-3810-4, Springer, The Netherlands, 2010.	CMAQ was used to predict air quality impacts (HAPs and PM) from three airports (Atlanta, Chicago O'Hare, and T.F. Green) using different grid resolutions.				X											X	X		X							X	X				
Arunachalam, S., M. Woody, B.H. Baek, U. Shankar, and J.I. Levy, (2011). "An Investigation of the Impacts of Aviation Emissions on Future Air Quality and Health," D.G. Steyn and S.T. Castelli (eds.), *Air Pollution Modeling and its Application XXI*, NATO Science for Peace and Security Series C: Environmental Security 4, DOI 10.1007/978-94-007-1359-8-108, Springer, The Netherlands, 2011.	CMAQ was used to conduct a health risk study for aviation operations in 2025. Includes the effects of various PM components including secondary sulfate and nitrate particles. The health risk assessments included the use of the EPA's SMAT.				X	X				X						X		X	X						X						
Athens International Airport (2008) "Air Quality Management at the Athens International Airport," presentation by Michael O'Connor.	Microsoft PowerPoint presentation on local air quality management and carbon at Athens International Airport. Provides a summary of the Airport's approach, monitoring and other initiatives.							X						X	X	X	X			X	X	X	X	X		X					
Athens International Airport (2009) "Atmosphere," in English and Greek.	Air quality monitoring results for 2008 at Athens International Airport.							X						X			X									X					X
Banatvala J. (2004) "Unhealthy Airports," *The Lancet*, 364, 646–648.	A general article offering observation and commentary on the health impacts for local communities of aircraft noise and airport air emissions. It makes the statement that health impact assessments (HIAs) should be carried out for significant airport developments and at the pre-planning stage.	X																													X
Barrett S.R.H., Yim S.H.L., Stettler M.E.J., and Eastham S. (2012) "Air Quality Impacts of U.K. Airport Capacity Expansion," A Report by the Laboratory for Aviation and the Environment at the Massachusetts Institute of Technology (MIT) in Collaboration with the Energy Efficient Cities Initiative at Cambridge University.	A 4-page non-technical report that summarizes the results of two peer-reviewed papers published in the U.K.-based scientific journal *Atmospheric Environment* (Stettle et al. 2011 and Yim et al. 2012) on the topic of emissions from U.K. airports, their impacts on public health today and in the future, and viable near-term mitigation approaches. Particular attention is paid to the potential for either expanding Heathrow or building a new hub airport in the Thames Estuary.	X														X			X												
Barrett S.R.H., Britter R.E., Waitz I.A. "Global Mortality Attributable to Aircraft Cruise Emissions," *Environ Sci Technol* 44:7736–7742 (2010).	Bottom-up modeling exercise using AEDT for emissions and GEOS-Chem for fate and transport globally, with application of PM concentration-response functions as derived from WHO.				x	x				x	x					x		x		x											

Bennett M. and Hoolhorst A. *Assessment and Integration Report: Control of Local Air Quality at European Airports*. ECATS-R-2010-01 report. 2010.	The authors review best practice air quality assessment and mitigation at European airports. There is a focus on NO_2 and $PM_{2.5}$, the main pollutants of concern at major European airports.	X		X				X	X		X			X		X			X						X	X	X				
Bennett M., Graham A. and Sinclair P. (2010) "A Statistical Study of the Impact on Local Air Quality of the Shutdown of European Airspace in April 2010," Manchester Metropolitan University, Manchester, U.K.	Air quality data have been compiled for monitoring sites near five European airports over the period 16–19 April 2010, when much of European airspace was shut as a result of the eruption of the Eyjafjalljökull volcano. These observations were compared with data for previous years and wind roses. At most sites, it is quite difficult to discern a significant decrease in local pollution as a result of the closure of the airport. Possible exceptions are Heathrow and Schiphol, where several monitoring sites lie essentially on the airport boundary and wind directions during the episode were suitable for demonstrating the resultant absence of NO_x emissions. PM_{10} concentrations at most sites were rather high and the implication is that the observed dust was in fact the volcanic ash.							X						X		X									X	X					
Bennett, M. and D. Raper, "Impact of Airports on Local Air Quality," Chapter EAE350, *Encyclopedia of Aerospace Engineering*, John Wiley & Sons, Ltd, 2010.	This chapter provides a good overview of the air quality practices at airports and provides additional details on the European experience. A monitoring overview is particularly important.	X		X	X			X	X		X			X		X			X						X	X	X				
Bennett, M. and D. Raper, "Impact of Airports on Local Air Quality," Chapter EAE350, *Encyclopedia of Aerospace Engineering,* John Wiley & Sons, Ltd, 2010.	This chapter provides a good overview of the air quality practices at airports and provides additional details on the European experience. A monitoring overview is particularly important.	X	X	X				X						X					X							X	X				

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Bennett M., Christie S.M., Graham A., Garry K.P., Velikov S., Poll D.I., Smith M.G., Mead M.I., Popoola O.A.M, Stewart G.B., and Jones R.L. "Abatement of an Aircraft Exhaust Plume Using Aerodynamic Baffles." Accepted for publication *Environ Sci Tech* 2013.	This paper demonstrates the effectiveness of a possible means of abating the impact of the exhaust emissions of commercial aircraft on the local community. Most substantial industrial emissions to atmosphere are via a tall stack; this is not feasible for the exhaust jet from an aircraft. It is not even practicable to install a blast wall to direct the emissions upward, since this would pose an unacceptable hazard to aircraft over-flying it. The paper points out, however, that the aerodynamic drag and lift delivered by a blast wall can be spread out quite effectively over a succession of modest baffles of light-weight construction. These then suck the momentum out of the jet, allowing its buoyancy to dominate more quickly. By setting the baffles at a suitable angle, they can also deliver significant aerodynamic lift to the exhaust jet. In effect, the array forms a "virtual chimney." A suitable design was arrived at using theoretical and wind tunnel modeling. It was then tested with a 124 kN exhaust jet, using point samplers and a scanning LIDAR to monitor the dispersion of the jet downstream. From theory and experiment, it was then clear that, if the array was placed suitably close to the source, the jet could be made to leave the surface quite rapidly (i.e., practically by the back row of the array). The array also provided effective shelter against jet blast (it halved the centerline jet velocity) and gave some modest reduction in the engine noise downstream.				X			X												X											
Blumenthal D.L., W.S Keifer, and J.A. McDonald, "Aircraft Measurements of Pollutants and Meteorological Parameters during the Sulfate Regional Experiment (SURE) Program," Electric Power Research Institute, Report EA-1909, Research Project 862-3, Apr 1981.	Data was collected for model validation of sulfur compounds. Two aircraft were operated for six 2-week intensive studies over various seasons. Measurements, methodologies, and results are described in detail. This document provides historic background.			X			X									X		X		X										x	
Boyle K.A. *Air Quality in Newport Beach, CA: Field Measurements of Ambient Particulates and Associated Trace Elements and Hydrocarbons.* Prepared for City of Newport Beach, Sept 2010.	Field measurements of ambient $PM_{2.5}$ were made at six locations in varying proximity to high-volume freeways and John Wayne Airport. Concentrations of particle-associated metals, trace elements, and hydrocarbons were measured and compared to determine if the relative contributions of airport vs. automotive emissions could be assessed for different sampling sites.				x			x								x	x		x						x		x				

Brunelle-Yeung, Elza and Ian Waitz (2008). "Impact of Subsonic Aviation on Nonmelanoma Skin Cancer Incidence due to Atmospheric Ozone Variation." Submitted to the Fourth Annual Joseph A. Hartman Student Paper Competition. Jan 31.	Paper suggests that an increase in ozone concentration due to aircraft NOx emissions may have contributed to decreased cases of nonmelanoma skin cancer. Aircraft ozone increases were obtained from the IPCC Aviation and the Global Atmosphere report and cancer data were obtained from various sources including the American Cancer Society.								X	X				X				X		X											
Buonanno G., Bernabei M., Avino P., and Stabile L. (2012) "Occupational Exposure to Airborne Particles and Other Pollutants in an Aviation Base," *Environ Pollut* 170, 78–87.	The authors monitored occupational exposure of a crew chief and hangar operator to airborne particles at Los Angeles Airport, USA. Monitoring was carried out downwind of the receptor site, close to the runway and personal monitoring. Various characteristics of airborne particles were measured and reported.							X						X		X			X									X			
Callahan, Colleen (2010). "The Plane Truth, Air Quality Impacts of Airport Operations and Strategies for Sustainability: A Case Study of the Los Angeles World Airports." The Coalition for Clean Air and Environment Now. June.	Provides overviews of the air quality contributions from various airports but mainly focuses on the LAWA airports. Provides recommendations for airports to reduce emissions such as the creation of a clean air action plan, banning leaded gas usage by General Aviation, and implementation of solar panels.	X												X		X	X		X							X	X	X	X		
Carr E., Lee M., Marin K., Holder C., Pedde M., Cook R., Touma J. "Development and Evaluation of an Air Quality Modeling Approach to Assess Near-Field Impacts of Lead Emissions from Piston-Engine Aircraft Operating on Leaded Aviation Gasoline." *Atmos Environ* 45:5795–5804 (2011).	Air quality modeling using AERMOD linked to comprehensive Pb emissions inventory, applied to ambient Pb near Santa Monica Airport. Monitoring data were used for comparison/calibration.				x	x		x							x				x						x			x	x		
Carslaw D.C., Ropkins K., Laxen D., Moorcroft S., Marner B. and Williams M.L. (2008) "Near-Field Commercial Aircraft Contribution to Nitrogen Oxides by Engine, Aircraft Type and Airline by Individual Plume Sampling," *Environ Sci Technol* 42, 1871–1876.	The researchers monitored NO_x concentrations in the plume of departing aircraft at Heathrow Airport. Monitored were 5618 plumes and, using aircraft movement and FDR data, plumes were correlated to aircraft type, engine type, and thrust setting. The study showed a good relationship between the monitored NO_x concentrations and the ICAO databank and a high impact on concentrations from varying takeoff weights and thrust settings.			X			X							X						X						X					
Carslaw D.C., Beevers S.D., Ropkins K., Bell M.C. "Detecting and Quantifying Aircraft and Other On-Airport Contributions to Ambient Nitrogen Oxides in the Vicinity of a Large International Airport." *Atmos Environ* 40 (2006) 5424–5434.	Study of NO_x concentrations near Heathrow. Used multiple approaches to isolate airport contributions using seven measurement sites near the airport.				x			x						x					x						x	x					

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Carslaw, D.C., Williams M.L. and Barratt B. (2012). "A Short-Term Intervention Study—Impact of Airport Closure due to the Eruption of Eyjafjallajökull on Near-Field Air Quality." *Atmos Environ* 54, 328–336, 2012.	During the Icelandic volcano eruption in April 2010, European airspace was closed for 6 days. In this study the authors quantified the impact of the airspace closure on concentrations of NO_x and NO_2 at measurement sites close to London Heathrow Airport. They found a clear effect on NO_x and NO_2 concentrations close to the airport. They also estimated the annual impact airport emissions have on mean concentrations of NO_x and NO_2 for different years and compared these estimates with a detailed dispersion modeling study and previous work that was based on the analysis of monitoring site data. For the receptor most affected by the flight-ban approximately 200 m south of the airport, the airport contributes about 13.5 mg m-3 NO_x, which is similar to dispersion modeling estimates of 12.0 mg m-3, but approximately twice that of other estimates based on the analysis of ambient measurements. Other measurement sites showed more mixed results.							X						X					X							X						
Castro, Adrian. "Santa Monica Airport Health Impact Assessment (HIA): A Health-Directed Summary of the Issues Facing the Community near the Santa Monica Airport." Feb 2010. University of California, Los Angeles, Community Health and Advocacy Training Program.	This study conducted a Health Impact Assessment (HIA) to provide decisionmakers with information to guide the future of the role of Santa Monica Airport. Investigators found significantly higher levels of total suspended particulate lead due to level of operations by piston-powered aircraft. Within and around takeoff runway end, lead levels were up to 25 times higher than the background levels. Takeoffs and landings are contributing to elevated levels of black carbon; elevated levels of ultrafine particles (UFP); and elevated levels of polycyclic aromatic hydrocarbons (PAH). Investigators recommended a "buffer zone" of at least 660 meters between the takeoff area and residents and installation of high-efficiency particle absorbing (HEPA) filters in surrounding schools and homes.							X		X			X		X	X	X			X							X					
CATE (2004). "Quotes on Air Pollution from the Aviation White Paper," Summary prepared by the Centre for Aviation, Transport and the Environment (CATE), Manchester Metropolitan University, Manchester, U.K.	A collection of quotations taken directly from the U.K. "The Future of Air Transport" white paper published in 2003. The extracted quotes relate to air quality, highlight how this is a key issue for airport expansion in the U.K., and how airports must monitor and manage their emissions.	X												X																	
CDM, et al. (2012). *ACRP Report 78: Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial.* Transportation Research Board.	A comprehensive review document of ground support equipment at airports and the practicalities of assessing their impact in terms of emissions and the opportunities for emissions reductions.			X																		X									

