Partnership for AiR Transportation
Noise and Emissions Reduction
An FAA/NASA/Transport Canada-
sponsored Center of Excellence

# Aircraft Impacts on Local and Regional Air Quality in the United States

PARTNER Project 15 final report

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# List of Acronyms

| | |
|---|---|
| $\mu g/m^3$ | Micrograms per Cubic Meter |
| AFP | Airspace Flow Program |
| APU | Auxiliary Power Unit |
| ASDE-X | Airport Surface Detection Equipment, Model X |
| ASPM | Aviation System Performance Metrics |
| ATADS | Air Traffic Activity Data System |
| ATM | Air Traffic Management |
| Avgas | Aviation gasoline |
| BenMAP | Environmental Benefits Mapping and Analysis Program |
| BTS | Bureau of Transportation Statistics |
| CAEP | ICAO Committee on Aviation Environmental Protection |
| CAFE | Clean Air for Europe |
| CAIR | Clean Air Interstate Rule |
| CAVS | CDTI Assisted Visual Separation |
| CDA | Continuous Descent Arrivals |
| CDTI | Cockpit Display of Traffic Information |
| CFR | Code of Federal Regulations |
| CMAQ | Community Multi-Scale Air Quality Modeling System |
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| COPD | Chronic Obstructive Pulmonary Disease |
| CSC | Computer Sciences Corporation |
| DFM | Departure Flow Management |
| DSP | Departure Spacing Programs |
| EAC | Early Action Compact |

| | |
|---|---|
| EDMS | Emissions and Dispersion Modeling System |
| EPA | U.S. Environmental Protection Agency |
| ETMS | FAA Enhanced Traffic Management System |
| FAA | Federal Aviation Administration |
| FIPS | Federal Information Processing Standard |
| FMS | Flight Management System |
| FOA | First Order Approximation |
| FOA3 | First Order Approximation version 3.0 |
| FOA3a | First Order Approximation version 3.0a |
| GA | General Aviation |
| GDP | Ground Delay Program |
| GPS | Global Positioning System |
| HAP | Hazardous Air Pollutant |
| HC | Hydrocarbons |
| $HO_2$ | Hydroperoxyl radical |
| IFR | Instrumental Flight Rules |
| ITWS | Integrated Terminal Weather System |
| LTO | Landing Take-Off |
| MIT | Massachusetts Institute of Technology |
| MRAD | Minor Restricted Activity Days |
| NAA | NonAttainment Area |
| NAAQS | National Ambient Air Quality Standards |
| NAS | National Airspace System |
| NASA | National Aeronautics and Space Administration |
| NASR | National Airspace System Resources |
| NEI | National Emissions Inventory |
| NMHC | Non-Methane Hydrocarbon |
| $NO_x$ | Oxides of Nitrogen |

| | |
|---|---|
| NPIAS | National Plan of Integrated Airport Systems |
| OEP | Operational Evolution Partnership |
| OH | Hydroxyl radical |
| PARTNER | Partnership for AiR Transportation Noise and Emissions Reduction |
| PM | Particulate Matter |
| $PM_{10}$ | Particulate Matter less than 10 μm in diameter |
| $PM_{2.5}$ | Particulate Matter less than 2.5 μm in diameter |
| ppb | Parts per billion |
| ppm | Parts per million |
| PRM | Precision Runway Monitor |
| RIA | Regulatory Impact Analysis |
| RNAV | Area Navigation |
| RNP | Required Navigation Performance |
| SAGE | FAA System for Assessing Aviation's Global Emissions |
| SI | Spark Ignition |
| SIP | State Implementation Plan |
| $SO_x$ | Oxides of Sulfur |
| SWAP | Severe Weather Avoidance Procedures |
| TAF | Terminal Area Forecast |
| THC | Total Hydrocarbon |
| TSD | Technical Support Document |
| VALE | Voluntary Airport Low Emissions Program |
| VFR | Visual Flight Rules |
| VOCs | Volatile Organic Compounds |

# 1 Executive Summary

This report documents the findings of a study undertaken to identify:

- The impact of aircraft emissions on air quality in nonattainment areas (NAAs);
- Ways to promote fuel conservation measures for aviation to enhance fuel efficiency and reduce emissions; and
- Opportunities to reduce air traffic inefficiencies that increase fuel burn and emissions.

This study was conducted by the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER), an FAA/NASA/Transport Canada-sponsored Center of Excellence. Appendix B contains the full list of study participants. The study was conducted through the coordinated efforts of five contractors and subcontractors.

Aircraft landing take-off (LTO) emissions include those produced during idle, taxi to and from terminal gates, take-off and climb-out, and approach to the airport. Aircraft LTO emissions contribute to ambient pollutant concentrations and are quantified in local and regional emissions inventories. This study analyzed aircraft LTO emissions at 325 airports with commercial activity (including 263 commercial service airports and 62 airports that are either reliever or general aviation airports) in the U.S for operations that occurred from June 2005 through May 2006. The flights studied represent 95% of the aircraft operations for which flight plans were filed during that time period (and 95% of the operations with International Civil Aviation Organization (ICAO) certified jet engines in the U.S.). Of the 325 airports, 148 are commercial service airports in ambient air quality nonattainment areas as specified by the National Ambient Air Quality Standards (NAAQS) (40 CFR Part 50). The airports involved are identified in Appendix B; the nonattainment areas are listed in Table 3.1. Each of these NAAs has at least one commercial service airport.

The study was designed to focus on the impact of aircraft emissions on air quality in NAAs. As is shown in Table 1.1, aircraft operations at the 148 commercial service airports in the 118 NAAs are less than 1 percent of emissions in these areas. Aircraft emissions data from 2005 were used for this study. In the table, non-aircraft emissions data are from EPA's year 2002 National Emissions Inventory. Note that EPA's year 2001 National Emissions Inventory was used for modeling the impact of aviation emissions on air quality and human health; see section 3.1 for details. (Note, some of the general aviation airports and reliever airports studied were located in NAAs, but they were not included with the below inventories for NAAs. The aircraft emissions from these airports are estimated to be a small fraction of the aircraft emissions in NAAs compared to those from commercial service airports because commercial aircraft are generally larger than general aviation aircraft and thus burn more fuel; emissions are proportional to fuel burn.)

**Table 1.1:** Contribution of aircraft LTO operations at commercial service, reliever, and general aviation airports with commercial activity to emissions inventories[a,b,c,d]

| Aircraft emissions inventory | CO | $NO_x$ | VOCs | $SO_x$ | $PM_{2.5}$ |
|---|---|---|---|---|---|
| **2002: average and range as a percentage of total emissions inventories in 118 NAAs with at least one commercial service airport (148 airports)** | 0.44%<br>0.06% to 4.36% | 0.66%<br>0.004% to 10.93% | 0.48%<br>0.05% to 5.03% | 0.37%<br>0.002% to 6.91% | 0.15%<br>0.002% to 2.57% |
| **2002: average and range as a percentage of Mobile Source emissions inventories in 118 NAAs with at least one commercial service airport (148 airports)** | 0.54%<br>0.089% to 4.72% | 1.04%<br>0.014% to 19.63% | 0.98%<br>0.064% to 9.04% | 2.24%<br>0.026% to 30.92% | 0.84%<br>0.016% to 8.88% |
| **As a percentage of EPA year 2002 National Emissions Inventory (325 airports)** | 0.18% | 0.41% | 0.23% | 0.07% | 0.05% |
| **As a percentage of Mobile Source emissions inventory from EPA year 2002 National Emissions Inventory (325 airports)** | 0.22% | 0.71% | 0.51% | 1.29% | 0.53% |

Notes:

[a] CO: carbon monoxide. $NO_x$: nitrogen oxides. VOCs: volatile organic compounds. $SO_x$: sulfur oxides. $PM_{2.5}$: particulate matter below 2.5 microns (μm) in diameter.

[b] If an area had more than type of nonattainment area (e.g., $PM_{2.5}$ and CO nonattainment areas), the nonattainment area was selected based on the area with the largest population base.

[c] Except for aircraft, the emission levels for categories are from the inventories developed for the 2008 Final Rule on Emission Standards for New Nonroad Spark-Ignition Engines, Equipment, and Vessels, which is available at http://www.epa.gov/otaq/equip-ld.htm .

[d] 2005 aircraft emissions were used for this study. Non-aircraft emissions shown in the table are from the 2002 National Emissions Inventory.

EPA regulates emissions from highway and nonroad engines under Title II of the Clean Air Act (42 U.S.C. 7401-7671q). EPA's authority for setting aircraft engine emissions is contained in section 231 of Title II. As part of this assessment it is interesting to consider the contribution of aircraft LTO emissions in the context of those from other mobile sources in the NAAs. Table 1.2 below presents aircraft LTO $NO_x$ emission inventories at the 148 commercial service airports in NAAs for year 2005 aircraft emissions together with those from other mobile sources categories (2002 is the base year for non-aircraft emission sources).

**Table 1.2:** NAA Annual NOx Emission Levels for Mobile and Other Source Categories for 2002 (148 Commercial Service Airports)[a, b, c, d, e]

| Category | 2002 | | | |
|---|---|---|---|---|
| | metric tons | % of off-highway | % of mobile | % of total |
| Aircraft | 73,152 | 3.73% | 1.25% | 0.80% |
| Recreational Marine Diesel | 13,520 | 0.69% | 0.23% | 0.15% |
| Commercial Marine (C1 & C2) | 398,338 | 20.34% | 6.78% | 4.33% |
| Land-Based Nonroad Diesel | 755,208 | 38.56% | 12.86% | 8.21% |
| Commercial Marine (C3) | 105,414 | 5.38% | 1.80% | 1.15% |
| Small Nonroad SI | 83,735 | 4.27% | 1.43% | 0.91% |
| Recreational Marine SI | 27,661 | 1.41% | 0.47% | 0.30% |
| SI Recreational Vehicles | 2,411 | 0.12% | 0.04% | 0.03% |
| Large Nonroad SI (>25hp) | 168,424 | 8.60% | 2.87% | 1.83% |
| Locomotive | 330,894 | 16.89% | 5.64% | 3.60% |
| Total Off-Highway | 1,958,755 | 100.00% | 33.36% | 21.29% |
| Highway non-diesel | 2,229,330 | | 37.97% | 24.23% |
| Highway Diesel | 1,683,882 | | 28.68% | 18.30% |
| Total Highway | 3,913,213 | | 66.64% | 42.53% |
| Total Mobile Sources | 5,871,967 | | 100.00% | 63.82% |

Notes:

[a] If an area had more than type of nonattainment area (e.g., $PM_{2.5}$ and CO nonattainment areas), the nonattainment area was selected based on the area with the largest population base.

[b] Except for aircraft, the emission levels for categories are from the inventories developed for the 2008 Final Rule on Emission Standards for New Nonroad Spark-Ignition Engines, Equipment, and Vessels, which is available at http://www.epa.gov/otaq/equip-ld.htm .

c 2005 (and not 2002 as for other emission sources) is the base year for aircraft emissions.

[d] SI means spark-ignition engine, usually gasoline-powered

[e] Categories 1, 2, and 3 (C1, C2, and C3, respectively) are EPA categories for marine engines with displacements of less than 5 liters per cylinder, between 5 and 30 liters per cylinder, and greater than 30 liters per cylinder, respectively. 72 FR 15937.

While aircraft contribute to the emission inventories of all the criteria pollutants, the analysis shows that the largest contributors to inventories are $NO_x$, VOCs ($NO_x$ and VOCs are ozone precursors; $NO_x$ is also a secondary PM precursor), $PM_{2.5}$ and $SO_x$ (also a secondary PM precursor). $SO_x$ emissions depend on fuel sulfur levels and overall fuel burn. NOx and $PM_{2.5}$ emissions depend on combustor and engine technology in addition to overall fuel burn. The contribution of aircraft emissions to the national annually-averaged ambient $PM_{2.5}$ level was estimated to be 0.01 $\mu g/m^3$. On a percentage basis, the contribution is approximately 0.08% for all counties and 0.06% for counties in nonattainment areas.[1] The aircraft contributions to county-level ambient $PM_{2.5}$ concentrations ranged from approximately 0% to 0.5%. Aircraft emissions were also estimated to contribute 0.12% (0.10 parts per billion) to average 8-hour ozone values in both attainment and NAAs. Near some urban centers aircraft emissions reduced ozone, whereas in suburban and rural areas, aircraft emissions increased ambient ozone levels. The largest county-level decrease was 0.6%; the largest county-level increase was 0.3%.

The air quality modeling performed for this analysis was based on the Community Multi-Scale Air Quality Model (CMAQ) with a 36-square-kilometer grid cell coverage across the contiguous lower 48 states. (Byun, D. W. and K. L. Schere 2006) Approximately 166 million people live within the 118 NAAs identified in Table 3.1 and of these, about 29 million live within 10 kilometers of a commercial service airport within the NAAs (based on population data for the year 2000).

The adverse health impacts of aircraft emissions were estimated to derive almost entirely from fine ambient particulate matter. Nationally, about 160 yearly incidences of PM-related premature mortality were estimated due to ambient particulate matter exposure attributable to the aircraft emissions estimated for this study (from 325 airports) (with a 90 percent confidence interval of 64 to 270 incidences). One-third of these 160 premature mortalities were estimated to occur within the greater Southern California region, while another fourteen counties (located within NY, NJ, IL, Northern CA, MI, TN, TX and OH) accounted for approximately 21 percent of total premature mortality. In total, 47 counties within the United States had a measurable PM-related premature mortality risk of greater than one premature mortality incidence associated with aircraft emissions. Other PM-related health impacts, such as chronic bronchitis, non-fatal heart attacks, respiratory and cardiovascular illnesses were also associated with aircraft emissions. No significant health impacts were estimated due to the changes in ambient ozone concentrations attributable to aircraft emissions. Although the health impacts estimated for aircraft LTO emissions are important, it is very likely[2] they constitute less than 0.6% of the total adverse health impacts due to poor local and regional air quality from anthropogenic emissions sources in the United States.

Evaluation of aviation emissions and their impacts on emission inventories, air quality, and public health is difficult. As discussed further within the text, there are several important assumptions and limitations associated with the results of this study, including some related to emission inventory development and air quality modeling. Measurement and modeling of aircraft PM emissions is still an emerging area, and there are data limitations and uncertainties.[3, 4] The

[1] Note that these estimates for percent contributions to total ambient concentrations carry uncertainties due to the fact that some emissions sources are not well-quantified in U.S. National Emissions Inventories.

[2] Greater than 90% probability based on judgment of the authors. This convention is based on that utilized by the Intergovernmental Panel on Climate Change (IPCC 2007), where “very likely” represents a 90 to 99% probability of an occurrence.

[3] The determination of fine particulate matter emissions from aircraft engines is an active area of research. Methods to estimate primary PM emissions from aircraft are relatively immature: test data are sparse, and test methods are still under development. ICAO and EPA do not have approved test methods or certification standards for aircraft PM emissions. ICAO’s Committee on Aviation Environmental Protection (CAEP) has developed and approved the use of an interim First Order Approximation (FOA3) method to estimate total PM emissions (or total fine PM emissions) from certified aircraft engines. Subsequent to the completion of FOA3, the FOA3 methodology was modified with margins to conservatively account for the potential effects of uncertainties that include the lack of a standard test procedure, poor definition of volatile PM formation in the aircraft plume, and the limited amount of data available on aircraft PM emissions. This modified methodology is known as FOA3a. FOA3a is currently the agreed upon method to estimate total PM emissions from aircraft engines, and it has been incorporated into the latest version of the FAA Emissions and Dispersion Modeling System (EDMS), version 5.02, June 2007. FOA3a was used in this study. FOA3a predicts fine PM inventory levels that are approximately 5 times those predicted by FOA3. The factor of 5 difference between

use of a 36 km x 36 km grid scale for the air quality analyses is expected to underestimate health impacts, especially those that may occur close to airport boundaries. Omitting the effect of cruise level emissions on surface air quality is also expected to lead to underestimation of health impacts by an unknown amount. Further, analysis of only one year of aircraft emissions data may lead to an over- or under-estimation of aircraft impacts on ambient air quality due to year-to-year changes in meteorology. Non-aircraft airport sources were also not included (e.g. emissions of ground service equipment and other airport sources). Finally, results are reported for one concentration-response relationship for the health effects of ambient PM; a range of concentration-response relationships has been reported in the literature. The net effect of these assumptions and limitations is not known.[5]

General aviation (GA) aircraft emissions were not included in our emissions inventory since GA aircraft were responsible for less than 1% of jet fuel use by volume in 2005. However, a separate estimate of lead emissions from GA aircraft was made (most piston-engine powered GA aircraft operate on leaded aviation gasoline (avgas); gas turbine powered jet engines and turboprops operate on Jet A which does not contain significant levels of lead). It is estimated that in 2002 approximately 281 million gallons of avgas were supplied for GA use in the U.S., contributing an estimated 563 metric tons of lead to the air, and comprising 46% of the EPA year 2002 National Emissions Inventory (NEI) for lead.[6] It is expected that about 50-60% of this inventory is related to LTO and local flying operations. The health impacts of these lead emissions were not estimated.

The contribution of aircraft emissions to poor air quality is influenced by air traffic management (ATM) inefficiencies that result in increased fuel burn and emissions. Emissions and fuel use are a function of the amount of time spent in each phase of aircraft operations, and delays cause longer idle and taxi times and introduce ground hold times, which in turn, increase fuel use and ground level emissions. From among the 148 U.S. airports in air quality nonattainment areas, 113 were selected for further study and it was estimated that delays at these airports account for approximately 320 million gallons of annual additional fuel usage due to increased taxi times. This is approximately 1% of all jet fuel used in the U.S. during 2005 and approximately 17% of fuel use during the LTO portion of the flight for these 113 airports. Based on these results, unimpeded taxi times would result in average LTO emissions reductions of 22% (28,000 metric tons) for CO, 7% (5,000 metric tons) for $NO_x$, 16% (4,000 metric tons) each for VOCs and non-methane hydrocarbons, 17% (1,000 metric tons) for $SO_x$, 15% (260 metric tons) for $PM_{2.5}$, and 17% (986,000 metric tons) for fuel. These values represent about five percent of LTO emissions in these non-attainment areas.

While there are many strategies available to reduce emissions, including aircraft and engine technology advancements, the relationship between taxi-out time and emissions suggests that ATM initiatives can play an important role in reducing emissions and fuel use at U.S. airports. This study suggests that initiatives such as airspace flow programs, schedule de-peaking, continuous descent arrivals, and new runways could offer viable means of reducing fuel burn and emissions. The analyses of these initiatives performed for this study were not

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the method used for this study and that determined by the ICAO method reflects the scientific uncertainty associated with PM emissions rates from aircraft engines.

[4] In particular, a fuel sulfur level of 400 parts per million (ppm) was assumed for some airports and 680 ppm was assumed for others. Our intention was to assume 680 ppm for all airports. However, year-to-year and location-to-location variations of fuel sulfur of this level (±200 ppm) are typical and are thus within the uncertainty of the estimation methods.

[5] Note that the uncertainties in the primary PM estimate (footnote 3), and the uncertainties in the $SO_2$ inventory level (footnote 4) were found to result in changes in the health impact assessment that fall within the quoted 90% confidence interval for yearly mortality incidences, and thus do not add a substantial amount of uncertainty to the estimate of health impacts.

[6] U.S. EPA, Correction to May 1, 2008 Memorandum titled, 'Revised Airport-specific Lead Emission Estimates,' Memorandum from Marion Hoyer, Solveig Irvine, Bryan Manning to Lead NAAQS Review Docket EPA-HQ-OAR-2006-0735, May 14, 2008.

intended to provide representative results for all airports, but to illustrate the extent to which such ATM initiatives reduce fuel use and emissions. In order to increase efficiency without adversely affecting safety, noise and security, these and other operational initiatives must be implemented with consideration of the larger system and numerous complex interdependencies. Moreover, there are no universal strategies for improving operational efficiency, and a single technology or procedure will not reduce fuel consumption and emissions at all U.S. airports.

## 2 Overview of Study and Report Organization

This study was conducted to identify:

- The impact of aircraft emissions on air quality in non-attainment areas;
- Ways to promote fuel conservation measures for aviation to enhance fuel efficiency and reduce emissions; and
- Opportunities to reduce air traffic inefficiencies that increase fuel burn and emissions.

The study considered how air traffic management inefficiencies, such as aircraft idling at airports, result in unnecessary fuel burn and air emissions. The study also makes recommendations on ways to address these inefficiencies without adversely affecting safety and security or increasing individual aircraft noise, and that it do so while taking account of all aircraft emissions and the impact of those emissions on human health. The scope of the study was limited to aircraft activities in and around airports (versus operational efficiencies at altitude and in the enroute airspace).

The Study was conducted by the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER), an FAA/NASA/Transport Canada-sponsored Center of Excellence. Appendix A contains the full list of study participants. The study was conducted through the coordinated efforts of five contractors and subcontractors: CSSI Inc. (CSSI), Metron Aviation (Metron), the Massachusetts Institute of Technology (MIT), Abt Associates, Inc. (Abt), and Computer Sciences Corporation (CSC). Figure 2.1 shows the objectives and their relationship to the tasks undertaken in the study.

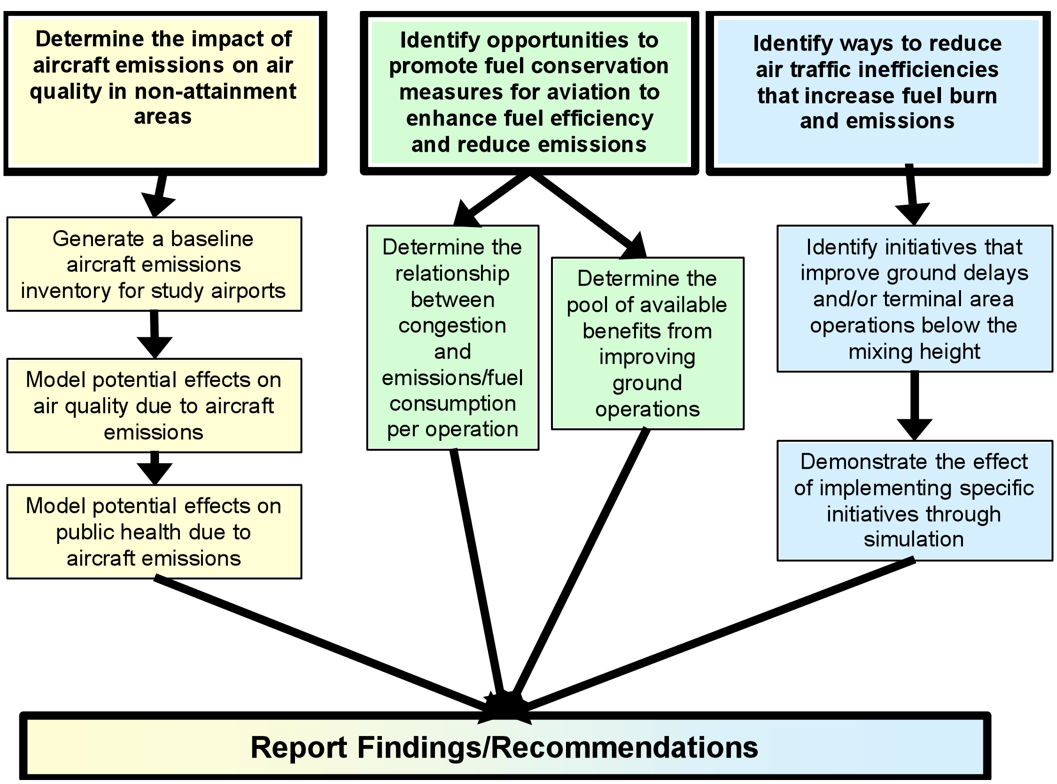


**Figure 2.1:** Organization of this study

This document is the final report resulting from the study. Sections 1 and 2 contain the Executive Summary and Study Overview, respectively. The body of the report is divided into three sections:

- Section 3 addresses the impact of aircraft emissions on air quality and public health. This section describes the methods used to estimate emissions from aircraft operating from U.S. commercial service airports, and includes a comparison of the resulting inventory to total emissions from anthropogenic sources. Section 3 also contains results of air quality modeling to determine how these aircraft emissions impact ambient concentrations of criteria pollutants. Finally, results of a health impact analysis are presented to estimate how these aircraft emissions contribute to adverse health consequences.
- Section 4 focuses on opportunities to reduce fuel burn and emissions by assessing the pool of available benefits that may be achieved by reducing ground delays.
- Section 5 identifies four air traffic management (ATM) initiatives aimed at reducing operational inefficiencies and examines the benefit of these initiatives for reducing fuel use and emissions. These initiatives do not represent a complete list, but are analyzed to provide illustrative estimates of the benefits that may be achieved by pursuing these and other initiatives.

Section 6 provides the study conclusions and recommendations.

# 3 The Impact of Aircraft Emissions on Nonattainment Area, Local, and Regional Air Quality and Public Health

The *Clean Air Act* requires the EPA to set standards for ambient levels of pollutants that have been shown to have negative impacts on public health and welfare (40 CFR part 50). The EPA has set standards, called National Ambient Air Quality Standards (NAAQS), for six pollutants: ozone, particulate matter (PM), carbon monoxide (CO), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$), and lead (Pb). Standards for these pollutants, called *criteria pollutants,* are set by developing human health-based and environmentally-based criteria from scientific studies. *Primary standards* are set to protect public health. *Secondary standards* are set to protect public welfare, including items such as crop damage and decreased visibility. These standards set the maximum concentration of the pollutant acceptable over a variety of averaging times dependent on the scientific literature. The averaging times vary by criteria pollutant. Areas that do not meet primary standards are called *nonattainment* areas (NAAs).

An assessment of the impact of aircraft emissions on air quality in NAAs was performed in this study. As is discussed further below, in 2005, there were a total of 118 NAAs in the US (see Table 3.1 below). Figure 3.1 shows the major commercial service airports located in ozone, $PM_{2.5}$, CO, $PM_{10}$, $NO_2$, and $SO_2$ NAAs.[7] There were 150 airports located in these areas in 2005, of which 148 were included.[8] This study also directly assessed the health impacts that result from the changes in air quality that could be attributable to aircraft operations. This section describes the three elements necessary to complete these study goals:

- A baseline aircraft emissions inventory was developed to provide an estimate of criteria pollutants and precursor emissions attributable to aircraft operations from U.S. commercial service airports (Section 3.1);
- Air quality modeling was performed to estimate the impacts of these emissions on ambient concentrations of PM and ozone[9] (Section 3.2); and
- Health impact analyses were conducted to determine the changes in public health endpoints if aircraft emissions at these airports were eliminated (Section 3.3).

In addition, an assessment of lead emissions from piston engine (general aviation) aircraft using aviation gasoline is provided (Section 3.4).

[7] Airports were identified based on airports listed in the FAA's Voluntary Airport Low Emissions Program (VALE), which focused on airports in CO, PM, and ozone non-attainment areas for 2005 see http://www.faa.gov/airports_airtraffic/airports/environmental/vale/media/vale_eligible_airports.xls.
[8] 148 of these airports were used in this study; Block Island State Airport (Block Island, Rhode Island) and Lake Hood Airport (Anchorage, Alaska) were not included due to insufficient aircraft operations data.
[9] It is typical EPA practice to focus on PM and ozone impacts in air quality analyses due to their importance for human health. Note that ozone and $PM_{2.5}$ nonattainment areas are more prevalent than $NO_2$, $SO_2$, CO, and lead nonattainment areas. Several EPA Regulatory Impact Analyses have considered changes in ambient concentrations of PM and ozone and resulting changes in health incidences (EPA 2005, EPA 2006).


**Figure 3.1:** Commercial service airports located in ozone, $PM_{2.5}$, CO, $PM_{10}$, $NO_2$, and $SO_2$ nonattainment areas in 2005.

## 3.1 Creation of a Baseline Inventory

Aircraft jet engines emit carbon dioxide ($CO_2$), water vapor, nitrogen oxides ($NO_x$), carbon monoxide, oxides of sulfur ($SO_x$), unburned hydrocarbons (HC), primary fine particulate matter ($PM_{2.5}$), and other trace compounds such as various hazardous air pollutants (e.g., formaldehyde, acetaldehyde). Typical emission indices for these pollutants are 3200 g $CO_2$/kg-fuel-burned, 1200 g water vapor/ kg-fuel-burned, 13 g $NO_x$/ kg-fuel-burned, 11 g CO/ kg-fuel-burned, 1 g $SO_x$/ kg-fuel-burned, 1 g HC/ kg-fuel-burned, and 0.06 g $PM_{2.5}$/ kg-fuel-burned. While some health impacts are related directly to the compounds being emitted (e.g. primary particulate matter) other health impacts result from the contributions that these emissions make to the formation of secondary pollutants, especially ozone and secondary ambient particulate matter. Aircraft jet engines do not emit lead, except perhaps in trace amounts, since lead is not added to jet fuel. However, most general aviation aircraft powered by piston engines use leaded gasoline as described in Section 3.4.

Aircraft emissions can be broken into two segments: cruise and LTO cycle. Most aircraft operating hours and emissions take place at cruise altitudes. Depending on the pollutant involved approximately 68-91% of full flight emissions occur during cruise operations.[10] However, it is aircraft emissions released in the lower layer of the atmosphere, that are typically quantified in local and regional emission inventories. The mixing height (the region of

[10] For domestic flights for 2004, FAA's System for Assessing Aviation's Global Emissions (SAGE) indicates that 91% of fuel burn and SOx, 90% of NOx, 72% of CO, and 68% of VOC emissions occurred outside the LTO. Data on $PM_{2.5}$ is not available. FAA, System for Assessing Aviation's Global Emissions, Version 1.5, Global Aviation Emissions Inventories for 2000 through 2004, FAA-EE-2005-02, September 2005, revised March 2008, available at http://www.faa.gov/about/office_org/headquarters_offices/aep/models/sage/

the atmosphere near the earth's surface in which turbulent mixing occurs) varies greatly by location, time of day, season, and synoptic meteorological pattern.  For this study, we considered only emissions that occur below 3,000 feet above ground level; this is normally deemed equivalent to emissions which occur during the LTO cycle. The LTO cycle includes idle, taxi to and from terminal gates, take-off and climb-out, and approach to the airport. To provide an estimate of the contribution of aircraft to the total emissions inventories associated with non-natural sources, and to provide a basis for the air quality modeling, a baseline inventory of aircraft LTO cycle emissions was created as described below.

**Airport Selection**

An emissions inventory for the study was generated for 325 airports with commercial activity in the United States. Of these 325 airports, there are 263 commercial service airports and 62 airports that are either reliever or general aviation airports with commercial activity.[11]  The decision to include these 325 airports was made in two phases. First, the study participants estimated aircraft emissions from those commercial service airports located in the NAAs. The U.S. Federal Aviation Administration Voluntary Airport Low Emissions Program (VALE)[12] identified 150 commercial service airports that are located in the 2005 ozone, $PM_{2.5}$, CO, $PM_{10}$, $NO_2$, and $SO_2$ NAAs areas as shown in Figure 3.1 and Table 3.1.

During the study, it also became apparent that aircraft emissions from upwind airports (in attainment areas) could influence air quality in NAAs because of atmospheric chemistry and regional transport processes. While it was not feasible to model aircraft emissions from all airports in the United States within the timeframe of this research, emissions data were generated for an additional 177 commercial service airports to account for upwind aircraft sources that could influence air quality in NAAs and to more fully estimate the impacts of aircraft activities. A total of 177 airports in attainment areas (those with the greatest number of operations and readily available flight operations data) were selected for inclusion in the analysis. The 325 airports modeled for the study cover all 50 states and approximately 95 percent of U.S. jet engine aircraft operations from June 2005 to May 2006 for which flight plans were filed (including commercial, military, and general aviation). (These airports also represent 95% of the operations with ICAO certified jet engines in the U.S.)  The study includes 63 percent of all U.S. commercial service airports (325 of 515 airports). Figure 3.2 shows the 148 NAA airports and the additional 177 airports modeled for the study. A list of the 325 airports and their number of aircraft operations (and LTOs) is provided in Appendix B.

[11] FAA's National Plan of Integrated Airport Systems (NPIAS) report at http://www.faa.gov/airports_airtraffic/airports/planning_capacity/npias/reports/ .
[12] http://www.faa.gov/airports_airtraffic/airports/environmental/vale/

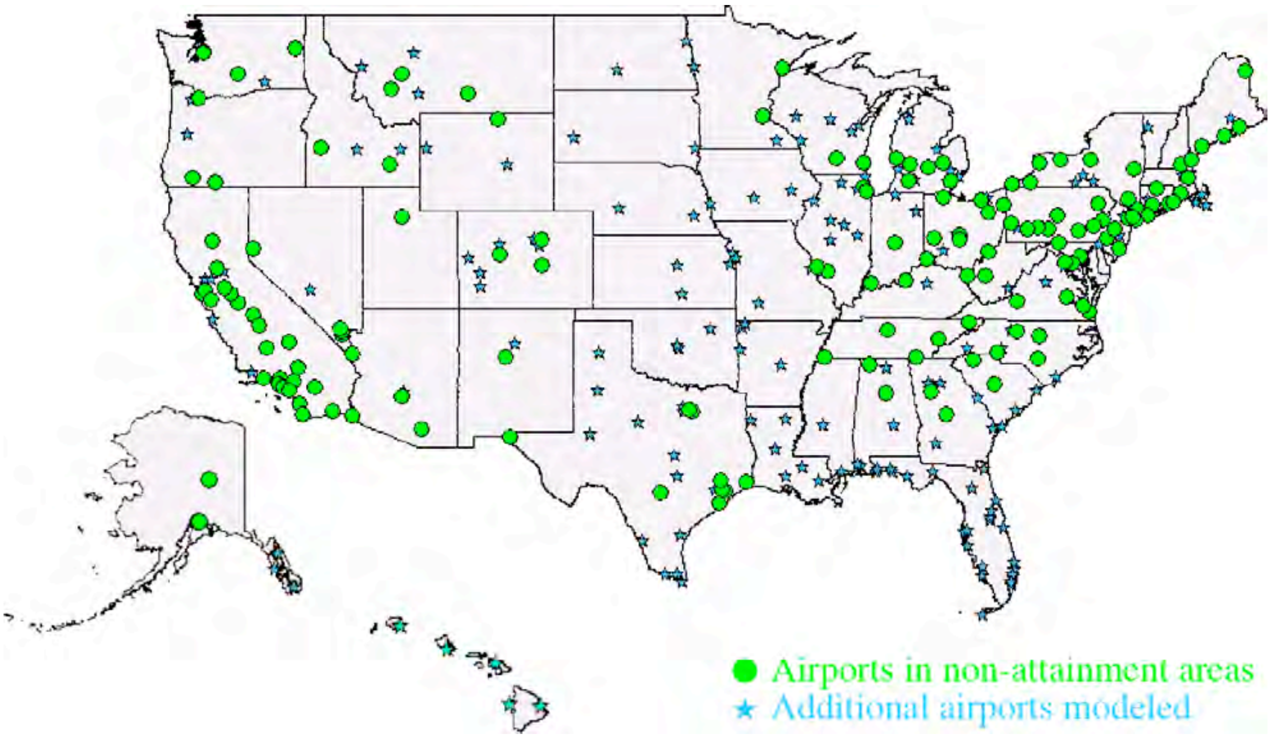


**Figure 3.2:** 148 Nonattainment airports and the additional 177 modeled for the study

**Data and Methods**

The aircraft emissions inventory used for this study was created with the FAA Emissions and Dispersion Modeling System (EDMS), a computer program used to estimate emissions in and around airports, and to provide dispersion calculations around airports. EDMS was developed in the mid-1980's (and has been regularly improved since that time) to assess the air quality impacts of proposed airport development projects. EDMS is the program required by the FAA for performing airport inventory and dispersion analyses for aviation.[13]

EDMS was used to generate an emissions inventory for LTO activity for flights arriving to, and departing from, the 325 study airports during the one-year period between June 2005 and May 2006. The inventory generated includes emissions from aircraft main engines, and also auxiliary power units (APUs). APUs are small, self-contained generators installed on aircraft that are used to start the main engines and to provide electricity and air conditioning to aircraft parked on the ground.

EDMS requires several data inputs. Operations data were obtained from the 2005 FAA Enhanced Traffic Management System (ETMS)[14], the Bureau of Transportation Statistics (BTS) On Time Performance Data[15], and the Air Traffic Activity Data System (ATADS).[16] EDMS also requires jet fuel quality data, main engine and APU specifications, aircraft weight, and ground operating times. These data were obtained from a number of sources

[13] More details regarding EDMS may be found at http://www.faa.gov/about/office_org/headquarters_offices/aep/models/edms_model/.
[14] http://www.fly.faa.gov/Products/Information/ETMS/etms.html
[15] http://www.transtats.bts.gov/OT_Delay/OT_DelayCause1.asp
[16] http://aspm.faa.gov/main/atads.asp

including BTS[17], the BACK fleet database[18], and the National Airspace System Resources (NASR)[19]. Figure 3.3 shows the data inputs to EDMS.

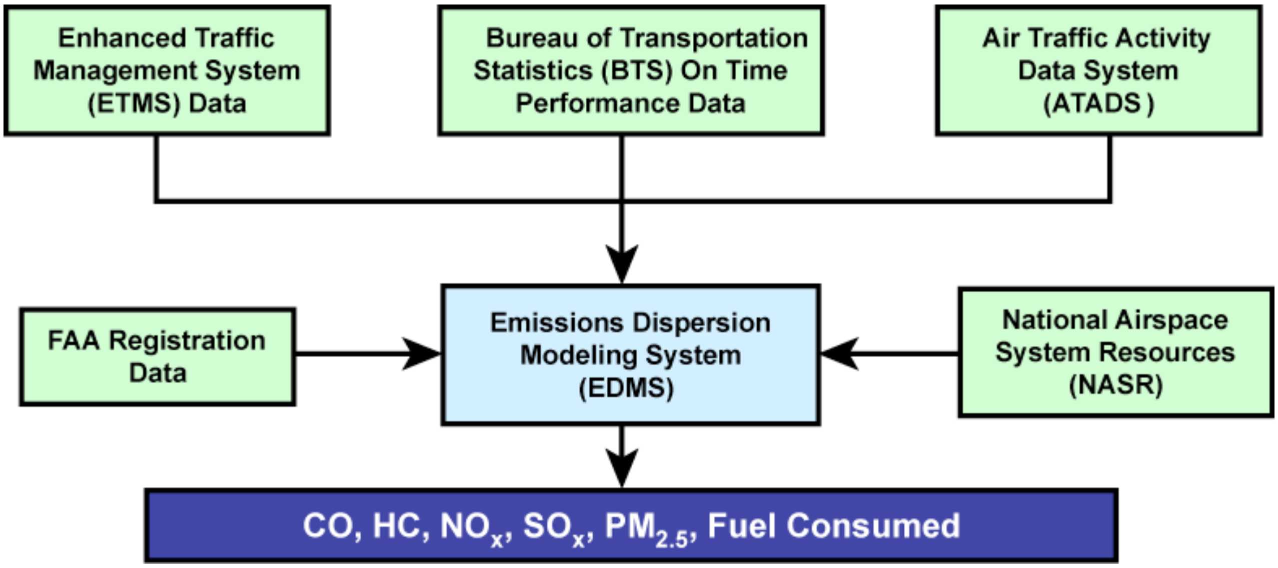


**Figure 3.3:** Overview of EDMS inputs

EDMS computes emissions of primary particulate matter, CO, hydrocarbons,[20] $NO_x$, and $SO_x$[21] for all phases of taxi and flight based on ICAO engine emissions indices. Emissions indices are estimates of the mass of pollutant produced per mass of fuel consumed and are measured during engine certification testing and reported in the ICAO Engine Emissions Certification Databank.[22] However, ICAO does not have a primary PM aircraft engine standard or test procedure, and, thus, PM emission indices are not reported in the ICAO Databank. To estimate total emissions of primary particulate matter (PM), a criteria pollutant composed of a complex mixture of solid particles and liquid droplets, EDMS relied on a research-based estimation technique to derive emissions indices from available data such as ICAO certification smoke number,[23] and experimental results, as described more fully below.

Historically, primary PM emissions from aircraft have been difficult to estimate due to the lack of physical understanding of their formation and evolution in gas turbine engines and exhaust plumes, and the difficulty in measuring fine particles in the hot, high speed flow at the point where the exhaust exits the engine. Aircraft PM exhaust emission data are sparse, and test methods are still under development. ICAO and EPA do not have approved test methods or certification standards for aircraft PM emissions. ICAO's Committee on Aviation

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[17] Bureau of Transportation Statistics, Airline On-Time Performance Data, June 2005 through May 2006, available from http://www.transtats.bts.gov/
[18] http://www.backaviation.com/Information_Services/
[19] Federal Aviation Administration, National Airspace System Resources (NASR) data, 2006.
[20] Hydrocarbons are classified as non-methane hydrocarbons (NMHC) & volatile organic compounds (VOCs). VOCs play a role in the formation of ozone.
[21] An error was made in the specification of the fuel sulfur level for some of the airports in this inventory such that the aircraft $SO_2$ inventory is expected to be biased towards underestimating the contribution of aircraft by approximately a factor of 0.8. In particular, a fuel sulfur level of 400 ppm was assumed for some airports and 680 ppm was assumed for others. Our intention was to assume 680 ppm for all airports. However, variations of fuel sulfur of this level (±200ppm) are typical and are thus within the uncertainty of the estimation methods.
[22] http://www.caa.co.uk/default.aspx?catid=702&pagetype=90
[23] Smoke number is a dimensionless measure that quantifies smoke emissions from aircraft engines. ICAO requires smoke number testing for engine certification.

Environmental Protection (CAEP) has developed and approved the use of an interim First Order Approximation (FOA3)[24] method to estimate total PM emissions (or total fine PM emissions) from certified aircraft engines. Subsequent to the completion of FOA3, the methodology was modified by adding margins to account for the potential effects of uncertainties that include the lack of a standard test procedure, poor definition of volatile PM formation in the aircraft plume, and the limited amount of data available on aircraft PM exhaust emission rates. This modified methodology is known as FOA3a. FOA3a is currently the agreed upon method to estimate PM emissions from aircraft engines, and it has been incorporated into the version of the FAA Emissions and Dispersion Modeling System (EDMS) that was used for this study, which was, version 5.02, June 2007. FOA3a predicts fine PM inventory levels that are approximately 5 times those predicted by FOA3 and reflects the scientific uncertainty associated with PM emissions rates from aircraft engines. This is discussed further in Appendix C.[25]

In addition to addressing the challenges of estimating aircraft PM emissions, another area requiring investigation was APU usage. APU usage depends on a range of factors including aircraft size, weather, and practices specific to individual airlines and pilots. One of the most important determinants of APU usage time is the availability of ground support equipment (e.g. preconditioned air) that can be used in place of the APU to heat or cool the cabin and provide ground-based power to aircraft parked at the gate. While many airlines have standard operating procedures for APU use, the ultimate decision rests with the pilot.

An APU usage survey was conducted and the results were integrated into EDMS for more accurate characterization of APU emissions. Because of the wide range of reported usage in the survey data, *low*, *medium*, and *high* values were analyzed to account for variations in aircraft size and the availability of ground support. For the study baseline inventory, a *medium* level of APU usage was used to account for a wide range of ground support access at the 325 airports, seasonal conditions, and other factors that define APU usage. The range of contribution of the medium level of APU usage to aircraft emissions below 3,000 feet is between 0% and slightly over 25%. The average is below 5% for CO and VOCs and under 10% for $NO_x$ and $SO_x$. For only four non-attainment areas considered in this report, the medium level of APU usage contributes more than 1% to census area emissions (or total emissions) as estimated in the EPA year 2002 National Emissions Inventory. A description of the APU survey methods and results can be found in Appendix D.

[24] Airport Air Quality Guidance Manual. Preliminary Edition 2007 (Doc 9889). http://www.icao.int/icaonet/dcs/9889/9889_en.pdf

Before discussing the inventory results, there is one other point which requires discussion. An error was made in the specification of the fuel sulfur level for 78 of the airports in this inventory such that the aircraft $SO_2$ inventory is expected to be biased towards underestimating the contribution of aircraft by approximately a factor of 0.8. In particular, a fuel sulfur level of 400 ppm was assumed for some airports and 680 ppm was assumed for others. The intention was to use 680 ppm for all airports. However, variations of fuel sulfur of this level (±200 ppm) are typical and are thus within the uncertainty of the estimation methods.

Using the above data and methods, EDMS was used to generate an emissions inventory for each of the 325 study airports. A more detailed description of EDMS, baseline runs, data inputs, model specifications, limitations, and sources of discrepancies in the EDMS inventory are discussed in Appendix E.

**Emissions Inventory Discussion**

The first step in assessing the contribution of aircraft operations to NAAQS non-attainment is to develop emission inventories for the primary pollutants ($NO_x$, $SO_x$, HC, CO, and primary $PM_{2.5}$) for each of the NAAs.[26] There were a total of 118 NAAs identified for this study; each contained at least one commercial service airport. The NAAs in the study and the commercial service airports in each area are listed in Table 3.1 (see Appendix B for the airport name that coincides with the airport code), together with the pollutant(s) of concern. Of the 325 airports modeled, 148 commercial service airports were located in a NAA. Emissions from the remaining airports potentially contribute to the emission concentrations in these NAAs, due to atmospheric transport of emissions.

**Table 3.1:** List of nonattainment areas with at least one commercial service airport, as of September 7, 2005[a]

| State | EPA Green Book Name[b] | Ozone (8-Hour)[c,d,e] | CO | $PM_{10}$ | $PM_{2.5}$ (V=violation) | Notes[f] | Airport Code[g] |
|---|---|---|---|---|---|---|---|
| AK | Anchorage, AK | | Serious | | | | ANC, MRI, LHD |
| AK | Fairbanks, AK | | Serious | | | | FAI |
| AL | Jefferson Co, AL | Subpart 1 | | | V | | BHM |
| AL | Colbert Co, AL | | | | | D | MSL |
| AZ | Phoenix, AZ | Subpart 1 | Maintenance | Serious | | | PHX |
| AZ | Tucson, AZ | | Maintenance | | | | TUS |
| AZ | Mohave Co, AZ | | | Maintenance | | | IFP |
| AZ | Yuma, AZ | | | Moderate | | | YUM |

[26] Secondary pollutants such as ozone and secondary particulate matter are not emitted directly from aircraft engines and require air quality modeling to simulate their formation.

| State | EPA Green Book Name[b] | Ozone (8-Hour)[c,d,e] | CO | $PM_{10}$ | $PM_{2.5}$ (V=violation) | Notes[f] | Airport Code[g] |
|---|---|---|---|---|---|---|---|
| CA | Los Angeles South Coast Air Basin, CA | Severe 17 | Serious | Serious | V | E | LAX, SNA, ONT, BUR, LGB |
| CA | San Francisco-Oakland-San Jose, CA | Marginal | Maintenance | | | | SFO, OAK, SJC |
| CA | San Diego, CA | Subpart 1 | | | | | SAN, CRQ |
| CA | Sacramento Co, CA | Serious | | Moderate | | | SMF |
| CA | Coachella Valley, CA | Serious | | Serious | | | PSP |
| CA | San Joaquin Valley, CA | Serious | Maintenance | Serious | V | | FAT, BFL, MOD, SCK, MCE, VIS |
| CA | San Bernardino Co, CA | Moderate | | Moderate | | | VCV |
| CA | Ventura Co, CA | Moderate | | | | | OXR |
| CA | Chico, CA | Subpart 1 | Maintenance | | | | CIC |
| CA | Indian Wells, CA | | | Maintenance | | | IYK |
| CA | Imperial Valley, CA | Marginal | | Moderate | | | IPL |
| CO | Denver Metro, CO | Subpt. 1 EAC[e] | Maintenance | Maintenance | | | DEN |
| CO | Colorado Springs, CO | | Maintenance | | | | COS |
| CO | Aspen, CO | | | Maintenance | | | ASE |
| CT | Hartford-New Britain-Middletown, CT | Moderate | Maintenance | | | | BDL |
| CT | New Haven Co, CT | Moderate | Maintenance | Moderate | V | | HVN |
| CT | Greater Connecticut, CT | Moderate | | | | | GON |
| GA | Atlanta, GA | Marginal | | | V | | ATL |

| State | EPA Green Book Name[b] | Ozone (8-Hour)[c,d,e] | CO | $PM_{10}$ | $PM_{2.5}$ (V=violation) | Notes[f] | Airport Code[g] |
|---|---|---|---|---|---|---|---|
| GA | Macon, GA | Subpart 1 | | | V | | MCN |
| ID | Boise-Northern Ada Co. ID | | Maintenance | Maintenance | | | BOI |
| ID | Fort Hall Reservation, ID | | | Moderate | | | PIH |
| IL | Chicago-Gary-Lake Counties IL-IN | Moderate | | | V | | ORD, MDW, BLV |
| IN | Marion County, IN | Subpart 1 | | | V | | IND |
| IN | Evansville, IN | Subpart 1 | | | V | | EVV |
| KY | Cinc.-Hamilton, OH-KY-IN | Subpart 1 | | | V | | CVG |
| KY | Louisville, KY-IN | Subpart 1 | | | V | | SDF |
| MA | Boston, MA | Moderate | Maintenance | | | | BOS |
| MD | Baltimore, MD | Moderate | | | V | | BWI |
| MD | Washington Co (Hagerstown), MD | Subpart 1 EAC | | | V | | HGR |
| ME | Portland, ME | Marginal | | | | | PWM |
| ME | Presque Isle, ME | | | Maintenance | | | PQI |
| ME | Hancock, Knox, Lincoln & Waldo Counties, ME | Subpart 1 | | | | | RKD, BHB |
| MI | Detroit-Ann Arbor, MI | Marginal | | | V | | DTW |
| MI | Grand Rapids, MI | Subpart 1 | | | | | GRR |
| MI | Flint, MI | Subpart 1 | | | | | FNT |
| MI | Lansing-East Lansing, MI | Subpart 1 | | | | | LAN |
| MI | Kalam.-Battle Creek, MI | Subpart 1 | | | | | AZO |
| MI | Muskegon, MI | Marginal | | | | | MKG |
| MN | Minneapolis-St Paul, MN | | Maintenance | | | C | MSP |
| MN | Duluth, MN | | Maintenance | | | | DLH |
| MO | St Louis, MO | Moderate | Maintenance | | V | | STL |
| MT | Laurel Area,Yellowstone Co. | | Maintenance | | | | BIL |
| MT | East Helena Area (Lewis and Clark Co.), MT | | | | | B,D | HLN |

| State | EPA Green Book Name[b] | Ozone (8-Hour)[c,d,e] | CO | $PM_{10}$ | $PM_{2.5}$ (V=violation) | Notes[f] | Airport Code[g] |
|---|---|---|---|---|---|---|---|
| MT | Butte, MT | | | Moderate | | | BTM |
| NC | Charlotte, NC | Moderate | Maintenance | | | | CLT |
| NC | Raleigh-Durham, NC | Subpart 1 | Maintenance | | | | RDU |
| NC | Greensboro-Winston Salem-High Point, NC | Moderate EAC[e] | | | V | | GSO |
| NC | Fayetteville, NC | Subpart 1 EAC | | | | | FAY |
| NH | Boston-Lawrence-Worcester (E. MA), MA | Moderate | Maintenance | | | | MHT |
| NH | Portsmouth-Dover-Rochester,NH | Moderate | | | | | PSM |
| NJ | New York-N. New Jersey-Long Island, NY-NJ-CT | Moderate | Maintenance | | V | | EWR, JFK, LGA, ISP, HPN |
| NJ | Atlantic City, NJ | Moderate | Maintenance | | | | ACY |
| NJ | Trenton, NJ | Moderate | Maintenance | | V | | TTN |
| NM | Albuquerque, NM | | Maintenance | | | | ABQ |
| NV | Clark Co, NV | Subpart 1 | Maintenance | Serious | | | LAS, VGT, HND |
| NV | Washoe Co, NV | | Moderate <= 12.7ppm | Serious | | | RNO |
| NY | Buffalo-Niagara Falls, NY | Subpart 1 | | | | | BUF |
| NY | Albany-Schenectady-Troy, NY | Subpart 1 | | | | | ALB |
| NY | Rochester, NY | Subpart 1 | | | | | ROC |
| NY | Syracuse, NY | | Maintenance | | | | SYR |
| NY | Poughkeepsie, NY | Moderate | | | V | | SWF |
| NY | Jamestown, NY | Subpart 1 | | | | | JHW |
| OH | Cuyahoga Co, OH | Moderate | Maintenance | Maintenance | V | C | CLE |

| State | EPA Green Book Name[b] | Ozone (8-Hour)[c,d,e] | CO | $PM_{10}$ | $PM_{2.5}$ (V=violation) | Notes[f] | Airport Code[g] |
|---|---|---|---|---|---|---|---|
| OH | Columbus, OH | Subpart 1 | | | V | | CMH, LCK |
| OH | Dayton-Springfield, OH | Subpart 1 | | | V | | DAY |
| OH | Cleve.-Akron-Lorain,OH | Moderate | | | V | | CAK |
| OH | Lucas Co, OH | Subpart 1 | | | | | TOL |
| OH | Youn.-Warren-Shar.OH-PA | Subpart 1 | | | | | YNG |
| OR | Portland OR-Vancouver WA area | | Maintenance | | | | PDX |
| OR | Medford-Ashland, OR | | Maintenance | Moderate | | | MFR |
| OR | Klamath Falls, OR | | Maintenance | Maintenance | | | LMT |
| PA | Phil.-Wilmington-Atl. City, PA-NJ-MD-DE | Moderate | | | V | | PHL |
| PA | Hazelwood, PA | Subpart 1 | Maintenance | | V | | PIT |
| PA | Harris.-Lebanon-Carlisle,PA | Subpart 1 | | | V | | MDT |
| PA | Allen.-Bethl.-Easton, PA | Subpart 1 | | | | | ABE |
| PA | Scranton-Wilkes-Barre, PA | Subpart 1 | | | | | AVP |
| PA | Erie, PA | Subpart 1 | | | | | ERI |
| PA | State College, PA | Subpart 1 | | | | | UNV |
| PA | Reading, PA | Subpart 1 | | | V | | RDG |
| PA | Pitts.-Beaver Valley, PA | Subpart 1 | | | V | | LBE |
| PA | Johnstown, PA | Subpart 1 | | | V | | JST |
| PA | Altoona, PA | Subpart 1 | | | | | AOO |
| RI | Providence (All RI), RI | Moderate | | | | | PVD, WST, BID |
| SC | Greenville-Spartanburg-Anderson, SC | Subpart 1 EAC | | | V | | GSP |
| SC | Columbia, SC | Subpart 1 EAC | | | | | CAE |
| TN | Memphis, TN | Marginal | Maintenance | | | | MEM |
| TN | Nashville, TN | Subpt. 1 EAC[e] | | | | | BNA |
| TN | Knoxville, TN | Subpart 1 | | | V | | TYS |
| TN | Chattanooga, TN-GA | Subpart 1 EAC | | | V | | CHA |

| State | EPA Green Book Name[b] | Ozone (8-Hour)[c,d,e] | CO | $PM_{10}$ | $PM_{2.5}$ (V=violation) | Notes[f] | Airport Code[g] |
|---|---|---|---|---|---|---|---|
| TN | Johnson City-Kingsport-Bristol, TN | Subpart 1 EAC | | | | | TRI |
| TX | Dallas-Fort Worth, TX | Moderate | | | | | DFW, DAL |
| TX | Houston-Galvest.-Braz, TX | Moderate | | | | | IAH, HOU, EFD, LBX |
| TX | San Antonio, TX | Subpart 1 EAC | | | | | SAT |
| TX | El Paso Co, TX | | | Moderate | | | ELP |
| TX | Beaumont-Port Arthur, TX | Marginal | | | | | BPT |
| UT | Salt Lake Co, UT | | Maintenance | Moderate | | C | SLC |
| VA | Washington, DC-MD-VA | Moderate | Maintenance | | V | | IAD, DCA |
| VA | Norfolk-Virginia Beach-Newport News (HR),VA | Marginal | | | | | ORF, PHF |
| VA | Richmond-Petersburg, VA | Marginal | | | | | RIC |
| VA | Roanoke, VA | Subpart 1 EAC | | | | | ROA |
| WA | Seattle-Tacoma, WA | | Maintenance | | | | SEA |
| WA | Spokane Co, WA | | Serious | Moderate | | | GEG |
| WA | Yakima Co, WA | | | Moderate | | | YKM |
| WA | King Co, WA | | Maintenance | Maintenance | | | BFI |
| WI | Milwaukee, WI | Moderate | | | | C | MKE |
| WI | Madison, WI | | | | | C | MSN |
| WV | Charleston, WV | Subpart 1 | | | V | | CRW |
| WV | Huntingt.-Ashland,WV-KY | Subpart 1 | | | V | | HTS |
| WV | Parkersb.-Marietta,WV-OH | Subpart 1 | | | V | | PKB |
| WY | Sheridan, WY | | | Moderate | | | SHR |

Notes:

| State | EPA Green Book Name[b] | Ozone (8-Hour)[c,d,e] | CO | $PM_{10}$ | $PM_{2.5}$ (V=violation) | Notes[f] | Airport Code[g] |
|---|---|---|---|---|---|---|---|

a Commercial service airports listed in the National Plan for Integrated Airport Systems (NPIAS) per §47102(7) of Title 49 USC.
An empty cell in criteria pollutant columns indicates that the airport is in attainment for that pollutant.

b **Green Book Name** is the name of the nonattainment area.

c The 8-hr. ozone national ambient air quality standard took effect on June 15, 2005, replacing the previous 1-hr. standard.

d **"Subpart 1"** denotes 8-hour ozone nonattainment areas that are covered under Subpart 1, Part D, Title I of the Clean Air Act. "Subpart 1" is considered nonattainment without a classification.

e **Early Action Compacts (EACs)** are not a classification, but areas for which the effective date of their nonattainment designation has been deferred because they are expected to reach or maintain attainment status by December 31, 2006.

f Notes description below:

| | | | |
|---|---|---|---|
| A - | Lead nonattainment or maintenance confirmed | D - | $SO_2$ nonattainment or maintenance unconfirmed |
| B - | Lead nonattainment or maintenance not confirmed | E - | $NO_2$ nonattainment or maintenance confirmed |
| C - | $SO_2$ nonattainment or maintenance confirmed | F - | $NO_2$ nonattainment or maintenance unconfirmed |

g The two airports that were not included in the study because of insufficient operations data are Block Island State Airport (BID) and Lake Hood Airport (LHD).
BID is in Block Island, Rhode Island and LHD is Anchorage, Alaska.

As part of this process, a quantitative comparison of the baseline aircraft inventory to total county level emissions inventories was performed for the primary pollutants. The county level inventories used for the aircraft inventory comparison shown in this section were derived from EPA's year 2002 National Emissions Inventory (NEI), a database of criteria pollutants and their precursors. The NEI provides emissions by Federal Information Processing Standards (FIPS) area; FIPS are generally the same as counties. An estimate of all FIPS area emissions was obtained by aggregating NEI data from all sources including point sources (e.g. smokestacks at a factory), mobile sources (e.g. cars) and area sources (e.g. gas stations). While the NEI does include aircraft emissions, the baseline aircraft emission inventory for each airport in this study was based on EDMS as described above, rather than the NEI.[27] That is, the baseline aircraft emissions inventory for each airport for the period June 2005 through May 2006 were used and aircraft emissions originally within the NEI were removed. The NAA and regional inventories were built from this county level inventory information. As presented below, the aircraft emissions inventory was then compared with total emissions inventories (which thus included EDMS aircraft emissions rather than NEI aircraft emissions) to get a measure of relative contributions.

