Technical Support Document (TSD) for the EPA's Proposed Finding that Lead Emissions from Aircraft Engines that Operate on Leaded Fuel Cause or Contribute to Air Pollution that May Reasonably Be Anticipated to Endanger Public Health and Welfare

United States
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Agency

Technical Support Document (TSD) for the EPA's Proposed Finding that Lead Emissions from Aircraft Engines that Operate on Leaded Fuel Cause or Contribute to Air Pollution that May Reasonably Be Anticipated to Endanger Public Health and Welfare

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

EPA United States Environmental Protection Agency

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The data presented in this document supports the EPA's Proposed Finding that Lead Emissions from Aircraft Engines that Operate on Leaded Fuel Cause or Contribute to Air Pollution that May Reasonably Be Anticipated to Endanger Public Health and Welfare. This TSD includes an overview of information regarding piston-engine aircraft and the use of leaded aviation gasoline, the inventory of lead emissions from piston-engine aircraft, concentrations of lead in air attributable to emissions from piston-engine aircraft, an overview of the fate and transport of emissions of lead from piston-engine aircraft and information regarding populations residing near and attending school near airports, including consideration of environmental justice. Appendices to this TSD include EPA's two peer-reviewed reports titled, "Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports"[1] and "National Analysis of the Populations Residing Near or Attending School Near U.S. Airports,"[2] and EPA's two Program Overviews reporting on airport lead monitoring.[3,4,5]

The EPA is proposing to find that lead air pollution may reasonably be anticipated to endanger the public health and welfare within the meaning of section 231(a) of the Clean Air Act. The EPA is also proposing to find that engine emissions of lead from certain aircraft cause or contribute to the lead air pollution that may reasonably be anticipated to endanger public health and welfare under section 231(a) of the Clean Air Act.

The proposed findings, if finalized, would not themselves apply new requirements to entities other than EPA and FAA. Specifically, if the EPA issues final findings that lead emissions from covered aircraft engines cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare, only then would EPA, under section 231 of the Clean Air Act, promulgate aircraft engine emission standards for that air pollutant. In contrast to the findings, those standards would apply to and have an effect on other entities outside the federal government. Such findings also would trigger the FAA's statutory mandate to prescribe standards for the composition or chemical or physical properties of an aircraft fuel or fuel additive to control or eliminate aircraft emissions which EPA has decided endanger public health or welfare under section 231(a) of the Clean Air Act.

Even in the event this proposed action is finalized, it is premature to speculate on the scope, applicability, timing, and nature of any subsequent rulemakings by EPA and FAA. The impact of any subsequent rulemaking cannot be evaluated with any reasonable amount of certainty at this point. We also understand that industry may now be taking, or in the future could take, voluntary actions related to aircraft lead emissions. As noted by the National Academies of Sciences, Engineering, and Medicine (NAS) in 2021, there are a number of regulatory and non-regulatory options to mitigate lead emissions from aircraft, including the potential use of existing unleaded

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[1] EPA (2020) Model-Extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports. EPA, Washington, DC, EPA-420-R-20-003, 2020. EPA responses to peer review comments on the report are available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YIWD.pdf.

[2] EPA (2020) Analysis of the Populations Residing Near or Attending School Near U.S. Airports. EPA-420-R-20-001, available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YG4A.pdf, and in the EPA responses to peer review comments on the report, available here: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YISM.pdf.

[3] EPA (2013) Program Update: Airport Lead Monitoring. EPA, Washington, DC, EPA-420-F-13-032, 2013. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100GNLC.PDF?Dockey=P100GNLC.PDF.

[4] EPA (2015) Program Overview: Airport Lead Monitoring. EPA, Washington, DC, EPA-420-F-15-003, 2015. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100LJDW.PDF?Dockey=P100LJDW.PDF.

[5] The appendices duplicate information included in those reports and also include two substantive footnotes in Appendix A, and a few editorial changes and corrections.

fuel options for the piston-engine aircraft fleet certified to operate safely on such fuels; potential future lead-free fuels and propulsion systems; and changes to operations and practices at airports.[6] Even if industry were to take such actions, however, industry's current independent, voluntary behavior, and industry's potential future action or inaction in response to the outcome of this proposed determination, is immaterial to this proposed action, which is limited to determining whether lead emissions from covered aircraft engines cause or contribute to air pollution which may reasonably be anticipated to endanger the public health and welfare within the meaning of CAA section 231(a).

Although not part of the supporting rationale for this action, for informational purposes only, we provide here reference to FAA and industry's evaluation of unleaded fuels to replace leaded aviation gasoline. The FAA currently has two integrated initiatives focused on transitioning safely away from the use of leaded fuel: The Piston Aviation Fuels Initiative (PAFI), and the FAA-industry partnership to Eliminate Aviation Gasoline Lead Emissions (EAGLE). [7,8,9]

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Appendices

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[6] National Academies of Sciences, Engineering, and Medicine 2021. *Options for Reducing Lead Emissions from Piston-Engine Aircraft*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26050.

[7] FAA (2012) Unleaded Avgas Transition Rulemaking Committee: Findings & Recommendations. Available at: https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/UATARC-1312011.pdf

[8] FAA Piston Aviation Fuel Initiative. Information is available at: https://www.faa.gov/about/initiatives/avgas/;

[9] FAA EAGLE Initiative. Information is available at: https://www.faa.gov/unleaded.

Overview of Aircraft Lead Emissions

We summarize here background information that provides context for the proposed finding that lead emissions from certain engines used in aircraft cause or contribute to air pollution that may reasonably be anticipated to endanger public health and welfare. This includes information on the population of aircraft that have piston engines, information on the use of leaded aviation gasoline (avgas) in aircraft, physical and chemical characteristics of lead emissions from engines used in aircraft that can operate on leaded fuel, concentrations of lead in air from these engine emissions, and the fate and transport of lead emitted by engines used in such aircraft. We also include here an analysis of populations residing near and attending school near airports and an analysis of potential environmental justice implications with regard to residential proximity to runways where piston-engine aircraft operate.

This proposal draws extensively from the EPA's scientific assessments for lead, which are developed as part of the EPA's periodic reviews of the air quality criteria[10] for lead and the lead NAAQS.[11] These scientific assessments provide a comprehensive review, synthesis, and evaluation of the most policy-relevant science that builds upon the conclusions of previous assessments. In the information that follows, we discuss and describe scientific evidence summarized in the most recent assessment, the EPA 2013 Lead Integrated Science Assessment (ISA)[12] as well as information summarized in previous EPA Air Quality Criteria Documents (AQCDs), including the 1977, 1986, and 2006 AQCDs.[13,14,15]

As described in the 2013 Lead ISA, lead emitted to ambient air is transported through the air and is distributed from air to other environmental media through deposition.[16] Lead emitted in the past can remain available for environmental or human exposure for extended time in some areas.[17] Depending on the environment where it is deposited, it may to various extents be resuspended into the ambient air, integrated into the media on which it deposits, or transported in

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[10] Under section 108(a)(2) of the CAA, air quality criteria are intended to "accurately reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of [a] pollutant in the ambient air …." Section 109 of the CAA directs the Administrator to propose and promulgate ''primary'' and ''secondary'' NAAQS for pollutants for which air quality criteria are issued. Under CAA section 109(d)(1), EPA must periodically complete a thorough review of the air quality criteria and the NAAQS and make such revisions as may be appropriate in accordance with sections 108 and 109(b) of the CAA. A fuller description of these legislative requirements can be found, for example, in the ISA (see 2013 Lead ISA, p. lxix).

[11] Section 109(b)(1) defines a primary standard as one ''the attainment and maintenance of which in the judgment of the Administrator, based on such criteria and allowing an adequate margin of safety, are requisite to protect the public health.'' A secondary standard, as defined in section 109(b)(2), must ''specify a level of air quality the attainment and maintenance of which, in the judgment of the Administrator, based on such criteria, is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air.''

[12] EPA (2013) ISA for Lead. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[13] EPA (1977) AQC for Lead. EPA, Washington, DC, EPA-600/8-77-017 (NTIS PB280411), 1977.

[14] EPA (1986) AQC for Lead. EPA, Washington, DC, EPA-600/8-83/028aF-dF (NTIS PB87142386), 1986.

[15] EPA (2006) AQC for Lead. EPA, Washington, DC, EPA/600/R-5/144aF, 2006.

[16] EPA (2013) ISA for Lead. Section 3.1.1. "Pathways for Pb Exposure." p. 3-1. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[17] EPA (2013) ISA for Lead. Section 3.7.1. "Exposure." p. 3-144. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

surface water runoff to other areas or nearby waterbodies.[18] Lead in the environment today may have been airborne yesterday or emitted to the air long ago.[19] Over time, lead that was initially emitted to air can become less available for environmental circulation by sequestration in soil, sediment and other reservoirs.[20]

The multimedia distribution of lead emitted into ambient air creates multiple air-related pathways of human and ecosystem exposure. These pathways may involve media other than air, including indoor and outdoor dust, soil, surface water and sediments, vegetation and biota. The human exposure pathways for lead emitted into air include inhalation of ambient air or ingestion of food, water or other materials, including dust and soil, that have been contaminated through a pathway involving lead deposition from ambient air.[21] Ambient air inhalation pathways include both inhalation of air outdoors and inhalation of ambient air that has infiltrated into indoor environments.[22] The air-related ingestion pathways occur as a result of lead emissions to air being distributed to other environmental media, where humans can be exposed to it via contact with and ingestion of indoor and outdoor dusts, outdoor soil, food and drinking water.

The scientific evidence documents exposure to many sources of lead emitted to the air that have resulted in higher blood lead levels, particularly for people living or working near sources, including stationary sources, such as mines and smelters, and mobile sources, such as cars and trucks when lead was a gasoline additive.[23,24,25,26,27,28] Similarly, with regard to emissions from engines used in piston-engine aircraft there have been studies reporting positive associations of children's blood lead levels with proximity to airports and activity by piston-engine aircraft,[29,30] thus indicating potential for children's exposure to lead from aircraft engine emissions. A recent study evaluating cardiovascular mortality rates in adults 65 and older living within a few kilometers and downwind of runways, while not evaluating blood lead levels, found higher

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[18] EPA (2013) ISA for Lead. Section 6.2. "Fate and Transport of Pb in Ecosystems." p. 6-62. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[19] EPA (2013) ISA for Lead. Section 2.3. "Fate and Transport of Pb." p. 2-24. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[20] EPA (2013) ISA for Lead. Section 1.2.1. "Sources, Fate and Transport of Ambient Pb;" p. 1-6. Section 2.3. "Fate and Transport of Pb." p. 2-24. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[21] EPA (2013) ISA for Lead. Section 3.1.1. "Pathways for Pb Exposure." p. 3-1. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[22] EPA (2013) ISA for Lead. Sections 1.3. "Exposure to Ambient Pb." p. 1-11. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[23] EPA (2013) ISA for Lead. Sections 3.4.1. "Pb in Blood." p. 3-85; Section 5.4. "Summary." p. 5-40. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[24] EPA (2006) AQC for Lead. Chapter 3. EPA, Washington, DC, EPA/600/R-5/144aF, 2006.

[25] EPA (1986) AQC for Lead. Section 1.11.3. EPA, Washington, DC, EPA-600/8-83/028aF-dF (NTIS PB87142386), 1986.

[26] EPA (1977) AQC for Lead. Section 12.3.1.1. "Air Exposures." p. 12-10. EPA, Washington, DC, EPA-600/8-77-017 (NTIS PB280411), 1977.

[27] EPA (1977) AQC for Lead. Section 12.3.1.2. "Air Exposures." p. 12-10. EPA, Washington, DC, EPA-600/8-77-017 (NTIS PB280411), 1977.

[28] EPA (1977) AQC for Lead. Section 12.3.1.1. "Air Exposures." p. 12-10. EPA, Washington, DC, EPA-600/8-77-017 (NTIS PB280411), 1977.

[29] Miranda et. al., 2011. A Geospatial Analysis of the Effects of Aviation Gasoline on Childhood Blood Lead Levels. *Environmental Health Perspectives.* 119:1513–1516.

[30] Zahran et. al., 2017. The Effect of Leaded Aviation Gasoline on Blood Lead in Children. *Journal of the Association of Environmental and Resource Economists*. 4(2):575-610.

mortality rates in adults living near single-runway airports in years with more piston-engine air traffic, but not in adults living near multi-runway airports, suggesting the potential for adverse adult health effects near some airports.[31]

A. Piston-Engine Aircraft and the Use of Leaded Aviation Gasoline

Aircraft operating in the U.S. are largely powered by either turbine engines or piston engines, although other propulsion systems are in use and in development. Turbine-engine powered aircraft and a small percentage of piston-engine aircraft (i.e., those with diesel engines) operate on fuel that does not contain a lead additive. Covered aircraft engines is defined here as any aircraft engine that is capable of using leaded aviation gasoline. Covered aircraft, which are predominantly piston-engine powered aircraft, operate on leaded avgas. Examples of covered aircraft include smaller piston-powered aircraft such as the Cessna 172 (single-engine aircraft) and the Beechcraft Baron G58 (twin-engine aircraft), as well as the largest piston-engine aircraft—the Curtiss C-46 and the Douglas DC-6. Additionally, some rotorcraft, such as the Robinson R44 helicopter, light-sport aircraft, and ultralight vehicles can have piston engines that operate using leaded avgas.

Lead is added to avgas in the form of tetraethyl lead. Tetraethyl lead helps boost fuel octane, prevents engine knock, and prevents valve seat recession and subsequent loss of compression for engines without hardened valves. There are three main types of leaded avgas: 100 Octane, which can contain up to 4.24 grams of lead per gallon (1.12 grams of lead per liter), 100 Octane Low Lead (100LL), which can contain up to 2.12 grams of lead per gallon (0.56 grams of lead per liter), and 100 Octane Very Low Lead (100VLL), which can contain up to 0.71 grams of lead per gallon (0.45 grams of lead per liter).[32] Currently, 100LL is the most commonly available and most commonly used type of avgas.[33] Tetraethyl lead was first used in piston-engine aircraft in 1927.[34] Commercial and military aircraft in the U.S. operated on 100 Octane leaded avgas into the 1950s, but in subsequent years, the commercial and military aircraft fleet largely converted to turbine-engine powered aircraft which do not use leaded avgas.[35,36] The use of avgas containing approximately 4 grams of lead per gallon continued in piston-engine aircraft until the early 1970s when 100LL became the dominant leaded fuel in use.

There are two sources of data from the federal government that provide annual estimates of the volume of leaded avgas supplied and consumed in the U.S.: the Department of Energy, Energy Information Administration (DOE EIA) provides information on the volume of leaded

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[31] Klemick et. al., 2022. Cardiovascular Mortality and Leaded Aviation Fuel: Evidence from Piston-Engine Air Traffic in North Carolina. *International Journal of Environmental Research and Public Health*. 19(10):5941.

[32] ASTM International (May 1, 2021) Standard Specification for Leaded Aviation Gasolines D910-21.

[33] National Academies of Sciences, Engineering, and Medicine (NAS). 2021.Options for Reducing Lead Emissions from Piston-Engine Aircraft. Washington, DC: The National Academies Press. https://doi.org/10.17226/26050.

[34] Ogston 1981. A Short History of Aviation Gasoline Development, 1903-1980. *Society of Automotive Engineers.* p. 810848.

[35] U.S. Department of Commerce Civil Aeronautics Administration. Statistical Handbook of Aviation (Years 1930-1959). https://babel.hathitrust.org/cgi/pt?id=mdp.39015027813032&view=1up&seq=899.

[36] U.S. Department of Commerce Civil Aeronautics Administration. Statistical Handbook of Aviation (Years 1960-1971). https://babel.hathitrust.org/cgi/pt?id=mdp.39015004520279&view=1up&seq=9&skin=2021.

avgas supplied in the U.S.,[37] and the Federal Aviation Administration (FAA) provides information on the volume of leaded avgas consumed in the U.S.[38] Over the ten-year period from 2011 through 2020, DOE estimates of the annual volume of leaded avgas supplied averaged 184 million gallons, with year-on-year fluctuations in fuel supplied ranging from a 25 percent increase to a 29 percent decrease. Over the same period, from 2011 through 2020, the FAA estimates of the annual volume of leaded avgas consumed averaged 196 million gallons, with year-on-year fluctuations in fuel consumed ranging from an eight percent increase to a 14 percent decrease. The FAA forecast for consumption of leaded avgas in the U.S. ranges from 185 million gallons in 2026 to 179 million gallons in 2041, a decrease of three percent in that period.[39] As described later in this section, while the consumption of leaded avgas is expected to decrease three percent from 2026 to 2041, FAA projects increased activity at some airports and decreased activity at other airports out to 2045.

The FAA's National Airspace System Resource (NASR)[40] provides a complete list of operational airport facilities in the U.S. Among the approximately 19,600 airports listed in the NASR, approximately 3,300 are included in the National Plan of Integrated Airport Systems (NPIAS) and support the majority of piston-engine aircraft activity that occurs annually in the U.S.[41] While less aircraft activity occurs at the remaining airports, that activity is conducted predominantly by piston-engine aircraft. Approximately 6,000 airports have been in operation since the early 1970s when the leaded fuel being used contained up to 4.24 grams of lead per gallon of avgas.[42] The activity by piston-engine aircraft spans a range of purposes, as described further below. In Alaska this fleet of aircraft currently play a critical role in the transportation infrastructure.

