United States
Environmental Protection
Agency

Air and Radiation

EPA420-R-99-013
April 1999

Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft

Printed on Recycled Paper

EPA420-R-99-013
April 1999

Final Report

Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft

Engine Programs and Compliance Division
Office of Mobile Sources
U.S. Environmental Protection Agency
Ann Arbor, Michigan 48105

Prepared for EPA by
ICF Consulting Group
EPA Contract No. 68-C-98-170
Work Assignment No. 0-3

ACKNOWLEDGEMENTS

The authors would like to acknowledge the people who have contributed to the development of this report. The report was peer reviewed by Dr. Roger Wayson of the University of Central Florida (Department of Civil and Environmental Engineering), who has expertise in environmental impact and air pollution analyses at airports. Dr. Wayson's comments were incorporated into the report appropriately.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency's (EPA's) Office of Mobile Sources initiated this study in order to assess the existing and potential impact of aircraft emissions on local air quality at ten selected cities. Aircraft emissions and airport related emissions have received considerable attention in recent years, both on national and international agendas.

Recent activities, such as the Clean Airport Summit (held in Denver December 1997), a National Resources Defense Council (NRDC) report, and correspondence from state and local air quality agencies, reflect increased awareness of ground-level aircraft emissions. State and local air quality officials are seeking strategies for cost-effective emissions reductions to comply with National Ambient Air Quality Standards. Perhaps most significant on the national agenda, EPA and Federal Aviation Administration (FAA) have convened a multi-stakeholder process to seek a voluntary agreement on ground-level emissions reductions actions for commercial aircraft and aviation-related emissions.

In order to focus the analysis, EPA made the following decisions regarding the scope of this study:

- Estimate the emissions from commercial jet aircraft only (exclude emissions from on board auxiliary power units)
- Select ten cities with current or potential local air quality problems, as indicated by compliance with the ozone National Ambient Air Quality Standards
- Rely on the methodology presented in EPA *Procedures for Emission Inventory Preparation, Volume 4 : Mobile Sources*, dated 1992
- Seek data sources that are national in scope and readily available
- Use 1990 as a base year, and 2010 as the projection year due to availability of total regional emission data for these years, and the desire to identify potential long-term trends in emissions growth.

In the study, one portion of the airport-related emissions, commercial aircraft, were projected to the year 2010. After an initial draft of the study was prepared, EPA invited comments on the draft report from the multi-stakeholder group. The most significant comments are included in text boxes throughout the report.

The analytical results of the study confirm that commercial aircraft emissions have the potential to significantly contribute to air pollution in the ten study areas. Study results indicate that in 1990, for NOx, the aircraft component of the regional mobile source emissions ranged from 0.6% to 3.6%. In the 2010 projection year for all cities studied, the projected ground-level emissions from commercial aircraft increased in absolute terms. The proportion of total urban emissions attributable to aircraft also increased for all ten cities (range from 1.9% to 10.4% of the regional mobile source NOx emissions); these proportions were calculated using aircraft emissions calculated in this study and total emissions from 1990 and 2010 inventories previously developed by EPA. While there is uncertainty associated with these estimates for the projection year, they generally suggest an increase in ground-level emissions from commercial aircraft as a result of forecast growth in the aviation sector.

Comments received from reviewers of the draft study indicated that uncertainty may exist in the national forecasts of growth in aircraft activity, on future composition of the aircraft fleet, and on the accuracy of a default mixing height. Such uncertainties carry over into projections of future emissions, and resolution of uncertainties may result in higher or lower ground-level emissions estimates from future aircraft. In order to reduce the uncertainty of the results presented, additional areas for investigation would be

- Improvements in activity forecasts to account for supply-side constraints that could dampen growth rates (e.g., infrastructure limitations, funding limitations, limited gate availability, regulatory constraints)

- Improvements in forecasts of national level fleet turnover

- Addition of sensitivity analyses for the above key parameters and others such as mixing height

Thus, this study has achieved its initial goals and creates a basic understanding of ground-level aircraft emissions contribution. It provides an estimation of the contribution of aircraft to air quality emissions in ten urban areas, confirms that investigation of cost-effective control options on aircraft emissions is warranted, and highlights the need for improvements in the quality of national level data as noted by reviewers of the draft study if more certainty is desired. Reliance upon the study’s conclusions should take into account the caveats noted in this report.

1 – INTRODUCTION

Many U.S. cities face significant air quality problems. New National Ambient Air Quality Standards (NAAQS) for ozone (O_3) and particulates (PM) promulgated in 1997 serve to highlight the continuing threat to public health posed by air pollution from human activities. In light of these challenges, air quality officials must evaluate all possible ways to control pollutant emissions. Consequently, all pollutant sources are being evaluated for potential emissions reductions. In this context, commercial jet aircraft are under increasing scrutiny because they are expected to comprise a growing proportion of regional emissions in the coming decades.

The U.S. Environmental Protection Agency (EPA)'s National Trends report of 1997 estimates that aircraft[1] are responsible for about one percent of the total U.S ground-level emissions from mobile sources[2]. Commercial aircraft comprise almost 70 percent of oxides of nitrogen (NOx) emissions from the total aircraft sector (commercial, military, and general aviation). They are one of the fastest growing segments of the transportation sector's regional pollutant contribution. As shown in Figure 1-1, between 1970 and 1995, hydrocarbon (HC) and NOx emissions from aircraft sources have grown 53 percent (EPA, 1997b) despite implementation of HC and NO_x standards for commercial aircraft engines.[3]

The purpose of this study is to investigate the relative importance of aircraft emissions as an emissions source that affects local air quality. In order to provide a specific context for the inquiry, emissions were calculated for a base year, 1990 and a projection year, 2010, for ten selected urban areas. The ten cities were selected based on their preexisting status as locations where air quality problems currently exist or are likely to become more significant. Thus, the study may not provide a comprehensive perspective on emissions and is not necessarily representative of aircraft emissions in all urban areas.

In conducting the analysis, the methodology outlined by EPA's guidance document for preparing emission estimates for mobile sources[4] was applied. In order to provide consistent estimates across the ten cities, nationwide data sources were sought. Available data, particularly on the future composition of the aircraft fleet and on the number of takeoffs and landings in future years, were limited to Federal Aviation Administration (FAA) Aviation Forecasts developed for FAA planning and decision making. These forecasts contain the basic information needed for the 2010 projections. FAA reported that when they have looked back to evaluate previous forecasts, they found that these forecasts were reasonably accurate. However, because they were not developed with the expressed purpose of emissions modeling, some additional information and analysis was needed to better reflect the impacts of changes in fleet composition. Even

---

[1] Including commercial, military and general aviation travel. This report looks at exhaust from main engines only and does not include auxiliary power unit emissions.

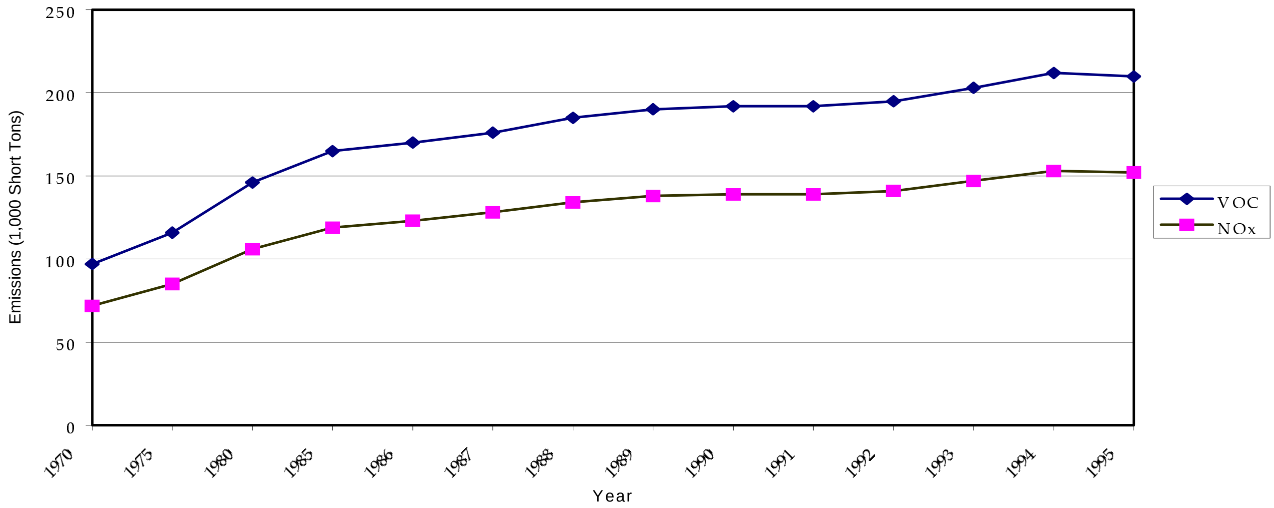
[2] The National Trends report is a nationwide emissions study, but it may not be representative of aviation's contribution in air quality problem areas that have few, if any, rural areas. The contribution varies by area, and in urban areas it is generally more. When aircraft emissions for CO, NOx, and VOC are summed they equal 1.27% and 1.38% as a percent of the total 1990 and 1996 mobile source inventories, respectively.

[3] For commercial aircraft engines greater than 26.7 kilonewtons (6000 lbs) rated output, the HC standard is 19.6 grams/kilonewton beginning in 1984. For NO_x, the standard was ((40+2 rated pressure ratio)g/kN rate output) beginning in 1986 (due to ICAO standards).

[4] *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources*, EPA-450/4-81-026d (Revised), U.S. Environmental Protection Agency, 1992.

though adjustments were made to make the FAA projections more useful, as is described later in the report, some uncertainty remains because the projections did not capture localized complexities such as each airline's decision-making about fleet composition and potential airport or airways capacity constraints (e.g., infrastructure, slot-controlled airports, general conformity). Taken as a whole, the FAA estimates were thought by EPA to be adequate for the purposes of this initial study.

Figure 1-1. U.S. Aircraft Emission Trends, 1970 - 1995.



EPA’s interest is not only the absolute emissions totals, but also in the relative proportion of regional inventories generated by commercial jet aircraft. Thus, in the final section of this report, the proportion of the total urban inventories attributable to aircraft are calculated.

Background – United States

In addition to EPA, many other groups have recently voiced their concern over aircraft emissions. In *Flying Off Course*, the Natural Resources Defense Council (NRDC) highlighted ground-level emissions from aircraft as one of the four most important environmental issues connected to airports.[5] The authors assert that there is an inadequate regulatory framework for addressing this issue, and point out that the projected increases in air travel in the coming decades will only exacerbate the problem. The results of the NRDC study were one of several key presentations at the October, 1997 Clean Airport Summit, co-sponsored in part by EPA, the U.S. Department of Energy’s Clean Cities Program, and several other public and private organizations.

The California Environmental Protection Agency (Cal/EPA), STAPPA/ALAPCO[6] and NESCAUM[7] recently sent letters to the United States Department of Transportation (USDOT) arguing for greater efforts on the part of FAA and EPA to require the aircraft industry to reduce emissions in a manner consistent with other regulated sources under the Clean Air Act (CAA)

---

[5] The other significant environmental issues were noise and land use, water pollution, and climate change/energy efficiency.

[6] State and Territorial Air Pollution Program/Association of Local Air Pollution Control Officials

[7] Northeast States for Coordinated Air Use Management.

(Kenny, 1998; Becker, Kodjak, 1998). More specifically, through its stationary source provisions found primarily in Title V, the CAA requires that new stationary and industrial sources install state-of-the-art technology and that existing sources retrofit their operations with reasonable and cost effective controls. For mobile sources, EPA continues to require new regulations for automobiles, even though these sources have reduced their emissions on a per vehicle basis by 98 percent over the past 25 years. In what is perhaps a more reasonable comparison to commercial aviation, locomotive emissions, which are unregulated until 2000 will be required to achieve a 66 percent reduction in NOx emissions beginning in 2005. The letters point out the importance of supporting not only the International Civil Aviation Organization's (ICAO) latest 16 percent reduction in new aircraft engine NO_x certification standards (see next section), but also advocate other aircraft emissions control programs.

Since the preparation of the draft study, EPA and FAA have convened a multi-stakeholder process to reach a voluntary agreement on measures to reduce the ground-level emissions from commercial aircraft and other aviation related sources. Participants in this process represent industry, airports, states, environmental groups and other stakeholders. As one of their initial tasks, participants reviewed a draft of this report. Considerable concern was voiced over the appropriateness of the methodology for reaching conclusions on the relative importance of aircraft emissions to urban area-wide emissions. Indeed, this study has prompted the multi-stakeholder group to work with EPA and FAA to pursue additional data and identify research needs for improving such an assessment including, in particular, data required to quantify future emissions growth with more certainty.

Background – International Perspective

Aircraft emissions are an issue of global concern.[8] In addition to the national level developments described above, ICAO has been evaluating current and projected pollutant contributions of aircraft and airport operations. In 1994, the Emissions at and around Airports Subgroup (EASG) of ICAO undertook a series of studies to develop future scenarios for seven representative airports around the world. The primary focus of the analysis was the assessment of emissions levels in the immediate vicinity of the airport facility. The results indicate that while overall emissions from these facilities will remain the same or decrease due to anticipated pollution controls on ground-support and service vehicles, aircraft-induced NO_x pollution will, depending on the specific scenario, increase by a factor of two to three between 1992 and 2015 (ICAO, 1994). While the EASG conclusions are an important addition to the study of air quality effects around airports resulting from aircraft operations, they do not address the contribution of aircraft emissions to regional air quality problems.

In a more recent study the Forecasting and Economic Analysis Subgroup (FESG) of ICAO's Committee on Aviation Environmental Protection (CAEP) developed long-term (to 2050), worldwide aircraft emissions scenarios based upon work previously conducted by National Aeronautics and Space Administration (NASA).[9] The NASA results indicate an 11 percent reduction in hydrocarbon emissions from scheduled air traffic (which is primarily commercial jet

---

[8] In both national and international assessments of aircraft technology options, safety concerns are a primary evaluation criterion, and any technology alternatives for emission reductions are screened for potential safety concerns prior to implementation recommendations.

[9] The NASA work relied on aviation traffic and activity forecasts made by Boeing for other purposes. See ICAO, 1998a, page 19.

aircraft) between 1992 and 2015. However, CO emissions show a 226 percent increase and NO_x a 190 percent increase over the same period. The estimated increase in NO_x is limited by the assumption that 70 percent of fuel consumption occurs in engines with NO_x certification standards between 20 and 40 percent below the current international standard (ICAO, 1998a). The new international NOx standard to be implemented beginning in 2004 is about 16 percent below the current standard, and thus, at this point it appears that the NASA study may underestimate future global NOx emissions. It is important to note, however, that the FESG effort was based upon international forecasts which included regions of the world that are growing two to three times as fast as the U.S.

The Committee on Aviation Environmental Protection CAEP/2 NOx certification standard represents a technology limit that is demonstrably achievable today. Regarding the next NOx standard agreed to at CAEP/4 in April 1998, the Forecasting and Economic Analysis Support Group (FESG) of the Committee on Aviation Environmental Protection (CAEP) concludes in its Working Paper 4 (WP/4) that the proposed increase in NOx stringency for new engines would have modest impacts on overall aircraft emissions. The CAEP/4 report should be referred to for a discussion of the stringency proposal (ICAO, 1998c). In fact, the majority of modern engine types in production and entering service are known to be compliant with the proposed CAEP/4 NOx standard. Some other engines currently in service can be brought to similar performance standards through modest-cost modifications. The FESG concludes, the benefits of the proposal in terms of reducing the global emissions burden will be marginal. The proposed standard merely insures that future engines will not have NOx emissions that are higher than present technology allows (ICAO, 1998b).

Public Health and Aircraft Emissions

As noted above, the new, more stringent NAAQS for ozone and PM highlight the need for state and local air quality officials to consider new ways to reduce regional emissions and achieve the health-based national air quality standards. In particular, they have significant concerns regarding the effect of NO_x on local and regional environments. Tropospheric NO_x has multiple environmental quality impacts including not only contributing to ground-level O_3 and PM, but also air toxic concentrations, excess nitrogen loads to sensitive water bodies, and acidification of sensitive ecosystems (EPA, 1997a).

Ultimately, EPA's principal concern in evaluating and controlling emissions is the preservation of human health and, secondarily, the protection of public welfare (including protection against damage to crops, vegetation, animals, and buildings). In this regard, some general observations about the entire category of mobile sources can be made. Mobile sources emit VOC and NO_x (O_3 precursors), PM (both PM_{10} and $PM_{2.5}$), SO_2 and CO. Other air pollutant species include polycyclic aromatic hydrocarbons (PAHs) found in the particulate emissions and certain volatile organic compounds (VOCs). The health effects of these pollutants are summarized in Table 1.1[10]; Table 1.2 summarizes the major environmental effects of the same pollutants. As with the health effects, these environmental effects will vary considerably with the amount of pollutant

---

[10] This information was compiled from official US EPA sources and is only an overview. More complete information is available in the appropriate Criteria Documents. See website www.epa.gov/ncea.

and the duration of its exposure to the environment. Appendix A provides a more detailed summary of the health effects of emissions from air pollution.

Table 1.1. Representative health effects of air pollutants.

Pollutant	***Representative Health Effects***
Ozone	Lung function impairment, effects on exercise performance, increased airway responsiveness, increased susceptibility to respiratory infection, increased hospital admissions and emergency room visits, and pulmonary inflammation, lung structure damage.
Carbon Monoxide	Cardiovascular effects, especially in those persons with heart conditions (e.g., decreased time to onset of exercise-induced angina).
Nitrogen Oxides	Lung irritation and lower resistance to respiratory infections
Particulate Matter	Premature mortality, aggravation of respiratory and cardiovascular disease, changes in lung function and increased respiratory symptoms, changes to lung tissues and structure, and altered respiratory defense mechanisms.
Volatile Organic Compounds	Eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment.

Table 1.2. Representative environmental effects of air pollutants.

Pollutant	***Representative Environmental Effects***
Ozone	Crop damage, damage to trees and decreased resistance to disease for both crops and other plants.
Carbon Monoxide	Similar health effects on animals as on humans.
Nitrogen Oxides	Acid rain, visibility degradation, particle formation, contribution towards ozone formation.
Particulate Matter	Visibility degradation and monument and building soiling, safety effects for aircraft from reduced visibility.
Volatile Organic Compounds	Contribution towards ozone formation, odors and some direct effect on buildings and plants.

Report Organization

The remainder of this report is organized as follows:

- Section 2 presents the methodology used to calculate commercial jet aircraft emissions for the selected cities;
- Section 3 presents the analysis results for the 1990 base year and 2010 future year;
- Section 4 discusses the implications for attainment of the NAAQS based upon the analysis results, and presents trends in air travel and aircraft emissions in the coming decades;
- Section 5 presents the conclusions of the initial study;
- Appendix A contains information regarding the health effects of aircraft emissions;

- Appendix B presents the methodology used to calculate aircraft emissions;
- Appendix C contains maps of the Ozone Nonattainment Areas selected for this study;
- Appendix D presents the airport activity projections;
- Appendix E contains time-in-mode data and assumptions;
- Appendix F contains the aircraft/engine emission factor database used for this study;
- Appendix G presents facility-specific and regional aircraft emissions summaries; and
- Appendix H summarizes selected EPA regional emission estimates for 1990 and 2010 for the ten cities.

2 – ESTIMATING COMMERCIAL JET AIRCRAFT EMISSIONS

This analysis estimates ground level emissions from aircraft; thus, the landing and takeoff cycle (LTO) defines the aircraft activity of interest. LTO emissions are all of these emissions which occur within the mixing layer, as discussed below. Emissions during flight at cruising altitude are not within the scope of this study. An LTO cycle begins as the aircraft descends from cruising altitude and approaches and lands at the airport. The second step in the landing portion of the cycle is taxi to the gate and subsequent idle. The next three steps are the three operating modes in the takeoff portion of the cycle: taxi-out/idle, takeoff, and climbout. These five LTO cycle operating modes are defined by the existence of standard power settings for a given aircraft, so the modes represent an appropriate basis for estimating emissions.

The five major air pollutant species which comprise the most significant emissions from commercial jet aircraft are volatile organic compounds (VOCs), carbon monoxide (CO), oxides of nitrogen (NOx), particulates (PM), and sulfur dioxide (SO_2). VOCs and CO emission rates are highest when engines are operating at low power, such as when idling or taxiing. Conversely, NOx emissions rise with increasing power level and combustion temperature. Accordingly, the highest NOx emissions occur during takeoff and climbout.

PM emissions result from the incomplete combustion of fuel. High power operation, such as takeoff and climbout, produce the highest PM emission rates due to the high fuel consumption under those conditions. PM emission test data for aircraft engines are sparse, and engine-specific PM emission factors are available for only a few engine models.

SO_2 emissions are created when sulfur in the fuel combines with oxygen during the combustion process. Fuels with higher sulfur contents will produce higher amounts of SO_2 than low-sulfur fuels.[11] It is generally assumed that during combustion, all sulfur in the fuel reacts to form SO_2 or sulfates.[12]

Methodology for Commercial Jet Aircraft Emissions Estimation

The EPA's basic methodology for calculating aircraft emissions at any given airport in any given year can be summarized in six steps:

1) Determine airport activity in terms of the number of landing and takeoffs (LTOs).
2) Determine the mixing height to be used to define an LTO cycle.
3) Define the fleet make-up at the airport.
4) Estimate time-in-mode (TIM).
5) Select emission factors.
6) Calculate emissions based on the airport activity, TIM, and aircraft emission factors.

---

[11] The sulfur content in commercial jet fuel is limited to 0.3 weight (wt) %; however, most in-use fuel has a sulfur content significantly less than this limit. The 1996 average sulfur concentration of U.S. commercial jet fuels found in-use was reported in the NIPER survey at 0.062wt % (Dickson and Sturm, 1997).

[12] In addition to SO2, a small amount of SO3 forms during combustion.

Steps five and six are repeated for each type of aircraft using a given airport. For the projection year in this study, 2010, the final step is to adjust the emission to account for fleet turnover during the 1990 to 2010 period.

Appendix B contains a detailed discussion of each analysis step, consistent with EPA's *Procedures for Emissions Inventory Preparation, Volume IV: Mobile Sources* (EPA, 1992). The remainder of this section describes the approaches and data sources used in each of the above steps to analyze commercial jet aircraft emissions in each of ten selected U.S. cities.

Selection of Metropolitan Areas

In order to illustrate the contribution of commercial jet aircraft to pollutant emissions levels, ten cities were selected for evaluation. Nine of these metropolitan areas are currently not in attainment of NAAQS for ozone; the tenth city has attained the ozone standard and is considered an ozone "maintenance" area. Areas were chosen based upon the severity of air quality problem, size and number of regional airports, and data availability. In selecting areas, the severity of the air quality problem was evaluated primarily based on ozone attainment status. With the promulgation of more restrictive NAAQS for ozone, states will need to examine new sources for ozone reduction. NO_X, a pollutant of concern from aircraft emissions, is an ozone precursor. Another criterion, geographic location, was used to select an area from each major region of the U.S. Table 2-1 presents the ten areas and their EPA-determined attainment status for ozone.

Table 2-1. Regions chosen for evaluation.