Focusing first on the NAAs, Table 3.2, below, shows a distribution of the percent contribution of emissions for aircraft in the 118 NAAs. The average value in each row reflects the average of the values for aircraft contributions in each of the 118 NAAs.[28] As seen in Table 3.2 the aircraft LTO emissions at the 148 commercial service airports within the 118 NAAs are small. (Note, some of the general aviation airports and reliever airports studied were located in NAAs, but they were not included with the below inventories for NAAs. The aircraft emissions from these airports are estimated to be a small fraction of the aircraft emissions in NAAs compared to those from commercial service airports. This is because commercial aircraft are generally larger than general aviation aircraft and thus burn more fuel; emissions are proportional to fuel burn.)

**Table 3.2:** Contribution of U.S. aircraft LTO operations at 148 commercial service airports to emission inventories in 118 NAAs [a, b, c, d]

| Aircraft Emissions Inventory | CO | $NO_x$ | VOCs | $SO_x$ | $PM_{2.5}$ |
|---|---|---|---|---|---|
| **2002: Average and range as a percentage of aircraft LTO contributions to emission inventories for 118 NAA with at least one commercial service airport** | 0.44%<br><br>0.06% to 4.36% | 0.66%<br><br>0.004% to 10.93% | 0.48%<br><br>0.05% to 5.03% | 0.37%<br><br>0.002% to 6.91% | 0.15%<br><br>0.002% to 2.57% |

Notes:

[a] This table presents aircraft LTO emission inventories for the 148 commercial service airports in the nonattainment

[27] EDMS aircraft emissions were used instead of NEI aircraft emissions because the level of fidelity for modeling aircraft in the 2001 NEI is lower than that for the inventories used for this study. In particular, NEI emissions for commercial aircraft were generated using the default EDMS times in mode (0.7 minutes for take-off, 2.2 minutes for climb-out, 4 minutes for approach, and 26 minutes for taxi and ground idle). Also, aircraft PM emissions in the 2001 NEI were based on several engines with PM emissions data in AP 42, which is an EPA publication of air pollutant emissions factors (http://www.epa.gov/ttn/chief/ap42/). For the aircraft inventory comparison in this study, NEI commercial aircraft emissions were instead replaced with aircraft emissions generated for this study using a newer version of EDMS (version 5.02) along with actual aircraft operational data and the PM emissions estimation method FOA3a as described in Appendix E. See Appendix J for a comparison of EDMS aircraft emissions with the 2002 NEI.

[28] If the values were calculated as total aircraft emissions over total NAA area inventories for each pollutant the values for each pollutant for 2002/2020 would be as follows: CO: 0.36/0.78%, $NO_x$: 0.80/2.27%, VOCs: 0.43/0.77%, $SO_x$: 0.12/0.32%, $PM_{2.5}$: 0.16/0.24%.

areas.
[b] If an area had more than type of nonattainment area (e.g., $PM_{2.5}$ and CO nonattainment areas), the nonattainment area was selected based on the area with the largest population base.
[c] Except for aircraft, the emission levels for categories are from the inventories developed for the 2008 Final Rule on Emission Standards for New Nonroad Spark-Ignition Engines, Equipment, and Vessels, which is available at http://www.epa.gov/otaq/equip-ld.htm .
[d] 2005 is the base year for aircraft emissions.

Looking deeper into the information, Table 3.3 and Table 3.4 show the top 25 $PM_{2.5}$ and $NO_x$ aircraft emission inventory NAAs ranked according to the percent of inventory contributed by aircraft emissions (from commercial service airports). Table 3.3 shows that for $PM_{2.5}$, 9 of the areas with the greatest aircraft direct PM contributions were also $PM_{2.5}$ NAAs in 2005. Similarly for ozone, Table 3.4 shows that 16 of the areas with the greatest aircraft $NO_x$ contributions were ozone NAAs in 2005 (as described earlier, 2002 is the base year for non-aircraft emissions, and 2005 is the base year for aircraft emissions).

**Table 3.3:** Top 25 NAAs according to aircraft $PM_{2.5}$ contribution

| NAA Name | % of total | % of mobile |
|---|---|---|
| Anchorage | 2.57% | 8.88% |
| Memphis | 1.14% | 4.06% |
| Salt Lake City | 0.85% | 3.99% |
| Las Vegas | 0.68% | 3.20% |
| Aspen | 0.44% | 5.20% |
| New York-N. New Jersey-Long Island* | 0.41% | 1.48% |
| Louisville* | 0.39% | 2.90% |
| Minneapolis-St. Paul | 0.39% | 1.87% |
| Chicago-Gary-Lake County* | 0.36% | 1.37% |
| Providence (all of RI) | 0.31% | 1.06% |
| Denver-Boulder-Greeley-Ft. Collins-Love. Area | 0.31% | 1.65% |
| Phoenix-Mesa | 0.30% | 1.29% |
| San Francisco-Bay Area | 0.29% | 1.23% |
| Charlotte-Gastonia-Rock Hill | 0.29% | 1.56% |
| Los Angeles-South Coast Air Basin* | 0.27% | 0.92% |
| Southeast Desert Modified AQMA (Riverside County, CA - Coachella Valley, CA Area) | 0.27% | 0.98% |
| Cincinnati-Hamilton* | 0.26% | 2.27% |
| Detroit-Ann Arbor* | 0.26% | 1.27% |
| Seattle-Tacoma | 0.25% | 0.87% |
| Dallas-Fort Worth | 0.23% | 1.52% |
| Atlanta* | 0.23% | 1.74% |
| Syracuse | 0.22% | 1.10% |
| Washington DC* | 0.21% | 1.49% |
| Philadelphia-Wilmington-Trenton* | 0.20% | 0.85% |

| NAA Name | % of total | % of mobile |
|---|---|---|
| Albuquerque | 0.19% | 1.28% |

* 2005 $PM_{2.5}$ NAA according to Table 3.1.

**Table 3.4:** Top 25 NAAs according to aircraft $NO_x$ contribution

| NAA name | % of total | % of mobile |
|---|---|---|
| Anchorage | 10.93% | 19.63% |
| Aspen | 4.45% | 5.16% |
| Memphis* | 3.23% | 4.76% |
| Las Vegas* | 3.06% | 7.13% |
| Salt Lake City | 2.98% | 3.64% |
| Dallas-Fort Worth* | 1.76% | 2.27% |
| Reno | 1.73% | 2.07% |
| Phoenix-Mesa* | 1.72% | 1.87% |
| San Francisco-Bay Area* | 1.57% | 1.85% |
| Lake Tahoe Nevada (Washoe County) | 1.43% | 1.75% |
| Denver-Boulder-Greeley-Ft. Collins-Love. Area* | 1.42% | 2.13% |
| New York-N. New Jersey-Long Island* | 1.40% | 1.98% |
| Charlotte-Gastonia-Rock Hill* | 1.39% | 2.05% |
| Atlanta* | 1.32% | 2.19% |
| Albuquerque | 1.27% | 1.62% |
| Chicago-Gary-Lake County* | 1.27% | 1.93% |
| Washington DC* | 1.22% | 1.93% |
| Minneapolis-St. Paul | 1.07% | 1.90% |
| Southeast Desert Modified AQMA (Riverside County, CA - Coachella Valley, CA Area)* | 1.07% | 1.28% |
| Seattle-Tacoma | 1.03% | 1.15% |
| Indianapolis* | 1.02% | 1.42% |
| Los Angeles-South Coast Air Basin* | 1.02% | 1.21% |
| San Diego* | 0.99% | 1.07% |
| Providence (all of RI)* | 0.95% | 1.19% |
| El Paso | 0.84% | 1.11% |

*2005 Ozone NAA according to Table 3.1.

It is also interesting to consider these inventory contributions from other perspectives. For the 118 NAAs listed in Table 3.1, Table 3.5 shows the 25 which are the busiest based on the total number of LTOs at all commercial service airports in that NAA. Of these, 21 of 25 were either an ozone or $PM_{2.5}$ NAA, or both, in 2005 (10 areas both ozone and $PM_{2.5}$ NAAs, 21 ozone NAAs, and 10 $PM_{2.5}$ NAAs). The airports associated with these LTOs are among the busiest in the nation. Also for the 118 NAAs listed above, Table 3.6 shows the 25 largest NAAs by population. The population (based on population data for the year 2000) in these NAAs represents 74 percent of those in all 118 NAAs. Many of the same busy airports are also shown in Table 3.5. Of the 25 large population centers in Table 3.6, 24 were either an ozone or $PM_{2.5}$ NAA, or both in 2005 (14 areas both ozone and $PM_{2.5}$ NAAs, 24 ozone NAAs, and 14 $PM_{2.5}$ NAAs). Both of these analyses indicate that airports are an important emissions source in these NAAs.

**Table 3.5:** Aircraft emissions contribution for top 25 NAAs according to LTOs ($NO_x$, VOCs, and $PM_{2.5}$)

| NAA Name | 2005 | $NO_x$ | | VOCs | | $PM_{2.5}$ | |
|---|---|---|---|---|---|---|---|
| | LTOs | % total | % mobile | % total | % mobile | % total | % mobile |
| Los Angeles-South Coast Air Basin[a,b] | 937,157 | 1.02% | 1.21% | 0.50% | 0.97% | 0.27% | 0.92% |
| New York-N. New Jersey-Long Island[a,b] | 930,014 | 1.40% | 1.98% | 0.42% | 0.93% | 0.41% | 1.48% |
| Southeast Desert Modified AQMA (Riverside County, CA - Coachella Valley, CA Area) [a] | 756,196 | 1.07% | 1.28% | 0.54% | 1.04% | 0.27% | 0.98% |
| Chicago-Gary-Lake County[a,b] | 660,721 | 1.27% | 1.93% | 0.49% | 1.02% | 0.36% | 1.37% |
| Houston-Galveston-Brazoria[a] | 512,986 | 0.68% | 1.08% | 0.49% | 1.25% | 0.16% | 0.81% |
| Atlanta[a,b] | 491,426 | 1.32% | 2.19% | 0.54% | 1.10% | 0.23% | 1.74% |
| Dallas-Fort Worth[a] | 486,402 | 1.76% | 2.27% | 0.58% | 1.05% | 0.23% | 1.52% |
| Las Vegas[a] | 481,057 | 3.06% | 7.13% | 1.71% | 2.34% | 0.68% | 3.20% |
| San Francisco-Bay Area[a] | 469,251 | 1.57% | 1.85% | 0.63% | 1.20% | 0.29% | 1.23% |
| Washington DC[a,b] | 393,169 | 1.22% | 1.93% | 0.57% | 1.14% | 0.21% | 1.49% |
| Philadelphia-Wilmington-Trenton[a,b] | 380,249 | 0.64% | 0.92% | 0.35% | 0.74% | 0.20% | 0.85% |
| Seattle-Tacoma | 318,786 | 1.03% | 1.15% | 0.28% | 0.45% | 0.25% | 0.87% |
| Phoenix-Mesa[a] | 308,259 | 1.72% | 1.87% | 0.61% | 1.12% | 0.30% | 1.29% |
| Denver-Boulder-Greeley-Ft. Collins-Love[a] | 303,065 | 1.42% | 0.67% | 0.54% | 0.58% | 0.31% | 0.60% |
| Boston-Worcester-Manchester[a] | 282,139 | 0.78% | 1.17% | 0.35% | 0.87% | 0.11% | 0.93% |
| Charlotte-Gastonia-Rock Hill[a] | 265,175 | 1.39% | 2.05% | 0.69% | 1.70% | 0.29% | 1.56% |

| NAA Name | 2005 LTOs | $NO_x$ % total | $NO_x$ % mobile | VOCs % total | VOCs % mobile | $PM_{2.5}$ % total | $PM_{2.5}$ % mobile |
|---|---|---|---|---|---|---|---|
| Detroit-Ann Arbor[a,b] | 255,504 | 0.64% | 1.06% | 0.42% | 0.73% | 0.26% | 1.27% |
| Minneapolis-St. Paul | 254,326 | 1.07% | 1.90% | 0.59% | 1.05% | 0.39% | 1.87% |
| San Joaquin Valley[a,b] | 249,458 | 0.04% | 0.06% | 0.10% | 0.29% | 0.01% | 0.06% |
| Anchorage | 248,459 | 10.93% | 19.63% | 3.89% | 5.78% | 2.57% | 8.88% |
| Salt Lake City | 227,358 | 2.98% | 3.64% | 1.13% | 2.12% | 0.85% | 3.99% |
| San Diego[a] | 222,798 | 0.99% | 1.07% | 0.37% | 0.76% | 0.16% | 0.63% |
| Cincinnati-Hamilton[a,b] | 220,115 | 0.62% | 1.37% | 1.45% | 2.99% | 0.26% | 2.27% |
| Memphis[a] | 196,202 | 3.23% | 4.76% | 2.95% | 5.93% | 1.14% | 4.06% |
| Cleveland-Akron-Lorain[a,b] | 184,501 | 0.41% | 0.62% | 0.33% | 0.62% | 0.13% | 0.51% |

Notes:

[a] Ozone NAA in 2005 according to Table 3.1.

[b] $PM_{2.5}$ NAA in 2005 according to Table 3.1.

**Table 3.6:** Aircraft emissions contribution for top 25 NAAs according to population ($NO_x$, VOCs, and $PM_{2.5}$)

| NAA Name | Year 2000 Population | $NO_x$ % total | $NO_x$ % mobile | VOCs % total | VOCs % mobile | $PM_{2.5}$ % total | $PM_{2.5}$ % mobile |
|---|---|---|---|---|---|---|---|
| New York-N. New Jersey-Long Island[a,b] | 20,364,647 | 1.40% | 1.98% | 0.42% | 0.93% | 0.41% | 1.48% |
| Los Angeles-South Coast Air Basin[a,b] | 14,593,587 | 1.02% | 1.21% | 0.50% | 0.97% | 0.27% | 0.92% |
| Chicago-Gary-Lake County[a,b] | 8,757,808 | 1.27% | 1.93% | 0.49% | 1.02% | 0.36% | 1.37% |
| Philadelphia-Wilmington-Trenton[a,b] | 7,333,475 | 0.64% | 0.92% | 0.35% | 0.74% | 0.20% | 0.85% |
| San Francisco-Bay Area[a] | 6,576,113 | 1.57% | 1.85% | 0.63% | 1.20% | 0.29% | 1.23% |
| Boston-Worcester-Manchester[a] | 6,230,843 | 0.78% | 1.17% | 0.35% | 0.87% | 0.11% | 0.93% |
| Dallas-Fort Worth[a] | 5,030,828 | 1.76% | 2.27% | 0.58% | 1.05% | 0.23% | 1.52% |
| Detroit-Ann Arbor[a,b] | 4,932,383 | 0.64% | 1.06% | 0.42% | 0.73% | 0.26% | 1.27% |
| Houston-Galveston-Brazoria[a] | 4,669,571 | 0.68% | 1.08% | 0.49% | 1.25% | 0.16% | 0.81% |
| Washington DC[a,b] | 4,654,618 | 1.22% | 1.93% | 0.57% | 1.14% | 0.21% | 1.49% |

| NAA Name | Year 2000 Population | $NO_x$ | | VOCs | | $PM_{2.5}$ | |
|---|---|---|---|---|---|---|---|
| | | % total | % mobile | % total | % mobile | % total | % mobile |
| Atlanta[a,b] | 4,231,750 | 1.32% | 2.19% | 0.54% | 1.10% | 0.23% | 1.74% |
| San Joaquin Valley[a,b] | 3,290,618 | 0.04% | 0.06% | 0.10% | 0.29% | 0.01% | 0.06% |
| Phoenix-Mesa[a] | 3,111,876 | 1.72% | 1.87% | 0.61% | 1.12% | 0.30% | 1.29% |
| Cleveland-Akron-Lorain[a,b] | 2,945,575 | 0.41% | 0.62% | 0.33% | 0.62% | 0.13% | 0.51% |
| San Diego[a] | 2,813,431 | 0.99% | 1.07% | 0.37% | 0.76% | 0.16% | 0.63% |
| Minneapolis-St. Paul | 2,723,925 | 1.07% | 1.90% | 0.59% | 1.05% | 0.39% | 1.87% |
| Denver-Boulder-Greeley-Ft. Collins-Loveland Area[a,] | 2,715,806 | 1.42% | 2.13% | 0.54% | 1.42% | 0.31% | 1.65% |
| Baltimore[a] | 2,512,431 | 0.82% | 1.40% | 0.30% | 0.70% | 0.14% | 1.04% |
| Greater Connecticut (Hartford-New Britain-Middletown Area, New Haven County)[a,b] | 2,510,470 | 0.41% | 0.52% | 0.12% | 0.28% | 0.08% | 0.41% |
| St. Louis[a,b] | 2,508,230 | 0.34% | 0.58% | 0.26% | 0.57% | 0.08% | 0.48% |
| Pittsburgh-Beaver Valley[a,b] | 2,433,999 | 0.26% | 0.62% | 0.39% | 0.80% | 0.05% | 0.63% |
| Sacramento Metro[a] | 1,978,348 | 0.61% | 0.74% | 0.28% | 0.54% | 0.07% | 0.53% |
| Cincinnati-Hamilton[a,b] | 1,891,518 | 0.62% | 1.37% | 1.45% | 2.99% | 0.26% | 2.27% |
| Milwaukee-Racine[a] | 1,839,149 | 0.45% | 0.81% | 0.33% | 0.99% | 0.12% | 0.82% |
| Indianapolis[a,b] | 1,607,486 | 1.02% | 1.42% | 0.63% | 1.17% | 0.13% | 1.02% |

Notes:

[a] Ozone NAA in 2005 according to Table 3.1.

[b] $PM_{2.5}$ NAA in 2005 according to Table 3.1.

It is also interesting to consider aircraft emissions in the context of other mobile source emission categories for the 118 NAAs. For example, Table 3.7 and Table 3.8 present $NO_x$ and $PM_{2.5}$ emissions for mobile source categories, including aircraft at the 148 commercial service airports. 2002 is the base year for non-aircraft emissions and 2005 is the base year for aircraft emissions. Appendix J contains similar information for VOCs, CO, and $SO_x$.

**Table 3.7:** Nonattainment area annual $NO_x$ emission levels for mobile sources(metric tons)[a,b,c,d]

| Source | $NO_x$ |
|---|---|
| Aircraft | 73,152 |
| Recreational Marine Diesel | 13,520 |
| Commercial Marine (C1 & C2) | 398,338 |
| Land-Based Nonroad Diesel | 755,208 |
| Commercial Marine (C3) | 105,414 |
| Small Nonroad SI | 83,735 |
| Recreational Marine SI | 27,661 |
| SI Recreational Vehicles | 2,411 |
| Large Nonroad SI (>25hp) | 168,424 |
| Locomotive | 330,894 |
| Total Off-Highway | 1,958,755 |
| Highway non-diesel | 2,229,330 |
| Highway Diesel | 1,683,882 |
| Total Highway | 3,913,213 |
| Total Mobile Sources | 5,871,967 |

Notes:

[a] This table presents aircraft LTO emission inventories for the 148 commercial service airports in the nonattainment areas.

[b] If an area had more than type of nonattainment area (e.g., $PM_{2.5}$ and CO nonattainment areas), the nonattainment area was selected based on the area with the largest population base.

[c] Except for aircraft, the emission levels for categories are from the inventories developed for the 2008 Final Rule on Emission Standards for New Nonroad Spark-Ignition Engines, Equipment, and Vessels, which is available at http://www.epa.gov/otaq/equip-ld.htm .

[d] 2005 is the base year for aircraft emissions.

**Table 3.8:** Nonattainment area annual $PM_{2.5}$ emission levels for mobile sources (metric tons)[a,b,c,d]

| Source | $PM_{2.5}$ |
|---|---|
| Aircraft | 1,948 |
| Recreational Marine Diesel | 368 |
| Commercial Marine (C1 & C2) | 14,342 |
| Land-Based Nonroad Diesel | 65,572 |
| Commercial Marine (C3) | 5,475 |

| Source | $PM_{2.5}$ |
|---|---|
| Small Nonroad SI | 14,304 |
| Recreational Marine SI | 6,488 |
| SI Recreational Vehicles | 2,668 |
| Large Nonroad SI (>25hp) | 833 |
| Locomotive | 8,301 |
| Total Off-Highway | 120,299 |
| Highway non-diesel | 28,504 |
| Highway Diesel | 42,729 |
| Total Highway | 71,233 |
| Total Mobile Sources | 191,532 |

Notes:

[a] This table presents aircraft LTO emission inventories for the 148 commercial service airports in the nonattainment areas.

[b] If an area had more than type of nonattainment area (e.g., $PM_{2.5}$ and CO nonattainment areas), the nonattainment area was selected based on the area with the largest population base.

[c] Except for aircraft, the emission levels for categories are from the inventories developed for the 2008 Final Rule on Emission Standards for New Nonroad Spark-Ignition Engines, Equipment, and Vessels, which is available at http://www.epa.gov/otaq/equip-ld.htm .

[d] 2005 is the base year for aircraft emissions.

As is shown in Table 3.2 above and also included in Table 3.9, aircraft operations at the 148 commercial service airports in the 118 NAAs are a relatively small source of emissions in these areas. Finally, as presented in Table 3.9, the study also examined contributions to national inventories for both mobile sources and total emissions for the 325 commercial service airports.

**Table 3.9:** Contribution of aircraft LTO operations at commercial service airports to emissions inventories

| Aircraft emissions inventory | CO | $NO_x$ | VOCs | $SO_x$ | $PM_{2.5}$ |
|---|---|---|---|---|---|
| **2002: average and range as a percentage of total emissions inventories in 118 NAAs with at least one commercial service airport (118 airports)** | 0.44% | 0.66% | 0.48% | 0.37% | 0.15% |
| | 0.06% to 4.36% | 0.004% to 10.93% | 0.05% to 5.03% | 0.002% to 6.91% | 0.002-2.57% |
| **2002: average and range as a percentage of Mobile Source emissions inventories in 118 NAAs with at least one commercial service airport (118 airports)** | 0.54% | 1.04% | 0.98% | 2.24% | 0.84% |
| | 0.089% to 4.72% | 0.014% to 19.63% | 0.064%% to 9.04% | 0.026% to 30.92% | 0.016% to 8.88% |

| Aircraft emissions inventory | CO | $NO_x$ | VOCs | $SO_x$ | $PM_{2.5}$ |
|---|---|---|---|---|---|
| **As a percentage of EPA year 2002 National Emissions Inventory (325 airports)** | 0.18% | 0.41% | 0.23% | 0.07% | 0.05% |
| **As a percentage of Mobile Source emissions inventory in EPA year 2002 National Emissions Inventory (325 airports)** | 0.22% | 0.71% | 0.51% | 1.29% | 0.53% |

## 3.2 Impact of Aircraft Emissions on Ambient Air Quality

The results of the baseline emissions inventory comparison presented in the previous section offer a first estimate of aviation's influence on air quality. However, these primary pollutants are subject to atmospheric transport and atmospheric chemistry processes that affect air quality levels downwind of primary sources. Atmospheric residence times can extend for multiple days and it is important to consider regional scales even when assessing aircraft emissions from distinct airport locations. Further, these processes lead to the formation of secondary pollutants such as ozone and secondary particulate matter – the latter results from the condensation of chemical species minutes to days after emission of the precursor emissions (predominantly $NO_x$ and $SO_x$ for aircraft). To determine the impact of the baseline aircraft emissions inventory on air quality, a national-scale air quality simulation was performed for the study.

**Air Quality Modeling Simulation- Data and Methods**

Consistent with EPA analyses such as the Clean Air Interstate Rule Regulatory Impact Analysis (EPA 2005), the air quality modeling performed for the study included the formation, transport, and destruction of two pollutants: ozone and fine particulate matter ($PM_{2.5}$). These two pollutants are expected to be the dominant causes of human health impacts associated with local air quality. To model changes in 8-hour ozone[29] and annual average $PM_{2.5}$[30] concentrations, an air quality simulation was performed using the Community Multiscale Air Quality (CMAQ) modeling system, a three dimensional grid-based, air quality model designed to estimate the fate of ozone precursors and primary and secondary particulate matter concentrations and their deposition over regional and urban scales (Byun and Schere 2006). The analysis used a 36 km x 36 km grid scale that is expected to lead to an underestimation of some local effects close to airport boundaries.

Inputs to the CMAQ modeling system include emissions estimates (from aircraft and other sources), initial/boundary conditions, and meteorological fields. While the baseline emissions inventory from EDMS for June 2005 through May 2006 was used to estimate total emissions from aircraft (see section 3.1), emissions estimates for non-aircraft sources were obtained from the EPA year 2001 National Emissions Inventory (NEI). The 2001 NEI, rather than the 2002 NEI, was used for the modeling of aircraft emissions impacts on air quality and human health because it was the most carefully assessed national inventory at the time and it was readily available for air quality modeling -- it had already been used for other rulemakings such as the proposed rule for "Control of Emissions of Air Pollution from Locomotives and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder", 72 FR 15938, April 3, 2007. For the annual $PM_{2.5}$ estimates, an entire year of meteorology was modeled. For 8-hour ozone estimates, a five month simulation was performed to account for the summer months in which ozone concentrations peak (May through September).

The air quality modeling methods used in this study have been used to support several regulatory actions initiated by EPA, including the final $PM_{2.5}$ NAAQS (EPA 2006), the 8-hour Ozone NAAQS (EPA 2008), and the rule for the "Control of Emissions of Air Pollution from Locomotives and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder" (EPA 2007c). A detailed description of the air quality modeling methods used for the study can be found in Appendix F.

**Air Quality Modeling Results**

For the study, three national emission scenarios were modeled with CMAQ to estimate the potential air quality impacts of aircraft emissions: a *base line* scenario with all 2001 NEI emissions (including NEI aircraft emissions), an

[29] Given in parts per billion (ppb). The averaging time for the ozone NAAQS is 8 hours.
[30] Given in micrograms per cubic meter ($\mu g/m^3$). The PM NAAQS is expressed as an annual average. There is also a 24-hour $PM_{2.5}$ NAAQS; however, this study only considered the annual average.

*EDMS aircraft emissions* scenario with a full set of emissions data for non-aircraft sources obtained from the 2001 NEI plus the specific aircraft emissions generated in the EDMS baseline inventory (see Section 3.1), and another with all aircraft emissions (both EDMS and NEI) removed. The difference in estimated pollutant concentrations between these two simulations was used to determine the local and regional air quality impacts of the aircraft emissions. The approach used is consistent with the EPA guidance document for modeling ozone and $PM_{2.5}$ (EPA 2007b) and is described more fully in Appendix F.

Turning first to $PM_{2.5}$, almost all areas experienced increases in annual average $PM_{2.5}$ concentrations due to modeled aircraft emissions. The CMAQ simulation for $PM_{2.5}$ utilized data from 557 counties with monitoring systems for this emission. Of the 557 counties with $PM_{2.5}$ monitoring data, 546 showed increases, 9 showed no change, and 2 showed decreases of less than 0.001 μg/$m^3$; these decreases are expected to be within the range of model uncertainty. On average, the modeling revealed that aircraft emissions contribute 0.01 μg/$m^3$ to overall annual average ambient $PM_{2.5}$ levels.

- The largest impact was found in Riverside County, CA where modeled aircraft emissions increased annual average $PM_{2.5}$ values by 0.15 μg/$m^3$ (a 0.52% increase from 28.73 to 28.88 μg/$m^3$).
- San Bernardino County, CA also showed an impact greater than 0.10 μg/$m^3$. Another 13 counties showed an impact of at least 0.05 μg/$m^3$ and another 38 counties in the U.S. had an impact of at least 0.02 μg/$m^3$.

The results of the PM modeling for NAAs and all counties appear below in Table 3.10. Figure 3.4 shows a map of the national changes in average annual PM determined by the air quality simulation. The individual results for the 557 U.S. counties with $PM_{2.5}$ monitoring data are provided in Appendix F.

**Table 3.10:** Average annual $PM_{2.5}$ estimates. Results are given in μg/$m^3$. The annual National Ambient Air Quality Standard for $PM_{2.5}$ is 15.0 μg/$m^3$.

| | **Without Aircraft Emissions (μg/$m^3$)** | **With Aircraft Emissions (μg/$m^3$)** | **Percent Increase Due to Aircraft Emissions** |
|---|---|---|---|
| **Non-Attainment Areas** | 17.75 | 17.76 | 0.06% |
| **All Counties** | 12.59 | 12.60 | 0.08% |

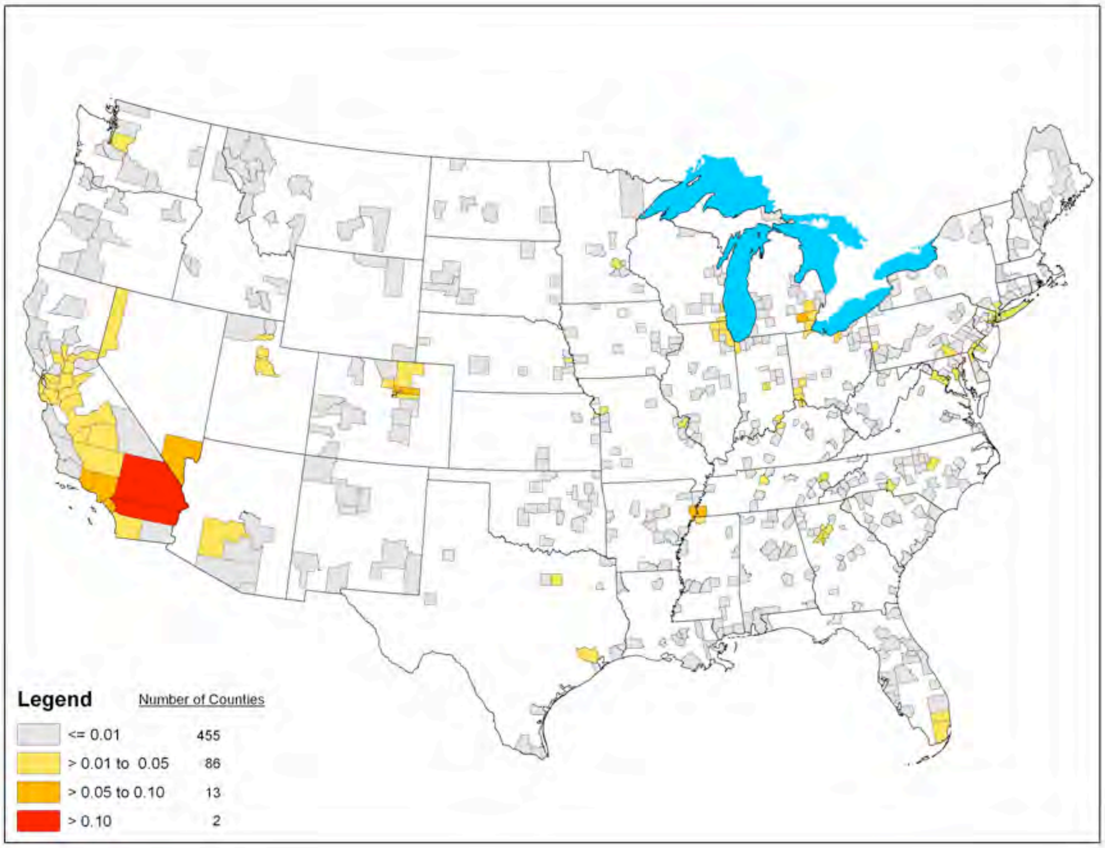


**Figure 3.4:** Estimated change in annual $PM_{2.5}$ concentrations (μg/m$^3$) due to aircraft emissions.

For ozone, the analysis revealed a mix of potential benefits and *disbenefits* resulting from aircraft emissions. The photochemistry associated with ozone formation is complex, depending on local quantities of $NO_x$, VOCs, and other ozone catalysts. Normally, increasing $NO_x$ emissions increases ozone concentrations in suburban and rural areas where VOC sources are plentiful. Sometimes however, the addition of $NO_x$ emissions (from aircraft and other sources) decreases ozone concentrations in urban cores, where VOC concentrations are more limited. The air quality modeling simulation revealed areas in which the addition of aircraft emissions increased ozone as well as areas in which decreased ozone concentrations (sometimes referred to as ozone or $NO_x$ *disbenefits*) were projected:

- The CMAQ simulation for ozone utilized monitoring data from 571 U.S. counties. For all of these counties, the average change in 8-hour average ozone values was found to be an increase of 0.10 parts per billion (ppb) due to modeled aircraft emissions. The largest increase due to aircraft emissions occurred near the Atlanta area, a 0.6% increase from 95.9 to 96.5 ppb.
- However, there were 24 counties across the U.S. where modeled aircraft emissions caused a decrease in 8-hour ozone values. The largest reduction was projected in Richmond County, NY, a 0.3% decrease from 96.3 to 96.0 ppb.

A summary of the results of the ozone modeling for NAAs and all counties appears below in Table 3.11. Individual results for the 571 U.S. counties with valid ozone monitoring data are provided in Appendix F. Figure 3.5 depicts the county-level changes in 8-hour ozone determined by the air quality simulation.

**Table 3.11:** Average 8-hour ozone values (ppb) with and without EDMS aircraft emissions. The National Ambient Air Quality Standard for 8 hour ozone is 80 ppb. Based on rounding convention, values greater than or equal to 85 ppb are considered non-attainment.

| | Without Aircraft Emissions (ppb) | With Aircraft Emissions (ppb) | Percent Increase Due to Aircraft Emissions |
|---|---|---|---|
| Nonattainment Areas | 91.10 | 91.21 | 0.12% |
| All Counties | 84.85 | 84.95 | 0.12% |

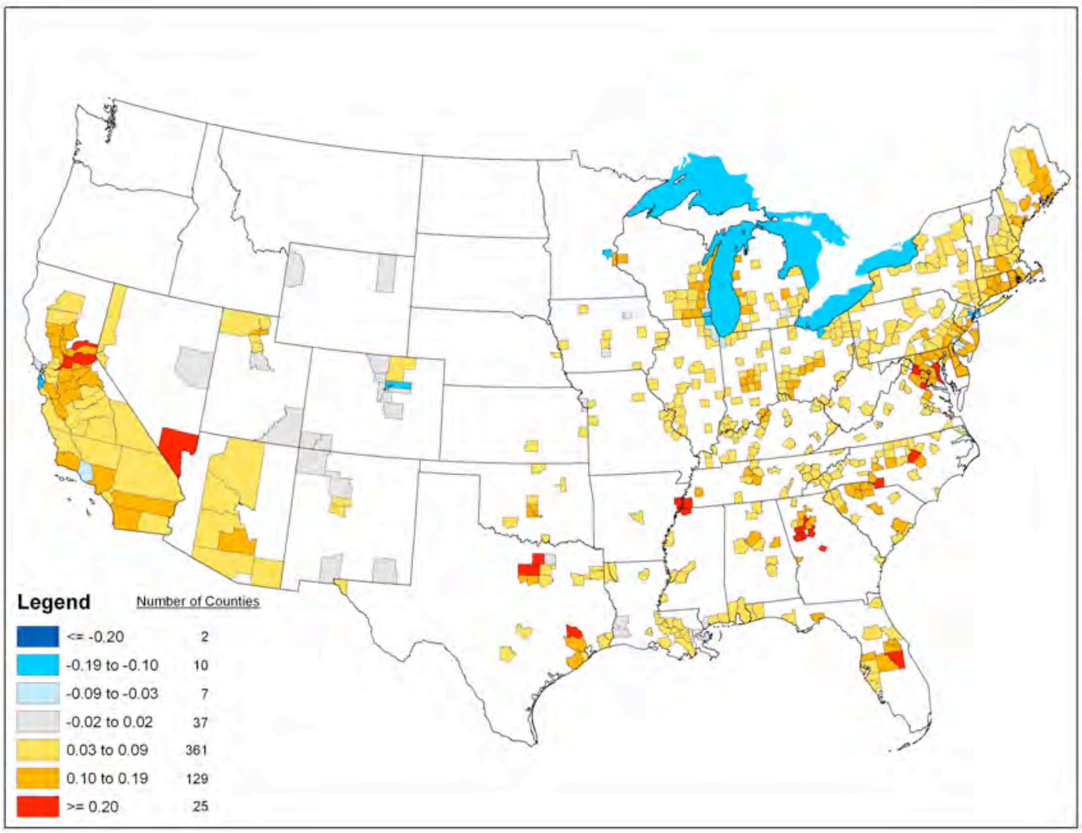


**Figure 3.5:** Estimated change in 8-hour ozone concentrations (ppb) due to aircraft emissions. Negative values represent regions where aircraft emissions reduce levels of ozone. Positive values represent regions where the aircraft emissions increase ozone levels.

The air quality modeling results presented above depict changes in ambient concentrations of ozone and PM that influence attainment of National Ambient Air Quality Standards and may result in changes in public health.[31] The

[31] Note that on March 27 of 2008, EPA published a rule revising the primary ozone NAAQS from 0.08 ppm to 0.075 ppm and setting the secondary ozone NAAQS to 0.075 ppm, effective May 27 of 2008. 73 FR 16436. Nonattainment statuses of the counties assessed in this study are from 2005; the effect of the new ozone NAAQS on the nonattainment statuses of these counties was not considered in this study.

following section describes the health impact analysis that was performed to assess the changes in public health due to aircraft contributions to ozone and ambient fine PM concentrations.

## 3.3 The Impact of Aircraft Emissions on Public Health

The health impact analysis performed for this study used a methodology consistent with benefit analyses performed by EPA for the PM NAAQS and the Ozone NAAQS (EPA 2006; EPA 2008). It should be noted that there are data limitations and uncertainties that may affect the results by an unknown amount (in terms of both under- and over-estimates). The use of a 36 km x 36 km grid cell size for the air quality analyses is expected to underestimate health impacts, especially those that may occur close to airport boundaries. The omission of air quality impacts from airports not included in this analysis is expected to lead to underestimation of aircraft-related health impacts. Omitting the effect of cruise level emissions on surface air quality is also expected to lead to underestimation of health impacts by an unknown amount. Further, analysis of only one year may lead to overestimation or underestimation of aircraft impacts due to year-to-year changes in meteorology. Non-aircraft sources were also not included (e.g. emissions of ground service equipment and other aircraft sources). Finally, we report the results for one concentration-response relationship for the health effects of ambient PM; a range of concentration-response relationships has been reported in the literature. The net effect of these assumptions and limitations is not known. Further research is recommended into these areas.[32]

EPA's general health impact analysis framework uses the following framework (EPA 2006):

- Given baseline and post-control[33] emissions inventories, EPA uses photochemical air quality modeling to estimate baseline and post-control ambient concentrations of the pollutant of concern.
- Changes in ambient concentrations of that pollutant are then combined with monitoring data to estimate population-level potential exposure to changes in ambient concentrations.
- Changes in population exposure are then used as input to impact functions to generate changes in the incidences of health effects, or changes in other exposure metrics are input into dose-response functions to generate changes in welfare effects.

The results of the air quality modeling described in the previous section were used as inputs to determine changes in human health effects across the continental United States. Consistent with EPA regulatory impact analyses such as the Clean Air Interstate Rule (CAIR), this analysis focused on the health effects linked to two pollutants, fine ambient particulate matter ($PM_{2.5}$) and ambient ozone. (EPA 2005)

The air quality modeling results described in Section 3.2 were processed for use in the Environmental Benefits Mapping and Analysis Program (BenMAP), an EPA tool that combines air pollution monitoring data, air quality modeling data, census data, and population projections to calculate a population's potential exposure to ambient air pollution (Abt 2005). Appendix G contains the specific health impact functions and baseline incidence rates used in BenMAP to perform the health impact analysis. Further information on the methodologies used for this health impact analysis and EPA benefit analyses can be found in the PM NAAQS Regulatory Impact Analysis or the Ozone NAAQS Regulatory Impact Analysis (EPA 2006; EPA 2008).

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[32] Note that the uncertainties in the primary PM estimate (footnote 3), and the uncertainties in the $SO_2$ inventory level (footnote 4) were found to result in changes in the health impact assessment that fall within the quoted 90% confidence interval for yearly mortality incidences, and thus do not add a substantial amount of uncertainty to the estimate of health impacts.

[33] For this study, the "baseline" inventory included EDMS aircraft emissions and 2001 NEI non-aircraft emissions, the "post-control" inventory was that with all aircraft emissions removed.

The national results of the health impact analysis appear below in Table 3.12. The mean incidence reduction for the continental U.S. represents the estimated change in number of yearly health incidents if all of the aircraft emissions were to be removed.

**Table 3.12:** Health effects due to aircraft emissions, continental United States.

| Health Effect | Yearly Baseline Incidence[34] | Yearly Mean Incidence Due to Aircraft Emissions[35] (90% Confidence Interval) |
|---|---|---|
| **PM-Related Endpoints:** | | |
| Premature mortality[36] | | |
| Adult, age 30 and over | 2,300,000 | 160 (64 – 270) |
| Infant, age <1 | 9,000 | 0 (0 – 1) |
| Chronic bronchitis (adult, age 27 – 99) | 630,000 | 110 (20 – 200) |
| Non-fatal myocardial infarction (adult, age 18 - 99) | 780,000 | 290 (160 – 430) |
| Hospital admissions–respiratory (adult, age 0 – 64)[37] | 640,000 | 26 (12 – 39) |
| Hospital admissions–respiratory (adult, age 65 – 99)[38] | 570,000 | 12 (6 – 16) |
| Hospital admissions–cardiovascular (adult, age 18 – 64)[39] | 1,400,000 | 24 (14 – 34) |
| Hospital admissions–cardiovascular (adult, age 65 – 99)[40] | 2,500,000 | 45 (29 – 60) |
| Emergency room visits for asthma (age 0 - 17) | 730,000 | 140 (81 – 194) |
| Acute bronchitis (children, age 8-12) | 880,000 | 340 (-12 – 700) |
| Upper respiratory symptoms (asthmatic children, age 9-11) | 87,000,000 | 2,700 (860 – 4,600) |

[34] We present total baseline incidence for each health effect. Baseline incidence represents all cases of a particular health effect in a specific population (*for all causes, not just air quality*), defined by the epidemiological study from which the health effect measure is derived.

[35] Mean incidences for the continental U.S. are rounded to the nearest whole number and to two significant figures where applicable. These represent the estimated changes in yearly health incidences due to modeled aircraft emissions.

[36] Adult premature mortality based upon the Pope et al., 2002 American Cancer Society cohort study. Infant premature mortality based upon studies by Woodruff, Grillo, and Schoendorf, 1997

[37] Respiratory hospital admissions ages 0 – 64 for PM include admissions for chronic obstructive pulmonary disease (COPD) and asthma.

[38] Respiratory hospital admissions ages 65 – 99 for PM include admissions for COPD and pneumonia.

[39] Cardiovascular admissions include cardiovascular ailments except for myocardial infarctions.

[40] Cardiovascular admissions include cardiovascular ailments and subcategories for ischemic heart disease, dysrhythmia and heart failure. Myocardial infarctions not included.

| Health Effect | | Yearly Baseline Incidence[34] | Yearly Mean Incidence Due to Aircraft Emissions[35] (90% Confidence Interval) |
|---|---|---|---|
| Lower respiratory symptoms (asthmatic children, age 7-14) | | 14,000,000 | 3,700 (1,800 – 5,700) |
| Asthma exacerbation (asthmatic children, age 6-18) | | 130,000,000 | 3,300 (370 – 9,600) |
| Work loss days (adults, age 18-64) | | 380,000,000 | 23,000 (20,000 – 25,000) |
| Minor restricted activity days (MRADs) (adults, age 18-64) | | 1,400,000,000 | 130,000 (110,000 – 150,000) |
| **Ozone-Related Endpoints:** | | | |
| Premature Mortality[41] (all ages) | | | |
| Bell et al. (2004) | | 930,000 | 0 (0 – -1) |
| Meta-Analyses | Bell et al. (2005) | 1,000,000 | -2 (-1 – -2) |
| | Levy et al. (2005) | 1,000,000 | -2 (-2 – -2) |
| | Ito et al. (2005) | 930,000 | -2 (-1 – -2) |
| Hospital admissions–respiratory causes (adults, age 65 – 99)[42] | | 450,000 | -3 (-5 – 0) |
| Hospital admissions–respiratory causes (children, age 0 – 1)[43] | | 180,000 | -6 (-3 – -10) |
| Emergency room visits for asthma (age 0 – 99) | | 710,000 | -4 (-12 – 0) |
| Minor restricted activity days (MRADs) (adults, age 18 – 65) | | 570,000,000 | -7,500 (-3,800 – -11,000) |
| School absence days (children, age 6 – 11) | | 3,200,000,000 | -2,800 (-4,700 – -990) |

The results of the BenMAP health impact analysis indicate that ambient particulate matter related to emissions of $NO_x$, $SO_x$ (both gaseous precursors to secondary PM) and primary $PM_{2.5}$ causes almost all of the total aircraft-related health impacts, including all of the mortality incidences. Approximately 160 yearly incidences of premature mortality were estimated due to ambient particulate matter exposure attributable to aircraft emissions (with a 90% confidence

[41] Consistent with the methodology used in the 2007 Ozone NAAQS Regulatory Impact Analysis, ozone mortality estimates are included with the recognition that the exact magnitude of the effects estimate is subject to continuing uncertainty. Effect estimates from Bell et al. (2004) as well as effect estimates from three meta-analyses are given. An effect estimate of zero is also given to account for the possibility that there is no causal association between ozone and mortality.

[42] Respiratory hospital admissions for ozone include admissions for all respiratory causes and subcategories for COPD and pneumonia.

[43] Respiratory hospital admissions for acute respiratory diseases.

interval of 64-270 yearly incidences).[44] The adverse health effects for aircraft emissions were localized to a small number of counties; 43% of the health impacts occurred in 10 counties, 5 of which are in southern California. The 10 counties with the highest PM-related mortality incidences due to aircraft emissions appear in Table 3.13. A list of the twenty counties with the highest PM-related mortality incidences can be found in Appendix H.

**Table 3.13:** Ten counties with highest PM-related mortality incidences[45]

| Rank | County | State | Incidences | Percent of Total |
|---|---|---|---|---|
| 1 | Los Angeles | CA | 28 | 18 |
| 2 | Orange | CA | 8 | 5 |
| 3 | San Diego | CA | 6 | 3 |
| 4 | San Bernardino | CA | 5 | 3 |
| 5 | Cook | IL | 5 | 3 |
| 6 | Riverside | CA | 4 | 3 |
| 7 | Nassau | NY | 4 | 3 |
| 8 | Alameda | CA | 4 | 2 |
| 9 | Queens | NY | 3 | 2 |
| 10 | Kings | NY | 3 | 2 |
| | All other counties | | 94 | 57 |

The results of the health impact analysis also indicated that ozone exposure related to aircraft emissions, in comparison to $PM_{2.5}$ exposure related to aircraft emissions, produces small health impacts. This is expected due to the small changes in ambient ozone concentrations presented in Section 3.2.

As we also described in Section 3.2, due to the complex photochemistry of ozone production, reductions in $NO_x$ emissions (from aircraft and other sources) lead to both the formation and destruction of ozone, depending on the relative quantities of $NO_x$, VOCs, and ozone catalysts such as the OH and $HO_2$ radicals. In areas dominated by fresh emissions of $NO_x$, ozone catalysts are removed via the production of nitric acid, which slows the ozone formation rate. Because $NO_x$ is generally depleted more rapidly than VOCs, this effect is usually short-lived and the emitted $NO_x$ can lead to ozone formation later and further downwind. The terms "$NO_x$ disbenefits" or "ozone disbenefits" refer to the ozone increases that can result from the removal of $NO_x$ in these localized areas. According to the North American Research Strategy for Tropospheric Ozone (NARSTO) Ozone Assessment (NARSTO, 2000), these disbenefits are generally limited to small regions within specific urban cores (with relatively high population density) and are surrounded by larger regions in which $NO_x$ reductions are beneficial. The ozone-related health impacts shown in Table 3.12 are all negative (e.g. aviation emissions lead to fewer health incidences). This is because the ozone disbenefits due to aircraft emissions occur in regions of higher population than the regions of ozone benefits due to aircraft emissions. In addition, as discussed earlier, $NO_x$ emissions at low altitude also react in the atmosphere to form secondary particulate matter ($PM_{2.5}$), particularly ammonium nitrate, and contribute to regional haze. Thus, in areas or regions with ozone disbenefits, $NO_x$ reductions will still help reduce secondary PM levels and regional haze.

[44] Note that the uncertainties in the primary PM estimate uncertainties and the errors in the $SO_2$ inventory level were found to result in changes in the health impact assessment that fall within the quoted 90% confidence interval for yearly mortality incidences, and thus do not add a substantial amount of uncertainty to the estimate of health impacts.
[45] Yearly incidences of premature mortality from $PM_{2.5}$ based on upon the Pope et al., 2002 American Cancer Society cohort study. Incidences rounded to the nearest whole number and to two significant figures where applicable. Total refers to total nationwide premature mortality incidences from aviation-related $PM_{2.5}$ exposure (approximately 160).

It is important to note that aircraft-related $NO_x$ emissions modeled on their own, as was done for this analysis, may yield a different ambient ozone concentration than if $NO_x$ emission reductions are modeled in combination with other required, planned, or future $NO_x$ emission controls. For example, California State Implementation Plan (SIP) modeling indicates that with a combined program of national and local controls, Southern California can reach ozone attainment by 2024 through a mixture of substantial $NO_x$ (and VOC) reductions (SCAQMD, 2007). In areas prone to ozone disbenefits, our ability to draw conclusions about the future air quality and health impacts of a particular source of $NO_x$ is limited because our analytical approach does not reflect yet-to-occur emission reductions in these areas. Within a region such as Southern California, we expect that future $NO_x$ reductions from SIP-based controls will lead to fewer ozone disbenefits than the disbenefits modeled here. More detailed information about the air quality modeling conducted for this analysis is contained in Appendix F.

**Interpreting the PM Mortality Results for Aviation**

The health impacts from aircraft LTO emissions should be viewed in the context of the total health impacts of poor local air quality to avoid misperceptions of the relative risks associated with aircraft emissions. People frequently do not accurately perceive risks—such misperception of risk is not unique to aviation or air quality health impacts. However, the characteristics of aviation are such that the perceived risks (e.g. of safety-related fatalities) are often higher than the true risks; and the characteristics of local air quality health impacts are such that the perceived risks are often lower than the true risks. This is in part because people have a strong fear of catastrophic fatal events they cannot control, such as the crash of an airplane, and are less afraid of risks caused by events that occur over a long period of time, such as the chronic effects of poor air quality (cf. Slovic 2002).

Although the health impacts of aviation estimated by our study are important, it is very likely[46] that they constitute less than 0.6 percent of the total adverse health impacts due to poor local air quality from all sources in the United States. A detailed analysis of the total health effects due to poor air quality in the United States was not made for this study, but other sources and analyses suggest that the total number of yearly premature deaths due to poor air quality in the U.S. is very likely greater than 25,000 as described below.

EPA has finalized three mobile source air quality rules that mandate cleaner fuels (gasoline and diesel) as well as engine standards to control pollutant emissions such as direct PM and $NO_x$. In 2000, EPA finalized the Tier 2 rule, regulating the sulfur content in gasoline and setting vehicle and engine standards for passenger cars and trucks (EPA 1999). In 2000 and 2004, EPA finalized the Heavy Duty Diesel Rule and the Nonroad Diesel Engine Rule, respectively (EPA 2000, EPA 2004). Each of these mobile source rules is projected to control a significant fraction of the PM-related emissions associated with diesel and gasoline engines and fuels. It was projected that in 2030, the Tier 2 rule will reduce $NO_x$ emissions by 3.71 million metric tons, reduce total VOC emissions by 0.73 million metric tons, and reduce $SO_x$ emissions by 0.25 million metric tons. It was projected that in 2030, the Heavy Duty Diesel Rule will reduce vehicle $PM_{10}$ emissions by 0.09 million metric tons, $NO_x$ emissions by 2.25 million metric tons, and NMHC emissions by 0.07 million metric tons. It was also projected that in 2030, the Nonroad Diesel Engine Rule will reduce PM emissions by 0.12 million metric tons, reduce $NO_x$ emissions by 0.67 million metric tons, reduce VOC emissions by 0.03 million metric tons, and reduce $SO_x$ emissions by 0.34 million metric tons. By comparison, the EDMS aircraft emissions in this study *totaled* 0.01 million metric tons of $SO_x$, 0.08 million metric tons of $NO_x$, 0.04 million metric tons of VOC, 0.03 million metric tons of NMHC, and less than 0.01 million metric tons of primary PM. In terms of health impacts, EPA estimated that when fully implemented, these three mobile source programs will together prevent

[46] Greater than 90% probability based on judgment of the authors. This convention is based on that utilized by the Intergovernmental Panel on Climate Change (IPCC 2007), where "very likely" represents a 90 to 99% probability of an occurrence.

approximately 25,000 PM-related premature mortalities each year. The regulatory impact analyses for these rules used a health impacts methodology similar to that utilized in this study, and thus, may be used to put the health impacts we estimate for the commercial aircraft LTO inventory in context. (EPA 1999; 66 Fed. Reg. 5002, January 18, 2001; 69 Fed Reg. 38958, June 29, 2004).

Other studies corroborate the overall magnitude of health impacts from air pollution in the U.S. For example, Cohen et al. (2004) estimated that in the year 2000, urban PM accounted for approximately 28,000 premature mortalities for U.S. cities with a population of 100,000 or more. Furthermore, the Clean Air Task Force, using emissions projections for 2010, estimates that diesel soot is responsible for approximately 21,000 annual deaths in the U.S., and power plant emissions are responsible for approximately 24,000 annual deaths in the U.S. (Hill, 2005).

Our purpose in comparing the health impacts of aircraft LTO emissions to the larger total health impacts of poor local air quality from all sources in the United States and elsewhere is not to dismiss these aircraft impacts as being unimportant. Indeed, one of the challenges of improving poor local air quality is that it results from many small sources acting in concert. Still, we provide these overall impact estimates so that the risks imposed by aircraft LTO emissions can be understood in the context of the overall risks associated with poor local air quality.

### 3.4 Lead Emissions from Piston Engine Aircraft

In 1978 EPA established a National Ambient Air Quality Standard for lead of 1.5 micrograms per cubic meter, as a maximum quarterly average as measured in total suspended particulates. Currently, there are two areas officially designated as non-attainment for the lead NAAQS: Herculaneum in Jefferson County, Missouri and East Helena Area portion of Lewis and Clark Counties, Montana.[47] The main lead emission source associated with the East Helena Area closed in early 2001 and monitoring ceased in late 2001 so that location is not discussed here.

While commercial and military jet engine fuel contains only trace amounts of lead, tetraethyl lead is commonly added to aviation gasoline used in piston-engine powered, general aviation aircraft. Exhaust emissions from these piston-engine powered aircraft that operate on leaded aviation gasoline (avgas) contribute to levels of ambient lead. The most commonly used leaded avgas contains 2.12 grams of lead per gallon of fuel. In 2002 approximately 280 million gallons of aviation gasoline were supplied to the U.S. (DOE Energy Information Administration 2006) contributing an estimated 565 metric tons of lead to the air and comprising 46 percent of the EPA year 2002 National Emissions Inventory for lead. The 2002 NEI includes an analysis of the airport-specific contribution of lead for 3,410 airports located throughout the United States (EPA 2007a). These lead emissions are allocated to each airport based on its percentage of piston-engine operations nationwide. These operations for 2002 can be found in the Terminal Area Forecast system, which is the official forecast of aviation activity at the Federal Aviation Administration facilities. Airport-specific lead emissions estimates in the NEI include lead emitted during the entire flight (i.e., not limited to the landing and take-off cycle and local operations).[48] At this time, this allocation method for lead emissions was used here to account for all lead emissions associated with avgas use. Allocating lead emissions to airports from operations outside the landing-takeoff cycle and local flying operations has a tendency to overstate the local emissions near airports because longer duration (e.g., itinerant) flights emit lead at altitude as well as in the local flying area near the airport.

While there are no airports in the Herculaneum NAA (the city limits of Herculaneum), there are seven registered

[47] http://www.epa.gov/air/oaqps/greenbk/lnca.html
[48] Lead emissions from general aviation are calculated as the product of the fuel consumed, the concentration of Pb in the fuel and the factor 0.95 to account for an estimated 5 percent of Pb being retained in the engine and/or exhaust system of the aircraft. The estimate of 5 percent Pb retention was derived from measurements of lead in used oil samples and a factor for exhaust system retention from other literature.

airports within the twenty mile local flying area around Herculaneum where general aviation aircraft operate. A proposed revision to Missouri's SIP characterizes general aviation aircraft lead emissions as "background." This characterization seems appropriate since emissions from piston-powered aircraft operating on leaded aviation gasoline are expected to contribute to ambient concentrations of lead entering the Herculaneum NAA both from landing and take-off at local airports as well as piston-engine powered aircraft flying through the NAA. However, they are not necessarily the cause of the non-attainment problem.

EPA conducted a review of the lead NAAQS which has included the assessment of health and welfare effects of lead documented in the 2006 Air Quality Criteria Document for Lead (available at www.epa.gov/ncea). Integral to the NAAQS review were decisions regarding the adequacy of the current standard for lead and whether the Agency should retain or revise it. The final revisions to the lead NAAQS were published in the Federal Register on November 12 of 2008. 73 FR 66964. Additional information about the review is available at: http://www.epa.gov/ttn/naaqs/standards/pb/s_pb_index.html.

# 4 Opportunities to Enhance Fuel Efficiency and Reduce Emissions: Benefits of Reducing Airport Delays

Delay is often the result of the inability of the air transportation system to meet operational demands. The imbalance between demand and the timely operation of flights can be caused by over-scheduling of the airport, maintenance and airline operating inefficiencies, weather events, or air traffic management (ATM) programs that hold planes in a location because of congestion or weather elsewhere. Emissions and fuel use are tied to the amount of time spent in each phase of aircraft operations, and system delays can cause longer idle and taxi times, and in turn, increase fuel burn and ground level emissions.

This study investigates ways that ATM inefficiencies result in unnecessary fuel burn and air emissions, caused by factors such as aircraft idling at airports. The relationship between delay and emissions was examined to develop an estimate of the emissions reductions and improvements in fuel burn achievable in the absence of ground delays.

Note there are numerous opportunities to reduce aircraft fuel consumption and emissions beyond those associated with improving performance on the surface or in the vicinity of the airport (e.g. below 3,000 feet). These include enroute operational initiatives, the use of alternative fuels, improvements in aircraft and aircraft engine design, and policy options to promote these advances. Further research into ways to promote fuel efficiency should include an investigation of these opportunities in addition to further assessment of operational initiatives.

## 4.1 The Relationship between Delay and Emissions

Emissions are related to the amount of fuel consumed during each mode of aircraft operations. For ground delays this relationship is complicated by the fact that for some delays, airlines switch to APUs or use single-engine taxi rather than taxiing using all engines. Due to the high uncertainty associated with predicting when an aircraft may switch to APU power or to single-engine taxiing, full engine taxiing was modeled, even for longer delays. Therefore, the results of this analysis provide an upper bound for the effects of delays.

The relationship between delay and emissions is influenced by various factors including the fleet mix at the airport and the particular pollutant that is being evaluated. To provide a better understanding of these factors and to further explore the relationship between delay and emissions, we focus on the relationship between two metrics: taxi-out time and the mass of each pollutant emitted for specific aircraft types at three airports.

**Scoping & Airport Selection**

The delay and emissions analysis focused on the six-week period from November 15$^{th}$ through December 27$^{th}$, 2005, one of the busiest travel times of the year. While other time periods were considered, including those in which spring storms brought delays to the system, the November-December timeframe was chosen to focus more on volume-related congestion rather than delay that may be attributed to particular weather events—although the two are interdependent.

While the baseline inventory described in Section 3.1 was created using both instrument flight rules (IFR) and visual flight rules (VFR) operations, only IFR traffic was considered for the delay and emissions analysis, as VFR operations were assumed to operate at maximum efficiency.[49] Of the 325 airports selected for the creation of the baseline

[49] Instrument Flight Rules (IFR) are a set of procedures for operating aircraft where it is assumed that the pilot may not be able to see outside the aircraft. The majority of commercial flights operate under IFR. Visual Flight Rules (VFR) apply to flights in which it is assumed the pilot can use visual references to the ground and other aircraft. VFR flights are mainly performed by general aviation aircraft operating in good weather conditions.

inventory, three airports were studied in more depth to evaluate the relationship between delay and emissions. These airports were chosen because they represent a spectrum of operational delays and because there are a variety of aircraft types operating at these airports:

- Hartsfield-Jackson Atlanta International Airport (ATL) is one of the busiest airports in the National Airspace System (NAS), with over 480,000 annual operations, and is part of a large air traffic hub.[50] Almost all of these operations are commercial service flights. An assessment of delays from November 15th through December 27th at ATL indicated delays due to large numbers of departures during particular peak times of operation.