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[37] DOE. EIA. Petroleum and Other Liquids; Supply and Disposition. Aviation Gasoline in Annual Thousand Barrels. Fuel production volume data obtained from https://www.eia.gov/dnav/pet/pet_sum_snd_a_eppv_mbbl_a_cur-1.htm and https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=C400000001&f=A on Dec., 30, 2021.

[38] Department of Transportation (DOT). FAA. Aviation Policy and Plans. FAA Aerospace Forecast Fiscal Years 2009-2025. p. 81. Available at http://www.faa.gov/data_research/aviation/aerospace_forecasts/2009-2025/media/2009%20Forecast%20Doc.pdf. This document provides historical data for 2000-2008 as well as forecast data.

[39] DOT. FAA. Aviation Policy and Plans. Table 23. p. 111. FAA Aerospace Forecast Fiscal Years 2021-2041. Available at https://www.faa.gov/sites/faa.gov/files/data_research/aviation/aerospace_forecasts/FY2021-41_FAA_Aerospace_Forecast.pdf.

[40] *See* FAA. NASR. Available at https://www.faa.gov/air_traffic/flight_info/aeronav/aero_data/eNASR_Browser/.

[41] FAA (2020) National Plan of Integrated Airport Systems (NPIAS) 2021–2025 Published by the Secretary of Transportation Pursuant to Title 49 U.S. Code, Section 47103. Retrieved on Nov. 3, 2021 from: https://www.faa.gov/airports/planning_capacity/npias/current/media/NPIAS-2021-2025-Narrative.pdf.

[42] *See* FAA's NASR. Available at https://www.faa.gov/air_traffic/flight_info/aeronav/aero_data/eNASR_Browser/.

As of 2019, there were 171,934 piston-engine aircraft in the U.S.[43] This total includes 128,926 single-engine aircraft, 12,470 twin-engine aircraft, and 3,089 rotorcraft.[44] The average age of single-engine aircraft in 2018 was 46.8 years and the average age of twin-engine aircraft in 2018 was 44.7 years old.[45] In 2019, 883 new piston-engine aircraft were manufactured in the U.S. some of which are exported.[46] For the period from 2019 through 2041, the fleet of fixed wing[47] piston-engine aircraft is projected to decrease at an annual average rate of 0.9 percent, and the hours flown by these aircraft is projected to decrease 0.9 percent per year from 2019 to 2041.[48] An annual average growth rate in the production of piston-engine powered rotorcraft of 0.9 percent is forecast, with a commensurate 1.9 percent increase in hours flown in that period by piston-engine powered rotorcraft.[49] There were approximately 664,565 pilots certified to fly general aviation aircraft in the U.S. in 2021.[50] This included 197,665 student pilots and 466,900 non-student pilots. In addition, there were more than 301,000 FAA Non-Pilot Certificated mechanics.[51]

Piston-engine aircraft are used to conduct flights that are categorized as either general aviation or air taxi. General aviation flights are defined as all aviation other than military and those flights by scheduled commercial airlines. Air taxi flights are short duration flights made by small commercial aircraft on demand. The hours flown by aircraft in the general aviation fleet are comprised of personal and recreational transportation (67 percent), business (12 percent), instructional flying (8 percent), medical transportation (less than one percent), and the remainder includes hours spent in other applications such as aerial observation and aerial application.[52]

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[43] FAA. General Aviation and Part 135 Activity Surveys – CY 2019. Chapter 1: Historical General Aviation and Air Taxi Measures. Table 1.1 – General Aviation and Part 135 Number of Active Aircraft By Aircraft Type 2008-2019. Retrieved on Dec., 27, 2021 at https://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2019/. Separately, FAA maintains a database of FAA-registered aircraft and as of January 6, 2022 there were 222,592 piston-engine aircraft registered with FAA. See: https://registry.faa.gov/aircraftinquiry/.

[44] FAA. General Aviation and Part 135 Activity Surveys – CY 2019. Chapter 1: Historical General Aviation and Air Taxi Measures. Table 1.1 – General Aviation and Part 135 Number of Active Aircraft By Aircraft Type 2008-2019. Retrieved on Dec., 27, 2021 at https://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2019/.

[45] General Aviation Manufacturers Association (GAMA) (2019) General Aviation Statistical Databook and Industry Outlook, p.27. Retrieved on October 7, 2021 from: GAMA_2019Databook_Final-2020-03-20.pdf

[46] GAMA (2019) General Aviation Statistical Databook and Industry Outlook, p.16. Retrieved on October 7, 2021 from: GAMA_2019Databook_Final-2020-03-20.pdf.

[47] There are both fixed-wing and rotary-wing aircraft; and airplane is an engine-driven, fixed-wing aircraft and a rotorcraft is an engine-driven rotary-wing aircraft.

[48] *See* FAA Aerospace Forecast Fiscal Years 2021-2041. p. 28. Available at https://www.faa.gov/sites/faa.gov/files/data_research/aviation/aerospace_forecasts/FY2021-41_FAA_Aerospace_Forecast.pdf.

[49] FAA Aerospace Forecast Fiscal Years 2021-2041. Table 28. p. 116., and Table 29. p. 117. Available at https://www.faa.gov/sites/faa.gov/files/data_research/aviation/aerospace_forecasts/FY2021-41_FAA_Aerospace_Forecast.pdf.

[50] FAA. U.S. Civil Airmen Statistics. 2021 Active Civil Airman Statistics. Retrieved from U.S. Civil Airmen Statistics | Federal Aviation Administration (faa.gov) on May 20, 2022.

[51] FAA. U.S. Civil Airmen Statistics. 2021 Active Civil Airman Statistics. Retrieved from U.S. Civil Airmen Statistics | Federal Aviation Administration (faa.gov) on May 20, 2022.

[52] FAA. General Aviation and Part 135 Activity Surveys – CY 2019. Chapter 1: Historical General Aviation and Air Taxi Measures. Table 1.4 – General Aviation and Part 135 Total Hours Flown By Actual Use 2008-2019 (Hours in Thousands). Retrieved on Dec., 27, 2021 at https://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2019/.

Aerial application for agricultural activity includes crop and timber production, which involve fertilizer and pesticide application and seeding cropland. In 2019, aerial application in agriculture represented 883,600 hours flown by general aviation aircraft, and approximately 17.5 percent of these total hours were flown by piston-engine aircraft.[53]

Approximately 71 percent of the hours flown that are categorized as general aviation activity are conducted by piston-engine aircraft, and 17 percent of the hours flown that are categorized as air taxi are conducted by piston-engine aircraft.[54] From the period 2012 through 2019, the total hours flown by piston-engine aircraft increased nine percent from 13.2 million hours in 2012 to 14.4 million hours in 2019.[55,56]

As noted earlier, the U.S. has a dense network of airports where piston-engine aircraft operate, and a small subset of those airports have air traffic control towers which collect daily counts of aircraft operations at the facility (one takeoff or landing event is termed an "operation"). These daily operations are provided by the FAA in the Air Traffic Activity System (ATADS).[57] The ATADS reports three categories of airport operations that can be conducted by piston-engine aircraft: Itinerant General Aviation, Local Civil, and Itinerant Air Taxi. The sum of Itinerant General Aviation and Local Civil at a facility is referred to as general aviation operations. Piston-engine aircraft operations in these categories are not reported separately from operations conducted by aircraft using other propulsion systems (e.g., turboprop). Because piston-engine aircraft activity generally comprises the majority of general aviation activity at an airport, general aviation activity is often used as a surrogate measure for understanding piston-engine activity.

In order to understand the trend in airport-specific piston-engine activity in the past ten years, we evaluated the trend in general aviation activity. We calculated the average activity at each of the airports in ATADS over three-year periods for the years 2010 through 2012 and for the years 2017 through 2019. We focused this trend analysis on the airports in ATADS because these data are collected daily at an airport-specific control tower (in contrast with annual activity estimates provided at airports without control towers). There were 513 airports in ATADS for which data were available to determine annual average activity for both the 2010-2012 period and the 2017-2019 time period. The annual average operations by general aviation at each of these airports in the period 2010 through 2012 ranged from 31 to 346,415, with a median of 34,368; the annual average operations by general aviation in the period from 2017 through 2019 ranged from 2,370

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[53] FAA. General Aviation and Part 135 Activity Surveys – CY 2019. Chapter 3: Primary and Actual Use. Table 3.2 – General Aviation and Part 135 Total Hours Flown by Actual Use 2008-2019 (Hours in Thousands). Retrieved on Mar., 22, 2022 at https://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2019/.

[54] FAA. General Aviation and Part 135 Activity Surveys – CY 2019. Chapter 3: Primary and Actual Use. Table 3.2 – General Aviation and Part 135 Total Hours Flown by Actual Use 2008-2019 (Hours in Thousands). Retrieved on Mar., 22, 2022 at https://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2019/.

[55] FAA. General Aviation and Part 135 Activity Surveys – CY 2019. Chapter 3: Primary and Actual Use. Table 1.3 – General Aviation and Part 135 Total Hours Flown by Aircraft Type 2008-2019 (Hours in Thousands). Retrieved on Dec., 27, 2021 at https://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2019/.

[56] In 2012, the FAA Aerospace Forecast projected a 0.03 percent increase in hours flown by the piston-engine aircraft fleet for the period 2012 through 2032. FAA Aerospace Forecast Fiscal Years 2012-2032. p.53.

[57] *See* FAA's Air Traffic Activity Data. Available at https://aspm.faa.gov/opsnet/sys/airport.asp.

to 396,554, with a median of 34,365. Of the 513 airports, 211 airports reported increased general aviation activity over the period evaluated.[58] The increase in the average annual number of operations by general aviation aircraft at these 211 facilities ranged from 151 to 136,872 (an increase of two percent and 52 percent, respectively).

While national consumption of leaded avgas is forecast to decrease three percent from 2026 to 2045, this change in fuel consumption is not expected to occur uniformly across airports in the U.S. The FAA produces the Terminal Area Forecast (TAF), which is the official forecast of aviation activity for the 3,300 U.S. airports that are in the NPIAS.[59] For the 3,306 airports in the TAF, we compared the average activity by general aviation at each airport from 2017-2019 with the FAA forecast for general aviation activity at those airports in 2045. The FAA forecasts that activity by general aviation will decrease at 234 of the airports in the TAF, remain the same at 1,960 airports, and increase at 1,112 of the airports. To evaluate the magnitude of potential increases in activity for the same 513 airports for which we evaluated activity trends in the past ten years, we compared the 2017-2019 average general aviation activity at each of these airports with the forecasted activity for 2045 in the TAF.[60] The annual operations estimated for the 513 airports in 2045 ranges from 2,914 to 427,821 with a median of 36,883. The TAF forecasts an increase in activity at 442 of the 513 airports out to 2045, with the increase in operations at those facilities ranging from 18 to 83,704 operations annually (an increase of 0.2 percent and 32 percent, respectively).

B. Emissions of Lead from Piston-Engine Aircraft

This section describes the physical and chemical characteristics of lead emitted by covered aircraft, and the national, state, county and airport-specific annual inventories of these engine emissions of lead. Information regarding lead emissions from motor vehicle engines operating on leaded fuel is summarized in prior AQCDs for Lead, and the 2013 Lead ISA also includes information on lead emissions from piston-engine aircraft.[61,62,63] Lead is added to avgas in the form of tetraethyl lead along with ethylene dibromide, both of which were used in leaded gasoline for motor vehicles in the past. Therefore, the summary of the science regarding emissions of lead from motor vehicles presented in the 1997 and 1986 AQCDs for Lead is relevant to understanding some of the properties of lead emitted from piston-engine aircraft and the atmospheric chemistry these emissions are expected to undergo. Recent studies relevant to understanding lead emissions from piston-engine aircraft have also been published and are discussed here.

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[58] Geidosch. Memorandum to Docket EPA-HQ-OAR-2022-0389. Past Trends and Future Projections in General Aviation Activity and Emissions. June 1, 2022. Docket ID EPA-HQ-2022-0389.

[59] FAA's TAF Fiscal Years 2020-2045 describes the forecast method, data sources, and review process for the TAF estimates. The documentation for the TAF is available at https://taf.faa.gov/Downloads/TAFSummaryFY2020-2045.pdf.

[60] The TAF is prepared to assist the FAA in meeting its planning, budgeting, and staffing requirements. In addition, state aviation authorities and other aviation planners use the TAF as a basis for planning airport improvements. The TAF is available on the Internet. The TAF database can be accessed at: https://taf.faa.gov.

[61] EPA (1977) AQC for Lead. EPA, Washington, DC, EPA-600/8-77-017 (NTIS PB280411), 1977.

[62] EPA (1986) AQC for Lead. EPA, Washington, DC, EPA-600/8-83/028aF-dF (NTIS PB87142386), 1986.

[63] EPA (2013) ISA for Lead. Section 2.2.2.1 "Pb Emissions from Piston-engine Aircraft Operating on Leaded Aviation Gasoline and Other Non-road Sources." p. 2-10. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

1. Physical and Chemical Characteristics of Lead Emitted by Piston-Engine Aircraft

As with motor vehicle engines, when leaded avgas is combusted, the lead is oxidized to form lead oxide. In the absence of the ethylene dibromide lead scavenger in the fuel, lead oxide can collect on the valves and spark plugs, and if the deposits become thick enough, the engine can be damaged. Ethylene dibromide reacts with the lead oxide, converting it to brominated lead and lead oxybromides. These brominated forms of lead remain volatile at high combustion temperatures and are emitted from the engine along with the other combustion by-products.[64] Upon cooling to ambient temperatures these brominated lead compounds are converted to particulate matter. The presence of lead dibromide particles in the exhaust from a piston-engine aircraft has been confirmed by Griffith (2020) and is the primary form of lead emitted by engines operating on leaded fuel.[65] In addition to lead bromides, ammonium salts of other lead halides were also emitted by motor vehicles and would be expected in the exhaust of piston-engine aircraft.[66]

Uncombusted alkyl lead was also measured in the exhaust of motor vehicles operating on leaded gasoline and is therefore likely to be present in the exhaust from piston-engine aircraft.[67] Alkyl lead is the general term used for organic lead compounds and includes the lead additive tetraethyl lead. Summarizing the available data regarding emissions of alkyl lead from piston-engine aircraft, the 2013 Lead ISA notes that lead in the exhaust that might be in organic form may potentially be 20 percent (as an upper bound estimate).[68] In addition, tetraethyl lead is a highly volatile compound and therefore, a portion of tetraethyl lead in fuel exposed to air will partition into the vapor phase.[69]

Particles emitted by piston-engine aircraft are in the submicron size range (less than one micron in diameter). The Swiss Federal Office of Civil Aviation (FOCA) published a study of piston-engine aircraft emissions including measurements of lead.[70] The Swiss FOCA reported the mean particle diameter of particulate matter emitted by one single-engine piston-powered aircraft ranged from 0.049 to 0.108 microns under different power conditions (lead particles would be expected to be present, but these particles were not separately identified in this study). The particle number concentration ranged from 5.7×10^6 to 8.6×10^6 particles per cm^3. The authors noted that these particle emission rates are comparable to those from a typical diesel

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[64] EPA (1986) AQC for Lead. EPA, Washington, DC, EPA-600/8-83/028aF-dF (NTIS PB87142386), 1986.

[65] Griffith 2020. Electron microscopic characterization of exhaust particles containing lead dibromide beads expelled from aircraft burning leaded gasoline. *Atmospheric Pollution Research* 11:1481-1486.

[66] EPA (1986) AQC for Lead. Volume 2: Chapters 5 & 6. EPA, Washington, DC, EPA-600/8-83/028aF-dF (NTIS PB87142386), 1986.

[67] EPA (2013) ISA for Lead. Table 2-1. "Pb Compounds Observed in the Environment." p. 2-8. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[68] EPA (2013) ISA for Lead. Section 2.2.2.1 "Pb Emissions from Piston-engine Aircraft Operating on Leaded-Aviation Gasoline and Other Non-road Sources." p. 2-10. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[69] Memorandum to Docket EPA-HQ-OAR-2022-0389. Potential Exposure to Non-exhaust Lead and Ethylene Dibromide. June 15, 2022. Docket ID EPA-HQ-2022-0389.

[70] Swiss FOCA (2007) Aircraft Piston Engine Emissions Summary Report. 33-05-003 Piston Engine Emissions_Swiss FOCA_Summary. Report_070612_rit. Available at https://www.bazl.admin.ch/bazl/en/home/specialists/regulations-and-guidelines/environment/pollutant-emissions/aircraft-engine-emissions/report--appendices--database-and-data-sheets.html.

passenger car engine without a particle filter.[71] Griffith (2020) collected exhaust particles from a piston-engine aircraft operating on leaded avgas and examined the particles using electron microscopy. Griffith reported that the mean diameter of particles collected in exhaust was 13 nanometers (0.013 microns) consisting of a 4 nanometer (0.004 micron) lead dibromide particle surrounded by hydrocarbons.