Nonattainment Area	***Designation***[13]	***Population (000's)***[14]
Atlanta	Serious	2,654
Boston-Lawrence-Worcester	Serious	5,506
Charlotte-Gastonia	Attainment (at risk)	687
Chicago-Gary-Lake County	Severe-17	7,886
Houston-Galveston-Brazoria	Severe-17	3,731
New York-New Jersey-Long Island	Severe-17	17,651
Philadelphia	Serious	6,010
Phoenix	Serious	2,092
Los Angeles Air Basin	Extreme	13,000
Washington, D.C.	Serious	3,921

Appendix C contains maps of the nine areas designated as nonattainment.

---

[13] See www.epa.gov/oar/oaqps/greenbk/define.html#Designations for the existing ozone nonattainment area designation definitions.

[14] Populations are from EPA web site as of July 3, 1998. www.epa.gov/oar/oaqps/greeenbk/ontc.html. For Charlotte-Gastonia, the final portion of the address is omtc.html. The populations in Table 2-1 are for the entire metropolitan area and do not reflect the much smaller populations living near airports.

As can be seen, the majority of the selected areas are designated as Serious nonattainment or worse for ozone. Phoenix and Charlotte were also included due to predicted regional growth over the next 20 years and because of their high-traffic airports. Phoenix was recently re-designated as a serious ozone nonattainment area, and Charlotte faces potential re-designation as nonattainment under the new NAAQS for ozone.[15]

Nineteen airport facilities with significant commercial jet aircraft activity were identified within the nonattainment (or potential nonattainment) boundaries of the selected areas. Table 2-2 lists each facility and its corresponding FAA code, as well as its rank nationally in terms of passenger enplanements.

Each area and airport facility has unique attributes that determine the magnitude of aircraft emissions. The following presents the analysis assumptions used to estimate jet aircraft emissions contribution to regional emissions for each of the above regions of interest.

Airport Activity

As noted above, the rate at which an engine emits a particular pollutant is directly related to its activity. Both the frequency and mode of operation are important components of this activity.[16] For the purpose of emissions estimation, commercial aircraft activity is measured in LTO cycles. For the Los Angeles region, a detailed summary of 1990 airport activity is available in the technical support document for the California Federal Implementation Plan (FIP) (EPA, 1994). For other regions, the analysis relied upon the EPA-recommended source for activity data on commercial aircraft, *Airport Activity Statistics of Certificated Route Air Carriers*, which is published annually by the FAA and provides departures by air carrier for each airport (USDOT, 1990a). The report covers all air carriers that are required to file certain information with the DOT. These air carriers are those with at least one aircraft that has more than 60 passenger seats or a maximum cargo capacity above 18,000 pounds. All such US air carriers that meet the criteria and that use an airport in a given year are included in this report. Because each LTO cycle includes one departure and one landing, the number of departures in the DOT data were assumed to equal the number of LTO cycles.

The following aircraft are not included in the FAA statistics: aircraft owned and operated by foreign air carriers; aircraft owned by U.S. air carriers that perform commuter and on-demand operations,[17]; general aviation aircraft; and military aircraft. Of these activities, the most frequent are those of non-U.S. carriers, so they were accounted for in the analysis. Non-U.S. carriers are required to report to DOT all non-stop route segments when at least one point is in a U.S. State or territory, and DOT compiles monthly summaries of this information in its T100 database

---

[15] EPA will designate areas as nonattainment for new NAAQS of ozone by the year 2000. Areas have up to ten years after the date of designation to attain the revised standards. For areas not meeting the existing ozone NAAQS, the existing NAAQS remains in effect until EPA determines that an area has air quality meeting the existing standards.

[16] For an individual aircraft, the key factors are frequency (i.e., number of takeoffs and landings), mode of operations (i.e., time in mode), and number of engines. For an individual engine a complex matrix of interrelated factors influences emissions. These include bypass ratios, combustor technology, pressure ratios, combustor temperature, thrust, and engine design.

[17] By definition, aircraft in this category do not have more than 60 passenger seats or a maximum cargo capacity above 18,000 pounds.

(USDOT, 1990b). For all selected areas except Los Angeles, 1990 foreign carrier activity was extracted from this database. For the Los Angeles air basin, the aircraft activity used in the California FIP included both U.S. and foreign carriers (EPA, 1994). No readily available data source was identified for air carriers whose fleets are comprised solely of smaller aircraft or for general aviation aircraft because such activity was beyond the scope of this study.

Table 2-2. Airport facilities of interest by region

Nonattainment Area	*Airport Name*	*FAA Code*	*Rank*[18]
Atlanta	Hartsfield	ATL	2
Boston-Lawrence-Worcester**	Logan	BOS	16
Charlotte	Douglas*	CLT	20
Chicago-Gary-Lake County	Midway*	MDW	39
	O'Hare Intl.*	ORD	1
Houston-Galveston-Brazoria**	George Bush Intl.	IAH	17
	Hobby	HOU	41
Los Angeles Air Basin**	Burbank	BUR	60
	John Wayne	SNA	42
	Long Beach	LGB	156
	Los Angeles Intl.	LAX	3
	Ontario	ONT	51
New York-New Jersey-Long Island**	Kennedy	JFK	8
	La Guardia	LGA	21
	Newark	EWR	12
Philadelphia	Philadelphia Intl.	PHL	24
Phoenix	Sky Harbor Intl.*	PHX	10
Washington, D.C.**	Dulles	IAD	31
	Washington National	DCA	26

* Indicates military aircraft are present at airport.

** Military operates aircraft at separate military bases in nonattainment area.

Note: Military air activity at above airports are probably small Air National Guard units, except at Sky Harbor International, which contains an Air Force base.

---

[18] Rank order by total enplaned passengers for 1996 (USDOT, 1996).

Future Aircraft Activity Projections

For the years 1990 through 1996, total actual commercial aircraft operations for each airport were used to calculate an annual activity growth rate[19]. For years 1997 through 2010, forecast operations by facility were obtained from *FAA Aviation Forecasts, 1997-2008* and *FAA Aviation Forecasts, 1999-2010*[20]. Facility-specific operations forecasts were used to calculate 1997 through 2010 annual growth rates, which were then used to estimate total LTOs for each year. Prior to applying the fleet turnover assumptions (described below), all airlines and aircraft types at a particular facility were assumed to experience the same rate of growth. The assumption was required because only facility-level growth projections were readily available. It is appropriate because the growth is distributed across the same range of aircraft sizes as currently in service at a facility. Table 2-3 summarizes the estimated growth in LTOs from 1990 to 2010 for each airport of interest and Figure 2-1 presents the data graphically. Appendix D provides more detailed tabular and graphical summaries of assumed yearly LTO growth for each facility. For the 19 airports listed, growth averaged 31 percent for the 20 years from 1990 to 2010. This corresponds to an annual growth rate of approximately 1.4 percent.

As can be seen, there is wide variation in the expected activity change both regionally and for each facility. While some airports are predicted to have minimal growth, others such as Charlotte's Douglas, Washington's Dulles, and Houston's Intercontinental airports are predicted to have significant air traffic increases over 1990 activity levels. This can be expected to cause an associated increase in the pollutant emissions attributable to commercial aircraft in these regions.

✈ *Stakeholder Comments – Growth Projections*

Extensive comments were received from stakeholders on the appropriateness of using the FAA Aviation Forecast as a surrogate indicator for projecting the number of future year takeoffs and landings. In particular, industry members of the stakeholder group indicated that the forecast likely does not account for limitations on growth due to

(1) regulatory constraints such as general conformity, federal and state land use limitations, and supply-side constraints;
(2) physical constraints on capacity such as gate and runway availability; and
(3) funding/cost constraints for airport capacity enhancements.

These reviewers stated that if accounted for, the growth rate at the airports included in this study could be lower. Other reviewers, such as state regulators, noted that advances in air traffic control could result in higher numbers of takeoffs and landings, thus, increasing the growth rate at airports. There is not an existing national data source that accounts for the factors identified. Moreover, each of these factors will be airport-specific.

---

[19] At the time of this analysis, airport operations totals for 1997 were not yet available from FAA.

[20] These reports, prepared by FAA's Statistics and Forecasts Branch, are used in that agency's planning and decision-making processes. The 1997-2008 report can be downloaded from the Internet at the following address: http://api.hq.faa.gov/apo_pubs.htm.

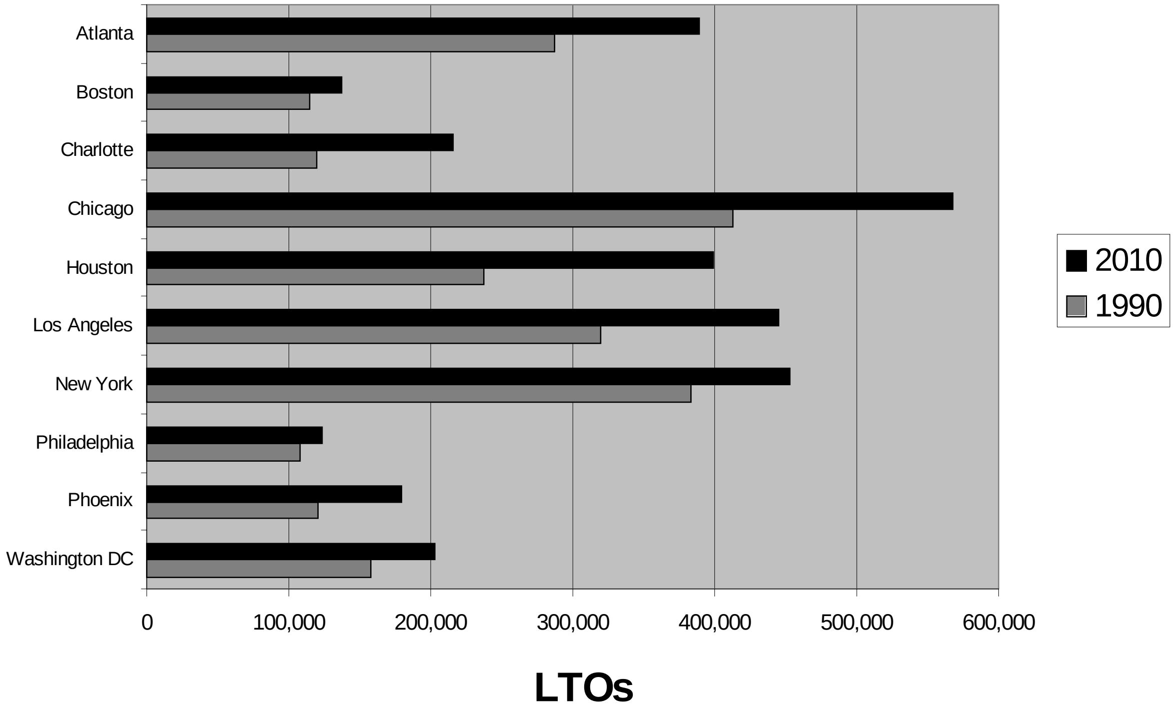
Table 2-3. Estimated commercial jet aircraft activity growth, 1990 – 2010.

Airport	*FAA Code*	*1990 LTOs*	*2010 LTOs*	*Growth for 20-year period*
Hartsfield	ATL	287,080	388,728	35.4%
Logan	BOS	114,282	137,137	20.0%
Douglas	CLT	119,990	215,726	79.8%
Midway	MDW	65,135	66,510	2.1%
O'Hare International	ORD	347,653	500,767	44.0%
George Bush Intercontinental	IAH	181,214	337,080	86.0%
Hobby	HOU	55,770	61,621	10.5%
Burbank	BUR	26,129	30,607	17.1%
John Wayne	SNA	28,291	33,043	16.8%
Long Beach	LGB	12,984	14,790	13.9%
Los Angeles International	LAX	212,041	312,976	47.6%
Ontario	ONT	40,323	53,445	32.5%
Kennedy	JFK	94,382	111,360	18.0%
La Guardia	LGA	154,700	158,209	2.5%
Newark	EWR	134,124	183,381	36.7%
Philadelphia International	PHL	107,646	123,177	14.4%
Sky Harbor International	PHX	121,024	179,265	48.1%
Dulles	IAD	60,787	105,888	73.9%
Washington National[21]	DCA	96,931	97,268	0.3%

---

[21] This facility has been recently renamed to Ronald Reagan Washington National Airport.

Figure 2-1. 1990 and 2010 LTOs



Time-in-Mode (TIM) Estimation

An LTO cycle is broken down into five specific components:

1) Approach – measured from moment aircraft enters the pollutant "mixing zone" to when it lands;

2) Taxi/Idle-in – time spent after landing until aircraft is parked at the gate and engines turned off;

3) Taxi/Idle-out – period from engine startup to takeoff;

4) Takeoff – characterized primarily by full-throttle operation that lasts until the aircraft reaches 500 to 1,000 feet (152 to 305 meters)

5) Climbout – period following takeoff that concludes when aircraft passes out of mixing zone.

As stated in EPA's *Volume IV* guidance for mobile source emission estimation, engines operate at a fairly standard power setting during each mode, so emissions are calculated by using emission factors specific to those settings.[22] The emission factors provided in EPA's *Volume IV* guidance use engine- and operating mode-specific fuel flow rates (pounds of fuel per minute), so an emission factor for the time spent in each mode for each aircraft category must be determined in order to calculate emissions. Appendix B contains the emissions calculation methodology.

Taxi/idle time depends on airport-specific operational procedures. Taxi-in and taxi-out queue statistics for each airport were provided by the FAA's Office of Aviation Policy Plans, Planning Analysis Division (USDOT, 1997) and included seasonal estimates for selected airlines. Because not all airlines at each facility were represented in the data, facility-average taxi-in and taxi-out values were calculated. Seasonal average taxi-in/taxi-out times by airline were calculated, then weighted using actual LTO numbers. The resulting taxi-in and taxi-out values were then summed and used as the average idle time for that facility. Appendix E contains the detailed taxi-in/taxi-out data provided by FAA, the facility-level time-in-mode values assumed for this study.

The takeoff mode is fairly standard and does not vary much from place to place or among aircraft categories. The default takeoff time for commercial aircraft of 0.7 minutes provided in the EPA guidance was used for our calculations. A four minute default approach time, also in the EPA guidance, was used for this study (EPA, 1992). In other studies, when accounting for reverse thrust, adjustments have been made to the time in mode assumptions (e.g., lengthening the default take off time-in-mode) that directly impact the emissions estimates. No such adjustment was made in this study.

The assumed time spent in approach and climbout modes is directly related to the height of the "mixing zone." The mixing zone is the layer of the earth's atmosphere where chemical reactions of pollutants can ultimately affect ground level pollutant concentrations. The height of the mixing zone for a given location typically varies significantly by season and time of day; the higher the assumed mixing height, the greater the total emissions from an LTO. Although EPA and CARB guidance (EPA, 1992; CARB, 1994) indicate that a default mixing height of 3,000 feet is

✈ Stakeholder Comments – Mixing Heights

Many comments were received from stakeholders on the selection of mixing heights. Commenters representing state air quality agencies indicated that because their major air quality concern was ozone events in the summer, use of a summer afternoon mixing height would be appropriate. Under stagnant conditions, emissions from the morning stay aloft during the day, and become a part of the afternoon mixing zone as the zone rises during the day. In addition, summertime mixing heights are higher than wintertime mixing heights and ozone formation is confined to the summer months in most areas of the country. State air quality commenters indicated that summertime, afternoon mixing zones range from 3,600 to 7,200 feet in the ten cities studied, and thus they believe a default value of 3,000 feet underestimates aircraft emissions contributions during the summer ozone season. Commenters from industry disputed these assumptions and pointed out that mixing heights present at the time emissions occur would more accurately represent the quantity of ozone precursors present during the formation of ozone (i.e., the presence of a higher mixing height during the ozone exceedance does not warrant the use of that mixing height, because the pollutants accumulate throughout the day). Therefore, industry commenters recommend using a flight operations weighted average of mixing heights throughout the day.

---

[22] *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources*, EPA-450/4-81-026d (Revised), U.S. Environmental Protection Agency, 1992.

acceptable for preparing aircraft emissions inventories, for many areas of the U.S. the mean mixing zone is significantly lower. Generally, in the summer season the mixing zone is higher for a given time of day than in winter. The 3,000-foot default mixing height is assumed to approximate summertime conditions. Accordingly, in this analysis emissions were calculated for specific airports using both the 3,000 foot default and the mean annual mixing height (CARB, 1994). Table 2-4 summarizes the latter (rounded to nearest 50 feet/meters) for each area selected for this study.

Table 2-4. Annual mean mixing heights for selected regions.

Region	***Mean Annual Mixing Height (Feet)***	***Mean Annual Mixing Height (Meters)***
Atlanta	1,300	400
Boston	2,100	650
Charlotte	1,300	400
Chicago	1,650	500
Houston	2,000	600
Los Angeles	1,650	500
New York	2,600	800
Philadelphia	2,300	700
Phoenix	1,000	300
Washington, D.C.	2,000	600

The procedures used to adjust EPA's default climbout and approach times using alternative mixing heights are included in Appendix B.

Fleet Characterization

In order to assign appropriate emission rates to aircraft activity, the fleet mix must be defined for each category of aircraft in use at a given airport. For commercial, subsonic jet aircraft (defined as those used for scheduled service transporting passengers and/or freight), the source of fleet mix data recommended in the EPA guidance is *Airport Activity Statistics of Certified Route Air Carriers*, which is published annually by FAA. As noted above, these data do not include activity information for non-U.S. airlines. For foreign airlines, the T100 segment data were used to develop the 1990 base fleet for these carriers.

✈ Stakeholder Comments – Fleet Turnover

Comments were received from stakeholders on the appropriateness of the selected fleet turnover methodology. The basic adjustment used for fleet turnover does not account for many variables. A more specific determination of fleet composition in future years could be made by compiling information from each airline. In general, a specific airport can perform this level of data collection and analysis (to the extent that it is not confidential), however, as a nationwide exercise, it would be quite extensive. It is not intuitively clear whether a more accurate adjustment for fleet turnover would lead to an increase or decrease in the projection year emissions estimates. The airlines believe, however, that revised estimates of fleet composition would yield lower emissions forecasts. Using the average emission factor for 20 year-old engines to represent the entire new portion of the 2010 fleet is problematic. Due to emission standards, airlines assert that aircraft coming into the fleet will be significantly cleaner than those already in service in 1990.

Neither of these databases contained detailed information regarding the future composition of the commercial jet aircraft fleet. Consequently, fleet turnover between 1990 and 2010 was addressed by the following steps:

1. Using FAA's *Aviation Forecasts*, identify the aircraft types in the 1990 inventory that will not be in service in 2010.[23]
2. For each airport facility, subtract the activity for the "removed" aircraft types. This activity will be assigned to an "average future" aircraft.
3. For the remaining aircraft types at the facility, calculate total emissions and LTOs.
4. Using the emissions and activity numbers from Step 3, calculate an average future emission rate by dividing total emissions by total activity (for the remaining aircraft only). This emission rate represents an "average future" aircraft for the facility.
5. Multiply the average emission rate calculated in Step 4 by the LTOs from the "removed" aircraft in Step 2 to get total emissions from the "average future" aircraft.
6. Sum emissions and activity from actual and "average future" aircraft to get 2010 totals.

This basic adjustment retired all of the oldest aircraft in the 1990 fleet and replaced them with the newest portion of the 1990 fleet. In all likelihood, fewer aircraft will be retired between 1990 and 2010, and some of those retired will be replaced with aircraft that are cleaner than the "unretired" portion of the 1990 fleet.

Emission Factor Selection

The emissions characteristics of aircraft vary by number and type of engine used. The primary source for the VOC, NOx, and CO emission factors used in this analysis is FAA's Engine Emission Factor Database (FAEED) (USDOT, 1995**)**. [24] This database lists each aircraft body type, the type of engines used, and the operating mode-specific pollutant emission rates for those engines. Aircraft with the same body type can have different engine models. In these cases, the FAEED lists all known engine types used for that model and the estimated proportion of the fleet using that engine. These percentages are used to create one weighted-average emission rate for each pollutant and operating mode for that aircraft type.

The activity for some of the selected airport facilities contained data for some aircraft types not included in the FAEED. In the majority of cases, these models were variations of aircraft that were included in FAEED. Most of these "missing" models and their corresponding engine types were extracted from the California Air Resources Board (CARB) report, *Air Pollution Mitigation Measures for Airports and Associated Activities* (CARB, 1994). This document also provided supplemental information regarding appropriate aircraft/engine assumptions and equivalents[25].

---

[23] These were all Stage II aircraft that are phased out by 1999, and are referred to as "removed" aircraft in subsequent steps.

[24] The initial analysis for this report was completed in the fall of 1997. The most recent version of the FAEED available at the time was used, supplemented by the ICAO database. A preliminary comparison of the 1998 FAEED, available at the time this report was finalized, indicates that few significant updates have been made.

[25] An example is the DC-9-80, the assumed equivalent of the MD-80, which is not included in FAEED.

In cases where neither data source provided information for a specific aircraft type, the activity was assigned to its nearest equivalent. Appendix F contains a summary of these assumptions and the final table of aircraft/engine types used for this analysis.

The data sources discussed above provided VOC, NOx, and CO emission factors. Modal SO_2 emission rates for civil aircraft engines were obtained from *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources.*[26] As noted previously, aircraft also produce particulate emissions, primarily $PM_{2.5}$. Because of extremely limited engine- and mode-specific PM rates, however, these emissions were not calculated in this analysis.

Section 3 presents the emissions calculated for the 19 airport facilities in the 10 areas of interest.

---

[26] The FAEED SO_2 emission factors were not used since the data appeared to be several orders of magnitude lower than the EPA values based on fuel sulfur content. For VOC, NOx, and CO, the FAEED emission factors were compared to the values given in the EPA guidance and found to agree.

3 – AIRCRAFT EMISSIONS ANALYSIS RESULTS

This section presents the results of the commercial jet aircraft emissions analysis described in Section 2.0 and Appendix B. Tables 3-1 summarizes 1990 and 2010 VOC, NOx, CO, and SO_2 emissions for the ten selected areas using the 3,000-foot default mixing height. Figure 3-1 presents this information graphically for NOx. Table 3-2 provides similar information for 1990 and 2010 emissions estimates based on area-average mixing height assumptions. All emissions estimates in this section are provided in short tons per year.[27] Appendix G presents facility-specific and regional emissions totals in both short and metric tons per year.[28]

It is clear from comparing Tables 3-1 and 3-2 that mixing height has a significant impact on emissions estimates, most notably NOx, which decreases overall by 29 percent when using the area-specific rather than default mixing heights. SO_2 totals decrease 23 percent, VOCs by 3 percent, and CO emissions decrease 4 percent when the non-default mixing heights are applied. The annual mean mixing heights used in this analysis represent only one general step towards a more-detailed, area-specific inventory. Additional improvement could be made by using seasonal- and time of-day-specific mixing height assumptions, available from EPA or other regional meteorological databases. This more rigorous approach would likely result in increases in estimated emissions for some areas, and decreases in others. Even using the default mixing height, the estimated tons of pollutants per LTO cycle varies widely among regions. This can be attributed primarily to differences in the aircraft fleet serving each airport facility, and variations in the time-in-mode assumed. This again underscores the need to focus on airport-specific parameters to project future emissions totals if more certainty is desired.