DEFRA (2007). "The Air Quality Strategy for England, Scotland, Wales and Northern Ireland (Volume 1)," Department for the Environment, Food and Rural Affairs, London, U.K., Cm 7169.	The Environment Act 1995 requires the U.K. government to produce a national air quality strategy containing standards, objectives, and measures for improving ambient air quality and to keep these policies under review. This document is the third and latest Air Quality Strategy; previous ones have established the framework for achieving improvements in ambient air quality in the U.K. The strategy describes the history and scope of U.K. air quality legislation, objectives, and pollutants covered; current policies and new measures; and a longer-term view.	X	X																												
DEFRA (2010) "Air Pollution: Action in a Changing Climate," Department for the Environment, Food and Rural Affairs, London, U.K., PB13378.	This U.K. government report sets out the U.K.'s commitments on improving local air quality and its low carbon transition plan. Significantly, it explores the interrelationships of the two areas and highlights benefits of integrating policies.	X																													
DfT (2003) "The Future of Air Transport—Summary," Department for Transport, 76 Marsham Street, London SW1P 4DR, U.K.	This U.K. white paper provides a national strategic framework for the future development of airport capacity in the U.K., looking forward 30 years. One reason given for this was the requirement to address the environmental impacts that air travel generates. This document is a summary—the full report runs to many documents and pages. The white paper noted the "severe environmental disadvantages" of Heathrow and the government would only support a third runway once it could be confident that the key condition relating to compliance with air quality limits can be met—annual mean concentrations of NO_2 must not exceed 40 µg/m3. The government's support is also conditional on measures to prevent deterioration of the noise climate and improve public transport access.	X																													

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DfT (2006A) "Project for the Sustainable Development of Heathrow—Report of the Air Quality Technical Panels," Department for Transport, 76 Marsham Street, London SW1P 4DR, U.K.	This major study was commissioned in 2004 by the U.K. government's Department for Transport, as a result of a recommendation made in the U.K. Future of Air Transport white paper, and reported in July 2006. It reported in the following areas: 1. Synthesis of key issues and findings including recommendations made to the DfT for what tools should be used to assess air quality at Heathrow Airport. 2. Establish what constitutes best practice for monitoring and measurement for model development, and its applicability, at Heathrow. 3. Identifying emission sources and calculating emissions, in the form of a detailed "bottom-up" emissions inventory, as an input for dispersion modeling. 4. Dispersion modeling of airport and local emissions. This included an assessment of 5 dispersion models and concluded that the most appropriate model for use at U.K. airports was ADMS-Airport (model developer: Cambridge Environmental Research Consultants http://www.cerc.co.uk/index.php). The whole study was subject to a peer review panel and the final report included their commentary. Although now a dated study, it arguably defined best practice airport air quality assessment at the time. Overall, the panels found that the key pollutants were nitrogen dioxide (NO_2), nitrogen oxides (NO_x), and particulate matter (PM_{10}). The study found that the statutory annual mean NO_2 objective (40 µg/m3) was exceeded at some locations around Heathrow. The study found no breaches of any statutory PM_{10} objectives.			X										X		X			X							X					
DfT (2006B) "Project for the Sustainable Development of Heathrow—Report of the Air Quality Technical Panels. Appendices 1–11," Department for Transport, 76 Marsham Street, London SW1P 4DR, U.K.	The appendices to the full report (DfT, 2006A).			X										X		X			X							X					
Diez D.M., Dominici F., Zarubiak D., Levy J.I. "Statistical Approaches for Identifying Air Pollutant Mixtures Associated with Aircraft Departures at Los Angeles International Airport," *Environ Sci Technol* 46:8229–8235 (2012).	This study examined concentrations of continuously monitored air pollutants measured in 2008 near a departure runway at LAX, considering single-pollutant associations with landing and takeoff (LTO) as well as multipollutant predictors of binary LTO activity.				x			x						x						x						x					

Dodson R.E., Houseman E.A., Morin B., Levy J.I. "An Analysis of Continuous Black Carbon Concentrations in Proximity to an Airport and Major Roadways," *Atmos Environ* 43:3764–3773 (2009).	BC was measured at 5 monitoring sites on grounds of T.F. Green Airport from 2005–2006. Statistical analysis approaches included smoothed functions of wind speed and direction to determine likely source contributions, and regression models predicting concentrations as function of real-time flight activity and meteorological data.				x			x								x			x						x		x			x	
Duchene N., E. Flueti, I. Fuller, P. Hofmann, U. Janicke, and C. Talerico, "Comparison of Measured and Modeled NO_2 Values at Zurich Airport, Sensitivity of Aircraft NO_X Emissions Inventory and NO_2 Dispersion Parameters: Proceedings of the 11th International Conference on Harmonisation within Atmospheric Dispersion Modeling for Regulatory Purposes," pp. 367–371.	Measurements at 21 locations near and around the Zurich Airport are described using passive NO_2 sampling tubes and a standard analyzer at one location. A sensitivity study of the impact, as well as comparison to modeling, is included.		X	X				X						X					X						X	X			X		
Düsseldorf International Airport (2004) "Umweltreport," Flughafen Düsseldorf, Germany.	A general environmental report published by the airport for public consumption. It describes (among other things) how air quality is monitored near the runways. Annual mean NO_2 concentrations in 2003 were marginally below 40 µg m-3 at both ends of both runways.							X						X												X					
Düsseldorf International Airport (2009) "Luftqualitätsmessungen, September 2009," Flughafen Düsseldorf, Germany.	Air quality measurements, September 2009. A monthly summary of air quality measurements at the airport. Oddly, this seemed to be the only one immediately available. NO_2, O_3, SO_2, benzene, toluene, and PM_{10} were reported, together with a summary of basic meteorological statistics.							X						X		X	X									X				X	
ECAC (2011) "Recommendation ECAC//27-4 NO_x Emission Classification Scheme," European Civil Aviation Conference, 3, bis Villa Emile Bergerat, 92522 Neuilly sur Seine Cedex, France.	The standardized approach to the calculation of an aircraft engine emissions factor for airline charging purposes to be used at any EU airport that wishes to adopt differential charging based on local air quality emissions.			X										X			X														
Ellermann T. and Massling A. (2010) "Measurement of Ultrafine Particles at the Apron of Copenhagen Airport, Kastrup in Relation to Work Environment," Danmarks iljøundersøgelser ved Aarhus Universitet (Denmarks Environmental Investigations, University of Aarhus), Aarhus, Denmark.	This report presents the results of measurements of number and size-distribution of ultrafine particles at the apron of Copenhagen Airport, Kastrup. In the measuring period, the average number of particles was about 4.4 times higher at the apron (43.000 particles/cm3) than at H.C. Andersens Boulevard (9.800 particles/cm3), which is estimated to be one of the most air polluted streets in Copenhagen. Measurements of the particles' size-distribution showed that about 90% of the particles at the apron are in the size-fraction from 6–40nm. About 8% of the particles are in the size-fraction from 40–110 nm, and only 2% lie in the size-fraction from 110–700 nm.						X	X					X			X										X	X				

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ENVIRON (2000). *Preliminary Study and Analysis of Toxic Air Pollutants from O'Hare International Airport and the Resulting Health Risks Created by These Toxic Emissions in Surrounding Residential Communities.* Park Ridge, IL.	A study was conducted due to concerns of potential impacts from toxic air pollutants emitted from the airport. Health risk assessments were conducted of the fence line concentrations and the impacts to surrounding residential communities.				X		X	X		X	X					X	X	X	X					X		X			X		
ENVIRON (2008). *Teterboro Airport, Detailed Air Quality Evaluation*. Prepared for the New Jersey Department of Environmental Protection (NJDEP), Trenton, New Jersey. ENVIRON International Corportation, Groton, Massachusetts, Newark, New Jersey. Project #08-14189A, Final Report. February 11.	Funded by the New Jersey Department of Environmental Protection (NJDEP), the study assessed local air quality contributions from Teterboro Airport including potential health impacts and emissions mitigation measures.			X	X	X	X	X		X				X	X	X	X	X	X					X				X			
EPA Office of Air and Radiation. Sep 2004. *Guidance on Airport Emission Reduction Credits for Early Measures through Voluntary Airport Low Emission Programs.* Available from the FAA at http://www.faa.gov/airports/environmental/vale	This document provides guidance on the Voluntary Airport Low Emission (VALE) program. VALE allows airport managers to reduce emissions accounted for under the General Conformity and New Source Review (NSR) programs. VALE is intended to reduce criteria pollutants and precursors, improve regional air quality, and accelerate the use of new and cleaner technology before an EA or EIS is prepared, and establishes a program to obtain emission "credits."	X		X															X												
EU (2008) "Directive 2008/50/EC of the European Parliament and of the Council on Ambient Air Quality and Cleaner Air for Europe," *Official Journal of the European Union*, European Commission, Brussels, Belgium.	From 1/1/2010, two EU limit values for NO_2 entered into force: 200 µg/m3 over 1 hour averaging period with 18 permitted exceedences each year and 40 µg/m3 over a 1-year period. From 1/1/2005, two limit values for PM_{10} entered into force: 50 µg/m3 over 24 hours averaging period with 35 permitted exceedences each year and 40 µg/m3 over a 1-year period. From 1/1/2015 there will be a limit value for $PM_{2.5}$ coming into force: 25 µg/m3 over a 1-year averaging period. Prior to the limit value entering force, there is a target value that entered into force from 1/1/2010 of 25 µg/m3 over a 1-year averaging period, the same as the limit value. The Directive also sets out limit or target values for SO_2, lead, CO, ozone, arsenic, cadmium, nickel, and polycyclic aromatic hydrocarbons. An average exposure indicator (AEI) will be introduced for $PM_{2.5}$ in 2015: 20 µg/m3 based on a 3-year average (so in 2015 this will be 2013, 2014, 2015). It is the $PM_{2.5}$ concentration averaged over the selected monitoring stations in agglomerations and larger urban areas, set in urban background locations to best assess the $PM_{2.5}$ exposure of the general population. An "exposure reduction target" to be set on AEI in 2010, is to be achieved in 2020. Limit and target values have historically been based on the work of the Air Pollution and Clean Air for Europe (CAFÉ) initiative.	X	X											X	X	X	X	X													

Eurocontrol (2005A) "Airport Local Air Quality Studies (ALAQS) Concept Document," Eurocontrol, Brussels, Belgium.	This report outlines the background, objectives, and approach of a Eurocontrol and ICAO project called Airport Local Air Quality Studies (ALAQS), now completed. It aimed to (1) promote best practice methods for airport LAQ analysis concerning issues such as emissions inventory, dispersion, and the data required for the calculations, including emission factors, operational data, and aircraft landing and takeoff profiles; (2) raise the awareness of LAQ issues among airport authorities, focusing on the practical issues of an LAQ study at an airport: data collection, pollutants, methods for inventory, and dispersion; and (3) develop an ALAQS-AV toolset—a geographical information system-based (GIS-based) research tool. This is a test bed that can be used to investigate the sensitivity of different inventory and dispersion methodologies. The choice of a GIS as a test bench simplifies the process of defining the various airport elements (runways, taxiways, buildings, etc.) and allows the spatial distribution of emissions to be visualized. The ALAQS project approach was based on delivering case study reports, guidance material, a database of default parameters for European LAQ, and the ALAQS-AV toolset.			X	X																										
Eurocontrol (2005B) "ALAQS Chopin Airport Case Study, Part 1: Emission Inventory," Eurocontrol, Brussels, Belgium.	This report describes an emissions inventory that was completed for Chopin Airport, Warsaw, Poland. It was one of four airport emissions inventories case studies completed as part of ALAQS. The second phase of this case study was a dispersion modeling study.			X	X																										
Federal Aviation Administration. 2005. *O'Hare Modernization Environmental Impact Statement*. Federal Aviation Administration. Great Lakes Region FAA	EIS for the modernization of the Chicago O'Hare International Airport. Provides a comprehensive modeling and measurement assessment of emissions and air quality impacts for both criteria and hazardous air pollutants (HAPs).				X			X						X	X	X	X	X	X					X	X	X			X	X	
FAA, "Fact Sheet – Voluntary Airport Low Emission Program," Oct 9, 2012. Available from the FAA at http://www.faa.gov/airports/environmental/vale	Provides the latest information about the VALE Program and an overview of FY2012 VALE grants.	X																	X												
FAA, VALE Program grant summary FY 2005-FY 2012. 2013. Available from the FAA at http://www.faa.gov/airports/environmental/vale	This Microsoft EXCEL spreadsheet lists all the VALE program grants, amounts, project descriptions, and sponsors.	X																	X												
FAA, "Voluntary Airport Low Emissions (VALE) Program Brochure," 2013. Available from the FAA at http://www.faa.gov/airports/environmental/vale	The brochure provides an overview of the VALE program, a list and description of eligible project types, and case studies of selected completed VALE projects.	X																	X												

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Fanning E., Yu R.C., Lu R., Froines J. "Monitoring and Modeling of Ultrafine Particles and Black Carbon at the Los Angeles International Airport: Final Report," ARB Contract #04-325, 2007.	Three field studies were performed in and around LAX in 2005 and 2006.				x	x		x								x	x		x						x	x					
Fanning, E. et al. (2007) "Monitoring and Modeling of Ultrafine Particles and Black Carbon at the Los Angeles International Airport: Final Report," ACB Contract #04-325. California Air Resources Board, June 20.	Study involved a measurement campaign to characterize LAX contributions of PM to surrounding communities. The UFP max spike was seen to occur at 15 nm and the average at 14 nm—these were detectable up to 600 m from the airport. While particle numbers were noticeable in community areas, mass-based concentrations (e.g., $PM_{2.5}$) were not above background levels.							X								X			X							X					
Fine, P., A. Polidori, S. Teffera (2010) "General Aviation Airport Air Monitoring Study, Final Report," South Coast Air Quality Management District, Aug 2010.	This study was part of a Community-Scale Air Toxics Ambient Monitoring Grant and characterizes the ambient levels of several air toxics adjacent to the Van Nuys and Santa Monica Airports. These are very busy GA airports with Van Nuys having about 450,000 annual LTOs. The document describes the monitoring and provides key findings of concentrations of lead, VOCs, PM, and CO.							X			X			X	X	X	X		X									X			
Fraport (2004A) "Lufthygenische Kurzbericht," Fraport AG, APF-US, 60547 Frankfurt, 22/1/2004.	A short report on air quality. This single page report introduces the SOMMI 1 (Self Operating Measuring and Monitoring Installation) in the E corner of Frankfurt International Airport (i.e., between the airfield and a motorway), and reports annual concentrations for the period 1/7/2002 to 30/6/2003. Pollutants measured were CO, NO, NO_2, SO_2, O^3, benzene, and PM_{10}. In subsequent years, toluene, xylene, and ethyl benzene were added to this list.							X						X		X	X									X					
Fraport (2004B) "Lufthygienischer Jahresbericht 2003," Fraport AG, FBA-RU, 60547 Frankfurt.	Annual report on air quality, 2003. This is the first of a series of annual air quality reports by Fraport. Following Fraport 2004A, it describes the commissioning of a mobile monitoring station, SOMMI 2. This was located at two places, both within the airport boundary, over the course of the year. It was noted that 2003 was an exceptional year meteorologically. Mean NO_2 concentration at SOMMI 1 over the year was 50 µg m-3. Pollution rose analysis showed that most of this came from the neighboring motorway. Typically, these reports state relevant statistics of the monitored pollutants, adding some helpful technical commentary.							X						X		X	X								X	X					