2. Inventory of Lead Emitted by Piston-Engine Aircraft

Lead emissions from covered aircraft are the largest single source of lead to air in the U.S. in recent years, contributing over 50 percent of lead emissions to air starting in 2008 (Table 1).[72] In 2017, approximately 470 tons of lead were emitted by engines in piston-powered aircraft, which constituted 70 percent of the annual emissions of lead to air in that year.[73] Lead is emitted at and near thousands of airports in the U.S. as described in Section A. The EPA's method for developing airport-specific lead estimates is described in the EPA's Advance Notice of Proposed Rulemaking on Lead Emissions from Piston-Engine Aircraft Using Leaded Aviation Gasoline[74] and in the document titled "Calculating Piston-Engine Aircraft Airport Inventories for Lead for the 2008 National Emissions Inventory."[75] The EPA's National Emissions Inventory (NEI) reports airport estimates of lead emissions as well as estimates of lead emitted in-flight, which are allocated to states based on the fraction of piston-engine aircraft activity estimated for each state. These inventory data are briefly summarized here at the state, county, and airport level.[76]

Table 1. Piston-Engine Emissions of Lead to Air

	2008	2011	2014	2017
Piston-engine emissions of lead to air, tons	560	490	460	470
Total U.S. lead emissions, tons	950	810	720	670
Piston-engine emissions as a percent of the total U.S. lead inventory	59%	60%	64%	70%

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[71] Swiss FOCA (2007) Aircraft Piston Engine Emissions Summary Report. 33-05-003 Piston Engine Emissions_Swiss FOCA_Summary. Report_070612_rit. Section 2.2.3.a. Available at https://www.bazl.admin.ch/bazl/en/home/specialists/regulations-and-guidelines/environment/pollutant-emissions/aircraft-engine-emissions/report--appendices--database-and-data-sheets.html.

[72] The lead inventories for 2008, 2011 and 2014 are provided in the U.S. EPA (2018b) Report on the Environment Exhibit 2. Anthropogenic lead emissions in the U.S. Available at https://cfpub.epa.gov/roe/indicator.cfm?i=13#2.

[73] EPA 2017 NEI. Available at https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data.

[74] Advance Notice of Proposed Rulemaking on Lead Emissions from Piston-Engine Aircraft Using Leaded Aviation Gasoline. 75 FR 2440 (April 28, 2010).

[75] Airport lead annual emissions data used were reported in the 2017 NEI. Available at https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data. The methods used to develop these inventories are described in EPA (2010) Calculating Piston-Engine Aircraft Airport Inventories for Lead for the 2008 NEI. EPA, Washington, DC, EPA-420-B-10-044, 2010. (Also available in the docket for this action, EPA-HQ-OAR-2022-0389).

[76] The 2017 NEI utilized 2014 aircraft activity data to develop airport-specific lead inventories. Details can be found on page 3-17 of the document located here: https://www.epa.gov/sites/default/files/2021-02/documents/nei2017_tsd_full_jan2021.pdf#page=70&zoom=100,68,633.

At the state level, the EPA estimates of lead emissions from piston-engine aircraft range from 0.3 tons (Rhode Island) to 50.5 tons (California), 47 percent of which is emitted in the landing and takeoff cycle and 53 percent of which the EPA estimates is emitted in-flight, outside the landing and takeoff cycle.[77] Among the counties in the U.S. where the EPA estimates engine emissions of lead from covered aircraft, lead inventories range from 0.00005 tons per year to 4.1 tons per year and constitute the only source of air-related lead in 1,140 counties (the county estimates of lead emissions include the lead emitted during the landing and takeoff cycle and not lead emitted in-flight).[78] In the counties where engine emissions of lead from aircraft are the sole source of lead to these estimates, annual lead emissions from the landing and takeoff cycle ranged from 0.00015 to 0.74 tons. Among the 1,872 counties in the U.S. with multiple sources of lead, including engine emission from covered aircraft, the contribution of aircraft engine emissions ranges from 0.0006 to 0.26 tons, comprising 0.0065 to 99.98 percent of the county total, respectively.

The EPA estimates that among the approximately 20,000 airports in the U.S., airport lead inventories range from 0.00005 tons per year to 0.9 tons per year.[79] In 2017, the EPA's NEI includes 638 airports where the EPA estimates engine emissions of lead from covered aircraft were 0.1 ton or more of lead annually. Using the FAA's forecasted activity in 2045 for the approximately 3,300 airports in the NPIAS (as described in Section A), the EPA estimates airport-specific inventories may range from 0.00003 tons to 1.28 tons of lead (median of 0.03 tons), with 656 airports estimated to have inventories above 0.1 tons in 2045.[80]

We estimate that piston-engine aircraft have consumed approximately 38.6 billion gallons of leaded avgas in the U.S. since 1930, excluding military aircraft use of this fuel, emitting approximately 113,000 tons of lead to the air.[81]

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[77] Lead emitted in-flight is assigned to states based on their overall fraction of total piston-engine aircraft operations. The state-level estimates of engine emissions of lead include both lead emitted in the landing and takeoff cycle as well as lead emitted in-flight. The method used to develop these estimates is described in EPA (2010) Calculating Piston-Engine Aircraft Airport Inventories for Lead for the 2008 NEI, available here: https://nepis.epa.gov/Exe/ZyPDF.cgi/P1009I13.PDF?Dockey=P1009I13.PDF.

[78] Airport lead annual emissions data used were reported in the 2017 NEI. Available at https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data. In addition to the triennial NEI, the EPA collects from state, local, and Tribal air agencies point source data for larger sources every year (see https://www.epa.gov/air-emissions-inventories/air-emissions-reporting-requirements-aerr for specific emissions thresholds). While these data are not typically published as a new NEI, they are available publicly upon request and are also included in https://www.epa.gov/air-emissions-modeling/emissions-modeling-platforms that are created for years other than the triennial NEI years. County estimates of lead emissions from non-aircraft sources used in this action are from the 2019 inventory. There are 3,012 counties and statistical equivalent areas where EPA estimates engine emissions of lead occur.

[79] *See* EPA 2017 NEI. Available at https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data.

[80] EPA used the method describe in EPA (2010) Calculating Piston-Engine Aircraft Airport Inventories for Lead for the 2008 NEI to estimate airport lead inventories in 2045. This document is available here: https://nepis.epa.gov/Exe/ZyPDF.cgi/P1009I13.PDF?Dockey=P1009I13.PDF.

[81] Geidosch. Memorandum to Docket EPA-HQ-OAR-2022-0389. Lead Emissions from the use of Leaded Aviation Gasoline from 1930 through 2020. June 1, 2022. Docket ID EPA-HQ-2022-0389.

C. Concentrations of Lead in Air Attributable to Emissions from Piston-Engine Aircraft

In this section, we describe the concentrations of lead in air resulting from emissions of lead from covered aircraft. Air quality monitoring and modeling studies for lead at and near airports have identified elevated concentrations of lead in air from piston-engine aircraft exhaust at, and downwind of, airports where these aircraft are active.[82,83,84,85,86,87] This section provides a summary of the literature regarding the local-scale impact of aircraft emissions of lead on concentrations of lead at and near airports, with specific focus on the results of air monitoring for lead that the EPA required at a subset of airports and an analysis conducted by the EPA to estimate concentrations of lead at 13,000 airports in the U.S., titled “Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports.”[88]

Gradient studies evaluate how lead concentrations change with distance from an airport where piston-engine aircraft operate. These studies indicate that concentrations of lead in air are estimated to be one to two orders of magnitude higher at locations proximate to aircraft emissions, compared to nearby locations not impacted by a source of lead air emissions

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[82] Carr et. al., 2011. Development and evaluation of an air quality modeling approach to assess near-field impacts of lead emissions from piston-engine aircraft operating on leaded aviation gasoline. *Atmospheric Environment*, 45 (32), 5795-5804. DOI: http://dx.doi.org/10.1016/j.atmosenv.2011.07.017.

[83] Feinberg et. al., 2016. Modeling of Lead Concentrations and Hot Spots at General Aviation Airports. *Journal of the Transportation Research Board*, No. 2569, Transportation Research Board, Washington, D.C., pp. 80-87. DOI: 10.3141/2569-09.

[84] Municipality of Anchorage (2012). *Merrill Field Lead Monitoring Report*. Municipality of Anchorage Department of Health and Human Services. Anchorage, Alaska. Available at http://www.muni.org/Departments/health/Admin/environment/AirQ/Documents/Merrill%20Field%20Lead%20Monitoring%20Study_2012/Merrill%20Field%20Lead%20Study%20Report%20-%20final.pdf.

[85] Environment Canada (2000) *Airborne Particulate Matter, Lead and Manganese at Buttonville Airport.* Conor Pacific Environmental Technologies for Environmental Protection Service. Ontario.

[86] Fine et. al., 2010. *General Aviation Airport Air Monitoring Study*. South Coast Air Quality Management District. Available at http://www.aqmd.gov/docs/default-source/air-quality/air-quality-monitoring-studies/general-aviation-study/study-of-air-toxins-near-van-nuys-and-santa-monica-airport.pdf.

[87] Lead emitted from piston-engine aircraft in the particulate phase would also be measured in samples collected to evaluate total ambient PM2.5 concentrations.

[88] EPA (2020) Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports. EPA, Washington, DC, EPA-420-R-20-003, 2020. Available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YG52.pdf. EPA responses to peer review comments on the report are available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YIWD.pdf. These documents are also available in the docket for this action (Docket EPA-HQ-OAR-2022-0389). This report is Appendix A in this TSD.

(concentrations for periods of approximately 18 hours to three-month averages).[89,90,91,92,93,94] The magnitude of lead concentrations at and near airports is highly influenced by the amount of aircraft activity (i.e., the number of take-off and landing operations, particularly if concentrated at one runway) and the time spent by aircraft in specific modes of operation. The most significant emissions in terms of ground-based activity, and therefore ground-level concentrations of lead in air, occur near the areas with greatest fuel consumption where the aircraft are stationary and running.[95,96,97] For piston-engine aircraft these areas are most commonly locations in which pilots conduct engine tests during run-up operations prior to take-off (e.g., magneto checks during the run-up operation mode). Run-up operations are conducted while the brakes are engaged so the aircraft is stationary and are often conducted adjacent to the runway end from which the aircraft will take off. Additional modes of operation by piston-engine aircraft, such as taxiing or idling near the runway, may result in additional hotspots of elevated lead concentration (e.g., start-up and idle, maintenance run-up).[98]

The lead NAAQS was revised in 2008.[99] The 2008 decision revised the level, averaging time and form of the standards to establish the current primary and secondary standards, which are both 0.15 micrograms per cubic meter of air, in terms of consecutive three-month average of lead in total suspended particles.[100] In conjunction with strengthening the lead NAAQS in 2008, the EPA enhanced the existing lead monitoring network by requiring monitors to be placed in areas with sources such as industrial facilities and airports with estimated lead emissions of 1.0 ton or more per year. Lead monitoring was conducted at two airports following from these requirements (Deer Valley Airport, AZ and the Van Nuys Airport, CA). In 2010, the EPA made

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[89] These studies report monitored or modeled data for averaging times ranging from approximately 18 hours to three-month averages.

[90] Carr et. al., 2011. Development and evaluation of an air quality modeling approach to assess near-field impacts of lead emissions from piston-engine aircraft operating on leaded aviation gasoline. *Atmospheric Environment,* 45 (32), 5795-5804. DOI: http://dx.doi.org/10.1016/j.atmosenv.2011.07.017.

[91] Heiken et. al., 2014. Quantifying Aircraft Lead Emissions at Airports. ACRP Report 133. http://www.nap.edu/catalog/22142/quantifying-aircraft-lead-emissions-at-airports.

[92] Hudda, et. al., 2022. Substantial Near-Field Air Quality Improvements at a General Aviation Airport Following a Runway Shortening. *Environmental Science & Technology*. DOI: 10.1021/acs.est.1c06765.

[93] Fine et. al., 2010. General Aviation Airport Air Monitoring Study. South Coast Air Quality Management District. http://www.aqmd.gov/docs/default-source/air-quality/air-quality-monitoring-studies/general-aviation-study/study-of-air-toxins-near-van-nuys-and-santa-monica-airport.pdf.

[94] EPA (2020) Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports. EPA, Washington, DC, EPA-420-R-20-003, 2020.

[95] EPA (2010) Development and Evaluation of an Air Quality Modeling Approach for Lead Emissions from Piston-Engine Aircraft Operating on Leaded Aviation Gasoline. EPA, Washington, DC, EPA-420-R-10-007, 2010. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1007H4Q.PDF?Dockey=P1007H4Q.PDF.

[96] EPA (2020) Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports. EPA, Washington, DC, EPA-420-R-20-003, 2020. EPA responses to peer review comments on the report are available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YIWD.pdf.

[97] Feinberg et. al., 2016. Modeling of Lead Concentrations and Hot Spots at General Aviation Airports. *Journal of the Transportation Research Board*, No. 2569, Transportation Research Board, Washington, D.C., pp. 80-87. DOI: 10.3141/2569-09.

[98] Feinberg et. al., 2016. Modeling of Lead Concentrations and Hot Spots at General Aviation Airports. *Journal of the Transportation Research Board*, No. 2569, Transportation Research Board, Washington, D.C., pp. 80-87. DOI: 10.3141/2569-09.

[99] 73 FR 66965 (Nov. 12, 2008).

[100] 40 CFR 50.16 (Nov. 12, 2008).

further revisions to the monitoring requirements such that state and local air quality agencies are now required to monitor near industrial facilities with estimated lead emissions of 0.50 tons or more per year and at airports with estimated emissions of 1.0 ton or more per year.[101] As part of this 2010 requirement to expand lead monitoring, the EPA also required a one-year monitoring study of 15 additional airports with estimated lead emissions between 0.50 and 1.0 ton per year in an effort to better understand how these emissions affect concentrations of lead in the air at and near airports. Further, to help evaluate airport characteristics that could lead to ambient lead concentrations that approach or exceed the lead NAAQS, airports for this one-year monitoring study were selected based on factors such as the level of piston-engine aircraft activity and the predominant use of one runway due to wind patterns.

As a result of these requirements, state and local air authorities collected and certified lead concentration data for at least one year at 17 airports with most monitors starting in 2012 and generally continuing through 2013. The data presented in Table 2 are based on the certified data for these sites and represent the maximum concentration monitored in a rolling three-month average for each location.[102]

Table 2. Lead Concentrations Monitored at 17 Airports in the U.S.

Airport, State	**Lead Design Value,[103] µg/m^3**
Auburn Municipal Airport, WA	0.06
Brookhaven Airport, NY	0.03
Centennial Airport, CO	0.02
Deer Valley Airport, AZ	0.04
Gillespie Field, CA	0.07
Harvey Field, WA	0.02
McClellan-Palomar Airport, CA	0.17
Merrill Field, AK	0.07
Nantucket Memorial Airport, MA	0.01
Oakland County International Airport, MI	0.02
Palo Alto Airport, CA	0.12
Pryor Field Regional Airport, AL	0.01
Reid-Hillview Airport, CA	0.10
Republic Airport, NY	0.01
San Carlos Airport, CA	0.33
Stinson Municipal, TX	0.03
Van Nuys Airport, CA	0.06

Monitored lead concentrations violated the lead NAAQS at two airports in 2012: the McClellan-Palomar Airport and the San Carlos Airport. At both of these airports, monitors were located in close proximity to the area at the end of the runway most frequently used for pre-flight safety checks (i.e., run-up). Alkyl lead emitted by piston-engine aircraft would be expected to

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[101] 75 FR 81226 (Dec. 27, 2010).

[102] EPA (2015) Program Overview: Airport Lead Monitoring. EPA, Washington, DC, EPA-420-F-15-003, 2015. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100LJDW.PDF?Dockey=P100LJDW.PDF. This document is Appendix D in this TSD.

[103] A design value is a statistic that summarizes the air quality data for a given area in terms of the indicator, averaging time, and form of the standard. Design values can be compared to the level of the standard and are typically used to designate areas as meeting or not meeting the standard and assess progress towards meeting the NAAQS.

partition into the vapor phase and would not be collected by the monitoring conducted in this study, which is designed to quantitatively collect particulate forms of lead.[104]

Airport lead monitoring and modeling studies have identified the sharp decrease in lead concentrations with distance from the run-up area and therefore the importance of considering monitor placement relative to the run-up area when evaluating the maximum impact location attributable to lead emissions from piston-engine aircraft. The monitoring data in Table 2 reflect differences in monitor placement relative to the run-up area as well as other factors; this study also provided evidence that air lead concentrations at and downwind from airports could be influenced by factors such as the use of more than one run-up area, wind speed, and the number of operations conducted by single- versus twin-engine aircraft.[105]

The EPA recognized that the airport lead monitoring study provided a small sample of the potential locations where emissions of lead from piston-engine aircraft could potentially cause concentrations of lead in ambient air to exceed the lead NAAQS. Because we anticipated that additional airports and conditions could lead to exceedances of the lead NAAQS at and near airports where piston-engine aircraft operate, and in order to understand the range of lead concentrations at airports nationwide, we developed an analysis of 13,000 airports in the peer-reviewed report titled, "Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports."[106] This report provides estimated ranges of lead concentrations that may occur at and near airports where leaded avgas is used. The study extrapolated modeling results from one airport to estimate air lead concentrations at the maximum impact area near the run-up location for over 13,000 U.S. airports.[107] The model-extrapolated lead estimates in this study indicate that some additional U.S. airports may have air lead concentrations above the NAAQS at this area of maximum impact. The report also indicates that, at the levels of activity analyzed at the 13,000 airports, estimated lead concentrations decrease to below the standard within 50 meters from the location of highest concentration.