Regardless of the mixing heights used, the expected growth in activity in each area corresponds to increases in aircraft emissions that are often quite substantial (> 50 percent) over the period 1990 to 2010. Overall, VOC emissions in the ten areas increase by more than 7600 tons (6900 metric tons or 65 percent); NOx increases by more than 21,500 tons (19,500 metric tons or 73 percent); and SO_2 increase by more than 580 tons (530 metric tons or 43 percent).

---

[27] A short ton is 2000 pounds.

[28] We have provided the emissions estimates in different units because U.S. inventories are generally compiled in short tons while the international community tends to use metric tons.

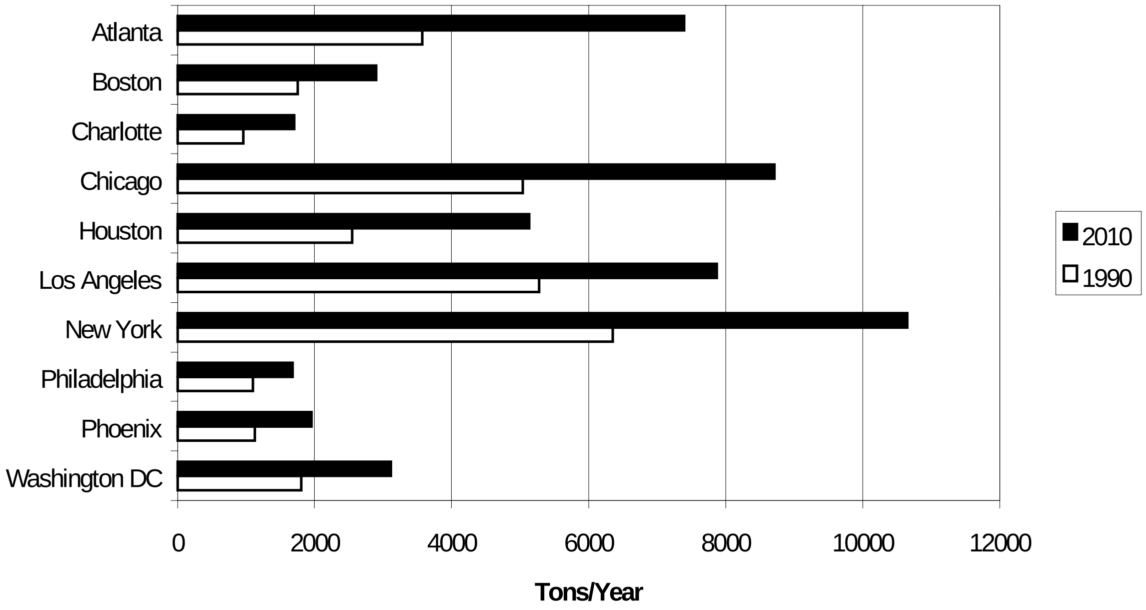
Table 3-1. 1990 and 2010 commercial jet aircraft emissions (short tons/year) default (3,000 ft.) mixing height.

Region	***Year***	***LTOs***	***VOC***	***NOx***	***SO2***	***CO***
Atlanta	1990	287,080	1,555.13	3,570.26	165.78	4,136.43
	2010	388,728	3,180.47	7,397.42	262.18	6,858.94
Boston	1990	114,282	894.28	1,752.92	77.07	2,295.22
	2010	137,137	1,461.75	2,897.56	104.64	3,417.41
Charlotte	1990	119,990	748.56	956.74	52.01	1,385.67
	2010	215,726	2,123.93	1,702.28	83.83	2,907.53
Chicago	1990	412,788	1,653.23	5,036.72	235.20	5,583.73
	2010	567,277	2,232.64	8,710.79	329.01	7,756.83
Houston	1990	236,993	669.68	2,552.27	122.83	2,484.80
	2010	398,701	1,007.71	5,129.52	207.91	3,940.03
Los Angeles	1990	306,784	2,099.38	5,274.95	216.57	6,125.31
	2010	444,860	3,088.35	7,871.08	296.89	8,828.05
New York	1990	383,206	3,050.22	6,351.61	291.41	8,816.72
	2010	452,950	4,872.19	10,650.50	394.01	12,935.80
Philadelphia	1990	107,646	354.67	1,098.41	53.11	1,127.38
	2010	123,177	439.86	1,678.46	64.66	1,293.80
Phoenix	1990	121,024	226.14	1,130.01	53.71	1,014.73
	2010	179,265	305.27	1,954.14	81.24	1,667.14
Washington, D.C.	1990	162,245	516.57	1,807.56	85.39	1,798.72
	2010	203,156	712.30	3,113.36	117.18	2,467.23

Table 3-2. 1990 and 2010 commercial jet aircraft emissions (short tons/year) annual average mixing height (see Table 2-4).

Region	***Year***	***LTOs***	***VOC***	***NOx***	***SO2***	***CO***
Atlanta	1990	287,080	1,468.13	2,058.41	111.16	3,791.43
	2010	388,728	3,026.52	4,189.04	171.53	6,318.79
Boston	1990	114,282	875.81	1,359.73	63.91	2,216.65
	2010	137,137	1,436.86	2,234.13	86.12	3,318.84
Charlotte	1990	119,990	720.88	549.60	34.41	1,273.40
	2010	215,726	2,070.46	962.20	55.16	2,715.44
Chicago	1990	412,788	1,580.10	3,337.09	173.31	5,249.79
	2010	567,277	2,149.64	5,710.94	239.60	7,386.88
Houston	1990	236,993	640.80	1,910.23	97.93	2,358.99
	2010	398,701	962.71	3,819.72	164.68	3,771.70
Los Angeles	1990	306,784	2,037.87	3,476.72	158.51	5,852.28
	2010	444,860	3,003.86	5,159.73	216.24	8,450.37
New York	1990	383,206	3,025.30	5,728.50	270.40	8,712.39
	2010	452,950	4,838.54	9,573.78	364.35	12,808.10
Philadelphia	1990	107,646	345.33	904.55	45.58	1,085.66
	2010	123,177	430.34	1,375.21	55.14	1,254.54
Phoenix	1990	121,024	208.35	555.32	31.12	914.35
	2010	179,265	289.28	944.02	46.22	1,533.12
Washington, D.C.	1990	162,245	497.34	1,355.32	68.53	1,713.17
	2010	203,156	691.86	2,317.00	93.30	2,377.53

Figure 3-1. 1990 and 2010 Commercial Jet Aircraft NOx Emissions



Inventory Limitations and Caveats

Emissions inventories are, by nature, an approximation of actual pollutant quantities. The appropriateness of the methodology, the technical judgements, and associated assumptions used to create these estimates will affect the accuracy of estimates calculated for a given pollutant species. For future year inventories, the robustness of forecast methodology has a significant influence on the associated certainty of the emissions estimates. Although the quantification of ranges of error relative to the assumptions used to produce the inventory estimate was beyond the scope of this report; this section provides a qualitative discussion.

The commercial jet aircraft emissions estimates contained in this report were prepared using the EPA-approved methodology for preparing inventories of this type. Further, the FAEED database of emission factors (USDOT, 1995) was updated to include some additional aircraft types for which there were activity data[29]. While this approach produced relatively robust inventories for each of the ten areas, room remains for additional refinements, particularly in the 2010 estimates.

Future Year Fleet Composition. As noted in Section 2, some of the newer aircraft in today's commercial fleet were not explicitly included in the analysis, because these aircraft types were not in service in 1990. However, the projections prepared for 2010 do include a simplified set of assumptions regarding fleet turnover and aircraft replacement that implicitly account for the retirement of older aircraft and the introduction of newer aircraft engines available as of 1990 (see Section 2). In the stakeholder comment box on this issue, the complexity of the fleet turnover issue is detailed. A more robust future year inventory would incorporate a more detailed understanding of the future year fleet. This could produce different ground-level emissions forecasts for 2010, as discussed in the stakeholder box on fleet turnover.

Greater implementation of clean engine technology (i.e., fuel efficient/low NOx) is another area that could change the future-year emissions estimated for this study. On the other hand, most existing aircraft that remain in the 2010 projection already comply with the most recent ICAO standards. Further, there has been little market indication that cleaner engines will be pursued in future purchase decisions. Addressing the future fleet composition as described above would be one step towards an improved representation of the emissions benefits of newer aircraft complying with present ICAO NOx certification standards. Engines that significantly reduce NOx below the current and future standard already exist, and wider use of these engines or the implementation of larger compliance margins on other engines could result in greater aircraft emissions reductions.

Future Year Aircraft Activity. FAA future year forecasts of operations by facility were used to project aircraft activity. These forecasts were only available at the facility level, not for individual aircraft types. Consequently, for a given airport, the same change in activity between 1990 and 2010 was assumed for all aircraft types. This does not account for any shifts in activity between aircraft types that may occur (e.g., an airline might increase its number of shuttle flights

---

[29] FAEED emission rates were supplemented by the ICAO engine emission factor database (ICAO, 1995). These emission rates were used for all areas. Note that for Los Angeles, only activity data was extracted from the California FIP (EPA, 1994); emission rates and growth projections were from consistent sources for all airport facilities (see Section 2).

to a nearby city while keeping the same level of activity for longer flights using larger aircraft). Additionally, as detailed in the stakeholder comment box, the FAA forecasts do not incorporate the effects of regulatory constraints, physical capacity constraints, or funding constraints for airport capacity enhancements. However, FAA reported that when they have looked back to evaluate previous forecasts, they found that these forecasts were reasonably accurate.

In addition, the 2010 activity forecast was not adjusted to account for the introduction of communication, navigation, surveillance/ air traffic management (CNS/ATM), which if implemented could allow more flights without additional infrastructure.

Operational Practices that Affect Emissions. Existing aircraft operational practices that affect emissions were not considered when preparing the emissions estimates for the ten cities of interest. Operational practices such as single-engine taxi, reduced reverse thrust, and de-rated takeoffs that may reduce emissions were not included because these practices are not uniform across all facilities or even within the same airport. Determining the precise application of these measures and their impact on emissions was beyond the scope of this project. Instead, this study relied on standard power operations assumptions in EPA's Volume IV guidance.

CNS/ATM potential improvements to operations, which for example, could reduce the amount of taxi time, were also not considered. Further study could refine the emissions estimates presented above to account for these operational differences.

Other Issues. Seasonal and time-of-day variations were not considered in this study. LTO rates and aircraft time-in-mode often vary over the course of a day and throughout the year. For example, in peak traffic hours the amount of time in the "taxi/idle-out" mode can increase due to congestion. Variations in the mixing height also affect the time-in-mode for approach and climbout. Seasonal inventories reflecting activity and mixing height variability are thus likely to differ in the pounds per LTO cycle and total emissions estimates as compared to annual average emissions inventories for the same facility. Other operational differences, such as the use of auxiliary power units or longer time-in-mode due to weather conditions or air traffic control holds, were also not addressed.

Sensitivity Tests. Because no sensitivity tests were conducted on the assumptions supporting the emissions estimates, confidence intervals have not been established for these estimates. Although sensitivity analyses to determine the effects of key assumptions were beyond the scope of this initial study, they would be an appropriate area for further investigation given their importance in assessing the effect of those assumptions, particularly as they relate to projections of future emissions activity. For example, the sensitivity of the emission estimates to assumed growth rates for different aircraft types at a given airport would likely prove to be a valuable exercise. The comments from stakeholders, included in boxes throughout Section 2, indicate additional areas for further study and clarification.

4 – AIRCRAFT EMISSIONS CONTRIBUTION

While emissions from most transportation sources such as NOx from automobiles are predicted to stabilize and, in many cases, decrease from 1990 through 2010, ground-level emissions from commercial jet aircraft are expected to continue rising. In nonattainment areas with large airport facilities, commercial aircraft emissions represent a growing percentage of regional area source inventories as other area sources decrease due to implemented controls. Emissions for a given source category are the product of activity (e.g., vehicle miles traveled, LTO cycles) and technology based emissions factors. For many source categories (e.g., automobiles) lower total emissions are achieved in 2010 by the use of cleaner technology, even though activity levels increase.

Two national inventories provide county-level emissions estimates by source category: the *Regional Interim Emission Inventories* (EPA, 1993a/b) for 1990 and the *Regulatory Impact Analysis of the Proposed Ozone National Ambient Air Quality Standard* (EPA, 1996a) for 2010. Using the aircraft emissions estimates presented for the default mixing height in Section 3.0 (Table 3-1)[30], the percent contribution of aircraft to total nonroad[31] mobile, total mobile, and total emissions inventories can be calculated. Table 4-1[32] summarizes the estimated commercial aircraft portion of total regional inventories for the ten selected study areas in 1990 and 2010. Tables 4-2 and 4-3 show the commercial aircraft portions of regional mobile source (the sum of onroad and nonroad) and nonroad mobile source emissions, respectively. Figure 4-1 graphs the data from Table 4-2. Appendix H presents excerpts from the regional inventories used to calculate the percentages.

In each of the ten cities, commercial jet aircraft are a larger percentage of the inventory in 2010 than in 1990. In areas such as Charlotte, which has few large utilities or other industrial sources, aircraft are predicted to comprise over 7.5 percent of the total regional NOx in 2010. Even regions such as Los Angeles and New York, where aircraft are less than 5 percent of the total 1990 mobile source emissions, the percent contribution of aircraft to regional NOx more than doubles by 2010. The percent contributions of aircraft to the total regional inventory were calculated based on the default mixing height. However, as detailed in the stakeholder comment box on mixing heights, the selection of an appropriate mixing height for estimation of ozone production is a complex decision.

Overall, as the growth in air travel pushes up aircraft emissions totals, existing regulatory programs such as new heavy-duty truck engine, nonroad diesel engine, locomotive, and passenger vehicle standards will diminish the relative contribution of other mobile sources to

---

[30] The commercial jet aircraft emissions calculated for this study were used in place of the non-military, non-air taxi emissions contained in the national inventories. The subtracted aircraft emissions (ASC Code 2275020000) probably include some turboprop planes, but this is likely to be a very small percentage of the total emissions.

[31] Nonroad emissions include all mobile sources that are not on-road vehicles, such as construction equipment, locomotives, marine watercraft, etc.

[32] As noted, Tables 4-1 through 4-3 represent percent contributions based on the default mixing height of 3000 feet. Since the annual average mixing heights are lower for each of the ten areas, using the default mixing height may result in a higher estimate of the percent contribution than would be obtained using the annual average mixing height.

regional emissions inventories. The following examples indicate the types of regulatory programs in process:

- For heavy-duty diesel trucks, new NOx emission standards that represent a 50 percent reduction from the earlier standards were promulgated in 1997 for implementation beginning in 2004 (Federal Register Volume 62, page 54694, October 21, 1997).

- Two-thirds more stringent standards starting in 1999 for nonroad diesel equipment were promulgated in 1998 (Federal Register Volume 63, page 56968, October 23, 1998).

- Passenger vehicles in the new National Low Emission Vehicle Program will be 70 percent cleaner than today's models beginning in 1999 (Federal Register Volume 62, page 31192, June 6, 1997). Currently, the state of California has even more stringent emission requirements for motor vehicles. Another set of national level passenger vehicle standards for the 2004 timeframe is also under consideration (Tier 2 standards per section 202(i) of the Clean Air Act).

- A two-thirds reduction in NOx emissions from locomotives is expected from the first locomotive engine standards promulgated in a rulemaking completed in 1998 (Federal Register Volume 63, page 18978, April 16, 1998).

The new NAAQS for ozone and PM present even greater challenges to existing and potential nonattainment areas. As more CAA-mandated controls reach full implementation, air quality planners will need to look at all emissions sources for additional reductions. In most regions, overall mobile source emissions are projected to decrease significantly; however, emissions from aircraft do not follow this trend. While noise regulations and more fuel-efficient engines will reduce aircraft hydrocarbon emission rates, controlling NOx emissions is a much greater challenge.

Table 4-1. Aircraft component of total regional emissions, 1990 and 2010.

Region	***Year***	***VOC***	***NOx***	***SO2***
Atlanta	1990	0.7%	2.1%	0.1%
	2010	2.5%	8.1%	1.9%
Boston	1990	0.2%	0.6%	< 0.1%
	2010	0.7%	2.3%	0.7%
Charlotte	1990	1.2%	2.3%	0.1%
	2010	5.1%	7.6%	0.6%
Chicago	1990	0.3%	1.1%	0.1%
	2010	0.7%	3.4%	0.1%
Houston	1990	0.1%	0.5%	0.1%
	2010	0.3%	1.9%	0.1%
Los Angeles	1990	0.3%	0.9%	0.4%
	2010	0.9%	2.4%	0.6%
New York	1990	0.3%	0.9%	0.1%
	2010	1.7%	3.3%	0.4%
Philadelphia	1990	0.1%	0.4%	< 0.1%
	2010	0.2%	1.8%	0.1%
Phoenix	1990	0.2%	0.9%	0.7%
	2010	0.4%	1.8%	0.9%
Washington, DC	1990	0.3%	0.9%	< 0.1%
	2010	0.8%	3.7%	0.4%

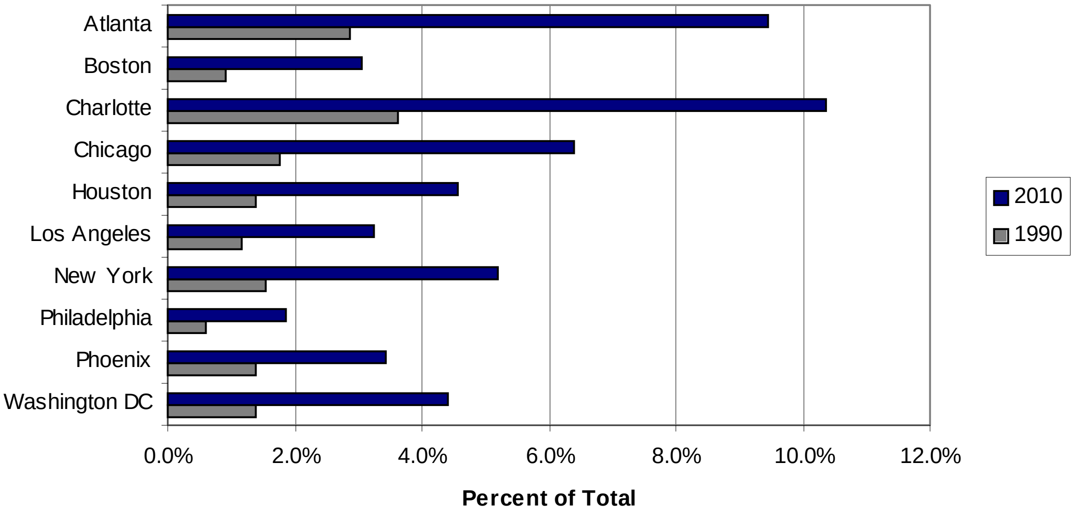
Table 4-2. Aircraft component of regional
mobile source emissions, 1990 and 2010.

Region	***Year***	***VOC***	***NOx***	***SO2***
Atlanta	1990	1.3%	2.9%	2.2%
	2010	6.2%	9.5%	4.1%
Boston	1990	0.5%	0.9%	0.6%
	2010	2.3%	3.1%	1.2%
Charlotte	1990	2.8%	3.6%	3.4%
	2010	14.9%	10.4%	6.8%
Chicago	1990	0.7%	1.8%	1.6%
	2010	2.8%	6.4%	2.9%
Houston	1990	0.4%	1.4%	0.5%
	2010	1.4%	4.6%	0.8%
Los Angeles	1990	0.6%	1.2%	0.5%
	2010	3.0%	3.2%	0.8%
New York	1990	0.8%	1.5%	0.8%
	2010	3.8%	5.2%	1.3%
Philadelphia	1990	0.2%	0.6%	0.4%
	2010	0.7%	1.9%	0.7%
Phoenix	1990	0.3%	1.4%	1.2%
	2010	0.8%	3.4%	1.9%
Washington, DC	1990	0.4%	1.4%	0.9%
	2010	1.6%	4.4%	1.6%

Table 4-3. Aircraft component of regional nonroad mobile source emissions, 1990 and 2010.

Region	***Year***	***VOC***	***NOx***	***SO2***
Atlanta	1990	6.5%	11.3%	20.1%
	2010	14.4%	28.5%	31.5%
Boston	1990	2.0%	4.2%	6.4%
	2010	4.2%	11.0%	9.8%
Charlotte	1990	11.8%	13.6%	37.8%
	2010	31.4%	28.3%	53.7%
Chicago	1990	2.1%	4.3%	7.9%
	2010	6.2%	16.7%	12.7%
Houston	1990	1.4%	3.4%	0.7%
	2010	2.5%	9.0%	1.1%
Los Angeles	1990	4.2%	3.7%	1.3%
	2010	5.6%	6.9%	1.7%
New York	1990	3.7%	6.5%	1.9%
	2010	7.8%	16.7%	2.7%
Philadelphia	1990	0.8%	2.4%	2.2%
	2010	1.3%	5.7%	2.9%
Phoenix	1990	1.1%	3.7%	7.2%
	2010	1.5%	8.0%	10.6%
Washington, DC	1990	1.9%	5.1%	3.9%
	2010	3.3%	13.7%	6.2%

Figure 4-1. 1990 and 2010 Aircraft Component of Regional Mobile Source NOx Emissions



5 – CONCLUSIONS

This study has achieved its goals and creates a basic understanding of aircraft emissions contribution. As detailed in Section 3, in 1990 commercial jet aircraft emitted a significant amount of pollutants into the air around the ten urban areas studied. The 2010 regional emissions inventory, which relies on forecasts developed for other purposes, projects growth in both absolute aircraft emissions and in the percent of the inventory attributable to aircraft.

State and local air quality officials must develop plans to bring their jurisdictions into compliance with new NAAQS. Section 233 of the Clean Air Act mandates that aircraft engine emissions standards are to be set only on a national level. Due to the need for a national policy, EPA and FAA have convened a multi-stakeholder group (including representatives from industry, state and local air quality agencies, airports and environmental groups) to seek a voluntary agreement on ground-level emissions reductions actions for commercial aircraft and aviation-related emissions.

Overall, this report provides an estimation of the contribution of aircraft to air quality emissions in ten urban areas, confirms that investigation of cost-effective control options on ground-level aircraft emissions is warranted, and highlights the need for improvements in the quality of national level data as noted by reviewers of the draft study if more certainty is desired.

REFERENCES

Becker, Kodjak, 1998. Letter from S. William Becker, STAPPA/ALAPCO and Drew Kodjak, NESCUAM to Rodney Slater, Secretary, U.S. Department of Transportation. 10 March 1998.

CARB, 1994. *Air Pollution Mitigation Measures for Airports and Associated Activities – Final Report*. Prepared for the California Air Resources Board by Energy and Environmental Analysis, Inc., Arlington Virginia, and K.T. Analytics, Inc., Frederick, Maryland. May, 1994. PB94-207610.

Dickson, C.L. and Sturm, G.P., "Aviation Turbine Fuels, 1996," NIPER-199 PPS, BDM Petroleum Technologies, Bartlesville, OK, April 1997.

EPA, 1997a. *Nitrogen Oxides: Impacts on Public Health and the Environment*. U.S. Environmental Protection Agency, Washington, D.C. August, 1997.

EPA, 1997b. *National Air Pollutant Emission Trends, 1990 - 1996.* U.S. Environmental Protection Agency, Washington, D.C. December, 1997. EPA-454/R-97-011.