Fraport (2005) "Lufthygienischer Jahresbericht 2004," Fraport AG, FBA-RU, 60547 Frankfurt.	Annual report on air quality, 2004. Another warm year, though not as hot as 2003. The report includes some discussion of the legal implications of pollution limit values. Since these require air quality in residential areas (rather than within the airfield) to be protected, a special measurement program was commissioned close to the nearby town of Kelsterbach, starting in June 2004. Mean NO_2 concentration at SOMMI 1 over the year was 42 µg m-3.	X						X						X		X	X									X					
Fraport (2006) "Lufthygienischer Jahresbericht 2005," Fraport AG, FBA-RU, 60547 Frankfurt.	Annual report on air quality, 2005. Mean NO_2 concentration at SOMMI 1 over the year was 46 µg m-3, that at SOMMI 2 on the apron was 57 µg m-3, and that at Kelsterbach 32 µg m-3.							X						X		X	X									X					
Fraport (2007) "Lufthygienischer Jahresbericht 2006," Fraport AG, FBA-RU, 60547 Frankfurt.	Annual report on air quality, 2006. Mean NO_2 concentration at SOMMI 1 over the year was 47 µg m-3, that at SOMMI 2 at the center of the airfield was 39 µg m-3, and that at Kelsterbach 32 µg m-3. Note that the SOMMI 2 value quoted here was between 1/5/2006 and 30/4/2007, since thunderstorms delayed the preparation of its new site. Time series now show that pollutant concentrations (other than those of CO) had all dropped following the exceptional year of 2003. The report discusses an episode of high PM_{10} concentrations in March 2007: hourly concentrations at SOMMI 1 peaked at >150 µg m-3. This seemed to be a regional phenomenon, but its source was unclear. Such episodes are not unusual.							X						X		X	X								X	X					X
Fraport (2008) "Lufthygienischer Jahresbericht 2007," Fraport AG, FBA-RU, 60547 Frankfurt.	Annual report on air quality, 2007. Mean NO_2 concentration at SOMMI 1 over the year was 42 µg m-3, that at SOMMI 2 at the center of the airfield was 39 µg m-3, and that at Kelsterbach 28 µg m-3. It may be noted that NO concentrations are much more differentiated, viz. 43, 23, and 16 µg m-3 respectively. These are much more closely related to the primary emissions, as could be seen from the pollution roses. The principal local source is the motorway immediately to the E of the airport. By the time this report was prepared, the source of the dust episode in March 2007 had been identified—it was apparently from a dust storm in the Ukraine, following a drought.							X						X		X	X								X	X				X	X
Fraport (2009A) "Lufthygienischer Jahresbericht 2008," Fraport AG, FBA-RU, 60547 Frankfurt.	Annual report on air quality, 2008. Because of construction work, SOMMI 1 had to be suspended at the end of September 2008. The mean NO_2 concentration at SOMMI 2 at the center of the airfield was 40 µg m-3, and that at Kelsterbach (now labeled SOMMI 3) 29 µg m-3. The September–September mean value at SOMMI 1 was 48 µg m-3. Through the use of a hi-vol sampler, BaP, As, Pb, Cd, and Ni were also measured at SOMMI 1, with mean concentrations of 0.2, 0.8, 7.2, 0.2, and 3.5 ng m-3 respectively—all well within regulatory limits.							X						X	X	X	X									X					X

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Fraport (2009B) "Verkurzte Umwelterklärung 2009 für den Standort Flughafen Frankfurt. Fortschreibung der Umwelterklärung 2008," Fraport AG, FBA-RU, 60547 Frankfurt.	Short report on the progress of Fraport toward its environmental goals up to 2008.	X						X						X		X	X		X						X	X					X
Fraport (2010) "Lufthygienischer Jahresbericht 2009," Fraport AG, FBA-RU, 60547 Frankfurt.	Annual report on air quality, 2009. SOMMI 1 restarted operations at a position 400 m SW of its original position, and some 200 m farther from the motorway, on 1/4/2008. The network was extended to monitor the fourth runway, now under construction, with SOMMI 4 between the new runway and the NW corner of the original airfield and SOMMI 5 S of Kelsterbach. The mean NO_2 concentration at SOMMI 2 was 41 µg m-3, and that at SOMMI 3 was 31 µg m-3. An attempt was made to correct the measured SOMMI 1 value (48 µg m-3) for the missing first quarter of data by interpolation from the SOMMI 2 values. A corrected mean of 48 µg m-3 was obtained. PM_{10} measurements were commissioned at SOMMI 3-5 to monitor dust from the construction works. It appeared that this was well controlled (on-site speed limits, water sprays on construction roads, etc.).							X						X	X	X	X								X	X					X
Fraport (2011) "Lufthygienischer Jahresbericht 2010," Fraport AG, FBA-RU, 60547 Frankfurt.	Annual report on air quality, 2010. The mean NO_2 concentration at SOMMI 1 over the year was estimated as 45 µg m-3 (from 1/11/2010, it was moved to another site further N), that at SOMMI 2 was 39 µg m-3, and that at SOMMI 3 was 31 µg m-3. A long-term decline in primary NO concentrations was attributed to diminishing emissions from motor vehicles. Airport operations in April of this year were greatly impacted by the eruption of Eyjafjallajökull, but modeling and measurements showed that this had only a modest effect on NO_2 concentrations at SOMMI 1-3. This was the general experience at European airports, as reported in "Effects of Air Traffic on Air Quality in the Vicinity of European Airports," published by ACI Europe. There was also some discussion of PM_{10} from construction activity. At SOMMI 4, beside the construction site of the new runway, this marginally exceeded the regulatory limit, but since the site was within the airport boundary, this was not a legal concern.				X			X						X	X	X	X								X	X					X

Fraport (2012) "Lufthygienischer Jahresbericht 2011," Fraport AG, FBA-RU, 60547 Frankfurt.	Annual report on air quality, 2011. This is a somewhat more substantial annual report than the previous ones, since topical issues required discussion of several additional themes. The new NW runway was in operation from 21/10/2011. Mean NO_2 concentrations at SOMMI 1-3 were 46 µg m-3, 36 µg m-3, and 31 µg m-3, respectively, though SOMMI 3 was decommissioned at the end of the year. Detailed dispersion modeling of NO_2 concentrations was carried out both for the base case of 2005 and for a 2020 planning scenario. Generally, off-site concentrations should be reduced as a result of reductions in road vehicle emissions; on-site concentrations may, however, increase with the growth in ATMs: concentrations on the aprons may exceed 60 µg m-3. There will also be an impact from Terminal 3, which will become operational in 2016. Close to the sources, agreement between the model and the 2005 monitored data is quite good; farther away, the model overestimates monitored concentrations. There is some discussion of the use of the Romberg formula to model the conversion of the primary NO_x emission to the regulated NO_2 concentration. The report also comments that the bulk (at least ⅔) of the local AQ impact from an aircraft in takeoff run originates from before the aircraft has left the ground. There is also some discussion of the modeling of odor nuisance from kerosene.	X			X			X						X	X	X	X								X	X					X
Fraport (2012) "Environmental Statement 2011 Including the Environmental Program until 2014, for the Organizations Fraport AG, N*ICE and FCS at Frankfurt Airport," published by Fraport AG, Frankfurt Airport Services Worldwide, Sustainability Management and Corporate Compliance 60547 Frankfurt am Main, Germany.	An annual environmental report for Fraport activities at Frankfurt Airport in Germany. The report is in English and data is up to and including 2010. A summary of air quality data is presented.	X					X	X						X		X	X									X					
Gatwick Airport Ltd (2013) "Gatwick Airport: Conditions of Use 2013/14 Including Airport Charges Effective 1st April 2013," Gatwick Airport Ltd, 5th Floor, Destination Place, South Terminal, Gatwick Airport, West Sussex, RH6 0NP, U.K.	Information issued by Gatwick Airport in the U.K., which includes details of its aircraft emissions charging scheme and charges.													X			X														

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German Federal Government (2012) "Gesundheitsgefährdung durch Schadstoffemissionen des Luftverkehrs. Antwort der Bundesregierung auf die Kleine Anfrage der Abgeordneten Sabine Stüber u.a. Bundestagsdrucksache 17/9630." ("Risks to Health from Toxic Emissions Arising from Air Transport. Reply of the Federal Government to the Short Questionnaire from the MPs Sabine Stüber et al., Federal Parliamentary Press, 17/9630").	A useful, brief, and clearly written response for non-technical readers. It stresses the importance of fine particulate as a delivery mechanism of toxins to the human body. Regarding toxicity, it refers to research work by DLR (Deutscher Luft- und Raumfahrt) and EASA (the European Aviation Safety Agency), without citing individual reports. There are some questions regarding fuel dumping, de-icing fluids, and CO emissions, which the government considers to be of minor relevance, though there may be environmental problems with benzotriazole in de-icing fluid. The response also references some studies of the external costs of air transport in Europe: the great bulk of this comes from climate change with only (supposedly) 1.58% from air pollution. The final question dealt with occupational disease among airport workers. Unsurprisingly, this mostly involved hearing impairment (59.5%), though skin diseases were also frequent (22.9%), and diseases related to asbestos exposure, sadly, still very common (10.9%). A list of AQ monitoring stations near German airports is provided.	X									X	X				X								X								
Graham A. and Raper D. (2003) "Air Quality in Airport Approaches: Impact of Emissions Entrained by Vortices in Aircraft Wakes," Manchester Metropolitan University, Manchester, U.K.	Exhaust from aeroplanes is entrained within a pair of wingtip vortices trailing in their wake. An aeroplane exerts a downward force on the air, and so the wake must descend. Exhaust pollutants may thus be conveyed to the ground close to airports far more effectively than through ambient atmospheric dispersion alone. A kinematic model of vortex-mediated pollutant transport has therefore been developed, harnessing results from dynamic models in the literature to estimate the size of the neglected term in ground-level concentrations. Model runs show that in (10 m) winds of 2–4 m s−1, nitrogen oxides (NO_x) in the vortex wakes of narrow-body turbofan aeroplanes may contribute 2 μg m−3 or more to mean diurnal ground-level concentrations, up to 2 km downwind of a busy runway.			X	X									X												X			X			
Graham, A., R. Jones, V. Tsanev, I. Mead, M. Bennett, S. Christie, M. Hilton, M. Walsh, D. Grainger, D. Peters, C. Ansell, R. Jones, and J. Lee, "Final Report: Aviation Emissions and their Impact on Air Quality," Omega Report, Manchester University, Feb 2009.	This document describes measurements at U.K. airports. While NO_x is the primary pollutant of concern, O_x, CO and CO_2 also are measured as well as meteorological parameters. Novel ideals of LIDAR and optical absorption spectroscopy are included.							X			X		X	X					X							X						

HAL (2011) "Heathrow Air Quality Strategy 2011–2020," Heathrow Airport Limited, London, U.K.	Describes the air quality situation at Heathrow, compliance with legal requirements and the airport strategy. An action plan is included for reducing emissions of NO_x and particulates. The document states that Heathrow Airport Ltd (HAL) recognizes that NO_2 concentrations are above EU limit values in some areas but it points out that HAL operations are not the only contributor to this. HAL says that it will work with other organizations to reduce emissions arising from road traffic and aircraft. There is a repeated message by HAL that poor air quality at Heathrow has a lot to do with non-airport-related road traffic and the general high level of local emissions. Also, that HAL is only directly responsible for some airport-related emissions, the others (e.g., road traffic and aircraft) are the direct responsibility of others and it can guide and influence these. HAL uses compliance, or not, with the EU limit values to decide if there is a public health impact. The focus is clearly on meeting the limits, which are not described in the strategy in terms of public health impacts.	X												X		X			X							X					
HAL (2013) "Heathrow Airport Limited Conditions of Use 2013/14 Including Airport Charges from 1 April 2013," Heathrow Airport Limited, The Compass Centre, Nelson Road, Hounslow, Middlesex TW6 2GW, U.K.	Information issued by Heathrow Airport in the U.K., which includes details of its aircraft emissions charging scheme and charges.													X			X														
Helmis C.G., Sgouros G., Flocas H., Schäfer K., Jahn C., Hoffman M., Heyder C.H., Kurtenbach R., Niedojadlo A., Wiesen P., O'Connor M., and Anamaterou E. (2009) "The role of Meteorology on the Background Air Quality at Athens International Airport," *Atmos Environ* 45, 5561–5571.	The authors undertook measurements of wind, mixing height, and air quality using remote sensing and surface-based single-point instrumentation. They found that under low background wind conditions, the development of local flows (sea and land breeze cells) over the greater area preserves high concentrations of air pollutants, which are mainly attributed to airport emissions, local activities and traffic. When the background flow is strong, the diurnal cycle of all concentrations was significantly reduced by more than 50%, due to advection and the subsequent mixing of the lower atmosphere. The calculated Hilbert spectra of the main pollutants showed that meteorology plays a prescriptive role on the evolution of air pollutants, determining the influence of local-scale characteristics at each monitoring station.							X						X		X		X								X			X		
Herndon, Scott, et al. (2012) *ACRP Report 63: Measurement of Gaseous HAP Emissions from Idling Aircraft as a Function of Engine and Ambient Conditions,* Transportation Research Board (TRB).	Discusses the work conducted in measuring aircraft emissions during idling conditions (lower than the standard ICAO 7% power). Provides a method to predict emissions indices based on fuel flow and ambient temperature for a representative engine.						X										X			X											