- Newport News/Williamsburg International Airport (PHF) has approximately 17,000 annual IFR flights and belongs to a small air traffic hub. This airport also serves a significant general aviation population with almost 100,000 VFR flights each year. PHF is a relatively uncongested airport that operates well below capacity. Congestion at other destination airports was the likely source for delayed flights departing from PHF during the November-December study timeframe. PHF was investigated because it contributes a relatively large percentage of emissions to Poquoson County's emissions inventory.

- Newark Liberty International Airport (EWR) is a busy airport with approximately 225,000 operations and is a large hub airport. Delays that occurred at EWR during the study timeframe were indicative of the departure demand generally exceeding the available departure capacity for the airport for almost all times of operation.

Differences in emissions were complicated by the different fleet mixes at these three airports, so two aircraft types were examined for the analysis: CRJ-200s at airports ATL and PHF, and B737s at ATL and EWR. There were not enough B737 operations at PHF to make a meaningful comparison. Additionally, there were very few CRJ-200 operations at EWR.

**The Relationship between Taxi-Out Time and Emissions**

The relationship between taxi-out time and total emissions for the individual aircraft types was examined at the three study airports. Figure 4.1 shows the relationship between taxi-out time (in minutes) and pollutants emitted (in grams per operation normalized by the departure mass in metric tons) for Boeing 737's at ATL. The variability in slope (most visible for CO) is due to two elements of the aggregations: Boeing 737's were aggregated together regardless of the specific type of 737 and the airframes have different engines that lead to different emission rates.

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[50] According to U.S. Department of Transportation Bureau of Transportation Statistics, *Airport Activity Statistics of Certificated Air Carriers - Summary Tables - twelve months ending December 31, 2000* (http://www.bts.gov/publications/airport_activity_statistics_of_certificated_air_carriers/2000/index.html) and the BTS Air Traffic Hubs 2007 map (http://www.bts.gov/programs/geographic_information_services/maps/hub_maps/2007/html/map.html), an air traffic hub is a geographic area that enplanes at least 0.05% of all enplaned passengers in the United States. A hub may have more than one airport in it. This definition of hub should not be confused with the definition used by the airlines in describing their "hub-and-spoke" route structures. Large air traffic hubs serve 1 percent or more of the total enplaned passengers in all services and all operations for all communities within the 50 states, the District of Columbia, and other U.S. areas, while medium hubs serve 0.25% to 0.99% and small hubs serve 0.05% to 0.24%.

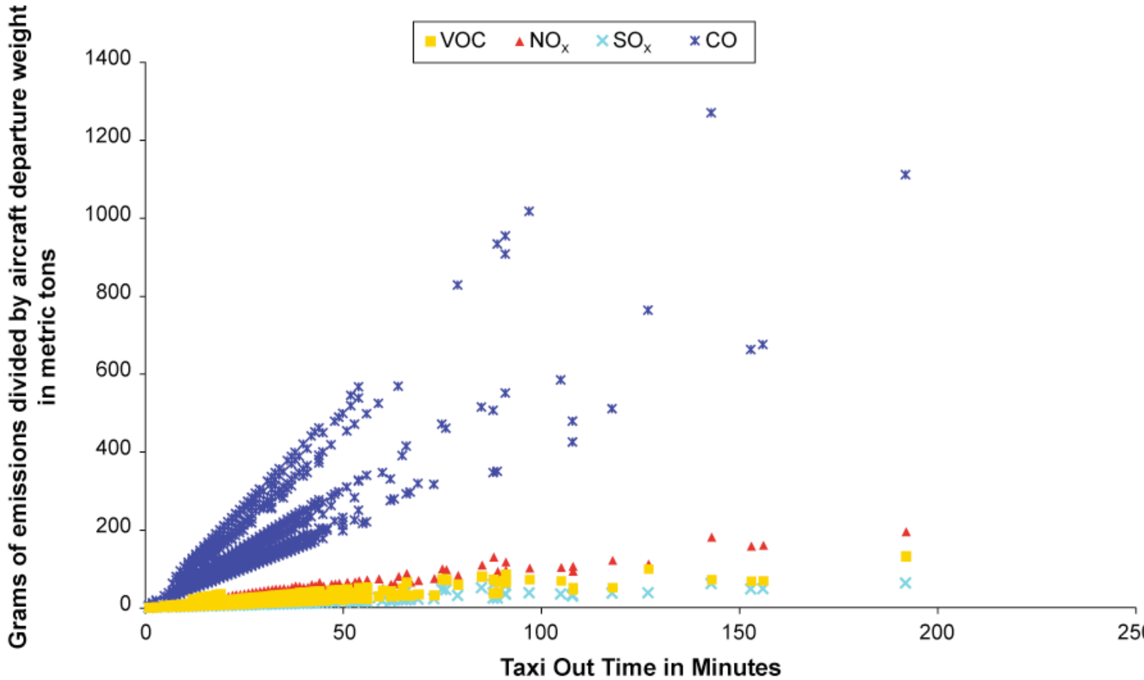


**Figure 4.1:** Taxi-Out Emissions of Boeing 737s at ATL Mapped to their Corresponding Taxi-Out Time. Grams of pollutant per operation are normalized by the mass of the aircraft in metric tons.

Similar results were produced for the aircraft types studied at EWR and PHF, each showing a similar relationship. The relationship between delay and emissions provides a common metric for examining the effects of delays that result from a range of sources. However, the appropriate mitigation techniques are directly tied to the particular source of delay. Examining the patterns of delay at the three airports used for the analysis, suggests different initiatives may be helpful for reducing emissions. Figure 4.2 through Figure 4.4 show the patterns of delay found at each of the airports examined for the analysis. Section 5 will discuss initiatives that target different sources of delay.

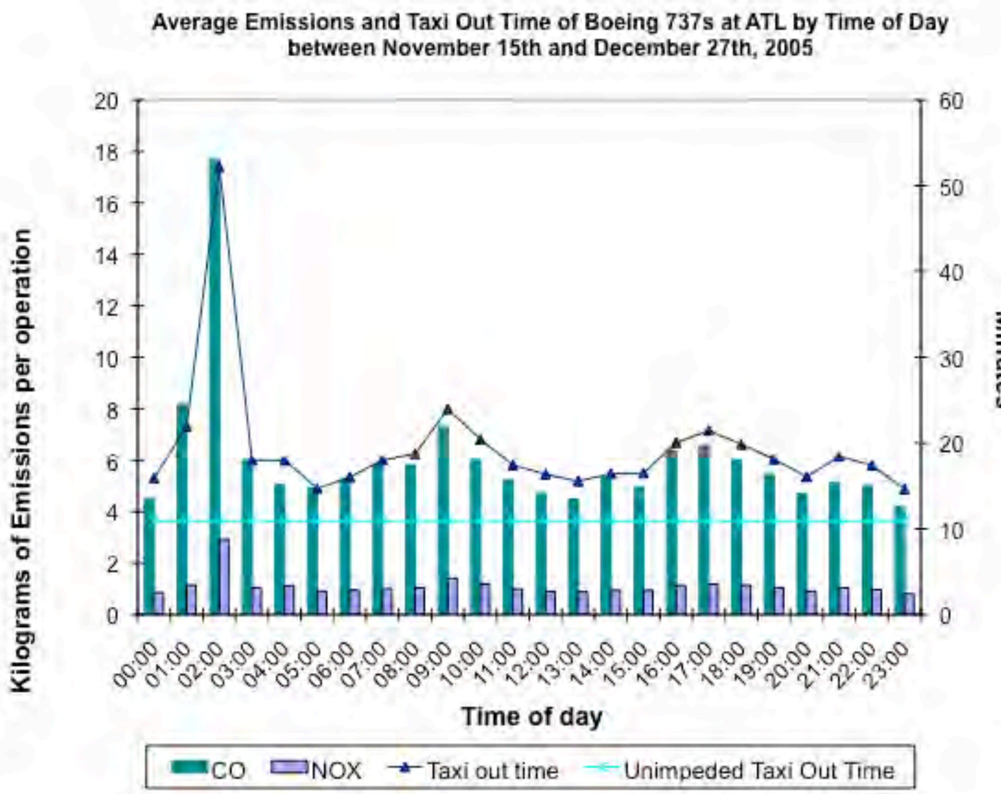


**Figure 4.2:** Average carbon monoxide (CO) and $NO_x$ emissions per operation as function of time of day for Boeing 737 aircraft at ATL averaged over the period between November 15th and December 27th, 2005. Increased emissions are found around 9 o'clock in the morning and between 4pm and 8pm in the evening, corresponding with increases in taxi out times. This pattern of delay and emissions is related directly to the increases in the number of departure operation during these times.[51]

[51] There were five flights that departed at 2am; one of these flights experienced a three-hour delay.

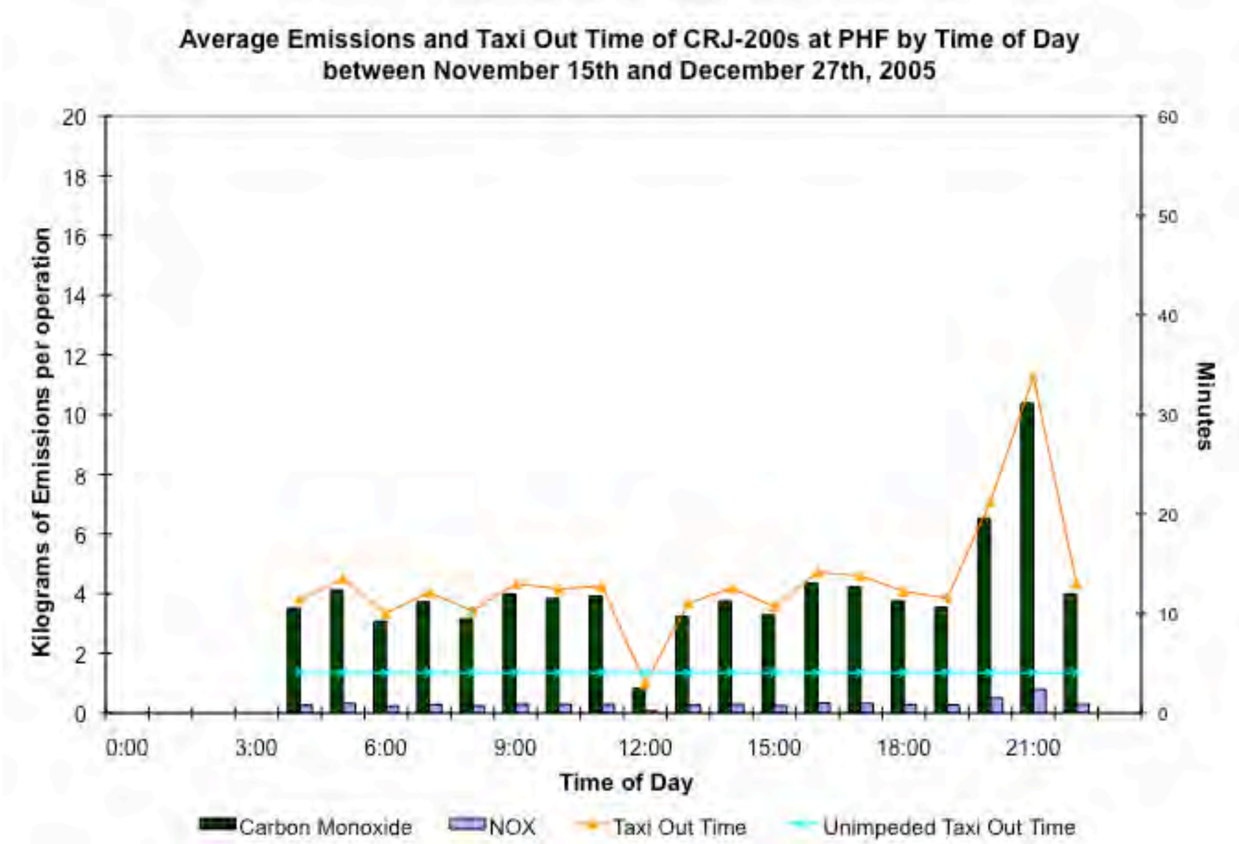


**Figure 4.3:** Average carbon monoxide (CO) and $NO_x$ emissions per operation as function of time of day for CRJ-200 aircraft at PHF averaged over the period between November 15th and December 27th, 2005. There is a consistent range of taxi out times between 10 and 15 minutes with the exception of three hours of operation. At noon there was only one operation. The delays at 8:00 PM are unlikely to be the result of congestion since the capacity at this airport is 55 operations per hour and during these two hours of the day only 32 aircraft departed over the six-week period. Congestion at other destinations likely delayed flights from PHF.

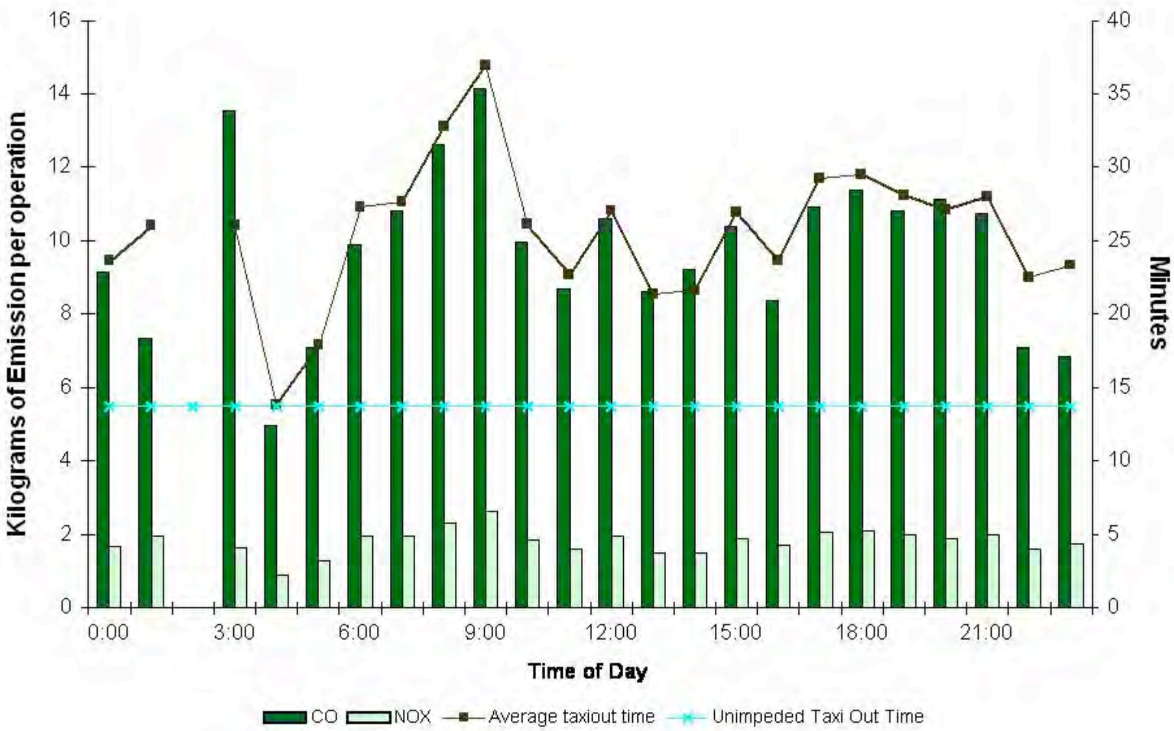


**Figure 4.4:** Average carbon monoxide (CO) and $NO_x$ emissions per operation as function of time of day from Boeing 737's at EWR averaged over the period between November 15th and December 27th, 2005. This delay pattern is more indicative of the departure demand generally exceeding the available departure capacity for the airport, with the exception of the time period between 4:00 AM and 6:00 AM, where the taxi-out times are below 20 minutes and very few flights depart relative to the rest of the day.

## 4.2 Potential Benefits from Reduced Ground Delays

Ideally, aircraft would leave the gate, taxi, take off, fly to their destinations, land, and taxi in without experiencing delay. To understand the potential reductions in local emissions and fuel use for such an ideal system, the pool of benefits achievable was estimated by comparing to a case with unimpeded taxi times.

The baseline inventory discussed in Section 3.1 was created using reported taxi times obtained from the Bureau of Transportation Statistics (BTS). BTS provides operations data that list taxi times for air carriers carrying more than 1% of the total passengers. BTS provided data for 113 of the 148 commercial service airports in non-attainment areas. (These 113 airports are listed in Appendix I.) Twenty-six minutes of taxi time per LTO cycle was conservatively assumed for those airports without BTS data based on the ICAO test procedure. To measure the effects of delays, only the 113 airports with BTS data were used in the comparison. As a basis for comparison, unimpeded taxi times were gathered from the Aviation System Performance Metrics (ASPM) for 75 airports.[52] For the remaining airports, unimpeded taxi times were calculated from the airport layout.

EDMS was used to compute total emissions and fuel consumed (see Section 3.1) and the outputs from the two

[52] Aviation System Performance Metrics provides information on individual flight performance and airport efficiency. See http://aspm.faa.gov/getInfo.asp.

scenarios were compared. Estimates of fuel consumed and mass of CO, hydrocarbons, $NO_x$, $SO_x$, and PM were compared and the difference between the values for each scenario was used as an estimate of the reductions possible with the absence of delay. Figure 4.5 shows fuel savings as a percentage of total fuel consumed for the LTO portion (below 3,000 feet above ground level) of all operations.[53] Figure 4.6 shows the metric tons of fuel saved for the 113 airports.

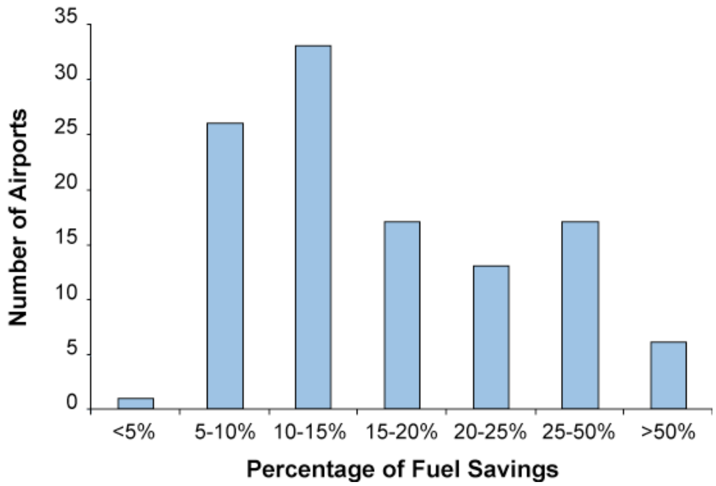


**Figure 4.5:** Percentage savings in LTO fuel use with the absence of ground delays at the 113 selected airports. With fewer operations and less fuel consumed, smaller airports are able to achieve large percentage changes when comparing the operational baseline to the no delay scenario. While at larger airports with more delay and operations, small percentage changes in the fuel consumption result in large quantities of fuel saved.

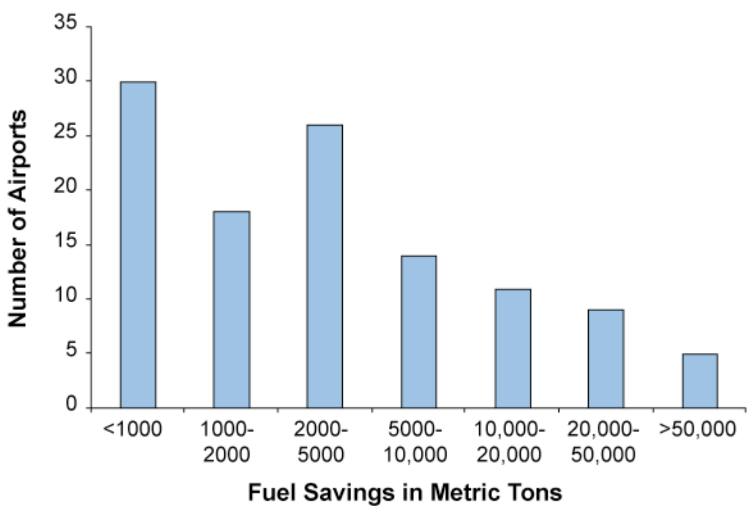


**Figure 4.6: Metric tons of fuel saved with the absence of ground delays for the 113 selected airports**[54]

The smallest potential savings for the 113 airports was approximately 23 metric tons over a year. The largest

[53] Taxi times were adjusted for IFR flights only, but total fuel use and emissions estimates include VFR traffic as well. VFR traffic was assumed to operate as efficiently as possible.
[54] Metric tons of kerosene-based fuel can be converted to gallons by multiplying by 326.13.

potential savings was over 86,000 metric tons. Overall 17% of the fuel burned below 3,000 feet could be saved with no taxi-in or taxi-out delay. This translates to 986,000 metric tons of fuel, approximately 320 million gallons per year out of 1.8 billion gallons (6 million metric tons) of fuel burned below 3,000 feet. 320 million gallons is approximately 1% of the 25.7 billion gallons of jet fuel used in 2005.

Table 4.1 shows how these fuel reductions translate into emissions reductions. Taxi-in and taxi-out are the only phases of the LTO cycle altered, but the percentage change in total LTO emissions is given in Table 4.1. From 260 metric tons of $PM_{2.5}$ to 28,071 metric tons of CO could be saved with no taxi-in or taxi-out delay.[55] A total of 42,668 metric tons of emission reductions is an overall 15% reduction in LTO emissions.

**Table 4.1:** Emissions reductions at selected airports with no ground delay[56]

| Pollutant | Mass Reduction (metric tons) | Percentage Reduction |
|---|---|---|
| **Carbon Monoxide** | 28,071 | 22% |
| **Non-Methane Hydrocarbons** | 3,978 | 16% |
| **Volatile Organic Carbons** | 4,266 | 16% |
| **$NO_x$** | 4,882 | 7% |
| **$SO_x$** | 1,211 | 17% |
| **$PM_{2.5}$** | 260 | 15% |
| **Fuel** | 985,954 | 17% |

[55] Not all engines have ICAO smoke numbers (and thus, nonvolatile PM emissions could not be computed for these engines). PM emissions from aircraft APUs were not computed.
[56] A list of the 113 airports used in the analysis of ground delays is shown in Appendix I.

# 5 Ways to Promote Fuel Conservation: Initiatives Aimed at Improving Air Traffic Efficiency

Section 4 describes the effects that ground delays can have on emissions and fuel burn. This study investigated ways to reduce these effects by promoting greater operational efficiency. To identify methods for improving air traffic efficiency, an examination of several surface and airspace ATM operational initiatives was conducted. This section provides illustrative examples of the reductions in ground-level emissions and fuel consumption that can be achieved by implementing specific ATM initiatives.

Eleven ATM initiatives were surveyed for the study, and four were chosen for modeling based on available data and publicly available assessments of the initiatives. The initiatives surveyed for this section have broad applicability in reducing delay throughout the system, and our estimates serve only as representative examples of the magnitude of their effects. However, understanding the full system-wide impact of multiple, interacting initiatives in different phases of maturity was beyond the scope of this study. Further research in this regard is recommended.

The 11 initiatives examined span a range of strategies and are described below:

- *New and extended runways* – New runways create capacity at congested airports and relieve delay by serving the already existing demand for flights. Runway extensions allow larger aircraft to operate and may allow more operations of these flights and therefore reduce delay.
- *Airport Surface Detection Equipment, Model X (ASDE-X)* – Airport surface-surveillance data with better accuracy, faster update rate, and stronger reliability can improve airport safety and efficiency in all weather conditions by giving the controllers better knowledge of aircraft locations on the ground.
- *Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS)* – This initiative aims to avoid capacity loss when weather or other environmental conditions like haze or smoke force an airport to use instrument approach operations. This is expected to allow airports to continue visual arrival rates under poor weather conditions, and reduce the frequency and duration of instrument approach operations.
- *Integrated Terminal Weather System (ITWS)* – This is an ATM tool that provides air traffic managers, controllers, and airlines with more accurate, easily understood, and immediately useable graphical weather information and hazard alerts on a single, integrated color display. It is anticipated that, among other effects, this will enable coordination of the movement of traffic through alternate arrival/departure routes and will result in overall increases in capacity and reduction of delays.
- *Precision Runway Monitor (PRM)* – PRM consists of enhanced surveillance capabilities and procedures to support simultaneous approaches to closely spaced parallel runways, with the goal of increasing throughput and reducing delays.
- *Departure Flow Management (DFM) and Departure Spacing Programs (DSP)* – DFM and DSP provide ATM with the capability to automate coordination of departure releases into congested airspace, with the goal of improving efficiency and reducing delays.
- *Schedule De-Peaking* – This refers to measures that adjust demand for departures and arrivals at congested airports to ensure that the demand does not exceed capacity. The objective is to reduce delays associated with operating airports at levels at or above capacity.
- *RNAV/RNP Arrivals and Departures* – RNAV (Area Navigation) refers to a method of navigation that enables aircraft to fly on more optimal flight paths within the coverage of reference navigation aids and/or within the limits of the capability of self-contained systems (Flight Management System [FMS]- or Global Positioning System [GPS]-based). RNP (Required Navigation Performance) refers to RNAV operations within navigation containment and monitoring, enabling the aircraft navigation system to monitor its achieved navigation

performance within specified tolerances.

- *More efficient de-icing procedures* – This refers to procedures that enable de-icing activities to be performed with less waiting time, fewer instances of repeated de-icing, etc.
- *Airspace Flow Program* – This is a new form of ATM control activity that applies the concept of a Ground Delay Program (GDP) to airspace regions whose capacity has been reduced due to bad weather or other factors. The objective is to balance demand and capacity for these airspace regions, and to perform this balancing with more specificity and less delay than was possible using GDPs.
- *Continuous Descent Arrivals (CDA)* – This refers to approach procedures that enable aircraft to use lower power settings during the approach to the airport therefore reducing noise and emissions.

**Choice of Metrics and Airport Selection**

Airports were selected based on available radar-based flight path data for the months of April 2005 and April 2006. Given the study's emphasis on ground-level emissions and fuel burn, taxi time was chosen as the appropriate metric to evaluate initiatives. Delays associated with departure taxi operations are generally longer than those associated with arrivals; thus, taxi-out time for departing flights was selected as the primary metric for matching airports to initiatives.[57]

By using BTS on-time performance data, taxi-out times were extracted and analyzed for Operational Evolution Partnership (OEP, formerly Operational Evolution Plan) airports that reside in non-attainment areas.58 Taxi-out times were reviewed in 15-minute bins to identify potential periods of airport or terminal-area congestion. Notable peaks in taxi-out times were identified.

Figure 5.1 shows the variation in taxi-out times for Cleveland Hopkins Airport (CLE[59]) for the month of April 2005.

[57] It is important to note that ATM initiatives effect other phases of flight although the focus of this study was on taxi times.
[58] The OEP is a rolling ten-year plan to address capacity and delay problems through the NAS by focusing on selected airports, with these airports changing over the years as various issues are corrected by the FAA. At the time of this research all OEP airports except those in Florida and Honolulu were located in non-attainment areas (30 of the 35). The 35 airports included in the OEP account for about 75 percent of all passenger enplanements.
[59] Part of a medium hub (http://www.bts.gov/programs/geographic_information_services/maps/hub_maps/2007/html/map.html).

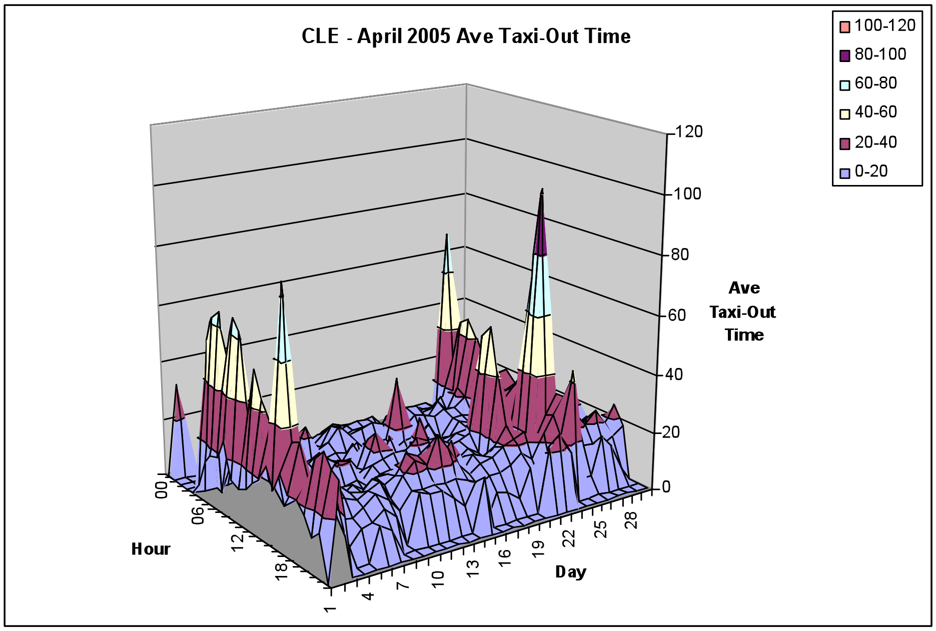


**Figure 5.1:** Taxi-out times for Cleveland Hopkins Airport (CLE) during the month of April 2005.

Plots similar to Figure 5.1 were created to determine the nature of delays at OEP airports in non-attainment areas. In this example, we see three days containing significant delay, with taxi-out times greater than 20 minutes throughout the day. Examining the hour axis we see consistent evening delays (around 18:00 hours or 6pm) throughout the month.

After examining the patterns of delay, OEP non-attainment area airports were matched to FAA initiatives based on the pattern of delay at the airport and the potential for improving operational efficiency with the particular initiative. Multiple airports were chosen for some initiatives (based on available data) to provide a range of the benefits.

The following sections provide estimates of the potential improvements in air traffic efficiency and fuel consumption that can be achieved with the implementation of four types of initiatives at representative airports:

- Airspace Flow Program effects at Boston Logan International Airport and O'Hare International Airport[60] (Section 5.1)
- Schedule De-peaking effects at Phoenix International Airport, Boston Logan International Airport, Minneapolis St. Paul International Airport, Dulles International Airport, and Memphis International Airport[61] (Section 5.2)
- Continuous Descent and Arrivals (CDAs) effects at Los Angeles International Airport[62] (Section 5.3)
- New Runways and Runway Extensions effects at Minneapolis St. Paul International Airport (Section 5.4)

[60] Boston Logan International and O'Hare International are each part of large hubs.
[61] Phoenix International, Minneapolis St. Paul International, and Dulles International are each part of large hubs; Memphis International is part of a medium hub.
[62] Los Angeles International Airport is part of a large hub.

## 5.1 Airspace Flow Programs in Support of Severe Weather Avoidance Procedures

Airspace Flow Programs (AFPs) refer to programs that allow air traffic management specialists to restrict flights with the use of defined airspace, as opposed to the use of Ground Delay Programs (GDPs). AFPs can help reduce delays when used during severe weather events.

Before the advent of AFPs, reductions in en route capacity caused by severe weather were addressed, in part, by using GDPs, which delay flights to and from airports on both sides of the bad-weather area, regardless of the proximity of the flight routes to the bad weather. With the introduction of AFPs, only flights flying through the affected area are delayed. Additionally, operators of those flights have the option of routing around the affected area, further reducing the number of flights delayed. This type of ATM initiative promotes greater specificity in the assignment of delay for flights attempting to depart: those not using the weather-impacted airspace will not be assigned delay under an AFP, whereas they might have been assigned delay under a GDP. Assuming that the AFP results in fewer delayed outbound flights, this will result in more departures and fewer taxi-out delays. Thus, while both AFPs and GDPs necessarily result in delays in order to cope with decreased en route capacity, AFPs have the potential to result in less widespread delays. To provide a measure of one of the benefits of implementing AFPs, this analysis provides an estimate of the fuel and emissions savings related to the reduced impacts of severe en route weather on taxi-out times.

**Impact Estimation Method**

To provide an estimate of the benefits of Airspace Flow Programs, changes in taxi-out times with the implementation of AFPs were compared to those resulting from Ground Delay Programs. The shorter delays associated with AFPs were used as an estimate of the benefits. Two sets of taxi times were examined: taxi-out times with and without GDPs and taxi-out times with and without AFPs (for the year 2005 and 2006 respectively). 26 airports had readily available data to support this analysis. This comparison indicated that, while AFPs applied to cope with severe en route weather resulted in shorter taxi-out times than GDPs for some airports (17 airports), others experienced longer taxi-out times with the use of AFPs (9 airports). Further analysis would be needed to understand the differences between these groups of airports. To focus solely on the benefits of this type of initiative, 2 of the 17 airports were selected for further examination.

Boston Logan International Airport (BOS) and O'Hare International Airport (ORD) were chosen for further analysis. Boston Logan International Airport (BOS) experienced a 20% average increase in taxi-out times when an AFP was implemented and a 30% increase when GDPs were implements. Similarly, Chicago O'Hare International Airport (ORD) showed a 27% increase with AFPs and a 30% increase for GDPs.

To estimate the impacts during periods of congestion, a sample day was selected on which multiple airports experienced increased delays as a result of severe weather (April 20, 2005). Bad weather over New York, Pennsylvania, Ohio, and Indiana affected airspace capacity, and ORD and BOS experienced delays during the afternoon hours.[63] Increased hourly taxi times for BOS and ORD are shown in Figure 5.2. BTS taxi-out data were obtained for that day and the estimated increases in taxi-out times obtained from the above comparison were then applied to the April 20 sample day.

[63] Note that a GDP was implemented at ORD, but not at BOS that day, and the decreases in taxi time reflect a different starting point.

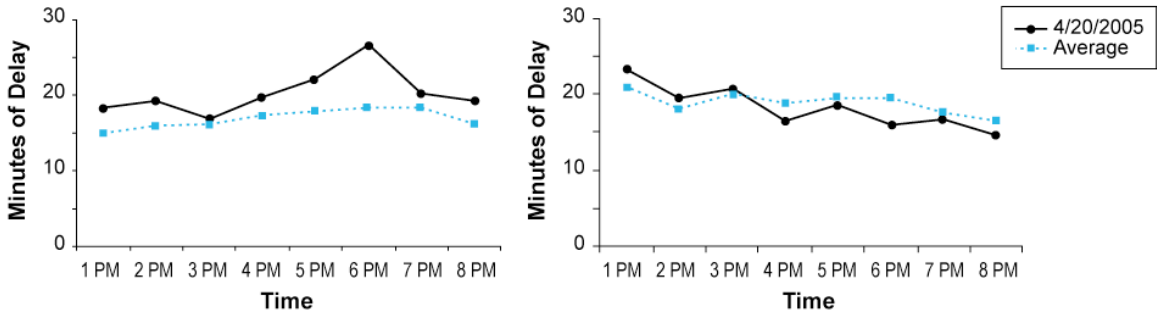


**Figure 5.2:** Hourly minutes of delay at BOS (left) and ORD (right) during the afternoon of April 20, 2005 compared to average minutes of delay for the entire month of April 2005. Bad weather brought delays resulting in longer taxi out times during the afternoon hours.

For the period of congestion observed in the BTS taxi-out data (1:00pm-4:00pm), BOS was estimated to experience 16% shorter taxi-out times for total flights with the implementation of an AFP instead of a GDP. ORD was estimated to experience an 11% reduction. These reduced taxi times were estimated to result in a 9% decrease in LTO fuel burn for BOS and a 4% reduction for ORD compared to what is expected with the use of GDPs. Reductions in emissions are shown in Table 5.1. (THC is total hydrocarbon.)

**Table 5.1:** Reduction in emissions and fuel burn due to the implementation of AFPs instead of GDPs at Boston Logon and Chicago O'Hare airports.

| | CO | THC | NMHC | VOCs | $NO_x$ | $SO_x$ | Fuel |
|---|---|---|---|---|---|---|---|
| BOS | 13.2% | 8.3% | 8.3% | 8.3% | 4.3% | 8.9% | 9.2% |
| ORD | 8.2% | 3.6% | 3.6% | 3.6% | 1.4% | 3.8% | 4.3% |

## 5.2 Schedule De-Peaking

Schedule de-peaking refers to reducing the demand for departures and arrivals during specific periods in which demand exceeds the capacity of the airport.[64] Reduction of demand peaks when demand is close to, or greater than maximum capacity, can significantly affect average delays and queue sizes, as well as their variability from flight to flight.

A range of studies was reviewed to develop a simplified means of estimating the effects of schedule de-peaking (Fan and Odoni 2002; Zhang, Menendez et al. 2003; Le, Donohue et al. 2005; Le 2006; Levine and Gao 2007). All sources suggest that bringing demand into alignment with capacity throughout the day can affect taxi-out times. However, the size and dynamics of the effect depend upon airport-specific factors and the timing and extent of the de-peaking. More thorough, nationwide analysis for specific airports was beyond the scope of this project. Instead, a conservative estimate of the magnitude of de-peaking effects was used. The study assumed that de-peaking would reduce excess taxi-out times (that is, times in excess of the unimpeded taxi-out time) by approximately half during times of excess

[64] This study did not evaluate the methods of achieving schedule de-peaking but rather the theoretical gains if the schedule was spread out across the day. Past and current initiatives to reduce schedules include voluntary efforts at Chicago and slot control at LaGuardia Airport (LGA). There are other methods including slot auctions, peak-time pricing, and other economic schemes to increase the cost of operating certain flights to reduce demand. However, pricing the operations is not the sole option to reduce the schedule of operations by carriers.

demand.

**Impact Estimation Method**

This assumption for de-peaking effects was modeled for five airports: Phoenix International Airport (PHX), Boston Logan International Airport (BOS), Minneapolis St. Paul International Airport (MSP), Dulles International Airport (IAD), and Memphis International Airport (MEM). For these 5 airports, unimpeded taxi-out time ranged from 7 to 10 minutes, and times in excess were divided by 2 to estimate the effects of de-peaking. The results of this for PHX for April 2005 appear in Figure 5.3.

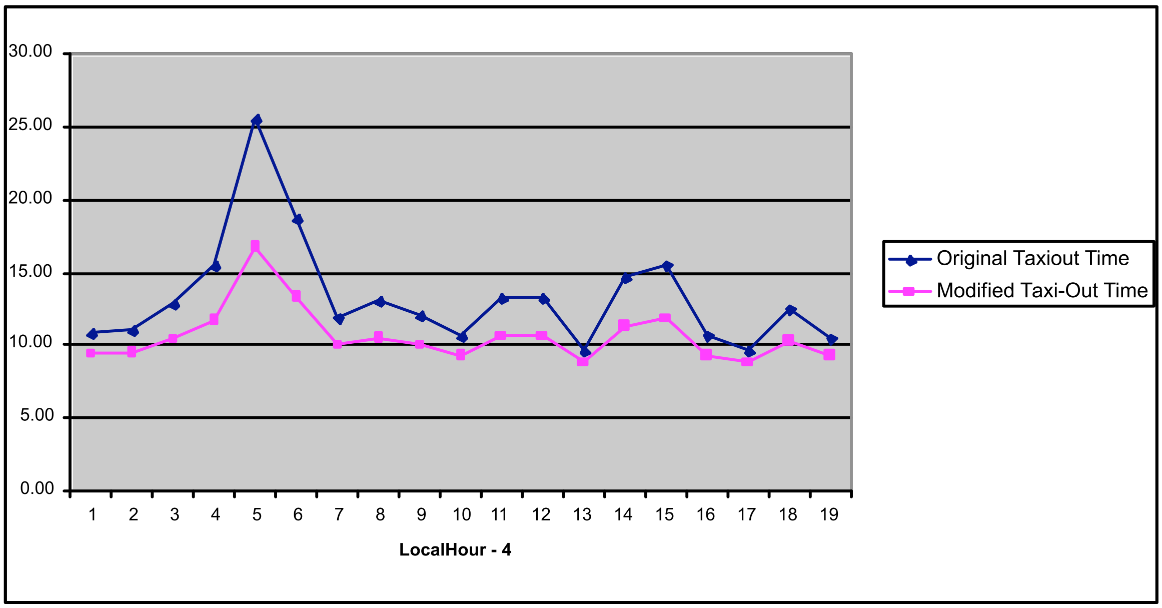


**Figure 5.3:** Original and modified hourly taxi-out times for PHX are based on monthly average for April 2005 (estimated unimpeded time of 8 minutes)

Using the new taxi-out times to estimate the effect of schedule de-peaking, taxi-out fuel burn reductions of between 16% and 23% were found. This translates to a range of 6% to 10% reduction for total LTO fuel burn. Fuel burn reductions for all 5 airports appear below in Table 5.2.

**Table 5.2:** Estimated reductions from schedule de-peaking

| | Carbon Monoxide | Non-Methane Hydrocarbons | Volatile Organic Carbons | $NO_x$ | $SO_x$ | Fuel |
|---|---|---|---|---|---|---|
| BOS | 17.5% | 9.6% | 9.5% | 3.6% | 9.6% | 10.4% |
| IAD | 13.6% | 6.3% | 6.3% | 2.3% | 6.1% | 6.1% |
| MEM | 17.0% | 7.4% | 7.4% | 1.8% | 6.9% | 7.9% |
| MSP | 18.0% | 8.7% | 8.7% | 3.4% | 9.3% | 10.1% |
| PHX | 14.5% | 6.1% | 6.1% | 2.0% | 6.1% | 6.9% |

## 5.3 Continuous Descent Arrivals

Continuous Descent Arrival procedures reduce noise and emissions by changing the approach path so that it more closely follows a 3˚ glide slope as shown in Figure 5.4. Using the 3˚ glide slope, aircraft are able to reduce the thrust of the engines to reduce fuel burn and lessen the noise impacts on approach. Figure 5.4 depicts the vertical dispersion that normally occurs on approach and landing using the downwind approach at Los Angeles International Airport (LAX).

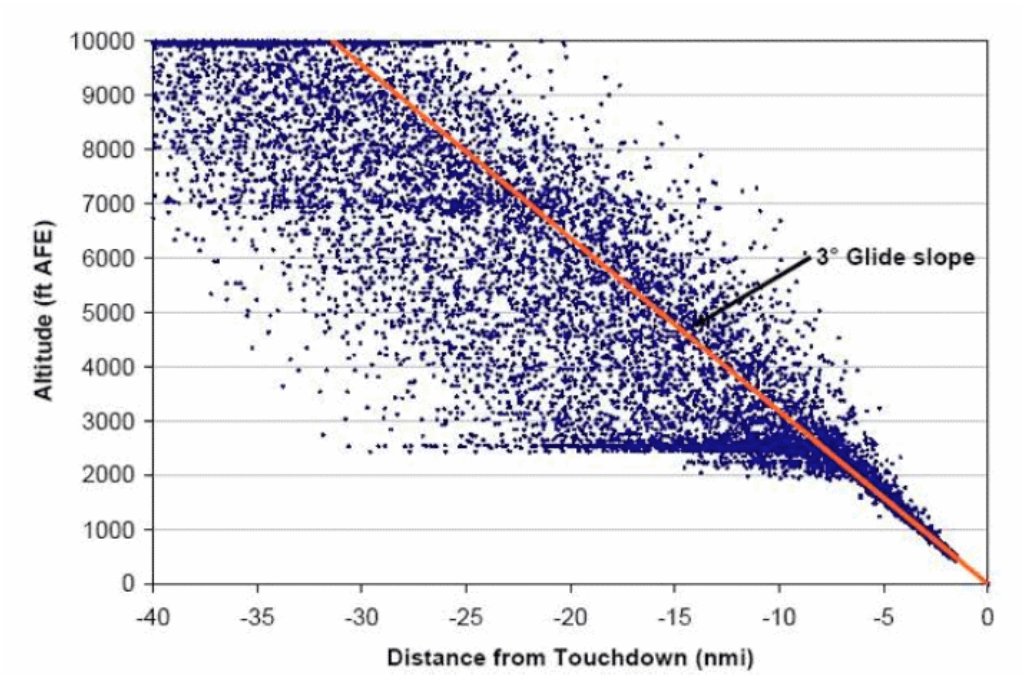


**Figure 5.4:** Baseline downwind approaches at LAX from Dinges, 2007.

An estimate of the benefits of implementing CDA procedures is provided by (Dinges 2007). Dinges evaluated the benefits for different fractions of the aircraft using CDA. The five threshold levels were 5.9% (threshold 1), 21% (threshold 2), 42.9% (threshold 3), 67.3% (threshold 4) and 100% (all-CDA). These thresholds were chosen to explore the space of potential benefits from CDA and illustrate the incremental gains available with varying levels of properly equipped aircraft and conditions suitable for flying the approach. Table 5.3 shows the range of benefits from converting to CDA paths.

**Table 5.3:** Emissions and fuel burn percentage reductions relative to the baseline below 3,000 feet, comparing five levels of CDA usage to the baseline for all modeled approaches to LAX (Dinges 2007).

| Category of Reduction | Percent Reduction for Each CDA Threshold Level | | | | |
|---|---|---|---|---|---|
| | 5.9% Threshold | 21% Threshold | 42.9% Threshold | 67.3% Threshold | 100% Threshold |
| CO | 0.2% | 1.6% | 3.7% | 5.5% | 6.8% |
| THC | 0.1% | 0.9% | 2.2% | 3.4% | 4.5% |
| VOC | 0.1% | 0.9% | 2.2% | 3.4% | 4.5% |
| $NO_X$ | 1.7% | 6.0% | 13.1% | 21.7% | 28.4% |
| $SO_X$ | 1.2% | 4.5% | 9.7% | 15.6% | 19.9% |

| Category of Reduction | Percent Reduction for Each CDA Threshold Level | | | | |
|---|---|---|---|---|---|
| | 5.9% Threshold | 21% Threshold | 42.9% Threshold | 67.3% Threshold | 100% Threshold |
| Fuel | 1.2% | 4.5% | 9.7% | 15.6% | 19.9% |

## 5.4 New Runways and Runway Extensions

New runways and runways extensions are part of the FAA Operational Evolution Partnership (Version 8, FAA 2006):

> New runways and runway extensions provide very significant capacity increases for the NAS. Since 1999, ten new runways have opened at the 35 Operational Evolution Plan airports, providing these airports with the potential to accommodate almost 1.2 million more operations annually. Currently, there are eight runway projects (five new runways, one runway extension, and two airfield reconfigurations) included in the OEP. All eight will be commissioned by 2010 providing these airports with the potential to accommodate more than one million more annual operations.

**Impact Estimation Method**

The impact of new runways was estimated by examining Minneapolis St. Paul International Airport (MSP), an airport in which an additional runway became operational between 2005 and 2006. The two days used for this comparison were April 2, 2005 (before the runway was completed) and April 26, 2006 (with the new runway operational). The period between 9:00 and 12:00 on April 2, 2005 was selected because of increased taxi out times. The post-enhancement period (9:00-12:00 on April 24, 2006) was selected because of similar weather and similar volume, as compared to the baseline period. These two data samples were used for estimating the benefits.

For the 2005 time period, flights had an average taxi-out time of 19 minutes; for the 2006 time period, flights had a taxi-out time of 16 minutes, an approximate 15% improvement. By applying, the 2006 taxi-out time to the 2005 flights, we determined how a 15% improvement would decrease the emissions of the 2005 flights. As noted in Section 4.1, we assume that emissions are linear with taxi out time so a 15% reduction in taxi out time reduces taxi-out emissions by 15%. However, taxi-out emissions are only a portion of the departure emissions below 3,000 feet. Table 5.4 shows the reduction of the LTO emissions for a 15% reduction in taxi time. A summary of all initiatives is shown in XXXX.

**Table 5.4:** Table of percentage reduction in fuel burn and emissions achieved by applying the 2006 taxi out time to the 2005 flights for an effective 15% reduction in taxi-out time

| Pollutant/Fuel | % Change |
|---|---|
| Carbon Monoxide | 12% |
| Hydrocarbons | 6% |
| VOC | 6% |
| $NO_x$ | 2% |
| $SO_x$ | 6% |
| Fuel | 7% |

**Table 5.1:** Summary of emissions reductions potential from operational initiatives

| Initiative | Emissions Reduction | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CO | | THC/NMHC[a] | | VOC | | $NO_x$ | | $SO_x$ | | Fuel | |
| | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max |
| AFPs (BOS, ORD) | 8.2% | 13.2% | 3.6% | 8.3% | 3.6% | 8.3% | 1.4% | 4.3% | 3.8% | 8.9% | 4.3% | 9.2% |
| Schedule depeaking (BOS, IAD, MEM, MSP, PHX) | 13.6% | 18.0% | 6.1% | 9.6% | 6.1% | 9.5% | 1.8% | 3.6% | 6.1% | 9.6% | 6.1% | 10.4% |
| CDA (LAX) | 0.2% | 6.8% | 0.1% | 4.5% | 0.1% | 4.5% | 1.7% | 28.4% | 1.2% | 19.9% | 1.2% | 19.9% |
| New Runways and Runway Extensions (MSP) | 12% | | 6% | | 6% | | 2% | | 6% | | 7% | |

Notes:

[a] NMHC for schedule depeaking initiative; THC for all other initiatives.

# 6 Conclusions and Recommendations

This study analyzed aircraft LTO emissions at 325 airports with commercial activity in the U.S (includes 263 commercial service airports and 62 airports that are either reliever or general aviation airports) for operations that occurred from June 2005 through May 2006. The flights studied represent 95 percent of the commercial jet aircraft operations for which flight plans were filed and 95 percent of the operations with ICAO certified engines. Of the 325 airports (or the 263 commercial service airports), 148 are commercial service airports in at least one of 118 ambient air quality NAAs (for ozone, CO, $PM_{2.5}$, $PM_{10}$, $SO_2$, or $NO_2$) for 2005 using the criteria specified by the National Ambient Air Quality Standards (40 CFR Part 50).

The purpose of this study was to assess the impact of aircraft operations on air quality in these NAAs. This study found that aircraft LTO emissions during the period June 2005 through May 2006 at the 148 U.S. commercial service airports in the 118 NAAs represented the following average percentages of the 2002 emissions inventory in these NAAs:[65] 0.44% of carbon monoxide (CO) emissions, 0.66% of oxides of nitrogen ($NO_x$) emissions, 0.48% of emissions of volatile organic compounds (VOCs), 0.37% of oxides of sulfur ($SO_x$) emissions, and 0.15% of fine particulate matter ($PM_{2.5}$) emissions.

Looking more broadly, this study found that aircraft LTO emissions during the period June 2005 through May 2006 at the 325 U.S. airports with commercial activity included in the study represented the following percentages of the total 2002 U.S. National Emissions Inventory: 0.18% of CO emissions, 0.41% of $NO_x$ emissions, 0.23% of VOCs, 0.07% of $SO_x$ emissions, and 0.05% of $PM_{2.5}$ emissions.

Air quality and health effects impacts from aircraft LTO operations were assessed by removing all aircraft operations from the inventories and modeling ozone and PM concentrations and population based health impacts. Within the capabilities of the modeling, the impacts on health from aircraft emissions were found to derive almost entirely from fine ambient particulate matter. The dominant emissions from aircraft that contribute to ambient $PM_{2.5}$ are the secondary PM precursor emissions, $SO_x$ and $NO_x$, as well as direct emissions of primary $PM_{2.5}$. $SO_x$ emissions depend on fuel sulfur levels and overall fuel burn. $NO_x$ and PM emissions depend on combustor and engine technology in addition to overall fuel burn. The contribution of aircraft emissions to the national annually-averaged ambient $PM_{2.5}$ level was estimated to be 0.01μg/m$^3$. On a percentage basis, the contribution is approximately 0.08% for all counties and 0.06% for counties in NAAs.[66] The aircraft contributions to county-level ambient $PM_{2.5}$ concentrations ranged from approximately 0% to 0.5%. Aircraft emissions were also estimated to contribute 0.12% (0.10 parts per billion) to average 8-hour ozone values in both attainment and non-attainment areas. Near some urban centers aircraft emissions reduced ozone, whereas in suburban and rural areas, aircraft emissions increased ambient ozone levels. The largest county-level decrease was 0.6%; the largest county-level increase was 0.3%.

The health impacts of aircraft LTO emissions were derived almost entirely from fine ambient particulate matter. Nationally, about 160 yearly incidences of PM-related premature mortality were estimated due to ambient particulate matter exposure attributable to aircraft emissions at the 325 airports studied (with a 90% confidence interval of 64 to 270 yearly incidences). Although the health impacts we estimate for aircraft LTO emissions are important, it is *very likely*[67] that they constitute less than 0.6% of the total adverse health impacts due to poor air quality from anthropogenic emissions sources in the United States. One-third of these 160 premature mortalities were estimated to occur within the greater Southern California region, while another fourteen counties (located within NY, NJ, IL,

[65] 2005 is the base year for aircraft emissions, and 2002 is the base year for non-aircraft emissions.
[66] Note that these estimates for percent contributions to total ambient concentrations carry uncertainties due to the fact that some emissions sources are not well quantified in U.S. National Emissions Inventories.
[68] Nonvolatile PM mass was not computed for non-ICAO certified aircraft engines; however, sulfates- and organics-related PM mass were computed. No PM mass was computed for APUs.

Northern CA, MI, TN, TX and OH) accounted for approximately 21 percent of total premature mortality. In total, 47 counties within the United States had a PM-related premature mortality risk associated with aircraft emissions that was greater than 1 incidence per year. Other health impacts, such as chronic bronchitis, non-fatal heart attacks, respiratory and cardiovascular illnesses were also associated with aircraft emissions. No significant health impacts were estimated due to changes in ozone concentrations attributable to aircraft emissions.

There are several important assumptions and limitations associated with the results of this study. The method used to estimate aircraft primary PM emissions in this study (known as FOA3a) includes margins to conservatively accommodate uncertainties in aircraft PM emissions. An error was made in the specification of the fuel sulfur level for some of the airports in this inventory such that the aircraft $SO_2$ inventory is expected to be biased towards underestimating the contribution of aircraft by 20 percent (i.e. the contribution of aircraft to the national $SO_2$ inventory may be closer to 0.07%). This would have an effect on sulfate secondary PM contributions to fine PM air quality and health effects as well. The use of a 36 km x 36 km grid scale for the air quality analyses is expected to underestimate health impacts, especially those that may occur close to airport boundaries. Omitting the effect of cruise level emissions on surface air quality is also expected to lead to underestimation of health impacts by an unknown amount, especially for fine primary and secondary PM. Further, analysis of only one year may lead to overestimation or underestimation of aircraft impacts due to year-to-year changes in meteorology. Non-aircraft sources were also not included (e.g. emissions of ground service equipment and other aircraft sources). Finally, we report the results for one concentration-response relationship for the health effects of ambient PM; a range of concentration-response relationships has been reported in the literature. The net effect of these assumptions and limitations is not known. Further research is recommended into these areas.

General aviation aircraft emissions were not included in our emissions inventory since GA aircraft are responsible for less than 1 percent of fuel use by volume. However, a separate estimate of lead emissions from GA aircraft was made (most piston-engine powered GA aircraft operate on leaded aviation gasoline; gas turbine powered jet engines and turboprops operate on Jet A which does not contain significant levels of lead). We estimate that in 2002 approximately 280 million gallons of aviation gasoline were supplied for GA use in the U.S., contributing an estimated 565 metric tons of lead to the air, and comprising 46 percent of the 2002 U.S. National Emissions Inventory (NEI) for lead. We did not estimate the health impacts of these lead emissions.

Aircraft emissions are influenced by weather, air traffic management, and other inefficiencies that compound, resulting in increased fuel burn and emissions. During a one-year period, airport delays accounted for approximately 320 million gallons of fuel use due to increased taxi times for the 113 non-attainment airports examined in Section 4. This is approximately 1% of all jet fuel used in the U.S. during 2005, and approximately 17% of fuel use during the LTO portion of the flight for these 113 airports. Based on these results, unimpeded taxi times would result in average LTO emissions reductions of 22% (28,000 metric tons) for CO, 7% (5,000 metric tons) for $NO_x$, 16% (4,000 metric tons) each for VOCs and non-methane hydrocarbons, 17% (1,000 metric tons) for $SO_x$, 15% (260 metric tons) for $PM_{2.5}$, and 17% (986,000 metric tons) for fuel. These values represent about five percent of LTO emissions in these non-attainment areas.

While there are many strategies available to achieve these reductions, including technological, operational and policy options, the relationship between taxi-out time and emissions suggests that ATM initiatives have the potential to play an important role in increasing operational efficiency and, in turn, reducing emissions and fuel use at U.S. airports. This study provides illustrative examples of potential reductions in fuel use and emissions that may be obtained through initiatives such as airspace flow programs, schedule de-peaking, continuous decent arrivals, and new runways. To increase efficiency without adversely affecting safety, noise and security, operational initiatives must be implemented with consideration of the larger system, and the numerous, complex interdependencies that are inherent in the system. Further, there are no universal mitigation strategies for operational efficiency, and a single technology or procedure will not be applicable at all U.S. airports.

This study highlights some of the needs for future work in the area of aviation fuel conservation and emissions reduction. Some of the data, methods, and modeling used for the study would benefit from further development:

The dominance of PM health effects suggests the need for more complete PM measurements from aircraft engines. An agreed upon test method is needed and is now under development. The current analytical methods (see Appendix B) are intended as temporary estimation methods until mass emissions data are collected for ICAO-certified engines. PM data is also needed for APUs and non-ICAO certified engines.[68]

As noted above, further analysis of air quality impacts of aviation emissions is required to understand the impacts cruise level emissions, better grid resolution (near airport health effects), and year-to-year meteorological variations.

Investigation of source-specific dose response functions for health impacts may also be beneficial. It is currently not known if primary particulate matter due to aviation has unique health impacts that differ from other emission sources. Currently, dose-response functions used to assess impacts of particulate matter do not discriminate between PM sources or components. Research is underway to better understand source-specific and component-specific health impacts of particulate matter.

There are numerous ATM initiatives that can effectively reduce delays. This study estimates the benefits of only a few; and even in these cases only illustrative cases are presented. Further study is recommended to more fully evaluate the potential benefits of different ATM initiatives. Moreover, there are numerous opportunities to reduce aircraft fuel consumption and emissions that are beyond the scope of this study including the use alternative fuels, improvements in aircraft and aircraft engine design, and policy options to promote these advances. Further research into ways to promote fuel efficiency should include an investigation of these opportunities in addition to further assessment of operational initiatives.

To better understand the relationship between delay and ground-level emissions and fuel burn, it is necessary to model the numerous factors that govern APU use and single engine taxi. Further analysis of variations in APU usage by carrier, aircraft type, airport, season, and operating environment is also needed to understand engine cut-off and APU use.