To estimate the potential ranges of lead concentrations at and downwind of the anticipated area of highest concentration at airports in the U.S., the relationship between piston-engine aircraft activity and lead concentration at and downwind of the maximum impact site at one

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[104] As noted earlier, when summarizing the available data regarding emissions of alkyl lead from piston-engine aircraft, the 2013 Lead ISA notes that an upper bound estimate of lead in the exhaust that might be in organic form may potentially be 20 percent (2013 Lead ISA, p. 2-10). Organic lead in engine exhaust would be expected to influence receptors within short distances of the point of emission from piston-engine aircraft. Airports with large flight schools and/or facilities with substantial delays for aircraft queued for takeoff could experience higher concentrations of alkyl lead in the vicinity of the aircraft exhaust.

[105] The data in Table 2 represent concentrations measured at one location at each airport and monitors were not consistently placed in close proximity to the run-up areas. Monitored concentrations of lead in air near airports are highly influenced by proximity of the monitor to the run-up area. In addition to monitor placement, there are individual airport factors that can influence lead concentrations (e.g., the use of multiple run-up areas at an airport, fleet composition, and wind speed). The monitoring data reported in Table 2 reflect a range of lead concentrations indicative of the location at which measurements were made and the specific operations at an airport.

[106] EPA (2020) Model-Extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports. EPA, Washington, DC, EPA-420-R-20-003, 2020.

[107] In this study, the EPA defined the maximum impact site as 15 meters downwind of the tailpipe of an aircraft conducting run-up operations in the area designated for these operations at a runway end. The maximum impact area was defined as approximately 50 meters surrounding the maximum impact site.

airport was applied to piston-engine aircraft activity estimates for each U.S. airport.[108] This approach for conducting a nationwide analysis of airports was selected due to the impact of piston-engine aircraft run-up operations on ground-level lead concentrations, which creates a maximum impact area that is expected to be generally consistent across airports. Specifically, these aircraft consistently take off into the wind and typically conduct run-up operations immediately adjacent to the take-off runway end, and thus, modeling lead concentrations from this source is constrained by variation in a few key parameters. These parameters include: 1) total amount of piston-engine aircraft activity, 2) the proportion of activity conducted at one runway end, 3) the proportion of activity conducted by multi-piston-engine aircraft, 4) the duration of run-up operations, 5) the concentration of lead in avgas, 6) wind speed at the model airport relative to the extrapolated airport, and 7) additional meteorological, dispersion model, or operational parameters. These parameters were evaluated through sensitivity analyses as well as quantitative or qualitative uncertainty analyses. To generate robust concentration estimates, the EPA evaluated these parameters, conducted wind-speed correction of extrapolated estimates, and used airport-specific information regarding airport layout and prevailing wind directions for the 13,000 airports.[109]

Results of this national analysis show that model-extrapolated three-month average lead concentrations in the maximum impact area may potentially exceed the lead NAAQS at airports with activity ranging from 3,616 - 26,816 Landing and Take-Off events (LTOs) in a three-month period.[110] The lead concentration estimates from this model-extrapolation approach account for lead engine emissions from aircraft only, and do not include other sources of air-related lead. The broad range in LTOs that may lead to concentrations of lead exceeding the lead NAAQS is due to the piston-engine aircraft fleet mix at individual airports such that airports where the fleet is dominated by twin-engine aircraft would potentially reach concentrations of lead exceeding the lead NAAQS with fewer LTOs compared with airports where single-engine aircraft dominate the piston-engine fleet.[111] Model-extrapolated three-month average lead concentrations from aircraft engine emissions were estimated to extend to a distance of at least 500 meters from the maximum impact area at airports with activity ranging from 1,275 - 4,302 LTOs in that three-month period.[112] In a separate modeling analysis at an airport at which hundreds of take-off and landing events by piston-engine aircraft occur per day, the EPA found that modeled 24-hour

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[108] Prior to this model extrapolation study, the EPA developed and evaluated an air quality modeling approach (this study is available here: https://nepis.epa.gov/Exe/ZyPDF.cgi/P1007H4Q.PDF?Dockey=P1007H4Q.PDF), and subsequently applied the approach to a second airport and again performed an evaluation of the model output using air monitoring data (this second study is available here: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YG52.pdf).

[109] EPA (2020) Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports. EPA, Washington, DC, EPA-420-R-20-003, 2020. Available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YG52.pdf. EPA responses to peer review comments on the report are available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YIWD.pdf. These documents are also available in the docket for this action (Docket EPA-HQ-OAR-2022-0389). This report is Appendix A in this TSD.

[110] EPA (2020) Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports. Table 6. p. 53. EPA, Washington, DC, EPA-420-R-20-003, 2020.

[111] *See* methods used in EPA (2020) Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports. Table 2. p.23. EPA, Washington, DC, EPA-420-R-20-003, 2020.

[112] EPA (2020) Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports, Table 6. p.53. EPA, Washington, DC, EPA-420-R-20-003, 2020.

concentrations of lead were estimated above background extending almost 1,000 meters downwind from the runway.[113]

Model-extrapolated estimates of lead concentrations in the EPA report "Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports" were compared with monitored values and show general agreement, suggesting that the extrapolation method presented in this report provides reasonable estimates of the range in concentrations of lead in air attributable to three-month activity periods of piston-engine aircraft at airports. The assessment included detailed evaluation of the potential impact of run-up duration, the concentration of lead in avgas, and the impact of meteorological parameters on model-extrapolated estimates of lead concentrations attributable to engine emissions of lead from piston-powered aircraft. Additionally, this study included a range of sensitivity analyses as well as quantitative and qualitative uncertainty analyses.

The EPA's model-extrapolation analysis of lead concentrations from engine emissions resulting from covered aircraft found that the lowest annual airport emissions of lead estimated to result in air lead concentrations approaching or potentially exceeding the NAAQS was 0.1 tons per year. There are key pieces of airport-specific data that are needed to fully evaluate the potential for piston-engine aircraft operating at an airport to cause concentrations of lead in the air to exceed the lead NAAQS, and the EPA's report "Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports" provides quantitative and qualitative analyses of these factors.[114] The EPA's estimate of airports that have annual lead inventories of 0.1 ton or more are illustrative of, and provide one approach for an initial screening evaluation of locations where engine emissions of lead from aircraft increase localized lead concentrations in air. Airport-specific assessments would be needed to determine the magnitude of the potential range in lead concentrations at and downwind of each facility.

As described in Section A, the FAA forecasts 0.9 percent decreases in piston-engine aircraft activity out to 2041, however these decreases are not projected to occur uniformly across airports. Among the more than 3,300 airports in the FAA TAF, the FAA forecasts both decreases and increases in general aviation, which is largely comprised of piston-engine aircraft. If the current conditions on which the forecast is based persist, then lead concentrations in the air may increase at the airports where general aviation activity is forecast to increase.

In addition to airport-specific modeled estimates of lead concentrations, the EPA also provides annual estimates of lead concentrations for each census tract in the U.S. as part of the Air Toxics Screening Assessment (AirToxScreen).[115] The census tract concentrations are averages of the area-weighted census block concentrations within the tract. Lead concentrations reported in the AirToxScreen are based on emissions estimates from anthropogenic and natural

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[113] Carr, et. al., 2011. Development and evaluation of an air quality modeling approach to assess near-field impacts of lead emissions from piston-engine aircraft operating on leaded aviation gasoline. *Atmospheric Environment* 45: 5795-5804.

[114] EPA (2020) Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports. Table 6. p.53. EPA, Washington, DC, EPA-420-R-20-003, 2020. EPA responses to peer review comments on the report are available here: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YIWD.pdf.

[115] *See* EPA's most recent AirToxScreen. Available at https://www.epa.gov/AirToxScreen.

sources, including aircraft engine emissions.[116] The 2017 AirToxScreen provides lead concentration estimates in air for 73,449 census tracts in the U.S.[117] Lead emissions from piston-engine aircraft comprised more than 50 percent of these census block area-weighted lead concentrations in over half of the census tracts, which included tracts in all 50 states, as well as Puerto Rico and the Virgin Islands.

D. Fate and Transport of Emissions of Lead from Piston-Engine Aircraft

This section summarizes the chemical transformation that piston-engine aircraft lead emissions are anticipated to undergo in the atmosphere and describes what is known about the deposition of piston-engine aircraft lead, and potential impacts on soil, food, and aquatic environments.

1. Atmospheric Chemistry and Transport of Emissions of Lead from Piston-Engine Aircraft

Lead emitted by piston-engine aircraft can have impacts in the local environment and, due to their small size (i.e., typically less than one micron in diameter),[118,119] lead-bearing particles emitted by piston engines may disperse widely in the environment. However, lead emitted during the landing and takeoff cycle, particularly during ground-based operations such as start-up, idle, preflight run-up checks, taxi and the take-off roll on the runway, may deposit to the local environment and/or infiltrate into buildings.[120] Depending on ambient conditions (e.g., ozone and hydroxyl concentrations in the atmosphere), alkyl lead may exist in the atmosphere for hours to days[121] and may therefore be transported off airport property into nearby communities.

Lead halides emitted by motor vehicles operating on leaded fuel were reported to undergo compositional changes upon cooling and mixing with the ambient air as well as during transport, and we would anticipate lead bromides emitted by piston-engine aircraft to behave similarly in the atmosphere. The water-solubility of these lead-bearing particles was reported to be higher

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[116] These concentration estimates are not used for comparison to the level of the Lead NAAQS due to different temporal averaging times and underlying assumptions in modeling. The AirToxScreen estimates are provided to help state, local and Tribal air agencies and the public identify which pollutants, emission sources and places they may wish to study further to better understand potential risks to public health from air toxics. There are uncertainties inherent in these estimates described by the EPA, some of which are relevant to these estimates of lead concentrations; however, these estimates provide perspective on the potential influence of piston-engine emissions of lead on air quality. *See* https://www.epa.gov/AirToxScreen/airtoxscreen-limitations.

[117] As airports are generally in larger census blocks within a census tract, concentrations for airport blocks dominate the area-weighted average in cases where an airport is the predominant lead emissions source in a census tract.

[118] Swiss FOCA (2007) Aircraft Piston Engine Emissions Summary Report. 33-05-003 Piston Engine Emissions_Swiss FOCA_Summary. Report_070612_rit. Available at https://www.bazl.admin.ch/bazl/en/home/specialists/regulations-and-guidelines/environment/pollutant-emissions/aircraft-engine-emissions/report--appendices--database-and-data-sheets.html.

[119] Griffith 2020. Electron microscopic characterization of exhaust particles containing lead dibromide bads expelled from aircraft burning leaded gasoline. *Atmospheric Pollution Research* 11:1481-1486.

[120] EPA (2013) ISA for Lead. Section 1.3. "Exposure to Ambient Pb." p. 1-11. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[121] EPA (2006) AQC for Lead. Section E.6. p. 2-5. EPA, Washington, DC, EPA/600/R-5/144aF, 2006.

for the smaller lead-bearing particles.[122] Lead halides emitted in motor vehicle exhaust were reported to break down rapidly in the atmosphere via redox reactions in the presence of atmospheric acids.[123] Tetraethyl lead has an atmospheric residence time ranging from a few hours to a few days. Tetraethyl lead reacts with the hydroxyl radical in the gas phase to form a variety of products that include ionic trialkyl lead, dialkyl lead and metallic lead. Trialkyl lead is slow to react with the hydroxyl radical and is quite persistent in the atmosphere.[124]

2. Deposition of Lead Emissions from Piston-Engine Aircraft and Soil Lead Concentrations to Which Piston-Engine Aircraft May Contribute

Lead is removed from the atmosphere and deposited on soil, into aquatic systems and on other surfaces via wet or dry deposition.[125] Meteorological factors (e.g., wind speed, convection, rain, humidity) influence local deposition rates. With regard to deposition of lead from aircraft engine emissions, the EPA modeled the deposition rate for aircraft lead emissions at one airport in a temperate climate in California with dry summer months. In this location, the average lead deposition rate from aircraft emissions of lead was 0.057 milligrams per square meter per year.[126]

Studies summarized in the 2013 Lead ISA suggest that soil is a reservoir for contemporary and historical emissions of lead to air.[127] Once deposited to soil, lead can be absorbed onto organic material, can undergo chemical and physical transformation depending on a number of factors (e.g., pH of the soil and the soil organic content), and can participate in further cycling through air or other media.[128] The extent of atmospheric deposition of lead from aircraft engine emissions would be expected to depend on a number of factors including the size of the particles emitted (smaller particles, such as those in aircraft emissions, have lower settling velocity and may travel farther distances before being deposited compared with larger particles), the temperature of the exhaust (the high temperature of the exhaust creates plume buoyancy), as well as meteorological factors (e.g., wind speed, precipitation rates). As a result of the size of the lead particulate matter emitted from piston-engine aircraft and as a result of these emissions occurring at various altitudes, lead emitted from these aircraft may distribute widely through the environment.[129] Murphy et. al. (2008) reported weekend increases in ambient lead monitored at remote locations in the U.S. that the authors attributed to weekend increases in piston-engine powered general aviation activity.[130]

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[122] EPA (1977) AQC for Lead. Section 6.2.2.1. EPA, Washington, DC, EPA-600/8-77-017, 1977.

[123] EPA (2006) AQC for Lead. Section E.6. EPA, Washington, DC, EPA/600/R-5/144aF, 2006.

[124] EPA (2006) AQC for Lead. Section 2. EPA, Washington, DC, EPA/600/R-5/144aF, 2006.

[125] EPA (2013) ISA for Lead. Section 1.2.1. “Sources, Fate and Transport of Ambient Pb;” p. 1-6; and Section 2.3. “Fate and Transport of Pb.” p. 2-24 through 2-25. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[126] Memorandum to Docket EPA-HQ-OAR-2022-0389. Deposition of Lead Emitted by Piston-engine Aircraft. June 15, 2022. Docket ID EPA-HQ-2022-0389.

[127] EPA (2013) ISA for Lead. Section 2.6.1. “Soils.” p. 2-118. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[128] EPA (2013) ISA for Lead. Chapter 6. “Ecological Effects of Pb.” p. 6-57. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[129] Murphy, et. al., 2008. Weekly patterns of aerosol in the United States. *Atmospheric Chemistry and Physics*. 8:2729–2739.

[130] Lead concentrations collected as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) network and the National Oceanic and Atmospheric Administration (NOAA) monitoring sites.

Heiken et. al. (2014) assessed air lead concentrations potentially attributable to resuspended lead that previously deposited onto soil relative to air lead concentrations resulting directly from aircraft engine emissions.[131] Based on comparisons of lead concentrations in total suspended particulate (TSP) and fine particulate matter (PM2.5) measured at the three airports, coarse particle lead was observed to account for about 20–30 percent of the lead found in TSP. The authors noted that based on analysis of lead isotopes present in the air samples collected at these airports, the original source of the lead found in the coarse particle range appeared to be from aircraft exhaust emissions of lead that previously deposited to soil and were resuspended by wind or aircraft-induced turbulence. Results from lead isotope analysis in soil samples collected at the same three airports led the authors to conclude that lead emitted from piston-engine aircraft were not the dominant source of lead in soil in the samples measured at the airports they studied. The authors note the complex history of topsoil can create challenges in understanding the extent to which aircraft lead emissions impact soil lead concentrations at and near airports (e.g., the source of topsoil can change as a result of site renovation, construction, landscaping, natural events such as wildfire and hurricanes, and other activities). Concentrations of lead in soil at and near airports servicing piston-engine aircraft have been measured using a range of approaches.[132,133,134,135,136,137] Kavouras et. al. (2013) collected soil samples at three airports and reported that construction at an airport involving removal and replacement of topsoil complicated interpretation of the findings at that airport and that the number of runways at an airport may influence resulting lead concentrations in soil (i.e., multiple runways may provide for more wide-spread dispersal of the lead over a larger area than that potentially affected at a single-runway airport).

3. Potential for Lead Emissions from Piston-Engine Aircraft to Impact Agricultural Products

Studies conducted near stationary sources of lead emissions (e.g., smelters) have shown that atmospheric lead sources can lead to contamination of agricultural products, such as vegetables.[138,139] In this way, air lead sources may contribute to dietary exposure pathways.[140] As described in Section A, piston-engine aircraft are used in the application of pesticides,

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[131] Heiken et. al., 2014. ACRP Web-Only Document 21: Quantifying Aircraft Lead Emissions at Airports. Contractor's Final Report for ACRP 02-34. Available at http://www.trb.org/Publications/Blurbs/172599.aspx.

[132] McCumber and Strevett 2017. A Geospatial Analysis of Soil Lead Concentrations Around Regional Oklahoma Airports. *Chemosphere* 167:62-70.