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Hoolhorst A., Beukenhorst O., and Brok P. (2009) "Options to Reduce Aircraft Emissions Impact in the Airport Environment," ECATS deliverable D5.c.31.	The authors assessed a range of options to reduce local air quality pollutants from aircraft and related emissions. Road traffic emissions are excluded. Technical, operational, and policy measures are included.													X		X	X			X	X	X									
Hoolhorst A., Erbrink J.J., and Scholten R.D.A. (2007) "Luchtkwaliteit rond luchthaven Schiphol Voor het MER korte termijn 'Verder werken aan de toekomst van Schiphol en de regio," National Aerospace Laboratory report no. NLR-CR-2007-361.	Annex B.2. Air quality around Schiphol airport. For the short-term environmental impact assessment: "Further Work on the Future of Schiphol and the Region." Extensive air quality modeling for the Schiphol area is reported. The authors use the KEMA STACKS model for a 2007 reference scenario and for two scenarios in 2010 allowing for passenger growth from 437 kPax to 493 kPax. In no scenario are the Dutch norms for PM_{10} or benzene exceeded. There could well be exceedences of the norm for NO_2, however, and this would partly arise from airport activities. A sensitivity analysis is carried out to investigate the effects of 10 possible measures to reduce the airport's impact; it appears that these could jointly be sufficiently effective. The most effective interventions seem to be (p. 38) the use of external sources of electricity and cabin air at the aircraft parking points (i.e., instead of using auxiliary power units) and the deployment of electrically powered service vehicles on the apron.				X									X		X	X		X	X	X	X	X	X	X	X					
Hoolhorst A., Erbrink J.J., Kokmeijer E., and Scholten R.D.A. (2008) "Luchtkwaliteit rond luchthaven Schiphol Verfijningsberekeningen voor het MER korte termijn 'Verder werken aan de toekomst van Schiphol en de regio," National Aerospace Laboratory report no. NLR-CR-2008-241.	Air quality around Schiphol airport. More detailed calculations for the short-term environmental impact assessment: "Further Work on the Future of Schiphol and the Region." This report describes more detailed concentrations than carried out by Hoolhorst et al. (2007). It also describes the model parameters in some detail. The two scenarios modeled assumed 447 kPax and 485 kPax. Potential layouts of ground source power were investigated. These calculations confirm the effectiveness of ground source power in reducing NO_2 concentrations on Schiphol Plaza.				X									X		X	X		X	X	X	X	X	X	X	X					
Hsu H.H., Adamkiewicz G., Houseman E.A., Vallarino J., Melly S.J., Wayson R.L., Spengler J.D., Levy J.I. "The Relationship between Aviation Activities and Ultrafine Particulate Matter Concentrations near a Mid-Sized Airport," *Atmos Environ* 50:328–337 (2012).	Monitored UFP data near T.F. Green Airport were used to develop regression models. The results showed relatively small contributions from the airport, mainly because of relatively low aircraft operations.			X				X								X			X								X				

Hsu H.H., Adamkiewicz G., Houseman E.A., Vallarino J., Melly S.J., Wayson R.L., Spengler J.D., Levy J.I. "The Relationship between Aviation Activities and Ultrafine Particulate Matter Concentrations near a Mid-Sized Airport," *Atmos Environ* 50: 328–337 (2012).	UFP concentrations were monitored with 1-minute resolution at 4 monitoring sites surrounding T.F. Green Airport in 2007 and 2008. Regression models were developed to predict concentrations as a function of LTO activity, meteorology, and other factors. To better pinpoint the timing in the LTO cycle most contributing to elevated concentrations, a lag model used considered terms between 5 minutes before and 5 minutes after the departure or arrival.				x			x								x				x							x				
Hsu H.H., Adamkiewicz G., Houseman E.A., Zarubiak D., Spengler J.D., Levy J.I. "Contributions of Aircraft Arrivals and Departures to Ultrafine Particle Counts Near Los Angeles International Airport," *Sci Tot Environ* 444:347–355 (2013).	Aircraft flight activity and near-field continuous UFP concentrations (≥ 6 nm) were measured at five monitoring sites over a 42-day field campaign at Los Angeles International Airport (LAX).				x			x								x				x						x					
Hsu H.H., Adamkiewicz G., Houseman E.A., Zarubiak D., Spengler J.D., Levy J.I. Contributions of Aircraft Arrivals and Departures to Ultrafine Particle Counts Near Los Angeles International Airport," *Sci Tot Environ* 444:347–355 (2013).	Monitored UFP data were regressed with aircraft activities at LAX. The results showed significant correlation and indicate significant contributions from aircraft.			X		X		X								X				X						X					
Hu S., Fruin S., Kozawa K., Mara S., Winer A.M., and Paulson S.E. (2009) "Aircraft Emission Impacts in a Neighborhood Adjacent to a General Aviation Airport in Southern California," *Environ Sci Technol* 43, 8039–8045.	The authors measured a range of air pollutants near a general aviation airport (Santa Monica Airport, CA) for private planes and corporate jets in the spring and summer of 2008. They found that emissions of ultrafine particles were significantly elevated when compared to background pollution levels. Levels of these pollutants were up to 10 times higher at a downwind distance from the airport equal to about one football field and as much as 2.5 times higher at distance equal to about six football fields. The study suggests that, "current land-use practices of reduced buffer areas around local airports may be insufficient."							X								X												X			
Hubbell, Bryan. 2001. *Evaluating the Health Benefits of Air Pollution Reductions: Recent Developments at the U.S. EPA*. U.S. EPA, Office of Air Quality Planning and Standards, Innovative Strategies and Economics Group.	An overview-type paper that describes the general monetization of air quality impacts from various industries, especially highway and stationary sources. Discusses the importance of epidemiologists and economists to work together in monetizing the benefits of air pollution regulation.								X	X		X				X	X														

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ICAO (2011) "Air Quality Guidance Manual." International Civil Aviation Organization, Montreal, Canada.	The industry guidance document for local air quality management at airports covers the preparation of an emissions inventory, dispersion modeling, measurements and mitigation options. Interestingly, the guidance sets out what would be required to produce an emissions inventory under different approaches—simple, advanced, and sophisticated. The report also sets the context for the guidance given, such as giving information on regulatory drivers and why an airport may choose to manage air quality.		X	X	X														X												
ICAO, "Airport Air Quality Manual," Doc. 9889, International Civil Aviation Organization, 2011.	Best practices for air quality measurements at airports are discussed in Chapter 6 of this report. Three appendices also discuss methods and references.	X		X				X						X		X			X							X					
Ionel I., Nicolae D., Popescu F., Talianu C., Belegante L., and Apostol G. (2009) "Measuring Air Pollutants in an International Romania Airport with Point and Open Path Instruments," *Rom Journ Phys* 56, 507–519.	Monitoring results for VOCs, SO_2, NO_x, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3 over a 3-day period are reported in this paper.						X	X						X		X	X	X								X					
Ionel, I., D. Nicolae, F. Popescu, C. Talianu, L. Belegante, and G. Aposol, "Measuring Air Pollutants in an International Romania Airport with Point and Open Path Instruments," *Rom Journ Phys*, Vol 56, Nos. 3–4, pp. 507–519, Bucharest, 2011.	Two monitoring stations were used near the apron to monitor VOCs, fine particulate matter ($PM_{2.5}$ and PM_{10}), NO, NO_2 and NO_x, CO, O_3, SO_2, and other gases for a 3-day continuous measurement project. Meteorology was also reported.		X	X				X						X		X	X		X								X				
Jamin Koo, Qiqi Wang, Daven K. Henze, Ian A. Waitz, Steven R.H. Barrett, 2013. "Spatial Sensitivities of Human Health Risk to Aircraft Emissions," *Atmos Environ* 71 (2013) 140–147. DOI: 10.1016/j.atmosenv.2013.01.025.	The GEOS-Chem global chemistry model was used to conduct a study to assess premature death from exposure to various pollutants emitted from aircraft. The study is global and provides sensitivities to pollutants by location.				X					X				X		X	X			X											
Jefferson T. and Ferroni E. (2009) "The Spanish Flu through the BMJ's Eyes: Observations and Unanswered Questions," *British Medical Journal*, 339, 1397–1399.	Included in this literature review as an example of the caution that should be applied in interpreting limit values for individual pollutants because humans compete for survival in a complex ecology. At the time of the Spanish flu epidemic, it was noted that exposure of workers to NO_2 appeared to reduce their susceptibility to influenza. NO_2 is certainly toxic to humans, but perhaps it is even more toxic to airborne viruses. (Gregor 1919, quoted by Jefferson and Ferroni 2009.)										X			X																	
Kim, Brian, et al. (2012). *ACRP Report 71: Guidance for Quantifying the Contribution of Airport Emissions to Local Air Quality*. Transportation Research Board (TRB).	Provides an overview of previous airport air quality studies. Presents a framework to include measurements with modeling to comprehensively understand airport contributions to local air quality. The measurement work provides indications of ambient concentration contributions from the airport as well as daily and seasonal trends.			X	X			X					X	X		X	X	X	X						X	X			X	X	

Kinsey, John S., et al. (2010). Physical Characterization of the Fine Particle Emissions from Commercial Aircraft Engines during the Aircraft Particle Emissions eXperiement (APEX) 1-3. *Atmos Environ* 44 (2010) 2137–2156.	Describes the work conducted during the three APEX 1-3 measurement campaigns to collect PM data, and their derivation of EI values. The size distributions of the primary modes were lognormal with minor accumulation modes at high power.						X									X				X											
Klapmeyer M.E. and Marr L.C. (2012). CO_2, NO_x, and particle emissions from aircraft and support activities at a regional airport, *Environmental Science and Technology* 46(20), 10974–10981.	CO_2, NO_x, and PM ambient measurements were performed next to an airport. Results showed meteorological factors affecting CO_2 and NO_x while PM was mainly affected by aircraft operations.							X						X		X			X								X				
KM Chng Environmental, Inc. 1999. *Findings Regarding Source Contribution to Soot Deposition, O'Hare International Airport and Surrounding Communities.* Burlington, MA.	Due to concerns from the local community, a study was conducted to determine the soot (PM) contributions from O'Hare International Airport. Using chemical fingerprinting techniques, samples from several sites around the airport showed that the soot did not resemble characteristics of jet exhaust but rather those of other urban sources including motor vehicles.					X	X	X								X				X					X	X					
Langridge J.M., Gustafsson R.J., Griffiths P.T., Cox R.A., Lambert R.M., and Jones R.L. (2009) "Solar Driven Nitrous Acid Formation on Building Material Surfaces Containing Titanium Dioxide: A Concern for Air Quality in Urban Areas?" *Atmos Environ* 43, 5128–5131.	The use of external building surfaces coated with titanium dioxide has been put forward as a method for removing NO_2 from the ambient air. It has been proposed at several European airports. This paper, while accepting that this occurs, challenges the concept because of the commensurate formation of gaseous nitrous acid.													X																	
Lee G. (2012) "Development of Techniques for Rapidly Assessing the Local Air Quality Impacts of Airports," Submitted to the Department of Aeronautics and Astronautics in Partial Fulfillment of the Requirements for the Degree of Master of Science in Aeronautics and Astronautics at the Massachusetts Institute of Technology, USA.	A M.Sc. thesis. In summary, it tests a methodology for carrying out dispersion modeling of $PM_{2.5}$ emissions for aircraft at a large number of airports. The approach taken using RDMS was found to over-predict AERMOD produced concentrations by ~5% but reduces modeling time by ~95%. The study also estimated early deaths as a result of the airport emissions.			X	X						X		X			X				X											
Levy J.I., Woody M., Baek B.H., Shankar U., Arunachalam S. "Current and Future Particulate Matter-Related Mortality Risks in the United States from Aviation Emissions During Landing and Takeoff. *Risk Anal* 32: 237–249 (2012).	Bottom-up model linking CMAQ with concentration-response functions for PM mortality in the U.S. Emphasis on emissions in 2005 and 2025 from 99 airports around the U.S., considering separately influence of emissions, population growth and aging, and changing non-aviation concentrations on the trajectory of health risks.				x	x				x	x					x		x		x											