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# Appendix B Study Airports

The study analyzed 325 airports with commercial activity (commercial service, reliever, and general aviation airports) in the U.S for operations that occurred from June 2005 through May 2006. These airports and their IFR and VFR operations (and LTOs) for this time period are shown below.

| Airport Code | Airport Name | County | State | Total operations[a]: IFR + VFR | Total LTOs[b]: IFR+VFR |
|---|---|---|---|---|---|
| ANC | TED STEVENS ANCHORAGE INTL | ANCHORAGE | AK | 311,729 | 155,865 |
| FAI | FAIRBANKS INTL | FAIRBANKS | AK | 109,190 | 54,595 |
| JNU | JUNEAU INTL | JUNEAU | AK | 12,875 | 6,438 |
| KTN | KETCHIKAN INTL | KETCHIKAN | AK | 8,218 | 4,109 |
| MRI | MERRILL FIELD | ANCHORAGE | AK | 185,188 | 92,594 |
| SIT | SITKA ROCKY GUTIERREZ | SITKA | AK | 3,807 | 1,904 |
| BFM | MOBILE DOWNTOWN | MOBILE | AL | 9,372 | 4,686 |
| BHM | BIRMINGHAM INTL | JEFFERSON | AL | 142,275 | 71,138 |
| HSV | HUNTSVILLE INTL | MADISON | AL | 36,868 | 18,434 |
| MGM | MONTGOMERY RGNL | MONTGOMERY | AL | 17,143 | 8,572 |
| MOB | MOBILE RGNL | MOBILE | AL | 23,176 | 11,588 |
| MSL | NORTHWEST ALABAMA RGNL | COLBERT | AL | 44,380 | 22,190 |
| FSM | FORT SMITH RGNL | SEBASTIAN | AR | 14,676 | 7,338 |
| LIT | ADAMS FIELD | PULASKI | AR | 65,507 | 32,754 |
| ROG | ROGERS MUNICIPAL-CARTER | BENTON | AR | 6,807 | 3,404 |
| XNA | NORTHWEST ARKANSAS RGNL | BENTON | AR | 35,054 | 17,527 |
| IFP | LAUGHLIN/BULLHEAD INTL | MOHAVE | AZ | 27,994 | 13,997 |
| PHX | PHOENIX SKY HARBOR INTL | MARICOPA | AZ | 616,517 | 308,259 |
| SDL | SCOTTSDALE | MARICOPA | AZ | 40,000 | 20,000 |
| TUS | TUCSON INTL | PIMA | AZ | 279,103 | 139,552 |
| YUM | YUMA INTL | YUMA | AZ | 174,259 | 87,130 |
| APC | NAPA COUNTY | NAPA | CA | 12,020 | 6,010 |
| BFL | MEADOWS FIELD | KERN | CA | 87,613 | 43,807 |
| BUR | BURBANK-GLENDALE-PASADE | LOS ANGELES | CA | 190,447 | 95,224 |
| CIC | CHICO MUNI | BUTTE | CA | 42,849 | 21,425 |
| CRQ | MC CLELLAN-PALOMAR | SAN DIEGO | CA | 199,877 | 99,939 |
| FAT | FRESNO YOSEMITE INTL | FRESNO | CA | 150,309 | 75,155 |
| IPL | IMPERIAL COUNTY | IMPERIAL | CA | 73,054 | 36,527 |
| IYK | INYOKERN | KERN | CA | 40,567 | 20,284 |
| LAX | LOS ANGELES INTL | LOS ANGELES | CA | 664,609 | 332,305 |
| LGB | LONG BEACH/ DAUGHERTY | LOS ANGELES | CA | 351,408 | 175,704 |
| MCE | MERCED MUNICIPAL/ MACREADY FIELD | MERCED | CA | 27,972 | 13,986 |
| MHR | SACRAMENTO MATHER | SACRAMENTO | CA | 20,396 | 10,198 |
| MOD | MODESTO CITY | STANISLAUS | CA | 75,379 | 37,690 |

| Airport Code | Airport Name | County | State | Total operations[a]: IFR + VFR | Total LTOs[b]: IFR+VFR |
|---|---|---|---|---|---|
| MRY | MONTEREY PENINSULA | MONTEREY | CA | 43,020 | 21,510 |
| OAK | METROPOLITAN OAKLAND INTL | ALAMEDA | CA | 340,174 | 170,087 |
| ONT | ONTARIO INTL | SAN BERNARDINO | CA | 139,930 | 69,965 |
| OXR | OXNARD | VENTURA | CA | 94,653 | 47,327 |
| PSP | PALM SPRINGS INTL | RIVERSIDE | CA | 92,722 | 46,361 |
| SAN | SAN DIEGO INTL-LINDBERG | SAN DIEGO | CA | 245,719 | 122,860 |
| SBA | SANTA BARBARA MUNI | SANTA BARBARA | CA | 69,657 | 34,829 |
| SCK | STOCKTON METROPOLITAN | SAN JOAQUIN | CA | 83,298 | 41,649 |
| SFO | SAN FRANCISCO INTL | SAN MATEO | CA | 376,966 | 188,483 |
| SJC | NORMAN Y. MINETA SAN JOSE INTL | SANTA CLARA | CA | 221,361 | 110,681 |
| SMF | SACRAMENTO INTL | SACRAMENTO | CA | 180,203 | 90,102 |
| SMO | SANTA MONICA MUNI | LOS ANGELES | CA | 32,647 | 16,324 |
| SNA | JOHN WAYNE AIRPORT | ORANGE | CA | 361,921 | 180,961 |
| SUU | TRAVIS AFB | SOLANO | CA | 1,091 | 546 |
| VCV | SOUTHERN CALIFORNIA LOGISTICS | SAN BERNARDINO | CA | 73,276 | 36,638 |
| VIS | VISALIA MUNI | TULARE | CA | 33,777 | 16,889 |
| VNY | VAN NUYS | LOS ANGELES | CA | 31,642 | 15,821 |
| APA | CENTENNIAL | ARAPAHOE | CO | 47,961 | 23,981 |
| ASE | ASPEN-PITKIN CO/ SARDY FIELD | PITKIN | CO | 43,939 | 21,970 |
| BJC | ROCKY MOUNTAIN METROPOLITAN | JEFFERSON | CO | 10,995 | 5,498 |
| COS | CITY OF COLORADO SPRING | EL PASO | CO | 155,740 | 77,870 |
| DEN | DENVER INTL | DENVER | CO | 606,129 | 303,065 |
| EGE | EAGLE COUNTY RGNL | EAGLE | CO | 20,701 | 10,351 |
| GJT | WALKER FIELD | MESA | CO | 23,049 | 11,525 |
| MTJ | MONTROSE RGNL | MONTROSE | CO | 13,601 | 6,801 |
| TEX | TELLURIDE RGNL | SAN MIGUEL | CO | 10,879 | 5,440 |
| BDL | BRADLEY INTL | HARTFORD | CT | 151,685 | 75,843 |
| GON | GROTON-NEW LONDON | NEW LONDON | CT | 56,706 | 28,353 |
| HVN | TWEED-NEW HAVEN | NEW HAVEN | CT | 62,430 | 31,215 |
| OXC | WATERBURY-OXFORD | NEW HAVEN | CT | 6,954 | 3,477 |
| DCA | RONALD REAGAN WASHINGTON | ARLINGTON | DC | 290,998 | 145,499 |
| IAD | WASHINGTON DULLES INTL | LOUDOUN | DC | 495,340 | 247,670 |
| ILG | NEW CASTLE COUNTY | NEW CASTLE | DE | 15,548 | 7,774 |
| APF | NAPLES MUNI | COLLIER | FL | 15,711 | 7,856 |

| Airport Code | Airport Name | County | State | Total operations[a]: IFR + VFR | Total LTOs[b]: IFR+VFR |
|---|---|---|---|---|---|
| BCT | BOCA RATON | PALM BEACH | FL | 10,162 | 5,081 |
| DAB | DAYTONA BEACH INTL | VOLUSIA | FL | 15,269 | 7,635 |
| DTS | DESTIN-FORT WALTON BEACH | OKALOOSA | FL | 11,419 | 5,710 |
| EYW | KEY WEST INTL | MONROE | FL | 7,481 | 3,741 |
| FLL | FORT LAUDERDALE/ HOLLYWOOOD | BROWARD | FL | 187,730 | 93,865 |
| FXE | FORT LAUDERDALE EXECUTIVE | BROWARD | FL | 10,059 | 5,030 |
| GNV | GAINESVILLE RGNL | ALACHUA | FL | 17,322 | 8,661 |
| JAX | JACKSONVILLE INTL | DUVAL | FL | 132,554 | 66,277 |
| MCO | ORLANDO INTL | ORANGE | FL | 311,475 | 155,738 |
| MIA | MIAMI INTL | MIAMI-DADE | FL | 160,937 | 80,469 |
| MLB | MELBOURNE INTL | BREVARD | FL | 8,428 | 4,214 |
| NPA | PENSACOLA NAS/ SHERMAN FIELD | ESCAMBIA | FL | 986 | 493 |
| OPF | OPA LOCKA | MIAMI-DADE | FL | 4,756 | 2,378 |
| ORL | EXECUTIVE | ORANGE | FL | 9,483 | 4,742 |
| PBI | PALM BEACH INTL | PALM BEACH | FL | 115,880 | 57,940 |
| PFN | PANAMA CITY-BAY CO INTL | BAY | FL | 16,173 | 8,087 |
| PIE | ST PETERSBURG-CLEARWATE | PINELLAS | FL | 13,021 | 6,511 |
| PNS | PENSACOLA RGNL | ESCAMBIA | FL | 38,375 | 19,188 |
| RSW | SOUTHWEST FLORIDA INTL | LEE | FL | 66,810 | 33,405 |
| SFB | ORLANDO SANFORD | SEMINOLE | FL | 5,685 | 2,843 |
| SRQ | SARASOTA/BRADENTON INTL | SARASOTA | FL | 31,752 | 15,876 |
| TLH | TALLAHASSEE RGNL | LEON | FL | 31,442 | 15,721 |
| TPA | TAMPA INTL | HILLSBOROUGH | FL | 171,621 | 85,811 |
| VPS | EGLIN AFB | OKALOOSA | FL | 13,585 | 6,793 |
| ABY | SOUTHWEST GEORGIA RGNL | DOUGHERTY | GA | 9,266 | 4,633 |
| AGS | AUGUSTA RGNL | RICHMOND | GA | 20,284 | 10,142 |
| ATL | HARTSFIELD INTL | FULTON | GA | 982,852 | 491,426 |
| FTY | FULTON COUNTY AIRPORT | FULTON | GA | 25,708 | 12,854 |

| Airport Code | Airport Name | County | State | Total operations[a]: IFR + VFR | Total LTOs[b]: IFR+VFR |
|---|---|---|---|---|---|
| LZU | GWINNETT COUNTY - BRISCOE FIELD | GWINNETT | GA | 10,309 | 5,155 |
| MCN | MIDDLE GEORGIA RGNL | BIBB | GA | 27,074 | 13,537 |
| PDK | DEKALB-PEACHTREE | DE KALB | GA | 48,484 | 24,242 |
| RYY | COBB COUNTY/ | COBB | GA | 8,364 | 4,182 |
| SAV | SAVANNAH/HILTON HEAD INTL | CHATHAM | GA | 48,867 | 24,434 |
| HNL | HONOLULU INTL | HONOLULU | HI | 97,849 | 48,925 |
| ITO | HILO INTL | HAWAII | HI | 14,216 | 7,108 |
| KOA | KONA INTL AT KEAHOLE | HAWAII | HI | 20,401 | 10,201 |
| LIH | LIHUE | KAUAI | HI | 17,381 | 8,691 |
| OGG | KAHULUI | MAUI | HI | 52,376 | 26,188 |
| CID | THE EASTERN IOWA | LINN | IA | 53,207 | 26,604 |
| DSM | DES MOINES INTL | POLK | IA | 68,129 | 34,065 |
| BOI | BOISE/GOWEN FIELD | ADA | ID | 171,910 | 85,955 |
| IDA | IDAHO FALLS RGNL | BONNEVILLE | ID | 19,294 | 9,647 |
| PIH | POCATELLO RGNL | POWER | ID | 44,705 | 22,353 |
| SUN | FRIEDMAN MEMORIAL | BLAINE | ID | 23,422 | 11,711 |
| BLV | SCOTT AFB/ MIDAMERICA | ST CLAIR | IL | 28,832 | 14,416 |
| BMI | CENTRAL IL RGNL | MC LEAN | IL | 23,261 | 11,631 |
| CMI | UNIVERSITY OF ILLINOIS | CHAMPAIGN | IL | 24,819 | 12,410 |
| CPS | ST LOUIS DOWNTOWN | ST CLAIR | IL | 14,281 | 7,141 |
| DPA | DUPAGE | DU PAGE | IL | 12,804 | 6,402 |
| MDW | CHICAGO MIDWAY INTL | COOK | IL | 300,110 | 150,055 |
| MLI | QUAD CITY INTL | ROCK ISLAND | IL | 45,378 | 22,689 |
| ORD | CHICAGO O'HARE INTL | COOK | IL | 1,021,331 | 510,666 |
| PIA | GREATER PEORIA RGNL | PEORIA | IL | 26,380 | 13,190 |
| PWK | PALWAUKEE MUNI | COOK | IL | 25,597 | 12,799 |
| RFD | GREATER ROCKFORD | WINNEBAGO | IL | 16,744 | 8,372 |
| SPI | CAPITAL | SANGAMON | IL | 16,331 | 8,166 |
| UGN | WAUKEGAN RGNL | LAKE | IL | 5,666 | 2,833 |
| EVV | EVANSVILLE RGNL | VANDERBURGH | IN | 66,915 | 33,458 |
| FWA | FORT WAYNE INTL | ALLEN | IN | 77,748 | 38,874 |
| IND | INDIANAPOLIS INTL | MARION | IN | 225,106 | 112,553 |
| SBN | SOUTH BEND RGNL | ST JOSEPH | IN | 61,758 | 30,879 |

| Airport Code | Airport Name | County | State | Total operations[a]: IFR + VFR | Total LTOs[b]: IFR+VFR |
|---|---|---|---|---|---|
| ICT | WICHITA MID-CONTINENTAL | SEDGWICK | KS | 46,156 | 23,078 |
| IXD | NEW CENTURY AIRCENTER | JOHNSON | KS | 3,182 | 1,591 |
| SLN | SALINA MUNI | SALINE | KS | 10,497 | 5,249 |
| CVG | CINCINNATI/NORTHERN KENTUCKY INTL | BOONE | KY | 440,229 | 220,115 |
| LEX | BLUE GRASS | FAYETTE | KY | 47,031 | 23,516 |
| SDF | LOUISVILLE INTL-STANDIFORD FIELD | JEFFERSON | KY | 180,463 | 90,232 |
| AEX | ALEXANDRIA INTL | RAPIDES | LA | 17,013 | 8,507 |
| BTR | BATON ROUGE METROPOLITAN | EAST BATON ROUGE | LA | 110,373 | 55,187 |
| LFT | LAFAYETTE RGNL | LAFAYETTE | LA | 26,262 | 13,131 |
| MLU | MONROE RGNL | OUACHITA | LA | 15,523 | 7,762 |
| MSY | LOUIS ARMSTRONG NEW ORLEANS | JEFFERSON | LA | 100,185 | 50,093 |
| SHV | SHREVEPORT RGNL | CADDO | LA | 43,429 | 21,715 |
| ACK | NANTUCKET MEMORIAL | NANTUCKET | MA | 153,631 | 76,816 |
| BED | LAURENCE G HANSCOM FIELD | MIDDLESEX | MA | 170,107 | 85,054 |
| BOS | GENERAL EDWARD LAWRENCE | SUFFOLK | MA | 428,546 | 214,273 |
| HYA | BARNSTABLE MUNI | BARNSTABLE | MA | 120,155 | 60,078 |
| MVY | MARTHAS VINEYARD | DUKES | MA | 52,133 | 26,067 |
| ADW | ANDREWS AFB | PRINCE GEORGES | MD | 10,263 | 5,132 |
| BWI | BALTIMORE-WASHINGTON INTL | ANNE ARUNDEL | MD | 311,503 | 155,752 |
| HGR | HAGERSTOWN RGNL | WASHINGTON | MD | 50,658 | 25,329 |
| BGR | BANGOR INTL | PENOBSCOT | ME | 33,927 | 16,964 |
| BHB | HANCOCK COUNTY-BAR HARBOR | HANCOCK | ME | 42,154 | 21,077 |
| PQI | NORTHERN MAINE RGNL | AROOSTOOK | ME | 7,346 | 3,673 |
| PWM | PORTLAND INTL JETPORT | CUMBERLAND | ME | 78,671 | 39,336 |
| RKD | KNOX COUNTY RGNL | KNOX | ME | 55,497 | 27,749 |
| AZO | KALAMAZOO/BATTLE CREEK INTL | KALAMAZOO | MI | 80,503 | 40,252 |
| BIV | TULIP CITY | ALLEGAN | MI | 3,886 | 1,943 |

| Airport Code | Airport Name | County | State | Total operations[a]: IFR + VFR | Total LTOs[b]: IFR+VFR |
|---|---|---|---|---|---|
| BTL | W K KELLOGG | CALHOUN | MI | 5,803 | 2,902 |
| DET | DETROIT CITY | WAYNE | MI | 7,612 | 3,806 |
| DTW | DETROIT METROPOLITAN WAYNE COUNTY | WAYNE | MI | 511,008 | 255,504 |
| FNT | BISHOP INTL | GENESEE | MI | 113,863 | 56,932 |
| GRR | GERALD R. FORD INTL | KENT | MI | 115,354 | 57,677 |
| LAN | CAPITAL CITY | CLINTON | MI | 82,792 | 41,396 |
| MBS | MBS INTL | SAGINAW | MI | 19,228 | 9,614 |
| MKG | MUSKEGON COUNTY | MUSKEGON | MI | 48,286 | 24,143 |
| PTK | OAKLAND COUNTY INTL | OAKLAND | MI | 30,586 | 15,293 |
| TVC | CHERRY CAPITAL | GRAND TRAVERSE | MI | 18,129 | 9,065 |
| YIP | WILLOW RUN | WAYNE | MI | 12,050 | 6,025 |
| DLH | DULUTH INTL | ST LOUIS | MN | 66,709 | 33,355 |
| MSP | MINNEAPOLIS-ST PAUL INTL | HENNEPIN | MN | 508,651 | 254,326 |
| RST | ROCHESTER INTL | OLMSTED | MN | 18,910 | 9,455 |
| STP | ST PAUL DOWNTOWN HOLMAN | RAMSEY | MN | 15,841 | 7,921 |
| MCI | KANSAS CITY INTL | PLATTE | MO | 231,832 | 115,916 |
| MKC | CHARLES B. WHEELER DOWN | CLAY | MO | 11,517 | 5,759 |
| SGF | SPRINGFIELD-BRANSON RGNL | GREENE | MO | 38,022 | 19,011 |
| STL | LAMBERT-ST LOUIS INTL | ST LOUIS CITY | MO | 294,159 | 147,080 |
| SUS | SPIRIT OF ST LOUIS | ST LOUIS | MO | 20,277 | 10,139 |
| GPT | GULFPORT-BILOXI INTL | HARRISON | MS | 22,775 | 11,388 |
| JAN | JACKSON INTL | RANKIN | MS | 40,968 | 20,484 |
| BIL | BILLINGS LOGAN INTL | YELLOWSTONE | MT | 102,361 | 51,181 |
| BTM | BERT MOONEY | SILVER BOW | MT | 19,369 | 9,685 |
| BZN | GALLATIN FIELD | GALLATIN | MT | 24,875 | 12,438 |
| GTF | GREAT FALLS INTL | CASCADE | MT | 26,926 | 13,463 |
| HLN | HELENA RGNL | LEWIS AND CLARK | MT | 55,581 | 27,791 |
| MSO | MISSOULA INTL | MISSOULA | MT | 28,702 | 14,351 |
| AVL | ASHEVILLE RGNL | BUNCOMBE | NC | 38,545 | 19,273 |
| CLT | CHARLOTTE/DOUGLAS INTL | MECKLENBURG | NC | 530,350 | 265,175 |

| Airport Code | Airport Name | County | State | Total operations[a]: IFR + VFR | Total LTOs[b]: IFR+VFR |
|---|---|---|---|---|---|
| FAY | FAYETTEVILLE REGIONAL/GRANNIS FIELD | CUMBERLAND | NC | 49,500 | 24,750 |
| GSO | PIEDMONT TRIAD INTL | GUILFORD | NC | 122,384 | 61,192 |
| ILM | WILMINGTON INTL | NEW HANOVER | NC | 41,803 | 20,902 |
| INT | SMITH REYNOLDS | FORSYTH | NC | 7,959 | 3,980 |
| JQF | CONCORD RGNL | CABARRUS | NC | 17,080 | 8,540 |
| RDU | RALEIGH-DURHAM INTL | WAKE | NC | 243,212 | 121,606 |
| BIS | BISMARCK MUNI | BURLEIGH | ND | 14,108 | 7,054 |
| FAR | HECTOR INTL | CASS | ND | 15,754 | 7,877 |
| GFK | GRAND FORKS INTL | GRAND FORKS | ND | 9,393 | 4,697 |
| LBF | NORTH PLATTE RGNL | LINCOLN | NE | 4,330 | 2,165 |
| LNK | LINCOLN MUNI | LANCASTER | NE | 24,535 | 12,268 |
| OMA | EPPLEY AIRFIELD | DOUGLAS | NE | 84,548 | 42,274 |
| MHT | MANCHESTER | HILLSBOROUGH | NH | 98,436 | 49,218 |
| PSM | PEASE INTL TRADEPORT | ROCKINGHAM | NH | 37,296 | 18,648 |
| ACY | ATLANTIC CITY INTL | ATLANTIC | NJ | 124,343 | 62,172 |
| EWR | NEWARK LIBERTY INTL | ESSEX | NJ | 452,350 | 226,175 |
| MMU | MORRISTOWN MUNI | MORRIS | NJ | 35,331 | 17,666 |
| TEB | TETERBORO | BERGEN | NJ | 154,674 | 77,337 |
| TTN | TRENTON MERCER | MERCER | NJ | 96,253 | 48,127 |
| WRI | MC GUIRE AFB | BURLINGTON | NJ | 1,840 | 920 |
| ABQ | ALBUQUERQUE INTL SUNPORT | BERNALILLO | NM | 197,525 | 98,763 |
| SAF | SANTA FE MUNI | SANTA FE | NM | 12,480 | 6,240 |
| HND | HENDERSON | CLARK | NV | 74,149 | 37,075 |
| LAS | MC CARRAN INTL | CLARK | NV | 654,117 | 327,059 |
| RNO | RENO/TAHOE INTL | WASHOE | NV | 155,785 | 77,893 |
| TNX | TALLAHASSEE RGNL | LEON | NV | 7,810 | 3,905 |
| VGT | NORTH LAS VEGAS | CLARK | NV | 233,847 | 116,924 |
| ALB | ALBANY INTL | ALBANY | NY | 113,233 | 56,617 |
| BGM | BINGHAMTON RGNL | BROOME | NY | 23,472 | 11,736 |
| BUF | BUFFALO NIAGARA INTL | ERIE | NY | 128,363 | 64,182 |
| ELM | ELMIRA/CORNING RGNL | CHEMUNG | NY | 21,645 | 10,823 |
| FRG | REPUBLIC | SUFFOLK | NY | 20,909 | 10,455 |
| HPN | WESTCHESTER COUNTY | WESTCHESTER | NY | 189,600 | 94,800 |

| Airport Code | Airport Name | County | State | Total operations[a]: IFR + VFR | Total LTOs[b]: IFR+VFR |
|---|---|---|---|---|---|
| ISP | LONG ISLAND MAC ARTHUR | SUFFOLK | NY | 181,621 | 90,811 |
| ITH | ITHACA TOMPKINS RGNL | TOMPKINS | NY | 16,015 | 8,008 |
| JFK | JOHN F KENNEDY INTL | QUEENS | NY | 369,410 | 184,705 |
| JHW | CHAUTAUQUA COUNTY/JAMES | CHAUTAUQUA | NY | 20,813 | 10,407 |
| LGA | LA GUARDIA | QUEENS | NY | 415,786 | 207,893 |
| ROC | GREATER ROCHESTER INTL | MONROE | NY | 140,653 | 70,327 |
| SWF | STEWART INTL | ORANGE | NY | 92,577 | 46,289 |
| SYR | SYRACUSE HANCOCK INTL | ONONDAGA | NY | 117,747 | 58,874 |
| BKL | BURKE LAKEFRONT | CUYAHOGA | OH | 22,694 | 11,347 |
| CAK | AKRON-CANTON RGNL | SUMMIT | OH | 110,365 | 55,183 |
| CGF | CUYAHOGA COUNTY | CUYAHOGA | OH | 11,129 | 5,565 |
| CLE | CLEVELAND-HOPKINS INTL | CUYAHOGA | OH | 258,636 | 129,318 |
| CMH | PORT COLUMBUS INTL | FRANKLIN | OH | 198,084 | 99,042 |
| DAY | JAMES M COX DAYTON INTL | MONTGOMERY | OH | 117,960 | 58,980 |
| ILN | AIRBORNE AIRPARK | CLINTON | OH | 44,748 | 22,374 |
| LCK | RICKENBACKER INTL | FRANKLIN | OH | 38,476 | 19,238 |
| LUK | CINCINNATI MUNI AIRPORT | HAMILTON | OH | 33,963 | 16,982 |
| OSU | OHIO STATE UNIVERSITY | FRANKLIN | OH | 11,217 | 5,609 |
| TOL | TOLEDO EXPRESS | LUCAS | OH | 66,174 | 33,087 |
| YNG | YOUNGSTOWN-WARREN RGNL | TRUMBULL | OH | 78,202 | 39,101 |
| OKC | WILL ROGERS WORLD | OKLAHOMA | OK | 96,843 | 48,422 |
| PWA | WILEY POST | OKLAHOMA | OK | 8,423 | 4,212 |
| TUL | TULSA INTL | TULSA | OK | 64,293 | 32,147 |
| EUG | MAHLON SWEET FIELD | LANE | OR | 40,428 | 20,214 |
| HIO | PORTLAND-HILLSBORO | WASHINGTON | OR | 8,575 | 4,288 |
| LMT | KLAMATH FALLS | KLAMATH | OR | 48,729 | 24,365 |
| MFR | ROGUE VALLEY INTL | JACKSON | OR | 61,595 | 30,798 |
| PDX | PORTLAND INTL | MULTNOMAH | OR | 260,005 | 130,003 |
| ABE | LEHIGH VALLEY INTL | LEHIGH | PA | 120,564 | 60,282 |
| AGC | ALLEGHENY COUNTY | ALLEGHENY | PA | 24,825 | 12,413 |
| AOO | ALTOONA-BLAIR COUNTY | BLAIR | PA | 27,260 | 13,630 |

| Airport Code | Airport Name | County | State | Total operations[a]: IFR + VFR | Total LTOs[b]: IFR+VFR |
|---|---|---|---|---|---|
| AVP | WILKES-BARRE/ SCRANTON INTL | LUZERNE | PA | 74,034 | 37,017 |
| ERI | ERIE INTL/TOM RIDGE FIELD | ERIE | PA | 48,659 | 24,330 |
| JST | JOHN MURTHA JOHNSTOWN | CAMBRIA | PA | 53,085 | 26,543 |
| LBE | ARNOLD PALMER RGNL | WESTMORELAND | PA | 42,541 | 21,271 |
| MDT | HARRISBURG INTL | DAUPHIN | PA | 69,276 | 34,638 |
| PHL | PHILADELPHIA INTL | PHILADELPHIA | PA | 539,901 | 269,951 |
| PIT | PITTSBURGH INTL | ALLEGHENY | PA | 260,027 | 130,014 |
| PNE | NORTHEAST PHILADELPHIA | PHILADELPHIA | PA | 15,173 | 7,587 |
| RDG | READING RGNL/ | BERKS | PA | 124,509 | 62,255 |
| UNV | UNIVERSITY PARK | CENTRE | PA | 64,416 | 32,208 |
| PVD | THEODORE FRANCIS GREEN | KENT | RI | 112,454 | 56,227 |
| WST | WESTERLY STATE | WASHINGTON | RI | 14,704 | 7,352 |
| CAE | COLUMBIA METROPOLITAN | LEXINGTON | SC | 104,926 | 52,463 |
| CHS | CHARLESTON AFB/INTL | CHARLESTON | SC | 83,563 | 41,782 |
| GSP | GREENVILLE-SPARTANBURG | GREENVILLE | SC | 60,933 | 30,467 |
| HXD | HILTON HEAD | BEAUFORT | SC | 14,476 | 7,238 |
| MYR | MYRTLE BEACH INTL | HORRY | SC | 37,695 | 18,848 |
| FSD | JOE FOSS FIELD | MINNEHAHA | SD | 31,690 | 15,845 |
| RAP | RAPID CITY RGNL | PENNINGTON | SD | 14,898 | 7,449 |
| BNA | NASHVILLE INTL | DAVIDSON | TN | 217,774 | 108,887 |
| CHA | LOVELL FIELD | HAMILTON | TN | 83,321 | 41,661 |
| MEM | MEMPHIS INTL | SHELBY | TN | 392,403 | 196,202 |
| TRI | TRI-CITIES RGNL | SULLIVAN | TN | 76,282 | 38,141 |
| TYS | MC GHEE TYSON | BLOUNT | TN | 130,699 | 65,350 |
| ABI | ABILENE RGNL | TAYLOR | TX | 13,354 | 6,677 |
| ADS | ADDISON | DALLAS | TX | 17,868 | 8,934 |
| AFW | FORT WORTH ALLIANCE | TARRANT | TX | 9,975 | 4,988 |
| AMA | AMARILLO INTL | POTTER | TX | 24,407 | 12,204 |
| AUS | AUSTIN-BERGSTROM INTL | TRAVIS | TX | 138,050 | 69,025 |
| BPT | SOUTHEAST TEXAS RGNL | JEFFERSON | TX | 63,014 | 31,507 |

| Airport Code | Airport Name | County | State | Total operations[a]: IFR + VFR | Total LTOs[b]: IFR+VFR |
|---|---|---|---|---|---|
| BRO | BROWNSVILLE/SOUTH PADRE | CAMERON | TX | 6,954 | 3,477 |
| CRP | CORPUS CHRISTI INTL | NUECES | TX | 24,344 | 12,172 |
| DAL | DALLAS LOVE FIELD | DALLAS | TX | 235,981 | 117,991 |
| DFW | DALLAS/FORT WORTH INTL | TARRANT | TX | 736,822 | 368,411 |
| EFD | ELLINGTON FIELD | HARRIS | TX | 135,087 | 67,544 |
| ELP | EL PASO INTL | EL PASO | TX | 101,701 | 50,851 |
| FTW | FORT WORTH MEACHAM INTL | TARRANT | TX | 12,445 | 6,223 |
| GRK | ROBERT GRAY AAF | BELL | TX | 13,856 | 6,928 |
| HOU | WILLIAM P HOBBY | HARRIS | TX | 238,555 | 119,278 |
| HRL | VALLEY INTL | CAMERON | TX | 21,353 | 10,677 |
| IAH | GEORGE BUSH INTERCONTINENTAL | HARRIS | TX | 589,437 | 294,719 |
| LBB | LUBBOCK INTL | LUBBOCK | TX | 42,677 | 21,339 |
| LBX | BRAZORIA COUNTY | BRAZORIA | TX | 62,893 | 31,447 |
| LRD | LAREDO INTL | WEBB | TX | 18,417 | 9,209 |
| MAF | MIDLAND INTL | MIDLAND | TX | 32,509 | 16,255 |
| MFE | MC ALLEN MILLER INTL | HIDALGO | TX | 15,937 | 7,969 |
| SAT | SAN ANTONIO INTL | BEXAR | TX | 211,356 | 105,678 |
| SGR | SUGAR LAND RGNL | FORT BEND | TX | 6,768 | 3,384 |
| SLC | SALT LAKE CITY INTL | SALT LAKE | UT | 454,715 | 227,358 |
| CHO | CHARLOTTESVILLE-ALBEMAR | ALBEMARLE | VA | 33,511 | 16,756 |
| HEF | MANASSAS RGNL | PRINCE WILLIAM | VA | 14,969 | 7,485 |
| ORF | NORFOLK INTL | NORFOLK | VA | 123,329 | 61,665 |
| PHF | NEWPORT NEWS/ WILLIAMSBURG | NEWPORT NEWS | VA | 228,525 | 114,263 |
| RIC | RICHMOND INTL | HENRICO | VA | 125,583 | 62,792 |
| ROA | ROANOKE RGNL/ WOODRUM FIELD | ROANOKE | VA | 85,338 | 42,669 |
| BTV | BURLINGTON INTL | CHITTENDEN | VT | 62,602 | 31,301 |
| BFI | BOEING FIELD/ | KING | WA | 290,752 | 145,376 |
| GEG | SPOKANE INTL | SPOKANE | WA | 99,770 | 49,885 |
| PSC | TRI-CITIES | FRANKLIN | WA | 34,108 | 17,054 |
| SEA | SEATTLE-TACOMA INTL | KING | WA | 346,820 | 173,410 |

| Airport Code | Airport Name | County | State | Total operations[a]: IFR + VFR | Total LTOs[b]: IFR+VFR |
|---|---|---|---|---|---|
| YKM | YAKIMA AIR TERMINAL/ MCALLISTER FIELD | YAKIMA | WA | 48,383 | 24,192 |
| ATW | OUTAGAMIE COUNTY RGNL | OUTAGAMIE | WI | 36,715 | 18,358 |
| CWA | CENTRAL WISCONSIN | MARATHON | WI | 13,693 | 6,847 |
| EAU | CHIPPEWA VALLEY RGNL | CHIPPEWA | WI | 6,173 | 3,087 |
| GRB | AUSTIN STRAUBEL INTL | BROWN | WI | 35,034 | 17,517 |
| LSE | LA CROSSE MUNI | LA CROSSE | WI | 16,159 | 8,080 |
| MKE | GENERAL MITCHELL INTL | MILWAUKEE | WI | 215,367 | 107,684 |
| MSN | DANE COUNTY RGNL | DANE | WI | 114,833 | 57,417 |
| CRW | YEAGER | KANAWHA | WV | 78,583 | 39,292 |
| HTS | TRI-STATE/MILTON | WAYNE | WV | 34,878 | 17,439 |
| LWB | GREENBRIER VALLEY | GREENBRIER | WV | 10,984 | 5,492 |
| PKB | WOOD COUNTY AIRPORT | WOOD | WV | 41,544 | 20,772 |
| CPR | NATRONA COUNTY INTL | NATRONA | WY | 20,278 | 10,139 |
| JAC | JACKSON HOLE | TETON | WY | 22,391 | 11,196 |
| SHR | SHERIDAN COUNTY | SHERIDAN | WY | 31,360 | 15,680 |
| TOTAL | | | | 34,044,499 | 17,022,250 |

Notes:

[a] Operations = departures and arrivals.

[b] LTOs = operations divided by 2.

# Appendix C PM Methodology Discussion Paper

Prepared by: John Kinsey (EPA-NRMRL) and Roger L. Wayson (Volpe)

**MISSION STATEMENT**

On April 11, 12, and 13, 2007, John Kinsey (EPA ORD) and Roger Wayson (FAA Volpe) were empowered to develop a total PM methodology from commercial aircraft engines for purposes of this study only. The developed methodology is meant to reflect current scientific understanding of aircraft PM measurements and include reasonable margins to accommodate uncertainties. The methodology should be developed to meet the requirements of CMAQ modeling - thereby, providing speciated estimates of (1) black carbon and volatile PM estimates from (2) sulfate and (3) organic emissions.

After a technically sound consensus was reached on the PM method and by close of business on April 13, they were expected to document the PM method (and the assumptions made) to the extent needed for other EPA and FAA people involved in this study to understand and apply the methodology to this study (this paper is the aforementioned documentation). Unless something is clearly wrong, the EPA and FAA agreed to move forward with their recommended PM methodology.

**BACKGROUND**

The estimation of particulate matter (PM) from aircraft is in its infancy with data being sparse and the test methods are still being refined.[69] There is an immediate need to estimate PM for airport planning and regulatory requirements, hence the development of the First Order Approximation (FOA). The FOA is only for estimation of PM emissions from jet turbine aircraft in the vicinity of airports. FOA 1.0[70] included only the non-volatile fraction of the PM emissions and is based on the ICAO smoke number (SN). Scaling the volatile and non-volatile components was included in FOA 2.0[71] to make it more complete.

However, a more in-depth procedure was needed to improve the fidelity of the approximation and better estimate the volatile fraction, resulting in further methodology development in FOA3. This methodology utilizes the ICAO SN to estimate the non-volatile component. The volatile component was estimated by breaking down the total volatile emissions into the most important components: sulphur, organics, and lubrication oil. Nitrates were not considered to be an important contributor based on available information.

This paper shows the formulation of each component for FOA 3.0 (FOA3) as developed by ICAO WG3 and then includes the changes made for the purposes of this study, which is utilizing the CMAQ model for air quality modeling. The modified version of FOA3 created for the purposes of this study is referred to as FOA 3.0a (FOA3a).

**OVERALL FORMULATION OF FOA3**

The FOA 3.0 breakdown by component led to a new general form of:

$$PMvols = F(\text{Fuel Sulfur Content}) + F(\text{Fuel Organics}) + F(\text{Lubrication Oil}) \qquad [1]$$

69 SAE E-31 Position Paper on Particle Matter Measurements
70 Wayson, R.L., G. Fleming, B. Kim, A Review of Literature on Particulate Matter Emissions from Aircraft, DTS-34-FA22A-LR1, Federal Aviation Administration, Office of Environment and Energy, Washington, D.C. 20591, December, 2003.
71 CAEP WP, A First Order Approximation (FOA) for Particulate Matter, Prepared by WG2, TG4.

PMnvols = SN v. Mass Relationship [2]

TOTAL PM = PMvols + PMnvols [3]

**INDIVIDUAL COMPONENTS**

***Non-volatiles (soot)***

The FOA 3.0 assumptions made were:

As proven by multiple researchers, SN correlates to non-volatile PM mass emissions.[2]

Average air-to-fuel ratios (AFR) per power setting[72] can be assumed for all commercial turbine jet aircraft as shown in Table C.1 using input from manufacturers.

Error in SN measurement by different researchers could be as great as ± 3 in extreme conditions. The actual measurements of the pollutants with different analyzers also have errors. However, a review of the standard deviations of the measurement error reported for APEX1 show that the values are far less than the SN possible error. As such, allowing the SN to change by a value of ± 3 form upper and lower bounds to the estimate.

A difference in the trends for SN and mass occur for those SNs ≤ 30 and those > 30. Most modern engines have SNs < 30 but older engines remain in the fleet and some method is necessary to allow prediction of these engines. As such, there must be a correlation for SN to mass for each of the four ICAO engine certification power settings as well as below and above a SN of 30, resulting in the use of eight equations.

The methodology is based on the available mass data at this time and is related to the smoke number (SN) so that emissions from the majority of jet turbine engines for commercial aircraft in the fleet can be approximated by using the ICAO emissions databank.

For the estimation of mass emissions for SNs less than 30, a correlation was used for measurement data developed by Dr. Hurley at Qinetiq in the United Kingdom. In-situ data from testing from DLR and the University of Missouri, Rolla were used for verification.

**Table C.1:** Assumed Average Air-to-Fuel Ratios by Power Setting

| Power Setting | AFR |
|---|---|
| 7% (idle) | 106 |
| 30% (approach) | 83 |
| 85% (climbout) | 51 |
| 100% (takeoff) | 45 |

The analysis of these data, based on mass per volume of exhaust, yielded an equation to predict the concentration index (CI) as compared to the SN as follows:

72 Eyers, C., CAEP/WG3/AEMTG/WP5, Improving the First Order Approximation (FOA) for Characterizing Particulate Matter Emissions from Aircraft Engines, Alternative Emissions Methodology Task Group (AEMTG) Meeting, Rio De Janeiro, Brazil.

$$CI = 0.0694(SN)^{1.23357} \quad [4]$$

Where: CI = concentration index (mg/M$^3$)

SN = smoke number ≤ 30

For SNs > 30 a different approach was utilized. In this case data from DLR in Germany as well as Hurley were used in the analysis.

$$CI = 0.0297(SN)^2 - 1.802(SN) + 31.94 \quad [5]$$

Where: SN = smoke number > 30

Final calculation of the non-volatile estimation of PM is based on two other derivations. The first is the calculation of the exhaust volume based on the AFR. This term is needed as a multiplier times the concentration index to allow an emission index directly tied to fuel usage as is customary. While details are presented in the working paper by Eyers[73], the reduced equation is:

$$Q = 0.776(AFR) + 0.733 \quad [6]$$

Where: Q = core exhaust volume (M$^3$)

AFR = modal air-to-fuel mass ratio

If the SN is measured with bypass air, the bypass ratio, β, will be used as a multiplier to estimate the exhaust volume. This would result in the form:

$$Q = \left[0.776(AFR) + 0.733\right](1 + \beta) \quad [7]$$

From this, the non-volatile PM EI for non-volatiles may be calculated from:

$$EI_{non\text{-}vol} = Q\,(CI) \quad [8]$$

Where: $EI_{non\text{-}vol}$ = emission Index (mg/kg fuel)

CI = emission concentration index (mg/M$^3$)

It is of note that upper limits were evaluated to provide a maximum bound to the predicted non-volatile EI and not necessarily as useable values. This was done by increasing the SN by a value of 3.

The equations that allow these conservative values are:

$$CI = 0.012(SN)^2 + 0.1312(SN) + 0.2255 \quad [9]$$

Where: SN = smoke number ≤ 30

$$CI = 0.0297(SN)^2 - 1.6238(SN) + 26.801 \quad [10]$$

Where: SN = smoke number > 30

One other problem exists. The ICAO database does not always contain complete SN information. A procedure was used based on dividing aircraft into groups by combustor design and using the trends of each group to fill in needed

[73] Eyers, C., CAEP/WG3/AEMTG/WP5, Improving the First Order Approximation (FOA) for Characterizing Particulate Matter Emissions from Aircraft Engines, Alternative Emissions Methodology Task Group (AEMTG) Meeting, Rio De Janeiro, Brazil.

SNs.[74] Use of this method allows modal calculations and prediction of the non-volatile EIs for the four defined modes for most engines listed in the ICAO database. The term most is used since some reported SNs are zero which result in extremely low EI values.

**MODIFICATIONS FOR NON-VOLATILE COMPONENT**

Two conservative approaches were reviewed: (1) the use of certification smoke numbers presented in the ICAO data bank plus 3 smoke numbers to bound the upper limit that could occur in smoke number measurement (Equation 9 and 10) or (2) adding a factor for bypass flow using the best estimate approach (Equation 7). Approach 1 was eliminated because the addition of 3 to a certification smoke number was meant to form an upper bound and not based on real conditions. For the purposes of this study, it was agreed to multiply the flow rate by the quantity (1+ bypass ratio). This approach was used for all engines, whether they are mixed flow turbofan engines or not. However, it is recognized that the bypass ratio multiplication factor is only appropriate for engines where the core and bypass flow are mixed prior to the engine exit (a small fraction of the existing in service engines). For engines where the core and bypass flow are mixed externally, use of this multiplication factor conservatively increases the value of the non-volatile primary PM component by as much as 9.40 using the ICAO bypass ratios.

***Sulfur Component***

The FOA3 assumptions made were:

Sulfur emissions are primarily a function of fuel sulfur since no other major source of sulfur exits.

Most sulfur results in gaseous emissions of $SO_2$ but some is converted from fuel sulfur to sulfuric acid ($H_2SO_4$). The total conversion requires a certain amount of residence time in the atmosphere and the sulfuric acid is being depleted at the same time by other atmospheric components. Sulfates would dominant PM found on an ambient air monitoring filter and a molecular weight of 96 for $SO_4$ was assumed.

Sulfur contents of fuels change from location to location and should remain a variable during the estimation process. Default values can be defined, however, based on published values.[75]

Conversion efficiencies also change from location to location but can be estimated and default values can be defined.[76]

These assumptions resulted in the form shown by Equation 11:

$$EI_{PMvols-FSC} = 1x10^6 \left[ \frac{FSC(\varepsilon)\, MW_{out}}{MW_S} \right] \quad [11]$$

Where: $EI_{PMvols-FSC}$ = EI for volatile fraction due to sulfur compounds emitted (mg/kg of fuel)

[74] W John Calvert, W.J., Revisions to Smoke Number Data in Emissions Databank, QinetiQ, Gas Turbine Technologies, 23 February 2006.

[75] Coordinating Research Council, Inc., Handbook of Aviation Fuel Properties, Third Edition, CRC Report No. 635, Alpharetta, GA., 2004.

[76] Schumann, U., F. Arnolod, R. Busen, J. Curtius, B. Karcher, A. Kiendler, A. Petzold, H. Schroder, and K.H. Wohlfrom (2002). Influence of fuels sulfur on the composition of aircraft exhaust plumes: The experiments SULFUR 1-7, Jour. of Geophysical Research, 107:D15, 4247.

| | |
|---|---|
| FSC | = fuel sulfur content (% by weight) |
| ε | = $S^{IV}$ to $S^{VI}$ conversion rate as a fraction |
| $MW_{out}$ | = 96 for sulfates in exhaust |
| $MW_S$ | = 32 for sulfur |

**MODIFICATIONS FOR SULFATES:**

Discussions for this study were based on three topics: fuel sulfur content, conversion efficiency, and final product. The typical value for fuel sulfur content listed in the Handbook of Aviation Fuel Properties, which is $0.068\%_{mass}$ (680 ppmm), was selected. Conversion of gaseous sulfur species, primarily $SO_2$, occur creating particulate matter. While much more is involved, the gas-to-particle conversion process can be simply described by the following major chemical reactions:

$$SO_2 + O(+M) \rightarrow SO_3(+M)$$
$$SO_3 + O \rightarrow SO_2 + O_2$$
$$SO_2 + OH \rightarrow SO_3 + H$$
$$SO_2 + OH(+M) \rightarrow HOSO_2(+M)$$
$$HOSO_2 + O_2 \rightarrow SO_3 + HO_2$$
$$SO_3 + H_2O \rightarrow H_2SO_4$$

Of note is that sulfuric acid ($H_2SO_4$) is hydroscopic and will combine readily with atmospheric moisture resulting in a hydrated compound. Aircraft engine literature indicates that as low as one molecule of water per two of sulfuric acid or as much as two molecules of water per molecule of sulfuric acid could occur resulting in a heavier compound.[77,78] Assuming a simple conversion efficiency for this complex set of reactions, several literature references were reviewed and an upper limit value of 5% was selected[79,80]. After discussion with the CMAQ modelling team, it was decided that the final product should not include hydration of $H_2SO_4$ since this is done as part of the CMAQ simulation process and that a molecular weight of 98 should be used as a modification of the term $MW_{out}$ in Equation 11.

**Fuel Organic Emissions**

The FOA3 assumptions made for PM fuel organics were:

Gas phase total hydrocarbons (HC) EIs are directly related to PM fuel organic emissions. That is, if unburned HC emissions increase, so do the overall PM organic emissions in a related fashion.

[77] Dakhel, P.M., S.P. Lukachko, I.A. Waitz, , R.C. Miake-Lye, and R.C. Brown (2005). Post-Combustion Evolution Of Soot Properties In An Aircraft Engine, Proc. Of GT2005, ASME Turbo Expo 2005: Power for Land, Sea and Air, Reno-Tahoe, NV., June 6-9.

[78] Arnold, F., T.H. Stilp, R. Busen, and U. Schumann (1998). Jet engine exhaust chemiion measurements implications for gaseous $SO_3$ and $H_2SO_4$, Atmospheric Environment, 32:18, 3073-3077.

[79] Sorokin, A., E. Katragkou, F. Arnold, R. Busen, and U. Schumann (2004). Gaseous $SO_3$ and $H_2SO_4$ in the exhaust of an aircraft gas turbine engine: measurements by CIMS and implications for fuel sulphur conversion to sulfur (VI) and conversion of $SO_3$ to $H_2SO_4$, Atmospheric Environment, 38, 449-456.

[80] Schumann, U., F. Arnold, R. Busen, J. Curtius, B. Karcher, A. Kiendler, A. Petzold, H. Schlager, F. Schroder, and K.H. Wohlfrom (2002). Influence of fuel sulfur on the composition of aircraft exhaust plumes: The experiments of SULFUR 1-7, Jour. of Geophysical Research, 107:D15, 4247.

Fuel PM organic emissions can be formed as a coating on non-volatile PM or due to condensation from the gas phase. This process is not well understood at this time and although these emissions are included, there is no separate calculation process.

Measurement data separating the organic fraction from the overall PM emissions from in-service engines are very limited. Information from APEX1 would seem to be the most reliable at this time. However, only one engine (CFM56-2-C1) is included and it is assumed that the trends shown in Figure D.1 are consistent for all commercial jet turbine engines in the ICAO database. As such, ICAO certification EIs for hydrocarbons can be related to the PM fuel organic emissions.

The data used is for a probe 30 meters behind the aircraft. It is assumed that in this distance volatile organic PM emissions are representative of those in the atmospheric in the vicinity of airports since other data is not available.

The overall estimation problem is multi-faceted & many details are not well known. As such, the organics methodology for PM fuel organics must be simplistic at this time.

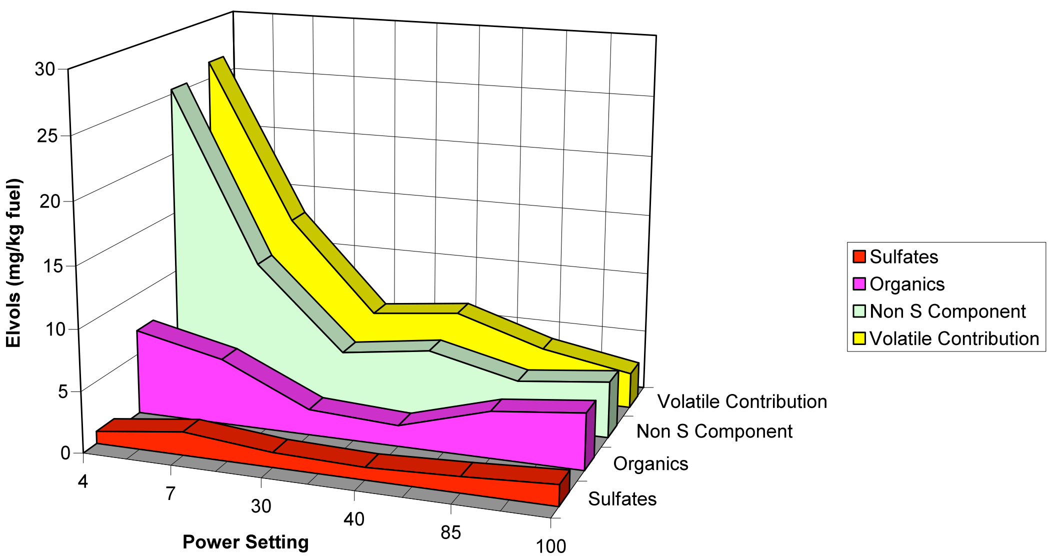


**Figure C.1:** Trends from APEX 1 for CFM56-2-C1 engine

The resulting “non S component” was derived by subtracting the “sulfates” from the “volatile contribution” except for the power settings of 85 and 100%. At these power settings, the values dropped below that shown as “organics” measured by a different instrument. In an attempt to not under-predict, the values of the “organics” curve shown in Figure D.1 for 85 and 100% power settings were used directly. This resulted in Equation 12 with all modes defined for the “non S component.”

$$PMvol_{fuel\_organic} = \frac{Non\_S\_Component}{EI_{HC(CFM56-2C5)}}(EI_{HC(Engine)}) \qquad [12]$$

Where: $PMvol_{fuel\ organic}$ = volatile PM emissions of organics (mg/kg fuel)
Non_S_Component = a constant ratio based on the trends shown in Figure D.1.
$EI_{HC(CFM56)}$ = ICAO emission index for hydrocarbons for the CFM56 engine
$EI_{HC(Engine)}$ = specific ICAO emission index for hydrocarbons for the engine of concern

**MODIFICATIONS ON FUEL ORGANICS:**

The CFM56 scaling method was reviewed and it was decided that a true mass balance represented a more consistent approach across the entire power spectrum. It was also agreed that a margin of conservatism should be added to the resulting values from the mass balance approach. This required modifications in two steps.

Step 1: The measured volatile component derived from APEX1 data was used and adjusted for the sulfur component (shown as “sulfates” in Figure D.1). In this approach, a single set of measurements was used to avoid conflicting data from different measurement techniques. This resulted in the curve shown as the “non S component” no longer being adjusted for the 85 and 100% power setting as was done in the FOA 3.0 approach described previously. Instead, the resulting curve used is simply the curve listed as the “volatile contribution” in Figure D.1 is subtracted off the values of the “sulfates” at each engine power setting so that sulfur is not counted twice. Also, to be conservative, it is assumed that 100% of the resulting “volatile component” curve are semi-volatile and in the particle phase.

Step 2: To ensure an even more conservative method, the APEX1 data set was further analyzed to determine total volatile PM. Again using the APEX1 data for the base fuel condition, the ratio of sulfur to organics was determined from reported measurements and this ratio used to subtract out the sulfate contribution from the total volatile PM. This resulted in a volatile PM component that did not include sulfur. These results are reported in Table C.2.

**Table C.2:** Derived “Non_S_Component values by mode [mg/kg fuel]

| Mode | Volatile Contribution | Sulfates | Derived Non_S_Component |
|---|---|---|---|
| Idle | 13.2 | 1.9 | 11.3 |
| Approach | 5.7 | 1.2 | 4.5 |
| Climbout | 4.2 | 1.3 | 2.9 |
| Takeoff | 2.9 | 1.7 | 1.2 |

The standard deviation of the individual data points for this derived volatile component, without sulfates, was then computed (see Table D.3) and added to the new derived “non S component”. This new, more conservative, ”non-S component” was used in Equation 12 to calculate the EI for PM organics.

This is shown in equation form as:

$$(\text{Total PM} - \text{Non-volatile PM})(1-(\text{sulfate/organics})) = PM_{non\text{-}S\ organics}$$

$$\text{Standard deviation}(PM_{non\text{-}S\ vol}) + \text{non S component (Figure D.1)} =$$
$$\text{Modified non S component (to be used in Equation 12)}$$

**Table C.3:** Computed standard deviations for the volatile PM component

| Mode | Std. Dev. [mg/ kg fuel] |
|---|---|
| Idle | 25 |
| Approach | 10 |
| Climbout | 16 |
| Takeoff | 19 |

**Lubrication Oil**

Emissions of lubrication oil are not well documented in the literature. As such, an approximation method for this component was not included in the FOA 3.0.

**DECISION ON LUBRICATION OIL:**

Data was extremely scarce and multiple engineering judgments had to be made based on data supplied by an engine manufacturer. Lubrication oil use increases with engine wear until a critical value of about 0.3 quarts per hour occurs. At this time, the engine is removed from service for substantial reworking and maintenance. Based on an assumption that about 0.1 of the value used for overhaul standards represents nominal operating consumption, it was determined that approximately 0.03 quarts per hour of lubrication oil are lost. Since venting is the primary release and tends to occur at the higher power settings, a ratio of the time in takeoff (0.7 minutes) and climb-out (2.2 minutes) modes were used and it was found that 0.00145 quarts could be emitted during these operations in the vicinity of airports. Using a specific gravity of 1.0035 reported for Mobil Jet Oil II (density = 1,003.5 kg/$m^3$ or 949.7 grams/quart)[81], it was found that approximately 1.4 grams of lubrication oil volatile organic PM could be released per landing and takeoff operation (LTO). This value is added to the volatile PM contribution from fuel organics to determine the total organic volatile component for input into the CMAQ model. Sulfur volatile emissions are handled separately in this method and this is also required by the CMAQ model.

The estimation of the lubrication oil emissions in equation form is:

Nominal consumption = 0.3 quarts/hr * 0.1 = 0.03 quarts/hr

Emissions per LTO = 0.03 quarts/hr * 1 hour/60 min * 2.9 min/LTO = 0.00145 quarts/LTO

Emissions (grams/LTO) = 0.00145 quarts/LTO * 949.7 grams/quart
≈ 1.4 grams of volatile PM from lubrication oil per LTO

**RESULTING EQUATIONS FOR CMAQ IMPLEMENTATION**

The inclusion of the modifications results in a different set of application equations. The terms of these equations are as previously defined unless noted. The equations for the method used in this study are:

Overall Equations:

PMvols = F(Fuel Sulfur Content) + F(Fuel Organics) + F(Lubrication Oil Organics) [1a]

[81] 1,003.5 kg/m3 * 1 m3/1,056.7 quarts * 1,000 grams/1 kg = 949.7 grams/quart

PMnvols = SN v. Mass Relationship = Q (CI) [2a]

TOTAL PM = PMvols + PMnvols [3a]

Detailed Equations:

$$CI = 0.0694(SN)^{1.23357} \text{ (for SN ≤ 30)} \quad [4a]$$

$$CI = 0.0297(SN)^2 - 1.802(SN) + 31.94 \text{ (for SN > 30)} \quad [5a]$$

Equation 6 is no longer used in the method employed in this study.

$$Q = \left[0.776(AFR) + 0.733\right](1 + \beta) \quad [7a]$$

$$EI_{non\text{-}vol} = Q\ (CI) \quad [8a]$$

Equations 9 and 10 are no longer used in the method employed in this study.

$$EI_{PMvols-FSC} = 1x10^6 \left[\frac{FSC(\varepsilon)\, MW_{out}}{MW_S}\right] \quad [11a]$$

Where: FSC = 0.00068 (typical mass fraction)
ε = 0.05 (conservative fractional conversion)
$MW_{out}$ = 98

$$PMvol_{fuel\_organic} = \frac{Non\_S\_Component}{EI_{HC(CFM56)}}(EI_{HC(Engine)}) \quad [12a]$$

Where: "Non_S_Component" is now the revised term and is the derived modal "Non_S_Component" (Table C.2) with the modal standard deviation added (Table D.3).

$$EI_{lube\ oil} = 1.4 \text{ grams/LTO} \quad [13a]$$

$EI_{lube\ oil}$ = Lubrication oil emission index per LTO cycle [g/engine-LTO]

To predict the total PM the procedure is:

Total PM EI w/o lubrication oil = (Equation 4a or 5a * Equation 7a) + Equation 11a + Equation 12a

The resulting EIs must then be multiplied by time in mode, fuel use by mode, and number of engines. Lubrication oil emissions are then added to each aircraft LTO cycle per engine (number of engines * number of LTOs * 1.4) and accounts for emissions separately using Equation 13a.

Lubrication oil may also be used as a typical EI with units of mg/kg fuel and applied in the climbout and takeoff modes. While the mass over an LTO will stay constant at 1.4 grams per LTO for all aircraft engine types, the value of the EI will vary dependent upon fuel use for a particular engine. This is necessary because of the units for EIs, mass per kilogram of fuel used. To apply lubrication oil volatile PM emissions in this way, the following is required.

- Determine the fuel use rate in kg/s from the ICAO data bank for the engine of concern.
- Multiply the modal fuel usage rate by the time in mode (132 seconds for climbout and 42 seconds for takeoff). This is the total fuel used in the vicinity of the airport during these two modes for the selected

engine.

- Divide the volatile PM from lubrication oil in each of the two modes by the total fuel use in each mode. The volatile PM for each mode is 1060 mg during the climbout mode and 340 mg during the takeoff mode. This final number has the units of mg/kg fuel as required.

An example of this application is included in the implementation section of this paper.

**IMPLEMENTATION**

The sum of the calculation for the volatile PM (sulfates, lubrication oil and organics) and the non-volatiles (soot) then provides an overall total EI for the PM emitted from jet turbine aircraft. The largest uncertainties are associated with the prediction of the volatile PM emissions; sulfur, fuel organics and lubrication oil emissions. Sulfur is better understood than the other two. These uncertainties can only be resolved by carefully planned measurements and further analysis. In sum, it is the opinion of the authors, that the FOA3.0a sufficiently serves the purpose of predicting the LTO emissions for use in CMAQ for this study.

The derived EI values for this study were compared to those of FOA3.0 for four engines often used in the fleet. The results are shown in Figure C.2 through Figure C.4. It should be noted that lubrication oil PM EIs were developed using the method described in the last section. The details of the EI derivation for lubrication oil follows.

At the present time lubrication oil is estimated as 1.4 grams / 2.9 minutes which is the time the engines are in the higher power settings in the vicinity of an airport (climbout and takeoff modes). Following the procedure in the last section of this paper the following steps were performed.

Step 1: The mass was divided into two fractions for lubrication oil.

Climbout mode = (2.2 min / 2.9 min) * 1.4 grams = 1.062 or ≈ 1060 mg

Takeoff mode = (0.7 min / 2.9 min) * 1.4 grams = 0.338 or ≈ 340 mg

The fuel usage rates were determined from the ICAO Emissions Databank for each mode. These are shown in Table C.4.