[133] Kavouras, et. al., 2013. Bioavailable Lead in Topsoil Collected from General Aviation Airports. *The Collegiate Aviation Review International* 31(1):57-68. Available at https://doi.org/10.22488/okstate.18.100438

[134] Heiken et. al., 2014. ACRP Web-Only Document 21: Quantifying Aircraft Lead Emissions at Airports. Contractor's Final Report for ACRP 02-34. Available at http://www.trb.org/Publications/Blurbs/172599.aspx.

[135] EPA (2010) Development and Evaluation of an Air Quality Modeling Approach for Lead Emissions from Piston-Engine Aircraft Operating on Leaded Aviation Gasoline. EPA, Washington, DC, EPA-420-R-10-007, 2010. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1007H4Q.PDckey=P1007H4Q.PDF.

[136] Environment Canada (2000) Airborne Particulate Matter, Lead and Manganese at Buttonville Airport. Toronto, Ontario, Canada: Conor Pacific Environmental Technologies for Environmental Protection Service, Ontario Region.

[137] Lejano and Ericson 2005. Tragedy of the Temporal Commons: Soil-Bound Lead and the Anachronicity of Risk. *Journal of Environmental Planning and Management*. 48(2):301-320.

[138] EPA (2013) ISA for Lead. Section 3.1.3.3. "Dietary Pb Exposure." p. 3-20 through 3-24. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[139] EPA (2006) AQC for Lead. Section 8.2.2. EPA, Washington, DC, EPA/600/R-5/144aF.

[140] EPA (2006) AQC for Lead. Section 8.2.2. EPA, Washington, DC, EPA/600/R-5/144aF.

fertilizers and seeding crops for human and animal consumption and as such, provide a potential route of exposure for lead in food. To minimize drift of pesticides and other applications from the intended target, pilots are advised to maintain a height between eight and 12 feet above the target crop during application.[141] The low flying height is needed to minimize the drift of the fertilizer and pesticide particles away from their intended target. An unintended consequence of this practice is that exhaust emissions of lead have a substantially increased potential for directly depositing on vegetation and surrounding soil. Lead halides, the primary form of lead emitted by engines operating on leaded fuel,[142] are slightly water soluble and, therefore, may be more readily absorbed by plants than other forms of inorganic lead.

The 2006 AQCD indicated that surface deposition of lead onto plants may be significant.[143] Atmospheric deposition of lead provides a pathway for lead in vegetation as a result of contact with above-ground portions of the plant.[144,145,146] Livestock may subsequently be exposed to lead in vegetation (e.g., grasses and silage) and in surface soils via incidental ingestion of soil while grazing.[147]

4. Potential For Lead Emissions from Piston-Engine Aircraft to Impact Aquatic Ecosystems

As discussed in Section 6.4 of the 2013 Lead ISA, lead bioaccumulates in the tissues of aquatic organisms through ingestion of food and water or direct uptake from the environment (e.g., across membranes such as gills or skin).[148] Alkyl lead, in particular, has been identified by the EPA as a Persistent, Bioaccumulative, and Toxic (PBT) pollutant.[149] There are 527 seaport facilities in the U.S., and landing and take-off activity by seaplanes at these facilities provides a direct pathway for emission of organic and inorganic lead to the air near/above inland waters and ocean seaports where these aircraft operate.[150] Inland airports may also provide a direct pathway for emission of organic and inorganic lead to the air near/above inland waters. Lead emissions from piston-engine aircraft operating at seaplane facilities as well as airports and heliports near

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[141] O'Connor-Marer. Aerial Applicator's Manual: A National Pesticide Applicator Certification Study Guide. p. 40. National Association of State Departments of Agriculture Research Foundation. Available at https://www.agaviation.org/Files/RelatedEntities/Aerial_Applicators_Manual.pdf.

[142] The additive used in the fuel to scavenge lead determines the chemical form of the lead halide emitted; because ethylene dibromide is added to leaded aviation gasoline used in piston-engine aircraft, the lead halide emitted is in the form of lead dibromide.

[143] EPA (2006) AQC for Lead. pp. 7–9 and AXZ7–39. EPA, Washington, DC, EPA/600/R-5/144aF.

[144] EPA (2006) AQC for Lead. p. AXZ7–39. EPA, Washington, DC, EPA/600/R-5/144aF.

[145] EPA (1986) AQC for Lead. Sections 6.5.3. EPA, Washington, DC, EPA-600/8-83/028aF-dF (NTIS PB87142386), 1986.

[146] EPA (1986) AQC for Lead. Section 7.2.2.2.1.EPA, Washington, DC, EPA-600/8-83/028aF-dF (NTIS PB87142386), 1986.

[147] EPA (1986) AQC for Lead. Section 7.2.2.2.2. EPA, Washington, DC, EPA-600/8-83/028aF-dF (NTIS PB87142386), 1986.

[148] EPA (2013) ISA for Lead. Section 6.4.2. "Biogeochemistry and Chemical Effects of Pb in Freshwater and Saltwater Systems." p. 6-147. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[149] EPA (2002) Persistent, Bioaccumulative, and Toxic Pollutants (PBT) Program. PBT National Action Plan for Alkyl-Pb. Washington, DC. June. 2002.

[150] *See* FAA's NASR. Available at https://www.faa.gov/air_traffic/flight_info/aeronav/aero_data/eNASR_Browser/.

water bodies can enter the aquatic ecosystem by either deposition from ambient air or runoff of lead deposited to surface soils.

In addition to deposition of lead from engine emissions by piston-powered aircraft, lead may enter aquatic systems from the pre-flight inspection of the fuel for contaminants that pilots conduct. While some pilots return the checked fuel to their fuel tank or dispose of it in a receptacle provided on the airfield, some pilots discard the fuel onto the tarmac, ground, or water, in the case of a fuel check being conducted on a seaplane. Lead in the fuel discarded to the environment may evaporate to the air and may be taken up by the surface on which it is discarded. Lead on tarmac or soil surfaces is available for runoff to surface water. Tetraethyl lead in the avgas directly discarded to water will be available for uptake and bioaccumulation in aquatic life. The National Academy of Sciences Airport Cooperative Research Program (ACRP) conducted a survey study of pilots' fuel sampling and disposal practices. Among the 146 pilots responding to the survey, 36 percent indicated they discarded all fuel check samples to the ground regardless of contamination status and 19 percent of the pilots indicated they discarded only contaminated fuel to the ground.[151] Leaded avgas discharged to the ground and water includes other hazardous fuel components such as ethylene dibromide.[152]

E. Consideration of Environmental Justice and Children in Populations Residing Near Airports

This section provides a description of how many people live in close proximity to airports where they may be exposed to airborne lead from aircraft engine emissions of lead (referred to here as the "near-airport" population). This section also provides the demographic composition of the near-airport population, with attention to implications related to environmental justice (EJ) and the population of children in this near-source environment. Consideration of EJ implications in the population living near airports is important because blood lead levels in children from low-income households remain higher than those in children from higher income households, and the most exposed Black children still have higher blood lead levels than the most exposed non-Hispanic White children.[153,154,155]

Executive Orders 12898 (59 FR 7629, February 16, 1994) and 14008 (86 FR 7619, February 1, 2021) direct federal agencies, to the greatest extent practicable and permitted by law, to make achieving EJ part of their mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on people of color populations and low-income populations in the United

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[151] National Academies of Sciences, Engineering, and Medicine 2014. Best Practices for General Aviation Aircraft Fuel-Tank Sampling. Washington, DC: The National Academies Press. https://doi.org/10.17226/22343.

[152] Memorandum to Docket EPA-HQ-OAR-2022-0389. Potential Exposure to Non-exhaust Lead and Ethylene Dibromide. June 15, 2022. Docket ID EPA-HQ-2022-0389.

[153] EPA (2013) ISA for Lead. Section 5.4. "Summary." p. 5-40. EPA, Washington, DC, EPA/600/R-10/075F, 2013.

[154] EPA. America's Children and the Environment. Summary of blood lead levels in children updated in 2022, available at https://www.epa.gov/americaschildrenenvironment/biomonitoring-lead. Data source: Centers for Disease Control and Prevention, National Report on Human Exposure to Environmental Chemicals. Blood Lead (2011 - 2018). Updated March 2022. Available at https://www.cdc.gov/exposurereport/report/pdf/cgroup2_LBXBPB_2011-p.pdf.

[155] The relative contribution of lead emissions from covered aircraft engines to these disparities has not been determined and is not a goal of the evaluation described here.

States. The EPA defines environmental justice as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.

Our consideration of EJ implications here is focused on describing baseline conditions using the most recent year for which demographic data are available. The analysis described here provides information regarding whether some demographic groups are more highly represented in the near-airport environment compared with people who live farther from airports. Residential proximity to airports implies that there is an increased potential for exposure to lead from covered aircraft engine emissions.[156] As described in Section C, several studies have measured higher concentrations of lead in air near airports with piston-engine aircraft activity. Additionally, as noted in Section A, two studies have reported increased blood lead levels in children with increasing proximity to airports.[157,158]

We first summarize here the literature on disparity with regard to those who live in proximity to airports. Then we describe the analyses the EPA has conducted to evaluate potential disparity in the population groups living near runways where piston-engine aircraft operate compared to those living elsewhere.

Numerous studies have found that environmental hazards such as air pollution are more prevalent in areas where people of color and low-income populations represent a higher fraction of the population compared with the general population, including near transportation sources.[159,160,161,162,163] The literature includes studies that have reported on communities in close proximity to airports that are disproportionately represented by people of color and low-income populations. McNair (2020) described nineteen major airports that underwent capacity expansion projects between 2000 and 2010, thirteen of which had a large concentration or presence of persons of color, foreign-born persons or low-income populations nearby.[164] Woodburn (2017) reported on changes in communities near airports from 1970-2010, finding

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[156] Residential proximity to a source of a specific air pollutant(s) is a widely used surrogate measure to evaluate the potential for higher exposures to that pollutant (EPA Technical Guidance for Assessing Environmental Justice in Regulatory Analysis. Section 4.2.1). Data presented in Section C demonstrate that lead concentrations in air near the runup area can exceed the lead NAAQS and concentrations decrease sharply with distance from the ground-based aircraft exhaust and vary with the amount of aircraft activity at an airport. Not all people living within 500 meters of a runway are expected to be equally exposed to lead.

[157] Miranda et. al., 2011. A Geospatial Analysis of the Effects of Aviation Gasoline on Childhood Blood Lead Levels. *Environmental Health Perspectives.* 119:1513–1516.

[158] Zahran et. al., 2017. The Effect of Leaded Aviation Gasoline on Blood Lead in Children. *Journal of the Association of Environmental and Resource Economists*. 4(2):575-610.

[159] Rowangould 2013. A census of the near-roadway population: public health and environmental justice considerations. *Transportation Research Part* D 25:59-67. http://dx.doi.org/10.1016/j.trd.2013.08.003

[160] Marshall, et. al., 2014. Prioritizing environmental justice and equality: diesel emissions in Southern California. *Environmental Science & Technology* 48: 4063-4068. https://doi.org/10.1021/es405167f

[161] Marshall 2008. Environmental inequality: air pollution exposures in California's South Coast Air Basin. *Atmospheric Environment* 21:5499-5503. https://doi.org/10.1016/j.atmosenv.2008.02.005

[162] Tessum et. al., 2021. PM2.5 polluters disproportionately and systemically affect people of color in the United States. *Science Advances* 7:eabf4491.

[163] Mohai et. al., 2009. Environmental justice. *Annual Reviews* 34:405-430. https://doi.org/10.1146/annurev-environ-082508-094348.

[164] McNair 2020. Investigation of environmental justice analysis in airport planning practice from 2000 to 2010. *Transportation Research Part D* 81:102286.

suggestive evidence that at many hub airports over time, the presence of marginalized groups residing in close proximity to airports increased.[165] Rissman et. al. (2013) reported that with increasing proximity to the Hartsfield-Jackson Atlanta International Airport, exposures to particulate matter were higher, and there were lower home values, income, education, and percentage of white residents.[166]

The EPA used two approaches to understand whether some members of the population (e.g., children five and under, people of color, indigenous populations, low-income populations) represent a larger share of the people living in proximity to airports where piston-engine aircraft operate compared with people who live farther away from these airports. In the first approach, we evaluated people living within, and children attending school within, 500 meters of all of the approximately 20,000 airports in the U.S., using methods described in the EPA's report titled "National Analysis of the Populations Residing Near or Attending School Near U.S. Airports."[167] In the second approach, we evaluated people living near the NPIAS airports in the conterminous 48 states. As noted in Section A, the NPIAS airports support the majority of piston-engine aircraft activity that occurs in the U.S. Among the NPIAS airports, we compared the demographic composition of people living within one kilometer of runways with the demographic composition of people living at a distance of one to five kilometers from the same airports.

The distances analyzed for those people living closest to airports (i.e., distances of 500 meters and 1,000 meters) were chosen for evaluation following from the air quality monitoring and modeling data presented in Section C. Specifically, the EPA's modeling and monitoring data indicate that concentrations of lead from piston-engine aircraft emissions can be elevated above background levels at distances of 500 meters over a rolling three-month period. On individual days, concentrations of lead from piston-engine aircraft emissions can be elevated above background levels at distances of 1,000 meters on individual days downwind of a runway, depending on aircraft activity and prevailing wind direction.[168,169,170]

Because the U.S. has a dense network of airports, many of which have neighboring communities, we first quantified the number of people living and children attending school within 500 meters of the approximately 20,000 airports in the U.S. The results of this analysis are summarized at the national scale in the EPA's report titled "National Analysis of the

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[165] Woodburn 2017. Investigating neighborhood change in airport-adjacent communities in multiairport regions from 1970 to 2010. *Journal of the Transportation Research Board*, 2626, 1-8.

[166] Rissman et. al., 2013. Equity and health impacts of aircraft emissions at the Hartfield-Jackson Atlanta International Airport. *Landscape and Urban Planning*, 120: 234-247.

[167] EPA (2020) Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports. EPA, Washington, DC, EPA-420-R-20-003, 2020. EPA responses to peer review comments on the report are available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YISM.pdf.

[168] EPA (2020) Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports. EPA, Washington, DC, EPA-420-R-20-003, 2020.

[169] Carr et. al., 2011. Development and evaluation of an air quality modeling approach to assess near-field impacts of lead emissions from piston-engine aircraft operating on leaded aviation gasoline. *Atmospheric Environment*, 45 (32), 5795-5804. DOI: http://dx.doi.org/10.1016/j.atmosenv.2011.07.017.

[170] We do not assume or expect that all people living within 500m or 1,000m of a runway are exposed to lead from piston-engine aircraft emissions, and the wide range of activity of piston-engine aircraft at airports nationwide suggests that exposure to lead from aircraft emissions is likely to vary widely.

Populations Residing Near or Attending School Near U.S. Airports."[171] From this analysis, the EPA estimates that approximately 5.2 million people live within 500 meters of an airport runway, 363,000 of whom are children age five and under. The EPA also estimates that 573 schools attended by 163,000 children in kindergarten through twelfth grade are within 500 meters of an airport runway.[172]

In order to identify potential disparities in the near-airport population, we first evaluated populations at the state level. Using the U.S. Census population data for each State in the U.S., we compared the percent of people by age, race and indigenous peoples (i.e., children five and under, Black, Asian, and Native American or Alaska Native) living within 500 meters of an airport runway with the percent by age, race, and indigenous peoples comprising the state population.[173] Using the methodology described in Clarke (2022), the EPA identified states in which children, Black, Asian, and Native American or Alaska Native populations represent a greater fraction of the population compared with the percent of these groups in the state population.[174] Results of this analysis are presented in the following tables.[175] This state-level analysis presents summary information for a subset of potentially relevant demographic characteristics. We present data in this section regarding a wider array of demographic characteristics when evaluating populations living near NPIAS airports.

Among children five and under, there were three states (Nevada, South Carolina, and South Dakota), in which the percent of children five and under living within 500 meters of a runway represent a greater fraction of the population by a difference of one percent or greater compared with the percent of children five and under in the state population (Table 3).

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[171] In this analysis, we included populations living in census blocks that intersected the 500-meter buffer around each runway in the U.S. Potential uncertainties in this approach are described in our report National Analysis of the Populations Residing Near or Attending School Near U.S. Airports. EPA-420-R-20-001, available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YG4A.pdf, and in the EPA responses to peer review comments on the report, available here: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YISM.pdf.

[172] EPA (2020) National Analysis of the Populations Residing Near or Attending School Near U.S. Airports. EPA-420-R-20-001. Available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100YG4A.pdf.

[173] Clarke. Memorandum to Docket EPA-HQ-OAR-2022-0389. Estimation of Population Size and Demographic Characteristics among People Living Near Airports by State in the United States. May 31, 2022. Docket ID EPA-HQ-2022-0389.

[174] Clarke. Memorandum to Docket EPA-HQ-OAR-2022-0389. Estimation of Population Size and Demographic Characteristics among People Living Near Airports by State in the United States. May 31, 2022. Docket ID EPA-HQ-2022-0389.

[175] These data are presented in tabular form for all states in this memorandum located in the docket: Clarke. Memorandum to Docket EPA-HQ-OAR-2022-0389. Estimation of Population Size and Demographic Characteristics among People Living Near Airports by State in the United States. May 31, 2022. Docket ID EPA-HQ-2022-0389.

Table 3. The Population of Children Five Years and Under Within 500 Meters of an Airport Runway Compared to the State Population of Children Five Years and Under.