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Levy, Jonathan, et al. (Oct 2008) “High-Priority Compounds Associated with Aircraft Emissions,” PARTNER Project 11, final report on subtask: Health Risk Prioritization of Aircraft Emissions Related Air Pollutants.	Report correctly points out that previous, similar papers have reported high-priority compounds based on emissions and toxicity alone without taking into account fate and transport (population exposure). Focused on total population health risk rather than individual health risk. Consideration for the spatial domain and differences in airports (e.g., different locations, seasons, etc.) also were taken into account. AERMOD and CMAQ were used for the dispersion modeling. Several criteria pollutants and HAPs species were selected as a starting point. The toxicity determinations of each pollutant are presented. Ultrafine PM risks outweigh those from HAPs, but there are high uncertainties. Among HAPs risks, Formaldehyde dominates. Although HAPs risk is less than PM, respiratory impacts from HAPs are a concern, especially with relatively higher exposure to acrolein.				X	X				X	X					X	X		X												
Lobo, Prem et al. (Jul 2011) SAE E31 Methodology Development and Associated PM Emissions Characteristics of Aircraft APUs Burning Conventional and Alternative Aviation Fuels. PARTNER Project 34 final report.	The purpose of the project was to test the SAE E31 measurement methodology and to gather further APU emissions data. Measurements were conducted at the University of Sheffield using a mounted APU. PM size distributions and non-volatile fractions were obtained. Emissions from biodiesel were found to be higher than those for Jet A and natural gas derived Fisher Tropsch fuel.						X									X					X										
Lobo, Prem, et al. (Oct 31, 2007). “The Development of Exhaust Speciation Profiles for Commercial Jet Engines.” Final Report. JETS APEX2. California Air Resources Board and the California Environmental Protection Agency.	The report presents aircraft emissions data collected from a measurement campaign conducted at Oakland International Airport. The pollutants measured included criteria pollutants, CO, and hydrocarbon species at various power settings. The development of the speciation profiles was the primary goal. PM size distributions were found to be lognormal. Gas-to-particle conversion was observed with increasing distance from the exhaust exit plane.						X							X		X	X			X											
Lobo, Prem et al. (2008). Delta-Atlanta Hartsfield (UNA-UNA) Study. PARTNER Report No. PARTNER COE-2008-002.	Describes the engine emissions measurements conducted at Atlanta Hartsfield-Jackson International Airport (previously known as UNA-UNA study). Various sensitivities and trends are discussed (e.g., emissions by engine type and power setting). Mainly focused on better understanding emissions by engine type.						X									X				X						X					

London Assembly (2012) "Plane Speaking, Air and Noise Pollution around a Growing Heathrow Airport," London Assembly Environment Committee. Published by Greater London Authority, City Hall, London, U.K.	The Committee comprises a small number of cross-party MPs. The report doesn't contain any new work but does provide a commentary on the air quality impacts of Heathrow Airport and makes recommendations. The report isn't concerned with the debate about a third runway but about Heathrow as it grows from a current passenger throughput of 69 million per year to a potential 90–95 million once the current terminal developments are completed. This is without a new runway and any significant increase in ATMs, as Heathrow is near its movement capacity limit, but is a result of larger aircraft. Recommendations include Heathrow Airport Limited increasing the number of greener, quieter aircraft; ensuring on-site vehicles meet the latest EU emissions standards; and reducing airport-related road traffic. The report highlights a range of issues that will need to be tackled to improve surface access to the airport and to encourage passengers and employees to use public transport more for their journeys to and from the airport.	X																							X						
London City Airport (2012) "Air Quality Action Plan 2012–2015," London City Airport, City Aviation House, Royal Docks, London, U.K.	This action plan sets out 19 specific mitigation measures to reduce airport-related air quality emissions. The document also sets out the broader context to these measures and includes information on the Airport's air quality measurement program. The number of odor complaints since 2000 is reported.	X																								X					
London Gatwick Airport (2006) "Gatwick Emission Inventory 2002/3 (Public Access Version)," London Gatwick Airport, 5th Floor, Destination Place, South Terminal, Gatwick Airport, West Sussex, RH6 0NP, U.K.	An airport emissions inventory for Gatwick Airport.				X									X		X			X							X					
MA (2012) "Air Quality Community Information Sheet," Manchester Airport plc, Manchester, U.K.	Several page, non-technical description of the air quality issue surrounding Manchester Airport. Monitored concentrations of NO_2 are presented for the last 15 years. Background information on odors and fuel jettisoning is also given.	X												X		X										X					X
Maurice, L. and David S. Lee (2007). *Assessing Current Scientific Knowledge, Uncertainties, and Gaps in Quantifying Climate Change, Noise, and Air Quality Aviation Impacts.* Final Report of the International Civil Aviation Organization (ICAO) Committee on Aviation and Environmental Protection (CAEP) Workshop. Montreal, Canada. Oct 29–Nov 2.	Provides an overview of the views on emissions/air quality (as well as other environmental concerns) by members of ICAO/CAEP—thus providing an overall international view. The paper acknowledges weaknesses in current understanding of PM and HAPs species emissions. Also, emissions inventories by themselves may satisfy certain regulatory requirements, but they need to be tied to dispersion modeling to provide a direct link to health assessments.	X	X	X										X		X	X														

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McGulley, Frick and Gilman, Inc. 1995. *Final Report: Air Quality Survey, Seattle-Tacoma International Airport.* Port of Seattle, WA.	An air quality measurement study was conducted in the vicinity of Seattle-Tacoma International (Sea-Tac) Airport. Ambient levels of various toxic organic compounds and carbon monoxide were measured. Comparisons to other urban areas were made and the resulting concentrations were found not to be similar.						X						X			X		X					X		X			X			
Milieu- en Natuurplanbureau (2006) "De luchtkwaliteit rond Schiphol. MNP-bevindingen over het onderzoek naar de uitstoot van het vliegverkeer en de luchtkwaliteit rond Schiphol door ADECS Airinfra BV in het kader van de Evaluatie Schipholbeleid," Report No. 500133001/2006, Milieu- en Natuurplanbureau, PB 303, 3720 AH Bilthoven, Netherlands.	Air quality around Schiphol. MNP's interpretation of the investigation by ADECS Airinfra BV of the emissions of air transport and of air quality around Schiphol within the framework of policy evaluation for Schiphol). This document criticizes ADS (2005). It reckons it is too optimistic. The document includes some interesting sensitivity analyses of NO_2 concentrations on the effective emissions height (raising this from 5 m to 15 m halves the modeled concentrations) and on the division between modes (~55% comes from take-off and most of the rest from idling). It complains that the ADS report does not list these sensitive parameters.	X		X	X									X		X	X			X					X	X					
Mitchell, Kenneth L. (2006). "Airports and Air Toxics," Airport Noise & Air Quality Symposium. University of California, Berkeley. Palm Springs, CA.	An overview presentation that provides coverage of airport contributions to air quality, especially focusing on PM and HAPs. Indicates the need for better measured data and better quantification methods/models.	X		X												X	X														
MNPCA, "Update on Air Monitoring Near the Minneapolis-St. Paul International Airport," Minnesota Pollution Control Agency, May 2006.	Starting in 2005, the Minnesota Pollution Control Agency (MPCA) added air toxic and fine particulate air monitoring sites in residential neighborhoods near the Minneapolis-St. Paul International Airport (MSP). This document reports the MPCA analysis of the first six months of air toxics and fine particulate data at the sites. The resulting air toxics concentrations were compared to other Twin Cities' monitoring locations as well as inhalation health benchmarks provided by the Environmental Protection Agency and the Minnesota Department of Health. The results of four locations are reported for $PM_{2.5}$, BC, and five HAPs.			X				X	X		X		X				X		X							X				X	X
Municipality of Anchorage, *Ted Stevens Anchorage International Airport Air Toxics Monitoring Study,* Environmental Services Division, Municipality of Anchorage, Apr 2003.	Ten monitoring stations were used to characterize the HAPs around the airport. While 34 compounds were attempted to be measured, only 8 were above reporting limits and included (benzene, toluene, ethylbenzene, m,p-xylene, o-xylene, CO, ethane, and ethyne). Results and methodology is included in the report.			X				X			X			X			X	X	X								X		X	X	

NASA (2006) "Aircraft Particle Emissions Experiment (APEX)."	This study ran an aircraft engine at a range of power settings and with different sulphur content fuels. Measurements were taken of non-volatile and volatile particles at varying distances from the engine exhaust. Gaseous pollutants, NO_x and NO_2 and hydrocarbons also were measured. The purpose of the measurements was to inform future emissions indices.						X									X				X											
NETCEN (2006) "Air Quality Modelling for Gatwick Airport 2002/03," National Environmental Technology Centre, AEA, Harwell, U.K.	A dispersion modeling study carried out for using a previously produced emissions inventory for Gatwick Airport. Contour maps are presented for NO_2 and also for total emissions and airport only emissions for NOx and PM_{10}.				X									X		X			X							X					
Onasch, T.B., J.T. Jayne, S. Herndon, D.R. Worsnop, R.C. Miake-Lye, I.P. Mortimer, and B.E. Anderson (2009). *Chemical Properties of Aircraft Engine Particulate Exhaust Emissions. Journal of Propulsion and Power*, 25(5): 1121–37.	The chemical properties of the particulate exhaust emissions from an in-use commercial aircraft engine were measured and characterized in April 2004, as part of the Aircraft Particle Emissions eXperiment (APEX) using a suite of instruments. The test engine was a CFM56-2-C1 and was sampled at 11 different throttle settings, using 3 fuel compositions, and at 3 sample distances. The differences in particulate matter emission number, size, mass, and chemical composition are reported.																														
Owen B. and Paling C. (2005) "Air Quality Assessment 2004 and 2019 Bristol International Airport." Report prepared by Centre for Aviation, Transport and the Environment, Manchester Metropolitan University, Manchester, U.K.	This study looks at the local air quality impacts of operations at Bristol International Airport. The emissions of key pollutants to the air have been estimated and then the dispersion of these pollutants has been plotted to determine the resultant ground level pollutant concentrations. Emission estimates (inventories) for Bristol International Airport have been constructed for the years 2004 and 2019. This report presents the methods and data sources used and the results of the air quality impacts. Aircraft represent the single largest source of emissions of NO_x, CO, HCs and PM_{10} at the airport. There were no major sources of SO_2 at the airport, with emissions from aircraft being low. All estimated air pollution concentrations indicate that there are no expected exceedences of air quality standards within the local airport area for 2004 for nitrogen dioxide or particulate matter. However, for 2019 exceedences of the annual average nitrogen dioxide standard are predicted for a small area within the airport boundary. Levels of nitrogen dioxide are predicted to be well below the annual average standard outside the airport perimeter and at any residential properties.				X									X		X	X		X									X			

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Passchier, W., Knottnerus, A., Albering, H., and Walda, I. Public Health Impact of Large Airports. *Reviews on Environmental Health*, 2000, Vol 15, No. 1-2, pp 83–96, Health Council of the Netherlands.	This study is a discussion of the probable influences on public health in the vicinity of airports. There are more factors to consider in addition to air pollution from aircraft, "An airport can operate only with an infrastructure of roads and railways, and with related business for freight handling lodging, catering, and so on, nearby." The dominant environmental factors are air pollution, noise, accidents, soil and water pollution, and the appearance of the environment. Thus, the environmental factors in an airport operations system affect the population cumulatively.	X								X															X						
Penn, S.L., S. Arunachalam, and J.I. Levy, 2012. "The Effects of Airport Activity on Black Carbon Concentrations Near Runways at Los Angeles International Airport." Presented at the 22nd Annual Meeting of Exposure Science, Seattle, WA, Oct 28–Nov 1, 2012.	Black carbon (BC) monitors were used to determine BC concentrations at various locations around a runway. The monitored data were regressed based on location and aircraft activities. Significant correlation with aircraft departures were found.			X				X								X				X						X					
Peters D., Grainger D., and Smith A. (2009) "Local Air Quality Characterising Near Surface Aircraft PM." Authors from University of Oxford, published by OMEGA project, Manchester Metropolitan University, Manchester, U.K.	The authors describe how they have created "SPARCLE," an instrument suitable for deployment in an airport environment that is capable of discriminating different types of particulate matter pollution—a "fingerprint." They show how this new instrument has been tested and shown to have the ability to distinguish between steel brake particles and tire particles, over the $PM_{2.5}$ and PM_{10} range. They state that such a tool will be very useful for air quality assessments at airports.			X				X								X															
Petzold A., Hotes A., and Radig A. (2008) "Measurement of Soot Particles with State-of-the-Art Methods as a Basis for a New Certification Approach," Deutsches Zentrum für Luft- und Raumfahrt Institut für Physik der Atmosphäre Oberpfaffenhofen 82234 Wessling, Germany and AVISTRA GmbH Reinhardtstr. 58 10117 Berlin, Germany.	The authors have carried out a literature review and desk-based study to investigate the concept of a limit value for aircraft engines at certification, along the lines of those for other pollutants. They draw a number of conclusions about how this may be done, such as, limit value would have to be related to the rated thrust in order to match the concept of limiting values for gaseous emissions from aircraft engines, agreement is required whether any limiting value has to take fuel composition (sulphur content, bio fuels) into account since fuel properties may influence engine emission properties, and whether the limit value applies to mass and/or number of particles. Combining the effects of fuel efficiency improvement and increase in air traffic numbers, any limiting value for particulate matter emissions has to aim at a reduction of particle emissions growth to less than 65% over the next 20 years; otherwise this limiting value will be without impact.		X	X												X				X											

Pope III C.A. and Dockery D.W. (2006) "Health Effects of Fine Particulate Air Pollution: Lines that Connect," *J Air & Waste Manage Assoc* 56, 709–742.	This paper is a review that focuses on six substantial lines of research that have helped elucidate the understanding about the effects of PM on human health. The review is long and contains a substantial amount of information on particulate matter and public health.	X									X					X															
Public Health Impact of Large Airports—Report. Health Council of the Netherlands: Committee on the Health Impact of Large Airports. The Hague: Health Council of the Netherlands (1999) 1999/14E. ISBN:90-5549-279-5.	A comprehensive report (1999) written in response to a request from the Dutch Government's Minister of Health, Minister of Transport, and Minister of the Environment. The report focuses directly on the public health impact of local changes in environmental factors including quality of life close to airports at distances up to 10 km and includes activities of businesses attracted to the airport region. The health impact of several factors are considered: (1) air pollution, (2) noise, (3) accidents, (4) soil and water pollution at the airport, (5) importation of infectious diseases, (6) appearance of the environment, (7) occupational health risks at the airport. The conclusion is that airport operations have the potential to cause clinically observable disease in the long-term although definitive assessments are lacking. The committee recommends that airport developments should be assessed on their public health consequences in an integrated manner. Over 280 references are cited. The report recognizes that contributions from aircraft, airport operations, and road traffic are intricately mixed, and air pollutant levels around large airports are similar to those in urbanized areas and are to a large extent determined by road traffic emissions. At such concentrations public health effects are to be expected. Also, there is evidence that episodes of air pollution can cause short-term effects like an increased mortality rate and an increased frequency of hospital admissions due to acute respiratory and cardiovascular morbidity. Although it is plausible that air pollutants contribute in a modest way to cancer incidence, there is no evidence for specific contributions from local sources in an airport operations system. Sufficient evidence exists for odor-induced annoyance. The study summarizes the health effects and assesses how good the evidence is on a three-point scale.	X											X																			