**Table C.4:** ICAO fuel use rates for three engines evaluated. [kg/s]

| Mode | CFM56-3 | RB211-535E4-B | PW4158 |
|---|---|---|---|
| Climbout | 0.878 | 1.65 | 2.004 |
| Takeoff | 1.056 | 2.08 | 2.481 |

Step 2: The fuel consumed for the time in mode were computed and are shown in Table D.5.

**Table C.5:** Total fuel use for climbout and takeoff modes [kg fuel]

| Mode | CFM56-3 | RB211-535E4-B | PW4158 |
|---|---|---|---|
| Climbout | 115.9 | 217.8 | 264.5 |
| Takeoff | 44.4 | 87.4 | 104.0 |

Step 3: The PM volatile mass from lubrication oil emissions for each of the two modes was divided by the fuel consumed in each mode and the final results are shown in Table C.6.

**Table C.6:** Lubrication oil EIs for climbout and takeoff for selected engines. [mg/kg fuel]

| Mode | CFM56-3 | RB211-535E4-B | PW4158 |
|---|---|---|---|
| Climbout | 9 | 5 | 4 |
| Takeoff | 8 | 4 | 3 |

These values were included in the overall EIs which are shown in Figure C.2 through Figure D.5.

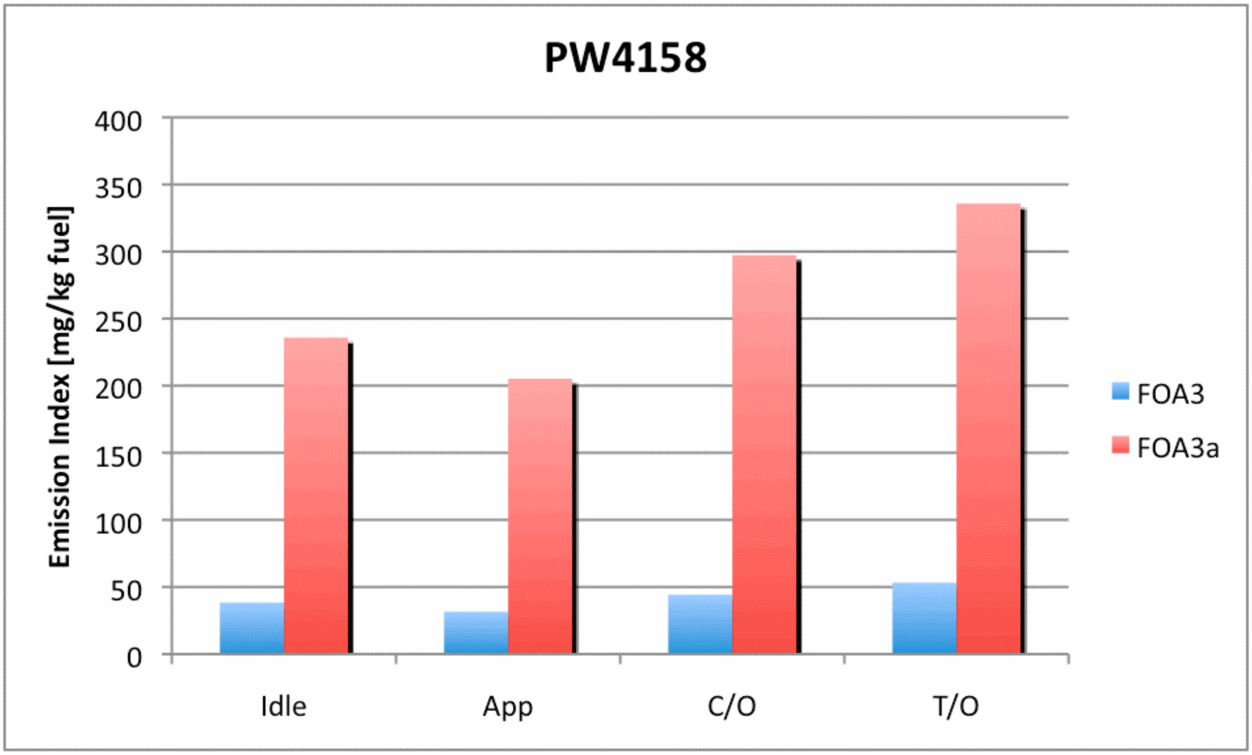


**Figure C.2:** Comparison of FOA3.0a to FOA 3.0 for the PW4158 engine

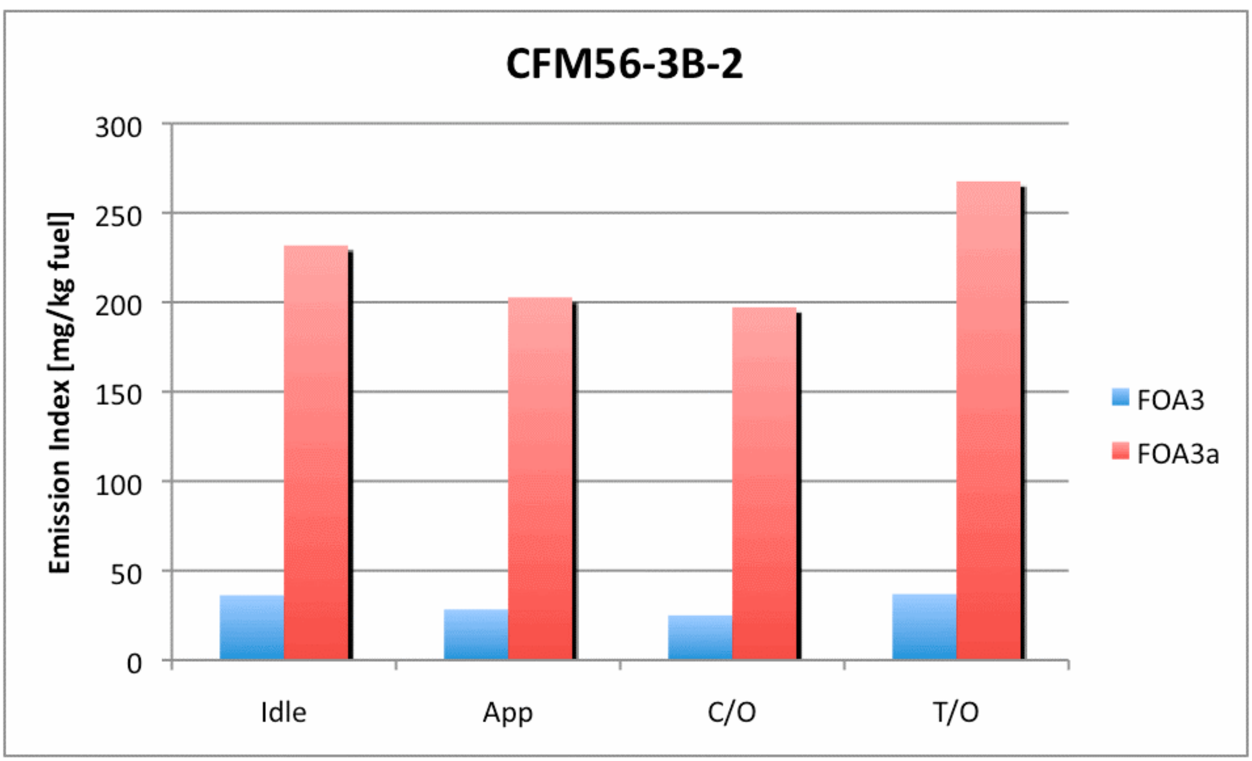


**Figure C.3:** Comparison of FOA3.0a method to FOA 3.0 for the CFM56-3B-2 engine.

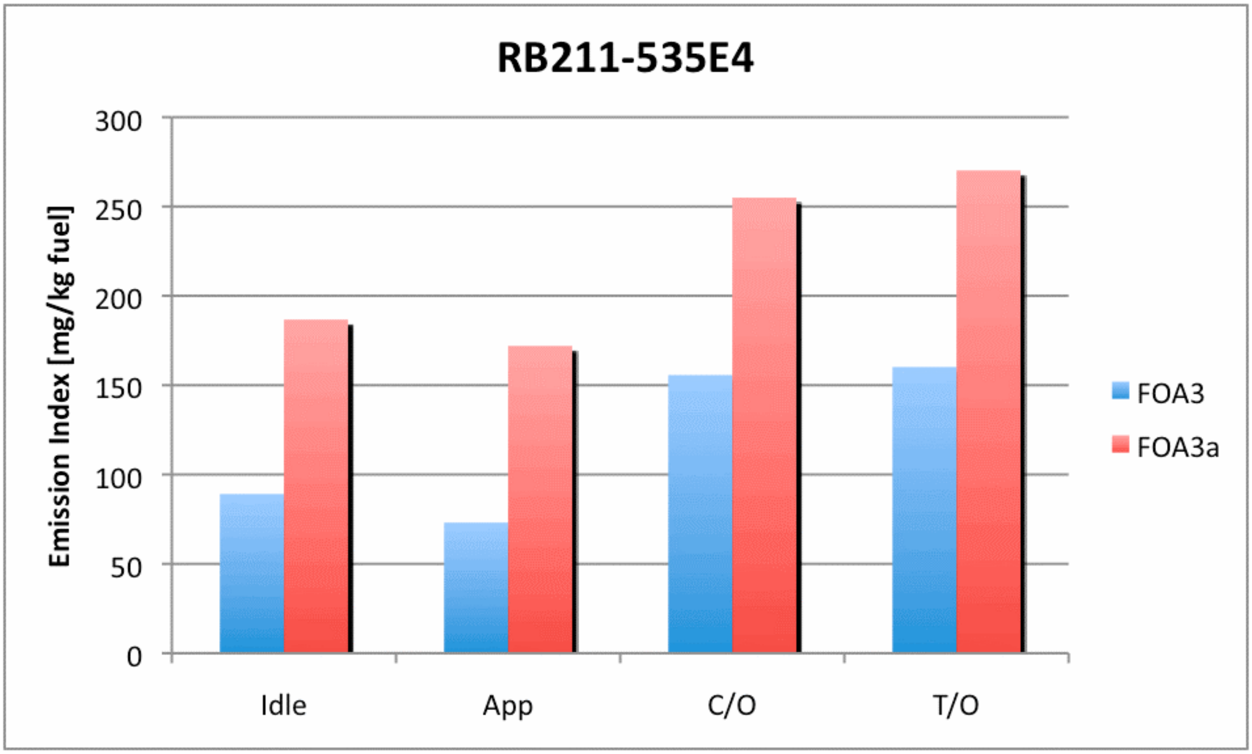

**Figure C.4:** Comparison of FOA3.0a method to FOA 3.0 for the RB211-535E4 engine.

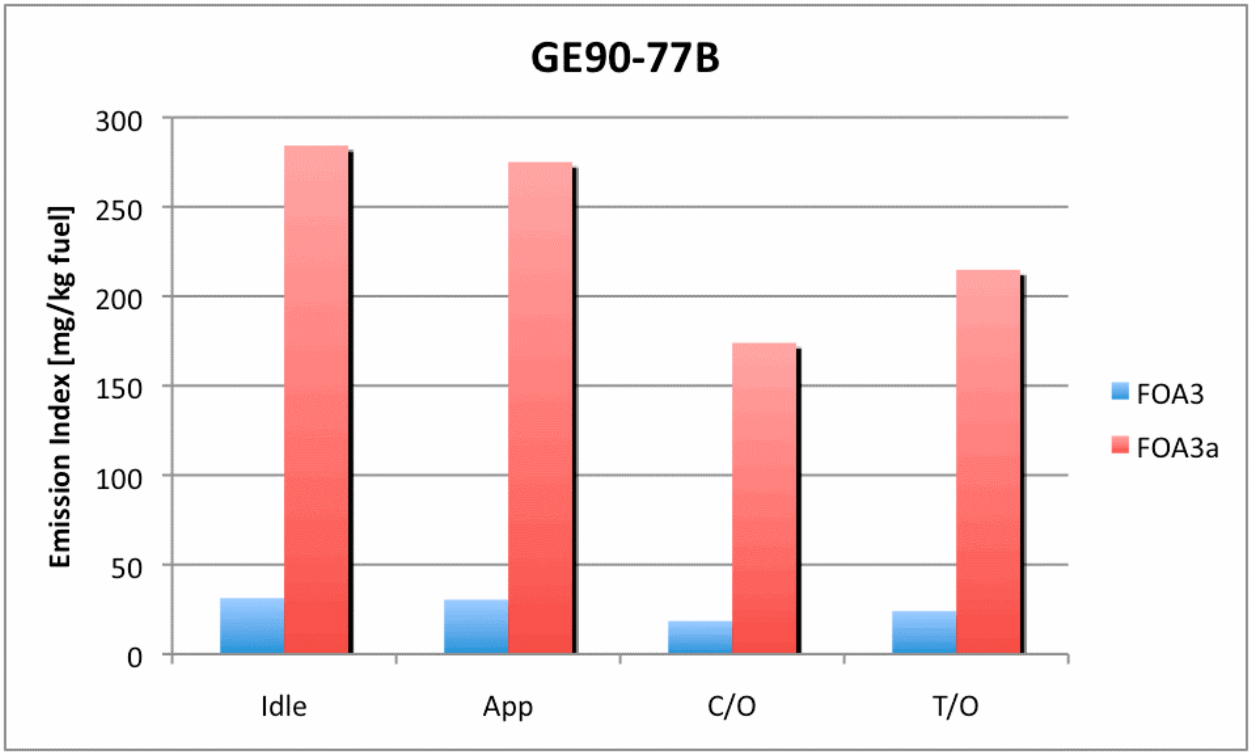


**Figure C.5:** Comparison of FOA3.0a method to FOA 3.0 for the GE90-77B engine.

**RECOMMENDATIONS**

1. For the purposes of this study only, the FOA3a method should be adopted as the current technique to estimate PM emissions from jet turbine aircraft in the vicinity of airports for CMAQ modeling.

2. Separate from this study, efforts should continue to improve the FOA until it can be replaced by measurement data.

# Appendix D Data Collection and Analysis of Aircraft Auxiliary Power Unit Usage

Prepared by Metron Aviation, Inc.

**Background**

As discussed in the body of the report, a part of the overall study approach required the collection of usage data for auxiliary power units (APUs). An APU is a relatively small self-contained generator used in aircraft to start the main engines, usually with compressed air. In addition, they provide electrical power and compressed air to operate the aircraft's instruments, lights, ventilation, and other equipment (typically while the aircraft is parked at the gate). In many aircraft, the APU can also provide electrical power for the aircraft while in the air. In most cases, the APU is powered by a small gas-turbine engine that provides compressed air from within or drives an air compressor.

APUs are routinely used throughout the time an aircraft is on the ground. APU usage is determined by individual airlines and varies with aircraft type and several other factors. For arrivals, some airlines will start the APU when the aircraft is on approach. It will stay on during the entire taxi-in phase to ensure its availability if the engines need to be restarted. Other airlines may operate the APUs during taxi-in if they are using reduced power or a single engine.

During the departure phase of a flight, the APU is used to start the main engine. Some airlines will keep the APU operating during taxi-out as a backup. In addition, when an aircraft is expected to temporarily park away from the gate, the APU will be used during the taxi-out phase of flight.

**Factors Affecting APU Usage**

APU use varies with aircraft type, airline, and airport. Aircraft size has an influence on the time it takes to service and load the aircraft, and thus influences the time that the APU is utilized. For a given aircraft type, the specific APU used will vary between airlines depending on the equipment onboard the aircraft.. For a particular airline, the APU unit may be used differently at two different airports. Factors such as availability of ground-based power units and airport environment, both climatologically and procedurally, affect the usage of APUs.

The availability of a ground-based power unit affects APU usage in several ways. If a pilot knows a ground-based unit exists at the gate, the APU may remain off during taxi-in time with the understanding that the ground-based unit will power the aircraft at the gate. Even when a ground-based unit is available at the gate, the airline may decide to start the APU during flight preparations.

With regard to airport location, a flight at an airport that is located in a warmer or colder climate will often need to use the APU longer than one operating at an airport in a more temperate location. In addition, APU usage generally increases during the summer and winter months due to increased need for cooling or heating.

There are at least four operational phases to consider when discussing APU use:

- Departure Preparations: If ground-based support is available, APUs may be turned on just prior to pushing back from the gate, or, if no ground support is available, the APUs may be started to help prepare the cabin for passengers or cargo.
- Departure Taxi: Once the aircraft leaves the gate the carrier may have a standard operating procedure to taxi on fewer than all of the engines. If the engines are not producing the needed power to maintain the cabin environment, the APU may be used as a supplement.
- Arrival Taxi: When the aircraft lands and taxis to the gate the APU again may be used to supplement power depending on the use of the aircraft's engines.

- Arrival at the Gate: If power and conditioned air are available at the airport's gate, the APU might remain on until the aircraft is properly connected to the ground source. If no ground support is available, the APU may be shut off or remain operating, depending on when the aircraft will be used next or for maintenance purposes.

APUs also have varying power settings, and therefore differences in resulting emissions per unit of operating time.

**Method and Results**

When computing emissions associated with flight operations, the FAA Emission and Dispersion Modeling System (EDMS) incorporates estimated APU usage times as part of the calculation. If the user cannot provide more detailed information, EDMS Version 4.11 provides a default APU operation time of 26 minutes per aircraft landing/take-off cycle (LTO), independent of any other factors. In EDMS Version 5.0, certain improvements have been made. In EDMS Version 5.0, APU times are now allocated to arrivals and departures separately to allow for analysis without looking at the entire LTO.

As an initial step toward providing additional information from which to estimate APU usage for this study, APU usage data was collected in a limited, informal fashion from several airlines. We discussed patterns of usage, dependencies on the factors discussed above, and the availability of carrier statistics. In addition to background information from several airlines, quantitative data was provided by three airlines. This quantitative data can be characterized as follows:

- *Airline A* – Partial data for four wide-body types and one narrow body type, covering 4-6 months of operation, but no information on numbers of aircraft or airports sampled. The range of usage for wide-body aircraft during the period was from 1 to 2.3 hours/flight, and 0.9 to 1.4 hours/flight for narrow-body aircraft. Some variation in seasonal use was apparent, with the monthly averages for all aircraft sampled ranging from about 1.1 to 2.0 hours/flight between the lowest-use month and the highest.
- *Airline B* – One year of data for airframes of a single narrow-body type, with the number of airframes sampled each month ranging from 54 to 78. The number of airports serviced was not captured, but was probably substantial. Some variation in seasonal use was apparent, with the monthly averages for all aircraft sampled ranging from about 0.9 to 1.1 hours/flight between the lowest-use month and the highest. Wide variation in usage between airframes was observed, with the yearly average ranging from about 0.3 to 3.4 hours/flight.
- *Airline C* – Average usage times per flight for one narrow-body aircraft and one wide-body aircraft. The amount of data used to develop these averages was not specified.

As contact was made with various carriers it became clear that collection and analysis of APU usage was at different levels of detail and maturity for each airline. Data has not been captured in a consistent fashion and is dependent on ease of availability and on the carrier's internal needs. Furthermore, although many carriers have standard operating procedures for when and how to use APUs, the ultimate decision rests with the pilot.

Collection of such data is challenging for two reasons. Some airlines believe the data to be proprietary and are reluctant to distribute it. In addition, APU usage data is evidently not trivial to record, and is consequently not recorded by airlines on a regular and systematic basis. Due to these challenges, APU times collected in this initial effort do not distinguish between APU usage during taxi and APU usage at the gate.

However, it should be noted that several airlines contacted were currently performing APU studies themselves to determine how to reduce APU time. As the price of jet fuel continues to rise, it is expected that more airlines will study APU usage and aim to improve efficiency. More systematic data may then become available.

Once the available data was assembled, the aircraft types represented were aggregated into two classes: wide-body and narrow-body jet. In addition, the wide range of the available data was represented by three values of APU usage per LTO cycle in each class: low, moderate, and high. The usage estimates derived from the available data are as follows:

**Table D.1:** APU use per LTO cycle (minutes)

| Narrow Body | | | Wide Body | | |
|---|---|---|---|---|---|
| Low | Moderate | High | Low | Moderate | High |
| 31 | 48 | 65 | 96 | 130 | 163 |

The available data is not sufficiently specific to draw strong conclusions, but an interim approach might be to use the lower values to represent situations in which aircraft have access to ground support, while the upper values could represent situations where ground support is not available. Additional judicious use of these values might represent differences in seasonal use and airport climatic conditions.

**Next Steps**

To better estimate the usage of APUs at airports, more data and supporting analysis is needed. With the assistance of appropriate trade organizations, additional carriers should be contacted to increase the sample size, as well as the level of detail. It would appear that some carriers are modifying operating practices in this area, and an understanding of trends in these changes should be developed. In addition, airport-oriented data collection could be undertaken to determine the availability of ground-based units, the average time planes are parked somewhere other than at the gate, meteorological conditions through the year, etc. From these types of data, more accurate estimates of APU usage under different conditions, as well as sensitivities to other factors, could be derived.

**Effects of Auxiliary Power Units**

The baseline inventory described in Section 3.1 provided the basis for the NEI comparison, the air quality modeling, and health impact analysis. This inventory was created assuming a medium level of APU usage. An assessment of the impacts of APUs on LTO emissions was performed, requiring two additional inventories with different APU assumptions. In addition, for evaluation purposes in regard to the 148 airports in non-attainment areas, a total of three emissions inventories were created using the *high*, *medium*, and *low* APU times. These APU inventories were then compared to total aircraft LTO emissions.

Under the low APU usage scenario, the greatest percentage that APUs contributed to total aircraft emissions at an airport was under 10% for CO and between 15 and 20% for $NO_x$ and $SO_x$. For the high APU usage scenario, the percentages increased to over 15% for CO and over 30% for $NO_x$ and $SO_x$. However, investigating the airports where APU emissions were a high percentage of total LTO emissions revealed that these airports served a higher percentage of business jet operations. For certain small business jets with small taxi times, an hour of APU time (the upper value) can produce enough $SO_x$ emissions to account for more than 30% of LTO emissions. This analysis likely overstates the contribution of APU emissions since it may not be realistic to assume that a business jet will spend an hour with the APU operating during an LTO when there is limited loading and unloading of passengers.

Additionally, an inventory of all 325 airports with VFR and IFR traffic was created using the *medium* level of APU usage; the range of contribution of the medium level of APU usage to aircraft emissions below 3,000 feet is between 0% and slightly over 25%, as shown in Figure E.1.[82] The average is below 5% for CO and VOCs and under 10% for $NO_x$ and $SO_x$. For only four non-attainment areas considered in this report, the medium level of APU usage contributes over 1% to census area emissions (or total emissions) as estimated in the 2002 National Emissions Inventory.

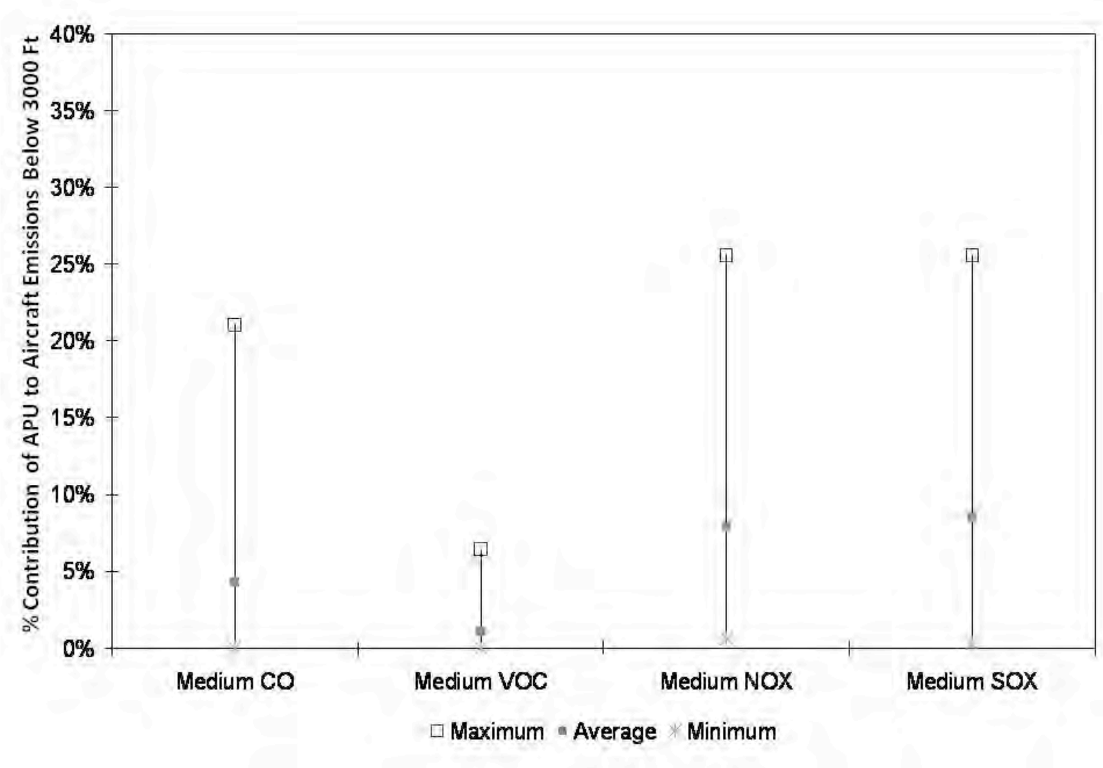


**Figure D.1:** Range of the percentage of aircraft emissions due to APU at 325 airports studied

In airports with a high volume of operations, the effect of APUs is overshadowed by the emissions from the main engines. However, in areas with fewer operations with less delay, APU emissions play a greater role.

Using data that were generated for Section 4.2, the effects of APU usage were evaluated in a no ground delay scenario. If the aircraft experienced no delay and the APU usage remained the same (currently there is no extra APU usage assumed for periods of delay), then at medium levels of usage APUs would result in more than 15% of the aircraft emissions for CO, greater than 25% for $NO_x$ and greater than 30% for $SO_x$. As the system is driven to less ground delay, APUs may play a greater role in aircraft emissions below the mixing height.

[82] It is possible for airports to have aircraft that do not have APUs.

# Appendix E Emissions and Dispersion Modeling System (EDMS) Baseline Aircraft Emissions Inventory

A baseline emissions inventory for all aircraft arriving to and departing from the 325 study airports was generated using aircraft operations data from the most current FAA Enhanced Traffic Management System (ETMS)[83] data for the period between June 2005 and May 2006, providing one year of operations for each airport. The operations data was used as input to the FAA Emissions and Dispersion Modeling System (EDMS[84]), version 5.02 An older version of EDMS was used to generate aircraft emissions inventories for the 2001 EPA National Emissions Inventory; PM emissions factors for this version of EDMS were based on data for several engines in AP 42, which is an EPA compilation of air pollutant emissions factors,[85] In contrast, version 5.02 of EDMS contains the FOA3a method for estimating PM emissions from aviation (described in Appendix C), and actual aircraft operational data was used as an input to EDMS version 5.02 to generate aviation emissions estimates for this study. Rather than assuming a particular national mix of engines and airframes, data on specific engine-airframe combinations were used. Additionally, modeled operations were based solely on the data available and were not averaged across months to give annual estimates of emissions. Thus, the aviation emissions data generated by EDMS 5.02 was of a higher fidelity than the aviation emissions data in the 2001 NEI. For this reason, the EDMS emissions inventory was used for this study.

General information on Instrument Flight Rules (IFR) flights was gathered from ETMS.[86] ETMS provides the flight number, the origin and destination airport for the flight, and a generic aircraft type. The generic aircraft type is not suitable for modeling emissions; specific airframe and engine combinations are required. The Bureau of Transportation Statistics (BTS) On-Time Performance Database[87] was used to match flight numbers to aircraft registration numbers (tail number), in order to match each flight to a specific aircraft type. Over 12.5 million operations were generated by combining these two sources.

Registration information for the aircraft was obtained from the commercially-available BACK fleet database[88] or the FAA's aircraft registration database.[89] These databases were used to determine the engine models installed on individual aircraft based on the tail number. The BTS data also provides aircraft pushback, wheels up, touchdown, and gate arrival times. This allowed outbound and inbound taxi times to be calculated for input into EDMS. Since not all flights appear in the BTS data, flights not reported in BTS were assumed to have taxi times equal to the average of the reporting flights at the airport performing a similar operation during the same hour.

The data gathered through ETMS and BTS provided only a portion of the operational profile (IFR traffic). Visual Flight Rules (VFR) traffic operations were estimated by subtracting IFR operations from the total operations for the airport as listed in the Air Traffic Activity Data System (ATADS). The fleet mix of VFR aircraft was estimated from typical aircraft categories based at each airport.

Aircraft operations were aggregated by airframe, engine and takeoff weight to ease the computational requirements

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[83] http://www.fly.faa.gov/Products/Information/ETMS/etms.html
[84] http://www.faa.gov/about/office_org/headquarters_offices/aep/models/edms_model/
[85] http://www.epa.gov/ttn/chief/ap42/
[86] IFR traffic refers to aircraft that operate using an internal mechanism to show visually or aurally the attitude, altitude or operation of the aircraft. These flights include electronic devices for automatically controlling the aircraft in flight. The majority of commercial flights operate under IFR. VFR traffic refers to flights in which the pilot has responsibility for maintaining separation distances visually. VFR flights are mainly performed by general aviation traffic operating small aircraft.
[87] http://www.transtats.bts.gov/OT_Delay/OT_DelayCause1.asp
[88] http://www.backaviation.com/Information_Services/
[89] Federal Aviation Administration Registry Database, Fall 2006, available from http://registry.faa.gov/.

of EDMS. The taxi in and out times were averaged across those operations at an airport level by engine and airframe type. These averages were computed by month. If sufficient engine and airframe data did not exist, default averages for the airport were used; if airport defaults did not exist, ICAO default taxi times were used. To compute an upper bound on aircraft emissions during taxi, all operations were assumed to taxi in and out using all engines for the entire estimated taxi time.[90]

The FAA registration database and the National Airspace System Resources (NASR)[91] were used as additional data sources to help determine VFR operations at airports in nonattainment areas, and the operational profile was fed into EDMS. Inventories were generated for CO, hydrocarbons, $NO_x$, and $SO_x$ for all phases of taxi and flight based on International Civil Aviation Organization (ICAO) engine emissions indices—estimates of the mass of pollutant produced per mass of fuel consumed as contained in the International Civil Aviation Organization (ICAO) Engine Emissions Certification Databank.[92] To estimate total emissions of particulate matter (PM), a criteria pollutant composed of a complex mixture of solid particles and liquid droplets, EDMS must rely on research-based estimation techniques integrated into EDMS (see Appendix C). Emissions were then aggregated by month and mode for use in the air quality analysis.

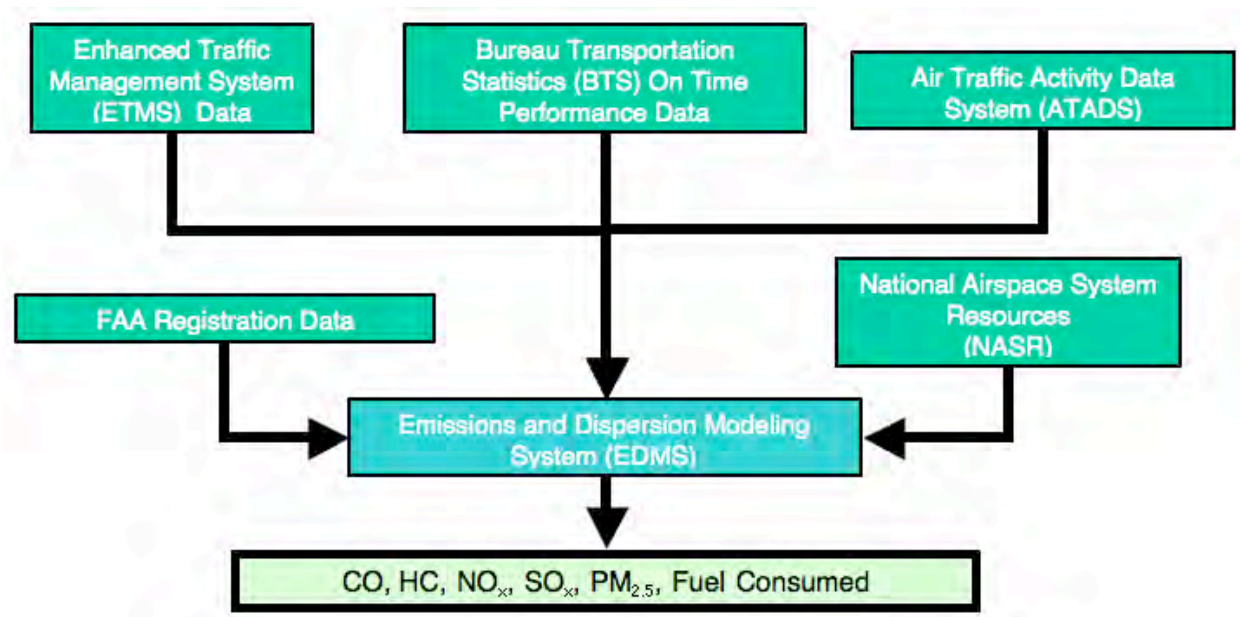


**Figure E.1:** Overview of the generation of the baseline inventory

**Inventory Limitations and Sources of Discrepancies**

Several generalizations, estimations and approximations were made in creating the baseline inventory that served as

[90] Carriers frequently use single engine taxi going to and from terminal gates. Additionally, pilots often shut off main engines and switch to APUs during long delays. The circumstances of single engine taxi use and APU use during extended delays could not be adequately defined for consistent, realistic modeling across the variety of carriers, airports and weather conditions.
[91] Federal Aviation Administration, National Airspace System Resources (NASR) data, 2006.
[92] http://www.caa.co.uk/default.aspx?catid=702&pagetype=90

the basis for the air quality modeling and health impact analysis. These discrepancies were mitigated when possible, but some remain as discussed in this section.

**Taxi Times**

When available, exact taxi times from BTS data were used. If taxi times were not listed, the average taxi time for the departure/arrival hour at the origin/destination was used. If there were no BTS flights during that hour, the average for the year was used. If annual BTS information was not available for the airport, the ICAO standard time of 19 minutes for taxi-out and 7 minutes for taxi-in was assumed.

Additionally, taxi times were assumed to consist of full engine taxi regardless of the type of aircraft or the length of the taxi time. Anecdotally, it is known that aircraft often taxi-out on one engine and use APUs instead of main engines during long delays, but we chose to create a conservative estimate due to the uncertainty associated with the exact timing of how and when the aircraft may switch to APU or a single engine taxi.

**APUs**

The APU survey provided information about the range of APU use (see Appendix D). However, the survey was centered on commercial carriers, not business jets. While, commercial aircraft have longer boarding and disembarkment times than business jets, the APU assumptions were applied uniformly to both types of aircraft.

For departing flights, anticipated delays may prompt pilots to shut off main engines and run APUs to conserve fuel. Although airlines have individual operating procedures, the ultimate decision rests with the pilot, making modeling very difficult. The estimates of APU usage do not account for the fact that pilots may turn off main engines and use the APU during periods of long delay.

**Default Engines**

Engines were matched to air frames based on tail number. However, for some flights, there was no BTS information to provide tail numbers. In addition, some tail numbers did not match specific information in Campbell-Hill, BACK or FAA registration databases. For these aircraft, the EDMS default engine, the most commonly occurring engine for that air frame in the US was used.

**International Flights**

International flights are not listed in the BTS data set. This limits the specific information available about these flights and requires a greater number of default values for inputs. Default values are particularly problematic as international flights tend to operate heavy aircraft with higher fuel burn. ETMS was used to obtain information on international flights. Because ETMS does not contain taxi data, international flights were assigned airport-level default taxi times when possible. For airports that did not have default taxi times, the ICAO default taxi/idle time was used. Accurately portraying these flights with the correct engines and taxi times is required to more correctly estimate total emissions at international airports.

**Particulate Matter Emissions Inventory**

The measurement methodology for PM for jet turbine aircraft is still being developed and data are sparse. Measurement and modeling of aircraft PM emissions is still an emerging area and there are data limitations and uncertainties.[93,94] A small data set (APEX-1[95]) not used for development of the PM model was used as a

[93] The determination of fine particulate matter emissions from aircraft engines is an active area of research. Methods to estimate primary PM emissions from aircraft are relatively immature: test data are sparse, and test methods are

comparison to estimate non-volatile confidence limits. Additionally, limits on measurement errors of the independent variable for non-volatile estimation (based on the reported smoke number) were evaluated as well to determine upper and lower bounds of the estimation technique. For the non-volatiles, no direct comparison to measured data was possible due to a lack of data.

The PM emissions inventory contains two known errors: The primary PM inventories for 78 of the 325 study airports were generated using a fuel sulfur emissions index of 0.8 g/kg-fuel burned (corresponding to a fuel sulfur concentration of 400 ppm), versus a value of 1.36 g/kg-fuel burned (corresponding to a fuel sulfur concentration of 680 ppm which is more representative of the current jet fuel supply). The higher fuel sulfur emissions index was used to generate the results in Sections 4 and 5; however, time and resources were not available to repeat the air quality and health effects modeling. The error in the sulfur specification impacted both the volatile component of the primary PM emissions, and the secondary PM precursor emissions. By analyzing the changes in the inventories we estimate that this led to an underestimation of the health effects of approximately 10%. However, this underestimation is approximately offset by the conservatively-biased assumptions in the primary PM inventory estimation method (FOA3a) such that the net effect is that the health effects shown in the body of the report are not biased high or low.

The second problem that occurred was an incorrect factor used for the fuel organics portion of the volatile PM component. (PM emissions include volatile and non-volatile components – see Appendix C.) This was extensively evaluated and found to cause an approximate 3% error. This error is less than the expected uncertainties of the model and calculations show that no changes in the conclusions would occur.

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still under development. ICAO and EPA do not have approved test methods or certification standards for aircraft PM emissions. ICAO's Committee on Aviation Environmental Protection has developed and approved the use of an interim First Order Approximation (FOA3) method to estimate total PM emissions (or total fine PM emissions) from certified aircraft engines. Subsequent to the completion of FOA3, the FOA3 methodology was modified with margins to conservatively account for the potential effects of uncertainties that include the lack of a standard test procedure, poor definition of volatile PM formation in the aircraft plume, and the limited amount of data available on aircraft PM emissions. This modified methodology is known as FOA3a. FOA3a is currently the agreed upon method to estimate total PM emissions from aircraft engines, and it has been incorporated into the latest version of the FAA Emissions and Dispersion Modeling System (EDMS), version 5.02, June 2007. FOA3a was used in this study. FOA3a predicts fine PM inventory levels that are approximately 5 times those predicted by FOA3. The factor of 5 difference between the method used for this study and that determined by the ICAO method reflects the scientific uncertainty associated with PM emissions rates from aircraft engines.

[94] In particular, a fuel sulfur level of 400 ppm was assumed for some airports and 680 ppm was assumed for others. Our intention was to assume 680 ppm for all airports. However, year-to-year and location-to-location variations of fuel sulfur of this level (±200 ppm) are typical and are thus within the uncertainty of the estimation methods.

[95] Wey, C. C. et al. (2006). Aircraft particle emissions experiment (APEX). NASA TM-2006-214382, National Aeronautics and Space Administration, Washington, DC, September.

# Appendix F Modeling of the Impact of Aircraft Emissions on Air Quality in Nonattainment Areas

U.S. Environmental Protection Agency

Office of Air Quality Planning and Standards
Air Quality Assessment Division
Research Triangle Park, NC

## I. Introduction

A national scale air quality modeling analysis was performed to estimate the impact of emissions from 325 commercial service airports across the U.S. on annual fine particulate matter ($PM_{2.5}$) concentrations and daily maximum 8-hour ozone concentrations. These 325 commercial service airports include 148 airports located in nonattainment areas, and 177 airports in attainment areas.[96] This document describes the air quality modeling portion of this analysis.

To model the air quality benefits of this rule we used the Community Multiscale Air Quality (CMAQ)[97] model. CMAQ simulates the numerous physical and chemical processes involved in the formation, transport, and destruction of ozone and particulate matter. Inputs to the CMAQ model include: emissions estimates (from aircraft and all other sources), meteorological fields, and initial and boundary condition data. For this study, two annual, national CMAQ sensitivity scenarios were modeled focusing on aircraft emissions, one with the specific aircraft emissions (based on 2005 activity at 325 commercial service airports) that were calculated by utilizing FAA's Emissions and Dispersion Modeling System (EDMS)[98] model and one without those emissions. The difference in estimated pollutant concentrations between these two simulations indicates the regional air quality impacts of the aircraft emissions included in the base simulation. These projections were used as inputs to the calculation of health impacts resulting from the 2005 aircraft emissions at the 325 airports. The EDMS modeling[99] and the health impact estimation are described in separate documentation[100].

## II. CMAQ Model Configuration, Inputs, Evaluation, and Methodology

The air quality modeling platform used in this study to estimate the impacts from EDMS aircraft emissions has been used to support several other major regulatory actions initiated by EPA, including:

- the final $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS) regulatory impact analysis[101],

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[96] The 325 airports represent 63 percent (325 of 515) of the commercial service airports in the U.S.
[97] Byun, D.W., and K. L. Schere, 2006: Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. Applied Mechanics Reviews, Volume 59, Number 2 (March 2006), pp. 51-77.
[98] This study utilized a research version of EDMS 5.0.2, and this version was designed to meet the needs of the study. Documentation about the model is available at http://www.faa.gov/about/office_org/headquarters_offices/aep/models/edms_model/.
[99] CSSI, Inc., 2005, Emissions and Dispersion Modeling System (EDMS) User's Manual, Washington, DC, CSSI, Inc. Prepared for the Federal Aviation Administration Office of Environment and Energy.
[100] Abt Associates Inc., 2005, Environmental Benefits Mapping and Analysis Program (BenMAP) User's Manual. Bethesda, MD, Abt Associates, Inc. Prepared for the U.S. Environmental Protection Agency Office of Air Quality and Standards.
[101] U.S. Environmental Protection Agency, Final RIA PM NAAQS, Chapter 2: Defining the PM2.5 Air Quality Problem, http://www.epa.gov/ttn/ecas/ria.html, October 2006.

- the draft 8-hour ozone NAAQS regulatory impact analysis (RIA)[102], and
- the proposed rule for the "Control of Emissions of Air Pollution from Locomotives and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder"[103].

As a result of these previous exercises, EPA is confident in the suitability of this modeling platform for this study. The subsequent sections will describe the model configuration for the base and sensitivity simulations and provide an evaluation of model performance for the base year.

**A. Model version**

The CMAQ model is a three-dimensional grid-based Eulerian air quality model designed to estimate the formation and fate of oxidant precursors, primary and secondary particulate matter concentrations and deposition over regional and urban spatial scales. The CMAQ model was peer-reviewed[104] in 2003 for EPA and is a freely-available, non-proprietary model. The latest version of CMAQ available at the time of this study, version 4.5, was employed for this analysis[105]. This version reflects updates in a number of areas to improve the underlying science and address comments from the peer-review including:

- a state-of-the-science inorganic nitrate partitioning module (ISORROPIA) and updated gaseous, heterogeneous chemistry in the calculation of nitrate formation,
- a secondary organic aerosol (SOA) module that includes a more comprehensive gas-particle partitioning algorithm from both anthropogenic and biogenic SOA,
- an in-cloud sulfate chemistry module that accounts for the nonlinear sensitivity of sulfate formation to varying pH, and
- an updated CB-IV gas-phase chemistry mechanism and aqueous chemistry mechanism that provide a comprehensive simulation of aerosol precursor oxidants.

**B. Model domain and grid resolution**

The CMAQ modeling analyses were performed for a domain covering the majority of the United States (i.e., the lower 48 States), as shown in Figure F.1. This domain has a horizontal grid resolution of 36 km. The use of this relatively coarse resolution limits the analysis to an assessment of regional impacts of the EDMS emissions, as opposed to highly-localized ozone impacts which would require finer resolution modeling. The model extends vertically from the surface to 100 millibars (approximately 15,674 meters above sea level) using a sigma-pressure coordinate system consisting of 14 vertical layers. The model domain uses a Lambert Conformal map projection with true latitudes at 33 and 45 degrees N. The center of the domain is at latitude 40 N, longitude 97 W. The dimensions of the modeling grid are 148 columns by 112 rows.

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[102] U.S. Environmental Protection Agency, Regulatory Impact Analysis of the Proposed Revisions to the National Ambient Air Quality Standards for Ground-Level Ozone, http://www.epa.gov/ttn/ecas/ria.html#ria2007 July 2007.
[103] U.S. Environmental Protection Agency; Technical Support Document for the Proposed Locomotive-Marine Rule: Air Quality Modeling; Office of Air Quality Planning and Standards; EPA 454/R-07-004; RTP, NC; March 2007
[104] Amar, P., R. Bornstein, H. Feldman, H. Jeffries, D. Steyn, R. Yamartino, and Y. Zhang. 2004. Final Report Summary: December 2003 Peer Review of the CMAQ Model, pp. 7.
[105] U.S. Environmental Protection Agency, Community Multiscale Air Quality (CMAQ), http://www.epa.gov/asmdnerl/CMAQ/release45.html, January 2009.

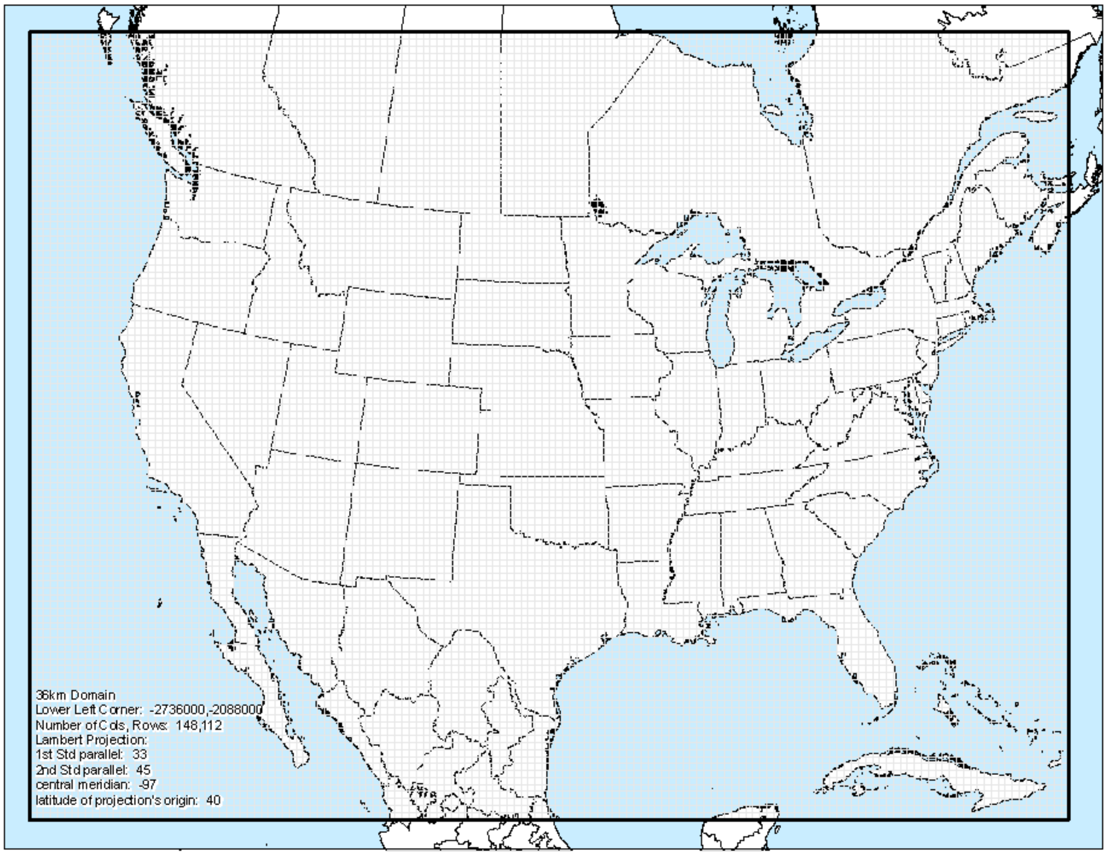


**Figure F.1:** Map of the CMAQ modeling domain. The box outlined in black denotes the 36 km modeling domain.

**C. Modeling Period**

There are several considerations involved in selecting the appropriate duration of an air quality modeling analysis[106]. In general, the goal is to model several types of meteorological conditions that lead to ambient $PM_{2.5}$ levels and ozone levels similar to an area's design value[107]. For the annual $PM_{2.5}$ standard, it was determined that modeling an entire year of meteorology (2001) was needed to estimate the impacts of the EDMS emissions upon annual average levels of $PM_{2.5}$, because seasonal changes in atmospheric composition and meteorology affect the final annual average $PM_{2.5}$ values. For the 8-hour ozone standard, we only used the simulation days within the May through September 2001 period to estimate the impacts of the aircraft sector, as only several days of simulation are needed to determine 8-hour ozone values and May through September is the typical ozone season in the continental United States.[108] Over most parts of the U.S., this period should be sufficient to capture typical conditions that lead to high

[106] U.S. EPA, Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8- hour Ozone NAAQS; EPA-454/R-05-002; Research Triangle Park, NC; October 2005.

[107] A design value is a statistic, specific to a given criteria pollutant and based on measurements of the concentration of that pollutant in the local atmosphere of a given area, that describes the air quality status of a given area relative to the level of the National Ambient Air Quality Standards (NAAQS) for that criteria pollutant. The methodologies for deriving design values for ozone and $PM_{2.5}$ are contained in 40 CFR 50 Appendix H and 40 CFR 50 Appendix N, respectively. Historical design values can be found at http://www.epa.gov/airtrends/values.html.

[108] U.S. EPA, Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze; EPA-454/B-07-002; Research Triangle Park, NC; April 2007.

ozone concentrations as it is shown for other similar source-specific emission impact studies (need a reference here).

**D. Model Inputs: Emissions, Meteorology and Boundary Conditions**

The 2001 CMAQ modeling platform was used for the air quality modeling of this study's scenarios. In addition to the CMAQ model code itself, the modeling platform also consists of the base year emissions estimates, meteorological fields, as well as initial and boundary condition data all of which are inputs to the air quality model. Each of these model input components are described below.

*Base Year Emissions:* The basis for the 2001 base year emission inventory used in this analysis is the EPA year 2001 National Emission Inventory (NEI), which includes emissions of CO, $NO_X$, VOC, $SO_2$, $NH_3$, $PM_{10}$, and $PM_{2.5}$. The CMAQ model requires hourly emissions of those pollutants for every grid cell within the domain. The base year inventory data used in this analysis are identical to those used in the EPA Clean Air Interstate Rule (CAIR) modeling. Those interested in additional technical detail describing how EPA developed the 2001 emissions estimates should consult the CAIR technical support documentation[109].

*Meteorological Input Data:* The gridded meteorological data for 2001 at 36 km resolution were derived from simulations of the Pennsylvania State University / National Center for Atmospheric Research Mesoscale Model. This model, commonly referred to as MM5[110], is a limited-area, nonhydrostatic, terrain-following system that solves for the full set of physical and thermodynamic equations which govern atmospheric motions. For this analysis, version 3.6.1 of MM5 was used. Complete descriptions of the configurations of the 2001 meteorological modeling are contained in McNally (2003)[111]. This meteorological data set has been used in numerous EPA applications, including CAIR. Those interested in additional technical detail describing how EPA developed the 2001 meteorological inputs should consult the CAIR technical support documentation[112].

The meteorological outputs from MM5 were processed to create model-ready inputs for CMAQ using version 3.1 of the Meteorology-Chemistry Interface Processor (MCIP)[113]. The 2001 MM5 simulation utilized 34 vertical layers (up to an altitude of 15,674 m) with a surface layer of approximately 38 meters. The MM5 and CMAQ vertical structures are shown in Table F.1. Note the first layer (surface layer) is shared between both models.

**Table F.1:** Vertical layer structure for MM5 and CMAQ (heights are layer top).

| CMAQ Layers | MM5 Layers | Sigma P | Approximate Height (m) | Approximate Pressure (mb) |
|---|---|---|---|---|
| 0 | 0 | 1.000 | 0 | 1000 |
| 1 | 1 | 0.995 | 38 | 995 |
| 2 | 2 | 0.990 | 77 | 991 |
| 3 | 3 | 0.985 | 115 | 987 |
| | 4 | 0.980 | 154 | 982 |

[109] U.S. EPA, Clean Air Interstate Rule Emissions Inventory Technical Support Document; Research Triangle Park, NC; March 2005. http://www.epa.gov/cleanairinterstaterule/pdfs/finaltech01.pdf.
[110] Grell, G., J. Dudhia, and D. Stauffer, 1994: A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5), NCAR/TN-398+STR., 138 pp, National Center for Atmospheric Research, Boulder CO.
[111] McNally, D, Annual Application of MM5 for Calendar Year 2001, Topical report to EPA, March 2003.
[112] U.S. EPA, Technical Support Document for the Final Clean Air Interstate Rule Air Quality Modeling; Research Triangle Park, NC; March 2005. http://www.epa.gov/cleanairinterstaterule/pdfs/finaltech02.pdf.
[113] Byun, D.W., and Ching, J.K.S., Eds, 1999. Science algorithms of EPA Models-3 Community Multiscale Air Quality (CMAQ modeling system, EPA/600/R-99/030, Office of Research and Development). Please also see: http://www.cmascenter.org.

| CMAQ Layers | MM5 Layers | Sigma P | Approximate Height (m) | Approximate Pressure (mb) |
|---|---|---|---|---|
| 4 | 5 | 0.970 | 232 | 973 |
| | 6 | 0.960 | 310 | 964 |
| 5 | 7 | 0.950 | 389 | 955 |
| | 8 | 0.940 | 469 | 946 |
| 6 | 9 | 0.930 | 550 | 937 |
| | 10 | 0.920 | 631 | 928 |
| | 11 | 0.910 | 712 | 919 |
| 7 | 12 | 0.900 | 794 | 910 |
| | 13 | 0.880 | 961 | 892 |
| | 14 | 0.860 | 1,130 | 874 |
| 8 | 15 | 0.840 | 1,303 | 856 |
| | 16 | 0.820 | 1,478 | 838 |
| | 17 | 0.800 | 1,657 | 820 |
| 9 | 18 | 0.770 | 1,930 | 793 |
| | 19 | 0.740 | 2,212 | 766 |
| 10 | 20 | 0.700 | 2,600 | 730 |
| | 21 | 0.650 | 3,108 | 685 |
| 11 | 22 | 0.600 | 3,644 | 640 |
| | 23 | 0.550 | 4,212 | 595 |
| 12 | 24 | 0.500 | 4,816 | 550 |
| | 25 | 0.450 | 5,461 | 505 |
| | 26 | 0.400 | 6,153 | 460 |
| 13 | 27 | 0.350 | 6,903 | 415 |
| | 28 | 0.300 | 7,720 | 370 |
| | 29 | 0.250 | 8,621 | 325 |
| | 30 | 0.200 | 9,625 | 280 |
| 14 | 31 | 0.150 | 10,764 | 235 |
| | 32 | 0.100 | 12,085 | 190 |
| | 33 | 0.050 | 13,670 | 145 |
| | 34 | 0.000 | 15,674 | 100 |

*Initial and Boundary Conditions:* The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM[114] model. The global GEOS-CHEM model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth Observing System (GEOS). This model was run for 2001 with a grid resolution of 2.0 degree x 2.5 degree (latitude-longitude) and 20 vertical layers. The predictions were used to provide one-way dynamic boundary conditions at three-hour intervals and an initial concentration field for the CMAQ simulations.

**E. CMAQ Modeling Scenarios**

The CMAQ modeling system was used to estimate annual $PM_{2.5}$ concentrations, daily 8-hour ozone concentrations, and visibility estimates for four emissions scenarios:

1. a 2001 base case

[114] Yantosca, B., 2004. GEOS-CHEMv7-01-02 User's Guide, Atmospheric Chemistry Modeling Group, Harvard University, Cambridge, MA, October 15, 2004.

2. a 2001 base line,
3. a 2001 “no_aircraft” base case with all emissions from the EPA year 2001 National Emissions Inventory aircraft sectors removed, and
4. scenario #2 with EPA year 2001 National Emissions Inventory aircraft sector emissions removed and replaced with the EDMS emissions from 325 commercial service airports.

The 2001 *base case* (scenario #1) was modeled in order to evaluate the performance of the CMAQ model and as such included day-specific emissions wherever possible. The results of this evaluation are described in the next section. The 2001 *base line* simulation (scenario #2) was modeled to serve as a comparison for the two aircraft sensitivity scenarios #3 and #4 based on EPA methodology for applying CMAQ to estimate the impacts of source emissions on ambient ozone and $PM_{2.5}$ concentrations; see section G of this Appendix. The base line simulation does not include emissions specific to particular days in 2001. For the "no_aircraft" simulation (sensitivity scenario #3) we removed emissions from six source classification categories (SCCs) contained in the EPA year 2001 National Emissions Inventory:

- 2275000000 Mobile Sources Aircraft All Types and Operations
- 2275001000 Mobile Sources Aircraft Military Aircraft
- 2275020000 Mobile Sources Aircraft Commercial Aircraft
- 2275050000 Mobile Sources Aircraft General Aviation
- 2275060000 Mobile Sources Aircraft Air Taxi
- 2275070000 Mobile Sources Aircraft Auxiliary Power Units

For the fourth scenario, we added 2005 commercial service aircraft emissions from the EDMS model as provided by CSSI, Inc[115]. These emissions capture 95 percent of nationwide activity of aircraft with engines certified to the International Civil Aviation Organization (ICAO) emission standards (specifically, those with ICAO smoke numbers), at commercial service airports[116]. Also, as described earlier, the 325 airports represent 63 percent (325 of 515) of the commercial service airports in the U.S. The EDMS emissions were provided for CO, VOC, $SO_2$, $NO_x$, primary $PM_{2.5}$, and three $PM_{2.5}$ species (sulfates, organic carbon, and elemental carbon). Monthly emissions were provided for seven operating modes: engine startup, auxiliary power units (APUs) , aircraft taxiing in, aircraft taxiing out, takeoff w/ initial climb, climb out, and approach mode, for each of the 325 airports. The aircraft emissions from the seven operating modes were allocated to CMAQ layers (shown in Table F.1), as follows:[117]

- Engine startup: CMAQ layer 1
- APUs: CMAQ layer 1
- Aircraft Taxi (in): CMAQ layer 1
- Aircraft Taxi (out): CMAQ layer 1
- Takeoff w/ initial climb: emissions equally divided between layers 1 – 5
- Climb out: emissions equally divided between layers 6 – 7
- Approach mode: emissions equally divided between layers 1 – 7

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[115] CSSI, Inc., 2005, Emissions and Dispersion Modeling System (EDMS) User’s Manual, Washington, DC, CSSI, Inc. Prepared for the Federal Aviation Administration Office of Environment and Energy.

[116] ICAO emission standards apply to aircraft gas turbine engines with thrust greater than 26.7 kN, which includes engines on commercial single-aisle, twin-aisle, and larger aircraft as well as small regional jets (and some business jets).

[117] Aircraft emissions should ideally be allocated to CMAQ layers based on layer thickness and how much time is spent by an aircraft within a given CMAQ layer.

Table F.2 shows the relative proportion of CO, NOx, VOC, $PM_{2.5}$, and $SO_2$ emissions from the EDMS aircraft to the overall base line emissions inventory of all sources nationally, and for 12 select areas (i.e., the areas with the largest $PM_{2.5}$ contribution from this sector). On a national average level, the EDMS aircraft emissions represent a relatively small percentage of the national $PM_{2.5}$, $PM_{2.5}$ precursor, and ozone precursor emissions. However, the percentage contributions can be larger in individual metropolitan areas, based on the amount of aviation emissions vs. the amount of emissions from other sources in those metropolitan areas.