State	Percent of Children Aged Five Years and Under Within 500 Meters	Percent of Children Aged Five Years and Under Within the State	Number of Children Aged Five Years and Under Within 500 Meters	Number of Children Aged Five Years and Under in the State
Nevada	10%	8%	1000	224,200
South Carolina	9%	8%	400	361,400
South Dakota	11%	9%	3,000	71,300

There were nine states in which the Black population represented a greater fraction of the population living in the near-airport environment by a difference of one percent or greater compared with the state as a whole. These states were California, Kansas, Kentucky, Louisiana, Mississippi, Nevada, South Carolina, West Virginia, and Wisconsin (Table 4).

Table 4. The Black Population Within 500 Meters of an Airport Runway and the Black Population, by State.

State	Percent Black Within 500 Meters	Percent Black Within the State	Black Population Within 500 Meters	Black Population in the State
California	8%	7%	18,981	2,486,500
Kansas	8%	6%	1,240	173,300
Kentucky	9%	8%	3,152	342,800
Louisiana	46%	32%	14,669	1,463,000
Mississippi	46%	37%	8,542	1,103,100
Nevada	12%	9%	1,794	231,200
South Carolina	31%	28%	10,066	1,302,900
West Virginia	10%	3%	1,452	63,900
Wisconsin	9%	6%	4,869	367,000

There were three states with a greater fraction of Asians in the near-airport environment compared with the state as a whole by a difference of one percent or greater: Indiana, Maine, and New Hampshire (Table 5).

Table 5. The Asian Population Within 500 Meters of an Airport Runway and the Asian Population, by State.

State	Percent Asian Within 500 Meters	Percent Asian Within the State	Asian Population Within 500 Meters	Asian Population in the State
Indiana	4%	2%	1,681	105,500
Maine	2%	1%	406	13,800
New Hampshire	4%	2%	339	29,000

Among Native Americans and Alaska Natives, there were five states (Alaska, Arizona, Delaware, South Dakota, and New Mexico) where the near-airport population had greater representation by Native Americans and Alaska Natives compared with the portion of the population they comprise at the state level by a difference of one percent or greater. In Alaska, as anticipated due to the critical nature of air travel for the transportation infrastructure in that state, the disparity in residential proximity to a runway was the largest; 16,000 Alaska Natives were estimated to live within 500 meters of a runway, representing 48 percent of the population within 500 meters of an airport runway compared with 15 percent of the Alaska state population (Table 6).

Table 6. The Native American and Alaska Native Population Within 500 Meters of an Airport Runway and the Native American and Alaska Native Population, by State.

State	Percent Native American and Alaska Native Within 500 Meters	Percent Native American and Alaska Native Within the State	Native American and Alaska Native Population Within 500 Meters	Native American and Alaska Native Population in the State
Alaska	48%	15%	16,020	106,300
Arizona	18%	5%	5,017	335,300
Delaware	2%	1%	112	5,900
New Mexico	21%	10%	2,265	208,900
South Dakota	22%	9%	1,606	72,800

In a separate analysis, the EPA focused on evaluating the potential for disparities in populations residing near the NPIAS airports. The EPA compared the demographic composition of people living within one kilometer of runways at 2,022 of the approximately 3,300 NPIAS airports with the demographic composition of people living at a distance of one to five kilometers from the same airports.[176,177] In this analysis, over one-fourth of airports (i.e., 515) were identified at which children under five were more highly represented in the zero to one kilometer distance compared with the percent of children under five living one to five kilometers away (Table 7). There were 666 airports where people of color had a greater presence in the zero to one kilometer area closest to airport runways than in populations farther away. There were 761 airports where people living at less than two-times the Federal Poverty Level represented a higher proportion of the overall population within one kilometer of airport runways compared with the proportion of people living at less than two-times the Federal Poverty Level among people living one to five kilometers away.

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[176] For this analysis, we evaluated the 2,022 airports with a population of greater than 100 people inside the zero to one kilometer distance to avoid low population counts distorting the assessment of percent contributions of each group to the total population within the zero to one kilometer distance.

[177] Kamal et. al., Memorandum to Docket EPA-HQ-OAR-2022-0389. Analysis of Potential Disparity in Residential Proximity to Airports in the Conterminous United States. May 24, 2022. Docket ID EPA-HQ-2022-0389. Methods used are described in this memo and include the use of block group resolution data to evaluate the representation of different demographic groups near-airport and for those living one to five kilometers away.

Table 7. Number of Airports (Among the 2,022 Airports Evaluated) With Disparity for Certain Demographic Populations Within One Kilometer of an Airport Runway in Relation to the Comparison Population Between One and Five Kilometers from an Airport Runway.

	Number of Airports with Disparity[a]				
Demographic Group	Total Airports with Disparity	Disparity 1-5%	Disparity 5-10%	Disparity 10-20%	Disparity 20%+
Children under five years of age	515	507	7	1	0
People with income less than twice the Federal Poverty Level	761	307	223	180	51
People of Color (all races, ethnicities and indigenous peoples)	666	377	126	123	40
Non-Hispanic Black	405	240	77	67	21
Hispanic	551	402	85	47	17
Non-Hispanic Asian	268	243	18	4	3
Non-Hispanic Native American or Alaska Native[178]	144	130	6	7	1
Non-Hispanic Hawaiian or Pacific Islander	18	17	1	0	0
Non-Hispanic Other Race	11	11	0	0	0
Non-Hispanic Two or More Races	226	226	0	0	0

To understand the extent of the potential disparity among the 2,022 NPIAS airports, Table 7 provides information about the distribution in the percent differences in the proportion of children, individuals with incomes below two-times the Federal Poverty Level, and people of color living within one kilometer of a runway compared with those living one to five kilometers away. For children, Table 7 indicates that for the vast majority of these airports where there is a higher percentage of children represented in the near-airport population, differences are relatively small (e.g., less than five percent). For the airports where disparity is evident on the basis of poverty, race and ethnicity, the disparities are potentially large, ranging up to 42 percent for those with incomes below two-times the Federal Poverty Level, and up to 45 percent for people of color.[179]

There are uncertainties in the results provided here inherent to the proximity-based approach used. These uncertainties include the use of block group data to provide population numbers for each demographic group analyzed, and uncertainties in the Census data, including from the use of data from different analysis years (e.g., 2010 Census Data and 2018 income data). These uncertainties are described, and their implications discussed in Kamal et. al. (2022).[180]

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[178] This analysis of 2,022 NPIAS airports did not include airports in Alaska.

[179] Kamal et. al., Memorandum to Docket EPA-HQ-OAR-2022-0389. Analysis of Potential Disparity in Residential Proximity to Airports in the Conterminous United States. May 24, 2022. Docket ID EPA-HQ-2022-0389.

[180] Kamal et. al., Memorandum to Docket EPA-HQ-OAR-2022-0389. Analysis of Potential Disparity in Residential Proximity to Airports in the Conterminous United States. May 24, 2022. Docket ID EPA-HQ-2022-0389.

The data summarized here indicate that there is a greater prevalence of children under five years of age, an at-risk population for lead effects, within 500 meters or one kilometer of some airports compared to more distant locations. This information also indicates that there is a greater prevalence of people of color and of low-income populations within 500 meters or one kilometer of some airports compared with people living more distant. If such differences were to contribute to disproportionate and adverse impacts on people of color and low-income populations, they could indicate a potential EJ concern. Given the number of children in close proximity to runways, including those in EJ populations, there is a potential for substantial implications for children's health.

Appendix A:

Model-extrapolated Estimates of Airborne Lead Concentrations at U.S. Airports

Table of Contents

Abbreviations

Air Quality (AQ)
Air Quality Factor (AQF)
Air Taxi (AT)
Air Traffic Activity Data System (ATADS)
Airport Cooperative Research Program (ACRP)
American Meteorological Society/Environmental Protection Regulatory Model (AERMOD)
Clean Air Act (CAA)
US Environmental Protection Agency (EPA)
US Federal Aviation Administration (FAA)
General Aviation (GA)
General Aviation and Air Taxi Activity Survey (GAATA)
Landing and take-off operations (LTOs)
Multi-Engine (ME)
National Ambient Air Quality Standard (NAAQS)
National Academies of Sciences (NAS)
National Emissions Inventory (NEI)
One hundred octane low lead (100LL)
Reid-Hillview Airport of Santa Clara County (RHV)
Santa Monica Municipal Airport (SMO)
Single-Engine (SE)
Terminal Area Forecast (TAF)
Tetraethyl lead (TEL)
Touch-and-Go (T&G)

Summary

The main objective of the analyses presented in this report is to estimate the potential ranges of lead concentrations at and downwind of the anticipated area of highest concentration at airports in the US. To accomplish this objective, the relationship between piston-engine aircraft activity and lead concentration at and downwind of the maximum impact site at one airport was applied to piston-engine aircraft activity estimates for each US airport. This approach for conducting a nationwide analysis of airports was selected due to the dominant impact of piston-engine aircraft run-up operations on ground-level lead concentrations, which creates a maximum impact area that is expected to be generally consistent across airports. Specifically, these aircraft consistently take-off into the wind and typically conduct run-up operations immediately adjacent to the take-off runway end, and thus, modeling lead concentrations from this source is constrained to variation in a few key parameters. These parameters include: 1) total amount of piston-engine aircraft activity, 2) the proportion of activity conducted at one runway end, 3) the proportion of activity conducted by multi-piston-engine aircraft, 4) the duration of run-up operations, 5) the concentration of lead in avgas, 6) wind speed at the model airport relative to the extrapolated airport, and 7) additional meteorological, dispersion model, or operational parameters. These parameters were evaluated through sensitivity analyses across airports or using quantitative or qualitative uncertainty analyses.

Results of the national analysis show that model-extrapolated 3-month average lead concentrations in the maximum impact area range from less than 0.0075 μg/m^3 up to 0.475 μg/m^3 at airports nationwide. The range of model-extrapolated concentrations in the maximum impact area aligns with expectations from previous monitoring at airports that showed exceedances of the lead NAAQS in the maximum impact area of some airports.[181] Results of the national analysis also demonstrate and quantify the gradient in lead concentrations with the highest concentrations in locations closer to the maximum impact area than those further downwind.

For the subset of airports where estimated lead concentrations could potentially be above the lead NAAQS, the analysis was further refined using a set of sensitivity analyses and airport-specific data. This airport-specific analysis identified some airports where model-extrapolated lead concentration estimates suggest the potential for piston-engine aircraft activity to cause lead concentrations above the lead NAAQS in the area of maximum impact with unrestricted public access. Lead concentration estimates in this analysis should not be used to evaluate attainment of the lead NAAQS.

Overall, comparisons of both national and airport-specific model-extrapolated concentrations to monitored values show general agreement and suggest that the extrapolation method presented in this report provides reasonable estimates of the range in concentrations of lead in air attributable to peak activity periods of piston-engine aircraft at

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[181] For additional information on monitoring data collected at airports see: https://www.epa.gov/regulations-emissions-vehicles-and-engines/airport-lead-inventories-air-quality-monitoring-air.

airports. Uncertainty in the national and airport-specific activity analyses were evaluated using a Monte Carlo analysis, which characterized how variability in run-up duration and avgas lead concentrations influence model-extrapolated lead concentrations. Results showed that model-extrapolated lead concentrations may increase at airports with average run-up durations that are longer than the average run-up duration observed at the model airport, even if the avgas lead concentration is lower than that used in the national analysis. Additional, qualitative analyses were used to evaluate sources of uncertainty that were not addressed in sensitivity or Monte Carlo analyses.

Quantitative and qualitative evaluations of meteorological parameters that can impact model-extrapolated concentrations focused on adjusting concentrations to reflect site-specific wind speeds (See Section 3.2 for details) and evaluating changes in wind direction, mixing height, and temperature. While the wind speed adjustment did not meaningfully impact the range of concentrations in the maximum impact area of US airports, this adjustment does have an important impact on model-extrapolated concentrations at individual airports, particularly at those airports where wind speeds during the maximum activity period differ significantly from those observed at the model airport. As discussed in Section 4.4.1, minimal uncertainty is expected in model-extrapolated concentrations due to shifts in wind direction given that most airports are built with the predominate runway facing into the wind. It is also anticipated that mixing height has a minimal impact on uncertainty in model-extrapolated concentrations at the maximum impact area, because of the dominant impact of the very localized run-up emissions at this location and the fact that GA and AT aircraft activity occurs almost entirely during the day when vertical mixing is greatest. At downwind locations, mixing height may play a larger role and would be an important variable to examine when evaluating individual airports, particularly those with mixing height characteristics significantly different from the model airport. Finally, ambient temperature and other microclimate or meteorological variables are not expected to meaningfully impact nationwide results, however, there is more uncertainty in model-extrapolated concentrations at airports that have maximum activity periods during meteorological conditions not observed at the model airport.

Additional sources of potential uncertainty that were evaluated qualitatively included dispersion modeling inputs and operational parameters. While dispersion modeling inputs such as surface roughness, Bowen Ratio, and albedo may result in some uncertainty at downwind locations, their impact on variability near the maximum impact site is mitigated due to consistency in on-airport characteristics and land-use requirements immediately downwind of runways based on landing and take-off safety requirements. As with meteorological parameters, the appropriateness of dispersion modeling inputs used in this analysis for individual airports with meaningful differences in land use of the areas immediately surrounding a runway would need to be considered on a case-by-case basis. Differences in operational parameters (e.g., piston/turboprop split and single-engine/multi-engine split, distribution of aircraft engine types operating at the airport, diurnal activity patterns) are not expected to contribute significantly to uncertainty in extrapolated concentration estimates for airports nationwide; however, in modeling individual airports, national fleet and operational data should be supplemented with local data where available and feasible.

The model-extrapolated lead concentrations provided in this report reflect only lead concentrations in air attributable to piston-engine aircraft activity and only at the area of maximum concentration and downwind of that location. Additional analyses, which are outside of the scope set by the objective of this report, would be necessary to evaluate concentrations of lead in air at other areas at and near airports. In addition, to understand total lead concentrations in air, other airborne sources of lead (e.g., nearby industrial sources, sources contributing to local background concentrations) would need to be considered. Understanding total lead exposure, which is relevant for understanding blood lead levels, would also need to consider exposure to lead from additional media (e.g., soil, drinking water).

1. Introduction

The United States (US) Environmental Protection Agency (EPA) is evaluating the air quality impact of emissions of lead from piston-engine aircraft operating on leaded fuel. One component of the evaluation includes conducting an analysis of concentrations of lead in air at and downwind of airports. This analysis was conducted to provide an understanding of the potential range in lead concentrations in air at the approximately 13,000 airports with piston-engine aircraft activity in the US. This report describes the methods that the EPA used to estimate these lead concentrations and presents the results of this analysis along with a quantitative uncertainty analysis. Background information is presented immediately below in order to provide a general understanding of the use of leaded fuel in aircraft, and the state of the science on modeling concentrations of lead in air from aircraft emissions at individual airports. Subsequent sections provide details on the analysis approach for airports nationwide.

1.1 Use of Leaded Avgas in Piston-Engine Aircraft

Emissions of lead from aircraft operating on leaded aviation gasoline (avgas) are the largest source of lead released into the atmosphere in the US, accounting for 62% of lead (456 tons) in the 2014 National Emissions Inventory (NEI) (USEPA 2016a). Leaded avgas is used in piston-engine aircraft, of which there are approximately 140,000 in the US (FAA 2014) . These aircraft operate at most of the approximately 20,000 US airport facilities (approximately 13,000 of which are airports, while the remainder are heliports, balloon ports, and other facility types) (FAA 2017).[182,183] Piston-engine aircraft conduct approximately 32 million landing and take-off

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[182] This report focuses on fixed-wing piston-engine airplane activity at airports. Facility types other than airports are not included in this report; seaports and water runways at airports are both excluded from analyses in this report, and rotorcraft operations at airports are not included in this report. Appendix B provides some information on conducting additional rotorcraft analyses in the future.

[183] Data on airport facilities was downloaded from FAA Air Traffic Activity Data System (ATADS) at http://aspm.faa.gov/opsnet/sys/Airport.asp on 13 February 2014.

operations (LTOs) annually (USEPA 2011).[184] Most piston-engine aircraft operations fall into the categories of either General Aviation (GA) or Air Taxi (AT) activity. GA is defined as the operation of civilian aircraft for purposes other than commercial, such as passenger or freight transport, including personal, business and instructional flying; AT is scheduled or on-demand services that carry limited payload and/or passengers (FAA 2012).

Piston-engine aircraft rely on lead as an additive to avgas to help boost fuel octane and prevent engine knock, as well as prevent valve seat recession and subsequent loss of compression for engines without hardened valves.[185] Lead is added to the fuel in the form of tetraethyl lead (TEL) along with ethylene dibromide, which acts as a lead scavenger to prevent lead deposits on valves and spark plugs. Currently one hundred octane low lead (100LL), which contains up to 2.12 grams of lead per gallon, is the most commonly used type of avgas in the US, although FAA survey data reports limited use of a leaded avgas containing 4.24 grams of lead per gallon, known as "100 Octane," and unleaded avgas (FAA 2015). Lead is not added to jet fuel, which is used in commercial aircraft, most military aircraft, and other turbine-engine aircraft.