EPA, 1996a. *Regulatory Impact Analysis for Proposed Ozone National Ambient Air Quality Standard*. Prepared by Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards. Research Triangle Park, N.C. December 1996. Additional related information can be found in the EPA publication *2010 Clean Air Act Amendment Baseline Emissions Projections for the Integrated Ozone, Particulate Matter, and Regional Haze Cost Analysis.* July 18, 1997.

EPA, 1996b. *Ozone Air Quality Criteria Document*. U.S. Environmental Protection Agency, Washington, D.C. June, 1996.

EPA, 1994. *Technical Support Document, Civil and Military Aviation, California FIP NPRM*. Prepared for the U.S. Environmental Protection Agency by Energy and Environmental Analysis, Inc. March 24, 1994.

EPA, 1993a. *Regional Interim Emission Inventories (1987 – 1991), Volume I: Development Methodologies*. U.S. Environmental Protection Agency, Washington, D.C. May, 1993. EPA-454/R-93-021a.

EPA, 1993b. *Regional Interim Emission Inventories (1987 – 1991), Volume II: Emissions Summaries*. U.S. Environmental Protection Agency, Washington, D.C. May, 1993. EPA-454/R-93-021a.

EPA, 1992. *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources*. U.S. Environmental Protection Agency, Washington, D.C. 1992. EPA-450/4-81-026d (Revised).

EPA, 1985. *Compilation of Air Pollutant Emission Factors, Volume 2: Mobile Sources (4 th Edition)*. U.S. Environmental Protection Agency, Ann Arbor, Michigan. September, 1985. PB87-205266.

ICAO, 1998a. "Report of the Forecasting and Economic Analysis Sub-Group (FESG) - CAEP Steering Group Meeting, Canberra, Australia," Tables 5.3, 5.5, and 5.7, January, 1998

ICAO, 1998b. "FESG Report on EPG NOx Stringency Proposal," Prepared by the Forecasting and Economic Analysis Sub-Group for the Committee on Aviation Environmental Protection - Fourth Meeting, 12 March 1998.

ICAO, 1998c. "Committee on Aviation Environmental Protection – Fourth Meeting - Report," Doc 9720, CAEP/4, Montreal, 6-8 April 1998.

ICAO, 1995. “Aircraft Engine Exhaust Emissions Databank – Addendum.” Committee on Aviation and Environmental Protection, ICAO. December, 1995.

ICAO, 1994. “Report to Working Group 2 from the Emissions at and around Airports Subgroup.” Prepared by the Emissions at and around Airports Subgroup for the Committee on Aviation and Environmental Protection. 18 July 1994.

Kenny, 1998. Letter from Michael P. Kenny, Executive Officer, Cal/EPA to Rodney E. Slater, Secretary, U.S. Department of Transportation. 13 March 1998.

NRDC, 1996. *Flying Off Course: Environmental Impacts of America’s Airports*. Natural Resources Defense Council. October, 1996.

USDOT. *FAA Aviation Forecasts*, electronically obtained from USDOT via World Wide Web.

USDOT, 1997. Information from FAA’s Office of Aviation Policy, Plans, and Analysis. September, 1997.

USDOT, 1996. *Statistical Handbook of Aviation, 1996.* U.S. Department of Transportation, Federal Aviation Administration. Washington, D.C. 1996.

USDOT, 1995. *FAA Aircraft Engine Emissions Database*. U.S. Department of Transportation, Federal Aviation Administration. Washington, D.C. 1995.

USDOT, 1990a. *Airport Activity Statistics of Certificated Route Air Carriers*. U.S. Department of Transportation, Washington, D.C. 1990.

USDOT, 1990b. “T-100 & T-100(f) International Segment Data.” U.S. Department of Transportation, Office of Airline Statistics. December, 1990.

APPENDIX A
HEALTH EFFECTS OF AIR POLLUTION

APPENDIX A
HEALTH AND ENVIRONMENTAL EFFECTS FROM AIR POLLUTION

Health effects due to pollutants may be divided into two major classes: those due to acute exposures and those due to chronic exposure. Acute health effects are experienced immediately or within a few hours of the exposure. Health effects due to chronic exposure may only become apparent after an extended period of time, typically months or years. Cancer is an example of a health effect generally resulting from chronic exposure. Some pollutants can cause both acute and chronic health effects. For a given air pollutant, the chances of an person experiencing a health effect generally increase as the exposure concentration and duration increase. The exposure component of the health effects is discussed below. Determining the source of a pollutant involved in an exposure can be complicated, given the multiplicity of emission sources in most urban areas. Furthermore, the varying individual sensitivity to specific pollutants make the health effects of any individual pollutant exposure difficult to quantify, although for many pollutants the risk to the general population can be characterized. Epidemiological studies and clinical studies to estimate health effects have been performed for a number of pollutants, many of which are associated with aircraft and airport operations.

Environmental effects can also be divided into three broad categories: ecological effects (effects on plants and animals other than humans), damage to materials (soiling, etc.) and visibility (effects on transmission of light through the atmosphere).

A brief highlight of the health effects of chemicals associated with airports follows. A summary of some of the environmental effects for each identified chemical follow each health effects discussion.

SPECIFIC AIR POLLUTANTS ASSOCIATED WITH AIRPORTS

A number of air pollutants are associated with emissions from airports. These include the major criteria pollutants that one would expect from any combustion source: ozone or O_3 (not directly emitted, but formed from other precursor compounds that are emitted), carbon monoxide (CO), nitrogen oxides (NO_X), volatile organic compounds (VOCs), and particulate matter (both PM_{10} and $PM_{2.5}$). Other pollutants include polycyclic aromatic hydrocarbons (PAHs) found in the particulate emissions and certain VOCs. The health and other environmental effects of these chemicals are briefly outlined below. This information was compiled from official US EPA sources and is only an overview. More complete information is available in the appropriate Criteria Documents (e.g., EPA, 1996b).

Ozone (O_3)

Ozone health effects are induced by short-term (1 to 2 hours) exposures to O_3[1], generally while individuals are engaged in moderate or heavy exertion, and by prolonged exposures

---

[1] Observed at concentrations as low as 0.12 ppm.

(6 to 8 hours) to O_3[2], typically while individuals are engaged in moderate exertion. Individuals experience moderate exertion levels more frequently than heavy exertion levels.

Acute health effects of O_3 are defined as those effects induced by short-term and prolonged exposures to O_3. Examples of these effects are functional, symptomatic, biochemical, and physiologic changes. The acute health effects include transient pulmonary function responses, transient respiratory symptoms, effects on exercise performance, increased airway responsiveness, increased susceptibility to respiratory infection, increased hospital admissions and emergency room visits, and transient pulmonary inflammation.

Acute health effects have been observed following prolonged exposures during moderate exertion at concentrations of O_3 as low as 0.08 ppm. Groups at increased risk of experiencing such effects include active children and outdoor workers who regularly engage in outdoor activities and individuals with preexisting respiratory disease (e.g., asthma or chronic obstructive lung disease). Furthermore, it is recognized that some individuals are unusually responsive to O_3 and may experience much greater functional and symptomatic effects from exposure to O_3 than the average individual.

Chronic health effects of O_3 are defined as those effects induced by repeated, long-term exposures to O_3. Examples of these effects are chronic inflammation and structural damage to lung tissue and accelerated decline in baseline lung function. With regard to chronic health effects, the collective data from studies of laboratory animals and human populations have many ambiguities and provide only suggestive evidence of such effects in humans. It is clear from toxicological data that O_3-induced lung injury is roughly similar across species (including monkeys, rats, and mice) with responses that are concentration dependent. Currently available information provides, at a minimum, a biologically plausible basis for the possibility that the repeated lung inflammation associated with O_3 exposure may, over a lifetime, result in sufficient damage to respiratory tissue to result in a reduced quality of life, although such relationships remain uncertain.

Ground-level ozone interferes with the ability of plants to produce and store food so that growth, reproduction and overall plant health are compromised. By weakening trees and other plants, ozone can make plants more susceptible to disease, insect attacks, and harsh weather. Agricultural yields for many economically important crops (e.g., soybean, kidney bean, wheat, cotton) may be reduced, and the quality of some crops may be damaged, thereby reducing their market value. Ground-level ozone can also kill or damage leaves so that they fall off the plants too soon or become spotted or brown. These effects can significantly decrease the natural beauty of an area, such as in national parks and recreation areas.

---

[2] Observed at concentrations as low as 0.08 ppm.

Carbon Monoxide (CO)

Carbon monoxide (CO) is an odorless, colorless gas that is a by-product of the incomplete burning of fuels. CO reduces oxygen carrying capacity of blood and weakens the contractions of the heart, thus reducing the amount of blood pumped to various parts of the body and, therefore, the oxygen available to the muscles and various organs. In a healthy person, this effect can significantly reduce the ability to perform physical exercises. In persons with chronic heart disease, these effects can threaten the overall quality of life, since their systems are unable to compensate for the decrease in oxygen. CO pollution is also likely to cause such individuals to experience angina during exercise. Adverse effects have also been observed in individuals with heart conditions who are exposed to CO pollution in heavy freeway traffic for 1 to 2 hours or more.

Nitrogen Dioxide (NO_2)

Healthy individuals experience respiratory problems when exposed to high levels of NO_2 for short duration (less than three hours). Asthmatics are especially sensitive and changes in airway responsiveness have been observed in some studies of exercising asthmatics exposed to relatively low levels of NO_2. Studies also indicate a relationship between indoor NO_2 exposures and increased respiratory illness rates in young children, but definitive results are still lacking. Many animal studies suggest that NO_2 impairs respiratory defense mechanisms and increases susceptibility to infection.

Several studies also show that chronic exposure to relatively low NO_2 pollution levels may cause structural changes in the lungs of animals. These studies suggest that chronic exposure to NO_2 could lead to adverse health effects in humans, but specific levels and the exposure duration likely to cause such effects have not yet been determined.

NO_2 is an important precursor to both ozone and acidic precipitation, which harms both terrestrial and aquatic ecosystems. Emitted from hydrocarbon combustion at high temperatures, NO and NO_2 (collectively called NO_x) react with gaseous hydrocarbons to form ozone. The mixture of NO_X and ozone in urban air is commonly called “smog”.

NO_x also plays a role in the formation of acid rain. Acid rain causes surface water acidification and damages trees at high elevations (for example, red spruce trees over 2,000 feet in elevation). In addition, acid rain accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our nation's cultural heritage.

NO_x contributes to the formation of particles in the atmosphere, with the resulting health and visibility effects discussed in the “PM” section, below. Nationally, about 5 percent of NO_x is transformed into particle nitrate in the atmosphere. Even when it does not form particles, NO_x itself is a brown gas that largely contributes to the visible smog effect evident in the major metropolitan areas of the U.S.

Particulate Matter (PM)

PM is the generic term for a broad class of chemically and physically diverse substances that exist as discrete particles (either liquid droplets or solids) over a wide range of sizes. PM originates from a variety of anthropogenic stationary and mobile sources as well as from natural sources. PM may either be emitted directly or formed in the atmosphere by the transformations of gaseous emissions of compounds including NO_x, VOCs, and sulfur oxides (SO_x). The chemical and physical properties of PM vary greatly with time, region, meteorology, and source category, thus complicating the assessment of health and welfare effects.

PM_{10} refers to particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers. Technical details further specifying the measurement of PM_{10} are contained in 40 CFR part 50, Appendices J and M. PM_{10} is a measure of both fine particles (less than 2.5 microns (µm)) and the coarse particle fraction (particles between 2.5 and 10 µm)[3]. In addition to the evidence found for health effects associated with fine particles, research indicates that exposure to coarse fraction particles is associated with aggravation of asthma and increased respiratory illness, and that there may be chronic health effects associated with long-term exposure to high concentrations of coarse particles (FR, July 18, 1997). A more complete history of the PM NAAQS is presented in section II.B of the OAQPS staff paper, “Review of National Ambient Air Quality Standards for Particulate Matter: Assessment of Scientific and Technical Information.”

$PM_{2.5}$ is comprised of particulate matter with a diameter less than or equal to 2.5 µm. The new $PM_{2.5}$ NAAQS were promulgated in July, 1997 and new monitoring requirements for $PM_{2.5}$ are included in Appendix L of 40 CFR Part 50. A discussion of $PM_{2.5}$ health effects is presented in *the Criteria Document for Particulate Matter*, which describes:

- the nature of the effects that have been reported to be associated with ambient PM, including premature mortality, aggravation of respiratory and cardiovascular disease (as indicated by increased hospital admissions and emergency room visits, school absences, work loss days, and restricted activity days), changes in lung function and increased respiratory symptoms, changes to lung tissues and structure, and altered respiratory defense mechanisms; and

- sensitive sub-populations that appear to be at greater risk to such effects, specifically individuals with respiratory disease and cardiovascular disease and the elderly (premature mortality and hospitalization), children (increased respiratory symptoms and decreased lung function), and asthmatic children and adults (aggravation of symptoms).

The environmental effects of particles center principally on two areas: visibility and soiling. The visibility impacts are immediately apparent to anyone who has seen a major

---

[3] Coarse particles are larger than 2.5 micrometers, and the PM10 standard does not apply to coarse particles above 10 micrometers.

metropolitan area on a hazy day. Visibility impairment can result from either the direct emission of particles or the formation of particles from the nitrogen oxides and VOCs. The soiling effect of particles is observable on both buildings and vehicles. The soiling can also contribute to the degradation of monuments and artwork. In addition to the "quality of life" effects of visibility reduction there is an additional safety problem for aircraft operating in areas of reduced visibility, in the terms of landing and avoidance of other aircraft.

Volatile Organic Compounds (VOCs)

Organic chemicals emitted into the atmosphere are typically described as VOCs (or "hydrocarbons")[4]. They can arise from evaporation or incomplete fuel combustion. As a class, VOCs react with NO_X in the atmosphere to form ozone, but individual VOCs may have additional health effects. Some VOCs have little or no known direct health effect, while other VOCs, such as benzene, are carcinogens. As with other pollutants, the extent and nature of the health effect will depend on many factors, including level of exposure and length of time exposed. Eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment are among the immediate symptoms that some people have experienced soon after exposure to some organics.

VOCs can cause a variety of environmental effects depending on their chemical nature and the quantity present. At high levels, VOCs can have a damaging effect on plants, crops, buildings and materials. Of course, the principal environmental effect of VOCs is their contribution to the formation of ozone with its concomitant environmental effects. Likewise VOCs can contribute to the formation of particles (either directly through cooling down of hot engine exhaust or indirectly through chemical conversion and condensation) which have the environmental effects listed above. VOCs that contain chlorine can also contribute to stratospheric ozone depletion.

---

[4] See Code of Federal Regulations, Title 40 part 5/Section 100 for complete definition.

APPENDIX B
EMISSIONS CALCULATION METHODOLOGY

APPENDIX B
EMISSIONS CALCULATION METHODOLOGY

EPA's recommended emissions calculation methodology for a given airport in any given year[1]can be summarized in six steps:

1) Determine the mixing height to be used to define a landing and takeoff (LTO) cycle.
2) Determine airport activity in terms of the number of LTOs.
3) Define the fleet make-up at the airport.
4) Select emission factors.
5) Estimate time-in-mode (TIM).
6) Calculate emissions based on the airport activity, TIM, and aircraft emission factors.

Steps two through five are repeated for each type of aircraft using a given airport. This methodology is essentially the same as that used in the FAA *Aircraft Engine Emissions Database* (FAEED) model (USDOT, 1995).

Section 2 contains a detailed discussion of the activity and fleet information used for this analysis.

Time in Mode Calculations

The duration of the approach and climbout modes depends largely on the mixing height selected. EPA guidance provides approach and climbout times for a default mixing height of 3000 feet, and a procedure for adjusting these times for different mixing heights. The adjustments are calculated using the following equations:

Climbout:

$$TIM_{adj} = TIM_{dflt} * \left[\frac{MixingHeight - 500}{3000 - 500} \right]$$

Approach:

$$TIM_{adj} = TIM_{dflt} \cdot \left[\frac{MixingHeight}{3000} \right]$$

---

[1] The analysis presented in this appendix is consistent with EPA's *Procedures for Emissions Inventory Preparation, Volume IV: Mobile Sources* (EPA, 1992).

where TIM_{adj} is the adjusted time-in-mode for approach or climbout, and TIM_{dflt} is the default time-in-mode. Mixing height is by default given in feet. The equation for climbout assumes that 500 feet is the demarcation between the takeoff and climbout modes. Expressed in metric units, the approach and climbout adjustment equations are as follows:

Climbout:

$$TIM_{adj} = TIM_{dflt} * \left[\frac{MixingHeight - 152}{915 - 152} \right]$$

Approach:

$$TIM_{adj} = TIM_{dflt} \cdot \left[\frac{MixingHeight}{915} \right]$$

Default mixing height is 915 meters, with the demarcation between approach and climbout modes at 152 meters.

Consistent with EPA guidance (EPA, 1992), a four-minute default approach time was assumed for this study.

Section 2 provides a discussion of the mixing heights assumed for this analysis[2].

Emissions Calculation

The weighted-average emission factor represents the average emission factor per LTO cycle for all engine models used on a particular type of aircraft. The weighted-average emission factor per 1000 pounds of fuel is calculated as follows:

$$\overline{EF}_{ijk} = \sum_{m=1}^{NM_j} \left(X_{mj} \cdot EF_{imk} \right)$$

where

EF_{imk} = the emission factor for pollutant i, in pounds of pollutant per 1000 pounds of fuel (or kilograms pollutant per 1000 kilograms fuel), for engine model m and operating mode k;

X_{mj} = the fraction of aircraft type j with engine model m; and

NM_j = the total number of engine models associated with aircraft type j.

Note that, for a given aircraft type j, the sum of X_{mj} for all engine models associated with aircraft j is 1.

Total emissions per LTO cycle for a given aircraft type are calculated using the following equation:

$$E_{ij} = TIM_{jk} \bullet \frac{FF_{jk}}{1000} \bullet EF_{ijk} \bullet NE_j$$

---

[2] As described in EPA's *Procedures for Emissions Inventory Preparation, Volume IV* (EPA, 1992), morning (a.m.) mixing heights were used in this study.

where

TIM_{jk} = time in mode k (min) for aircraft type j;

FF_{jk} = fuel flow for mode k (lbs/min or kg/min) for each engine used on aircraft type j;

$\overline{EF}_{ijk}$ = weighted-average emission factor for pollutant i, in pounds of pollutant per 1000 pounds of fuel (kilograms pollutant per 1000 kilograms fuel), for aircraft type j in operating mode k; and

NE_j = number of engines on aircraft type j.

Once the preceding calculations are performed for each aircraft type, total emissions for that aircraft type are computed by multiplying the emissions for one LTO cycle by the number of LTO cycles at a given location:

$$E_i = (E_{ij} \cdot LTO_j)$$

where

E_{ij} = the total emissions for pollutant i from aircraft type j;
LTO_j = the number of LTOs for aircraft type j.

Total emissions for each aircraft type are then summed to yield total commercial exhaust emissions for the facility as shown below:

$$ET_i = \sum_{j=1}^{N} (E_{ij} \cdot LTO_j)$$

where

ET_i = the total emissions for pollutant i from all aircraft types;

E_{ij} = the emissions of pollutant i from aircraft type j;

LTO_j = the number of LTOs for aircraft type j; and

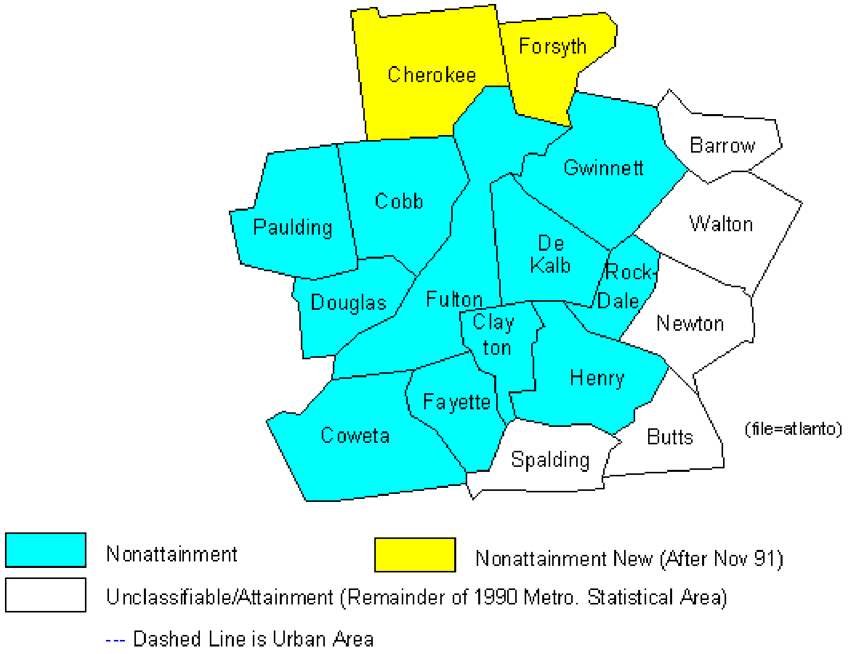
N = the total number of aircraft types.

APPENDIX C
OZONE NONATTAINMENT AREA MAPS[1]

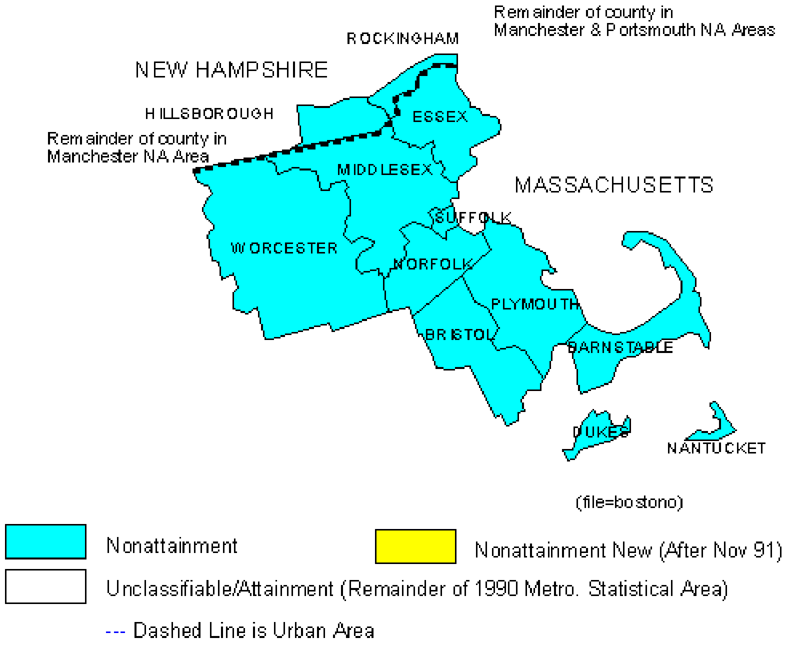
---

[1] Maps obtained from the U.S. EPA's "Green Book" World Wide Web site (http://www.epa.gov/oar/oaqps/greenbk/).