**Table F.2:** Ratios of EDMS emissions to overall base line (scenario #2) emissions averaged nationally, and for the 12 cities with the largest modeled PM2.5 impact from EDMS aircraft emissions.

| Area | % CO | % $NO_X$ | % VOC | % $SO_2$ | % $PM_{2.5}$ |
|---|---|---|---|---|---|
| **Los Angeles** | 0.34 % | 1.00 % | 0.42 % | 1.84 % | 0.18 % |
| **Atlanta** | 0.42 % | 1.59 % | 0.65 % | 0.25 % | 0.17 % |
| **Las Vegas** | 1.39 % | 2.80 % | 1.44 % | 0.35 % | 0.36 % |
| **Denver** | 0.41 % | 1.53 % | 0.86 % | 0.64 % | 0.20 % |
| **Memphis** | 0.80 % | 2.38 % | 1.85 % | 0.43 % | 0.41 % |
| **San Francisco** | 0.33 % | 1.53 % | 0.47 % | 1.15 % | 0.14 % |
| **Detroit** | 0.19 % | 0.60 % | 0.39 % | 0.11 % | 0.18 % |
| **New York City** | 0.38 % | 1.36 % | 0.49 % | 0.36 % | 0.29 % |
| **Louisville** | 0.45 % | 0.71 % | 1.33 % | 0.06 % | 0.27 % |
| **Minneapolis** | 0.30 % | 1.03 % | 0.49 % | 0.21 % | 0.15 % |
| **Salt Lake City** | 0.53 % | 1.27 % | 0.63 % | 0.49 % | 0.20 % |
| **Philadelphia** | 0.31 % | 0.72 % | 0.41 % | 0.10 % | 0.16 % |
| **National Average**[118] | 0.17 % | 0.40 % | 0.23 % | 0.06 % | 0.03 % |

**F. CMAQ Base Case Model Performance Evaluation**

*1. $PM_{2.5}$:* An operational model performance evaluation for $PM_{2.5}$ and its related speciated components (e.g., sulfate, nitrate, elemental carbon, organic carbon, etc.) was conducted using the base case (scenario #1) simulation data in order to estimate the ability of the CMAQ modeling system to replicate $PM_{2.5}$ and $PM_{2.5}$ species concentrations. In summary, model performance statistics were calculated for observed/predicted pairs of daily, monthly, seasonal, and annual concentrations. Statistics were generated for the following geographic groupings: domain wide, Eastern U.S, and Western U.S. (divided based on the 100th meridian). The "acceptability" of model performance was judged by comparing our CMAQ 2001 performance results to the range of performance found in regional $PM_{2.5}$ model applications for certain other, non-EPA studies[119]. Overall, the fractional bias (FB), fractional error (FE), normalized mean bias (NMB), and normalized mean error (NME) statistics shown in Table F.3 are within the range or close to that found by other groups in certain other applications.[120] The model performance results give us confidence that our application of CMAQ using this modeling platform provides a scientifically credible approach for assessing $PM_{2.5}$ concentrations for the purposes of this study. A more detailed summary of the CMAQ model performance evaluation

[118] The national average was determined by averaging emissions of a given pollutant (according to the 2001 EPA NEI) across all sources in the continental United States.
[119] See Appendix C of the CMAQ Model Performance Evaluation Report for 2001 updated March 2005 (CAIR Docket OAR-2005-0053-2149). These other modeling studies represent a wide range of modeling analyses which cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules.
[120] Note that aircraft gas turbine engines do not emit ammonia or $PM_{10}$.

for $PM_{2.5}$ is available within the PM NAAQS RIA, Appendix O[121].

**Table F.3:** Annual CMAQ 2001 model performance statistics for 2001 base case (scenario #1)

| Pollutant | Measurement Network | Region | # of Obs | FB (%) | FE (%) | NMB(%) | NME(%) |
|---|---|---|---|---|---|---|---|
| $PM_{2.5}$ Total Mass | STN[122] | National | 6356 | -10 | 42 | -8 | 39 |
| | | East | 5124 | -5 | 39 | -2 | 35 |
| | | West | 1232 | -29 | 53 | -36 | 54 |
| | IMPROVE[123] | National | 13218 | -11 | 51 | -11 | 47 |
| | | East | 5606 | -11 | 47 | -11 | 41 |
| | | West | 7612 | -10 | 54 | -12 | 55 |
| Sulfate | STN | National | 6723 | -16 | 45 | -13 | 36 |
| | | East | 5478 | -8 | 41 | -9 | 34 |
| | | West | 1245 | -52 | 64 | -51 | 58 |
| | IMPROVE | National | 13477 | -21 | 50 | -20 | 39 |
| | | East | 5657 | -15 | 41 | -16 | 34 |
| | | West | 7790 | -26 | 57 | -33 | 52 |
| | CASTNet[124] | National | 3791 | -29 | 37 | -21 | 27 |
| | | East | 2784 | -22 | 29 | -19 | 25 |
| | | West | 1007 | -47 | 59 | -45 | 51 |
| Nitrate | STN | National | 5883 | -39 | 89 | -15 | 74 |
| | | East | 4673 | -23 | 81 | 14 | 70 |
| | | West | 1210 | -103 | 116 | -76 | 82 |
| | IMPROVE | National | 13398 | -72 | 116 | -10 | 86 |
| | | East | 5636 | -53 | 109 | 16 | 90 |
| | | West | 7762 | -85 | 121 | -42 | 82 |
| Total Nitrate (NO3 + HNO3) | CASTNet | National | 3788 | 4 | 38 | 9 | 35 |
| | | East | 2781 | 13 | 34 | 14 | 33 |
| | | West | 1007 | -21 | 51 | -27 | 47 |
| Ammonium | STN | National | 6723 | 20 | 63 | 6 | 54 |
| | | East | 5478 | 27 | 59 | 16 | 51 |
| | | West | 1245 | 13 | 78 | -53 | 75 |
| | CASTNet | National | 3791 | -17 | 38 | -11 | 31 |
| | | East | 2784 | -8 | 32 | -10 | 29 |
| | | West | 1007 | -39 | 57 | -37 | 51 |
| Elemental Carbon | STN | National | 6842 | 19 | 60 | 22 | 69 |
| | | East | 5551 | 26 | 59 | 34 | 71 |
| | | West | 1291 | -8 | 65 | -13 | 63 |
| | IMPROVE | National | 13441 | -15 | 60 | -2 | 63 |
| | | East | 5646 | -26 | 53 | -18 | 46 |
| | | West | 7795 | -7 | 66 | 19 | 85 |
| Organic Carbon | STN | National | 6685 | -46 | 65 | -43 | 54 |
| | | East | 5401 | -45 | 65 | -41 | 51 |
| | | West | 1284 | -46 | 68 | -47 | 61 |
| | IMPROVE | National | 13428 | 6 | 63 | 4 | 68 |
| | | East | 5658 | -28 | 60 | -24 | 51 |
| | | West | 7770 | 31 | 64 | 38 | 88 |

[121] U.S. EPA, Final RIA PM NAAQS, Appendix O: CMAQ Model Performance Evaluation for 2001. October 2006. http://www.epa.gov/ttn/ecas/regdata/RIAs/Appendix%20O--Model%20Eval.pdf
[122] EPA's Speciation Trends Network, which monitors $PM_{2.5}$ species. http://epa.gov/ttn/amtic/specgen.html
[123] The Interagency Monitoring of Protected Visual Environments network, which monitors visibility in specific National Parks and Wilderness Areas in the U.S. http://vista.cira.colostate.edu/improve/
[124] The Clean Air Status and Trends Network, which aids in assessment of acid deposition. http://www.epa.gov/CASTNET/

*2. Ozone:* Performance for the 36 km ozone modeling was calculated over the period from May 1 to September 30, 2001. Over 1000 ozone monitoring sites were used in these model-to-monitor comparisons. Table F.4 lists the average monthly NMB and NME values for daily maximum 8-hourly ozone over the 36 km domain. This statistical comparison only looks at observed values greater than 60 ppb, in order to focus on the upper end of the observed ozone spectrum that are of most significance from a regulatory perspective.[125] The model generally tends to underestimate daily 8-hour ozone peaks on the order of 3-13 percent when averaged over individual months.

**Table F.4:** CMAQ 8-hourly daily maximum ozone model performance statistics calculated for a threshold of 60 ppb over the entire 36 km domain for 2001.

| | NMB (%) | NME (%) |
|---|---|---|
| May | -3.0 | 12.3 |
| June | -3.8 | 12.4 |
| July | -10.6 | 15.7 |
| August | -10.3 | 15.5 |
| September | -12.6 | 16.3 |

Table F.5 lists the average monthly NMB and NME values for daily maximum 8-hourly ozone over specific subdomains within the 36 km domain. While the resolution is less than ideal for an ozone impact analysis it is encouraging that the operational performance statistics are within the range of certain other regional modeling applications such as CAIR.

**Table F.5:** CMAQ 8-hourly daily maximum ozone model performance statistics (NMB and NME) calculated for specific subdomains and using a threshold of 60 ppb over the entire domain for 2001.

| | Central Regional Air Planning Association (CENWRAP)[126] | Lake Michigan Air Directors Consortium (LADCO)[127] | Mid-Atlantic/Northeast Visibility Union (MANE-VU)[128] | Visibility Improvement State and Tribal Association of the Southeast (VISTAS)[129] | Western Regional Air Partnership (WRAP)[130] |
|---|---|---|---|---|---|
| **May** | -1.8 / 11.5 | 0.6 / 11.3 | -1.7 / 9.9 | -5.9 / 11.1 | -2.4 / 15.3 |
| **June** | -4.2 / 11.8 | -0.2 / 10.5 | -3.2 / 11.3 | -0.7 / 10.3 | -9.8 / 17.1 |
| **July** | -9.8 / 14.1 | -7.2 / 14.3 | -4.5 / 13.3 | -7.4 / 12.5 | -19.3 / 21.3 |

125 U.S. EPA, Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze; EPA-454/B-07-002; Research Triangle Park, NC; April 2007.
126 Includes nine states - Nebraska, Kansas, Oklahoma, Texas, Minnesota, Iowa, Missouri, Arkansas, and Louisiana.
127 Includes five states - Illinois, Indiana, Michigan, Ohio, and Wisconsin.
128 Includes Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Northern Virginia, and suburbs of Washington, D.C.
129 Member States and Tribes include: the States of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina,
Tennessee, Virginia, and West Virginia and the Eastern Band of the Cherokee Indians.
130 Includes the states of Alaska, Arizona, California, Colorado, Idaho, Montana, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming. Also includes Tribes of the Campo Band of Kumeyaay Indians, Confederated Salish and Kootenai Tribes, Cortina Indian Rancheria, Hopi Tribe, Hualapai Nation of the Grand Canyon, Native Village of Shungnak, Nez Perce Tribe, Northern Cheyenne Tribe, Pueblo of Acoma, Pueblo of San Felipe, and Shoshone-Bannock Tribes of Fort Hall.

| | Central Regional Air Planning Association (CENWRAP)[126] | Lake Michigan Air Directors Consortium (LADCO)[127] | Mid-Atlantic/Northeast Visibility Union (MANE-VU)[128] | Visibility Improvement State and Tribal Association of the Southeast (VISTAS)[129] | Western Regional Air Partnership (WRAP)[130] |
|---|---|---|---|---|---|
| **August** | -10.2 / 14.7 | -2.4 / 11.3 | -9.6 / 15.3 | -5.7 / 11.3 | -17.1 / 20.6 |
| **September** | -15.6 / 18.4 | -8.7 / 12.5 | -13.7 / 15.0 | -9.5 / 12.3 | -15.9 / 18.0 |

**G. Applications of CMAQ Modeling Output**

Model predictions are used in a relative sense to estimate scenario-specific design values of $PM_{2.5}$ and ozone. This is done by calculating the simulated air quality ratios between any particular sensitivity simulation (e.g., the no_aircraft scenario #3) and the 2001 base line (scenario #2). These predicted change ratios are then applied to ambient base year design values to predict the impact of the source emissions of interest (e.g. EDMS aircraft emissions) upon ambient air quality, quantified as a change in pollutant concentration in $\mu g/m^3$ (for $PM_{2.5}$) or ppb (for ozone). These quantified changes are then used as inputs to the health and welfare impact functions of the benefits analysis. The design value projection methodology used in this analysis is standard protocol and followed EPA guidance documentation[131] for such analyses. The methodology is described below; see the guidance documentation for further details.

*Projection Methodology for Annual Average $PM_{2.5}$ Design Values*: The projected annual design values were calculated using the Speciated Modeled Attainment Test (SMAT) approach. This approach is used to ensure that the $PM_{2.5}$ concentrations are closely related to the observed ambient data. The SMAT procedure combines absolute concentrations of ambient data with the relative change in PM species from the CMAQ model. The SMAT uses a Federal Reference Method (FRM) mass construction methodology that results in reduced nitrates (relative to the amount measured by routine speciation networks), higher mass associated with sulfates (reflecting water included in FRM measurements), and a measure of organic carbonaceous mass that is derived from the difference between measured $PM_{2.5}$ and its noncarbon components. This characterization of $PM_{2.5}$ mass also reflects elemental carbon, crustal material and other minor constituents. The resulting characterization provides a complete mass balance. The SMAT methodology uses the following $PM_{2.5}$ species components from the FRM construction methodology as inputs: sulfates, nitrates, ammonium, organic carbon mass, elemental carbon, crustal, water, and blank mass (a fixed value of 0.5 $\mu g/m^3$). More complete details of the SMAT procedures used in this analysis can be found in the revised SMAT procedure for CAIR report[132]. Below are the steps we followed for projecting scenario-specific $PM_{2.5}$ concentrations. These steps were performed to estimate sensitivity case concentrations at each FRM monitoring site. The starting point for these projections is a 5 year weighted average design value for each site, based on measurements of total ambient $PM_{2.5}$ concentrations at each FRM monitoring site. The weighted average is calculated as the average of the 1999–2001, 2000–2002, and 2001–2003 design values at each monitoring site. This approach has the desired benefits of (1) weighting the $PM_{2.5}$ values towards the middle year of the five-year period (2001), which is the base year for the emissions projections, and (2) smoothing out the effects of year-to-year variability in emissions and meteorology that occurs over the full five-year period of monitoring.

[131] U.S. EPA, Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-hour Ozone NAAQS; EPA-454/R-05-002; Research Triangle Park, NC; October 2005.
[132] U.S. EPA, Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT), 2004. http://www.epa.gov/interstateairquality/pdfs/Revised-SMAT.pdf.

Step 1: Calculate quarterly mean ambient concentrations for each of the major components of $PM_{2.5}$ (i.e., sulfate, nitrate, ammonium, elemental carbon, organic carbon, water, and crustal material) using the component species concentrations estimated for each FRM site. Because not all FRM sites have co-located speciation monitors, the component species concentrations were estimated using an average of 2002 and 2003 ambient data from EPA speciation monitors, which was the speciation data available at the time. The speciation data was interpolated to provide estimates for all FRM sites across the country. The interpolated component concentration information was used to calculate species fractions at each FRM site. The estimated fractional composition of each species (by quarter) was then multiplied by the 5-year weighted average 1999–2003 FRM quarterly mean concentrations at each site (e.g., 20% sulfate multiplied by 15.0 $\mu g/m^3$ of $PM_{2.5}$ equals 3 $\mu g/m^3$ sulfate). The end result is a quarterly concentration for each of the $PM_{2.5}$ species at each FRM site.

Step 2: Calculate quarterly average Relative Reduction Factors (RRFs) for sulfate, nitrate, elemental carbon, organic carbon, and crustal material.[133] The species-specific RRFs for the location of each FRM are the ratio of quarterly average model predicted species concentrations between the sensitivity cases (i.e., #3 "no_aircraft" and #4 "EDMS") and the base line (scenario #2) simulation. The species-specific quarterly RRFs are then multiplied by the corresponding 1999–2003 quarterly species concentration from Step 1. The result is the scenario case quarterly average concentration for each of these species for each sensitivity scenario.

Step 3: Calculate sensitivity case quarterly average concentrations for ammonium and particle-bound water. The "no_aircraft" and "EDMS" case concentrations for ammonium are calculated using the sensitivity case sulfate and nitrate concentrations determined from Step 2 along with the degree of neutralization of sulfate (held constant from the base year). Concentrations of particle-bound water are calculated using an empirical equation using concentrations of sulfate, nitrate, and ammonium as inputs.

Step 4: Calculate the mean of the four quarterly average sensitivity case concentrations to estimate the annual average concentration for each component species. The annual average concentrations of the components are added together to obtain the annual average concentration for $PM_{2.5}$ in the sensitivity cases.

Step 5: For counties with only one monitoring site, the projected value at that site is the projected value for that county. For counties with more than one monitor, the highest value in the county is selected as the concentration for that county.

*Change in Annual Average $PM_{2.5}$ for the Benefits Calculations:* For the purposes of projecting sensitivity case $PM_{2.5}$ concentrations for input to the benefits calculations, we applied the SMAT procedure using the 2001 base line modeling scenario (scenario #2) and both of the sensitivity scenarios #3 and #4. The SMAT procedures for calculating PM benefits are the same as documented above.

*Projection Methodology for 8-hour Ozone Design Values:* For the purpose of estimating impacts on 8-hour ozone design values due to EDMS aircraft emissions, a similar relative approach was used as described above. Relative reduction factors (sensitivity / baseline) were calculated for each model grid cell that contains an ozone monitor for each of the two sensitivity scenarios. These RRF values were calculated using methodology prescribed in existing

[133] Note that aircraft gas turbine engines emit crustal material only in trace amounts (e.g. small bits of metal due to engine wear).

EPA guidance[134]. As with $PM_{2.5}$, these ratios were used to adjust ambient design values to project sensitivity scenario design values.

## III. CMAQ Model Results

### A. Impacts of EDMS Aircraft Emissions on Annual Average Design Values of $PM_{2.5}$

The modeling results indicate that the EDMS emissions generally contribute in small quantities (~ 0.01 µg/m$^3$) to overall ambient $PM_{2.5}$ levels over the U.S. Table F.6 shows the projected average annual $PM_{2.5}$ design values in 2001 with and without the EDMS aircraft emissions. Average design values are shown for the 39 existing nonattainment $PM_{2.5}$ areas, all 557 counties with base year $PM_{2.5}$ monitoring data, and all 826 $PM_{2.5}$ base year monitors within the U.S. Appendix A contains a table of design values by county for each modeling scenario.

**Table F.6:** Average projected $PM_{2.5}$ design values over the U.S. for the base line (scenario #2) and the two modeling scenarios #3 and #4 (no aircraft emissions, and with EDMS aircraft emissions, respectively). Units are µg/m$^3$.

| | Base line (scenario #2) | No aircraft emissions (scenario #3) | EDMS aircraft emissions (scenario #4) | Percent concentration due to EDMS aircraft emissions[135] |
|---|---|---|---|---|
| **NA Areas** | 17.77 | 17.75 | 17.76 | 0.06% |
| **All Counties** | 12.61 | 12.59 | 12.60 | 0.08% |
| **All Monitors** | 12.83 | 12.81 | 12.82 | 0.08% |

Table F.7 contains a subset of the model results for the highest counties in the 37 existing $PM_{2.5}$ nonattainment areas. EDMS aircraft emissions cause increases in $PM_{2.5}$ concentrations of up to 0.15 µg/m$^3$.

**Table F.7:** For the 37 existing $PM_{2.5}$ nonattainment areas, model-estimated $PM_{2.5}$ design values for scenarios #4 and #3, along with average ambient FRM design values. Units are µg/m$^3$.

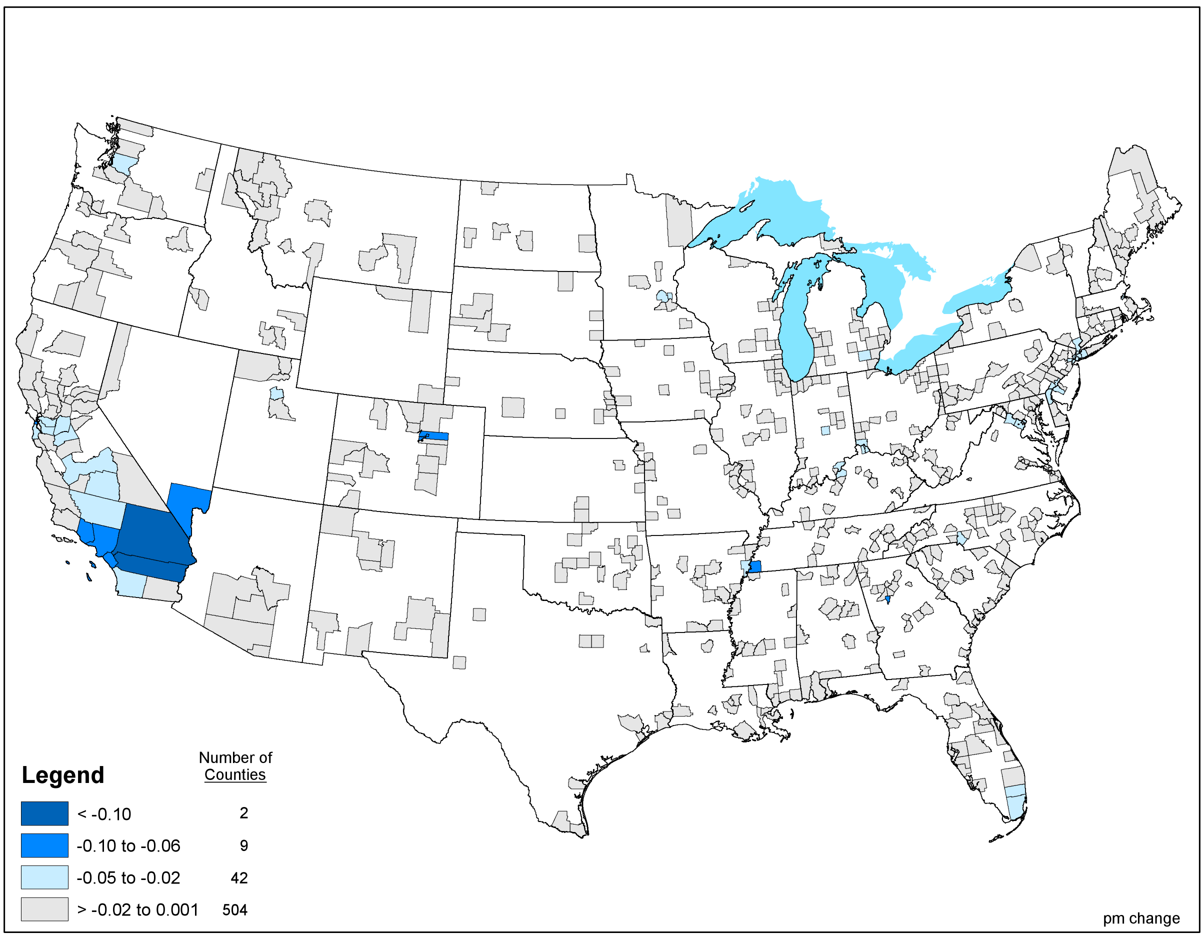
| Present-Day Nonattainment Area | $PM_{2.5}$ Design Value, EDMS aircraft emissions (scenario #4) | $PM_{2.5}$ Design Value, no aircraft (scenario #3) | Change in $PM_{2.5}$ concentration due to EDMS aircraft emissions | Avg 99-03 Ambient FRM $PM_{2.5}$ design value |
|---|---|---|---|---|
| **Los Angeles CA** | 28.88 | 28.73 | 0.15 | 28.83 |
| **San Joaquin Valley CA** | 23.05 | 23.02 | 0.03 | 23.06 |
| **Pittsburgh PA** | 21.16 | 21.16 | 0.01 | 21.18 |
| **Huntington-Ashland WV-KY** | 19.54 | 19.53 | 0.00 | 19.54 |
| **Atlanta GA** | 19.51 | 19.50 | 0.01 | 19.52 |
| **Cleveland OH** | 19.25 | 19.24 | 0.01 | 19.26 |

[134] U.S. EPA, Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-hour Ozone NAAQS; EPA-454/R-05-002; Research Triangle Park, NC; October 2005.
[135] Determined by subtracting scenario #3 concentrations from scenario #4 concentrations and dividing the result by scenario #4 concentrations.

| Present-Day Nonattainment Area | $PM_{2.5}$ Design Value, EDMS aircraft emissions (scenario #4) | $PM_{2.5}$ Design Value, no aircraft (scenario #3) | Change in $PM_{2.5}$ concentration due to EDMS aircraft emissions | Avg 99-03 Ambient FRM $PM_{2.5}$ design value |
|---|---|---|---|---|
| **Birmingham AL** | 19.05 | 19.04 | 0.00 | 19.05 |
| **Cincinnati OH** | 18.52 | 18.48 | 0.04 | 18.55 |
| **Steubenville-Weirton OH-WV** | 18.36 | 18.36 | 0.00 | 18.36 |
| **Knoxville TN** | 18.09 | 18.08 | 0.01 | 18.11 |
| **Chicago IL** | 17.99 | 17.97 | 0.02 | 18.00 |
| **Canton OH** | 17.84 | 17.84 | 0.01 | 17.85 |
| **Charleston, WV** | 17.74 | 17.73 | 0.01 | 17.75 |
| **New York City, NY-NJ-CT** | 17.54 | 17.50 | 0.03 | 17.56 |
| **St. Louis, MO-IL** | 17.40 | 17.39 | 0.01 | 17.41 |
| **Columbus, OH** | 17.28 | 17.27 | 0.01 | 17.28 |
| **Chattanooga, TN-GA** | 17.23 | 17.22 | 0.01 | 17.24 |
| **Baltimore, MD** | 17.11 | 17.10 | 0.01 | 17.12 |
| **Louisville, KY-IN** | 17.08 | 17.04 | 0.04 | 17.08 |
| **Lancaster, PA** | 16.99 | 16.98 | 0.01 | 16.99 |
| **Indianapolis, IN** | 16.87 | 16.84 | 0.02 | 16.88 |
| **Parkersburg-Marietta, WV-OH** | 16.88 | 16.87 | 0.00 | 16.88 |
| **York, PA** | 16.69 | 16.68 | 0.01 | 16.70 |
| **Greensboro, NC** | 16.56 | 16.56 | 0.00 | 16.56 |
| **Macon, GA** | 16.42 | 16.42 | 0.01 | 16.43 |
| **Philadelphia, PA-NJ-DE** | 16.40 | 16.36 | 0.04 | 16.42 |
| **Washington, DC-MD-VA** | 16.23 | 16.21 | 0.02 | 16.25 |
| **Libby, MT** | 16.25 | 16.24 | 0.00 | 16.25 |
| **Reading, PA** | 16.24 | 16.23 | 0.01 | 16.24 |
| **Hickory, NC** | 16.20 | 16.19 | 0.00 | 16.20 |
| **Martinsburg, WV-MD** | 16.18 | 16.18 | 0.00 | 16.18 |
| **Wheeling, WV-OH** | 16.07 | 16.06 | 0.00 | 16.07 |
| **Evansville, IN-KY** | 16.03 | 16.02 | 0.00 | 16.03 |
| **Dayton, OH** | 15.74 | 15.72 | 0.01 | 15.75 |
| **Johnstown, PA** | 15.62 | 15.62 | 0.00 | 15.63 |
| **Harrisburg, PA** | 15.60 | 15.60 | 0.00 | 15.60 |
| **Detroit, MI** | 15.34 | 15.32 | 0.02 | 15.34 |

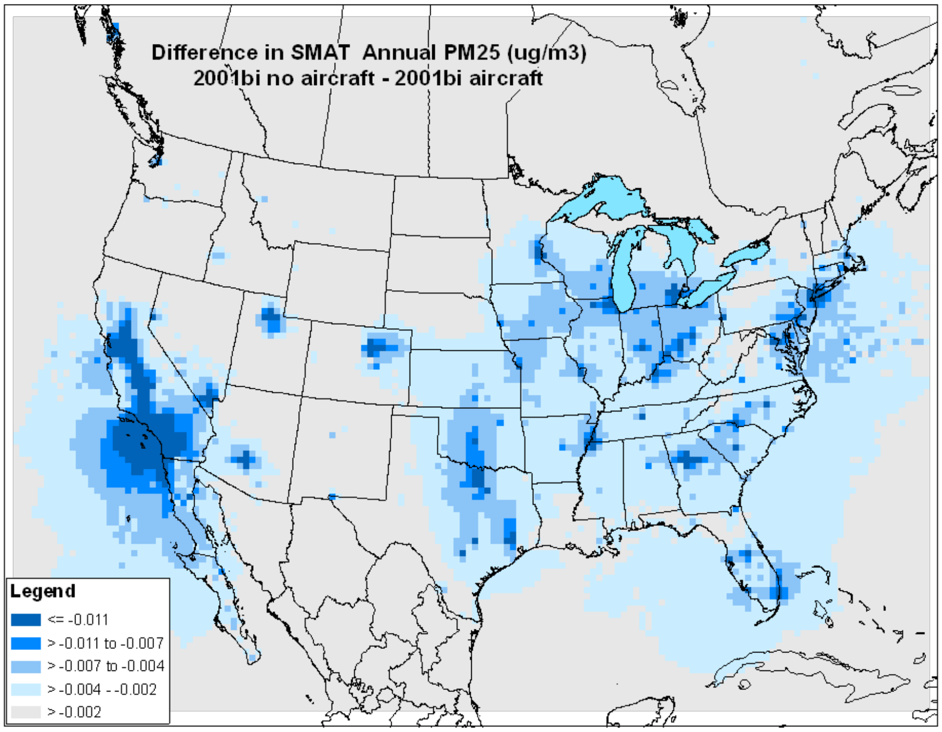
The greatest impacts from the emissions in question tend to occur in counties with high-activity airports and can be larger than the overall national average impact because some of the emissions impact from airport activity occurs within the county containing the airport. Figure F.2 displays the impact of EDMS aircraft emissions on county-level, annual $PM_{2.5}$ design values. The largest impact is in Riverside County, CA where EDMS aircraft emissions increase annual average $PM_{2.5}$ concentrations by 0.15 μg/m$^3$ (from 28.73 to 28.88 μg/m$^3$ [136]). This is 0.52 percent of the 5-year average ambient $PM_{2.5}$ design value for the county. San Bernardino County, CA shows an impact of 0.11 μg/m$^3$, or 0.43 percent of the 5-year average ambient $PM_{2.5}$ design value for San Bernardino County. Another 13 counties show an impact of at least 0.05 μg/m$^3$ and another 38 counties in the U.S. have an impact of at least 0.02 μg/m$^3$. As discussed in section II.G.1 of this Appendix, we can only project the impact of these emissions on county-level $PM_{2.5}$ design values for those counties with present-day ambient monitoring data. Figure F.2 and Figure F.3 show the gridded fields of model response in annual average concentrations as described in section II.G.2 of this Appendix.

**Figure F.2:** Model-projected impacts of removing EDMS emissions on annual $PM_{2.5}$ design values. Units are μg/m$^3$. Negative values indicate annual $PM_{2.5}$ levels would be lower without the aircraft emissions contribution.




[136] Note that the National Ambient Air Quality Standard for $PM_{2.5}$ is 15.0 μg/m$^3$.

**Figure F.3:** Model-projected impacts of removing EDMS emissions on annual average $PM_{2.5}$. Units are $\mu g/m^3$. Negative values indicate annual $PM_{2.5}$ levels would be lower without the aircraft emissions contribution.




**B. Impact of EDMS Aircraft Emissions on 8-Hour Ozone Design Values**

This section summarizes the results of our modeling of ozone air quality impacts from the EDMS aircraft emissions. The modeling results indicate that the EDMS emissions generally contribute in small quantities (~ 0.10 ppb) to overall 8-hour ozone design values over the U.S. Table F.8 shows the average, model-projected, 8-hour ozone concentrations for the project scenarios discussed in section II.E of this Appendix. Average design values are shown for the 126 designated ozone nonattainment areas, all 645 counties with base year ozone monitoring data, and all 1,105 eligible ozone monitors within the U.S. Section V of this Appendix contains design values by county for each modeling scenario.

**Table F.8:** Average projected 8-hour ozone design values for primary strategy modeling scenario. Units are ppb.

| | Base line (scenario #2) | No aircraft emissions (scenario #3) | EDMS aircraft emissions (scenario #4) | Percent concentration due to EDMS aircraft emissions[137] |
|---|---|---|---|---|
| **NA Areas** | 91.20 | 91.10 | 91.21 | 0.12% |

[137] Determined by subtracting scenario #3 concentrations from scenario #4 concentrations and dividing the result by scenario #4 concentrations.

| | Base line (scenario #2) | No aircraft emissions (scenario #3) | EDMS aircraft emissions (scenario #4) | Percent concentration due to EDMS aircraft emissions[137] |
|---|---|---|---|---|
| **All Counties** | 84.95 | 84.85 | 84.95 | 0.12% |
| **All Monitors** | 83.49 | 83.41 | 83.50 | 0.11% |

As with $PM_{2.5}$, the greatest ozone impacts from the EDMS aircraft emissions tend to occur in counties with high-traffic airports and can be larger than the overall national average impact because some of the impact of airport activity occurs within the county boundary. Figure F.4 displays the impact of EDMS aircraft emissions on county-level, 8-hour ozone design values. The largest impact is in Rockdale County, GA where the addition of the EDMS aircraft emissions increases projected ozone design values by 0.60 ppb (from 95.9 to 96.5 ppb[138]). This is 0.62 percent of the 5-year average ambient ozone design value for this county. Another 12 counties show an impact of at least 0.30 ppb and another 11 counties in the U.S. have an impact of at least 0.20 ppb. Figure F.5 shows sample gridded fields of model response in monthly average ozone concentrations.

While the modeling indicates that the impact of EDMS aircraft emissions is typically positive (i.e., results in higher ozone concentrations), there are 24 counties across the U.S. where these aircraft emissions actually lower 8-hour ozone design values. This is known as a “disbenefit” because if there were no aircraft emissions in these areas, ozone concentrations would be higher instead of lower. The largest negative impact of EDMS aircraft emissions is in Richmond County, NY (reduction of 0.27 ppb). Due to the complex photochemistry of ozone production, $NO_x$ emissions can lead to both the formation and destruction of ozone, depending on the local quantities of $NO_x$, VOC, and ozone catalysts such as the OH and $HO_2$ radicals. In areas dominated by fresh emissions of $NO_x$, ozone catalysts are removed via the production of nitric acid, which slows the ozone formation rate. Because $NO_x$ is generally depleted more rapidly than VOC, this effect is usually short-lived and the emitted $NO_x$ can lead to ozone formation further downwind. Also, the ozone increases (negative impacts) tend to occur more frequently at lower ozone concentrations. As a result, metrics like monthly average ozone (e.g., monthly average ozone in Figure F.5) tend to indicate more frequent "disbenefits" than metrics that focus on the upper end of ozone observations (e.g., projected design values in Figure F.4).

[138] Note that the National Ambient Air Quality Standard for 8-hour ozone is 0.08 ppm.

**Figure F.4:** Model-projected impacts of removing EDMS emissions on 8-hour ozone design values. Units are ppb. Negative values indicate annual ozone levels would be lower without the aircraft emissions contribution. Positive values indicate that the inclusion of EDMS aircraft emissions suppresses average ozone levels.

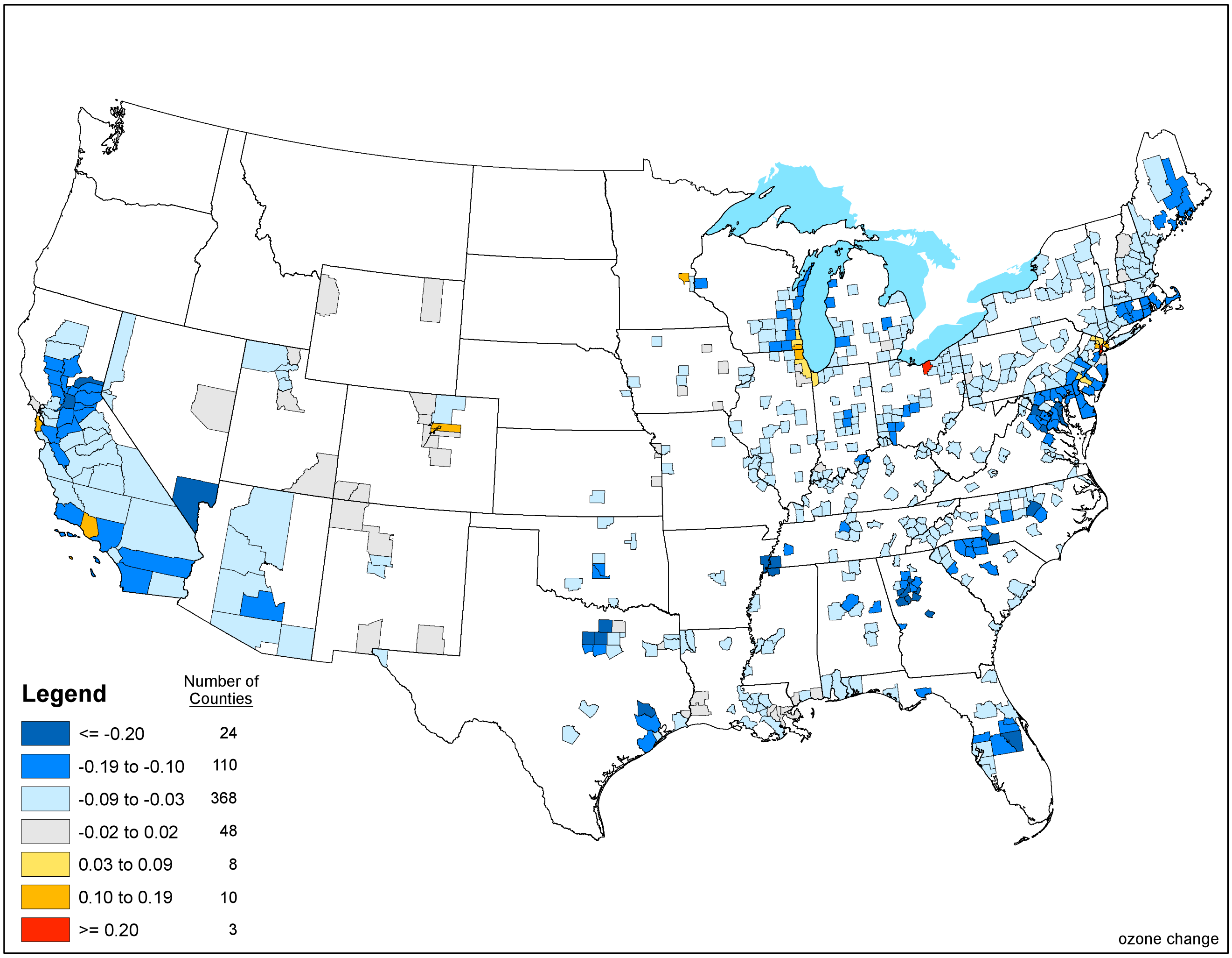
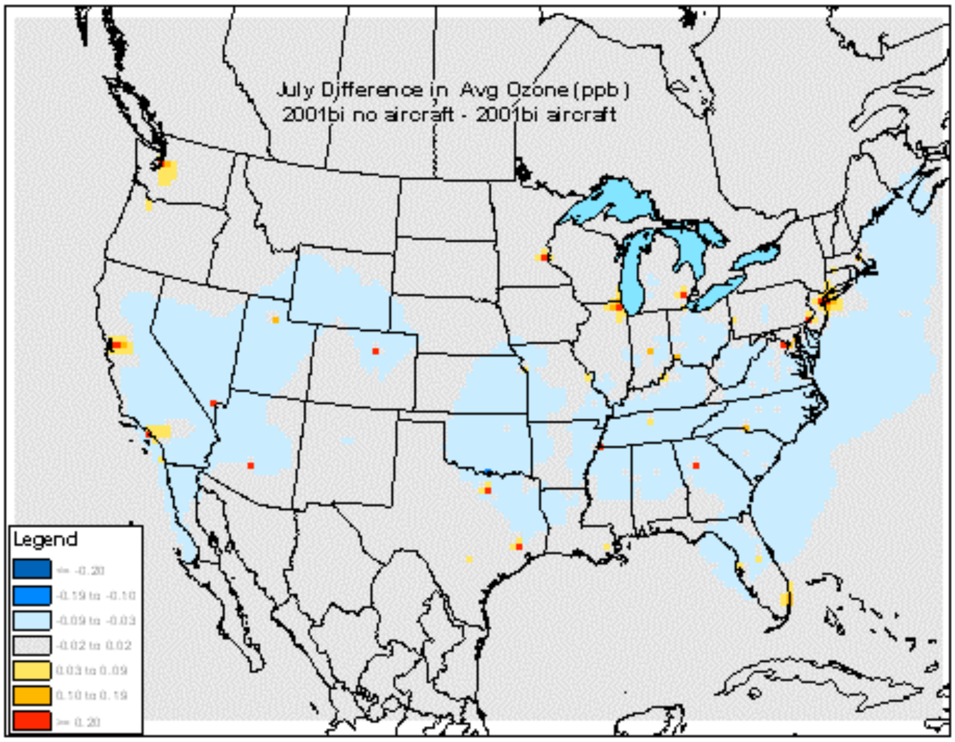


**Figure F.5:** Model-projected impacts of removing EDMS emissions on July average ozone. Units are ppb. Negative values indicate monthly average ozone levels would be lower without the EDMS aircraft emissions contribution. Positive values indicate that the inclusion of EDMS aircraft emissions suppresses average ozone levels.




**C. Impacts of Proposed Rule on Visibility**

The modeling conducted as part of this study was also used to project the impacts of these aircraft sources on visibility conditions over 116 mandatory class I federal areas across the U.S with ambient monitoring data. Class I federal lands include areas such as national parks, national wilderness areas, and national monuments. These areas are granted special air quality protections under Section 162(a) of the federal Clean Air Act.[139] The results indicate that the EDMS aircraft emissions have small impacts on visibility when averaged over all 116 mandatory class I federal areas. The average deciview reduction due to EDMS aircraft emissions is 0.01. The greatest visibility impacts are projected to occur at Agua Tibia Wilderness where EDMS aircraft emissions reduce visibility by 0.06 deciviews. As a comparison, the average of the baseline 2000 to 2004 (5-year) deciview values of the 108 sites in the VIEWS with all five years of data was 13.06 deciviews.[140]

[139] There are 156 protected areas designated as mandatory federal Class I areas for the purposes of the visibility protection program. A map is available at: http://www.epa.gov/ttn/oarpg/t1/fr_notices/classimp.gif.

[140] http://vista.cira.colostate.edu/DataWarehouse/IMPROVE/Data/SummaryData/RHR2_Baseline_20070829.xls