1.2 Lead Concentrations in Air from Leaded Avgas Use in Piston-Engine Aircraft at Individual Airports

Lead emissions from piston-engine aircraft operating on leaded avgas increase concentrations of lead in air at and downwind of airports (Environment Canada 2000, Fine et. al. 2010, Carr et. al. 2011, Anchorage DHHS 2012, Feinberg et. al. 2016). Gradient studies evaluating lead concentrations near airports where piston-engine aircraft operate indicate that concentrations of lead in air are one to two orders of magnitude higher at locations proximate to aircraft emissions compared to locations approximately 500- to 1000-meters downwind (Fine et. al. 2010, USEPA 2010a, Carr et. al. 2011, Feinberg et. al. 2016). The most significant emissions in terms of ground-based activity, and therefore ground-level concentrations of lead in air, occur near the areas with greatest fuel consumption where the aircraft are stationary for a period of time (USEPA 2010a, Carr et. al. 2011, ICF 2014, Feinberg et. al. 2016). For piston-engine aircraft these areas are most commonly locations in which pilots conduct engine tests during run-up operations prior to take-off (i.e., magneto checks during the run-up operation mode). Run-up operations are typically conducted adjacent to the runway end from which

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[184] Piston-engine aircraft conduct two types of operational cycles, or cycle-types. These cycle-types include: 1) a full landing-and-take-off operation (full LTO) during which the pilot conducts all pre-flight engine checks and completes full take-off and landing operations, and 2) a touch-and-go operation (T&G) during which the pilot briefly touches down on a runway before taking-off again almost immediately in order to practice take-off and landing procedures. This is a training exercise most commonly performed by student pilots. Throughout this report, "cycle-type" is used to refer to the full LTO and T&G categories, while "LTOs" is used to refer more generally to all cycle-types (i.e., both full LTO and T&G).

[185] Minimum octane requirements as well as other carefully controlled fuel parameters in avgas prevent the general use of unleaded motor vehicle fuel in piston-engine aircraft.

aircraft take-off and the brakes are engaged so the aircraft is stationary.[186] As a result of the aircraft being stationary, duration of run-up, and high fuel consumption rate, emissions from run-up activity are the largest contributor to local maximum atmospheric lead concentrations; run-up emissions are estimated to contribute over 80% of the lead concentrations at and immediately downwind of the area where the run-up mode of operation occurs, even though this mode of operation does not have the highest fuel consumption rate (Appendix A). Hence, the area adjacent to the runway end at which run-up operations most frequently occur is identified here as the maximum impact site for lead concentrations.[187,188]

1.3 Characterizing Maximum Impact Area Lead Concentrations from Piston-Engine Activity at U.S. Airports

The understanding of piston-engine aircraft lead emissions and resulting concentrations in air was developed through detailed monitoring and modeling studies at individual airports. However, conducting detailed air quality monitoring or modeling for lead at each of the 13,000 US airports is not feasible; thus, the analysis of concentrations of lead in air at and downwind of airports nationwide is based on detailed air quality modeling at a representative, model airport. The modeling results were used to develop factors that relate piston-engine aircraft activity to concentrations of lead in air. The factors, termed Air Quality Factors (AQFs), were used in conjunction with estimates of piston-engine aircraft activity at airports nationwide to calculate model-extrapolated concentrations at and downwind of each US airport.

The rationale for this approach is based on the consistent set of parameters required for the safe operation of a piston-engine aircraft. Specifically, piston-engine aircraft consistently conduct run-up operations prior to take-off, and the run-up activity has the following characteristics: 1) run-up operations require high fuel consumption rates while the aircraft is stationary, and thus are the location of the maximum impact site for lead concentrations, 2) the location of run-up activity occurs in a designated area proximate to the runway end from which aircraft take-off, and 3) the runway end used for take-off, and hence the location of run-up operations, can be identified using wind direction since piston-engine aircraft takeoff into the wind.

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[186] A single "runway" has a magnetic heading designation for each "runway end" in order to distinguish which direction the aircraft is taking off from or landing on to; we use "runway end" throughout this report.

[187] For purposes of this report and the underlying analysis, the maximum impact site is defined as 15 meters downwind of the tailpipe of an aircraft conducting run-up operations in the area designated for these operations at a runway end. The maximum impact area is the approximately 50 meters surrounding the maximum impact site. The downwind gradient is the approximately 500-meter area that extends from the maximum impact site. Additional characterization of the maximum impact site, area, and downwind gradient is provided in Section 2.

[188] While run-up operations are most frequently the location of the maximum impact site of aircraft lead emissions at airports, at some airports other operations such as taxi or idling near the runway may result in a hotspot of emissions. This report focuses on run-up as the location of the maximum impact site in an effort to characterize concentrations of lead in air at the location of maximum impact for most US airports. Additional analyses would be necessary to more specifically characterize concentrations of lead in air at individual airports.

This analysis focuses on the maximum impact areas at airports nationwide (i.e., the 50 meters surrounding the maximum impact site adjacent to run-up operations). Notably, the maximum impact area lead concentration estimates provided in this report are based on average values for several key input variables; thus, the concentrations are not “worst-case” estimates (i.e., they do not reflect the use of the maximum values for all the key input parameters). For each US airport, model-extrapolated lead concentrations are calculated as 3-month average values to maintain consistency with the form of the National Ambient Air Quality Standard (NAAQS) for lead (i.e., a maximum 3-month average of 0.15 $\mu g/m^3$) (National primary and secondary ambient air quality standards for lead 40 CFR 50.12, USEPA 2016b). Importantly, while model-extrapolated concentrations are calculated and presented in a manner consistent with the lead NAAQS, these results should not be used to determine attainment of the lead NAAQS at individual airports. Information on the process that EPA, the states, and the Tribes follow to determine whether or not an area is meeting the NAAQS for lead is described on the EPA website (USEPA). Lead concentration estimates presented in this report are provided to inform an understanding of the potential range of impacts that lead emissions from piston-engine aircraft alone may have on air quality in close proximity to this source of lead. Due to the inherent uncertainties in extrapolating relationships between concentration and activity from one well-characterized model airport to others, uncertainty and variability in model-extrapolated lead concentrations is characterized.

This document is organized to first provide the methods and results of detailed air quality modeling of lead at a model airport (Section 2). Section 3 describes how the modeling results were used to develop a quantitative relationship between piston-engine aircraft activity and lead concentrations; this section further provides the methodology to estimate piston-engine aircraft activity at airports nationwide, which is used to calculate lead concentrations at airports nationwide based on the relationship between activity and lead concentrations. Section 3 also presents methods to identify a subset of airports for more in-depth analyses using airport-specific data. Section 4 presents the model-extrapolated lead concentrations that result from combining piston-engine aircraft activity estimates with the relationship between activity and lead concentrations in the maximum impact area and locations downwind at each airport nationwide. In addition, Section 4 characterizes uncertainty and variability in these model-extrapolated lead concentrations.

2. Air Quality Modeling of Lead from Piston-Engine Aircraft at a Model Airport

To characterize concentrations of lead in air at and downwind of the maximum impact area of airports nationwide, EPA first conducted detailed air quality modeling at a model airport. The results of this detailed air quality modeling were used to develop factors, known as AQFs, which provide quantitative relationships between piston-engine aircraft activity and lead concentrations at and downwind of the maximum impact site at the modeled airport. The AQFs were subsequently applied to estimates of aircraft activity at other airports across the country in order to calculate model-extrapolated lead concentrations at and downwind of the maximum impact area of airports nationwide. In this section we briefly explain the overall approach for the detailed air quality modeling at the model facility, summarize the model performance, and then discuss how the air quality modeling was conducted to develop the AQFs.

Overview of Air Quality Modeling at a Model Airport

In order to characterize local-scale air quality impacts of lead at a model airport, EPA applied the air quality model that is used for EPA and Federal Aviation Administration (FAA) regulatory analysis of near-field gradients of primary pollutants such as lead, namely the American Meteorological Society (AMS)/EPA Regulatory Model (AERMOD).[189,190] Since AERMOD had not been previously applied to modeling lead emissions from piston-engine aircraft activity, EPA developed the necessary model inputs and parameters, including: piston-engine aircraft parameters (i.e., sub-daily time-in-mode activity, dispersion due to aircraft turbulent wake, allocation of approach and climb-out emissions at altitude) and emissions characteristics of non-aircraft sources (e.g., nearby roads) (USEPA 2010a, Carr et. al. 2011). These model inputs were developed and first applied at a GA airport (Santa Monica Airport, SMO) that was selected due to the availability of previously collected lead monitoring data, which indicated elevated concentrations of lead in air at and near the runway (Fine et. al. 2010). Additional monitoring data were collected in parallel to the development of AERMOD modeling inputs in order to evaluate model performance. Details regarding the AERMOD inputs, model performance, and results are published elsewhere (USEPA 2010a, Carr et. al. 2011).

The foundational work to establish AERMOD inputs for modeling lead emissions from piston-engine aircraft at SMO provided an understanding of the key characteristics of the relationship between aircraft activity and concentrations of lead in air. Some of the key findings from this work, included: 1) piston-engine aircraft operations increase ground-level concentrations of lead, with the largest concentrations resulting from engine checks prior to take-off (i.e., run-up operations), 2) lead concentrations attributable to piston-engine aircraft decrease with increasing distance from the run-up location, such that the maximum impact location is

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[189] AERMOD is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain. Additional details about AERMOD are available at: https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models

[190] The FAA inventory tool for air emissions and noise, Aviation Environmental Design Tool (AEDT), does not include lead emissions (https://aedt.faa.gov/Documents/AEDT_2b_NEPA_Guidance.pdf).

immediately adjacent to the run-up area at a runway end, and 3) above-background lead concentrations occur up to 900 and 450 meters downwind of the maximum impact location on a daily and average 3-month basis, respectively (USEPA 2010a, Carr et. al. 2011). The National Academies of Sciences (NAS) Airport Cooperative Research Program (ACRP) subsequently conducted a similar study of airport lead concentrations at three airports and similarly identified run-up as a critical operation mode to evaluate when modeling the impact of piston-engine aircraft lead emissions on ground-based lead concentrations (Heiken et. al. 2014, Feinberg et. al. 2016). These findings presented a clear approach for conducting air quality modeling at an airport, which would be used as a model facility for developing AQFs and subsequently characterizing concentrations of lead in air at and downwind of airports nationwide.

Reid-Hillview Airport of Santa Clara County (RHV) was selected as a representative GA airport for use as the model airport.[191] To apply AERMOD at the model airport, aircraft and meteorological data, similar to those collected at SMO, were collected at RHV. Specifically, data collected at this facility included: 1) number and type of piston-engine aircraft LTOs, 2) time in each operating mode, 3) time-of-day and day-of-week patterns of aircraft activity, 4) the concentration of lead in avgas, and 5) meteorological data (i.e., wind direction, wind speed, mixing height, temperature). These inputs were collected first for a seven-day period in order to characterize model performance at the model airport through comparisons of modeled and monitored concentrations. After characterizing model performance, additional activity and meteorology data were collected to model a yearlong period, which was then used to develop AQFs. Information on model performance at the model facility is presented immediately below in Section 2.2; information on the yearlong modeling is in Section 2.3. Appendix A provides details on specific AERMOD inputs at the model airport study, as well as information regarding the piston-engine aircraft modeled at the model airport compared to the national piston-engine aircraft fleet.

Air Quality Model Performance at a Model Airport

Comparisons of modeled and monitored daily average concentrations at the model airport were conducted over a seven-day period at three monitoring sites (upwind, 60 meters downwind, and at the maximum impact site). The daily average was over 15 hours, from the hours of 7 a.m. to 10 p.m. local time, representing the time when the airport was operational. The overall R^2 value across the three monitoring sites regressed against the paired modeled concentrations was 0.83, as shown in Figure 1. At the maximum impact site, the model tended to under-predict monitored concentrations for the seven days of comparison conducted, but was generally within 20% of monitored values and was within the 2:1 and 1:2 lines for all but one monitored value.[192] The generally good agreement between modeled and monitored

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[191] RHV is considered generally representative of GA airports based on several factors, including: type of piston-engine aircraft operations, runway configuration, fleet composition of piston-driven aircraft engine technology types, and diurnal profile of piston-engine aircraft activity (see Appendices A and B for comparisons of RHV fleet and diurnal profiles relative to other GA airports).

[192] Agreement with monitored concentrations within a factor of two is a common model evaluation criterion Chang, J. and S. Hanna (2004). Air quality model performance evaluation. *Meteorology and Atmospheric Physics,*

concentrations was also observed in previous studies comparing AERMOD air quality dispersion model output with on-site monitoring data for lead at airports (Carr et. al. 2011; Feinberg et. al. 2016). As observed in these other studies, modeled lead concentrations can be both slightly over- and underestimates of on-site monitored values, and the performance observed for the model airport is considered to be aligned with prior work. We focused on understanding discrepancy between modeled and monitored concentrations on the few days when the discrepancy was greater than 20%. For these days, sensitivity analyses were conducted to identify possible reasons for the divergence. Details on the sensitivity analyses are presented in Appendix A, but generally showed that run-up location, run-up duration, and relative levels of multi-engine aircraft activity explained instances when the model under- or over-predicted monitored concentrations; uncertainty and variability in monitored values are not evaluated here, but also contribute to the divergence in these comparisons with modeled data. In addition, variability in emission rates for a given engine and across engine types will also contribute to variability in measured concentrations, as discussed in Section 4.4. The application of a 3-month averaging time is expected to minimize the impact of individual days in which the model may have over- or under-predicted lead concentrations. Comparisons between model-extrapolated concentrations, based on the AQFs developed at the model airport, and monitored concentrations at airports other than the model airport are presented in Section 4.

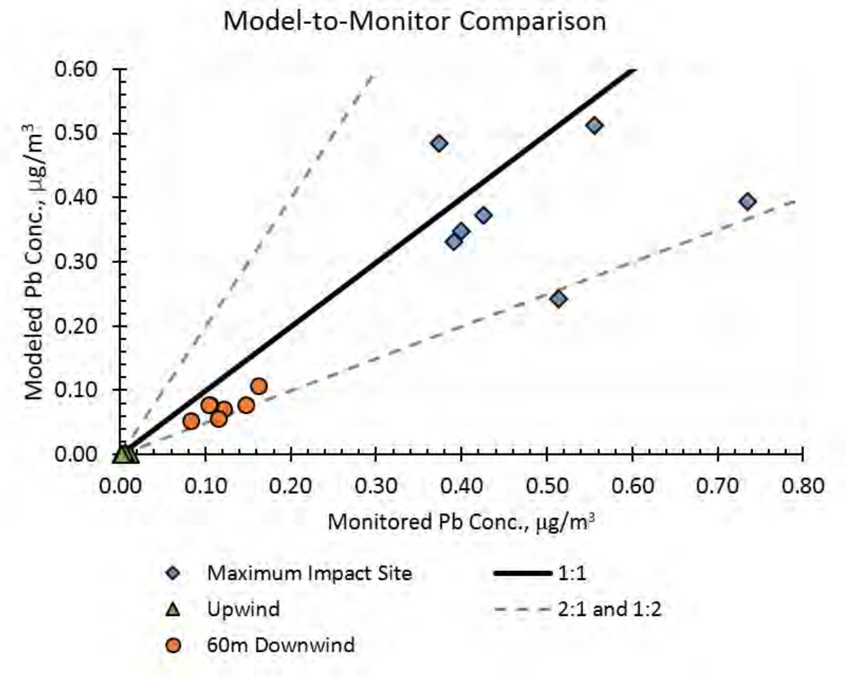

Figure 1. Comparison of modeled and monitored daily average concentrations at three sites at the model airport during a 7-day period.

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87 (1), 167-196, Luecken, D., W. Hutzell and G. Gipson (2006). Development and analysis of air quality modeling simulations for hazardous air pollutants. *Atmospheric Environment,* 40 (26), 5087-5096.

The model performance at the model airport confirmed previous work showing that a limited set of parameters influence concentration in the maximum impact site, and supported moving forward with the development of AQFs to characterize the relationship between piston-engine aircraft activity and lead concentrations at and downwind of a maximum impact area.

Yearlong Air Quality Modeling to Develop AQFs at a Model Airport

This section provides general information used to model yearlong concentrations of lead in air that were subsequently used to calculate 3-month average AQFs at the model facility. Details regarding inputs to AERMOD including aircraft emission inventories, source parameterization, meteorological inputs, and receptor placement are provided in Appendix A.

As noted above, air quality modeling for this work built on prior piston-engine aircraft modeling in which aircraft- and airport-specific parameterizations were used in AERMOD to evaluate near-field gradients in ambient lead concentrations. Inputs in the yearlong modeling included 1) a detailed inventory for emissions of lead from piston-engine aircraft (i.e., aircraft activity, source locations, and lead emission rates), 2) meteorological data, 3) a dense receptor grid, and 4) piston-engine aircraft characterization and parameterization. Using previously published modeling methods, which are further described in Appendix A, Section 1.5, aircraft lead emissions were modeled as volume sources. The parameterization of aircraft lead emissions at the model airport included aircraft wake turbulence, and plume rise from ground-based aircraft emissions. Specific values for the initial vertical and horizontal dispersion by operation mode are provided in Appendix A.