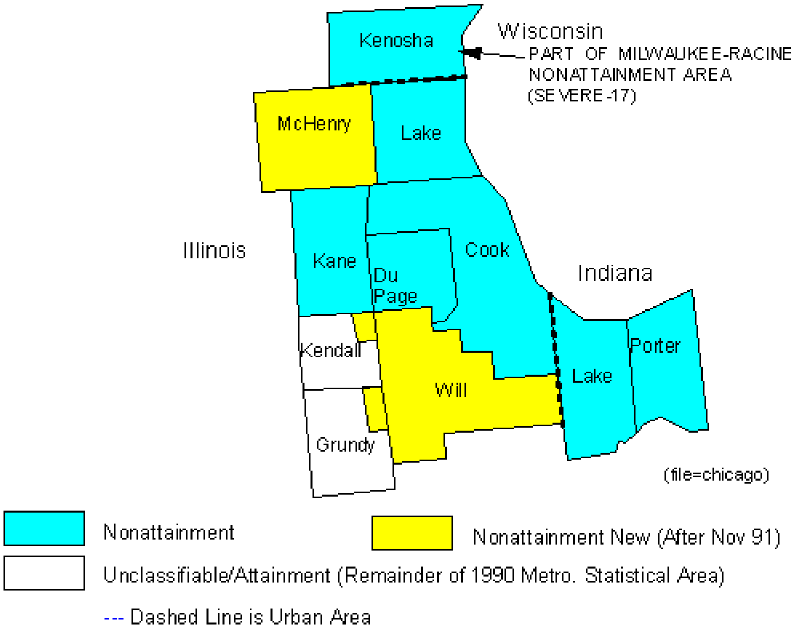
ATLANTA, GA
SERIOUS OZONE NONATTAINMENT AREA



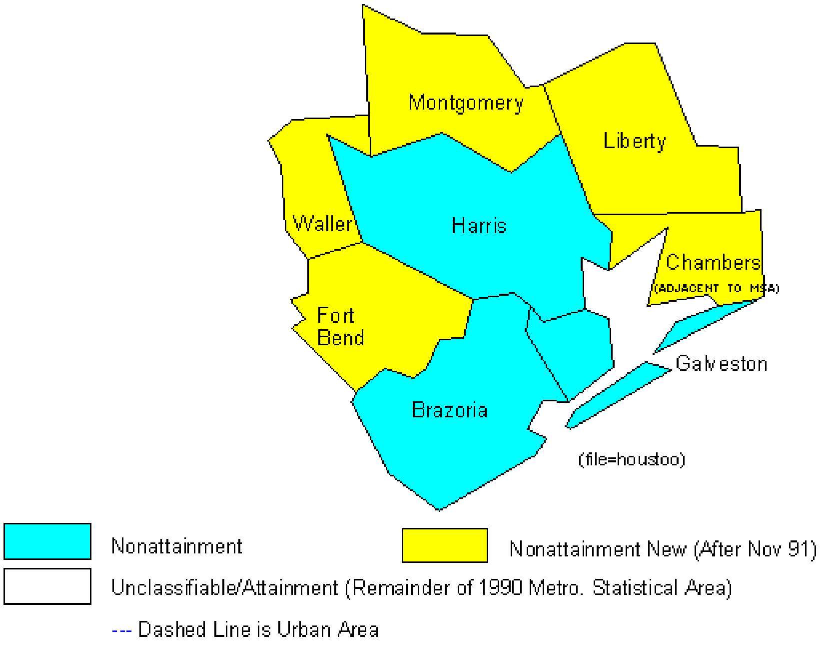
BOSTON-LAWRENCE-WORCESTER, MA-NH
SERIOUS OZONE NONATTAINMENT AREA



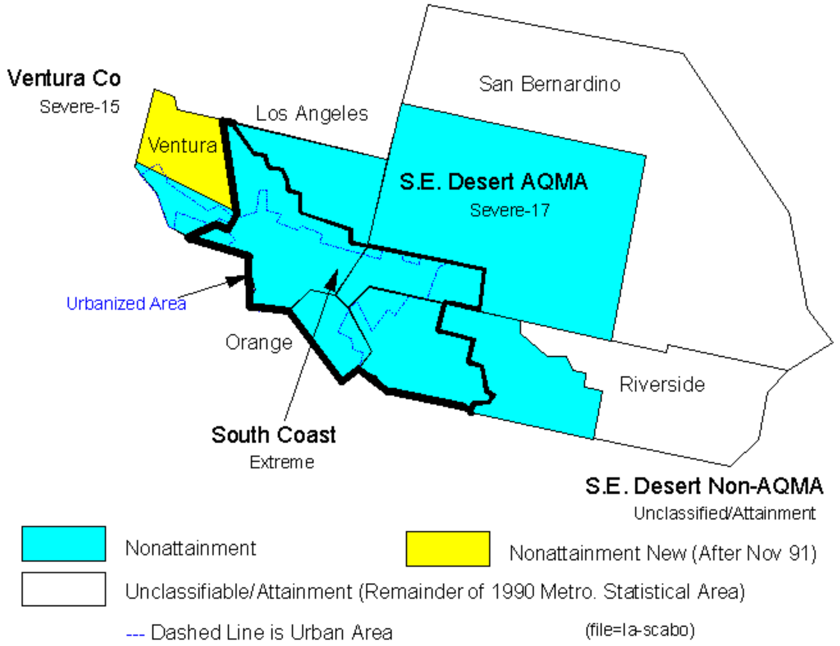
CHICAGO-GARY-LAKE COUNTY, IL-IN
SEVERE-17 OZONE NONATTAINMENT AREA



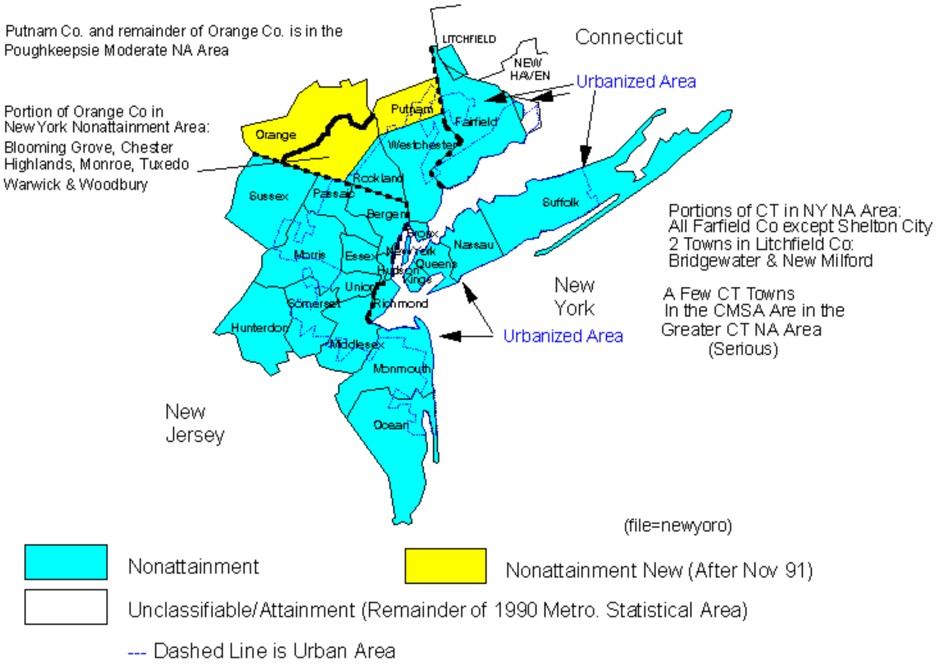
HOUSTON-GALVESTON-BRAZORIA, TX
SEVERE-17 OZONE NONATTAINMENT AREA



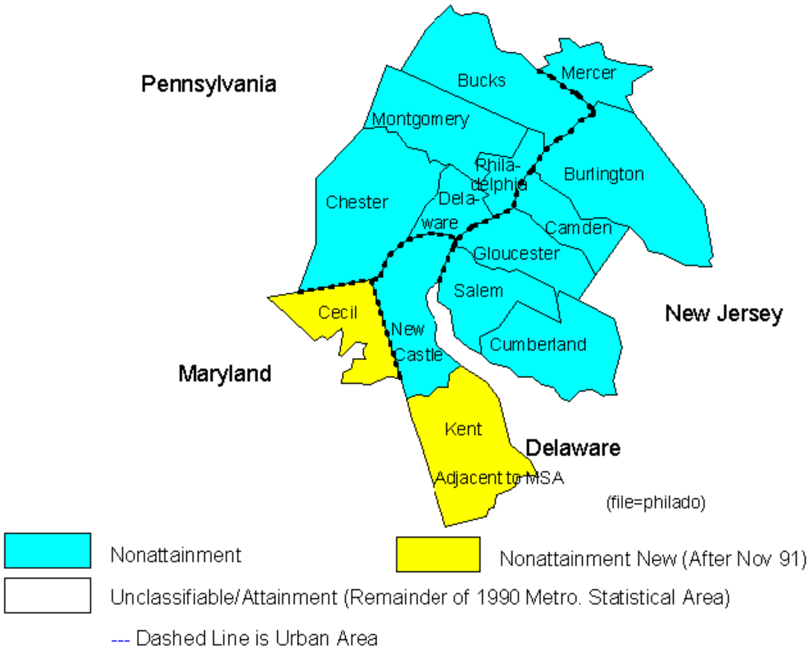
LOS ANGELES SOUTH COAST AIR BASIN, CA
EXTREME OZONE NONATTAINMENT AREA



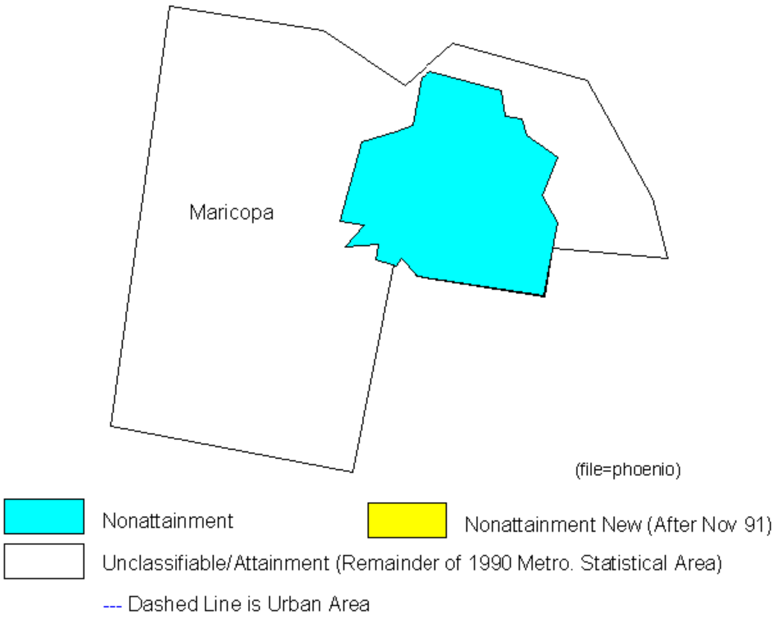
NEW YORK-NORTHERN NEW JERSEY-LONG ISLAND, NY-NJ-CT
SEVERE-17 OZONE NONATTAINMENT AREA



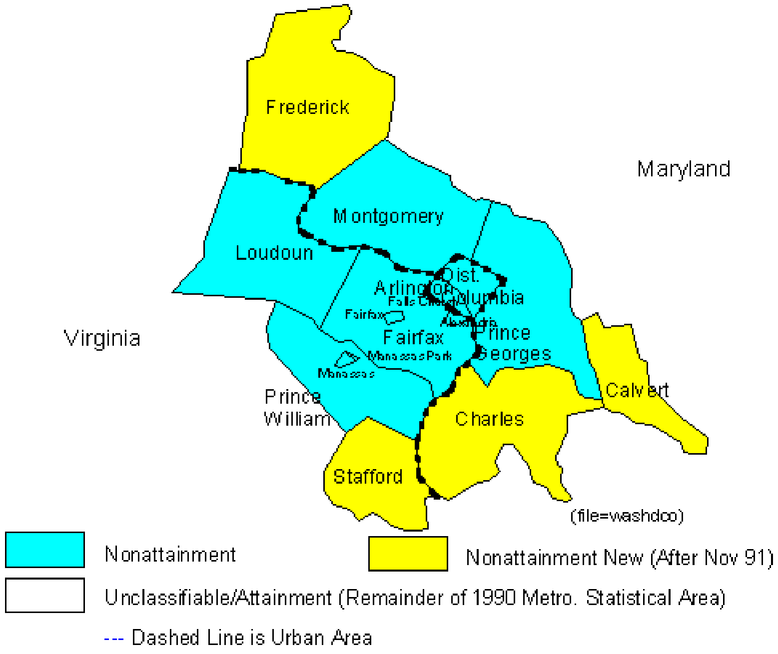
PHILADELPHIA-WILMINGTON-TRENTON, PA-NJ-DE-MD
SEVERE-15 OZONE NONATTAINMENT AREA



PHOENIX, AZ
MODERATE OZONE NONATTAINMENT AREA



WASHINGTON, DC-MD-VA
SERIOUS OZONE NONATTAINMENT AREA



APPENDIX D
AIRPORT ACTIVITY PROJECTIONS[1]

---

[1] All projections based upon FAA *Terminal Area Forecasts* (USDOT, 1997a). Annual average growth rates are also summarized in Table D-1.

Table D-1. Commercial aircraft activity growth rates* for selected airports, 1990 through 2010.

YEAR	ATL	BOS	BUR	CLT	DCA	EWR	HOU	IAD	IAH	JFK
1990-1991	-17.9%	-1.7%	-2.2%	-2.5%	-7.1%	-0.6%	0.0%	11.3%	0.0%	-11.1%
1991-1992	-4.4%	9.5%	-6.6%	5.8%	4.9%	5.8%	-9.1%	7.5%	3.2%	8.0%
1992-1993	7.6%	2.7%	-3.2%	-4.3%	1.5%	6.9%	-1.4%	-3.4%	10.0%	6.9%
1993-1994	6.2%	-3.4%	-6.4%	5.6%	0.0%	2.3%	-1.2%	6.7%	0.0%	0.4%
1994-1995	6.8%	-0.1%	-5.1%	0.7%	-0.1%	-3.0%	3.8%	5.1%	6.5%	-2.1%
1995-1996	14.5%	0.4%	2.4%	-0.2%	0.2%	4.1%	1.6%	1.8%	4.4%	0.8%
1996-1997	0.0%	1.3%	3.1%	2.0%	0.1%	1.3%	1.5%	2.1%	3.6%	0.9%
1997-1998	1.8%	0.8%	3.4%	2.0%	0.1%	1.3%	1.4%	2.1%	3.6%	0.9%
1998-1999	1.8%	0.8%	3.2%	2.0%	0.1%	1.2%	1.4%	2.1%	3.6%	0.9%
1999-2000	1.7%	0.8%	3.2%	2.0%	0.1%	1.2%	1.4%	2.1%	3.6%	0.9%
2000-2001	1.7%	0.8%	2.6%	2.0%	0.1%	1.2%	1.2%	2.0%	2.5%	1.1%
2001-2002	1.7%	0.8%	2.6%	2.0%	0.1%	1.2%	1.2%	2.0%	2.5%	1.1%
2002-2003	1.7%	0.8%	2.6%	2.0%	0.1%	1.2%	1.2%	2.0%	2.5%	1.1%
2003-2004	1.6%	0.8%	2.6%	2.0%	0.1%	1.2%	1.2%	2.0%	2.5%	1.1%
2004-2005	1.6%	0.8%	2.6%	2.0%	0.1%	1.2%	1.2%	2.0%	2.5%	1.1%
2005-2006	1.6%	0.8%	2.4%	1.7%	0.1%	1.1%	1.0%	2.0%	2.5%	1.2%
2006-2007	1.6%	0.8%	2.4%	1.7%	0.1%	1.1%	1.0%	2.0%	2.5%	1.2%
2007-2008	1.5%	0.8%	2.4%	1.7%	0.1%	1.1%	1.0%	2.0%	2.5%	1.2%
2008-2009	1.5%	0.8%	2.5%	1.7%	0.1%	1.1%	1.0%	2.0%	2.5%	1.2%
2009-2010	1.5%	0.8%	2.5%	1.8%	0.1%	1.1%	1.0%	2.0%	2.5%	1.2%

Table D-1. Commercial travel activity growth rates for selected airports, 1990 through 2010 (concluded).

YEAR	LAX	LGA	LGB	MDW	ONT	ORD	ORH	PHL	PHX	SNA
1990-1991	-1.2%	-8.8%	-4.4%	-6.4%	3.5%	-0.3%	-34.9%	-5.5%	0.4%	5.3%
1991-1992	2.7%	1.3%	-6.4%	-39.0%	-2.2%	3.6%	-22.4%	-1.5%	-2.3%	1.2%
1992-1993	0.5%	-0.6%	-1.4%	3.1%	0.0%	1.6%	1.7%	3.6%	6.7%	-11.3%
1993-1994	0.8%	0.1%	11.5%	34.2%	3.7%	3.7%	-18.8%	3.1%	-2.4%	3.0%
1994-1995	4.2%	3.4%	3.5%	5.5%	-0.2%	1.0%	4.5%	1.6%	2.9%	-3.1%
1995-1996	4.4%	0.8%	0.6%	1.1%	1.6%	2.4%	0.2%	-0.2%	5.5%	1.3%
1996-1997	2.3%	0.5%	0.8%	11.2%	1.8%	2.1%	0.2%	0.9%	3.9%	1.7%
1997-1998	2.2%	0.5%	1.0%	0.9%	1.9%	1.9%	0.2%	0.9%	3.3%	1.9%
1998-1999	2.2%	0.5%	0.8%	0.9%	1.7%	1.9%	0.2%	0.9%	2.6%	1.3%
1999-2000	2.1%	0.5%	0.8%	0.9%	1.7%	1.9%	0.2%	0.9%	2.0%	1.5%
2000-2001	2.1%	0.5%	0.8%	0.6%	1.6%	1.8%	0.2%	0.9%	1.9%	1.4%
2001-2002	2.1%	0.5%	0.8%	0.6%	1.6%	1.8%	0.2%	0.9%	1.9%	1.4%
2002-2003	2.0%	0.5%	0.8%	0.7%	1.6%	1.8%	0.2%	0.9%	1.8%	1.5%
2003-2004	2.0%	0.5%	0.8%	0.7%	1.6%	1.7%	0.2%	0.9%	1.8%	1.5%
2004-2005	1.9%	0.5%	0.7%	0.7%	1.5%	1.7%	0.2%	0.9%	1.8%	1.4%
2005-2006	1.9%	0.5%	0.7%	0.5%	1.5%	1.7%	0.2%	0.9%	1.7%	1.3%
2006-2007	1.9%	0.5%	0.7%	0.5%	1.5%	1.7%	0.2%	0.9%	1.7%	1.3%
2007-2008	1.8%	0.5%	0.7%	0.5%	1.4%	1.6%	0.2%	0.9%	1.7%	1.3%
2008-2009	1.8%	0.5%	0.7%	0.6%	1.5%	1.6%	0.2%	0.9%	1.7%	1.4%
2009-2010	1.8%	0.5%	0.7%	0.6%	1.4%	1.6%	0.2%	0.9%	1.6%	1.4%

* Annual average growth rates.

APPENDIX E
TIME-IN-MODE DATA AND ASSUMPTIONS[1]

---

[1] Information provided as hardcopy from FAA's Office of Aviation Policy, Plans and Analysis. Some of these pages also contain information on airports that are not evaluated in this report. Bryan Manning, US EPA, (734) 214-4832, can provide further details about the potential availability of this report upon request.

APPENDIX F
AIRCRAFT/ENGINE EMISSION FACTOR DATABASE

The following tables present the aircraft emission rates used for this study. Table F-1 presents the aircraft/engine type cross-reference list obtained from the FAEED model (FAA, 1995)[1]. Many aircraft models have multiple possible engine configurations; the "%" column next to each engine type is the estimated percentage of a given aircraft body type using that engine. These distributions were used as weighting factors to create the emission rates presented in Tables F-2 and F-3. Table F-2 provides rates in pounds per LTO cycle; Tables F-3 presents rates in kilograms per LTO cycle. For selected aircraft/engine combinations, an emission factor was not located at the time of the analysis. In Table F-4, we present the equivalencies that were assumed for a limited number of aircraft/engine combinations.

---

[1] Supplemented by the ICAO engine emission factor database (ICAO, 1995).

Table F-1. Aircraft/engine type cross-reference.