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Puente-Lelievre (2009) "La Qualité de l'air en Milieu Aéroportuaire: étude sur l'aéroport Paris-Charles-De-Gaulle," Thèse de Doctorat, Université de Paris XII.	Air quality in an airport environment: study of Paris-CDG airport. This is a modeling and monitoring study of NO_x, O_3 and hydrocarbons around Paris-CDG airport. The model was used to simulate the regional impact of the airport on a summer O_3 event and a winter NO_2 event: it struggled with the latter since the spatial resolution was rather coarse and the winds were light. At a downwind site, the airport perhaps contributes 15–20 µg m-3 to short-term NO_x concentrations. Measured airside concentrations of HCs showed concentrations of saturated HCs at 5–7 µg m-3 and of aromatics at 10–15 µg m-3. This is similar to what is seen as urban background. Being a doctoral thesis, the document includes an extensive bibliography of air quality around airports, but associated with measuring and modeling air quality, rather than with health effects.				X		X	X						X			X		X	X	X	X	X	X	X	X				X	
Ratliff, Gayle, et al. (2009) "Aircraft Impacts on Local and Regional Air Quality in the United States," PARTNER Project 15, final report. Oct.	A system-level analysis of U.S. airports was conducted using the top 325 airports for nonattainment areas. Emissions from non-aviation sources were obtained from the EPA's National Emissions Inventory, and CMAQ was used for the dispersion modeling work. The overall results generally showed less than 1% concentration.				X					X				X		X				X						X	X	X			
RIDEM, "Characterization of Ambient Air Toxics in Neighborhoods Abutting T.F. Green Airport and Comparison Sites: Final Report," Rhode Island Department of Environmental Management, Apr 2008.	This report describes sampling methods and results performed between April 2005 and August 2006 by RIDEM. HAPs, associated with aircraft operations were monitored and concentrations reported. Toxics reported to be elevated in local neighborhoods were benzene, 1,3-butadiene, toluene, naphthalene, formaldehyde, acetaldehyde, acrolein, polycyclic aromatic hydrocarbons (PAHs), diesel particulate and fine particles (PM2.5). Due to methodological limitations, PAHs, acrolein and naphthalene were not measured in this study. Thirty different volatile organic compounds (VOC) associated with mobile and stationary sources were successfully monitored.	X						X									X	X	X								X			X	X
SAL (2010) "Creating an Atmosphere for Change, Stansted Air Quality Strategy 2010–2015," Stansted Airport Limited, Essex, U.K.	An air quality strategy document for London Stansted Airport for the period 2010–2015. It is typical of such documents and sets out the context for the strategy—about Stansted Airport and its development, the regulatory context, existing air quality measurements data and the results of an emissions inventory and dispersion modeling exercise. It then goes on to describe the broader strategy before giving the specific actions and timescales. Performance indicators are also presented.	X																	X							X					

SCAQMD, "General Aviation Airport Air Monitoring Study: Follow-Up Monitoring Campaign at the Santa Monica Airport, Final Report," South Coast Air Quality Management District, Apr 2011.	Between April 2006 and March 2007, the South Coast Air Quality Management District (AQMD) conducted a field study at the Santa Monica Municipal Airport (SMO) to characterize the impact of aircraft emissions and airport activities on the surrounding communities. Ambient concentrations of total suspended particulate lead (from the leaded fuel used in piston-driven aircraft) and ultrafine particles (UFP) were measured. This report took advantage of a temporary suspension of all airport activities due to construction and measured the ambient concentrations of combustion-related pollutants including UFP, black carbon (BC) and volatile organic compounds (VOC) before, during, and after curtailment of aircraft activities. Methods and results are presented.							X			X		X	X		X	X		X					X			X				X
Schlenker W., Walker W.R. "Airports, Air Pollution, and Contemporaneous Health," NBER Working Papers Series, Working Paper 17684 http://www.nber.org/papers/w17684, Dec 2011.	An econometric investigation that attempts to exploit the fact that network delays originating from large airports on the East Coast can increase runway congestion in California, with corresponding influence on local air pollution, without significant confounding from other local events.				x				x					x					x												
Schurmann G., Schafer K., Jahn C., Hoffmann H., Bauerfeind M., Fleuti E., and Rappengluck B. (2007) "The Impact of NO_x, CO, and VOC Emissions on the Air Quality of Zurich Airport," *Atmos. Environ* 41, 103–118, 2007.	Measurements of NO, NO_2, CO, and CO_2 were conducted with open path devices at Zurich Airport, Switzerland, to determine real in-use emission indices of aircraft during idling. Additionally, air samples were taken to analyze the mixing ratios of volatile organic compounds (VOC). Temporal variations of VOC mixing ratios on the airport were investigated, while other air samples were taken in the plume of an aircraft during engine ignition. A number of conclusions were drawn from the study. The authors also noted differences from emission indices published in the emission database of the International Civil Aviation Organization with their measurements.						X	X						X			X									X					
Sequeira C.J. (2008). "Relationships between Emissions-Related Aviation Regulations and Human Health." Presented at the 10th PARTNER Advisory Board Meeting. Ottawa, CA. Mar 15.	A study was conducted using 325 U.S. airports to determine potential stringency strategies to reduce health impacts. Emissions were modeled using EDMS and obtained from the EPA's NEI. Dispersion modeling was accomplished using CMAQ. Health cost-benefits were valued using BenMap. Reductions in NO_x emissions and fuel sulfur would help to reduce U.S.-wide premature mortality by 40%.				X					X				X		X	X														

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Sivertsen B (2003) "Air Pollution Impact Assessment for Sharm El-Sheikh Airport," report prepared by the Engineering Consultants Group (ECG) for the Ministry of State for Environmental Affairs, Egypt and Norwegian Institute for Air Research.	Part of an Environmental Impact Assessment (EIA) related to air pollution emitted from the different sources at the proposed Sharm El-Sheikh International Airport. Based on measurements and modeling of ground-level concentrations due to emissions from road traffic and aircraft operations. The study found that concentrations are normally well below the air quality limit values given in Law No. 4 of Egypt and by the World Health Organization guideline values. The most "critical" case is the maximum 1-hour average NO_2 concentration in the unloading and parking zone at the terminal building. The maximum concentration may reach 75% of the air quality limit for Egypt, and is higher than the WHO guideline. The main air pollution problem in the background atmosphere is suspended particles originating mainly from natural wind-blown dust.				X									X		X	X			X					X			X			
Society of Automotive Engineers (SAE) (2009). "Procedures for the Calculation of Aircraft Emissions." SAE AIR 5715. July.	Provides guidance on modeling aircraft emissions and performance. Emissions models include the ICAO standard method, BFFM2, P3T3, the DLR Method, FOA, etc. Some uncertainty assessments showing potential errors and comparisons of the methods are presented.			X	X									X		X	X			X											
South Coast Air Quality Management District (SCAQMD) (2010). *General Aviation Airport Air Monitoring Study, Final Report.* USEPA. Aug.	Measurement study to characterize concentration levels around VNY and SMO. These are very busy GA airports with Van Nuys having about 450,000 annual LTOs. The document describes the monitoring and provides key findings of concentrations of lead, VOCs, PM, and CO. Lead concentrations were 2 to 9 times higher than background, but generally lower than the 150 ng/m3 standard. Lead build-up on nearby soil is a concern. $PM_{2.5}$, EC, and OC were similar or below those of background. UFP levels were significantly higher than background (600 times). CO from airport was not shown to be significant. HAPs were higher in the winter than in the summer.						X							X	X	X	X											X			

Stettler M.E.J, Eastham S., Barrett S.R.H. (2011) "Air Quality and Public Health Impacts of U.K. Airports. Part I: Emissions," *Atmos. Environ.* 45, 5415–5424. 2011	This study is an emissions inventory of U.K. airports (95% of U.K. passengers) for the local air quality pollutants (NO_2, CO, SO_2, HC, $PM_{2.5}$) and CO_2 for the year 2005. The authors have calculated emissions from three sources at each airport: (1) aircraft landing and takeoff (LTO) operations, (2) APUs, and (3) airside support equipment (or GSE). Uncertainties are quantified, based on an analysis of data from aircraft emissions measurement campaigns and analyses of aircraft operations. The authors have reviewed previous methodologies and emissions measurement studies to inform their calculations, e.g., the First-Order Approximation (FOA3) method, currently the standard approach used to estimate particulate matter emissions from aircraft, was found to be over an order of magnitude different compared to measurements. Modified methods to approximate organic carbon emissions, arising from incomplete combustion and lubrication oil, and black carbon are used. The study makes assumptions on times in mode for each airfield. The calculated emissions from this study are used as the basis for Part II of this work (Yim et al., 2013).				X									X		X	X			X						X	X	X			
Steve H.L. Yim, S.H.L.; Barrett, S.R.H., "Public Health Impacts of Combustion Emissions in the United Kingdom," *Environ Sci Tech* 46, 4291–4296. 2012.	This study quantifies the number of early deaths per year in the U.K. from $PM_{2.5}$ exposure from combustion emissions. Included within combustion emissions is aviation within a category of "other transport." The same research team at the Massachusetts Institute of Technology (MIT) has completed two other studies that look specifically at U.K. aviation emissions (Stettler 2011 and Yim 2013).				X						X					X															
SUVA (2011) "Grenzwerte am Arbeitsplatz, 2011," Schweizerische Unfallversicherungsanstalt. "Limit Values at the Workplace," 2011, Swiss Accident Insurance Institute.	This does what it says on the tin, being a list of short-term and long-term occupational exposure limits for a wide range of chemicals. In format, it is very similar to the equivalent British EH40. Besides the quantitative limit values, the document includes useful explanatory material regarding aspects of toxicity and other hazards to health.		X								X			X	X	X	X														
Tarrasón L., Jonson J.E., Berntsen T.K., Rypdal K. *Study on Air Quality Impacts of Non-LTO Emissions from Aviation*, final report to the European Commission under contract B4-3040/2002/343093/MAR/C1. 2004.	Literature review and modeling study to determine the contribution of LTO emissions vs. cruise emissions to air quality in Europe.				x	x								x		x	x	x		x											

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Tesseraux I. (2004) "Risk factors of Jet Fuel Combustion Products." *Toxicology Letters,* 149, 295–300.	A publication looking at the speciation of HC emissions in jet engine exhausts and comparing them with what is typically seen in diesel engine emissions. Nothing distinctive was found in the jet engine exhausts. By implication, there was "no air pollution–derived health risk indicator for urban emissions other than the ones present in urban air." Note, however, that the author makes no discussion of the physical state of the HC: there is nothing regarding particulate matter.				X												X			X											
Tesseraux I. (2006) Ausbau Flughafen Frankfurt Main. "Unterlagen zum Planfeststellungsverfahren. Gutachten G14: Humantoxikologie. Karlsruhe," 17.12.2006. "Extension to Frankfurt Airport. Basis for the Planning Process, Deliverable G14: Human toxicology."	A highly relevant document, containing an excellent review and bibliography. The author recognizes (p 38) that morbidity and mortality from air pollution are especially dominated by ultrafine particulate matter. There may also be synergistic effects, e.g., between VOCs and NO_2 or fine particles—or even noise! The author reviews limit values and estimated quantitative health impacts published by WHO, the EU and the Bundesrepublik. It is noted (p 52) that NO_2 concentrations in the neighborhood of the airport exceed the EU limit value of 40 µg m-3, particularly at heavily trafficked locations. Dispersion calculations for the current (2005) situation and for a base case and a planning case in 2020 are made for a range of toxicologically relevant pollutants. The toxicological analysis then amounts to comparing calculated concentrations with limit values and guide values. Calculated concentrations for 2005 agree well with the monitored values (p 67). Limits are exceeded for some pollutants (NO_2, soot, BaP), but there are generally only small differences between the three modeled cases. There seems to be no evidence that emissions specifically from an airport are any more toxic than those in a conventional urban environment. Emission estimates in other deliverables are referenced.	X	X	X	X		X	X	X		X			X	X	X	X	X		X	X	X	X	X	X	X					

Tesseraux, I. "Risk Factors of Jet Fuel Combustion Products," *Toxicology Letters*, 2004. 149: pp 295–300. Proceedings of EUROTOX 2003. Science for Safety.	Authors found aircraft emissions vary with engine type, engine load, and fuel. Among jet aircrafts there are differences between civil and military jet engines and their fuels. Combustion of jet fuel results in CO_2, H_2O, CO, C, NO_x, particles, and a great number of organic compounds. Among the emitted hydrocarbons (HCs), no compound (indicator) characteristic for jet engines could be detected so far. Jet engines do not seem to be a source of halogenated compounds or heavy metals. They contain, however, various toxicologically relevant compounds including carcinogenic substances. A comparison between organic compounds in the emissions of jet engines and diesel vehicle engines revealed no major differences in the composition. Risk factors of jet engine fuel exhaust can only be named in the context of exposure data. Using available monitoring data, the possibilities and limitations for a risk assessment approach for the population living around large airports are presented. The analysis of such data shows that there is an impact on the air quality of the adjacent communities, but this impact does not result in levels higher than those in a typical urban environment.							X		X				X		X	X									X					
Tetra Tech, Inc. (2013). LAX Air Quality and Source Apportionment Study, Volume 1. Executive Summary. Final Report. June 18.	One of the largest and most comprehensive airport measurement (including some modeling) studies was conducted to assess airport contributions of air pollutants to local air quality. The study showed that while most criteria gas concentrations around the airport were below the NAAQS, PM2.5 levels were close to the NAAQS with less than 20% contributed by the airport. The smaller-sized ultrafine particulate (UFP) matter were found to originate from jet exhaust while the larger UFP were found to be from motor vehicles. Further studies on UFP health effects are necessary.				X	X	X	X						X	X	X	X	X	X	X				X	X	X			X	X	
The Danish Ecocouncil (2012) "Air Pollution in Airports. Ultrafine Particles, Solutions, and Successful Cooperation," the Danish Ecocouncil, Copenhagen, Denmark.	This study was carried out by a number of partner organizations at Copenhagen Airport. Pollutant measurements were made and a comparison was made to occupational exposure standards as set out in the Danish "Health and Safety at Work Act." The authors conclude employee exposure to ultrafine exhaust particles from aircraft and diesel engines in airports is an urgent and overlooked work-related challenge potentially affecting the health of millions of people. The report makes a number of recommendations to be adopted by ICAO and another set of recommendations for every airport.						X									X			X							X					