## IV. $PM_{2.5}$ Modeling Results from Modeling Scenarios. Units are µg/m$^3$.

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Alabama | Baldwin Co | 11.43 | 11.42 | 0.00 | 11.43 |
| Alabama | Clay Co | 14.26 | 14.26 | 0.00 | 14.27 |
| Alabama | Colbert Co | 13.94 | 13.94 | 0.00 | 13.95 |
| Alabama | DeKalb Co | 15.62 | 15.62 | 0.00 | 15.62 |
| Alabama | Escambia Co | 13.02 | 13.02 | 0.00 | 13.03 |
| Alabama | Houston Co | 14.69 | 14.69 | 0.00 | 14.70 |
| Alabama | Jefferson Co | 19.05 | 19.04 | 0.00 | 19.05 |
| Alabama | Madison Co | 14.82 | 14.81 | 0.00 | 14.82 |
| Alabama | Mobile Co | 13.68 | 13.68 | 0.00 | 13.69 |
| Alabama | Montgomery Co | 15.41 | 15.41 | 0.00 | 15.41 |
| Alabama | Morgan Co | 15.79 | 15.79 | 0.01 | 15.81 |
| Alabama | Russell Co | 16.29 | 16.29 | 0.00 | 16.29 |
| Alabama | Shelby Co | 15.33 | 15.32 | 0.00 | 15.33 |
| Alabama | Sumter Co | 13.28 | 13.28 | 0.00 | 13.28 |
| Alabama | Talladega Co | 16.05 | 16.04 | 0.00 | 16.05 |
| Arizona | Gila Co | 9.54 | 9.53 | 0.00 | 9.54 |
| Arizona | Maricopa Co | 11.36 | 11.34 | 0.01 | 11.37 |
| Arizona | Pima Co | 7.46 | 7.46 | 0.00 | 7.47 |
| Arizona | Pinal Co | 8.32 | 8.31 | 0.01 | 8.33 |
| Arizona | Santa Cruz Co | 11.88 | 11.88 | 0.00 | 11.89 |
| Arkansas | Arkansas Co | 12.38 | 12.38 | 0.00 | 12.38 |
| Arkansas | Ashley Co | 12.72 | 12.72 | 0.00 | 12.72 |
| Arkansas | Craighead Co | 12.39 | 12.38 | 0.00 | 12.39 |
| Arkansas | Crittenden Co | 13.34 | 13.28 | 0.06 | 13.35 |
| Arkansas | Faulkner Co | 12.57 | 12.57 | 0.00 | 12.58 |
| Arkansas | Jefferson Co | 13.28 | 13.28 | 0.00 | 13.28 |
| Arkansas | Mississippi Co | 12.05 | 12.04 | 0.01 | 12.05 |
| Arkansas | Phillips Co | 12.50 | 12.49 | 0.01 | 12.50 |
| Arkansas | Polk Co | 11.35 | 11.35 | 0.00 | 11.35 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Arkansas | Pope Co | 12.48 | 12.48 | 0.00 | 12.48 |
| Arkansas | Pulaski Co | 14.52 | 14.51 | 0.01 | 14.55 |
| Arkansas | Sebastian Co | 12.66 | 12.65 | 0.00 | 12.67 |
| Arkansas | Union Co | 13.03 | 13.03 | 0.00 | 13.03 |
| Arkansas | White Co | 11.92 | 11.92 | 0.00 | 11.92 |
| California | Alameda Co | 11.94 | 11.91 | 0.04 | 11.96 |
| California | Butte Co | 14.31 | 14.30 | 0.01 | 14.32 |
| California | Calaveras Co | 9.06 | 9.05 | 0.01 | 9.07 |
| California | Colusa Co | 9.88 | 9.88 | 0.01 | 9.88 |
| California | Contra Costa Co | 11.06 | 11.03 | 0.03 | 11.07 |
| California | El Dorado Co | 7.84 | 7.84 | 0.00 | 7.84 |
| California | Fresno Co | 21.81 | 21.78 | 0.04 | 21.85 |
| California | Humboldt Co | 8.86 | 8.86 | 0.00 | 8.86 |
| California | Imperial Co | 15.22 | 15.21 | 0.01 | 15.23 |
| California | Inyo Co | 6.23 | 6.22 | 0.00 | 6.23 |
| California | Kern Co | 22.71 | 22.67 | 0.04 | 22.75 |
| California | Kings Co | 18.52 | 18.50 | 0.02 | 18.52 |
| California | Lake Co | 5.00 | 5.00 | 0.00 | 5.01 |
| California | Los Angeles Co | 24.19 | 24.11 | 0.08 | 24.22 |
| California | Mendocino Co | 8.08 | 8.08 | 0.00 | 8.08 |
| California | Merced Co | 16.73 | 16.71 | 0.02 | 16.73 |
| California | Monterey Co | 8.46 | 8.45 | 0.01 | 8.46 |
| California | Nevada Co | 8.31 | 8.31 | 0.00 | 8.31 |
| California | Orange Co | 20.39 | 20.30 | 0.09 | 20.40 |
| California | Placer Co | 12.21 | 12.19 | 0.02 | 12.21 |
| California | Riverside Co | 28.88 | 28.73 | 0.15 | 28.83 |
| California | Sacramento Co | 12.94 | 12.92 | 0.02 | 12.96 |
| California | San Bernardino Co | 25.52 | 25.41 | 0.11 | 25.49 |
| California | San Diego Co | 16.44 | 16.41 | 0.03 | 16.45 |
| California | San Francisco Co | 11.77 | 11.71 | 0.06 | 11.81 |
| California | San Joaquin Co | 15.45 | 15.42 | 0.03 | 15.47 |
| California | San Luis Obispo Co | 9.67 | 9.67 | 0.00 | 9.68 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircaft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| California | San Mateo Co | 11.07 | 11.05 | 0.03 | 11.10 |
| California | Santa Barbara Co | 9.69 | 9.69 | 0.00 | 9.69 |
| California | Santa Clara Co | 11.45 | 11.43 | 0.02 | 11.45 |
| California | Santa Cruz Co | 8.57 | 8.55 | 0.01 | 8.57 |
| California | Shasta Co | 9.66 | 9.66 | 0.00 | 9.66 |
| California | Solano Co | 12.18 | 12.17 | 0.01 | 12.19 |
| California | Sonoma Co | 10.55 | 10.55 | 0.00 | 10.55 |
| California | Stanislaus Co | 17.86 | 17.83 | 0.03 | 17.87 |
| California | Sutter Co | 12.08 | 12.07 | 0.01 | 12.08 |
| California | Tulare Co | 23.05 | 23.02 | 0.03 | 23.06 |
| California | Ventura Co | 14.58 | 14.50 | 0.07 | 14.59 |
| California | Yolo Co | 10.85 | 10.84 | 0.02 | 10.87 |
| Colorado | Adams Co | 10.32 | 10.25 | 0.06 | 10.38 |
| Colorado | Arapahoe Co | 8.89 | 8.88 | 0.01 | 8.89 |
| Colorado | Boulder Co | 9.36 | 9.35 | 0.01 | 9.37 |
| Colorado | Delta Co | 8.35 | 8.34 | 0.00 | 8.35 |
| Colorado | Denver Co | 10.80 | 10.74 | 0.06 | 10.87 |
| Colorado | Elbert Co | 4.34 | 4.34 | 0.00 | 4.35 |
| Colorado | El Paso Co | 7.74 | 7.73 | 0.01 | 7.75 |
| Colorado | Gunnison Co | 6.72 | 6.71 | 0.00 | 6.72 |
| Colorado | La Plata Co | 5.49 | 5.49 | 0.00 | 5.49 |
| Colorado | Larimer Co | 8.04 | 8.03 | 0.01 | 8.05 |
| Colorado | Mesa Co | 7.61 | 7.61 | 0.00 | 7.61 |
| Colorado | Pueblo Co | 7.99 | 7.99 | 0.00 | 8.00 |
| Colorado | Routt Co | 7.46 | 7.46 | 0.00 | 7.47 |
| Colorado | San Miguel Co | 5.61 | 5.61 | 0.00 | 5.61 |
| Colorado | Weld Co | 9.58 | 9.57 | 0.02 | 9.59 |
| Connecticut | Fairfield Co | 13.39 | 13.38 | 0.01 | 13.40 |
| Connecticut | Hartford Co | 12.72 | 12.72 | 0.00 | 12.72 |
| Connecticut | New Haven Co | 13.95 | 13.94 | 0.01 | 13.95 |
| Connecticut | New London Co | 11.74 | 11.74 | 0.00 | 11.75 |
| Delaware | Kent Co | 13.12 | 13.11 | 0.01 | 13.14 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Delaware | New Castle Co | 16.40 | 16.36 | 0.04 | 16.42 |
| Delaware | Sussex Co | 14.07 | 14.07 | 0.01 | 14.08 |
| District of Columbia | District of Columbia | 16.23 | 16.21 | 0.02 | 16.25 |
| Florida | Alachua Co | 10.35 | 10.35 | 0.00 | 10.35 |
| Florida | Brevard Co | 7.88 | 7.88 | 0.01 | 7.89 |
| Florida | Broward Co | 8.47 | 8.45 | 0.02 | 8.52 |
| Florida | Citrus Co | 9.69 | 9.69 | 0.00 | 9.69 |
| Florida | Duval Co | 10.82 | 10.82 | 0.00 | 10.83 |
| Florida | Escambia Co | 12.20 | 12.20 | 0.00 | 12.21 |
| Florida | Hillsborough Co | 11.85 | 11.84 | 0.01 | 11.86 |
| Florida | Lee Co | 8.94 | 8.93 | 0.00 | 8.94 |
| Florida | Leon Co | 12.92 | 12.92 | 0.01 | 12.93 |
| Florida | Manatee Co | 9.96 | 9.96 | 0.00 | 9.97 |
| Florida | Marion Co | 10.37 | 10.37 | 0.00 | 10.37 |
| Florida | Miami-Dade Co | 9.66 | 9.64 | 0.03 | 9.82 |
| Florida | Orange Co | 10.73 | 10.72 | 0.01 | 10.74 |
| Florida | Palm Beach Co | 7.70 | 7.69 | 0.01 | 7.70 |
| Florida | Pinellas Co | 11.13 | 11.13 | 0.01 | 11.15 |
| Florida | Polk Co | 10.90 | 10.90 | 0.00 | 10.91 |
| Florida | St. Lucie Co | 9.00 | 9.00 | 0.00 | 9.01 |
| Florida | Sarasota Co | 9.86 | 9.86 | 0.00 | 9.87 |
| Florida | Seminole Co | 9.78 | 9.77 | 0.01 | 9.79 |
| Florida | Volusia Co | 9.80 | 9.80 | 0.00 | 9.82 |
| Georgia | Bibb Co | 16.42 | 16.42 | 0.01 | 16.43 |
| Georgia | Chatham Co | 14.99 | 14.98 | 0.01 | 15.00 |
| Georgia | Clarke Co | 17.07 | 17.06 | 0.01 | 17.07 |
| Georgia | Clayton Co | 17.46 | 17.37 | 0.09 | 17.52 |
| Georgia | Cobb Co | 17.12 | 17.11 | 0.01 | 17.12 |
| Georgia | DeKalb Co | 17.65 | 17.64 | 0.01 | 17.66 |
| Georgia | Dougherty Co | 15.10 | 15.10 | 0.00 | 15.11 |
| Georgia | Floyd Co | 16.67 | 16.67 | 0.00 | 16.67 |
| Georgia | Fulton Co | 19.51 | 19.50 | 0.01 | 19.52 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Georgia | Glynn Co | 12.01 | 12.01 | 0.00 | 12.02 |
| Georgia | Gwinnett Co | 16.34 | 16.33 | 0.01 | 16.34 |
| Georgia | Hall Co | 16.08 | 16.08 | 0.01 | 16.08 |
| Georgia | Houston Co | 12.85 | 12.85 | 0.00 | 12.85 |
| Georgia | Lowndes Co | 12.05 | 12.04 | 0.00 | 12.05 |
| Georgia | Muscogee Co | 16.33 | 16.33 | 0.00 | 16.33 |
| Georgia | Paulding Co | 15.35 | 15.34 | 0.01 | 15.35 |
| Georgia | Richmond Co | 15.87 | 15.86 | 0.01 | 15.87 |
| Georgia | Walker Co | 15.56 | 15.56 | 0.01 | 15.57 |
| Georgia | Washington Co | 15.44 | 15.44 | 0.00 | 15.45 |
| Georgia | Wilkinson Co | 16.27 | 16.26 | 0.00 | 16.27 |
| Idaho | Ada Co | 9.41 | 9.41 | 0.01 | 9.42 |
| Idaho | Bannock Co | 9.31 | 9.30 | 0.00 | 9.31 |
| Idaho | Bonneville Co | 6.72 | 6.72 | 0.00 | 6.72 |
| Idaho | Canyon Co | 9.97 | 9.97 | 0.01 | 9.98 |
| Idaho | Power Co | 10.68 | 10.68 | 0.00 | 10.69 |
| Idaho | Shoshone Co | 12.77 | 12.76 | 0.00 | 12.77 |
| Illinois | Adams Co | 13.04 | 13.04 | 0.00 | 13.04 |
| Illinois | Champaign Co | 12.93 | 12.92 | 0.00 | 12.93 |
| Illinois | Cook Co | 17.99 | 17.97 | 0.02 | 18.00 |
| Illinois | DuPage Co | 15.01 | 15.00 | 0.01 | 15.02 |
| Illinois | Kane Co | 14.39 | 14.37 | 0.01 | 14.40 |
| Illinois | Lake Co | 12.97 | 12.96 | 0.01 | 12.99 |
| Illinois | McHenry Co | 13.13 | 13.12 | 0.01 | 13.14 |
| Illinois | McLean Co | 13.87 | 13.87 | 0.00 | 13.88 |
| Illinois | Macon Co | 14.22 | 14.22 | 0.00 | 14.22 |
| Illinois | Madison Co | 17.40 | 17.39 | 0.01 | 17.41 |
| Illinois | Peoria Co | 14.33 | 14.32 | 0.00 | 14.33 |
| Illinois | Randolph Co | 13.06 | 13.06 | 0.00 | 13.07 |
| Illinois | Rock Island Co | 12.45 | 12.44 | 0.01 | 12.45 |
| Illinois | St. Clair Co | 16.87 | 16.86 | 0.01 | 16.87 |
| Illinois | Sangamon Co | 13.60 | 13.59 | 0.00 | 13.60 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Illinois | Will Co | 15.35 | 15.34 | 0.01 | 15.35 |
| Indiana | Allen Co | 14.52 | 14.52 | 0.01 | 14.53 |
| Indiana | Clark Co | 16.91 | 16.87 | 0.04 | 16.91 |
| Indiana | Delaware Co | 14.71 | 14.70 | 0.01 | 14.71 |
| Indiana | Dubois Co | 16.03 | 16.02 | 0.00 | 16.03 |
| Indiana | Elkhart Co | 15.31 | 15.31 | 0.01 | 15.32 |
| Indiana | Floyd Co | 15.36 | 15.35 | 0.01 | 15.36 |
| Indiana | Henry Co | 13.55 | 13.55 | 0.01 | 13.55 |
| Indiana | Howard Co | 14.88 | 14.88 | 0.01 | 14.89 |
| Indiana | Knox Co | 13.83 | 13.83 | 0.00 | 13.84 |
| Indiana | Lake Co | 15.47 | 15.45 | 0.01 | 15.48 |
| Indiana | La Porte Co | 13.52 | 13.51 | 0.01 | 13.52 |
| Indiana | Madison Co | 14.82 | 14.82 | 0.01 | 14.82 |
| Indiana | Marion Co | 16.87 | 16.84 | 0.02 | 16.88 |
| Indiana | Porter Co | 14.01 | 14.00 | 0.01 | 14.01 |
| Indiana | St. Joseph Co | 14.35 | 14.34 | 0.01 | 14.35 |
| Indiana | Spencer Co | 14.43 | 14.43 | 0.00 | 14.44 |
| Indiana | Vanderburgh Co | 15.60 | 15.60 | 0.00 | 15.60 |
| Indiana | Vigo Co | 14.88 | 14.87 | 0.00 | 14.88 |
| Iowa | Black Hawk Co | 11.48 | 11.48 | 0.00 | 11.48 |
| Iowa | Cerro Gordo Co | 10.55 | 10.54 | 0.00 | 10.55 |
| Iowa | Clinton Co | 12.26 | 12.26 | 0.01 | 12.26 |
| Iowa | Emmet Co | 8.82 | 8.82 | 0.00 | 8.83 |
| Iowa | Johnson Co | 11.52 | 11.52 | 0.01 | 11.52 |
| Iowa | Linn Co | 11.23 | 11.22 | 0.01 | 11.23 |
| Iowa | Muscatine Co | 13.03 | 13.02 | 0.00 | 13.03 |
| Iowa | Polk Co | 10.68 | 10.67 | 0.01 | 10.68 |
| Iowa | Pottawattamie Co | 10.49 | 10.48 | 0.00 | 10.49 |
| Iowa | Scott Co | 12.76 | 12.75 | 0.01 | 12.76 |
| Iowa | Van Buren Co | 10.46 | 10.45 | 0.00 | 10.46 |
| Iowa | Woodbury Co | 10.07 | 10.07 | 0.00 | 10.08 |
| Kansas | Johnson Co | 11.95 | 11.94 | 0.00 | 11.95 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircaft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Kansas | Linn Co | 10.92 | 10.92 | 0.00 | 10.92 |
| Kansas | Sedgwick Co | 11.39 | 11.39 | 0.00 | 11.40 |
| Kansas | Shawnee Co | 11.03 | 11.03 | 0.00 | 11.04 |
| Kansas | Sumner Co | 10.31 | 10.30 | 0.00 | 10.31 |
| Kansas | Wyandotte Co | 13.67 | 13.65 | 0.02 | 13.70 |
| Kentucky | Bell Co | 14.98 | 14.98 | 0.00 | 14.98 |
| Kentucky | Boyd Co | 15.16 | 15.16 | 0.00 | 15.16 |
| Kentucky | Bullitt Co | 15.41 | 15.40 | 0.01 | 15.41 |
| Kentucky | Campbell Co | 14.30 | 14.27 | 0.03 | 14.32 |
| Kentucky | Carter Co | 12.48 | 12.48 | 0.00 | 12.48 |
| Kentucky | Christian Co | 14.06 | 14.06 | 0.00 | 14.07 |
| Kentucky | Daviess Co | 14.81 | 14.81 | 0.00 | 14.81 |
| Kentucky | Fayette Co | 16.06 | 16.06 | 0.00 | 16.06 |
| Kentucky | Franklin Co | 14.06 | 14.05 | 0.01 | 14.07 |
| Kentucky | Hardin Co | 14.36 | 14.36 | 0.01 | 14.36 |
| Kentucky | Jefferson Co | 17.08 | 17.04 | 0.04 | 17.08 |
| Kentucky | Kenton Co | 15.35 | 15.32 | 0.03 | 15.37 |
| Kentucky | McCracken Co | 14.16 | 14.16 | 0.00 | 14.16 |
| Kentucky | Madison Co | 14.00 | 13.99 | 0.00 | 14.00 |
| Kentucky | Perry Co | 13.54 | 13.54 | 0.00 | 13.54 |
| Kentucky | Pike Co | 14.34 | 14.33 | 0.00 | 14.34 |
| Kentucky | Warren Co | 14.52 | 14.51 | 0.00 | 14.52 |
| Louisiana | Caddo Parish | 13.14 | 13.13 | 0.00 | 13.14 |
| Louisiana | Calcasieu Parish | 12.01 | 12.01 | 0.00 | 12.02 |
| Louisiana | East Baton Rouge Parish | 13.71 | 13.71 | 0.00 | 13.71 |
| Louisiana | Iberville Parish | 13.08 | 13.08 | 0.00 | 13.08 |
| Louisiana | Jefferson Parish | 12.81 | 12.80 | 0.01 | 12.83 |
| Louisiana | Lafayette Parish | 11.59 | 11.59 | 0.00 | 11.60 |
| Louisiana | Orleans Parish | 13.03 | 13.03 | 0.01 | 13.05 |
| Louisiana | Ouachita Parish | 12.16 | 12.15 | 0.00 | 12.16 |
| Louisiana | St. Bernard Parish | 10.89 | 10.88 | 0.00 | 10.89 |
| Louisiana | Tangipahoa Parish | 12.15 | 12.15 | 0.00 | 12.16 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircaft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Louisiana | Terrebonne Parish | 10.62 | 10.62 | 0.00 | 10.62 |
| Louisiana | West Baton Rouge Parish | 13.29 | 13.29 | 0.00 | 13.29 |
| Maine | Androscoggin Co | 10.60 | 10.60 | 0.00 | 10.60 |
| Maine | Aroostook Co | 11.17 | 11.17 | 0.00 | 11.17 |
| Maine | Cumberland Co | 11.44 | 11.44 | 0.00 | 11.45 |
| Maine | Hancock Co | 6.20 | 6.20 | 0.00 | 6.20 |
| Maine | Kennebec Co | 10.54 | 10.54 | 0.00 | 10.55 |
| Maine | Oxford Co | 10.30 | 10.29 | 0.00 | 10.30 |
| Maine | Penobscot Co | 9.87 | 9.87 | 0.00 | 9.88 |
| Maine | York Co | 9.62 | 9.62 | 0.00 | 9.63 |
| Maryland | Anne Arundel Co | 15.44 | 15.43 | 0.02 | 15.47 |
| Maryland | Baltimore Co | 15.09 | 15.08 | 0.01 | 15.09 |
| Maryland | Harford Co | 13.26 | 13.25 | 0.01 | 13.27 |
| Maryland | Montgomery Co | 12.97 | 12.97 | 0.00 | 12.97 |
| Maryland | Washington Co | 14.35 | 14.35 | 0.00 | 14.36 |
| Maryland | Baltimore city | 17.11 | 17.10 | 0.01 | 17.12 |
| Massachusetts | Berkshire Co | 12.26 | 12.26 | 0.00 | 12.26 |
| Massachusetts | Hampden Co | 13.73 | 13.73 | 0.01 | 13.74 |
| Massachusetts | Plymouth Co | 11.19 | 11.18 | 0.00 | 11.19 |
| Massachusetts | Suffolk Co | 12.74 | 12.72 | 0.02 | 12.76 |
| Michigan | Allegan Co | 12.37 | 12.36 | 0.01 | 12.37 |
| Michigan | Bay Co | 11.22 | 11.22 | 0.00 | 11.22 |
| Michigan | Berrien Co | 12.60 | 12.60 | 0.01 | 12.61 |
| Michigan | Chippewa Co | 8.29 | 8.29 | 0.00 | 8.29 |
| Michigan | Genesee Co | 12.70 | 12.69 | 0.01 | 12.71 |
| Michigan | Ingham Co | 13.34 | 13.34 | 0.01 | 13.35 |
| Michigan | Kalamazoo Co | 14.91 | 14.90 | 0.01 | 14.92 |
| Michigan | Kent Co | 13.90 | 13.89 | 0.01 | 13.91 |
| Michigan | Macomb Co | 13.31 | 13.31 | 0.01 | 13.32 |
| Michigan | Monroe Co | 15.34 | 15.32 | 0.02 | 15.34 |
| Michigan | Muskegon Co | 12.23 | 12.22 | 0.01 | 12.24 |
| Michigan | Oakland Co | 14.85 | 14.84 | 0.01 | 14.85 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircaft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Michigan | Ottawa Co | 13.40 | 13.39 | 0.01 | 13.41 |
| Michigan | Saginaw Co | 10.80 | 10.80 | 0.00 | 10.81 |
| Michigan | St. Clair Co | 13.92 | 13.91 | 0.01 | 13.92 |
| Michigan | Washtenaw Co | 14.54 | 14.48 | 0.05 | 14.57 |
| Michigan | Wayne Co | 19.62 | 19.61 | 0.02 | 19.63 |
| Minnesota | Dakota Co | 10.32 | 10.32 | 0.01 | 10.32 |
| Minnesota | Hennepin Co | 10.81 | 10.77 | 0.04 | 10.81 |
| Minnesota | Mille Lacs Co | 7.40 | 7.40 | 0.00 | 7.40 |
| Minnesota | Olmsted Co | 11.17 | 11.16 | 0.01 | 11.17 |
| Minnesota | Ramsey Co | 12.23 | 12.19 | 0.04 | 12.24 |
| Minnesota | St. Louis Co | 8.41 | 8.41 | 0.00 | 8.41 |
| Minnesota | Scott Co | 10.43 | 10.42 | 0.00 | 10.43 |
| Minnesota | Stearns Co | 9.65 | 9.65 | 0.00 | 9.65 |
| Mississippi | Adams Co | 11.35 | 11.35 | 0.00 | 11.35 |
| Mississippi | Bolivar Co | 12.81 | 12.80 | 0.00 | 12.81 |
| Mississippi | DeSoto Co | 13.18 | 13.17 | 0.01 | 13.18 |
| Mississippi | Forrest Co | 13.54 | 13.54 | 0.00 | 13.54 |
| Mississippi | Hancock Co | 10.98 | 10.98 | 0.00 | 10.98 |
| Mississippi | Harrison Co | 11.55 | 11.55 | 0.00 | 11.56 |
| Mississippi | Hinds Co | 14.06 | 14.06 | 0.00 | 14.07 |
| Mississippi | Jackson Co | 12.56 | 12.56 | 0.00 | 12.56 |
| Mississippi | Jones Co | 15.28 | 15.27 | 0.00 | 15.29 |
| Mississippi | Lauderdale Co | 13.34 | 13.33 | 0.00 | 13.35 |
| Mississippi | Lee Co | 13.20 | 13.20 | 0.00 | 13.21 |
| Mississippi | Lowndes Co | 13.69 | 13.68 | 0.00 | 13.69 |
| Mississippi | Pearl River Co | 11.68 | 11.68 | 0.00 | 11.69 |
| Mississippi | Rankin Co | 13.35 | 13.35 | 0.00 | 13.35 |
| Mississippi | Scott Co | 11.88 | 11.88 | 0.00 | 11.88 |
| Mississippi | Warren Co | 12.50 | 12.50 | 0.00 | 12.50 |
| Missouri | Buchanan Co | 12.53 | 12.53 | 0.01 | 12.54 |
| Missouri | Cass Co | 11.39 | 11.39 | 0.00 | 11.40 |
| Missouri | Cedar Co | 11.61 | 11.61 | 0.00 | 11.61 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Missouri | Clay Co | 12.86 | 12.84 | 0.02 | 12.89 |
| Missouri | Greene Co | 12.27 | 12.27 | 0.00 | 12.27 |
| Missouri | Jackson Co | 12.27 | 12.26 | 0.01 | 12.27 |
| Missouri | Jasper Co | 13.85 | 13.85 | 0.00 | 13.86 |
| Missouri | Jefferson Co | 14.80 | 14.79 | 0.00 | 14.80 |
| Missouri | Monroe Co | 11.16 | 11.15 | 0.00 | 11.16 |
| Missouri | St. Charles Co | 14.52 | 14.52 | 0.00 | 14.53 |
| Missouri | Ste. Genevieve Co | 13.98 | 13.98 | 0.00 | 13.99 |
| Missouri | St. Louis Co | 14.40 | 14.38 | 0.02 | 14.46 |
| Missouri | St. Louis city | 15.62 | 15.61 | 0.01 | 15.62 |
| Montana | Cascade Co | 6.04 | 6.04 | 0.00 | 6.05 |
| Montana | Flathead Co | 8.55 | 8.55 | 0.00 | 8.55 |
| Montana | Gallatin Co | 8.72 | 8.72 | 0.00 | 8.72 |
| Montana | Lake Co | 9.69 | 9.69 | 0.00 | 9.69 |
| Montana | Lincoln Co | 16.25 | 16.24 | 0.00 | 16.25 |
| Montana | Missoula Co | 11.04 | 11.03 | 0.00 | 11.04 |
| Montana | Ravalli Co | 9.32 | 9.32 | 0.00 | 9.32 |
| Montana | Rosebud Co | 6.98 | 6.98 | 0.00 | 6.98 |
| Montana | Sanders Co | 6.52 | 6.51 | 0.00 | 6.52 |
| Montana | Silver Bow Co | 8.74 | 8.74 | 0.00 | 8.74 |
| Montana | Yellowstone Co | 7.61 | 7.61 | 0.00 | 7.63 |
| Nebraska | Cass Co | 10.39 | 10.38 | 0.00 | 10.39 |
| Nebraska | Douglas Co | 10.82 | 10.80 | 0.01 | 10.83 |
| Nebraska | Hall Co | 8.55 | 8.55 | 0.00 | 8.56 |
| Nebraska | Lancaster Co | 10.01 | 10.00 | 0.00 | 10.02 |
| Nebraska | Lincoln Co | 7.10 | 7.10 | 0.00 | 7.11 |
| Nebraska | Sarpy Co | 10.33 | 10.32 | 0.00 | 10.33 |
| Nebraska | Scotts Bluff Co | 6.03 | 6.03 | 0.00 | 6.03 |
| Nebraska | Washington Co | 9.91 | 9.90 | 0.00 | 9.91 |
| Nevada | Clark Co | 10.89 | 10.82 | 0.07 | 10.96 |
| Nevada | Washoe Co | 9.34 | 9.33 | 0.01 | 9.38 |
| New Hampshire | Cheshire Co | 11.81 | 11.81 | 0.00 | 11.81 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircaft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| New Hampshire | Coos Co | 10.11 | 10.11 | 0.00 | 10.11 |
| New Hampshire | Merrimack Co | 9.95 | 9.95 | 0.01 | 9.96 |
| New Hampshire | Sullivan Co | 9.95 | 9.95 | 0.00 | 9.96 |
| New Jersey | Bergen Co | 14.09 | 14.08 | 0.01 | 14.10 |
| New Jersey | Camden Co | 14.54 | 14.53 | 0.01 | 14.54 |
| New Jersey | Gloucester Co | 13.99 | 13.96 | 0.03 | 14.00 |
| New Jersey | Hudson Co | 15.38 | 15.33 | 0.05 | 15.39 |
| New Jersey | Mercer Co | 14.27 | 14.26 | 0.01 | 14.27 |
| New Jersey | Middlesex Co | 12.67 | 12.66 | 0.01 | 12.67 |
| New Jersey | Morris Co | 12.68 | 12.67 | 0.01 | 12.68 |
| New Jersey | Union Co | 15.92 | 15.86 | 0.05 | 15.94 |
| New Jersey | Warren Co | 13.56 | 13.55 | 0.00 | 13.56 |
| New Mexico | Bernalillo Co | 6.48 | 6.47 | 0.01 | 6.50 |
| New Mexico | Chaves Co | 6.78 | 6.78 | 0.00 | 6.79 |
| New Mexico | Dona Ana Co | 11.18 | 11.18 | 0.00 | 11.19 |
| New Mexico | Grant Co | 5.97 | 5.97 | 0.00 | 5.97 |
| New Mexico | Lea Co | 6.77 | 6.77 | 0.00 | 6.77 |
| New Mexico | Sandoval Co | 10.17 | 10.17 | 0.00 | 10.18 |
| New Mexico | San Juan Co | 6.29 | 6.29 | 0.00 | 6.30 |
| New Mexico | Santa Fe Co | 4.88 | 4.88 | 0.00 | 4.89 |
| New York | Bronx Co | 15.97 | 15.94 | 0.03 | 15.99 |
| New York | Chautauqua Co | 10.97 | 10.97 | 0.00 | 10.97 |
| New York | Erie Co | 14.35 | 14.35 | 0.00 | 14.36 |
| New York | Essex Co | 6.49 | 6.49 | 0.00 | 6.50 |
| New York | Kings Co | 14.90 | 14.85 | 0.05 | 14.91 |
| New York | Monroe Co | 11.52 | 11.51 | 0.01 | 11.52 |
| New York | Nassau Co | 12.37 | 12.32 | 0.05 | 12.37 |
| New York | New York Co | 17.54 | 17.50 | 0.03 | 17.56 |
| New York | Niagara Co | 12.25 | 12.24 | 0.01 | 12.26 |
| New York | Onondaga Co | 10.68 | 10.68 | 0.01 | 10.69 |
| New York | Orange Co | 11.63 | 11.63 | 0.01 | 11.64 |
| New York | Queens Co | 13.56 | 13.53 | 0.03 | 13.57 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| New York | Richmond Co | 12.34 | 12.30 | 0.04 | 12.36 |
| New York | St. Lawrence Co | 8.62 | 8.62 | 0.00 | 8.62 |
| New York | Steuben Co | 9.96 | 9.96 | 0.00 | 9.96 |
| New York | Suffolk Co | 12.40 | 12.38 | 0.01 | 12.41 |
| New York | Westchester Co | 12.54 | 12.51 | 0.02 | 12.56 |
| North Carolina | Alamance Co | 14.47 | 14.47 | 0.00 | 14.47 |
| North Carolina | Buncombe Co | 13.67 | 13.67 | 0.00 | 13.68 |
| North Carolina | Cabarrus Co | 15.03 | 15.02 | 0.01 | 15.03 |
| North Carolina | Caswell Co | 13.90 | 13.90 | 0.00 | 13.90 |
| North Carolina | Catawba Co | 16.20 | 16.19 | 0.00 | 16.20 |
| North Carolina | Chatham Co | 12.81 | 12.81 | 0.00 | 12.82 |
| North Carolina | Cumberland Co | 14.69 | 14.69 | 0.01 | 14.70 |
| North Carolina | Davidson Co | 16.56 | 16.56 | 0.00 | 16.56 |
| North Carolina | Duplin Co | 12.37 | 12.37 | 0.00 | 12.38 |
| North Carolina | Durham Co | 14.65 | 14.65 | 0.00 | 14.65 |
| North Carolina | Forsyth Co | 15.41 | 15.40 | 0.00 | 15.41 |
| North Carolina | Gaston Co | 14.62 | 14.61 | 0.01 | 14.63 |
| North Carolina | Guilford Co | 15.12 | 15.11 | 0.00 | 15.12 |
| North Carolina | Haywood Co | 14.18 | 14.17 | 0.00 | 14.18 |
| North Carolina | Jackson Co | 12.59 | 12.59 | 0.00 | 12.59 |
| North Carolina | Lenoir Co | 11.94 | 11.94 | 0.00 | 11.94 |
| North Carolina | McDowell Co | 15.07 | 15.07 | 0.00 | 15.07 |
| North Carolina | Mecklenburg Co | 15.74 | 15.70 | 0.04 | 15.77 |
| North Carolina | Mitchell Co | 14.39 | 14.39 | 0.00 | 14.39 |
| North Carolina | Montgomery Co | 12.57 | 12.56 | 0.00 | 12.57 |
| North Carolina | Onslow Co | 11.60 | 11.60 | 0.00 | 11.60 |
| North Carolina | Orange Co | 13.67 | 13.66 | 0.00 | 13.67 |
| North Carolina | Pitt Co | 12.56 | 12.56 | 0.00 | 12.57 |
| North Carolina | Robeson Co | 12.75 | 12.75 | 0.00 | 12.75 |
| North Carolina | Swain Co | 13.16 | 13.16 | 0.00 | 13.16 |
| North Carolina | Wake Co | 14.51 | 14.50 | 0.01 | 14.54 |
| North Carolina | Wayne Co | 14.50 | 14.50 | 0.00 | 14.50 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircaft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| North Dakota | Billings Co | 4.52 | 4.52 | 0.00 | 4.52 |
| North Dakota | Burke Co | 5.76 | 5.76 | 0.00 | 5.76 |
| North Dakota | Burleigh Co | 6.76 | 6.75 | 0.00 | 6.76 |
| North Dakota | Cass Co | 8.11 | 8.11 | 0.00 | 8.12 |
| North Dakota | Mercer Co | 6.22 | 6.22 | 0.00 | 6.23 |
| Ohio | Athens Co | 12.47 | 12.47 | 0.00 | 12.48 |
| Ohio | Butler Co | 16.77 | 16.76 | 0.01 | 16.79 |
| Ohio | Clark Co | 14.67 | 14.66 | 0.01 | 14.68 |
| Ohio | Cuyahoga Co | 19.25 | 19.24 | 0.01 | 19.26 |
| Ohio | Franklin Co | 17.28 | 17.27 | 0.01 | 17.28 |
| Ohio | Hamilton Co | 18.52 | 18.48 | 0.04 | 18.55 |
| Ohio | Jefferson Co | 18.36 | 18.36 | 0.00 | 18.36 |
| Ohio | Lake Co | 13.75 | 13.74 | 0.01 | 13.75 |
| Ohio | Lawrence Co | 16.32 | 16.31 | 0.00 | 16.32 |
| Ohio | Lorain Co | 13.85 | 13.83 | 0.02 | 13.89 |
| Ohio | Lucas Co | 15.08 | 15.06 | 0.02 | 15.08 |
| Ohio | Mahoning Co | 15.77 | 15.77 | 0.00 | 15.78 |
| Ohio | Montgomery Co | 15.74 | 15.72 | 0.01 | 15.75 |
| Ohio | Portage Co | 14.89 | 14.88 | 0.00 | 14.89 |
| Ohio | Preble Co | 13.51 | 13.51 | 0.01 | 13.52 |
| Ohio | Scioto Co | 19.54 | 19.53 | 0.00 | 19.54 |
| Ohio | Stark Co | 17.84 | 17.84 | 0.01 | 17.85 |
| Ohio | Summit Co | 16.98 | 16.97 | 0.00 | 16.98 |
| Ohio | Trumbull Co | 15.60 | 15.59 | 0.00 | 15.61 |
| Oklahoma | Caddo Co | 8.66 | 8.65 | 0.01 | 8.66 |
| Oklahoma | Canadian Co | 8.99 | 8.98 | 0.01 | 8.99 |
| Oklahoma | Carter Co | 10.21 | 10.20 | 0.01 | 10.21 |
| Oklahoma | Cherokee Co | 11.72 | 11.72 | 0.00 | 11.72 |
| Oklahoma | Garfield Co | 10.04 | 10.03 | 0.01 | 10.04 |
| Oklahoma | Kay Co | 10.71 | 10.71 | 0.00 | 10.72 |
| Oklahoma | Lincoln Co | 10.08 | 10.07 | 0.00 | 10.08 |
| Oklahoma | Mayes Co | 12.02 | 12.01 | 0.00 | 12.02 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Oklahoma | Muskogee Co | 12.17 | 12.16 | 0.00 | 12.17 |
| Oklahoma | Oklahoma Co | 10.61 | 10.60 | 0.01 | 10.62 |
| Oklahoma | Ottawa Co | 11.78 | 11.78 | 0.00 | 11.78 |
| Oklahoma | Pittsburg Co | 11.52 | 11.52 | 0.00 | 11.53 |
| Oklahoma | Seminole Co | 9.48 | 9.47 | 0.00 | 9.48 |
| Oklahoma | Tulsa Co | 12.01 | 12.00 | 0.01 | 12.04 |
| Oregon | Columbia Co | 6.38 | 6.38 | 0.00 | 6.38 |
| Oregon | Deschutes Co | 7.35 | 7.35 | 0.00 | 7.35 |
| Oregon | Jackson Co | 11.34 | 11.34 | 0.00 | 11.35 |
| Oregon | Klamath Co | 10.16 | 10.16 | 0.00 | 10.17 |
| Oregon | Lane Co | 13.43 | 13.43 | 0.00 | 13.43 |
| Oregon | Linn Co | 8.33 | 8.33 | 0.00 | 8.33 |
| Oregon | Multnomah Co | 8.81 | 8.80 | 0.01 | 8.82 |
| Oregon | Union Co | 6.78 | 6.78 | 0.00 | 6.78 |
| Oregon | Wasco Co | 7.70 | 7.70 | 0.00 | 7.70 |
| Oregon | Washington Co | 9.54 | 9.54 | 0.00 | 9.55 |
| Pennsylvania | Adams Co | 13.35 | 13.35 | 0.00 | 13.35 |
| Pennsylvania | Allegheny Co | 21.16 | 21.16 | 0.01 | 21.18 |
| Pennsylvania | Beaver Co | 15.90 | 15.88 | 0.02 | 15.97 |
| Pennsylvania | Berks Co | 16.24 | 16.23 | 0.01 | 16.24 |
| Pennsylvania | Bucks Co | 13.93 | 13.92 | 0.01 | 13.93 |
| Pennsylvania | Cambria Co | 15.62 | 15.62 | 0.00 | 15.63 |
| Pennsylvania | Centre Co | 13.01 | 13.01 | 0.00 | 13.02 |
| Pennsylvania | Dauphin Co | 15.60 | 15.60 | 0.00 | 15.60 |
| Pennsylvania | Delaware Co | 15.26 | 15.22 | 0.04 | 15.28 |
| Pennsylvania | Erie Co | 13.43 | 13.43 | 0.00 | 13.44 |
| Pennsylvania | Lackawanna Co | 12.21 | 12.20 | 0.00 | 12.21 |
| Pennsylvania | Lancaster Co | 16.99 | 16.98 | 0.01 | 16.99 |
| Pennsylvania | Lehigh Co | 14.11 | 14.10 | 0.01 | 14.11 |
| Pennsylvania | Luzerne Co | 12.89 | 12.88 | 0.00 | 12.89 |
| Pennsylvania | Mercer Co | 14.28 | 14.27 | 0.00 | 14.29 |
| Pennsylvania | Montgomery Co | 13.96 | 13.95 | 0.01 | 13.96 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircaft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Pennsylvania | Northampton Co | 14.30 | 14.29 | 0.01 | 14.30 |
| Pennsylvania | Perry Co | 12.83 | 12.83 | 0.00 | 12.83 |
| Pennsylvania | Philadelphia Co | 16.38 | 16.34 | 0.04 | 16.40 |
| Pennsylvania | Washington Co | 15.58 | 15.57 | 0.00 | 15.58 |
| Pennsylvania | Westmoreland Co | 15.56 | 15.55 | 0.00 | 15.56 |
| Pennsylvania | York Co | 16.69 | 16.68 | 0.01 | 16.70 |
| Rhode Island | Kent Co | 8.79 | 8.78 | 0.00 | 8.79 |
| Rhode Island | Providence Co | 11.35 | 11.34 | 0.01 | 11.36 |
| South Carolina | Beaufort Co | 11.03 | 11.02 | 0.00 | 11.03 |
| South Carolina | Charleston Co | 11.90 | 11.90 | 0.01 | 11.91 |
| South Carolina | Chesterfield Co | 12.40 | 12.40 | 0.00 | 12.40 |
| South Carolina | Edgefield Co | 12.80 | 12.80 | 0.00 | 12.80 |
| South Carolina | Florence Co | 13.22 | 13.22 | 0.00 | 13.22 |
| South Carolina | Georgetown Co | 13.25 | 13.25 | 0.00 | 13.25 |
| South Carolina | Greenville Co | 15.33 | 15.33 | 0.00 | 15.33 |
| South Carolina | Greenwood Co | 13.96 | 13.95 | 0.01 | 13.96 |
| South Carolina | Horry Co | 11.12 | 11.12 | 0.00 | 11.13 |
| South Carolina | Lexington Co | 14.52 | 14.51 | 0.01 | 14.52 |
| South Carolina | Oconee Co | 11.42 | 11.41 | 0.00 | 11.42 |
| South Carolina | Richland Co | 14.43 | 14.42 | 0.01 | 14.43 |
| South Carolina | Spartanburg Co | 14.35 | 14.34 | 0.01 | 14.36 |
| South Dakota | Brookings Co | 9.37 | 9.36 | 0.00 | 9.37 |
| South Dakota | Brown Co | 8.31 | 8.31 | 0.00 | 8.32 |
| South Dakota | Jackson Co | 5.51 | 5.51 | 0.00 | 5.51 |
| South Dakota | Meade Co | 6.25 | 6.25 | 0.00 | 6.25 |
| South Dakota | Minnehaha Co | 9.82 | 9.82 | 0.00 | 9.82 |
| South Dakota | Pennington Co | 7.74 | 7.74 | 0.00 | 7.75 |
| Tennessee | Blount Co | 14.11 | 14.10 | 0.01 | 14.12 |
| Tennessee | Davidson Co | 15.53 | 15.52 | 0.01 | 15.56 |
| Tennessee | Dyer Co | 12.36 | 12.35 | 0.00 | 12.36 |
| Tennessee | Hamilton Co | 17.23 | 17.22 | 0.01 | 17.24 |
| Tennessee | Knox Co | 18.09 | 18.08 | 0.01 | 18.11 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Tennessee | Lawrence Co | 12.65 | 12.65 | 0.00 | 12.65 |
| Tennessee | McMinn Co | 15.35 | 15.34 | 0.00 | 15.35 |
| Tennessee | Maury Co | 13.65 | 13.64 | 0.00 | 13.65 |
| Tennessee | Montgomery Co | 13.75 | 13.75 | 0.00 | 13.76 |
| Tennessee | Putnam Co | 13.70 | 13.70 | 0.00 | 13.70 |
| Tennessee | Roane Co | 15.38 | 15.38 | 0.00 | 15.38 |
| Tennessee | Shelby Co | 14.80 | 14.74 | 0.06 | 14.81 |
| Tennessee | Sullivan Co | 15.56 | 15.56 | 0.01 | 15.57 |
| Tennessee | Sumner Co | 14.47 | 14.46 | 0.01 | 14.48 |
| Texas | Bowie Co | 14.10 | 14.09 | 0.00 | 14.10 |
| Texas | Cameron Co | 9.89 | 9.89 | 0.00 | 9.90 |
| Texas | Dallas Co | 13.79 | 13.77 | 0.01 | 13.82 |
| Texas | Ector Co | 7.57 | 7.57 | 0.00 | 7.57 |
| Texas | Galveston Co | 9.63 | 9.63 | 0.00 | 9.64 |
| Texas | Gregg Co | 12.49 | 12.49 | 0.00 | 12.49 |
| Texas | Harris Co | 14.12 | 14.11 | 0.01 | 14.13 |
| Texas | Hidalgo Co | 10.84 | 10.83 | 0.00 | 10.84 |
| Texas | Jefferson Co | 11.25 | 11.25 | 0.00 | 11.26 |
| Texas | Lubbock Co | 7.65 | 7.65 | 0.00 | 7.66 |
| Texas | Nueces Co | 10.30 | 10.29 | 0.00 | 10.30 |
| Texas | Orange Co | 11.41 | 11.41 | 0.00 | 11.41 |
| Texas | Tarrant Co | 12.36 | 12.35 | 0.01 | 12.37 |
| Utah | Box Elder Co | 9.01 | 9.01 | 0.00 | 9.01 |
| Utah | Cache Co | 12.90 | 12.89 | 0.00 | 12.90 |
| Utah | Salt Lake Co | 14.03 | 13.99 | 0.04 | 14.06 |
| Utah | Utah Co | 10.81 | 10.80 | 0.01 | 10.81 |
| Utah | Weber Co | 9.77 | 9.76 | 0.01 | 9.78 |
| Vermont | Chittenden Co | 9.36 | 9.36 | 0.00 | 9.37 |
| Virginia | Arlington Co | 14.59 | 14.57 | 0.02 | 14.61 |
| Virginia | Charles City Co | 13.30 | 13.29 | 0.01 | 13.31 |
| Virginia | Chesterfield Co | 13.89 | 13.88 | 0.01 | 13.90 |
| Virginia | Fairfax Co | 14.26 | 14.22 | 0.04 | 14.29 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircaft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| Virginia | Henrico Co | 13.91 | 13.90 | 0.01 | 13.92 |
| Virginia | Loudoun Co | 13.62 | 13.59 | 0.04 | 13.65 |
| Virginia | Page Co | 13.16 | 13.16 | 0.00 | 13.16 |
| Virginia | Bristol city | 15.21 | 15.21 | 0.00 | 15.21 |
| Virginia | Chesapeake city | 12.97 | 12.96 | 0.00 | 12.98 |
| Virginia | Hampton city | 12.94 | 12.93 | 0.01 | 12.95 |
| Virginia | Newport News city | 12.30 | 12.29 | 0.01 | 12.31 |
| Virginia | Norfolk city | 13.29 | 13.28 | 0.01 | 13.30 |
| Virginia | Richmond city | 14.46 | 14.45 | 0.01 | 14.47 |
| Virginia | Roanoke city | 14.84 | 14.83 | 0.01 | 14.84 |
| Virginia | Salem city | 14.95 | 14.94 | 0.01 | 14.96 |
| Virginia | Virginia Beach city | 12.82 | 12.82 | 0.01 | 12.84 |
| Washington | Benton Co | 6.84 | 6.84 | 0.00 | 6.84 |
| Washington | Clark Co | 9.82 | 9.82 | 0.00 | 9.83 |
| Washington | King Co | 11.51 | 11.47 | 0.04 | 11.59 |
| Washington | Pierce Co | 11.15 | 11.15 | 0.00 | 11.15 |
| Washington | Snohomish Co | 11.44 | 11.44 | 0.00 | 11.45 |
| Washington | Spokane Co | 10.33 | 10.32 | 0.00 | 10.34 |
| Washington | Thurston Co | 9.49 | 9.49 | 0.00 | 9.49 |
| Washington | Whatcom Co | 7.67 | 7.67 | 0.00 | 7.68 |
| Washington | Yakima Co | 10.31 | 10.31 | 0.00 | 10.32 |
| West Virginia | Berkeley Co | 16.18 | 16.18 | 0.00 | 16.18 |
| West Virginia | Brooke Co | 16.96 | 16.95 | 0.00 | 16.96 |
| West Virginia | Cabell Co | 17.22 | 17.22 | 0.00 | 17.23 |
| West Virginia | Hancock Co | 17.40 | 17.40 | 0.00 | 17.41 |
| West Virginia | Harrison Co | 14.40 | 14.39 | 0.00 | 14.40 |
| West Virginia | Kanawha Co | 17.74 | 17.73 | 0.01 | 17.75 |
| West Virginia | Marion Co | 15.58 | 15.58 | 0.00 | 15.58 |
| West Virginia | Marshall Co | 16.07 | 16.06 | 0.00 | 16.07 |
| West Virginia | Mercer Co | 12.98 | 12.97 | 0.00 | 12.98 |
| West Virginia | Monongalia Co | 14.96 | 14.95 | 0.00 | 14.96 |
| West Virginia | Ohio Co | 15.37 | 15.37 | 0.00 | 15.38 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient FRM DV |
|---|---|---|---|---|---|
| West Virginia | Raleigh Co | 13.54 | 13.54 | 0.00 | 13.54 |
| West Virginia | Summers Co | 10.47 | 10.46 | 0.00 | 10.47 |
| West Virginia | Wood Co | 16.88 | 16.87 | 0.00 | 16.88 |
| Wisconsin | Brown Co | 11.52 | 11.51 | 0.00 | 11.52 |
| Wisconsin | Dane Co | 12.81 | 12.81 | 0.01 | 12.81 |
| Wisconsin | Dodge Co | 11.39 | 11.38 | 0.01 | 11.39 |
| Wisconsin | Grant Co | 11.78 | 11.78 | 0.00 | 11.79 |
| Wisconsin | Kenosha Co | 11.89 | 11.88 | 0.01 | 11.90 |
| Wisconsin | Manitowoc Co | 10.09 | 10.09 | 0.00 | 10.09 |
| Wisconsin | Milwaukee Co | 13.73 | 13.71 | 0.02 | 13.74 |
| Wisconsin | Outagamie Co | 11.04 | 11.04 | 0.00 | 11.04 |
| Wisconsin | Vilas Co | 6.27 | 6.26 | 0.00 | 6.27 |
| Wisconsin | Waukesha Co | 13.55 | 13.54 | 0.01 | 13.55 |
| Wyoming | Campbell Co | 6.35 | 6.35 | 0.00 | 6.35 |
| Wyoming | Laramie Co | 5.12 | 5.12 | 0.00 | 5.13 |
| Wyoming | Sheridan Co | 10.77 | 10.77 | 0.00 | 10.77 |

## V: Ozone Modeling Results from Modeling Scenarios. Units are ppb.

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Alabama | Baldwin | 79.0 | 78.9 | 0.04 | 79.0 |
| Alabama | Clay | 82.0 | 81.9 | 0.13 | 82.0 |
| Alabama | Elmore | 78.3 | 78.2 | 0.08 | 78.3 |
| Alabama | Jefferson | 87.3 | 87.2 | 0.15 | 87.3 |
| Alabama | Madison | 82.7 | 82.6 | 0.05 | 82.7 |
| Alabama | Mobile | 79.0 | 78.9 | 0.04 | 79.0 |
| Alabama | Montgomery | 80.0 | 79.9 | 0.06 | 80.0 |
| Alabama | Morgan | 82.9 | 82.9 | 0.08 | 83.0 |
| Alabama | Shelby | 91.7 | 91.6 | 0.09 | 91.7 |
| Alabama | Tuscaloosa | 78.0 | 77.9 | 0.09 | 78.0 |
| Arizona | Cochise | 70.3 | 70.2 | 0.04 | 70.3 |
| Arizona | Coconino | 73.0 | 72.9 | 0.04 | 73.0 |
| Arizona | Maricopa | 85.3 | 85.2 | 0.07 | 85.3 |
| Arizona | Pima | 72.3 | 72.2 | 0.06 | 72.3 |
| Arizona | Pinal | 83.0 | 82.8 | 0.15 | 83.0 |
| Arizona | Yavapai | 79.5 | 79.4 | 0.05 | 79.5 |
| Arkansas | Crittenden | 92.9 | 92.6 | 0.31 | 92.7 |
| Arkansas | Pulaski | 84.7 | 84.6 | 0.07 | 84.7 |
| California | Alameda | 82.3 | 82.3 | 0.04 | 82.3 |
| California | Amador | 88.0 | 87.9 | 0.11 | 88.0 |
| California | Butte | 89.0 | 88.8 | 0.16 | 89.0 |
| California | Calaveras | 92.3 | 92.2 | 0.11 | 92.3 |
| California | Colusa | 76.0 | 75.8 | 0.15 | 76.0 |
| California | Contra Costa | 80.0 | 80.0 | 0.04 | 80.0 |
| California | El Dorado | 105.7 | 105.5 | 0.20 | 105.7 |
| California | Fresno | 111.3 | 111.2 | 0.08 | 111.3 |
| California | Glenn | 74.7 | 74.5 | 0.13 | 74.7 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| California | Imperial | 87.0 | 86.9 | 0.09 | 87.0 |
| California | Inyo | 80.3 | 80.2 | 0.06 | 80.3 |
| California | Kern | 112.0 | 111.9 | 0.06 | 112.0 |
| California | Kings | 97.3 | 97.2 | 0.09 | 97.3 |
| California | Los Angeles | 113.3 | 113.1 | 0.14 | 113.3 |
| California | Madera | 90.7 | 90.6 | 0.06 | 90.7 |
| California | Marin | 48.7 | 48.6 | 0.01 | 48.7 |
| California | Mariposa | 90.3 | 90.2 | 0.09 | 90.3 |
| California | Merced | 101.3 | 101.2 | 0.10 | 101.3 |
| California | Monterey | 64.3 | 64.2 | 0.06 | 64.3 |
| California | Nevada | 97.7 | 97.5 | 0.20 | 97.7 |
| California | Orange | 82.8 | 82.7 | 0.04 | 82.7 |
| California | Placer | 100.3 | 100.1 | 0.19 | 100.3 |
| California | Riverside | 113.0 | 112.9 | 0.15 | 113.0 |
| California | Sacramento | 99.7 | 99.5 | 0.22 | 99.7 |
| California | San Benito | 81.0 | 80.9 | 0.10 | 81.0 |
| California | San Bernardino | 129.4 | 129.3 | 0.05 | 129.3 |
| California | San Diego | 94.0 | 93.8 | 0.18 | 94.0 |
| California | San Joaquin | 83.0 | 82.9 | 0.14 | 83.0 |
| California | San Luis Obisp | 73.0 | 72.9 | 0.04 | 73.0 |
| California | San Mateo | 53.0 | 53.2 | -0.12 | 53.0 |
| California | Santa Barbara | 82.0 | 81.8 | 0.13 | 82.0 |
| California | Santa Clara | 81.3 | 81.1 | 0.14 | 81.3 |
| California | Santa Cruz | 64.7 | 64.6 | 0.07 | 64.7 |
| California | Shasta | 74.3 | 74.2 | 0.04 | 74.3 |
| California | Solano | 72.3 | 72.2 | 0.08 | 72.3 |
| California | Stanislaus | 94.0 | 93.8 | 0.18 | 94.0 |
| California | Sutter | 84.3 | 84.1 | 0.16 | 84.3 |
| California | Tehama | 84.3 | 84.2 | 0.08 | 84.3 |
| California | Tulare | 105.3 | 105.2 | 0.05 | 105.3 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| California | Tuolumne | 91.5 | 91.4 | 0.10 | 91.5 |
| California | Ventura | 97.8 | 97.9 | -0.09 | 97.7 |
| California | Yolo | 82.7 | 82.6 | 0.13 | 82.7 |
| Colorado | Adams | 65.0 | 65.2 | -0.15 | 65.0 |
| Colorado | Arapahoe | 77.7 | 77.7 | 0.00 | 77.7 |
| Colorado | Boulder | 74.0 | 73.9 | 0.02 | 74.0 |
| Colorado | Denver | 72.7 | 72.9 | -0.16 | 72.7 |
| Colorado | Douglas | 82.5 | 82.4 | 0.01 | 82.5 |
| Colorado | El Paso | 71.0 | 70.9 | 0.02 | 71.0 |
| Colorado | Jefferson | 83.7 | 83.6 | 0.02 | 83.7 |
| Colorado | La Plata | 59.3 | 59.2 | 0.01 | 59.3 |
| Colorado | Larimer | 77.7 | 77.6 | 0.01 | 77.7 |
| Colorado | Montezuma | 68.3 | 68.2 | 0.01 | 68.3 |
| Colorado | Weld | 74.3 | 74.2 | 0.03 | 74.3 |
| Connecticut | Fairfield | 98.7 | 98.7 | 0.06 | 98.7 |
| Connecticut | Hartford | 89.3 | 89.2 | 0.11 | 89.3 |
| Connecticut | Litchfield | 83.0 | 82.9 | 0.06 | 83.0 |
| Connecticut | Middlesex | 98.0 | 97.9 | 0.12 | 98.0 |
| Connecticut | New Haven | 99.1 | 99.0 | 0.10 | 99.0 |
| Connecticut | New London | 90.7 | 90.6 | 0.11 | 90.7 |
| Connecticut | Tolland | 93.0 | 92.9 | 0.12 | 93.0 |
| Delaware | Kent | 91.3 | 91.1 | 0.18 | 91.3 |
| Delaware | New Castle | 95.3 | 95.2 | 0.11 | 95.3 |
| Delaware | Sussex | 93.3 | 93.1 | 0.18 | 93.3 |
| D.C. | Washington | 94.4 | 94.2 | 0.17 | 94.3 |
| Florida | Bay | 79.9 | 79.9 | 0.06 | 80.0 |
| Florida | Duval | 70.7 | 70.6 | 0.07 | 70.7 |
| Florida | Escambia | 83.7 | 83.6 | 0.06 | 83.7 |
| Florida | Hillsborough | 80.7 | 80.6 | 0.06 | 80.7 |
| Florida | Manatee | 83.0 | 82.9 | 0.07 | 83.0 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Florida | Marion | 75.7 | 75.6 | 0.03 | 75.7 |
| Florida | Orange | 78.3 | 78.1 | 0.13 | 78.3 |
| Florida | Osceola | 73.7 | 73.4 | 0.28 | 73.7 |
| Florida | Pasco | 78.0 | 77.9 | 0.14 | 78.0 |
| Florida | Pinellas | 78.3 | 78.2 | 0.06 | 78.3 |
| Florida | Polk | 78.7 | 78.6 | 0.11 | 78.7 |
| Florida | Santa Rosa | 82.0 | 81.9 | 0.04 | 82.0 |
| Florida | Sarasota | 82.3 | 82.2 | 0.08 | 82.3 |
| Florida | Seminole | 77.7 | 77.5 | 0.13 | 77.7 |
| Florida | Volusia | 72.0 | 71.9 | 0.06 | 72.0 |
| Florida | Wakulla | 76.0 | 75.9 | 0.11 | 76.0 |
| Georgia | Bibb | 92.0 | 91.8 | 0.24 | 92.0 |
| Georgia | Chatham | 71.0 | 70.9 | 0.07 | 71.0 |
| Georgia | Cherokee | 77.0 | 76.9 | 0.13 | 77.0 |
| Georgia | Cobb | 94.7 | 94.5 | 0.17 | 94.7 |
| Georgia | Coweta | 92.0 | 91.7 | 0.32 | 92.0 |
| Georgia | Dawson | 82.0 | 81.9 | 0.10 | 82.0 |
| Georgia | De Kalb | 95.3 | 95.2 | 0.18 | 95.3 |
| Georgia | Douglas | 94.8 | 94.4 | 0.39 | 94.7 |
| Georgia | Fayette | 91.1 | 90.7 | 0.38 | 90.7 |
| Georgia | Fulton | 99.4 | 99.0 | 0.41 | 99.0 |
| Georgia | Gwinnett | 89.3 | 89.2 | 0.17 | 89.3 |
| Georgia | Henry | 98.4 | 98.0 | 0.41 | 98.0 |
| Georgia | Murray | 86.0 | 85.9 | 0.04 | 86.0 |
| Georgia | Muscogee | 82.0 | 81.8 | 0.12 | 82.0 |
| Georgia | Paulding | 90.3 | 90.2 | 0.09 | 90.3 |
| Georgia | Rockdale | 96.5 | 95.9 | 0.60 | 96.3 |
| Illinois | Adams | 76.0 | 75.9 | 0.04 | 76.0 |
| Illinois | Champaign | 77.3 | 77.2 | 0.04 | 77.3 |
| Illinois | Clark | 75.0 | 74.9 | 0.03 | 75.0 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Illinois | Cook | 87.7 | 87.8 | -0.07 | 87.7 |
| Illinois | Du Page | 70.7 | 70.6 | 0.03 | 70.7 |
| Illinois | Effingham | 77.7 | 77.6 | 0.06 | 77.7 |
| Illinois | Hamilton | 78.7 | 78.6 | 0.03 | 78.7 |
| Illinois | Jersey | 89.0 | 88.9 | 0.09 | 89.0 |
| Illinois | Kane | 77.7 | 77.6 | 0.05 | 77.7 |
| Illinois | Lake | 83.3 | 83.4 | -0.15 | 83.3 |
| Illinois | McHenry | 83.3 | 83.2 | 0.05 | 83.3 |
| Illinois | McLean | 77.0 | 76.9 | 0.04 | 77.0 |
| Illinois | Macon | 76.7 | 76.6 | 0.04 | 76.7 |
| Illinois | Macoupin | 79.3 | 79.2 | 0.06 | 79.3 |
| Illinois | Madison | 84.9 | 84.9 | 0.07 | 85.0 |
| Illinois | Peoria | 79.0 | 78.9 | 0.05 | 79.0 |
| Illinois | Randolph | 78.7 | 78.6 | 0.05 | 78.7 |
| Illinois | Rock Island | 70.0 | 69.9 | 0.03 | 70.0 |
| Illinois | St Clair | 83.2 | 83.2 | 0.06 | 83.3 |
| Illinois | Sangamon | 76.0 | 75.9 | 0.05 | 76.0 |
| Illinois | Will | 79.3 | 79.2 | 0.03 | 79.3 |
| Illinois | Winnebago | 76.0 | 75.9 | 0.06 | 76.0 |
| Indiana | Allen | 87.7 | 87.6 | 0.06 | 87.7 |
| Indiana | Boone | 89.0 | 88.9 | 0.06 | 89.0 |
| Indiana | Carroll | 84.0 | 83.9 | 0.05 | 84.0 |
| Indiana | Clark | 89.4 | 89.3 | 0.10 | 89.3 |
| Indiana | Delaware | 88.0 | 87.9 | 0.08 | 88.0 |
| Indiana | Floyd | 83.7 | 83.6 | 0.08 | 83.7 |
| Indiana | Gibson | 71.7 | 71.6 | 0.03 | 71.7 |
| Indiana | Greene | 88.5 | 88.4 | 0.04 | 88.5 |
| Indiana | Hamilton | 93.3 | 93.2 | 0.12 | 93.3 |
| Indiana | Hancock | 91.7 | 91.6 | 0.08 | 91.7 |
| Indiana | Hendricks | 86.5 | 86.4 | 0.10 | 86.5 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Indiana | Huntington | 85.0 | 84.9 | 0.05 | 85.0 |
| Indiana | Jackson | 85.0 | 84.9 | 0.07 | 85.0 |
| Indiana | Johnson | 86.7 | 86.6 | 0.09 | 86.7 |
| Indiana | Lake | 90.7 | 90.8 | -0.07 | 90.7 |
| Indiana | La Porte | 90.0 | 89.9 | 0.06 | 90.0 |
| Indiana | Madison | 91.0 | 90.9 | 0.08 | 91.0 |
| Indiana | Marion | 90.0 | 89.9 | 0.12 | 90.0 |
| Indiana | Morgan | 86.7 | 86.6 | 0.10 | 86.7 |
| Indiana | Perry | 90.0 | 89.9 | 0.07 | 90.0 |
| Indiana | Porter | 89.0 | 89.0 | 0.04 | 89.0 |
| Indiana | Posey | 85.7 | 85.6 | 0.04 | 85.7 |
| Indiana | St Joseph | 89.0 | 88.9 | 0.09 | 89.0 |
| Indiana | Shelby | 93.5 | 93.4 | 0.10 | 93.5 |
| Indiana | Vanderburgh | 83.3 | 83.2 | 0.04 | 83.3 |
| Indiana | Vigo | 87.0 | 86.9 | 0.03 | 87.0 |
| Indiana | Warrick | 84.5 | 84.4 | 0.05 | 84.5 |
| Iowa | Bremer | 70.5 | 70.4 | 0.02 | 70.5 |
| Iowa | Clinton | 78.3 | 78.2 | 0.04 | 78.3 |
| Iowa | Harrison | 75.6 | 75.6 | 0.06 | 75.7 |
| Iowa | Linn | 71.0 | 70.9 | 0.03 | 71.0 |
| Iowa | Palo Alto | 66.0 | 65.9 | 0.03 | 66.0 |
| Iowa | Polk | 58.6 | 58.6 | 0.03 | 58.7 |
| Iowa | Scott | 79.0 | 78.9 | 0.04 | 79.0 |
| Iowa | Story | 63.2 | 63.2 | 0.03 | 63.3 |
| Iowa | Van Buren | 73.7 | 73.6 | 0.03 | 73.7 |
| Iowa | Warren | 63.3 | 63.2 | 0.02 | 63.3 |
| Kansas | Linn | 76.7 | 76.6 | 0.03 | 76.7 |
| Kansas | Sedgwick | 72.3 | 72.2 | 0.03 | 81.0 |
| Kansas | Wyandotte | 80.3 | 80.3 | 0.02 | 80.3 |
| Kentucky | Bell | 83.3 | 83.2 | 0.05 | 83.3 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Kentucky | Boone | 85.3 | 85.2 | 0.07 | 85.3 |
| Kentucky | Boyd | 88.3 | 88.2 | 0.04 | 88.3 |
| Kentucky | Bullitt | 83.7 | 83.6 | 0.08 | 83.7 |
| Kentucky | Campbell | 91.8 | 91.7 | 0.06 | 91.7 |
| Kentucky | Carter | 80.3 | 80.2 | 0.03 | 80.3 |
| Kentucky | Christian | 85.0 | 84.9 | 0.04 | 85.0 |
| Kentucky | Daviess | 77.3 | 77.2 | 0.04 | 77.3 |
| Kentucky | Edmonson | 84.0 | 83.9 | 0.05 | 84.0 |
| Kentucky | Fayette | 78.3 | 78.2 | 0.05 | 78.3 |
| Kentucky | Graves | 81.0 | 80.9 | 0.05 | 81.0 |
| Kentucky | Greenup | 84.0 | 83.9 | 0.03 | 84.0 |
| Kentucky | Hancock | 82.7 | 82.6 | 0.05 | 82.7 |
| Kentucky | Hardin | 80.7 | 80.6 | 0.07 | 80.7 |
| Kentucky | Henderson | 80.0 | 79.9 | 0.04 | 80.0 |
| Kentucky | Jefferson | 84.4 | 84.3 | 0.10 | 84.3 |
| Kentucky | Jessamine | 78.0 | 77.9 | 0.06 | 78.0 |
| Kentucky | Kenton | 86.4 | 86.3 | 0.06 | 86.3 |
| Kentucky | Livingston | 85.0 | 84.9 | 0.05 | 85.0 |
| Kentucky | McCracken | 81.7 | 81.6 | 0.05 | 81.7 |
| Kentucky | McLean | 84.0 | 83.9 | 0.04 | 84.0 |
| Kentucky | Oldham | 88.1 | 88.0 | 0.10 | 88.0 |
| Kentucky | Perry | 74.7 | 74.6 | 0.03 | 74.7 |
| Kentucky | Pike | 76.3 | 76.2 | 0.03 | 76.3 |
| Kentucky | Pulaski | 81.3 | 81.2 | 0.05 | 81.3 |
| Kentucky | Scott | 70.7 | 70.6 | 0.07 | 70.7 |
| Kentucky | Simpson | 84.0 | 83.9 | 0.04 | 84.0 |
| Kentucky | Trigg | 76.7 | 76.6 | 0.05 | 76.7 |
| Kentucky | Warren | 84.0 | 83.9 | 0.05 | 84.0 |
| Louisiana | Ascension | 81.7 | 81.6 | 0.03 | 81.7 |
| Louisiana | Beauregard | 75.0 | 74.9 | 0.02 | 75.0 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Louisiana | Bossier | 84.7 | 84.6 | 0.05 | 84.7 |
| Louisiana | Caddo | 79.7 | 79.6 | 0.05 | 79.7 |
| Louisiana | Calcasieu | 81.7 | 81.6 | 0.02 | 81.7 |
| Louisiana | East Baton Rou | 87.3 | 87.2 | 0.03 | 87.3 |
| Louisiana | Iberville | 86.7 | 86.6 | 0.03 | 86.7 |
| Louisiana | Jefferson | 85.3 | 85.3 | 0.02 | 85.3 |
| Louisiana | Lafayette | 80.7 | 80.6 | 0.03 | 80.7 |
| Louisiana | Lafourche | 81.0 | 80.9 | 0.04 | 81.0 |
| Louisiana | Livingston | 83.3 | 83.2 | 0.03 | 83.3 |
| Louisiana | Orleans | 72.0 | 72.0 | 0.02 | 72.0 |
| Louisiana | Ouachita | 78.7 | 78.6 | 0.05 | 78.7 |
| Louisiana | Pointe Coupee | 73.0 | 72.9 | 0.03 | 73.0 |
| Louisiana | St Bernard | 79.3 | 79.3 | 0.02 | 79.3 |
| Louisiana | St Charles | 81.7 | 81.6 | 0.03 | 81.7 |
| Louisiana | St James | 77.3 | 77.2 | 0.04 | 77.3 |
| Louisiana | St John The Ba | 81.7 | 81.6 | 0.03 | 81.7 |
| Louisiana | St Mary | 78.0 | 77.9 | 0.03 | 78.0 |
| Louisiana | West Baton Rou | 85.7 | 85.6 | 0.04 | 85.7 |
| Maine | Cumberland | 84.7 | 84.6 | 0.10 | 84.7 |
| Maine | Hancock | 92.0 | 91.8 | 0.16 | 92.0 |
| Maine | Kennebec | 77.7 | 77.6 | 0.11 | 77.7 |
| Maine | Knox | 83.3 | 83.2 | 0.14 | 83.3 |
| Maine | Oxford | 61.0 | 60.9 | 0.03 | 61.0 |
| Maine | Penobscot | 83.0 | 82.9 | 0.12 | 83.0 |
| Maine | Piscataquis | 65.0 | 64.9 | 0.03 | 65.0 |
| Maine | York | 89.0 | 88.9 | 0.08 | 89.0 |
| Maryland | Anne Arundel | 101.1 | 100.8 | 0.23 | 101.0 |
| Maryland | Baltimore | 93.0 | 92.9 | 0.14 | 93.0 |
| Maryland | Calvert | 89.0 | 88.8 | 0.26 | 89.0 |
| Maryland | Carroll | 91.3 | 91.2 | 0.15 | 91.3 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Maryland | Cecil | 102.7 | 102.6 | 0.12 | 102.7 |
| Maryland | Charles | 94.7 | 94.5 | 0.18 | 94.7 |
| Maryland | Frederick | 90.0 | 89.9 | 0.15 | 90.0 |
| Maryland | Harford | 103.7 | 103.5 | 0.16 | 103.7 |
| Maryland | Kent | 99.0 | 98.8 | 0.14 | 99.0 |
| Maryland | Montgomery | 88.7 | 88.6 | 0.10 | 88.7 |
| Maryland | Prince Georges | 95.0 | 94.9 | 0.11 | 95.0 |
| Maryland | Washington | 86.0 | 85.9 | 0.07 | 86.0 |
| Massachusetts | Barnstable | 94.7 | 94.6 | 0.10 | 94.7 |
| Massachusetts | Berkshire | 87.0 | 86.9 | 0.05 | 87.0 |
| Massachusetts | Bristol | 92.7 | 92.6 | 0.12 | 92.7 |
| Massachusetts | Essex | 89.7 | 89.6 | 0.07 | 89.7 |
| Massachusetts | Hampden | 90.3 | 90.2 | 0.08 | 90.3 |
| Massachusetts | Hampshire | 88.3 | 88.2 | 0.08 | 88.3 |
| Massachusetts | Middlesex | 88.7 | 88.6 | 0.09 | 88.7 |
| Massachusetts | Suffolk | 88.1 | 88.1 | -0.02 | 88.0 |
| Massachusetts | Worcester | 85.3 | 85.2 | 0.10 | 85.3 |
| Michigan | Allegan | 92.0 | 91.9 | 0.11 | 92.0 |
| Michigan | Benzie | 87.7 | 87.6 | 0.13 | 87.7 |
| Michigan | Berrien | 88.3 | 88.2 | 0.09 | 88.3 |
| Michigan | Cass | 90.0 | 89.9 | 0.06 | 90.0 |
| Michigan | Clinton | 83.3 | 83.2 | 0.09 | 83.3 |
| Michigan | Genesee | 86.7 | 86.6 | 0.11 | 86.7 |
| Michigan | Huron | 84.0 | 83.9 | 0.05 | 84.0 |
| Michigan | Ingham | 83.3 | 83.2 | 0.09 | 83.3 |
| Michigan | Kalamazoo | 83.0 | 82.9 | 0.06 | 83.0 |
| Michigan | Kent | 84.7 | 84.6 | 0.09 | 84.7 |
| Michigan | Lenawee | 85.0 | 84.9 | 0.08 | 85.0 |
| Michigan | Macomb | 91.0 | 90.9 | 0.08 | 91.0 |
| Michigan | Mason | 89.0 | 88.9 | 0.13 | 89.0 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Michigan | Missaukee | 80.3 | 80.2 | 0.06 | 80.3 |
| Michigan | Muskegon | 92.0 | 91.9 | 0.10 | 92.0 |
| Michigan | Oakland | 87.0 | 86.9 | 0.08 | 87.0 |
| Michigan | Ottawa | 86.0 | 85.9 | 0.07 | 86.0 |
| Michigan | St Clair | 87.7 | 87.6 | 0.09 | 87.7 |
| Michigan | Washtenaw | 88.4 | 88.4 | 0.00 | 88.3 |
| Michigan | Wayne | 88.0 | 87.9 | 0.08 | 88.0 |
| Minnesota | Anoka | 71.0 | 71.1 | -0.12 | 71.0 |
| Minnesota | Washington | 75.0 | 74.9 | 0.10 | 75.0 |
| Mississippi | Adams | 79.7 | 79.6 | 0.05 | 79.7 |
| Mississippi | Bolivar | 78.0 | 77.9 | 0.05 | 78.0 |
| Mississippi | De Soto | 84.4 | 84.2 | 0.22 | 84.3 |
| Mississippi | Hancock | 83.7 | 83.6 | 0.01 | 83.7 |
| Mississippi | Harrison | 83.3 | 83.2 | 0.04 | 83.3 |
| Mississippi | Hinds | 76.3 | 76.2 | 0.08 | 76.3 |
| Mississippi | Jackson | 83.0 | 82.9 | 0.03 | 83.0 |
| Mississippi | Madison | 76.3 | 76.2 | 0.08 | 76.3 |
| Mississippi | Warren | 76.7 | 76.6 | 0.04 | 76.7 |
| Missouri | Cass | 79.0 | 78.9 | 0.03 | 79.0 |
| Missouri | Clay | 84.3 | 84.2 | 0.03 | 84.3 |
| Missouri | Jefferson | 87.2 | 87.2 | 0.08 | 87.3 |
| Missouri | Monroe | 79.2 | 79.2 | 0.04 | 79.3 |
| Missouri | Platte | 81.7 | 81.7 | 0.02 | 81.7 |
| Missouri | St Charles | 90.7 | 90.6 | 0.09 | 90.7 |
| Missouri | Ste Genevieve | 83.9 | 83.9 | 0.05 | 84.0 |
| Missouri | St Louis | 89.4 | 89.3 | 0.09 | 89.3 |
| Missouri | St Louis City | 86.9 | 86.9 | 0.06 | 87.0 |
| Nebraska | Douglas | 67.5 | 67.4 | 0.03 | 67.5 |
| Nevada | Clark | 84.5 | 84.2 | 0.31 | 84.5 |
| Nevada | Douglas | 71.7 | 71.6 | 0.06 | 71.7 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Nevada | Washoe | 73.3 | 73.2 | 0.05 | 73.3 |
| Nevada | White Pine | 72.0 | 71.9 | 0.02 | 72.0 |
| Nevada | Carson City | 68.7 | 68.6 | 0.05 | 68.7 |
| New Hampshire | Belknap | 78.0 | 77.9 | 0.05 | 78.0 |
| New Hampshire | Carroll | 66.5 | 66.4 | 0.03 | 66.5 |
| New Hampshire | Cheshire | 73.7 | 73.6 | 0.03 | 73.7 |
| New Hampshire | Grafton | 69.7 | 69.6 | 0.02 | 69.7 |
| New Hampshire | Hillsborough | 85.0 | 84.9 | 0.06 | 85.0 |
| New Hampshire | Merrimack | 73.0 | 72.9 | 0.08 | 73.0 |
| New Hampshire | Rockingham | 82.7 | 82.6 | 0.09 | 82.7 |
| New Hampshire | Strafford | 77.3 | 77.2 | 0.05 | 77.3 |
| New Hampshire | Sullivan | 73.3 | 73.2 | 0.03 | 73.3 |
| New Jersey | Atlantic | 90.3 | 90.2 | 0.12 | 90.3 |
| New Jersey | Bergen | 92.5 | 92.5 | -0.02 | 92.5 |
| New Jersey | Camden | 102.3 | 102.2 | 0.14 | 102.3 |
| New Jersey | Cumberland | 96.7 | 96.5 | 0.16 | 96.7 |
| New Jersey | Essex | 67.0 | 67.2 | -0.19 | 67.0 |
| New Jersey | Gloucester | 100.4 | 100.4 | -0.06 | 100.3 |
| New Jersey | Hudson | 88.0 | 88.3 | -0.25 | 88.0 |
| New Jersey | Hunterdon | 97.3 | 97.2 | 0.09 | 97.3 |
| New Jersey | Mercer | 102.3 | 102.2 | 0.10 | 102.3 |
| New Jersey | Middlesex | 100.7 | 100.6 | 0.11 | 100.7 |
| New Jersey | Monmouth | 95.7 | 95.7 | -0.01 | 95.7 |
| New Jersey | Morris | 97.7 | 97.6 | 0.06 | 97.7 |
| New Jersey | Ocean | 109.0 | 108.9 | 0.12 | 109.0 |
| New Jersey | Passaic | 88.3 | 88.3 | -0.02 | 88.3 |
| New Mexico | Bernalillo | 75.7 | 75.6 | 0.03 | 75.7 |
| New Mexico | Dona Ana | 79.7 | 79.6 | 0.02 | 79.7 |
| New Mexico | Eddy | 69.0 | 68.9 | 0.02 | 69.0 |
| New Mexico | Sandoval | 72.0 | 71.9 | 0.02 | 72.0 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| New Mexico | San Juan | 75.0 | 74.9 | 0.02 | 75.0 |
| New Mexico | Valencia | 68.0 | 67.9 | 0.03 | 68.0 |
| New York | Albany | 83.0 | 82.9 | 0.05 | 83.0 |
| New York | Bronx | 82.8 | 82.9 | -0.14 | 82.7 |
| New York | Chautauqua | 91.7 | 91.6 | 0.06 | 91.7 |
| New York | Chemung | 81.0 | 80.9 | 0.04 | 81.0 |
| New York | Dutchess | 91.3 | 91.2 | 0.05 | 91.3 |
| New York | Erie | 96.0 | 95.9 | 0.06 | 96.0 |
| New York | Essex | 89.0 | 88.9 | 0.06 | 89.0 |
| New York | Hamilton | 79.0 | 78.9 | 0.04 | 79.0 |
| New York | Herkimer | 74.0 | 73.9 | 0.05 | 74.0 |
| New York | Jefferson | 91.7 | 91.6 | 0.07 | 91.7 |
| New York | Madison | 80.0 | 79.9 | 0.05 | 80.0 |
| New York | Monroe | 86.5 | 86.4 | 0.06 | 86.5 |
| New York | Niagara | 91.0 | 90.9 | 0.07 | 91.0 |
| New York | Oneida | 79.0 | 78.9 | 0.05 | 79.0 |
| New York | Onondaga | 83.0 | 82.9 | 0.05 | 83.0 |
| New York | Orange | 86.0 | 85.9 | 0.07 | 86.0 |
| New York | Putnam | 91.3 | 91.2 | 0.09 | 91.3 |
| New York | Queens | 85.1 | 85.3 | -0.14 | 85.0 |
| New York | Richmond | 96.0 | 96.3 | -0.27 | 96.0 |
| New York | Saratoga | 85.5 | 85.4 | 0.06 | 85.5 |
| New York | Schenectady | 77.3 | 77.2 | 0.05 | 77.3 |
| New York | Suffolk | 98.5 | 98.5 | 0.07 | 98.5 |
| New York | Ulster | 81.7 | 81.6 | 0.06 | 81.7 |
| New York | Wayne | 84.0 | 83.9 | 0.06 | 84.0 |
| New York | Westchester | 92.0 | 92.0 | 0.04 | 92.0 |
| North Carolina | Alexander | 88.7 | 88.6 | 0.07 | 88.7 |
| North Carolina | Avery | 78.3 | 78.2 | 0.04 | 78.3 |
| North Carolina | Buncombe | 82.0 | 81.9 | 0.05 | 82.0 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| North Carolina | Caldwell | 85.7 | 85.6 | 0.06 | 85.7 |
| North Carolina | Camden | 80.0 | 79.9 | 0.09 | 80.0 |
| North Carolina | Caswell | 89.7 | 89.6 | 0.06 | 89.7 |
| North Carolina | Chatham | 82.0 | 81.9 | 0.07 | 82.0 |
| North Carolina | Cumberland | 87.7 | 87.6 | 0.09 | 87.7 |
| North Carolina | Davie | 94.7 | 94.6 | 0.09 | 94.7 |
| North Carolina | Durham | 89.0 | 88.9 | 0.04 | 89.0 |
| North Carolina | Edgecombe | 88.0 | 87.9 | 0.08 | 88.0 |
| North Carolina | Forsyth | 93.7 | 93.6 | 0.07 | 93.7 |
| North Carolina | Franklin | 89.0 | 88.9 | 0.09 | 89.0 |
| North Carolina | Granville | 92.0 | 91.9 | 0.05 | 92.0 |
| North Carolina | Guilford | 90.7 | 90.6 | 0.05 | 90.7 |
| North Carolina | Haywood | 86.3 | 86.2 | 0.05 | 86.3 |
| North Carolina | Jackson | 85.5 | 85.4 | 0.03 | 85.5 |
| North Carolina | Johnston | 85.6 | 85.5 | 0.14 | 85.7 |
| North Carolina | Lincoln | 92.3 | 92.2 | 0.05 | 92.3 |
| North Carolina | Mecklenburg | 100.3 | 100.2 | 0.12 | 100.3 |
| North Carolina | New Hanover | 77.3 | 77.2 | 0.09 | 77.3 |
| North Carolina | Northampton | 83.3 | 83.2 | 0.05 | 83.3 |
| North Carolina | Person | 90.0 | 89.9 | 0.05 | 90.0 |
| North Carolina | Randolph | 85.0 | 84.9 | 0.10 | 85.0 |
| North Carolina | Rockingham | 88.7 | 88.6 | 0.05 | 88.7 |
| North Carolina | Rowan | 99.7 | 99.6 | 0.12 | 99.7 |
| North Carolina | Swain | 73.7 | 73.6 | 0.04 | 73.7 |
| North Carolina | Union | 87.7 | 87.5 | 0.23 | 87.7 |
| North Carolina | Wake | 92.7 | 92.5 | 0.23 | 92.7 |
| North Carolina | Yancey | 86.3 | 86.2 | 0.04 | 86.3 |
| Ohio | Allen | 87.7 | 87.6 | 0.04 | 87.7 |
| Ohio | Ashtabula | 94.0 | 93.9 | 0.08 | 94.0 |
| Ohio | Butler | 89.0 | 88.9 | 0.09 | 89.0 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Ohio | Clark | 88.3 | 88.2 | 0.07 | 88.3 |
| Ohio | Clermont | 89.7 | 89.6 | 0.14 | 89.7 |
| Ohio | Clinton | 95.7 | 95.6 | 0.14 | 95.7 |
| Ohio | Cuyahoga | 86.3 | 86.3 | 0.08 | 86.3 |
| Ohio | Delaware | 90.3 | 90.2 | 0.07 | 90.3 |
| Ohio | Franklin | 95.0 | 94.9 | 0.12 | 95.0 |
| Ohio | Geauga | 98.3 | 98.2 | 0.08 | 98.3 |
| Ohio | Greene | 87.0 | 86.9 | 0.07 | 87.0 |
| Ohio | Hamilton | 89.4 | 89.3 | 0.06 | 89.3 |
| Ohio | Jefferson | 85.3 | 85.2 | 0.05 | 85.3 |
| Ohio | Knox | 89.3 | 89.2 | 0.09 | 89.3 |
| Ohio | Lake | 92.7 | 92.7 | 0.07 | 92.7 |
| Ohio | Lawrence | 85.0 | 84.9 | 0.03 | 85.0 |
| Ohio | Licking | 89.0 | 88.9 | 0.10 | 89.0 |
| Ohio | Lorain | 86.0 | 86.2 | -0.19 | 85.3 |
| Ohio | Lucas | 88.7 | 88.7 | 0.07 | 88.7 |
| Ohio | Madison | 89.0 | 88.9 | 0.12 | 89.0 |
| Ohio | Mahoning | 87.3 | 87.2 | 0.06 | 87.3 |
| Ohio | Medina | 87.7 | 87.6 | 0.06 | 87.7 |
| Ohio | Miami | 86.3 | 86.2 | 0.07 | 86.3 |
| Ohio | Montgomery | 86.7 | 86.6 | 0.07 | 86.7 |
| Ohio | Portage | 92.0 | 91.9 | 0.07 | 92.0 |
| Ohio | Preble | 80.3 | 80.2 | 0.07 | 80.3 |
| Ohio | Stark | 89.0 | 88.9 | 0.06 | 89.0 |
| Ohio | Summit | 94.3 | 94.2 | 0.06 | 94.3 |
| Ohio | Trumbull | 91.0 | 90.9 | 0.08 | 91.0 |
| Ohio | Warren | 89.7 | 89.6 | 0.13 | 89.7 |
| Ohio | Washington | 87.0 | 86.9 | 0.04 | 87.0 |
| Ohio | Wood | 87.0 | 86.9 | 0.05 | 87.0 |
| Oklahoma | Cleveland | 77.3 | 77.2 | 0.11 | 77.3 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Oklahoma | Comanche | 79.0 | 78.9 | 0.06 | 79.0 |
| Oklahoma | Kay | 75.0 | 74.9 | 0.08 | 75.0 |
| Oklahoma | Mc Clain | 79.3 | 79.1 | 0.12 | 79.3 |
| Oklahoma | Marshall | 85.0 | 84.9 | 0.06 | 85.0 |
| Oklahoma | Oklahoma | 80.7 | 80.6 | 0.08 | 80.7 |
| Oklahoma | Tulsa | 86.7 | 86.6 | 0.06 | 86.7 |
| Pennsylvania | Allegheny | 93.0 | 92.9 | 0.06 | 93.0 |
| Pennsylvania | Armstrong | 92.0 | 91.9 | 0.05 | 92.0 |
| Pennsylvania | Beaver | 90.9 | 90.9 | -0.01 | 90.7 |
| Pennsylvania | Berks | 92.7 | 92.6 | 0.08 | 92.7 |
| Pennsylvania | Blair | 84.3 | 84.2 | 0.04 | 84.3 |
| Pennsylvania | Bucks | 103.0 | 102.9 | 0.11 | 103.0 |
| Pennsylvania | Cambria | 87.7 | 87.6 | 0.04 | 87.7 |
| Pennsylvania | Centre | 85.5 | 85.4 | 0.05 | 85.5 |
| Pennsylvania | Chester | 96.5 | 96.4 | 0.11 | 96.5 |
| Pennsylvania | Clearfield | 86.7 | 86.6 | 0.04 | 86.7 |
| Pennsylvania | Dauphin | 91.0 | 90.9 | 0.10 | 91.0 |
| Pennsylvania | Delaware | 93.8 | 93.8 | -0.06 | 93.7 |
| Pennsylvania | Erie | 89.0 | 88.9 | 0.07 | 89.0 |
| Pennsylvania | Franklin | 93.0 | 92.9 | 0.07 | 93.0 |
| Pennsylvania | Greene | 90.3 | 90.2 | 0.05 | 90.3 |
| Pennsylvania | Lackawanna | 85.3 | 85.2 | 0.05 | 85.3 |
| Pennsylvania | Lancaster | 94.0 | 93.9 | 0.09 | 94.0 |
| Pennsylvania | Lawrence | 78.7 | 78.7 | 0.05 | 78.7 |
| Pennsylvania | Lehigh | 93.3 | 93.2 | 0.08 | 93.3 |
| Pennsylvania | Luzerne | 84.7 | 84.6 | 0.05 | 84.7 |
| Pennsylvania | Lycoming | 78.3 | 78.2 | 0.05 | 78.3 |
| Pennsylvania | Mercer | 91.3 | 91.2 | 0.08 | 91.3 |
| Pennsylvania | Montgomery | 96.3 | 96.2 | 0.07 | 96.3 |
| Pennsylvania | Northampton | 93.0 | 92.9 | 0.09 | 93.0 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Pennsylvania | Perry | 84.7 | 84.6 | 0.05 | 84.7 |
| Pennsylvania | Philadelphia | 97.5 | 97.4 | 0.10 | 97.5 |
| Pennsylvania | Tioga | 83.7 | 83.6 | 0.04 | 83.7 |
| Pennsylvania | Washington | 87.7 | 87.6 | 0.05 | 87.7 |
| Pennsylvania | Westmoreland | 87.7 | 87.6 | 0.05 | 87.7 |
| Pennsylvania | York | 90.3 | 90.2 | 0.09 | 90.3 |
| Rhode Island | Kent | 95.3 | 95.2 | 0.15 | 95.3 |
| Rhode Island | Providence | 90.3 | 90.2 | 0.17 | 90.3 |
| Rhode Island | Washington | 93.3 | 93.1 | 0.14 | 93.3 |
| South Carolina | Abbeville | 84.0 | 83.8 | 0.18 | 84.0 |
| South Carolina | Anderson | 88.0 | 87.9 | 0.08 | 88.0 |
| South Carolina | Berkeley | 74.0 | 73.9 | 0.10 | 74.0 |
| South Carolina | Charleston | 72.0 | 71.9 | 0.06 | 72.0 |
| South Carolina | Cherokee | 86.0 | 85.9 | 0.11 | 86.0 |
| South Carolina | Chester | 84.3 | 84.1 | 0.17 | 84.3 |
| South Carolina | Darlington | 84.7 | 84.6 | 0.07 | 84.7 |
| South Carolina | Edgefield | 80.7 | 80.6 | 0.07 | 80.7 |
| South Carolina | Oconee | 84.5 | 84.4 | 0.04 | 84.5 |
| South Carolina | Pickens | 85.3 | 85.2 | 0.06 | 85.3 |
| South Carolina | Richland | 91.7 | 91.6 | 0.11 | 91.7 |
| South Carolina | Spartanburg | 90.0 | 89.9 | 0.10 | 90.0 |
| South Carolina | Union | 80.7 | 80.6 | 0.12 | 80.7 |
| South Carolina | York | 83.3 | 83.1 | 0.17 | 83.3 |
| Tennessee | Anderson | 89.7 | 89.6 | 0.05 | 89.7 |
| Tennessee | Blount | 94.0 | 93.9 | 0.07 | 94.0 |
| Tennessee | Davidson | 81.3 | 81.2 | 0.12 | 81.3 |
| Tennessee | Hamilton | 90.7 | 90.6 | 0.08 | 90.7 |
| Tennessee | Haywood | 85.3 | 85.2 | 0.13 | 85.3 |
| Tennessee | Jefferson | 94.0 | 93.9 | 0.06 | 94.0 |
| Tennessee | Knox | 94.7 | 94.6 | 0.08 | 94.7 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Tennessee | Lawrence | 79.3 | 79.2 | 0.04 | 79.3 |
| Tennessee | Meigs | 90.5 | 90.4 | 0.06 | 90.5 |
| Tennessee | Putnam | 85.0 | 84.9 | 0.05 | 85.0 |
| Tennessee | Rutherford | 83.3 | 83.2 | 0.10 | 83.3 |
| Tennessee | Sevier | 96.0 | 95.9 | 0.05 | 96.0 |
| Tennessee | Shelby | 90.9 | 90.5 | 0.38 | 90.7 |
| Tennessee | Sullivan | 89.3 | 89.2 | 0.07 | 89.3 |
| Tennessee | Sumner | 89.0 | 88.9 | 0.09 | 89.0 |
| Tennessee | Williamson | 86.3 | 86.2 | 0.07 | 86.3 |
| Tennessee | Wilson | 84.7 | 84.6 | 0.09 | 84.7 |
| Texas | Bexar | 85.7 | 85.6 | 0.06 | 85.7 |
| Texas | Brazoria | 91.0 | 90.9 | 0.11 | 91.0 |
| Texas | Collin | 93.3 | 93.3 | 0.00 | 93.3 |
| Texas | Dallas | 91.0 | 90.9 | 0.08 | 91.0 |
| Texas | Denton | 99.0 | 98.6 | 0.45 | 99.0 |
| Texas | Ellis | 85.3 | 85.2 | 0.09 | 85.3 |
| Texas | El Paso | 78.7 | 78.6 | 0.04 | 78.7 |
| Texas | Galveston | 92.0 | 91.9 | 0.05 | 92.0 |
| Texas | Gregg | 88.3 | 88.2 | 0.03 | 88.3 |
| Texas | Harris | 105.1 | 105.0 | 0.13 | 105.0 |
| Texas | Harrison | 76.0 | 75.9 | 0.04 | 76.0 |
| Texas | Hood | 84.0 | 83.8 | 0.16 | 84.0 |
| Texas | Jefferson | 90.5 | 90.4 | 0.03 | 90.5 |
| Texas | Johnson | 89.5 | 89.3 | 0.15 | 89.5 |
| Texas | Marion | 81.0 | 80.9 | 0.04 | 81.0 |
| Texas | Montgomery | 90.7 | 90.5 | 0.22 | 90.7 |
| Texas | Orange | 78.3 | 78.2 | 0.03 | 78.3 |
| Texas | Parker | 87.5 | 87.2 | 0.30 | 87.5 |
| Texas | Rockwall | 82.0 | 81.9 | 0.06 | 82.0 |
| Texas | Smith | 84.3 | 84.2 | 0.03 | 84.3 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Texas | Tarrant | 98.4 | 98.1 | 0.35 | 98.3 |
| Texas | Travis | 84.2 | 84.2 | 0.07 | 84.3 |
| Utah | Box Elder | 79.0 | 78.9 | 0.08 | 79.0 |
| Utah | Cache | 69.3 | 69.2 | 0.03 | 69.3 |
| Utah | Davis | 81.3 | 81.3 | 0.05 | 81.3 |
| Utah | Salt Lake | 80.0 | 80.0 | 0.04 | 80.0 |
| Utah | San Juan | 71.0 | 70.9 | 0.01 | 71.0 |
| Utah | Utah | 78.3 | 78.2 | 0.01 | 78.3 |
| Utah | Weber | 77.7 | 77.6 | 0.10 | 77.7 |
| Vermont | Bennington | 79.7 | 79.6 | 0.06 | 79.7 |
| Vermont | Chittenden | 76.7 | 76.6 | 0.04 | 76.7 |
| Virginia | Arlington | 95.8 | 95.6 | 0.17 | 95.7 |
| Virginia | Caroline | 84.0 | 83.9 | 0.13 | 84.0 |
| Virginia | Charles City | 89.3 | 89.2 | 0.08 | 89.3 |
| Virginia | Chesterfield | 86.0 | 85.9 | 0.07 | 86.0 |
| Virginia | Fairfax | 96.4 | 96.2 | 0.17 | 96.3 |
| Virginia | Fauquier | 81.0 | 80.9 | 0.12 | 81.0 |
| Virginia | Frederick | 84.3 | 84.2 | 0.04 | 84.3 |
| Virginia | Hanover | 94.0 | 93.9 | 0.08 | 94.0 |
| Virginia | Henrico | 90.0 | 89.9 | 0.08 | 90.0 |
| Virginia | Loudoun | 89.5 | 89.1 | 0.35 | 89.3 |
| Virginia | Madison | 86.3 | 86.2 | 0.09 | 86.3 |
| Virginia | Page | 81.3 | 81.2 | 0.09 | 81.3 |
| Virginia | Prince William | 85.7 | 85.6 | 0.15 | 85.7 |
| Virginia | Roanoke | 86.0 | 85.9 | 0.07 | 86.0 |
| Virginia | Rockbridge | 79.0 | 78.9 | 0.04 | 79.0 |
| Virginia | Stafford | 86.4 | 86.1 | 0.27 | 86.3 |
| Virginia | Wythe | 80.7 | 80.6 | 0.04 | 80.7 |
| Virginia | Alexandria Cit | 90.1 | 89.9 | 0.16 | 90.0 |
| Virginia | Hampton City | 88.7 | 88.6 | 0.09 | 88.7 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Virginia | Suffolk City | 87.3 | 87.2 | 0.09 | 87.3 |
| West Virginia | Berkeley | 86.0 | 85.9 | 0.04 | 86.0 |
| West Virginia | Cabell | 88.0 | 87.9 | 0.04 | 88.0 |
| West Virginia | Greenbrier | 81.7 | 81.6 | 0.04 | 81.7 |
| West Virginia | Hancock | 84.3 | 84.2 | 0.05 | 84.3 |
| West Virginia | Kanawha | 87.0 | 86.9 | 0.05 | 87.0 |
| West Virginia | Monongalia | 80.0 | 79.9 | 0.04 | 80.0 |
| West Virginia | Ohio | 84.7 | 84.6 | 0.05 | 84.7 |
| West Virginia | Wood | 87.7 | 87.6 | 0.04 | 87.7 |
| Wisconsin | Brown | 81.7 | 81.6 | 0.09 | 81.7 |
| Wisconsin | Columbia | 77.7 | 77.6 | 0.07 | 77.7 |
| Wisconsin | Dane | 77.3 | 77.2 | 0.07 | 77.3 |
| Wisconsin | Dodge | 81.0 | 80.9 | 0.07 | 81.0 |
| Wisconsin | Door | 92.7 | 92.6 | 0.12 | 92.7 |
| Wisconsin | Fond Du Lac | 79.0 | 78.9 | 0.11 | 79.0 |
| Wisconsin | Green | 74.5 | 74.4 | 0.05 | 74.5 |
| Wisconsin | Jefferson | 84.5 | 84.4 | 0.09 | 84.5 |
| Wisconsin | Kenosha | 98.7 | 98.9 | -0.18 | 98.7 |
| Wisconsin | Kewaunee | 90.0 | 89.9 | 0.13 | 90.0 |
| Wisconsin | Manitowoc | 90.0 | 89.9 | 0.12 | 90.0 |
| Wisconsin | Milwaukee | 91.6 | 91.7 | -0.07 | 91.3 |
| Wisconsin | Outagamie | 77.3 | 77.2 | 0.06 | 77.3 |
| Wisconsin | Ozaukee | 95.4 | 95.4 | 0.01 | 95.3 |
| Wisconsin | Racine | 91.7 | 91.7 | -0.06 | 91.7 |
| Wisconsin | Rock | 84.3 | 84.2 | 0.11 | 84.3 |
| Wisconsin | St Croix | 72.7 | 72.6 | 0.12 | 72.7 |
| Wisconsin | Sauk | 74.3 | 74.2 | 0.05 | 74.3 |
| Wisconsin | Sheboygan | 98.0 | 97.9 | 0.10 | 98.0 |
| Wisconsin | Walworth | 83.3 | 83.2 | 0.11 | 83.3 |
| Wisconsin | Washington | 82.7 | 82.6 | 0.13 | 82.7 |