Manufacturer	Body Type	#Eng	Engine 1	%	Engine 2	%	Engine 3	%	Engine 4	%	Engine 5	%	Engine 6	%	Engine 7	%	Engine 8	%	Engine 9	%	Engine 10	%	Engine 11	%	Total %
AIRBUS	A300-600	2	CF6-80C2A5	100																					100
AIRBUS	A300-B4	2	CF6-50	100																					100
AIRBUS	A310-200	2	JT9D-7R4E1	100																					100
AIRBUS	A310-300	2	PW4152	100																					100
AIRBUS	A320-200	2	CFM56-5-A1	100																					100
BEECH	18(CARG)	2	R-985-AN	100																					100
BEECH	B. 99A	2	PT6A-27	100																					100
BOEING	B707-300B	4	JT3D-3B	100																					100
BOEING	B707-300C	4	JT3D-3B	100																					100
BOEING	B727-100	3	JT8D-7 (OLD COMB.)	16	JT8D-7,7A & 7B (REC)	7	JT8D-7A	4	JT8D-7B	73															100
BOEING	B727-100(CARG)	3	JT8D-7A	6	JT8D-7B	91	JT8D-9	1	JT8D-9A	2															100
BOEING	B727-200	3	JT8D-17 (REV.)	1	JT8D-17A	1	JT8D-7	1	JT8D-15	26	JT8D-15A	21	JT8D-17A	1	JT8D-17R	3	JT8D-7,7A & 7B (REC)	1	JT8D-7B	16	JT8D-9	20	JT8D-9A	9	100
BOEING	B737-100	2	JT8D-15	10	JT8D-15A	24	JT8D-17	7	JT8D-17A	1	JT8D-7B	19	JT8D-9A	39											100
BOEING	B737-200	2	JT8D-15	10	JT8D-15A	24	JT8D-17	7	JT8D-17A	1	JT8D-7B	19	JT8D-9A	39											100
BOEING	B737-200(CARG)	2	JT8D-15	5	JT8D-17	32	JT8D-17A	32	JT8D-7A	10	JT8D-9	3	JT8D-9A	18											100
BOEING	B737-200C	2	JT8D-7A	10	JT8D-9/9A	5	JT8D-9A	16	JT8D-15	5	JT8D-17	32	JT8D-17A	32											100
BOEING	B737-300	2	CFM56-3B-2	100																					100
BOEING	B737-400	2	CFM56-3B-2	100																					100
BOEING	B737-500	2	CFM56-3C-1	100																					100
BOEING	B747	4	JT9D-7F	100																					100
BOEING	B747(CARG)	4	JT9D-7F (MOD V)	100																					100
BOEING	B747-200	4	CF6-50E2	3	JT9D-59A	7	JT9D-7 (ORIG.)	1	JT9D-70A	13	JT9D-7A	55	JT9D-7F (MOD V)	5	JT9D-7Q	13	JT9D-7R4G2	3							100
BOEING	B747-400	4	PW4056	100																					100
BOEING	B747-SP	4	JT9D-7F (MOD V)	85	JT9D-7F (MOD VI)	15																			100
BOEING	B747F(CARG)	4	JT9D-70A	39	JT9D-7F (MOD V)	33	JT9D-7Q	17	JT9D-7R4G2	11															100
BOEING	B757-200	2	RB211-535E4	1	PW2037	92	PW2040	7																	100
BOEING	B757-200(CARG)	2	PW2040	26	RB211-535E4	74																			100
BOEING	B767-200	2	CF6-80A2	59	CF6-80C2B2	12	JT9D-7R4D	29																	100
BOEING	B767-300	2	CF6-80C2B6	100																					100
BRITAIRCOR	BAE-111-200	2	ALF502R-5	100																					100
BRITAIRCOR	BAE-146-1	4	ALF502R-5	100																					100
CONVAIR	CV 640	2	DART 542-4	100																					100
DE HAVILLAND	DHC-6	2	PT6A-27	74	PT6A-20	26																			100
FAIRCHILD	FH-227	2	DART 532-7	100																					100
FOKKER	F-27 SERIES	2	DART 514-7	15	DART 528-7E	10	DART 532-7	5	DART 532-7N	3	DART 532-7P	24	DART 535-7R	3	DART 535-7R	9	DART 536-7E	2	DART 552-7R	29					100
FOKKER	F-28	2	SPEY MK555	100																					100
FOKKER	F100	2	TAY MK 620-15	100																					100
LOCKHEED	L-1011-100	3	RB211-22B	99	RB211-524B4	1																			100
LOCKHEED	L-1011-200	3	RB211-22B	99	RB211-524B4	1																			100
LOCKHEED	L-1011-500	3	RB211-524B4	100																					100
MCDONNELL DOUG	DC10-10	3	CF6-6D	100																					100
MCDONNELL DOUG	DC10-30	3	CF6-50C	100																					100
MCDONNELL DOUG	DC10-40	3	JT9D-20	100																					100
MCDONNELL DOUG	DC8	4	JT3D-3B	57	JT3D-7	43																			100
MCDONNELL DOUG	DC8-51	4	JT3D-3B	100																					100
MCDONNELL DOUG	DC8-52	4	JT3D-3B	100																					100
MCDONNELL DOUG	DC8-53	4	JT3D-3B	100																					100
MCDONNELL DOUG	DC8-55	4	JT3D-3B	100																					100
MCDONNELL DOUG	DC8-60	4	JT3D-3B	57	JT3D-7	43																			100
MCDONNELL DOUG	DC8-61	4	JT3D-3B	100																					100
MCDONNELL DOUG	DC8-61(CARG)	4	JT3D-3B	100																					100
MCDONNELL DOUG	DC8-62	4	JT3D-3B	100																					100
MCDONNELL DOUG	DC8-62(CARG)	4	JT3D-3B	15	JT3D-7	64	JT3D-3BDL	21																	100
MCDONNELL DOUG	DC8-63	4	JT3D-3B	100																					100
MCDONNELL DOUG	DC8-63F(CARG)	4	JT3D-3B	24	JT3D-7	42	JT8D-7,7A & 7B (REC)	27	JT3D-735E4	7															100
MCDONNELL DOUG	DC8-70	4	CFM56-2-C1	100																					100
MCDONNELL DOUG	DC8-71	4	CFM56-2	100																					100
MCDONNELL DOUG	DC8-73F(CARG)	4	CFM56-2-C1	100																					100
MCDONNELL DOUG	DC9-10	2	JT8D-7	100																					100
MCDONNELL DOUG	DC9-15F	2	JT8D-7	15	JT8D-7A	6	JT8D-7B	79																	100
MCDONNELL DOUG	DC9-30	2	JT8D-15	3	JT8D-17	1	JT8D-7A	5	JT8D-7B	68	JT8D-9A	23													100
MCDONNELL DOUG	DC9-40	2	JT8D-15	100																					100
MCDONNELL DOUG	DC9-50	2	JT8D-17	87	JT8D-17A	13																			100
MCDONNELL DOUG	DC9-80	2	JT8D-209	5	JT8D-217	12	JT8D-217A	36	JT8D-217C	25	JT8D-219	22													100
MCDONNELL DOUG	MD-11	3	CF6-80C2D1F	100																					100
NAMC	YS-11	2	DART 542-10J	25	DART 542-10K	75																			100

Table F-2. Engine Modal EFs (lbs/min)		TK	TK	TK	TK	CB	CB	CB	CB
Body Type		**THCef**	**COef**	**NOXef**	**SO2ef**	**THCef**	**COef**	**NOXef**	**SO2ef**
AIRBUS	A300-600	0.04780	0.35506	23.47520	0.36872	0.04406	0.28642	12.59135	0.29743
AIRBUS	A300-B4	0.38112	0.27223	16.87806	0.29400	0.31778	0.22699	11.89417	0.24515
AIRBUS	A310-200	0.08965	0.31939	23.30959	0.30258	0.05929	0.24173	15.59836	0.24629
AIRBUS	A310-300	0.07487	0.06911	15.49267	0.31101	0.07556	0.08028	10.71963	0.25500
AIRBUS	A320-200	0.06395	0.25024	6.83996	0.15015	0.05245	0.20524	4.46971	0.12314
BEECH	18(CARG)	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00000	0.00001
BEECH	B. 99A	0.00000	0.01415	0.11054	0.00764	0.00000	0.01600	0.09334	0.00720
BOEING	B707-300B	2.48470	0.93176	7.51621	0.33543	0.98626	1.38076	4.88199	0.26629
BOEING	B707-300C	2.48470	0.93176	7.51621	0.33543	0.98626	1.38076	4.88199	0.26629
BOEING	B727-100	0.15290	0.57233	6.71529	0.21198	0.15534	0.62362	4.35759	0.17385
BOEING	B727-100(CARG)	0.15549	0.58469	6.74443	0.21230	0.15893	0.63774	4.36100	0.17408
BOEING	B727-200	0.12645	0.41644	7.39783	0.21534	0.11476	0.43778	4.63878	0.17373
BOEING	B737-100	0.07816	0.30391	5.29978	0.15398	0.07644	0.29301	3.29808	0.12467
BOEING	B737-200	0.07816	0.30391	5.29978	0.15398	0.07644	0.29301	3.29808	0.12467
BOEING	B737-200(CARG)	0.12322	0.29161	5.76921	0.16429	0.11467	0.28772	3.57347	0.13201
BOEING	B737-200C	0.12498	0.29249	5.76161	0.16429	0.11597	0.29036	3.57218	0.13201
BOEING	B737-300	0.01006	0.25143	5.41977	0.15086	0.01092	0.20905	3.87906	0.12543
BOEING	B737-400	0.01006	0.25143	5.41977	0.15086	0.01092	0.20905	3.87906	0.12543
BOEING	B737-500	0.00916	0.27477	6.31963	0.16486	0.01010	0.22715	4.49246	0.13629
BOEING	B747	0.25841	0.25841	40.82822	0.69770	0.21160	0.21160	27.08498	0.57132
BOEING	B747(CARG)	0.34401	0.45867	52.74756	0.61921	0.28000	0.37334	32.10720	0.50401
BOEING	B747-200	0.27517	0.29706	42.00930	0.69302	0.22722	0.23841	27.58135	0.56592
BOEING	B747-400	0.02423	0.37270	31.95942	0.50315	0.02682	0.30646	20.91591	0.41372
BOEING	B747-SP	0.33117	0.42863	50.95966	0.63098	0.26974	0.34908	31.35387	0.51411
BOEING	B747F(CARG)	0.27944	0.39503	46.10919	0.67139	0.22615	0.30729	29.26705	0.54518
BOEING	B757-200	0.01976	0.16775	13.01970	0.22241	0.01947	0.13889	8.51834	0.18303
BOEING	B757-200(CARG)	0.01771	0.41623	23.34454	0.26204	0.00644	0.40344	13.42027	0.21342
BOEING	B767-200	0.13461	0.46921	18.10006	0.31165	0.12990	0.41876	12.98862	0.25859
BOEING	B767-300	0.04776	0.35479	21.02125	0.36843	0.04404	0.28628	12.62935	0.29729
BRITAIRCOR	BAE-111-200	0.00568	0.02842	1.28179	0.05116	0.00414	0.01954	0.82554	0.04222
BRITAIRCOR	BAE-146-1	0.01137	0.05684	2.56358	0.10232	0.00829	0.03909	1.65108	0.08443
CONVAIR	CV 640	0.00000	0.12397	0.24231	0.03043	0.00000	0.13492	0.17540	0.02429
DE HAVILLAND	DHC-6	0.01435	0.05234	4.50758	0.07025	0.01181	0.05121	3.16962	0.05848
FAIRCHILD	FH-227	0.04709	0.15069	0.26371	0.02543	0.04569	0.14537	0.18691	0.02243
FOKKER	F-27 SERIES	0.04709	0.15069	0.26371	0.02543	0.04569	0.14537	0.18691	0.02243

TK = Takeoff; CB = Climbout
AP = Approach; ID = Idle

Table F-2. Engine Modal EFs (lbs/min)		**TK**	**TK**	**TK**	**TK**	**CB**	**CB**	**CB**	**CB**
Body Type		**THCef**	**COef**	**NOXef**	**SO2ef**	**THCef**	**COef**	**NOXef**	**SO2ef**
FOKKER	F-28	0.16769	0.08385	3.60537	0.10290	0.02493	0.00000	2.28125	0.08414
FOKKER	F100	0.16085	0.14074	4.24240	0.10857	0.05000	0.13334	2.80005	0.09000
LOCKHEED	L-1011-100	0.26733	1.82419	25.61810	0.40060	0.23811	2.51013	15.79790	0.33097
LOCKHEED	L-1011-200	0.26733	1.82419	25.61810	0.40060	0.23811	2.51013	15.79790	0.33097
LOCKHEED	L-1011-500	0.34203	0.61390	45.86703	0.47358	0.18469	0.21310	27.13459	0.38358
MCDONNELL DOUG	DC10-10	0.20667	0.34445	27.55602	0.37201	0.17036	0.28393	18.51245	0.30665
MCDONNELL DOUG	DC10-30	0.56644	0.47203	33.04222	0.50979	0.53195	0.37997	22.03807	0.41036
MCDONNELL DOUG	DC10-40	0.08330	0.00000	32.23519	0.44979	0.07099	0.00000	20.23308	0.38336
MCDONNELL DOUG	DC8	1.55898	0.78796	7.90879	0.34531	0.65606	1.23302	5.03613	0.27854
MCDONNELL DOUG	DC8-51	2.48470	0.93176	7.51621	0.33543	0.98626	1.38076	4.88199	0.26629
MCDONNELL DOUG	DC8-52	2.48470	0.93176	7.51621	0.33543	0.98626	1.38076	4.88199	0.26629
MCDONNELL DOUG	DC8-53	2.48470	0.93176	7.51621	0.33543	0.98626	1.38076	4.88199	0.26629
MCDONNELL DOUG	DC8-55	2.48470	0.93176	7.51621	0.33543	0.98626	1.38076	4.88199	0.26629
MCDONNELL DOUG	DC8-60	1.55898	0.78796	7.90879	0.34531	0.65606	1.23302	5.03613	0.27854
MCDONNELL DOUG	DC8-61	2.48470	0.93176	7.51621	0.33543	0.98626	1.38076	4.88199	0.26629
MCDONNELL DOUG	DC8-61(CARG)	2.48470	0.93176	7.51621	0.33543	0.98626	1.38076	4.88199	0.26629
MCDONNELL DOUG	DC8-62	2.48470	0.93176	7.51621	0.33543	0.98626	1.38076	4.88199	0.26629
MCDONNELL DOUG	DC8-62(CARG)	1.10688	0.71773	8.10051	0.35014	0.49480	1.16087	5.11141	0.28452
MCDONNELL DOUG	DC8-63	2.48470	0.93176	7.51621	0.33543	0.98626	1.38076	4.88199	0.26629
MCDONNELL DOUG	DC8-63F(CARG)	0.79427	0.64351	8.36483	0.33243	0.37267	0.96709	5.36213	0.27094
MCDONNELL DOUG	DC8-70	0.02085	0.46906	9.64170	0.28143	0.02167	0.39001	6.93345	0.23400
MCDONNELL DOUG	DC8-71	0.02085	0.46906	9.64170	0.28143	0.02167	0.39001	6.93345	0.23400
MCDONNELL DOUG	DC8-73F(CARG)	0.02085	0.46906	9.64170	0.28143	0.02167	0.39001	6.93345	0.23400
MCDONNELL DOUG	DC9-10	0.06542	0.23553	4.50120	0.14132	0.05366	0.23610	3.00486	0.11590
MCDONNELL DOUG	DC9-15F	0.09879	0.36899	4.47895	0.14132	0.09927	0.40029	2.91365	0.11590
MCDONNELL DOUG	DC9-30	0.09052	0.36122	4.72992	0.14416	0.09157	0.38064	3.01430	0.11788
MCDONNELL DOUG	DC9-40	0.07791	0.21815	5.95243	0.16829	0.06250	0.25000	3.75006	0.13500
MCDONNELL DOUG	DC9-50	0.20781	0.24375	6.27234	0.17652	0.19092	0.26675	3.95440	0.14127
MCDONNELL DOUG	DC9-80	0.09817	0.27722	9.03852	0.18872	0.12254	0.35005	5.84919	0.15354
MCDONNELL DOUG	MD-11	0.07211	0.53569	33.63525	0.55630	0.06556	0.42612	19.68338	0.44251
NAMC	YS-11	0.00000	0.12397	0.24231	0.03043	0.00000	0.13492	0.17540	0.02429

TK = Takeoff; CB = Climbout
AP = Approach; ID = Idle

Table F-2. Engine Modal EFs (lbs/min)		AP	AP	AP	AP	ID	ID	ID	ID
Body Type		**THCef**	**COef**	**NOXef**	**SO2ef**	**THCef**	**COef**	**NOXef**	**SO2ef**
AIRBUS	A300-600	0.03635	0.35078	1.65573	0.09814	0.49232	2.28087	0.20755	0.02957
AIRBUS	A300-B4	0.16966	1.15677	1.29558	0.08329	1.37569	3.49213	0.17461	0.02857
AIRBUS	A310-200	0.02245	0.21246	1.79637	0.09327	0.06490	0.48352	0.23971	0.03157
AIRBUS	A310-300	0.02353	0.17100	1.74138	0.08472	0.03465	0.59750	0.22945	0.02529
AIRBUS	A320-200	0.03079	0.19246	0.61588	0.04157	0.03744	0.47074	0.10699	0.01444
BEECH	18(CARG)	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00000	0.00001
BEECH	B. 99A	0.01570	0.16705	0.06001	0.00387	1.92452	0.24550	0.00932	0.00207
BOEING	B707-300B	0.73229	4.48526	0.87875	0.09886	8.00012	7.00010	1.78574	0.03857
BOEING	B707-300C	0.73229	4.48526	0.87875	0.09886	8.00012	7.00010	1.78574	0.03857
BOEING	B727-100	0.17212	1.12614	0.63079	0.06131	0.51866	1.74267	0.13994	0.02766
BOEING	B727-100(CARG)	0.17967	1.17252	0.62656	0.06138	0.53526	1.79702	0.13873	0.02768
BOEING	B727-200	0.15050	0.85318	0.69272	0.06140	0.39427	1.39480	0.14842	0.02695
BOEING	B737-100	0.08260	0.41891	0.49328	0.04394	0.20068	0.76370	0.10591	0.01934
BOEING	B737-200	0.08260	0.41891	0.49328	0.04394	0.20068	0.76370	0.10591	0.01934
BOEING	B737-200(CARG)	0.10878	0.51058	0.53688	0.04675	0.29300	0.84939	0.11537	0.01998
BOEING	B737-200C	0.11057	0.52203	0.53632	0.04675	0.29780	0.86361	0.11537	0.01998
BOEING	B737-300	0.00606	0.28244	0.72271	0.04486	0.05509	0.94761	0.12908	0.01700
BOEING	B737-400	0.00606	0.28244	0.72271	0.04486	0.05509	0.94761	0.12908	0.01700
BOEING	B737-500	0.00622	0.27556	0.80890	0.04800	0.04658	0.87917	0.14106	0.01771
BOEING	B747	0.10800	0.61201	2.80805	0.19440	1.50479	6.64614	0.37620	0.06772
BOEING	B747(CARG)	0.16500	0.95702	2.57404	0.17820	3.01274	6.25724	0.35921	0.06257
BOEING	B747-200	0.11984	0.67125	2.81585	0.19303	1.59531	6.50782	0.37825	0.06708
BOEING	B747-400	0.04695	0.52170	2.76502	0.14086	0.18453	2.05850	0.34445	0.04429
BOEING	B747-SP	0.15645	0.90527	2.60914	0.18063	2.78655	6.31557	0.36176	0.06334
BOEING	B747F(CARG)	0.12184	0.71224	2.75947	0.18838	1.85708	5.94076	0.37873	0.06561
BOEING	B757-200	0.02210	0.24420	1.10835	0.05819	0.08452	0.87255	0.16522	0.02035
BOEING	B757-200(CARG)	0.01057	0.25864	1.19637	0.07857	0.06118	0.84192	0.20472	0.02584
BOEING	B767-200	0.05663	0.41024	1.81210	0.09538	0.23482	1.09225	0.16677	0.02444
BOEING	B767-300	0.03630	0.35027	1.65332	0.09800	0.49232	2.28142	0.20755	0.02957
BRITAIRCOR	BAE-111-200	0.00594	0.19422	0.18054	0.01477	0.05818	0.44179	0.04080	0.00583
BRITAIRCOR	BAE-146-1	0.01187	0.38844	0.36109	0.02954	0.11636	0.88358	0.08160	0.01166
CONVAIR	CV 640	0.00000	0.48426	0.04592	0.01127	0.12385	0.57611	0.02226	0.00751
DE HAVILLAND	DHC-6	0.01835	0.15389	0.44130	0.02103	0.14609	0.26615	0.07791	0.00814
FAIRCHILD	FH-227	0.00006	0.71711	0.01938	0.01163	0.32689	1.25011	0.00957	0.00739
FOKKER	F-27 SERIES	0.00006	0.71711	0.01938	0.01163	0.32689	1.25011	0.00957	0.00739

TK = Takeoff; CB = Climbout
AP = Approach; ID = Idle

Table F-2. Engine Modal EFs (lbs/min)		**AP**	**AP**	**AP**	**AP**	**ID**	**ID**	**ID**	**ID**
Body Type		**THCef**	**COef**	**NOXef**	**SO2ef**	**THCef**	**COef**	**NOXef**	**SO2ef**
FOKKER	F-28	0.40936	1.30501	0.34769	0.03171	2.82150	2.68429	0.05568	0.01643
FOKKER	F100	0.05476	0.23731	0.34683	0.03286	0.09894	0.70133	0.07275	0.01571
LOCKHEED	L-1011-100	1.68112	5.73505	1.77339	0.11867	5.83157	8.32072	0.24479	0.04867
LOCKHEED	L-1011-200	1.68112	5.73505	1.77339	0.11867	5.83157	8.32072	0.24479	0.04867
LOCKHEED	L-1011-500	0.17500	0.39001	2.45004	0.13500	0.18572	1.18002	0.40001	0.05143
MCDONNELL DOUG	DC10-10	0.13442	1.24818	2.18911	0.10369	1.44002	3.71663	0.30858	0.03703
MCDONNELL DOUG	DC10-30	0.25516	1.32685	2.39853	0.13779	1.93495	5.24120	0.29445	0.04543
MCDONNELL DOUG	DC10-40	0.31933	1.86686	1.86686	0.13265	3.02271	6.99995	0.25957	0.04522
MCDONNELL DOUG	DC8	0.60307	4.28066	0.96947	0.10409	8.13090	8.02539	1.08174	0.03766
MCDONNELL DOUG	DC8-51	0.73229	4.48526	0.87875	0.09886	8.00012	7.00010	1.78574	0.03857
MCDONNELL DOUG	DC8-52	0.73229	4.48526	0.87875	0.09886	8.00012	7.00010	1.78574	0.03857
MCDONNELL DOUG	DC8-53	0.73229	4.48526	0.87875	0.09886	8.00012	7.00010	1.78574	0.03857
MCDONNELL DOUG	DC8-55	0.73229	4.48526	0.87875	0.09886	8.00012	7.00010	1.78574	0.03857
MCDONNELL DOUG	DC8-60	0.60307	4.28066	0.96947	0.10409	8.13090	8.02539	1.08174	0.03766
MCDONNELL DOUG	DC8-61	0.73229	4.48526	0.87875	0.09886	8.00012	7.00010	1.78574	0.03857
MCDONNELL DOUG	DC8-61(CARG)	0.73229	4.48526	0.87875	0.09886	8.00012	7.00010	1.78574	0.03857
MCDONNELL DOUG	DC8-62	0.73229	4.48526	0.87875	0.09886	8.00012	7.00010	1.78574	0.03857
MCDONNELL DOUG	DC8-62(CARG)	0.53997	4.18073	1.01378	0.10665	8.19478	8.52612	0.73793	0.03722
MCDONNELL DOUG	DC8-63	0.73229	4.48526	0.87875	0.09886	8.00012	7.00010	1.78574	0.03857
MCDONNELL DOUG	DC8-63F(CARG)	0.40367	3.13100	1.00237	0.10020	6.05920	6.54217	0.55945	0.03708
MCDONNELL DOUG	DC8-70	0.01316	0.69112	1.34934	0.08886	0.12394	2.07919	0.27090	0.03657
MCDONNELL DOUG	DC8-71	0.01316	0.69112	1.34934	0.08886	0.12394	2.07919	0.27090	0.03657
MCDONNELL DOUG	DC8-73F(CARG)	0.01316	0.69112	1.34934	0.08886	0.12394	2.07919	0.27090	0.03657
MCDONNELL DOUG	DC9-10	0.03028	0.16652	0.47684	0.04087	0.12979	0.48840	0.10759	0.01844
MCDONNELL DOUG	DC9-15F	0.10748	0.70050	0.42537	0.04087	0.32720	1.10386	0.09452	0.01844
MCDONNELL DOUG	DC9-30	0.10558	0.65285	0.43434	0.04159	0.30620	1.05246	0.09541	0.01864
MCDONNELL DOUG	DC9-40	0.14855	0.86427	0.53117	0.04862	0.42982	1.39106	0.11722	0.02110
MCDONNELL DOUG	DC9-50	0.16697	0.72529	0.57315	0.05013	0.37691	1.10889	0.12707	0.02087
MCDONNELL DOUG	DC9-80	0.16179	0.42001	0.91827	0.05454	0.12240	0.44821	0.13223	0.01946
MCDONNELL DOUG	MD-11	0.05214	0.50579	2.38818	0.14079	0.70235	3.24961	0.29556	0.04200
NAMC	YS-11	0.00000	0.48426	0.04592	0.01127	0.12385	0.57611	0.02226	0.00751