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Thiemens, M.H., *Isotopic Measurement and Analysis Approach to Uniquely Relate Aircraft Emissions to Changes in Ambient Air Quality, Final Report*, PARTNER-COE, Project 33, Nov 2010. (need final pub details)	The isotopic measurement approach was used during the AAFEX (Alternative Aviation Fuels Emissions Experiment) campaign to measure the isotopic fractionation in secondary sulfate and nitrate particulate matter (PM) formed due to gaseous precursors released during aircraft engine combustion. This PM isotopic fractionation was measured as a function of distance and fuel type. The isotopic enrichments in these aircraft-related particulate matter were found to be highly distinctive. This unique isotopic fingerprint in aircraft-related PM is caused by a combination of chemical processes during combustion under high temperature and pressures. Uniqueness of this fingerprint in aircraft-related PM makes the isotopic a possible approach in linking aircraft emissions to airport community-scale variability in air quality.			X	X		X									X		X		X											
Thiemens M.H. (2011) *Use of Isotopic Measurement and Analysis Approach to Uniquely Relate Aircraft Emissions to Changes in Ambient Air Quality.* PARTNER Project 33 Final Report. June.	The study was conducted based on the premise that isotopes of sulfate particles from aircraft could be uniquely identified apart from particles from other sources. The study found that the relatively high humidity in the Los Angeles area may have diluted the ability to identify the isotopes. Also, the lower-than-expected concentrations caused issues in properly identifying isotopes. It is recommended that future research in this area be conducted in lower humidity areas.			X				X						X		X				X											
Tunnicliffe W.S., O'Hickey S.P., Fletcher T.J., Miles J.F., Burge P.S., Ayres J.G., "Pulmonary Function and Respiratory Symptoms in a Population of Airport Workers," *Occup Environ Med* 1999; 56:118–123.	Cross-sectional epidemiological investigation of workers at Birmingham International Airport (U.K.) to determine if exposure to aircraft fuel or jet exhaust might be associated with respiratory symptoms or abnormal lung function.				x				x										x							x					
Underwood B.Y. (2007) "Revised Emissions Methodology for Heathrow: Base Year 2002." AEA Energy & Environment, Birchwood Park, Warrington, U.K. 2007.	This inventory applies the PSDH recommendations to a previous emissions inventory that was completed to inform the U.K. Future of Air Transport White Paper.			X	X									X		X			X							X					
Underwood B.Y., Walker C.T., and Peirce M.J. (2010) "Heathrow Airport Air Quality Modelling for 2008/9: Results and Model Evaluation." AEA Energy & Environment, Birchwood Park, Warrington, U.K. 2007.	This report, produced by AEA for BAA, presents the results of an emissions inventory and dispersion modeling study carried out for Heathrow Airport for the year 2008/09. Aviation emissions sources and local major roads are included in the inventory. The authors also report on a model validation exercise. This report is the third of a series, the other two being the emissions inventory study and the dispersion modeling work. NO_x, NO_2, PM_{10}, and $PM_{2.5}$ pollutants are included in the study. Contour plots are provided for these pollutants. This study has formed the basis of the Heathrow Air Quality Strategy (HAL 2011).			X	X									X		X			X							X					

Unique (2005) "Airport APU Emissions at Zurich Airport," Unique (Flughafen Zürich AG), P.O. Box, CH-8058 Zurich.	The scope of this study is to present a methodology and emission factors for the emissions calculation of auxiliary power units (APU).				X									X			X				X					X					
United States Environmental Protection Agency (USEPA) (1999). *Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft.* USEPA, Air and Radiation. EPA420-R-99-013. April.	The EPA conducted an emissions inventory–based study of 10 U.S. airports to determine the contribution of airports to local air quality (no dispersion modeling was conducted). The comparison years were 1990 and 2010. The 1990 aircraft component of the regional mobile emissions ranged from 0.6–3.6% while the 2010 emissions ranged from 1.9–10.4%.				X									X					X						X						
URS Corp. 2003. *Select Resource Materials and Annotated Bibliography on the Topic of Hazardous Air Pollutants (HAPs) Associated with Aircraft, Airports, and Aviation,* Federal Aviation Administration.	Provides a summary of the knowledge base on airport/aircraft hazardous air pollutant (HAP) emissions, including a rank order of HAP species.			X						X				X	X	X	X	X		X						X					
USEPA (2006). *Expanding and Understanding the Master List of Compounds Emitted by Mobile Sources—Phase III. Final Report.* Assessment and Standards Division, Office of Transportation and Air Quality. USEPA. EPA420-R-06-005.	Provides a review of literature summarizing all of the chemical species emitted from mobile sources (including aircraft) in order to expand/update the EPA full report.	X												X	X	X	X		X						X						
USEPA (2006). *Master List of Compounds Emitted by Mobile Sources*. Assessment and Standards Division, Office of Transportation and Air Quality. USEPA. EPA420-B-06-002.	EPA's master list of compounds emitted from mobile sources including aircraft.	X												X	X	X	X		X						X						
Vanderbilt P. and Lowe J. (2002) "Health Risk Assessment of Air Toxics from Airports: The State of the Science & Strategies for the Future," presented at the Dreams of Flight Airport Air Quality Symposium, 28 Feb 2002 by Pamela Vanderbilt, CH2M HILL, 2485 Natomas Park Drive, Suite 600, Sacramento, USA and John Lowe, CH2M HILL, 1 South Main Street, Suite 1100, Dayton, USA.	PowerPoint presentation that describes an overview of the airport air quality situation. It covers regulatory requirements and current understanding of health impacts at the time—note that this was in 2002, and is dated now.			X										X		X	X														
Vennam L.P., Vizuete W., and Arunachalam S. (2011) "An Assessment of Aviation-Related Hazardous Air Pollutants from a U.S. airport using CMAQ," in Proceedings of the 10th Annual Models-3 CMAS Users Conference, Chapel Hill, NC, Oct 2011.	CMAQ was used to model contributions of HAPs contributions from T.F. Green Airport. Includes the impacts of seasons and spatial variability.				X												X		X								X				

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Verkehrs-Club der Schweiz (2012) 'Testparcours für die Messung der Feinstaubbelastung in acht Schweizer Städten'.	Test profiles for monitoring fine particulate concentrations in eight Swiss towns. A joint action of the Swiss Travel Club and the Doctors for the Environment Society. The study describes mobile measurements of fine particulate in eight Swiss cities in January and February 2012. Instruments used were (1) a 'miniDiSC' developed by Martin Fierz, (http://www.fierz.ch/minidisc/) that monitored both the particle number concentration in the range 103–106 cm-3 and the mean particle diameter in the range 10–300 nm with a 3 s sampling time; and (2) a Personal Dust Monitor (http://www.conteng.it/Bollettini/PersonalDustMonit_En.pdf) that measured gravimetric concentrations divided between PM_1, $PM_{2.5}$, and PM_{10} with a 1 minute sampling time. Though unrepresentative, measured concentrations of fine particulate seem high enough to be of concern. The report includes a modest discussion and bibliography of the health effects of such particulate.			X				X			X					X									X						
Wahl C., Rindlisbacher T., and Kapernaum M. (2009) "Online Determination of Aircraft Engine Nanoparticle Emission Indices at Zürich Airport," ECATS Progress Meeting Schliersee, Sept 2009.	PowerPoint presentation made at an ECATS meeting of the results of a study at Zurich Airport, Switzerland. The authors measured particle mass and number per kg fuel burnt (approx. 4% maximum thrust) for 11 aircraft taxi movements (10 different engine variants). They calculated the total particle mass using the ICAO CAEP First Order Approximation (FOA3) method and correlated these results with their measurements. They found a good correlation.						X									X				X						X					
Wayson R.L., Fleming G.G., and Kim B., *Final Report: The Use of LIDAR to Characterize Aircraft Initial Plume Characteristics*, FAA-AEE-04-01, DTS-34-FA34T-LR3, Federal Aviation Administration, Feb 2004.	LIDAR (LIght Detection And Ranging) equipment was chosen as the measurement technique to characterize aircraft plumes operating at LAX airport. By scanning with the LIDAR in a defined direction over a period of time with many LIDAR pulses, the distribution of particles over the region of the sweep (e.g., a vertical plane or plume cross section) can be determined and the plume characterized. Cross-sections of the plume were measured at a variety of distances behind the aircraft during takeoff roll. This final study report is based on an analysis of 4,138 LIDAR sweeps, or cross sections, collected at LAX. Methodology and results are included in the report. This report represents the first use of this technique for this source in the United States.			X	X			X								X				X						X					

Wayson, R.L., G.G. Fleming, G. Noel, J. MacDonald, W.L. Eberhard, B. McCarty, R. Marchbanks, S. Sandberg, J. George, and R. Iovinelli, *LIDAR Measurement of Exhaust Plume Characteristics from Commercial Jet Turbine Aircraft at the Denver International Airport*, FAA-AEE-08-02, DOT-VNTSC-FAA-08-05, Federal Aviation Administration, Apr 2008.	This is the third in a series of measurements on this topic with the first two conducted at Los Angeles International Airport (LAX) and Atlanta's Hartsfield-Jackson International Airport (ATL). This study was done at the Denver International Airport (DEN). A major goal in all three studies has been to measure the initial plume characteristics of jet exhaust in support of obtaining increased accuracy in air quality dispersion modeling efforts. All three studies have resulted in cross sections of the plume that can be quantified and visualized giving initial plume characteristics including plume rise, horizontal plume standard deviation, and vertical plume standard deviation. In addition, some local sampling was conducted on the airfield.			X	X			X								X				X						X					
Wayson, R., et al. (2009). "Methodology to Estimate Particulate Matter Emissions from Certified Commercial Aircraft Engines." Air & Waste Management Associated (A&WMA) 59:91–100, Jan.	Presents the First Order Approximation (FOA) used to derive PM EIs from Smoke Numbers, taking into account the sulfate and volatile (fuel organics).			X												X															
Webb S., et al. (2008). *ACRP Report 6: Research Needs Associated with Particulate Emissions at Airports.* Transportation Research Board (TRB).	Provides primer on aircraft particle emissions including composition. Recognizes lack of PM data and provides knowledge gaps. "The present understanding of particle properties is insufficient to evaluate the health and environmental effects from exposure to various types and sizes of PM." Aircraft PM emissions are primarily in the ultrafine range.						X									X															
Westerdahl D., Fruin S.A., Fine P.L., Sioutas C., "The Los Angeles International Airport as a Source of Ultrafine Particles and Other Pollutants to Nearby Communities," *Atmos Environ* 42 (2008) 3143–3155.	Air monitoring was performed in the vicinity of LAX during the spring of 2003, to determine the spatial extent of influence of airport emissions on downwind residential populations.				x			x						x		x	x		x						x	x					
Whitefield, P. et al (2008) *ACRP Report 9: Summarizing and Interpreting Aircraft Gaseous and Particulate Emissions Data.* Transportation Research Board (TRB).	Provides primer on better understanding aircraft PM emissions and their characteristics. Reviews and describes PM data from various measurement campaigns including APEX1, JETS-APEX2, Delta/Atlanta, and APEX3.			X			X									X															

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WHO (2003) "Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide," Report on a WHO Working Group, Bonn, Germany, 13–15 Jan 2003.	This report presents the findings of a review undertaken by a World Health Organization working group. The review looks at scientific evidence on the adverse health effects of particulate matter (PM), ozone (O_3) and nitrogen dioxide (NO_2) since the second edition of WHO's Air Quality Guidelines (AQG) for Europe in 1996. The working group recommends the use of fine particulate matter, ($PM_{2.5}$), as the indicator for health effects induced by particulate pollution such as increased risk of mortality in Europe, to supplement the commonly used PM_{10}. It also acknowledged the evidence that ozone produces short-term effects on mortality and respiratory morbidity, even at the low ozone concentrations experienced in many cities in Europe. Based on these findings, the group recommended that WHO should update exposure-response relationships for the most severe health outcomes induced by particulate matter and ozone presented by Air Quality Guidelines. The group also concluded that an update of the current WHO AQG for nitrogen dioxide was not warranted.	X	X											X		X		X													
WHO (2006) "Air quality guidelines. Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide." World Health Organization for Europe, Copenhagen, Denmark.	WHO produced air quality guidelines for Europe in 1987 and 1997. This report is an update produced in 2005 for four pollutants. Guidelines for other pollutants are as described in the 2nd edition (1997). This report is a review of the scientific literature and a consideration of its implications. Revised guidelines are set out.	X	X											X		X		X													
WHO (2006) "Health Risks of Particulate Matter from Long-Range Transboundary Air Pollution," World Health Organization for Europe, Copenhagen, Denmark.	Particulate matter is a type of air pollution that is generated by a variety of human activities, can travel long distances in the atmosphere, and causes a wide range of diseases and a significant reduction of life expectancy in most of the population of Europe. This report summarizes the evidence on transboundary PM pollution. It highlights its effects, as well as the sources of particulate matter, its transport in the atmosphere, measured and modeled levels of pollution in ambient air, and population exposure. It shows that long-range transport of particulate matter contributes significantly to exposure and to health effects. The authors conclude that international action must accompany local and national efforts to cut PM emissions.	X		X							X					X															