| State Name | County Name | Design Value with EDMS Aircraft Emissions | Design Value with No Aircraft Emissions | Change Due to Contribution of EDMS Aircraft Emissions | Average 99-03 Ambient DV |
|---|---|---|---|---|---|
| Wisconsin | Waukesha | 82.7 | 82.6 | 0.12 | 82.7 |
| Wisconsin | Winnebago | 80.0 | 79.9 | 0.08 | 80.0 |
| Wyoming | Campbell | 71.0 | 70.9 | 0.01 | 71.0 |
| Wyoming | Teton | 65.7 | 65.6 | 0.01 | 65.7 |

# Appendix G Health Impact Functions and Baseline Incidence Rates

Health impact functions relate the change in the number of observed health events for a population to a change in ambient concentration of a particular air pollutant. A standard health impact function has four components: 1) an effect estimate for a particular study; 2) a baseline incidence rate for the health effect (obtained from epidemiological literature or a source of public health statistics); 3) the size of the potentially affected population; 4) the estimated change in the relevant pollutant summary measure (for example, a change in ambient ozone or PM concentrations). Generally health impact functions are assumed to have a log-linear form:

$$\Delta y = y_0 \cdot (e^{ß \cdot \Delta P} - 1)$$

Where: $y_0$ is the baseline incidence rate (number of incidences in a specific subpopulation)
ß is the effect estimate provided by the study
$\Delta y$ is the change in health incidences
$\Delta P$ is the change in the summary measure of the pollutant being examined

The EPA Benefits Modeling and Analysis Program (BenMAP) incorporates the elements necessary to conduct a nationwide analysis by combining air pollution monitor data, air quality modeling data, census data, and population projections to calculate a population's potential exposure to ambient air pollution. This Appendix contains the health impact functions and incidence rates used in BenMAP.

**Table G.1:** Health impact functions used in BenMAP to estimate benefits of PM reductions

| Health Endpoint | Study | Population Used in BenMAP |
|---|---|---|
| Premature mortality | (Pope et al., 2002) (function based on average of $PM_{2.5}$ measures) | >29 years |
| | (Woodruff et al., 1997) | Infant (<1 year) |
| Chronic Illness | | |
| Chronic Bronchitis | (Abbey et al., 1995) | >26 years |
| Myocardial Infarctions, Nonfatal | (Peters et al., 2001) | >17 years |
| Hospital Admissions | | |
| Respiratory | (Moolgavkar, 2003) (COPD) | >64 years |
| | (Ito, 2003) (COPD) | >64 years |
| | (Moolgavkar, 2000a) (COPD, less Asthma) | 18-64 years |
| | (Ito, 2003) (Pneumonia) | >64 years |
| | (Sheppard, 2003) (Asthma) | <65 years |
| Cardiovascular | (Moolgavkar, 2000b) (All Cardiovascular, less MI) | 18-64 years |
| | (Moolgavkar, 2003) (All Cardiovascular, less MI) | >64 years |
| | (Ito, 2003) (Ischemic Heart Disease, less MI; Dysrhythmia; Heart Failure) | >64 years |
| ER Visits, Asthma | (Norris et al., 1999) | <18 years |
| Other Health Endpoints | | |
| Acute Bronchitis | (Dockery et al., 1996) | 8-12 years |
| Upper Respiratory Symptoms | (Pope et al., 1991) | 9-11 years |
| Lower Respiratory Symptoms | (Schwartz and Neas, 2000) | 7-14 years |
| Asthma Exacerbation | | |

| Health Endpoint | Study | Population Used in BenMAP |
|---|---|---|
| | (Ostro et al., 2001) (Wheeze, Cough, Shortness of Breath) | 6-18 years |
| | (Vedal et al., 1998) (Cough) | 6-18 years |
| Work Loss Days | (Ostro, 1987) | 18-64 years |
| Minor Restricted Activity Days | (Ostro and Rothschild, 1989) | 18-64 years |

**Table G.2:** Health impact functions used in BenMAP to estimate benefits of ozone reductions

| Health Endpoint | Study | Population Used in BenMAP |
|---|---|---|
| Premature mortality | (Bell et al., 2004)<br>Meta-analyses:<br>Bell et al. (2005)<br>Ito et al. (2005)<br>Levy et al. (2005) | All ages |
| Hospital Admissions | | |
| Respiratory | (Moolgavkar, 1997) (Pneumonia) | >64 years |
| | (Moolgavkar, 1997) (COPD) | >64 years |
| | (Schwartz, 1994a) (Pneumonia) | >64 years |
| | (Schwartz, 1994b) (COPD) | >64 years |
| | (Schwartz, 1995) | >64 years |
| | (Burnett et al. 2001) | <2 years |
| ER Visits, Asthma | (Jaffe et al., 2003) | 5-34 years |
| | (Peel et al., 2005) | All ages |
| | (Wilson et al., 2005) | All ages |
| Other Health Endpoints | | |
| School Absence Days | (Chen et al., 2000) | 5-17 years |
| | (Gilliland et al., 2001) | 5-17 years |
| Minor Restricted Activity Days | (Ostro and Rothschild, 1989) | 18-64 years |

**Table G.3:** Baseline incidence rates used in BenMAP for the general population

| Endpoint | Parameter | Incidence Value | Source |
|---|---|---|---|
| Mortality | Daily or annual mortality rate | Age-, cause-, and county-specific rate | CDC Wonder (1996-1998) |
| Hospitalizations | Daily hospitalization rate | Age-, region-, and cause-specific rate | 1999 National Hospital Discharge Survey (NHDS) public use data files[141] |
| Asthma ER Visits | Daily Asthma ER Visit Rate | Age- and Region-Specific | 2000 National Hospital Ambulatory Medical Care Survey (NHAMCS)[142], 1999 National Hospital Discharge Survey (NHDS)[143] |
| Chronic Bronchitis | Annual Prevalence Rate per person by age | 18-44: 0.0367<br>45-64: 0.0505<br>65+: 0.0587 | 1999 National Health Interview Survey (NHIS) (*American Lung Association*, 2002b) |
| | Annual Incidence Rate per person | 0.00378 | (Abbey et al., 1993) |
| Nonfatal Myocardial Infarction | Daily rates per person 18+ by region | Northeast: 0.0000159<br>Midwest: 0.0000135<br>South: 0.0000111<br>West: 0.0000100 | 1999 NHDS public use data files, adjusted by 0.93 for probability of surviving after 28 (Rosamond et al., 1999) |
| Asthma Exacerbations | Incidence (and Prevalence) among asthmatic African-American children | Daily Wheeze: 0.076 (0.173)<br>Daily Cough: 0.067 (0.145)<br>Daily shortness of breath: 0.037 (0.074) | (Ostro et al., 2001) |
| | Prevalence among asthmatic children | Daily Wheeze: 0.038<br>Daily Cough: 0.086<br>Daily shortness of breath: 0.045 | (Vedal et al., 1998) |
| Acute Bronchitis | Annual Rate[144], Children | 0.043 | (*American Lung Association*, 2002c) |
| Lower Respiratory Symptoms | Daily Rate, Children | 0.0012 | (Schwartz et al., 1994) |
| Upper Respiratory Symptoms | Daily Rate, Asthmatic Children | 0.3419 | (Pope et al., 1991) |

141 See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHDS
142 See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHAMCS
143 See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHDS
144 Defined as two or more of the following: cough, chest pain, phlegm, or wheeze

| Endpoint | Parameter | Incidence Value | Source |
|---|---|---|---|
| Work Loss Days | Daily Rate, by Age | 18-24: 0.00540<br>25-44: 0.00678<br>45-64: 0.00492 | 1996 National Health Interview Survey (HIS) (Adams, Hendershot, & Marano, 1999); U.S. Bureau of the Census |
| Minor Restricted Activity Days | Daily Rate per person | 0.02137 | (Ostro & Rothschild, 1989) |

**Table G.4:** Asthma prevalence rates used in BenMAP

| Population Group | Value | Source |
|---|---|---|
| All Ages | 0.0386 | (*American Lung Association*, 2002a) |
| <18 | 0.0527 | (*American Lung Association*, 2002a) |
| 5-17 | 0.0567 | (*American Lung Association*, 2002a) |
| 18-44 | 0.0371 | (*American Lung Association*, 2002a) |
| 45-64 | 0.0333 | (*American Lung Association*, 2002a) |
| 65+ | 0.0221 | (*American Lung Association*, 2002a) |
| Male, 27+ | 0.021 | 2000 NHIS Public Use Data Files[145] |
| African American, 5 to 17 | 0.0726 | (*American Lung Association*, 2002a) |
| African American <18 | 0.0735 | (*American Lung Association*, 2002a) |

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[145] See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHIS/2000/

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## Appendix H List of Counties by PM Mortality

| Rank | County | State | Incidences[146] | Percent of Total |
|---|---|---|---|---|
| 1 | Los Angeles | CA | 29 | 18% |
| 2 | Orange | CA | 8 | 5% |
| 3 | San Diego | CA | 6 | 3% |
| 4 | San Bernardino | CA | 5 | 3% |
| 5 | Cook | IL | 5 | 3% |
| 6 | Riverside | CA | 4 | 3% |
| 7 | Nassau | NY | 4 | 3% |
| 8 | Alameda | CA | 4 | 2% |
| 9 | Queens | NY | 3 | 2% |
| 10 | Kings | NY | 3 | 2% |
| 11 | Westchester | NY | 2 | 1% |
| 12 | Wayne | MI | 2 | 1% |
| 13 | Ventura | CA | 2 | 1% |
| 14 | Contra Costa | CA | 2 | 1% |
| 15 | Middlesex | NJ | 2 | 1% |
| 16 | Lake | IL | 2 | 1% |
| 17 | Union | NJ | 1 | 1% |
| 18 | Shelby | TN | 1 | 1% |
| 19 | Harris | TX | 1 | 1% |
| 20 | Hamilton | OH | 1 | 1% |
| | All other counties | | 78 | 47% |

[146] Incidences based upon studies by Pope et al., 2002. Counties not listed have mortality incidences considered to be within the range of modeling uncertainty.

## Appendix I Emissions Reductions at 113 Airports Due to Absence of Ground Delays

| FAA Code | ICAO Code | Metric Tons | | | | | | | % | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CO | NMHC | VOC | $NO_x$ | $SO_x$ | $PM_{2.5}$ | Fuel | CO | NMHC | VOC | $NO_x$ | $SO_x$ | $PM_{2.5}$ | Fuel |
| ABE | KABE | 90 | 19 | 21 | 8 | 3 | 0.82 | 2291 | 19% | 26% | 26% | 16% | 32% | 36% | 34% |
| ABQ | KABQ | 46 | 5 | 6 | 5 | 2 | 0.31 | 1250 | 4% | 4% | 4% | 2% | 5% | 4% | 5% |
| ACY | KACY | 25 | 5 | 5 | 3 | 1 | 0.23 | 782 | 3% | 9% | 9% | 6% | 15% | 17% | 15% |
| ALB | KALB | 89 | 12 | 13 | 10 | 3 | 0.66 | 2548 | 18% | 15% | 15% | 7% | 18% | 18% | 19% |
| ANC | PANC | 137 | 21 | 23 | 31 | 9 | 1.37 | 6434 | 4% | 4% | 4% | 2% | 5% | 4% | 6% |
| ASE | KASE | 38 | 13 | 13 | 2 | 1 | 0.33 | 624 | 29% | 22% | 22% | 5% | 15% | 18% | 16% |
| ATL | KATL | 2009 | 210 | 228 | 310 | 109 | 18.01 | 79882 | 35% | 22% | 22% | 8% | 20% | 19% | 22% |
| AVP | KAVP | 93 | 17 | 18 | 6 | 2 | 0.69 | 1688 | 25% | 38% | 38% | 32% | 49% | 53% | 51% |
| AZO | KAZO | 37 | 7 | 7 | 3 | 1 | 0.30 | 774 | 15% | 22% | 22% | 10% | 24% | 28% | 26% |
| BDL | KBDL | 89 | 12 | 13 | 15 | 5 | 0.90 | 3472 | 12% | 9% | 9% | 4% | 10% | 9% | 11% |
| BFL | KBFL | 8 | 1 | 1 | 0 | 0 | 0.05 | 130 | 2% | 4% | 4% | 4% | 7% | 9% | 8% |
| BHM | KBHM | 65 | 13 | 13 | 4 | 2 | 0.43 | 1312 | 9% | 9% | 9% | 3% | 8% | 9% | 8% |
| BIL | KBIL | 26 | 7 | 7 | 2 | 1 | 0.21 | 548 | 4% | 8% | 8% | 5% | 11% | 12% | 11% |
| BNA | KBNA | 119 | 17 | 18 | 13 | 5 | 0.89 | 3525 | 12% | 8% | 8% | 3% | 8% | 8% | 9% |
| BOI | KBOI | 53 | 9 | 10 | 6 | 2 | 0.44 | 1460 | 8% | 9% | 9% | 5% | 11% | 13% | 13% |
| BOS | KBOS | 584 | 71 | 76 | 90 | 28 | 5.40 | 20801 | 24% | 14% | 14% | 6% | 15% | 15% | 16% |
| BPT | KBPT | 27 | 7 | 7 | 1 | 0 | 0.17 | 326 | 9% | 25% | 25% | 11% | 30% | 35% | 28% |
| BTM | KBTM | 3 | 1 | 1 | 0 | 0 | 0.03 | 68 | 3% | 9% | 9% | 8% | 14% | 14% | 15% |
| BUF | KBUF | 55 | 8 | 9 | 7 | 2 | 0.47 | 1834 | 10% | 8% | 8% | 3% | 9% | 9% | 9% |
| BUR | KBUR | 43 | 6 | 6 | 5 | 2 | 0.36 | 1340 | 4% | 5% | 5% | 2% | 6% | 6% | 7% |
| BWI | KBWI | 166 | 19 | 20 | 29 | 9 | 1.68 | 6968 | 13% | 7% | 7% | 3% | 8% | 8% | 9% |
| CAE | KCAE | 374 | 78 | 84 | 34 | 12 | 3.21 | 9181 | 52% | 54% | 54% | 29% | 52% | 54% | 55% |
| CAK | KCAK | 62 | 10 | 11 | 5 | 2 | 0.43 | 1412 | 12% | 18% | 18% | 9% | 20% | 22% | 22% |
| CHA | KCHA | 98 | 26 | 27 | 5 | 2 | 0.70 | 1589 | 17% | 31% | 31% | 16% | 33% | 41% | 35% |
| CIC | KCIC | 3 | 0 | 0 | 0 | 0 | 0.01 | 38 | 2% | 5% | 5% | 7% | 11% | 21% | 10% |
| CLE | KCLE | 185 | 30 | 32 | 22 | 8 | 1.52 | 5584 | 18% | 10% | 10% | 4% | 10% | 10% | 11% |
| CLT | KCLT | 623 | 89 | 95 | 77 | 27 | 4.99 | 19686 | 25% | 16% | 16% | 6% | 16% | 15% | 17% |

| FAA Code | ICAO Code | Metric Tons | | | | | | | % | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CO | NMHC | VOC | $NO_x$ | $SO_x$ | $PM_{2.5}$ | Fuel | CO | NMHC | VOC | $NO_x$ | $SO_x$ | $PM_{2.5}$ | Fuel |
| CMH | KCMH | 173 | 33 | 34 | 20 | 7 | 1.47 | 5051 | 19% | 18% | 18% | 6% | 16% | 18% | 17% |
| COS | KCOS | 75 | 13 | 14 | 7 | 2 | 0.51 | 1787 | 9% | 14% | 14% | 7% | 16% | 17% | 17% |
| CRW | KCRW | 126 | 22 | 23 | 6 | 2 | 0.69 | 1741 | 26% | 33% | 33% | 20% | 39% | 43% | 42% |
| CVG | KCVG | 451 | 142 | 154 | 52 | 19 | 5.59 | 14088 | 25% | 29% | 29% | 6% | 15% | 17% | 17% |
| DAL | KDAL | 73 | 15 | 15 | 6 | 2 | 0.56 | 1657 | 5% | 6% | 6% | 2% | 6% | 8% | 7% |
| DAY | KDAY | 62 | 10 | 11 | 8 | 3 | 0.58 | 2266 | 9% | 9% | 9% | 4% | 11% | 11% | 12% |
| DCA | KDCA | 302 | 28 | 30 | 49 | 16 | 2.81 | 11935 | 28% | 13% | 13% | 6% | 14% | 14% | 16% |
| DEN | KDEN | 532 | 71 | 78 | 70 | 24 | 4.73 | 17453 | 18% | 10% | 10% | 4% | 10% | 10% | 12% |
| DFW | KDFW | 1201 | 80 | 87 | 209 | 74 | 10.26 | 54390 | 31% | 15% | 15% | 7% | 18% | 17% | 19% |
| DLH | KDLH | 10 | 2 | 2 | 1 | 0 | 0.09 | 234 | 4% | 8% | 8% | 4% | 10% | 9% | 11% |
| DTW | KDTW | 562 | 91 | 99 | 98 | 34 | 7.56 | 25282 | 22% | 13% | 13% | 5% | 14% | 12% | 15% |
| ELP | KELP | 39 | 6 | 6 | 3 | 1 | 0.23 | 823 | 8% | 6% | 6% | 2% | 5% | 6% | 5% |
| ERI | KERI | 25 | 6 | 6 | 1 | 1 | 0.19 | 391 | 14% | 19% | 19% | 12% | 23% | 27% | 25% |
| EVV | KEVV | 31 | 6 | 6 | 2 | 1 | 0.21 | 478 | 10% | 16% | 16% | 8% | 17% | 22% | 19% |
| EWR | KEWR | 1360 | 171 | 186 | 247 | 77 | 14.27 | 56382 | 40% | 24% | 24% | 10% | 25% | 25% | 27% |
| FAI | PAFA | 13 | 2 | 2 | 1 | 0 | 0.09 | 273 | 3% | 3% | 3% | 2% | 4% | 5% | 4% |
| FAT | KFAT | 28 | 4 | 4 | 2 | 1 | 0.17 | 677 | 4% | 8% | 8% | 6% | 13% | 13% | 14% |
| FAY | KFAY | 73 | 10 | 11 | 4 | 2 | 0.43 | 1238 | 30% | 43% | 43% | 36% | 53% | 57% | 56% |
| FNT | KFNT | 83 | 15 | 16 | 8 | 3 | 0.76 | 2239 | 22% | 28% | 28% | 13% | 31% | 34% | 33% |
| GEG | KGEG | 39 | 5 | 6 | 6 | 2 | 0.35 | 1327 | 9% | 8% | 8% | 5% | 11% | 12% | 13% |
| GRR | KGRR | 107 | 19 | 20 | 9 | 3 | 0.81 | 2422 | 17% | 19% | 19% | 7% | 18% | 21% | 20% |
| GSO | KGSO | 143 | 27 | 28 | 12 | 5 | 1.09 | 3347 | 23% | 22% | 22% | 8% | 20% | 24% | 23% |
| GSP | KGSP | 165 | 24 | 26 | 14 | 5 | 1.21 | 4012 | 50% | 35% | 36% | 17% | 34% | 37% | 37% |
| HLN | KHLN | 7 | 1 | 1 | 0 | 0 | 0.04 | 85 | 3% | 5% | 5% | 5% | 8% | 9% | 9% |
| HOU | KHOU | 80 | 14 | 14 | 7 | 3 | 0.59 | 1974 | 6% | 7% | 6% | 2% | 6% | 6% | 6% |
| HPN | KHPN | 155 | 49 | 50 | 10 | 4 | 1.56 | 3023 | 19% | 19% | 19% | 8% | 18% | 22% | 19% |
| HTS | KHTS | 43 | 9 | 9 | 3 | 1 | 0.29 | 799 | 19% | 40% | 39% | 34% | 51% | 56% | 52% |
| HVN | KHVN | 9 | 2 | 2 | 1 | 0 | 0.08 | 186 | 4% | 15% | 15% | 12% | 22% | 28% | 22% |

| FAA Code | ICAO Code | Metric Tons | | | | | | | % | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CO | NMHC | VOC | $NO_x$ | $SO_x$ | $PM_{2.5}$ | Fuel | CO | NMHC | VOC | $NO_x$ | $SO_x$ | $PM_{2.5}$ | Fuel |
| IAD | KIAD | 540 | 91 | 95 | 77 | 25 | 5.33 | 18365 | 22% | 15% | 15% | 5% | 13% | 13% | 15% |
| IAH | KIAH | 884 | 101 | 109 | 116 | 42 | 7.98 | 31211 | 30% | 17% | 17% | 6% | 16% | 16% | 18% |
| IND | KIND | 234 | 51 | 55 | 30 | 10 | 2.45 | 7539 | 17% | 11% | 11% | 3% | 10% | 12% | 11% |
| IPL | KIPL | 5 | 1 | 1 | 0 | 0 | 0.02 | 56 | 2% | 8% | 8% | 9% | 14% | 26% | 12% |
| ISP | KISP | 34 | 6 | 6 | 3 | 1 | 0.33 | 859 | 5% | 9% | 9% | 3% | 9% | 10% | 10% |
| IYK | KIYK | 2 | 0 | 0 | 0 | 0 | 0.01 | 49 | 2% | 2% | 2% | 13% | 19% | 29% | 20% |
| JFK | KJFK | 1356 | 149 | 162 | 309 | 91 | 14.94 | 67039 | 37% | 23% | 23% | 9% | 23% | 21% | 25% |
| LAN | KLAN | 42 | 10 | 11 | 5 | 1 | 0.40 | 1014 | 9% | 16% | 16% | 14% | 26% | 21% | 24% |
| LAS | KLAS | 652 | 72 | 75 | 145 | 25 | 5.76 | 22492 | 18% | 13% | 13% | 7% | 17% | 12% | 14% |
| LAX | KLAX | 840 | 88 | 95 | 221 | 39 | 7.21 | 31552 | 24% | 12% | 12% | 6% | 15% | 10% | 12% |
| LGA | KLGA | 857 | 91 | 98 | 168 | 31 | 7.93 | 32713 | 40% | 24% | 24% | 12% | 26% | 23% | 25% |
| LGB | KLGB | 25 | 3 | 3 | 7 | 1 | 0.20 | 753 | 2% | 4% | 4% | 5% | 10% | 6% | 6% |
| MCN | KMCN | 54 | 9 | 10 | 2 | 0 | 0.22 | 452 | 28% | 43% | 42% | 31% | 45% | 51% | 46% |
| MDT | KMDT | 215 | 59 | 64 | 21 | 5 | 2.20 | 5290 | 44% | 44% | 44% | 25% | 45% | 46% | 46% |
| MDW | KMDW | 226 | 32 | 34 | 50 | 9 | 2.21 | 7039 | 18% | 10% | 10% | 6% | 14% | 9% | 10% |
| MEM | KMEM | 557 | 142 | 154 | 112 | 19 | 5.94 | 15298 | 21% | 11% | 11% | 6% | 14% | 11% | 11% |
| MFR | KMFR | 9 | 1 | 1 | 1 | 0 | 0.05 | 173 | 5% | 6% | 6% | 10% | 16% | 10% | 10% |
| MHT | KMHT | 72 | 10 | 11 | 15 | 3 | 0.60 | 2142 | 19% | 10% | 10% | 7% | 15% | 11% | 12% |
| MKE | KMKE | 158 | 30 | 32 | 26 | 5 | 1.23 | 4067 | 17% | 10% | 10% | 6% | 14% | 9% | 10% |
| MOD | KMOD | 5 | 1 | 1 | 0 | 0 | 0.02 | 69 | 2% | 8% | 8% | 12% | 17% | 26% | 13% |
| MSN | KMSN | 65 | 13 | 13 | 8 | 2 | 0.55 | 1626 | 12% | 17% | 17% | 10% | 22% | 20% | 20% |
| MSP | KMSP | 744 | 114 | 123 | 170 | 31 | 9.37 | 30695 | 31% | 17% | 16% | 9% | 20% | 15% | 18% |
| OAK | KOAK | 151 | 22 | 24 | 41 | 7 | 1.36 | 4417 | 9% | 6% | 6% | 5% | 11% | 7% | 7% |
| ONT | KONT | 73 | 12 | 13 | 20 | 3 | 0.60 | 1994 | 11% | 6% | 6% | 5% | 11% | 5% | 6% |
| ORD | KORD | 2114 | 183 | 198 | 489 | 86 | 18.63 | 86439 | 36% | 20% | 20% | 11% | 24% | 19% | 22% |
| ORF | KORF | 132 | 20 | 21 | 17 | 4 | 0.98 | 3537 | 25% | 21% | 21% | 11% | 24% | 22% | 22% |
| OXR | KOXR | 4 | 1 | 1 | 0 | 0 | 0.01 | 35 | 1% | 4% | 4% | 9% | 11% | 13% | 6% |
| PDX | KPDX | 122 | 14 | 15 | 32 | 5 | 0.98 | 3653 | 12% | 7% | 7% | 5% | 11% | 7% | 7% |

| FAA Code | ICAO Code | Metric Tons | | | | | | | % | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CO | NMHC | VOC | $NO_x$ | $SO_x$ | $PM_{2.5}$ | Fuel | CO | NMHC | VOC | $NO_x$ | $SO_x$ | $PM_{2.5}$ | Fuel |
| PHF | KPHF | 134 | 20 | 21 | 12 | 3 | 0.92 | 2977 | 17% | 32% | 32% | 24% | 42% | 50% | 43% |
| PHL | KPHL | 1251 | 180 | 194 | 230 | 41 | 12.11 | 43716 | 40% | 24% | 23% | 14% | 28% | 22% | 27% |
| PHX | KPHX | 698 | 70 | 75 | 157 | 27 | 5.98 | 24317 | 26% | 13% | 13% | 8% | 18% | 12% | 15% |
| PIH | KPIH | 5 | 1 | 1 | 0 | 0 | 0.02 | 51 | 2% | 6% | 6% | 12% | 15% | 17% | 10% |
| PIT | KPIT | 208 | 34 | 36 | 36 | 7 | 1.63 | 5786 | 19% | 12% | 12% | 7% | 15% | 11% | 12% |
| PSP | KPSP | 24 | 5 | 5 | 4 | 1 | 0.17 | 515 | 7% | 9% | 9% | 6% | 14% | 9% | 9% |
| PVD | KPVD | 55 | 6 | 7 | 13 | 2 | 0.40 | 1573 | 13% | 8% | 8% | 5% | 12% | 7% | 8% |
| PWM | KPWM | 122 | 17 | 18 | 17 | 3 | 0.92 | 3587 | 33% | 32% | 32% | 24% | 41% | 38% | 42% |
| RDU | KRDU | 165 | 27 | 28 | 27 | 5 | 1.16 | 4041 | 16% | 12% | 12% | 6% | 14% | 10% | 10% |
| RIC | KRIC | 162 | 33 | 35 | 20 | 4 | 1.24 | 4015 | 28% | 22% | 22% | 11% | 25% | 20% | 23% |
| RNO | KRNO | 76 | 10 | 10 | 15 | 3 | 0.57 | 2083 | 11% | 10% | 10% | 7% | 15% | 11% | 12% |
| ROA | KROA | 315 | 56 | 59 | 25 | 6 | 2.25 | 6614 | 47% | 57% | 57% | 46% | 64% | 66% | 67% |
| ROC | KROC | 282 | 46 | 48 | 40 | 8 | 2.58 | 9138 | 40% | 38% | 38% | 22% | 41% | 43% | 42% |
| SAN | KSAN | 155 | 16 | 17 | 42 | 7 | 1.42 | 5546 | 16% | 9% | 9% | 6% | 13% | 8% | 9% |
| SAT | KSAT | 100 | 18 | 18 | 18 | 4 | 0.74 | 2358 | 11% | 8% | 8% | 6% | 12% | 7% | 8% |
| SDF | KSDF | 417 | 182 | 198 | 65 | 12 | 5.67 | 11065 | 29% | 21% | 21% | 9% | 20% | 14% | 18% |
| SEA | KSEA | 294 | 23 | 25 | 82 | 14 | 2.73 | 11475 | 21% | 10% | 10% | 6% | 14% | 9% | 11% |
| SFO | KSFO | 436 | 45 | 48 | 126 | 21 | 4.14 | 16969 | 21% | 11% | 11% | 7% | 15% | 10% | 12% |
| SJC | KSJC | 101 | 13 | 13 | 26 | 5 | 0.82 | 3010 | 13% | 7% | 7% | 5% | 11% | 7% | 7% |
| SLC | KSLC | 427 | 48 | 51 | 78 | 15 | 3.45 | 12015 | 21% | 13% | 13% | 9% | 18% | 12% | 14% |
| SMF | KSMF | 123 | 12 | 13 | 28 | 5 | 1.09 | 3992 | 19% | 11% | 11% | 7% | 16% | 12% | 13% |
| SNA | KSNA | 146 | 22 | 22 | 30 | 5 | 1.44 | 4620 | 11% | 11% | 11% | 7% | 15% | 11% | 12% |
| STL | KSTL | 185 | 23 | 25 | 36 | 7 | 1.19 | 5245 | 17% | 9% | 9% | 6% | 13% | 8% | 9% |
| SWF | KSWF | 21 | 5 | 5 | 3 | 1 | 0.19 | 531 | 5% | 8% | 8% | 5% | 13% | 12% | 10% |
| SYR | KSYR | 221 | 31 | 33 | 29 | 6 | 1.80 | 6516 | 36% | 36% | 36% | 22% | 40% | 43% | 41% |
| TOL | KTOL | 376 | 60 | 64 | 61 | 14 | 3.98 | 17311 | 52% | 47% | 47% | 49% | 70% | 66% | 72% |
| TRI | KTRI | 124 | 31 | 31 | 8 | 2 | 0.93 | 2179 | 24% | 43% | 42% | 28% | 47% | 52% | 48% |
| TUS | KTUS | 39 | 5 | 5 | 8 | 2 | 0.19 | 821 | 4% | 5% | 5% | 5% | 11% | 5% | 6% |

| FAA Code | ICAO Code | Metric Tons | | | | | | | % | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CO | NMHC | VOC | $NO_x$ | $SO_x$ | $PM_{2.5}$ | Fuel | CO | NMHC | VOC | $NO_x$ | $SO_x$ | $PM_{2.5}$ | Fuel |
| TYS | KTYS | 123 | 27 | 28 | 10 | 2 | 0.86 | 2190 | 16% | 19% | 19% | 13% | 24% | 18% | 22% |
| VIS | KVIS | 3 | 1 | 1 | 0 | 0 | 0.01 | 20 | 2% | 6% | 6% | 6% | 9% | 17% | 8% |

# Appendix J Comparison of EDMS Aircraft Emissions with Other Sectors in the 2002 NEI -- for NAAs

It is interesting to consider the aircraft LTO emissions during the period June 2005 through May 2006 in the context of other mobile source emission categories in NAAs. Table J.1 through Table J.5 present $NO_x$, $PM_{2.5}$, VOC, CO, and $SO_2$ emissions for 2002 in the 118 NAAs for mobile source categories, including aircraft at the 148 commercial service airports (2002 is the base year for non-aircraft emissions and 2005 is the base year for aircraft emissions).

**Table J.1:** Nonattainment area annual $NO_x$ emission levels for mobile source categories for 2002 [a,b,c,d]. Units are metric tons.

| Source | $NO_x$ |
|---|---|
| Aircraft | 73,152 |
| Recreational Marine Diesel | 13,520 |
| Commercial Marine (C1 & C2) | 398,338 |
| Land-Based Nonroad Diesel | 755,208 |
| Commercial Marine (C3) | 105,414 |
| Small Nonroad SI | 83,735 |
| Recreational Marine SI | 27,661 |
| SI Recreational Vehicles | 2,411 |
| Large Nonroad SI (>25hp) | 168,424 |
| Locomotive | 330,894 |
| Total Off-Highway | 1,958,755 |
| Highway non-diesel | 2,229,330 |
| Highway Diesel | 1,683,882 |
| Total Highway | 3,913,213 |
| Total Mobile Sources | 5,871,967 |

Notes:

[a] This table presents aircraft LTO emission inventories for the 148 commercial service airports in the nonattainment areas.

[b] If an area had more than type of nonattainment area (e.g., $PM_{2.5}$ and CO nonattainment areas), the nonattainment area was selected based on the area with the largest population base.

[c] Except for aircraft, the emission levels for categories are from the inventories developed for the 2008 Final Rule on Emission Standards for New Nonroad Spark-Ignition Engines, Equipment, and Vessels, which is available at http://www.epa.gov/otaq/equip-ld.htm .

[d] 2005 is the base year for aircraft emissions.

**Table J.2:** Nonattainment area annual $PM_{2.5}$ emission levels for mobile source categories for 2002. Units are metric tons.

| Source | $PM_{2.5}$ |
|---|---|
| Aircraft | 1,948 |
| Recreational Marine Diesel | 368 |
| Commercial Marine (C1 & C2) | 14,342 |
| Land-Based Nonroad Diesel | 65,572 |
| Commercial Marine (C3) | 5,475 |
| Small Nonroad SI | 14,304 |
| Recreational Marine SI | 6,488 |
| SI Recreational Vehicles | 2,668 |
| Large Nonroad SI (>25hp) | 833 |
| Locomotive | 8,301 |
| Total Off-Highway | 120,299 |
| Highway non-diesel | 28,504 |
| Highway Diesel | 42,729 |
| Total Highway | 71,233 |
| Total Mobile Sources | 191,532 |

**Table J.3:** Nonattainment area annual VOC emission levels for mobile source categories for 2002. Units are metric tons.

| Source | VOC |
|---|---|
| Aircraft | 33,681 |
| Recreational Marine Diesel | 725 |
| Commercial Marine (C1 & C2) | 10,408 |
| Land-Based Nonroad Diesel | 87,844 |
| Commercial Marine (C3) | 3,356 |
| Small Nonroad SI | 631,277 |
| Recreational Marine SI | 318,161 |
| SI Recreational Vehicles | 103,561 |

| Source | VOC |
|---|---|
| Large Nonroad SI (>25hp) | 42,398 |
| Locomotive | 15,380 |
| Total Off-Highway | 1,246,791 |
| Highway non-diesel | 2,282,459 |
| Highway Diesel | 90,383 |
| Total Highway | 2,372,841 |
| Total Mobile Sources | 3,619,633 |

**Table J.4:** Nonattainment area annual CO emission levels for mobile source categories for 2002. Units are metric tons.

| Source | CO |
|---|---|
| Aircraft | 162,469 |
| Recreational Marine Diesel | 2,496 |
| Commercial Marine (C1 & C2) | 72,673 |
| Land-Based Nonroad Diesel | 387,593 |
| Commercial Marine (C3) | 13,404 |
| Small Nonroad SI | 8,469,535 |
| Recreational Marine SI | 1,000,876 |
| SI Recreational Vehicles | 283,280 |
| Large Nonroad SI (>25hp) | 764,390 |
| Locomotive | 41,848 |
| Total Off-Highway | 11,198,562 |
| Highway non-diesel | 28,119,702 |
| Highway Diesel | 445,335 |
| Total Highway | 28,565,037 |
| Total Mobile Sources | 39,763,600 |

**Table J.5:** Nonattainment area annual $SO_2$ emission levels for mobile source categories for 2002. Units are metric tons.

| Source | $SO_2$ |
|---|---|
| Aircraft | 7,743 |
| Recreational Marine | 1,643 |

| Source | $SO_2$ |
|---|---|
| Diesel | |
| Commercial Marine (C1 & C2) | 51,177 |
| Land-Based Nonroad Diesel | 67,566 |
| Commercial Marine (C3) | 68,042 |
| Small Nonroad SI | 2,260 |
| Recreational Marine SI | 670 |
| SI Recreational Vehicles | 169 |
| Large Nonroad SI (>25hp) | 286 |
| Locomotive | 20,970 |
| Total Off-Highway | 220,525 |
| Highway non-diesel | 70,025 |
| Highway Diesel | 30,979 |
| Total Highway | 101,004 |
| Total Mobile Sources | 321,529 |