Table F-3. Engine Modal Efs (kgs/min)		**TK**	**TK**	**TK**	**TK**	**CB**	**CB**	**CB**	**CB**
Body Type		**THCef**	**COef**	**NOXef**	**SO2ef**	**THCef**	**COef**	**NOXef**	**SO2ef**
AIRBUS	A300-600	0.02168	0.16106	10.64828	0.16725	0.01999	0.12992	5.71140	0.13491
AIRBUS	A300-B4	0.17287	0.12348	7.65584	0.13336	0.14415	0.10296	5.39516	0.11120
AIRBUS	A310-200	0.04067	0.14487	10.57316	0.13725	0.02689	0.10965	7.07537	0.11172
AIRBUS	A310-300	0.03396	0.03135	7.02743	0.14107	0.03427	0.03641	4.86239	0.11567
AIRBUS	A320-200	0.02901	0.11351	3.10258	0.06811	0.02379	0.09310	2.02745	0.05586
BEECH	18(CARG)	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00000	0.00001
BEECH	B. 99A	0.00000	0.00642	0.05014	0.00347	0.00000	0.00726	0.04234	0.00327
BOEING	B707-300B	1.12705	0.42264	3.40933	0.15215	0.44736	0.62631	2.21445	0.12079
BOEING	B707-300C	1.12705	0.42264	3.40933	0.15215	0.44736	0.62631	2.21445	0.12079
BOEING	B727-100	0.06935	0.25961	3.04604	0.09615	0.07046	0.28287	1.97659	0.07886
BOEING	B727-100(CARG)	0.07053	0.26521	3.05925	0.09630	0.07209	0.28928	1.97814	0.07896
BOEING	B727-200	0.05736	0.18889	3.35563	0.09768	0.05206	0.19858	2.10413	0.07880
BOEING	B737-100	0.03545	0.13785	2.40397	0.06984	0.03467	0.13291	1.49600	0.05655
BOEING	B737-200	0.03545	0.13785	2.40397	0.06984	0.03467	0.13291	1.49600	0.05655
BOEING	B737-200(CARG)	0.05589	0.13227	2.61690	0.07452	0.05202	0.13051	1.62092	0.05988
BOEING	B737-200C	0.05669	0.13267	2.61345	0.07452	0.05260	0.13171	1.62033	0.05988
BOEING	B737-300	0.00456	0.11405	2.45839	0.06843	0.00495	0.09482	1.75953	0.05689
BOEING	B737-400	0.00456	0.11405	2.45839	0.06843	0.00495	0.09482	1.75953	0.05689
BOEING	B737-500	0.00415	0.12463	2.86657	0.07478	0.00458	0.10303	2.03776	0.06182
BOEING	B747	0.11721	0.11721	18.51956	0.31647	0.09598	0.09598	12.28567	0.25915
BOEING	B747(CARG)	0.15604	0.20805	23.92613	0.28087	0.12701	0.16935	14.56373	0.22862
BOEING	B747-200	0.12482	0.13475	19.05529	0.31435	0.10306	0.10814	12.51082	0.25670
BOEING	B747-400	0.01099	0.16906	14.49670	0.22823	0.01216	0.13901	9.48739	0.18766
BOEING	B747-SP	0.15022	0.19443	23.11515	0.28621	0.12236	0.15834	14.22202	0.23320
BOEING	B747F(CARG)	0.12675	0.17918	20.91499	0.30454	0.10258	0.13938	13.27545	0.24729
BOEING	B757-200	0.00896	0.07609	5.90570	0.10088	0.00883	0.06300	3.86390	0.08302
BOEING	B757-200(CARG)	0.00804	0.18880	10.58901	0.11886	0.00292	0.18300	6.08740	0.09680
BOEING	B767-200	0.06106	0.21283	8.21013	0.14136	0.05892	0.18995	5.89160	0.11730
BOEING	B767-300	0.02166	0.16093	9.53518	0.16712	0.01998	0.12986	5.72864	0.13485
BRITAIRCOR	BAE-111-200	0.00258	0.01289	0.58142	0.02321	0.00188	0.00887	0.37446	0.01915
BRITAIRCOR	BAE-146-1	0.00516	0.02578	1.16283	0.04641	0.00376	0.01773	0.74892	0.03830
CONVAIR	CV 640	0.00000	0.05623	0.10991	0.01380	0.00000	0.06120	0.07956	0.01102
DE HAVILLAND	DHC-6	0.00651	0.02374	2.04463	0.03186	0.00536	0.02323	1.43773	0.02653
FAIRCHILD	FH-227	0.02136	0.06835	0.11962	0.01153	0.02072	0.06594	0.08478	0.01017
FOKKER	F-27 SERIES	0.02136	0.06835	0.11962	0.01153	0.02072	0.06594	0.08478	0.01017

TK = Takeoff; CB = Climbout
AP = Approach; ID = Idle

Table F-3. Engine Modal Efs (kgs/min)		**TK**	**TK**	**TK**	**TK**	**CB**	**CB**	**CB**	**CB**
Body Type		**THCef**	**COef**	**NOXef**	**SO2ef**	**THCef**	**COef**	**NOXef**	**SO2ef**
FOKKER	F-28	0.07606	0.03803	1.63539	0.04668	0.01131	0.00000	1.03477	0.03817
FOKKER	F100	0.07296	0.06384	1.92434	0.04925	0.02268	0.06048	1.27009	0.04082
LOCKHEED	L-1011-100	0.12126	0.82745	11.62029	0.18171	0.10800	1.13859	7.16588	0.15012
LOCKHEED	L-1011-200	0.12126	0.82745	11.62029	0.18171	0.10800	1.13859	7.16588	0.15012
LOCKHEED	L-1011-500	0.15514	0.27846	20.80515	0.21481	0.08377	0.09666	12.30817	0.17399
MCDONNELL DOUG	DC10-10	0.09374	0.15624	12.49933	0.16874	0.07727	0.12879	8.39719	0.13909
MCDONNELL DOUG	DC10-30	0.25693	0.21411	14.98785	0.23124	0.24129	0.17235	9.99640	0.18614
MCDONNELL DOUG	DC10-40	0.03778	0.00000	14.62178	0.20402	0.03220	0.00000	9.17766	0.17389
MCDONNELL DOUG	DC8	0.70715	0.35742	3.58740	0.15663	0.29759	0.55929	2.28438	0.12634
MCDONNELL DOUG	DC8-51	1.12705	0.42264	3.40933	0.15215	0.44736	0.62631	2.21445	0.12079
MCDONNELL DOUG	DC8-52	1.12705	0.42264	3.40933	0.15215	0.44736	0.62631	2.21445	0.12079
MCDONNELL DOUG	DC8-53	1.12705	0.42264	3.40933	0.15215	0.44736	0.62631	2.21445	0.12079
MCDONNELL DOUG	DC8-55	1.12705	0.42264	3.40933	0.15215	0.44736	0.62631	2.21445	0.12079
MCDONNELL DOUG	DC8-60	0.70715	0.35742	3.58740	0.15663	0.29759	0.55929	2.28438	0.12634
MCDONNELL DOUG	DC8-61	1.12705	0.42264	3.40933	0.15215	0.44736	0.62631	2.21445	0.12079
MCDONNELL DOUG	DC8-61(CARG)	1.12705	0.42264	3.40933	0.15215	0.44736	0.62631	2.21445	0.12079
MCDONNELL DOUG	DC8-62	1.12705	0.42264	3.40933	0.15215	0.44736	0.62631	2.21445	0.12079
MCDONNELL DOUG	DC8-62(CARG)	0.50208	0.32556	3.67437	0.15882	0.22444	0.52657	2.31852	0.12906
MCDONNELL DOUG	DC8-63	1.12705	0.42264	3.40933	0.15215	0.44736	0.62631	2.21445	0.12079
MCDONNELL DOUG	DC8-63F(CARG)	0.36028	0.29189	3.79426	0.15079	0.16904	0.43867	2.43225	0.12290
MCDONNELL DOUG	DC8-70	0.00946	0.21276	4.37344	0.12766	0.00983	0.17691	3.14499	0.10614
MCDONNELL DOUG	DC8-71	0.00946	0.21276	4.37344	0.12766	0.00983	0.17691	3.14499	0.10614
MCDONNELL DOUG	DC8-73F(CARG)	0.00946	0.21276	4.37344	0.12766	0.00983	0.17691	3.14499	0.10614
MCDONNELL DOUG	DC9-10	0.02968	0.10683	2.04173	0.06410	0.02434	0.10709	1.36300	0.05257
MCDONNELL DOUG	DC9-15F	0.04481	0.16737	2.03164	0.06410	0.04503	0.18157	1.32162	0.05257
MCDONNELL DOUG	DC9-30	0.04106	0.16385	2.14548	0.06539	0.04153	0.17266	1.36728	0.05347
MCDONNELL DOUG	DC9-40	0.03534	0.09895	2.70000	0.07634	0.02835	0.11340	1.70102	0.06124
MCDONNELL DOUG	DC9-50	0.09426	0.11057	2.84511	0.08007	0.08660	0.12100	1.79371	0.06408
MCDONNELL DOUG	DC9-80	0.04453	0.12575	4.09984	0.08560	0.05559	0.15878	2.65318	0.06965
MCDONNELL DOUG	MD-11	0.03271	0.24299	15.25685	0.25233	0.02974	0.19329	8.92832	0.20072
NAMC	YS-11	0.00000	0.05623	0.10991	0.01380	0.00000	0.06120	0.07956	0.01102

TK = Takeoff; CB = Climbout
AP = Approach; ID = Idle

Table F-3. Engine Modal Efs (kgs/min)		**AP**	**AP**	**AP**	**AP**	**ID**	**ID**	**ID**	**ID**
Body Type		**THCef**	**COef**	**NOXef**	**SO2ef**	**THCef**	**COef**	**NOXef**	**SO2ef**
AIRBUS	A300-600	0.01649	0.15911	0.75104	0.04452	0.22331	1.03460	0.09414	0.01341
AIRBUS	A300-B4	0.07696	0.52471	0.58767	0.03778	0.62401	1.58402	0.07920	0.01296
AIRBUS	A310-200	0.01019	0.09637	0.81483	0.04231	0.02944	0.21932	0.10873	0.01432
AIRBUS	A310-300	0.01067	0.07757	0.78988	0.03843	0.01572	0.27103	0.10408	0.01147
AIRBUS	A320-200	0.01397	0.08730	0.27936	0.01886	0.01698	0.21352	0.04853	0.00655
BEECH	18(CARG)	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00000	0.00001
BEECH	B. 99A	0.00712	0.07577	0.02722	0.00176	0.87296	0.11136	0.00423	0.00094
BOEING	B707-300B	0.33216	2.03450	0.39860	0.04484	3.62883	3.17522	0.81001	0.01750
BOEING	B707-300C	0.33216	2.03450	0.39860	0.04484	3.62883	3.17522	0.81001	0.01750
BOEING	B727-100	0.07807	0.51081	0.28613	0.02781	0.23526	0.79047	0.06348	0.01255
BOEING	B727-100(CARG)	0.08150	0.53185	0.28421	0.02784	0.24279	0.81513	0.06293	0.01256
BOEING	B727-200	0.06827	0.38700	0.31422	0.02785	0.17884	0.63268	0.06732	0.01223
BOEING	B737-100	0.03747	0.19002	0.22375	0.01993	0.09103	0.34641	0.04804	0.00877
BOEING	B737-200	0.03747	0.19002	0.22375	0.01993	0.09103	0.34641	0.04804	0.00877
BOEING	B737-200(CARG)	0.04934	0.23160	0.24353	0.02120	0.13290	0.38528	0.05233	0.00906
BOEING	B737-200C	0.05015	0.23679	0.24327	0.02120	0.13508	0.39173	0.05233	0.00906
BOEING	B737-300	0.00275	0.12811	0.32782	0.02035	0.02499	0.42983	0.05855	0.00771
BOEING	B737-400	0.00275	0.12811	0.32782	0.02035	0.02499	0.42983	0.05855	0.00771
BOEING	B737-500	0.00282	0.12499	0.36692	0.02177	0.02113	0.39879	0.06398	0.00804
BOEING	B747	0.04899	0.27761	1.27372	0.08818	0.68257	3.01467	0.17064	0.03072
BOEING	B747(CARG)	0.07484	0.43410	1.16758	0.08083	1.36657	2.83826	0.16294	0.02838
BOEING	B747-200	0.05436	0.30448	1.27726	0.08756	0.72363	2.95193	0.17157	0.03043
BOEING	B747-400	0.02130	0.23664	1.25420	0.06389	0.08370	0.93373	0.15624	0.02009
BOEING	B747-SP	0.07097	0.41063	1.18350	0.08193	1.26397	2.86473	0.16409	0.02873
BOEING	B747F(CARG)	0.05526	0.32307	1.25169	0.08545	0.84237	2.69471	0.17179	0.02976
BOEING	B757-200	0.01002	0.11077	0.50274	0.02639	0.03834	0.39579	0.07494	0.00923
BOEING	B757-200(CARG)	0.00479	0.11732	0.54267	0.03564	0.02775	0.38189	0.09286	0.01172
BOEING	B767-200	0.02569	0.18609	0.82196	0.04326	0.10651	0.49544	0.07565	0.01109
BOEING	B767-300	0.01646	0.15888	0.74994	0.04445	0.22331	1.03484	0.09414	0.01341
BRITAIRCOR	BAE-111-200	0.00269	0.08810	0.08189	0.00670	0.02639	0.20039	0.01851	0.00264
BRITAIRCOR	BAE-146-1	0.00539	0.17620	0.16379	0.01340	0.05278	0.40079	0.03701	0.00529
CONVAIR	CV 640	0.00000	0.21966	0.02083	0.00511	0.05618	0.26132	0.01010	0.00341
DE HAVILLAND	DHC-6	0.00832	0.06980	0.20017	0.00954	0.06626	0.12073	0.03534	0.00369
FAIRCHILD	FH-227	0.00003	0.32528	0.00879	0.00527	0.14828	0.56705	0.00434	0.00335
FOKKER	F-27 SERIES	0.00003	0.32528	0.00879	0.00527	0.14828	0.56705	0.00434	0.00335

TK = Takeoff; CB = Climbout
AP = Approach; ID = Idle

Table F-3. Engine Modal Efs (kgs/min)		AP	AP	AP	AP	ID	ID	ID	ID
Body Type		**THCef**	**COef**	**NOXef**	**SO2ef**	**THCef**	**COef**	**NOXef**	**SO2ef**
FOKKER	F-28	0.18568	0.59195	0.15771	0.01439	1.27983	1.21759	0.02525	0.00745
FOKKER	F100	0.02484	0.10764	0.15732	0.01490	0.04488	0.31812	0.03300	0.00713
LOCKHEED	L-1011-100	0.76255	2.60140	0.80441	0.05383	2.64518	3.77425	0.11103	0.02208
LOCKHEED	L-1011-200	0.76255	2.60140	0.80441	0.05383	2.64518	3.77425	0.11103	0.02208
LOCKHEED	L-1011-500	0.07938	0.17691	1.11133	0.06124	0.08424	0.53525	0.18144	0.02333
MCDONNELL DOUG	DC10-10	0.06097	0.56617	0.99297	0.04704	0.65319	1.68585	0.13997	0.01680
MCDONNELL DOUG	DC10-30	0.11574	0.60185	1.08797	0.06250	0.87769	2.37739	0.13356	0.02061
MCDONNELL DOUG	DC10-40	0.14485	0.84680	0.84680	0.06017	1.37109	3.17516	0.11774	0.02051
MCDONNELL DOUG	DC8	0.27355	1.94169	0.43975	0.04722	3.68815	3.64029	0.49067	0.01708
MCDONNELL DOUG	DC8-51	0.33216	2.03450	0.39860	0.04484	3.62883	3.17522	0.81001	0.01750
MCDONNELL DOUG	DC8-52	0.33216	2.03450	0.39860	0.04484	3.62883	3.17522	0.81001	0.01750
MCDONNELL DOUG	DC8-53	0.33216	2.03450	0.39860	0.04484	3.62883	3.17522	0.81001	0.01750
MCDONNELL DOUG	DC8-55	0.33216	2.03450	0.39860	0.04484	3.62883	3.17522	0.81001	0.01750
MCDONNELL DOUG	DC8-60	0.27355	1.94169	0.43975	0.04722	3.68815	3.64029	0.49067	0.01708
MCDONNELL DOUG	DC8-61	0.33216	2.03450	0.39860	0.04484	3.62883	3.17522	0.81001	0.01750
MCDONNELL DOUG	DC8-61(CARG)	0.33216	2.03450	0.39860	0.04484	3.62883	3.17522	0.81001	0.01750
MCDONNELL DOUG	DC8-62	0.33216	2.03450	0.39860	0.04484	3.62883	3.17522	0.81001	0.01750
MCDONNELL DOUG	DC8-62(CARG)	0.24493	1.89637	0.45985	0.04838	3.71713	3.86742	0.33472	0.01688
MCDONNELL DOUG	DC8-63	0.33216	2.03450	0.39860	0.04484	3.62883	3.17522	0.81001	0.01750
MCDONNELL DOUG	DC8-63F(CARG)	0.18310	1.42021	0.45467	0.04545	2.74844	2.96751	0.25377	0.01682
MCDONNELL DOUG	DC8-70	0.00597	0.31349	0.61205	0.04031	0.05622	0.94311	0.12288	0.01659
MCDONNELL DOUG	DC8-71	0.00597	0.31349	0.61205	0.04031	0.05622	0.94311	0.12288	0.01659
MCDONNELL DOUG	DC8-73F(CARG)	0.00597	0.31349	0.61205	0.04031	0.05622	0.94311	0.12288	0.01659
MCDONNELL DOUG	DC9-10	0.01373	0.07553	0.21629	0.01854	0.05887	0.22154	0.04880	0.00837
MCDONNELL DOUG	DC9-15F	0.04875	0.31775	0.19295	0.01854	0.14841	0.50071	0.04287	0.00837
MCDONNELL DOUG	DC9-30	0.04789	0.29613	0.19701	0.01887	0.13889	0.47739	0.04328	0.00846
MCDONNELL DOUG	DC9-40	0.06738	0.39203	0.24093	0.02205	0.19497	0.63098	0.05317	0.00957
MCDONNELL DOUG	DC9-50	0.07574	0.32899	0.25998	0.02274	0.17096	0.50299	0.05764	0.00947
MCDONNELL DOUG	DC9-80	0.07339	0.19051	0.41652	0.02474	0.05552	0.20331	0.05998	0.00883
MCDONNELL DOUG	MD-11	0.02365	0.22943	1.08327	0.06386	0.31858	1.47402	0.13407	0.01905
NAMC	YS-11	0.00000	0.21966	0.02083	0.00511	0.05618	0.26132	0.01010	0.00341

TK = Takeoff; CB = Climbout
AP = Approach; ID = Idle

Table F-4. Assumed aircraft body type equivalencies.*

LTO Data Aircraft Type	**Assumed Aircraft Type**
A-300B	A-300B4
A-320-100	A-320-200
B-707-300B/C	B-707-300
B-727-200 (CARGO)	B-727-200
B-727-200C	B-727-200
B-737-100 (CARGO)	B-737-100
B-737-100/200	B-737-100 (50%), B-737-200 (50%)
B-767-200ER	B-767-200
BAE-146-100/200	BAE-146-1 (same as BAE-146-2)
DC-10-10 (CARGO)	DC-10-10
DC-10-30 (CARGO)	DC-10-30
DC-8-50F	DC-8-50
DC-8-73F (CARGO)	DC-8-73F
DC-8-73	DC-8-73F
L-1011-100/200	L-1011-100 (same as L-1011-200)
L-1011-500TR	L-1011-500
MD-8-63F	DC-8-63F

* Equivalencies based upon available databases and literature (e.g., FAEED, 1995; ICAO, 1995; CARB, 1994) and engineering judgement. For three of these equivalencies, emission factors were located for the aircraft type during the final review of the document. Comparison of the actual to the assumed equivalent confirmed that minimal changes would occur in the emissions estimates.

APPENDIX G
FACILITY-SPECIFIC AND REGIONAL EMISSIONS SUMMARIES

Table G-1. 1990 Commercial Aircraft Emissions (short tons/year), Default Mixing Height

	LTOS	**VOC**	**CO**	**NOx**	**SO2**
Hartsfield (ATL)	287,080	1555.13	4136.43	3570.26	165.78
Atlanta Total	**287,080**	**1555.13**	**4136.43**	**3570.26**	**165.78**
Logan (BOS)	114,282	894.28	2295.22	1752.92	77.07
Boston Total	**114,282**	**894.28**	**2295.22**	**1752.92**	**77.07**
Douglas (CLT)	119,990	748.56	1385.67	956.74	52.01
Charlotte Total	**119,990**	**748.56**	**1385.67**	**956.74**	**52.01**
Midway (MDW)	65,135	119.11	446.16	483.95	25.37
O'Hare (ORD)	347,653	1534.13	5137.57	4552.77	209.84
Chicago Total	**412,788**	**1653.23**	**5583.73**	**5036.72**	**235.20**
Hobby (HOU)	55,779	72.80	352.25	441.03	22.07
Intercontinental (IAH)	181,214	596.88	2132.56	2111.24	100.76
Houston Total	**236,993**	**669.68**	**2484.80**	**2552.27**	**122.83**
Burbank (BUR)	26,129	16.55	160.76	213.79	9.77
Los Angeles Intl. (LAX)	212,041	1958.73	5321.53	4202.68	168.69
Long Beach (LGB)	12,984	13.38	81.65	134.65	5.76
Ontario (ONT)	40,323	78.59	347.42	452.82	20.33
John Wayne (SNA)	28,291	32.13	213.94	271.01	12.02
Los Angeles Total	**319,768**	**2099.38**	**6125.31**	**5274.95**	**216.57**
Newark (EWR)	134,124	773.48	2241.86	1722.35	84.38
John F. Kennedy (JFK)	94,382	1398.94	4082.31	2806.06	113.34
La Guardia (LGA)	154,700	877.80	2492.55	1823.20	93.68
New York Total	**383,206**	**3050.22**	**8816.72**	**6351.61**	**291.41**
Philadelphia Intl. (PHL)	107,646	354.67	1127.38	1098.41	53.11
Philadelphia Total	**107,646**	**354.67**	**1127.38**	**1098.41**	**53.11**
Sky Harbor (PHX)	121,024	226.14	1014.73	1130.01	53.71
Phoenix Total	**121,024**	**226.14**	**1014.73**	**1130.01**	**53.71**
National (DCA)	96,931	249.45	930.37	1007.71	49.37
Dulles (IAD)	60,787	267.12	868.35	800.15	36.03
Washington, DC Total	**157,718**	**516.57**	**1798.72**	**1807.86**	**85.39**
Grand Total	**2,260,495**	**11,767.86**	**34,768.71**	**29,531.76**	**1,353.08**

Table G-2. 2010 Commercial Aircraft Emissions (short tons/year), Default Mixing Height