Wood E.C., Herndon S.C., Timko M.T., Yelvington P.E., and Miake-Lye R.C. (2008) "Speciation and Chemical Evolution of Nitrogen Oxides in Aircraft Exhaust Near Airports," *Environ Sci Technol*, 42, 1884–1891.	This study utilizes a chemical kinetics combustion model to better understand the previously observed measurements of the mix of NO and NO_2 from aircraft engine exhausts. Experimental evidence is presented of rapid conversion of NO to NO_2 in the exhaust plume from engines at low thrust. The rapid conversion and the high NO_2/NOx emission ratios observed are unrelated to ozone chemistry. NO_2 emissions from a CFM56-3B1 engine account for approximately 25% of the NO_x emitted below 3000 feet (916 m) and 50% of NO_x emitted below 500 feet (153 m) during a standard ICAO landing and takeoff cycle. Nitrous acid (HONO) accounts for 0.5% to 7% of NOy emissions from aircraft exhaust depending on thrust and engine type. Implications for photochemistry near airports resulting from aircraft emissions are discussed.				X		X							X						X											
Wood E., et al. (2008) *ACRP Report 7: Aircraft and Airport-Related Hazardous Air Pollutants: Research Needs and Analysis.* Transportation Research Board (TRB).	Provides a prioritization of HAPs species based on toxicity and emission rates. Discusses sources and potential risks, but does not significantly include discussion of atmospheric concentrations.			X						X	X						X		X												
Woody, et al. (2011) "An Enhanced Sub-Grid Scale Approach to Characterize Air Quality Impacts of Aircraft Emissions at the Hartsfield-Jackson Atlanta International Airport," 10th Annual CMAS User's Conference, Chapel Hill, NC.	The Puff-in-Grid (PinG) capability within AMSTERDAM/CMAQ was used to model PM concentrations and compared to the non PinG approach. The puff approach showed noticeably higher airport contributions from ATL airport.				X											X			X							X					
Woody M., Arunachalam S., West J.J., and Shankar U. (2010) "A Comparison of CMAQ Predicted Contributions to $PM_{2.5}$ from Aircraft Emissions to CMAQ Results Post-Processed Using the Speciated Modeled Attainment Test," in Proceedings of the 9th Annual Models-3 CMAS Users Conference, Chapel Hill, NC, Oct 2010.	The EPA's SMAT is used with CMAQ to determine the potential for use of SMAT. The results indicate that the use of SMAT produces results similar to those from CMAQ alone and are not unexpected.				X											X			X												
Woody, M. (2010) "The Impacts of Aviation Emissions on Current and Future Particulate Matter: The Effects of the Speciated Model Attainment Test on the Community Multiscale Air Quality Model Results," paper submitted to the PARTNER Joseph A. Hartman Student Paper Competition, Feb 7.	Aviation contributions to U.S. air quality were modeled for 2005 (0.037 ug/m3) and 2025 (0.0127 ug/m3). The CMAQ results were post-processed through SMAT. "The combination of higher amounts of aircraft emissions and lower background emissions in the future lead to the increased absolute contributions of $PM_{2.5}$ from aircraft."				X					X						X				X											

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Woody M. (2012) "Aircraft Emissions' Contributions to Organic Aerosols in a Regional Air Quality Model using the Volatility Basis Set," paper submitted to the PARTNER Joseph A. Hartman Student Paper Competition, Jan 31.	The volatility basis set (VBS) was used within CMAQ to predict organic aerosol concentration contributions from aircraft emissions. The starting aircraft emissions were predicted using the FOA3 method. The CMAQ-VBS modeling work appeared to produce better predictions of $PM_{2.5}$ and total carbon.				X					X						X				X											
Yim S.H.L., Stettler M.E.J., and Barrett S.R.H. (2013) "Air Quality and Public Health Impacts of U.K. Airports, Part II: Impacts and Policy Assessment," *Atmos Environ* 67, 184–192, 2013	Using the emission estimates made in Part I of this study (Stettler et al. 2011), the authors assess current (2005) and future (2030) aviation impacts on U.K. air quality and public health using a multi-scale air quality modeling approach under three scenarios: (1) no capacity increase; (2) unconstrained growth with a third runway at Heathrow Airport; and (3) unconstrained growth with Heathrow replaced by a new Thames Estuary hub airport. Options for mitigating both present-day and future impacts: (1) desulphurizing jet fuel; (2) electrifying GSE; (3) widespread use of single engine taxiing; and (4) use of fixed ground electrical power so as to avoid use of aircraft APUs. LTO, APU, and GSE emissions are spatially apportioned and industry-derived approach and climb-out angles are used. Regional and local-scale dispersion models are used to derive $PM_{2.5}$ concentrations. The two model outputs are combined. A concentration-response function is then applied to estimate the increase in early deaths due to aviation-related emissions and the associated $PM_{2.5}$ exposure, using population data. The authors document how they have projected data for 2030. The authors estimate that 110 early deaths occur in the U.K. each year due to U.K. airport emissions (2005 data). They estimate that up to 65% of the health impacts of U.K. airports could be mitigated by desulphurizing jet fuel, electrifying GSE, avoiding use of APUs and use of single-engine taxiing (caution needs to be applied because of the assumptions made here). Two plans for the expansion of U.K. airport capacity are examined—expansion of London Heathrow and new hub airport in the Thames Estuary. The authors report on the relative changes in attributable early deaths due to $PM_{2.5}$ exposure of aviation-related emissions.				X									X		X	X			X						X	X	X			

Yu, K.N., Cheung Y.P., Cheung T., and Henry R.C. (2004) “Identifying the Impact of Large Urban Airports on Local Air Quality by Nonparametric Regression,” *Atmos Environ* 38, 4501–4507.	This study examined hourly concentrations of CO, NO_x, SO_2, and respirable suspended particles (RSP) taken in the vicinity of Hong Kong International Airport (HKIA) and Los Angeles International Airport (LAX). The average concentration as a function of wind speed and direction was estimated by a mathematical technique called nonparametric regression. Their results show that SO_2 can be used to identify wind speeds and directions associated with emissions from aircraft. Using this assumption and the nonparametric regression plots for the other pollutants the authors say that you can identify the impact of aircraft on local air quality. At LAX, CO and NO_x are dominated by emissions from ground vehicles going in and out of the airport. However, near HKIA, aircraft are an important contributor to CO and RSP.			X				X						X		X										X					
Zhu, Y., et al. (2011) “Aircraft Emissions and Local Air Quality Impacts from Takeoff Activities at a Large International Airport,” *Atmos Environ* 43, 6526–6533.	Study involved the use of SMPS next to LAX to count particles by size ranges to develop distributions. The highest counts were correlated with aircraft takeoff events, and highest size counts were around 14 nm. The mean particle size seemed to slightly increase with aircraft weight. Concentrations of UFP were found to be elevated at 600 m downwind as opposed to UFP from freeways that seem to dissipate to background levels after 300 m.							X								X			X												

APPENDIX B

Frequently Asked Questions

Question: What types of health impacts can airport emissions cause?

Answer: In general, both gaseous and particulate matter emissions from airports can cause harm to the human respiratory and cardiovascular systems. Effects can range from minor exacerbations of existing conditions to increased risk of hospitalization and premature death. Exposure to certain pollutants also can cause skin irritations and other physical effects, especially in sensitive individuals.

Question: What are the main air pollutants of concern?

Answer: As with other transportation sources, airport sources can emit all of the criteria pollutants (CO, NO_x, VOC, SO_x, Pb, PM_{10}, and $PM_{2.5}$) including the precursors that form O_3 and other secondary pollutants including various PM species. Also, HAPs such as formaldehyde, acrolein, acetaldehyde, etc., can be emitted from various sources. However, the main pollutant from a local health risk potential is $PM_{2.5}$, with important effects of ozone at longer range and increasing concern about ultrafine particles in the near field. Formaldehyde tends to have the most cancer risk among HAPs species. Important non-cancer effects of HAPs may exist but are challenging to quantify.

Question: What are the differences between ambient standards, exposure thresholds, and cancer risk indicators?

Answer: Ambient standards, such as the National Ambient Air Quality Standards (NAAQS) are outdoor air pollutant concentration levels maintained by the EPA to monitor air pollution levels in different regions of the country. These are generally intended to be adequately protective of sensitive subpopulations. Exposure thresholds for air pollutants generally refer to concentration levels where below those levels, human beings are not considered to be at health risk. More specifically, exposure threshold levels and limits have been used by various organizations such as OSHA, NIOSH, and ACGIH to define and recommend levels/limits for workplaces to protect workers from harmful exposure. Cancer risk factors for air pollution are factors that may directly or indirectly cause or support the formation of cancer due to pollutant exposure. These factors may include a person's age, sex, family cancer history, etc., and can serve to help determine the probability (the risk) of developing cancer.

Question: Besides pollutant type, what other factors affect public health?

Answer: Besides pollutant type, emission rates, toxicity, individual and population exposure, and vulnerability attributes are important factors that can affect public health. Indeed, all of these factors are important components in properly assessing the health risk of each pollutant. Individual exposure encompasses the pathway from the source to human activity locations (e.g., homes, workplaces, etc.) as well as how long a person is exposed to the pollutants. Population exposure integrates across individual exposures to provide measures relevant to the entire population. In addition, a person's background and condition also can play a significant role in affecting his/her health. Factors such as age, gender, pre-existing disease status, and co-exposures to other risk factors can all affect susceptibility to air pollutants.

Question: What are the significant sources of pollutants at an airport?

Answer: The significant sources of pollutants at an airport generally arise from the combustion of fuels—for example from an aircraft engine, ground support equipment (GSE), etc. The highest contributing emissions sources tend to be aircraft, GSE, and ground access vehicles (GAVs). Aircraft engines are significant sources of emissions in all phases of their operation, such as approach, landing, idling/taxiing, takeoff, and climb out, but the significance for each pollutant depends on the mode (or phase) of aircraft operation.

Question: What emissions mitigation measures have airports implemented?

Answer: Airports have implemented mitigation measures to address the key pollutants and the most significant sources. To mitigate aircraft emissions, airports have implemented measures to reduce taxiing and runway holding times, electrified gates to provide preconditioned air and power, etc. The use of electric GSE and alternative fuels (e.g., CNG) also has helped reduce emissions in gate areas. For mitigating road traffic emissions, airports are dependent on influencing individuals and other organizations to change their behavior or practices. Many airports have promoted public transport use, especially where this involves low-emitting vehicles, and have invested in consolidating certain activities, such as rental car facilities, into one location.

Question: What are the differences between criteria pollutants and HAPs?

Answer: In the 1970 Clean Air Act Amendments, the EPA established criteria, or ambient air concentrations, that define the maximum acceptable level for each of the six criteria pollutants that affect public health and the environment. The concentrations are referred to as the National Ambient Air Quality Standards (NAAQS), and the criteria pollutants include carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), lead (Pb), and particulate matter (PM) in two forms, inhalable (coarse) particulate matter (PM_{10}), and fine particulate matter ($PM_{2.5}$), which are very small particles with a diameter 2.5 micrometers or less.

The U.S. Environmental Protection Agency (EPA) identified 187 hazardous air pollutants (HAPs) that cause other more serious health effects, and are known to, or suspected of, causing cancer in humans. Hazardous air pollutants also are referred to as toxic air pollutants (or air toxics), and the terms can be used interchangeably. Most HAPs are emitted from anthropogenic (manmade) sources such as exhaust from aircraft engines powered by fossil fuels and from stationary sources such as boilers and power plants. Examples of HAPs (and their sources) include formaldehyde (aircraft), benzene (gasoline), perchloroethylene (dry cleaning), and methylene chloride (paint stripper).

Question: What are the differences between primary and secondary pollutants?

Answer: Primary air pollutants are emitted directly from a source such as aircraft and GSE engines containing pollutants such as CO, NO_x, SO_x, $PM_{2.5}$, HAPs, etc. However, some pollutants are not emitted directly and form only as a result of complex chemical reactions in the atmosphere involving precursor pollutants. These formed pollutants are referred to as secondary pollutants. For example, ozone is generally not emitted directly from a source but is formed through the photochemical reaction of naturally occurring oxygen in the atmosphere, together with emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. Fine particulate matter ($PM_{2.5}$), a pollutant that has been associated with increased mortality and morbidity in areas where concentrations of the pollutant are elevated, also has significant contributions from secondary formation. Although $PM_{2.5}$ can be emitted directly, the pollutant also can be formed through chemical reactions involving NO_x, SO_2, and VOCs, leading to formation of sulfate, nitrate, and organic aerosol particles.

Primary and secondary pollutants are not to be confused with the primary and secondary standards established for the National Ambient Air Quality Standards (NAAQS). The NAAQS establish the maximum allowable concentrations of the criteria air pollutants for the protection of public health (primary standards) and protection of the environment (secondary standards).

Question: What health-related airport air quality studies have been conducted?

Answer: Although the overall literature on this topic is relatively small compared to studies that have been conducted for roadway sources and other industries, the breadth and depth of research in this area has been growing. Sections 5.1 and 5.2 provide reviews of selected airport air quality and health studies. Appendix A, Literature Review Summary and References, provides a larger list of studies reviewed under this project. The studies range from specific airport health research to more general airport air quality and health studies for other industries.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
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	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
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
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

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