	LTOs	**VOC**	**CO**	**NOx**	**SO2**
Hartsfield (ATL)	388,728	3,180.47	6,858.94	7,397.42	262.18
Atlanta Total	**388,728**	**3,180.47**	**6,858.94**	**7,397.42**	**262.18**
Logan (BOS)	137,137	1,461.75	3,417.41	2,897.56	104.64
Boston Total	**137,137**	**1,461.75**	**3,417.41**	**2,897.56**	**104.64**
Douglas (CLT)	215,726	2,123.93	2,907.53	1,702.28	83.83
Charlotte Total	**215,726**	**2,123.93**	**2,907.53**	**1,702.28**	**83.83**
Midway (MDW)	66,510	121.62	455.59	494.16	25.90
O'Hare (ORD)	500,767	2,111.02	7,301.24	8,216.63	303.11
Chicago Total	**567,277**	**2,232.64**	**7,756.83**	**8,710.79**	**329.01**
Hobby (HOU)	61,621	80.39	389.06	487.13	24.37
Intercontinental (IAH)	337,080	927.31	3,550.96	4,642.39	183.53
Houston Total	**398,701**	**1,007.71**	**3,940.03**	**5,129.52**	**207.91**
Burbank (BUR)	30,607	18.68	187.52	250.41	11.41
Los Angeles Intl. (LAX)	312,976	2,956.98	7,870.28	6,454.80	237.37
Long Beach (LGB)	14,790	13.70	89.26	153.72	6.49
Ontario (ONT)	53,445	72.94	442.26	694.10	27.89
John Wayne (SNA)	33,043	26.05	238.73	318.06	13.73
Los Angeles Total	**444,860**	**3,088.35**	**8,828.05**	**7,871.08**	**296.89**
Newark (EWR)	183,381	1,377.01	3,642.37	3,317.04	127.39
John F. Kennedy (JFK)	111,360	1,690.74	5,548.37	4,169.16	154.16
La Guardia (LGA)	158,209	1,804.44	3,745.06	3,164.30	112.46
New York Total	**452,950**	**4,872.19**	**12,935.80**	**10,650.50**	**394.01**
Philadelphia Intl. (PHL)	123,177	439.86	1,293.80	1,678.46	64.66
Philadelphia Total	**123,177**	**439.86**	**1,293.80**	**1,678.46**	**64.66**
Sky Harbor (PHX)	179,265	305.27	1,667.14	1,954.14	81.24
Phoenix Total	**179,265**	**305.27**	**1,667.14**	**1,954.14**	**81.24**
National (DCA)	97,268	132.18	643.28	1,180.26	46.49
Dulles (IAD)	105,888	580.12	1,823.95	1,933.10	70.69
Washington, DC Total	**203,156**	**712.30**	**2,467.23**	**3,113.36**	**117.18**
Grand Total	**3,110,977**	**19,424.48**	**52,072.75**	**51,105.12**	**1,941.56**

Table G-3. 1990 Commercial Aircraft Emissions (short tons/year), Variable Mixing Height

	LTOS	**VOC**	**CO**	**NOx**	**SO2**
Hartsfield (ATL)	287,080	1468.13	3791.43	2058.41	111.16
Atlanta Total	**287,080**	**1468.13**	**3791.43**	**2058.41**	**111.16**
Logan (BOS)	114,282	875.81	2216.65	1359.73	63.91
Boston Total	**114,282**	**875.81**	**2216.65**	**1359.73**	**63.91**
Douglas (CLT)	119,990	720.88	1273.40	549.60	34.41
Charlotte Total	**119,990**	**720.88**	**1273.40**	**549.60**	**34.41**
Midway (MDW)	65,135	109.67	403.30	317.76	18.01
O'Hare (ORD)	347,653	1470.43	4846.49	3019.34	155.29
Chicago Total	**412,788**	**1580.10**	**5249.79**	**3337.09**	**173.31**
Hobby (HOU)	55,779	68.40	328.86	327.49	17.17
Intercontinental (IAH)	181,214	572.40	2030.13	1582.74	80.76
Houston Total	**236,993**	**640.80**	**2358.99**	**1910.23**	**97.93**
Burbank (BUR)	26,129	15.26	149.96	138.92	6.84
Los Angeles Intl. (LAX)	212,041	1907.90	5104.69	2776.14	124.63
Long Beach (LGB)	12,984	11.77	75.07	87.79	4.08
Ontario (ONT)	40,323	72.92	321.79	296.30	14.45
John Wayne (SNA)	28,291	30.01	200.77	177.57	8.52
Los Angeles Total	**319,768**	**2037.87**	**5852.28**	**3476.72**	**158.51**
Newark (EWR)	134,124	765.89	2209.60	1553.81	78.28
John F. Kennedy (JFK)	94,382	1392.04	4056.67	2530.61	105.44
La Guardia (LGA)	154,700	867.37	2446.12	1644.08	86.68
New York Total	**383,206**	**3025.30**	**8712.39**	**5728.50**	**270.40**
Philadelphia Intl. (PHL)	107,646	345.33	1085.66	904.55	45.58
Philadelphia Total	**107,646**	**345.33**	**1085.66**	**904.55**	**45.58**
Sky Harbor (PHX)	121,024	208.35	914.35	555.32	31.12
Phoenix Total	**121,024**	**208.35**	**914.35**	**555.32**	**31.12**
National (DCA)	96,931	237.33	878.59	755.69	39.47
Dulles (IAD)	60,787	260.01	834.57	599.63	29.07
Washington, DC Total	**157,718**	**497.34**	**1713.17**	**1355.32**	**68.53**
Grand Total	**2,260,495**	**11,399.92**	**33,168.11**	**21,235.47**	**1,054.87**

Table G-4. 2010 Commercial Aircraft Emissions (short tons/year), Variable Mixing Height

	LTOs	**VOC**	**CO**	**NOx**	**SO2**
Hartsfield (ATL)	388,728	3,026.52	6,318.79	4,189.04	171.53
Atlanta Total	**388,728**	**3,026.52**	**6,318.79**	**4,189.04**	**171.53**
Logan (BOS)	137,137	1,436.86	3,318.84	2,234.13	86.12
Boston Total	**137,137**	**1,436.86**	**3,318.84**	**2,234.13**	**86.12**
Douglas (CLT)	215,726	2,070.46	2,715.44	962.20	55.16
Charlotte Total	**215,726**	**2,070.46**	**2,715.44**	**962.20**	**55.16**
Midway (MDW)	66,510	111.98	411.82	324.47	18.39
O'Hare (ORD)	500,767	2,037.66	6,975.06	5,386.47	221.21
Chicago Total	**567,277**	**2,149.64**	**7,386.88**	**5,710.94**	**239.60**
Hobby (HOU)	61,621	75.56	363.30	361.79	18.97
Intercontinental (IAH)	337,080	887.15	3,408.40	3,457.94	145.72
Houston Total	**398,701**	**962.71**	**3,771.70**	**3,819.72**	**164.68**
Burbank (BUR)	30,607	17.22	175.02	162.67	7.98
Los Angeles Intl. (LAX)	312,976	2883.37	7553.99	4237.86	174.29
Long Beach (LGB)	14,790	11.92	82.13	100.17	4.59
Ontario (ONT)	53,445	66.72	414.08	451.04	19.67
John Wayne (SNA)	33,043	24.62	225.14	207.99	9.71
Los Angeles Total	**444,860**	**3,003.86**	**8,450.37**	**5,159.73**	**216.24**
Newark (EWR)	183,381	1,366.78	3,603.28	2,982.78	117.75
John F. Kennedy (JFK)	111,360	1,683.33	5,523.48	3,750.82	143.13
La Guardia (LGA)	158,209	1,788.44	3,681.34	2,840.18	103.47
New York Total	**452,950**	**4,838.54**	**12,808.10**	**9,573.78**	**364.35**
Philadelphia Intl. (PHL)	123,177	430.34	1,254.54	1,375.21	55.14
Philadelphia Total	**123,177**	**430.34**	**1,254.54**	**1,375.21**	**55.14**
Sky Harbor (PHX)	179,265	289.28	1,533.12	944.02	46.22
Phoenix Total	**179,265**	**289.28**	**1,533.12**	**944.02**	**46.22**
National (DCA)	97,268	122.99	610.10	878.86	36.79
Dulles (IAD)	105,888	568.87	1,767.43	1,438.13	56.51
Washington, DC Total	**203,156**	**691.86**	**2,377.53**	**2,317.00**	**93.30**
Grand Total	**3,110,977**	**18,900.07**	**49,935.31**	**36,285.77**	**1,492.32**

Table G-5. 1990 Commercial Aircraft Emissions (metric tons/year), Default Mixing Height

	LTOS	**VOC**	**CO**	**NOx**	**SO2**
Hartsfield (ATL)	287,080	1410.80	3752.55	3238.92	150.39
Atlanta Total	**287,080**	**1410.80**	**3752.55**	**3238.92**	**150.39**
Logan (BOS)	114,282	811.29	2082.21	1590.24	69.92
Boston Total	**114,282**	**811.29**	**2082.21**	**1590.24**	**69.92**
Douglas (CLT)	119,990	679.09	1257.07	867.95	47.18
Charlotte Total	**119,990**	**679.09**	**1257.07**	**867.95**	**47.18**
Midway (MDW)	65,135	108.05	404.76	439.03	23.01
O'Hare (ORD)	347,653	1391.75	4660.77	4130.25	190.36
Chicago Total	**412,788**	**1499.80**	**5065.53**	**4569.28**	**213.37**
Hobby (HOU)	55,779	66.05	319.56	400.10	20.02
Intercontinental (IAH)	181,214	541.48	1934.64	1915.30	91.41
Houston Total	**236,993**	**607.53**	**2254.20**	**2315.40**	**111.43**
Burbank (BUR)	26,129	15.01	145.84	193.95	8.86
Los Angeles Intl. (LAX)	212,041	1776.95	4827.66	3812.64	153.04
Long Beach (LGB)	12,984	12.14	74.08	122.15	5.22
Ontario (ONT)	40,323	71.29	315.18	410.79	18.44
John Wayne (SNA)	28,291	29.14	194.08	245.86	10.90
Los Angeles Total	**319,768**	**1904.54**	**5556.84**	**4785.41**	**196.47**
Newark (EWR)	134,124	701.69	2033.80	1562.51	76.55
John F. Kennedy (JFK)	94,382	1269.11	3703.45	2545.64	102.82
La Guardia (LGA)	154,700	796.34	2261.22	1653.99	84.99
New York Total	**383,206**	**2,767.14**	**7,998.48**	**5,762.15**	**264.36**
Philadelphia Intl. (PHL)	107,646	321.76	1022.75	996.47	48.18
Philadelphia Total	**107,646**	**321.76**	**1022.75**	**996.47**	**48.18**
Sky Harbor (PHX)	121,024	205.15	920.56	1025.14	48.73
Phoenix Total	**121,024**	**205.15**	**920.56**	**1025.14**	**48.73**
National (DCA)	96,931	226.30	844.03	914.19	44.79
Dulles (IAD)	60,787	242.33	787.76	725.89	32.68
Washington, DC Total	**157,718**	**468.63**	**1631.79**	**1640.08**	**77.47**
Grand Total	**2,260,495**	**10,675.73**	**31,541.97**	**26,791.03**	**1,227.50**

Table G-6. 2010 Commercial Aircraft Emissions (metric tons/year), Default Mixing Height

	LTOs	**VOC**	**CO**	**NOx**	**SO2**
Hartsfield (ATL)	388,728	2,885.33	6,222.43	6,710.94	237.85
Atlanta Total	**388,728**	**2,885.33**	**6,222.43**	**6,710.94**	**237.85**
Logan (BOS)	137,137	1,326.10	3,100.27	2,628.67	94.93
Boston Total	**137,137**	**1,326.10**	**3,100.27**	**2,628.67**	**94.93**
Douglas (CLT)	215,726	1,926.83	2,637.71	1,544.31	76.05
Charlotte Total	**215,726**	**1,926.83**	**2,637.71**	**1,544.31**	**76.05**
Midway (MDW)	66,510	110.33	413.31	448.31	23.50
O'Hare (ORD)	500,767	1,915.12	6,623.68	7,454.13	274.98
Chicago Total	**567,277**	**2,025.45**	**7,036.99**	**7,902.43**	**298.48**
Hobby (HOU)	61,621	72.93	352.96	441.92	22.11
Intercontinental (IAH)	337,080	841.26	3,221.43	4,211.58	166.50
Houston Total	**398,701**	**914.19**	**3,574.39**	**4,653.50**	**188.61**
Burbank (BUR)	30,607	16.94	170.11	227.17	10.35
Los Angeles Intl. (LAX)	312,976	2,682.57	7,139.92	5,855.79	215.34
Long Beach (LGB)	14,790	12.43	80.98	139.45	5.89
Ontario (ONT)	53,445	66.17	401.22	629.68	25.30
John Wayne (SNA)	33,043	23.64	216.57	288.54	12.45
Los Angeles Total	**444,860**	**2,801.75**	**8,008.81**	**7,140.65**	**269.34**
Newark (EWR)	183,381	1,249.22	3,304.36	3,009.22	115.57
John F. Kennedy (JFK)	111,360	1,533.84	5,033.48	3,782.26	139.85
La Guardia (LGA)	158,209	1,636.98	3,397.52	2,870.65	102.02
New York Total	**452,950**	**4,420.05**	**11,735.35**	**9,662.13**	**357.45**
Philadelphia Intl. (PHL)	123,177	399.05	1,173.74	1,522.70	58.66
Philadelphia Total	**123,177**	**399.05**	**1,173.74**	**1,522.70**	**58.66**
Sky Harbor (PHX)	179,265	276.94	1,512.43	1,772.79	73.70
Phoenix Total	**179,265**	**276.94**	**1,512.43**	**1,772.79**	**73.70**
National (DCA)	97,268	119.92	583.58	1,070.73	42.18
Dulles (IAD)	105,888	526.28	1,654.69	1,753.71	64.13
Washington, DC Total	**203,156**	**646.20**	**2,238.27**	**2,824.44**	**106.31**
Grand Total	**3,110,977**	**17,621.88**	**47,240.40**	**46,362.56**	**1,761.38**

Table G-7. 1990 Commercial Aircraft Emissions (metric tons/year), Variable Mixing Height

	LTOS	**VOC**	**CO**	**NOx**	**SO2**
Hartsfield (ATL)	287,080	1331.88	3439.57	1867.38	100.84
Atlanta Total	**287,080**	**1331.88**	**3439.57**	**1867.38**	**100.84**
Logan (BOS)	114,282	794.53	2010.93	1233.54	57.98
Boston Total	**114,282**	**794.53**	**2010.93**	**1233.54**	**57.98**
Douglas (CLT)	119,990	653.98	1155.22	498.59	31.22
Charlotte Total	**119,990**	**653.98**	**1155.22**	**498.59**	**31.22**
Midway (MDW)	65,135	99.49	365.87	288.27	16.34
O'Hare (ORD)	347,653	1333.97	4396.70	2739.13	140.88
Chicago Total	**412,788**	**1433.46**	**4762.58**	**3027.39**	**157.22**
Hobby (HOU)	55,779	62.05	298.34	297.09	15.57
Intercontinental (IAH)	181,214	519.28	1841.72	1435.85	73.27
Houston Total	**236,993**	**581.33**	**2140.06**	**1732.95**	**88.84**
Burbank (BUR)	28,291	27.23	182.14	161.09	7.73
Los Angeles Intl. (LAX)	26,129	13.85	136.04	126.03	6.20
Long Beach (LGB)	212,041	1730.84	4630.94	2518.50	113.07
Ontario (ONT)	40,323	66.16	291.93	268.80	13.11
John Wayne (SNA)	12,984	10.68	68.10	79.65	3.70
Los Angeles Total	**319,768**	**1848.74**	**5309.16**	**3154.06**	**143.80**
Newark (EWR)	134,124	694.81	2004.54	1409.61	71.02
John F. Kennedy (JFK)	94,382	1262.85	3680.18	2295.75	95.65
La Guardia (LGA)	154,700	786.87	2219.11	1491.50	78.64
New York Total	**383,206**	**2744.53**	**7903.83**	**5196.86**	**245.31**
Philadelphia Intl. (PHL)	107,646	313.28	984.91	820.60	41.35
Philadelphia Total	**107,646**	**313.28**	**984.91**	**820.60**	**41.35**
Sky Harbor (PHX)	121,024	189.02	829.49	503.78	28.23
Phoenix Total	**121,024**	**189.02**	**829.49**	**503.78**	**28.23**
National (DCA)	96,931	215.31	797.06	685.56	35.80
Dulles (IAD)	60,787	235.88	757.12	543.98	26.37
Washington, DC Total	**157,718**	**451.19**	**1554.17**	**1229.54**	**62.17**
Grand Total	**2,260,495**	**10341.94**	**30089.91**	**19264.69**	**956.97**

Table G-8. 2010 Commercial Aircraft Emissions (metric tons/year), Variable Mixing Height

	LTOs	**VOC**	**CO**	**NOx**	**SO2**
Hartsfield (ATL)	388,728	2745.66	5732.40	3800.30	155.61
Atlanta Total	**388,728**	**2745.66**	**5732.40**	**3800.30**	**155.61**
Logan (BOS)	137,137	1303.52	3010.85	2026.80	78.12
Boston Total	**137,137**	**1303.52**	**3010.85**	**2026.80**	**78.12**
Douglas (CLT)	215,726	1878.32	2463.45	872.91	50.04
Charlotte Total	**215,726**	**1878.32**	**2463.45**	**872.91**	**50.04**
Midway (MDW)	66,510	101.59	373.60	294.36	16.69
O'Hare (ORD)	500,767	1848.56	6327.78	4886.61	200.68
Chicago Total	**567,277**	**1950.15**	**6701.38**	**5180.96**	**217.36**
Hobby (HOU)	61,621	68.55	329.59	328.21	17.21
Intercontinental (IAH)	337,080	804.82	3092.10	3137.04	132.19
Houston Total	**398,701**	**873.37**	**3421.69**	**3465.25**	**149.40**
Burbank (BUR)	30,607	15.63	158.78	147.58	7.24
Los Angeles Intl. (LAX)	312,976	2615.79	6852.98	3844.58	158.11
Long Beach (LGB)	14,790	10.81	74.51	90.87	4.17
Ontario (ONT)	53,445	60.53	375.65	409.19	17.84
John Wayne (SNA)	33,043	22.33	204.25	188.69	8.81
Los Angeles Total	**444,860**	**2725.10**	**7666.17**	**4680.91**	**196.17**
Newark (EWR)	183,381	1239.94	3268.89	2705.98	106.82
John F. Kennedy (JFK)	111,360	1527.11	5010.90	3402.74	129.84
La Guardia (LGA)	158,209	1622.47	3339.71	2576.61	93.87
New York Total	**452,950**	**4389.53**	**11619.51**	**8685.33**	**330.54**
Philadelphia Intl. (PHL)	123,177	390.41	1138.12	1247.59	50.02
Philadelphia Total	123,177	390.41	1138.12	1247.59	50.02
Sky Harbor (PHX)	179,265	262.44	1390.84	856.41	41.93
Phoenix Total	**179,265**	**262.44**	**1390.84**	**856.41**	**41.93**
National (DCA)	97,268	111.57	553.49	797.30	33.37
Dulles (IAD)	105,888	516.08	1603.41	1304.67	51.27
Washington, DC Total	**203,156**	**627.66**	**2156.89**	**2101.98**	**84.64**
Grand Total	**3,110,977**	**17,146.14**	**45,301.31**	**32,918.45**	**1,353.83**

APPENDIX H
EPA REGIONAL EMISSION ESTIMATES FOR 1990 AND 2010[1]

---

[1] Sources: EPA 1993b; EPA 1996a

APPENDIX H
EPA REGIONAL EMISSION ESTIMATES FOR 1990 AND 2010

Table H-1. Total regional emissions (short tons/year) from all sources.

	1990			2010		
Region	**VOC**	**NOx**	**SO2**	**VOC**	**NOx**	**SO2**
Atlanta	224748	167080	174090	128042	91732	14336
Boston	377304	284640	229486	217451	126178	63966
Charlotte	63066	41391	36069	41483	23237	13908
Chicago	539292	458495	339631	334749	259702	264691
Houston	1159232	565690	269067	337886	271033	188596
Los Angeles	694080	564901	56578	357299	322695	53735
New York	918914	697440	376663	454301	308530	140533
Philadelphia	522672	290781	148648	229269	145326	113657
Phoenix	133710	120251	8068	86542	112346	9614
Washington DC	195562	205038	242901	94514	83792	29775

Table H-2. Total mobile source emissions (short tons/year).

	1990			2010		
Region	**VOC**	**NOx**	**SO2**	**VOC**	**NOx**	**SO2**
Atlanta	124967	124551	7610	54149	78718	6580
Boston	178146	195213	11947	66478	96947	9034
Charlotte	27381	26736	1556	14141	17360	1283
Chicago	245150	284120	14415	86198	137996	11634
Houston	162671	183341	25359	72169	111856	24763
Los Angeles	379604	445087	40804	103619	243259	38649
New York	387005	412802	37793	131625	204286	31327
Philadelphia	175189	180575	12169	63558	91511	9294
Phoenix	76525	81246	4644	41854	57860	4370
Washington DC	117036	130674	9021	44929	70569	7539

Table H-3. Total nonroad mobile source emissions (short tons/year).

	1990			2010		
Region	**VOC**	**NOx**	**SO2**	**VOC**	**NOx**	**SO2**
Atlanta	25410	32245	862	25041	26467	962
Boston	45849	42548	1240	37867	28944	1229
Charlotte	6625	7453	152	6692	6955	203
Chicago	82315	116102	2977	41797	53852	2771
Houston	49285	74067	17319	43575	56383	18691
Los Angeles	49766	140936	16447	56997	114210	17421
New York	82947	97157	15639	65267	63190	14680
Philadelphia	45263	46484	2455	35474	30996	2299
Phoenix	21409	31070	770	22100	25722	838
Washington DC	28471	35418	2193	23273	22716	1917

Table H-4. Total regional emissions (metric tons/year) from all sources.

	1990			2010		
Region	**VOC**	**NOx**	**SO2**	**VOC**	**NOx**	**SO2**
Atlanta	203890	151574	157933	116159	83219	13006
Boston	342288	258224	208188	197270	114468	58030
Charlotte	57213	37550	32722	37633	21080	12617
Chicago	489242	415944	308111	303682	235600	240126
Houston	1051648	513191	244096	306528	245880	171093
Los Angeles	629665	512475	51327	324140	292747	48748
New York	833633	632713	341706	412139	279897	127491
Philadelphia	474165	263795	134853	207991	131839	103109
Phoenix	121301	109091	7319	78510	101920	8722
Washington DC	177413	186009	220358	85743	76016	27012

Table H-5. Total mobile source emissions (metric tons/year).

	1990			2010		
Region	**VOC**	**NOx**	**SO2**	**VOC**	**NOx**	**SO2**
Atlanta	113369	112992	6904	49124	71413	5969
Boston	161613	177096	10838	60308	87950	8196
Charlotte	24840	24255	1412	12829	15749	1164
Chicago	222399	257752	13077	78198	125189	10554
Houston	147574	166326	23006	65471	101475	22465
Los Angeles	344374	403780	37017	94003	220683	35062
New York	351089	374492	34286	119409	185327	28420
Philadelphia	158930	163817	11040	57659	83018	8431
Phoenix	69423	73706	4213	37970	52490	3964
Washington DC	106174	118547	8184	40759	64020	6839

Table H-6. Total nonroad mobile source emissions (metric tons/year).

	1990			2010		
Region	**VOC**	**NOx**	**SO2**	**VOC**	**NOx**	**SO2**
Atlanta	23052	29252	782	22717	24011	873
Boston	41594	38599	1125	34353	26258	1115
Charlotte	6010	6761	138	6071	6310	184
Chicago	74676	105327	2701	37918	48854	2514
Houston	44711	67193	15712	39531	51150	16956
Los Angeles	45147	127856	14921	51707	103611	15804
New York	75249	88140	14188	59210	57326	13318
Philadelphia	41062	42170	2227	32182	28119	2086
Phoenix	19422	28187	699	20049	23335	760
Washington DC	25829	32131	1989	21113	20608	1739