Aircraft activity data for the yearlong modeling at the model facility used on-site observations in conjunction with on-site daily operations data collected by FAA. [193] Hourly aircraft activity profiles were developed from on-site observations for single-engine and multi-engine aircraft conducting either full landing and take-off or touch-and-go operation cycles. Time spent in each mode (i.e., start-up, idle, taxi, run-up, take-off and landing) was recorded during the days of observation and was used along with fuel consumption rates by mode to calculate emissions by mode. Source locations for all modes of aircraft activity (i.e., start-up, idle, taxi, run-up, take-off and landing) are described in Appendix A; emissions at altitude were represented using volume sources at 50-meter intervals up to approximately 500 meters and release heights for ground-based activity were 0.5 meters.

Surface and upper-air meteorological data (from stations 10 km, and 55 km away from the model facility, respectively) were processed using AERMOD's meteorological preprocessor, AERMET, to produce hourly data on mixing heights, stability, wind direction, wind speed, temperature, and precipitation. The wind direction data were used to identify the runway end from which piston-engine aircraft took off during each hour of each day in the year of modeling

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[193] As discussed in Section 3, FAA data does not indicate which aircraft operations are conducted by piston-engine aircraft, compared to turboprop or other engine types. Rather activity is reported as specific to GA or AT, which can be used to estimate activity specific to piston-engine aircraft based on national averages or airport-specific data. For the model airport, data collected at the airport during the model-to-monitor comparison evaluation provided inputs to appropriately allocate GA and AT aircraft activity to piston-engine activity. For additional information see Appendix A.

(2010). Surface characteristics and AERSURFACE parameterization are described in the Appendix A.

To identify the spatial extent of elevated lead concentrations within the vicinity of the airport, 2,250 receptor locations were used, with the most densely located receptors placed at 50-meter intervals at and near ground-based aircraft activity, as well as out to 1 km downwind from run-up and take-off activity. Receptor spacing was at 100-meter intervals at other locations within the 1 km perimeter of the runway centroid, and increased to 200 meters after 2 km.

Results of the yearlong model run provided daily lead concentrations at and downwind of the maximum impact site that are attributable to piston-engine aircraft activity (i.e., do not include background lead concentrations from other sources). These daily average lead concentrations were used to calculate 3-month, rolling-average lead concentrations. As detailed in Section 3 below, the 3-month, rolling average lead concentrations were then used to calculate AQFs that relate piston-engine aircraft activity over 3-month periods to lead concentrations at and downwind of the maximum impact site. The combination of the AQFs and activity estimates at other US airports provides model-extrapolated lead concentrations for a national analysis of lead concentrations at and downwind of maximum impact areas at airports nationwide.[194]

3. Method to Calculate Model-Extrapolated Lead Concentrations Nationwide

In this section we discuss the methods for calculating model-extrapolated lead concentrations at US airports. Section 3.1 provides the AQFs developed from the yearlong air quality modeling at the model airport discussed above. Section 3.2 provides the methodology for estimating activity at each airport and shows how we use activity estimates for each airport in combination with the AQFs to develop a national analysis of model-extrapolated concentrations of lead attributable to piston-engine aircraft at and downwind of the maximum impact area at approximately 13,000 US airports. This national analysis uses US average statistics for the fraction of GA and AT activity conducted by piston-engine aircraft. This analysis is further refined using airport-specific data for a subset of airports as described in Section 3.3. Section 3.4 then describes quantitative Monte Carlo uncertainty analyses for both the national and airport-specific analyses.

3.1 Calculation of AQFs for Piston-Engine Aircraft Activity and Lead Concentrations

The AQFs were calculated for the different piston-engine aircraft cycle types and engine classes. Specifically, piston-engine GA and AT aircraft perform two types of operational cycles: 1) full LTOs, in which aircraft start or end the operation in a full stop outside of the active

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[194] As stated in Section 1 we define maximum impact site as the 15 meters immediately adjacent to run-up and the maximum impact area as the 50 meters surrounding the maximum impact site. 'Maximum impact site' is used in the context of the model airport and 'maximum impact area' is used in the context of airports for which we calculated model-extrapolated lead concentrations.

runway, and 2) T&Gs, in which aircraft land and take-off without coming to a full stop.[195] Further, fixed-wing piston-engine GA and AT aircraft can be subdivided into two classes, single-engine (SE) and multi-engine (ME) planes. Due to differences in fuel consumption and time in each operational mode between aircraft classes and cycle-types, respectively, an AQF was calculated specific to each aircraft class (i.e., single- or multi-engine, SE or ME) and cycle-type (i.e., full LTO or T&G). Accordingly, four different types of AQFs (i.e., SE full LTO, SE T&G, ME full LTO, ME T&G) were calculated for nine specific receptor sites at and downwind of the maximum impact site, which was the runway end at which LTOs most frequently occurred at the model airport facility. The AQFs are calculated as the ratio of the average lead concentration over rolling 3-month time periods to piston-engine aircraft LTOs at the most frequently used runway end over the same 3-month period.[196] For example, the SE full LTO AQF at the maximum impact site is the ratio of the 3-month average modeled lead concentration ($\mu g/m^3$) attributed to SE LTO at the model airport maximum impact site and the number of full LTOs conducted by SE piston aircraft at the most frequently used runway end in the same 3-month period (Equation 1).[197]

$$\text{Eq. 1: SE full LTO AQF at maximum impact site} = \frac{\text{3-month average modeled lead concentration } \left(\frac{\mu g}{m^3}\right)}{\text{\# of full SE LTOs during 3-month period}}$$

The specific steps to calculate AQFs at and downwind of the maximum impact site are:

1. Calculate average modeled daily lead concentrations at each of the nine receptor locations over fourteen consecutive one-month periods separately for emissions from each aircraft class and cycle-type (e.g., SE T&G, ME full LTO).
2. Calculate rolling 3-month average modeled lead concentrations at each of the nine receptor locations by averaging across monthly average concentrations attributable to each aircraft class and cycle-type (e.g., SE T&G, ME full LTO).
3. Sum piston-engine activity by cycle-type and aircraft class (e.g., SE T&G, ME full LTO) in the 3-month periods.
4. Divide each 3-month average ambient lead concentration at each receptor site for each cycle-type and aircraft class by the corresponding total number of LTOs separated by cycle-type and aircraft class (e.g., ambient lead concentration from SE full LTO emissions at 50 m during July – Sept. 2011 / # of SE full LTOs during July – Sept. 2011).
5. Calculate the average AQF across the 12 rolling 3-month periods separately for each aircraft class and operation-type pair at each of the nine receptor locations (e.g., average of the 12, 3-month AQFs for SE full LTOs at the 50-meter receptor site).

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[195] As noted in Footnote 3, for simplicity, both types of LTOs (i.e., full LTO and T&G) are referred to as LTOs, while "cycle-type" is used to denote the categories of full LTO and T&G.

[196] As noted in Section 1, this analysis uses 3-month average lead concentrations to allow for comparisons with the 3-month average concentration set for the lead NAAQS USEPA (2016b). Review of the National Ambient Air Quality Standards for Lead EPA–HQ–OAR–2010–0108; FRL–9952–87–OAR.

[197] Both full LTO and T&G AQFs include concentration attributable to emissions from aircraft operating in all modes (e.g., taxi, take-off, run-up), with the exception that T&G AQFs do not include the lead concentration due run-up emissions.

As Steps 1 through 4 above describe, for each aircraft class and operation-type pair 12 AQFs were calculated for each set of 3 consecutive months in a 14-month period. The set of 12 AQFs for each aircraft class and operation type were used to evaluate variability in AQFs due to changes in meteorology over a 14-month period.[198] In order to average across the largest range in meteorology inputs to AQFs (e.g., wind speed), the resulting 12 AQFs were averaged to provide a single 3-month AQF for each aircraft class, operation-type, and location combination (Table 1). The extent to which meteorology variability included in the modeling to calculate AQFs is representative of the range of meteorology at airports across the country is discussed further in Section 4.

Table 1. Average of the 12 rolling 3-month AQFs (μg Pb/m^3/LTO) at and downwind of the maximum impact site [199]

AQFs	**Distance (meters)**								
	Max Impact Site	**50 m**	**100 m**	**150 m**	**200 m**	**250 m**	**300 m**	**400 m**	**500 m**
SE Full LTO	$1.5x10^{-5}$	$3.5x10^{-6}$	$1.6x10^{-6}$	$1.1x10^{-6}$	$9.2x10^{-7}$	$7.6x10^{-7}$	$5.5x10^{-7}$	$4.0x10^{-7}$	$2.9x10^{-7}$
SE T&G	$1.7x10^{-7}$	$1.6x10^{-7}$	$1.7x10^{-7}$	$1.3x10^{-7}$	$1.2x10^{-7}$	$1.0x10^{-7}$	$8.0x10^{-8}$	$6.1x10^{-8}$	$5.5x10^{-8}$
ME Full	$9.0x10^{-5}$	$2.3x10^{-5}$	$1.1x10^{-5}$	$8.2x10^{-6}$	$6.6x10^{-6}$	$5.5x10^{-6}$	$4.0x10^{-6}$	$3.0x10^{-6}$	$2.2x10^{-6}$
ME T&G	$6.8x10^{-7}$	$5.0x10^{-7}$	$4.5x10^{-7}$	$3.3x10^{-7}$	$2.7x10^{-7}$	$2.2x10^{-7}$	$1.7x10^{-7}$	$1.3x10^{-7}$	$1.2x10^{-7}$

When each AQF is multiplied by the number of corresponding LTOs (full LTOs or T&Gs) that occur at the most frequently used runway end during a 3-month period, the sum of the products equals the lead concentration over the 3-month period at each of the nine locations. The concentration of lead in air, [Pb]$_{Air}$, is calculated by Equation 2, where Avgas[Pb] is the concentration of lead in fuel and PA is piston activity for the given engine and operation type. The next section describes how the number of piston-engine LTOs, specific to aircraft class and operation-types, was estimated for each US airport in order to calculate 3-month average model-extrapolated concentrations of lead in air at each airport.

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[198] Variation in the rolling 3-month average AQFs for full LTOs is generally +/-25% of the mean across all 12 AQFs. Specifically, rolling 3-month average AQFs for SE full LTOs vary from 28% greater to 14% less than the associated mean AQFs. For ME full LTOs, the individual rolling 3-month AQFs vary from 23% greater to 13% less than the associated mean AQFs. The variation is consistent across locations. While ME aircraft typically have two engines, ME AQFs are more than double the equivalent SE AQFS due to greater fuel consumption of their engines and differences in time-in-modes. The T&G AQFs are one to two orders of magnitude smaller than the full LTO AQFs in the same location, and variability between AQFs is somewhat larger by percentage (46% greater to 16% less than the associated mean AQFs) but smaller in absolute terms.

[199] Additional information on the relationships between AQFs and distances downwind is available in Appendix C.

Eq. 2[200,201]:

$$[\mathrm{Pb}]_{\mathrm{Air}} =$$

$$\frac{\mathrm{Avgas[Pb]}\,\frac{\mathrm{g\ Pb}}{\mathrm{gal}}}{2.12\ \frac{\mathrm{g\ Pb}}{\mathrm{gal}}}\left[\left(\mathrm{PA}_{\mathrm{SE,Full}}\times\mathrm{AQF}_{\mathrm{SE,\ Full}}\right)+\left(\mathrm{PA}_{\mathrm{SE,\ T\&G}}\times\mathrm{AQF}_{\mathrm{SE,\ T\&G}}\right)+\left(\mathrm{PA}_{\mathrm{ME,\ Full}}\times\mathrm{AQF}_{\mathrm{ME,\ Full}}\right)+\left(\mathrm{PA}_{\mathrm{ME,\ T\&G}}\times\mathrm{AQF}_{\mathrm{ME,\ T\&G}}\right)\right]$$

3.2 National Analysis Methods

This section summarizes the approach and rationale for the national analysis of lead concentrations at and downwind of the maximum impact area at US airports. At a high-level, this approach entails estimating piston-engine aircraft activity at each runway end of each airport, and then combining activity estimates from the most actively used runway end in a 3-month period with the AQFs presented in the previous section. The following text describes, in brief, the methods used to estimate 3-month maximum piston-engine aircraft activity at each runway end for airports nationwide; the detailed methods for this analysis are provided in Table 2.

Airport-specific piston-engine aircraft activity data are not collected by FAA or reported by airports in a national data source. Rather, piston-engine aircraft activity is reported by FAA as part of GA and AT activity, which can also include jet-engine aircraft activity. To estimate piston-engine activity, we used national datasets as described in Appendix B and FAA survey data regarding the national average for number of hours flown by piston-engine GA or AT aircraft nationwide.[202] Specifically, the percent of hours flown by piston-engine aircraft categorized as GA (72%) and, separately, AT (23%) was used to estimate the number of LTOs conducted by piston-engine aircraft at US airports that report GA and AT LTOs (e.g., if an airport reports 100 GA LTOs and 10 AT LTOs, then 72 and 2 LTOs would be attributed to piston-engine aircraft for each respective category). For airports that do not report LTOs conducted by GA and AT, EPA expanded on an FAA method to estimate LTOs using data on the number of aircraft

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[200] Per the description in the above text, the concentration of lead in air is calculated at nine distances starting immediately adjacent to run-up out to 500 meters downwind.

[201] The scalar for the concentration of lead in avgas is used to normalize the lead concentration to the ASTM specification for 100 LL (ASTM International (2016). *Standard Specification for Leaded Aviation Gasolines*. https://compass.astm.org/EDIT/html_annot.cgi?D910+19). The impact of variability in avgas lead concentrations on model-extrapolated lead concentrations is discussed in Section 3.4.

[202] Data on hours flown by piston-engine aircraft is consistent with activity data (LTOs), but activity data are reported as number of LTOs conducted by piston-engine aircraft in both GA and AT categories, whereas hours flown data are reported for piston-engine aircraft in GA and, separately, AT categories. Piston-engine aircraft flew 65.8% of hours categorized as GA and AT combined compared to conducting 65.7% of LTOs categorized as GA and AT combined. Piston-engine aircraft flew 72% of hours categorized as GA, and, separately, 23% of those categorized as AT.

based at the airport (i.e., aircraft that are air worthy and operational that are based at an airport for the majority of the year, commonly referred to as "based aircraft").[203] This approach to estimate piston-engine LTOs is routinely applied in the EPA National Emissions Inventory and is documented in full on the EPA website.[204] The national analysis of lead concentrations at and downwind of airports nationwide used these annual piston-engine LTO estimates to calculate the number of piston-engine LTOs at each runway end of US airports over 3-month rolling periods as described below (Figure 2).[205] For this analysis, annual piston-engine LTO estimates from 2011 formed the basis of calculating activity at each runway end over 3-month rolling periods. Additional discussion on piston-engine activity in 2011 compared to other recent years is provided in Appendix B, Section 1. For a subset of airports, airport-specific data were used to provide an additional estimate piston-engine LTOs, as detailed in Section 3.3.

Annual GA and, separately, AT piston-engine LTOs at each US airport were separated into the four categories of the aircraft classes and cycle-types: SE full LTO, SE T&G, ME full LTO, and ME T&G, based on FAA data for GA and AT activity. Next, annual LTOs in each of these four categories at each airport were temporally allocated into daily and then hourly periods based on a combination of daily activity data from FAA and observations of hourly activity patterns at the model airport. The allocation of annual to daily piston-engine aircraft activity was accomplished by calculating a daily fraction of activity (i.e., GA or AT LTOs on a given day/annual GA or AT LTOs) for each airport. The daily fraction was then multiplied by the number of piston-engine LTOs in each of the four aircraft class and cycle-type categories. The resulting number of daily LTOs in each category was then allocated to each hour of each day based on a diurnal profile (i.e., fraction of daily LTOs per hour) from the model airport described in Section 2.2. Appendix B provides additional information on the diurnal profile observed at the model facility compared to observations at other airports.

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[203] When airports do not report LTOs specific to GA and AT activity, then the number of aircraft that can use leaded fuel (i.e., SE, ME, helicopters, and ultralight vehicles) that are based at a given airport was used to help estimate the number of LTOs conducted by each category of activity (GA or AT) out of the total number of LTOs conducted at that airport. Airports lacking data on both the number of LTOs and the number of based aircraft were assigned 1 LTO per year based on a review of available information. For more information, see Sections 4a and 4b of: http://nepis.epa.gov/Exe/ZyPDF.cgi/P1009I13.PDF?Dockey=P1009I13.PDF.

[204] See Sections 4 and 6a of: http://nepis.epa.gov/Exe/ZyPDF.cgi/P1009I13.PDF?Dockey=P1009I13.PDF

[205] The method used to estimate piston-engine aircraft activity at specific runway ends has inherent uncertainty from both underlying operational data and local airport traffic patterns. Nevertheless, comparisons of the methodology presented here to airport-specific observations and data suggest that this method is appropriate for estimating piston-engine specific activity (See Section 3.3). EPA acknowledges that there are other methods to estimate piston-engine specific activity (Heiken et. al. 2016), and that the national analysis focuses on activity estimates during a single year (2011), which does not capture the annual variability in piston-engine aircraft activity at each airport due to local circumstances or national trends.

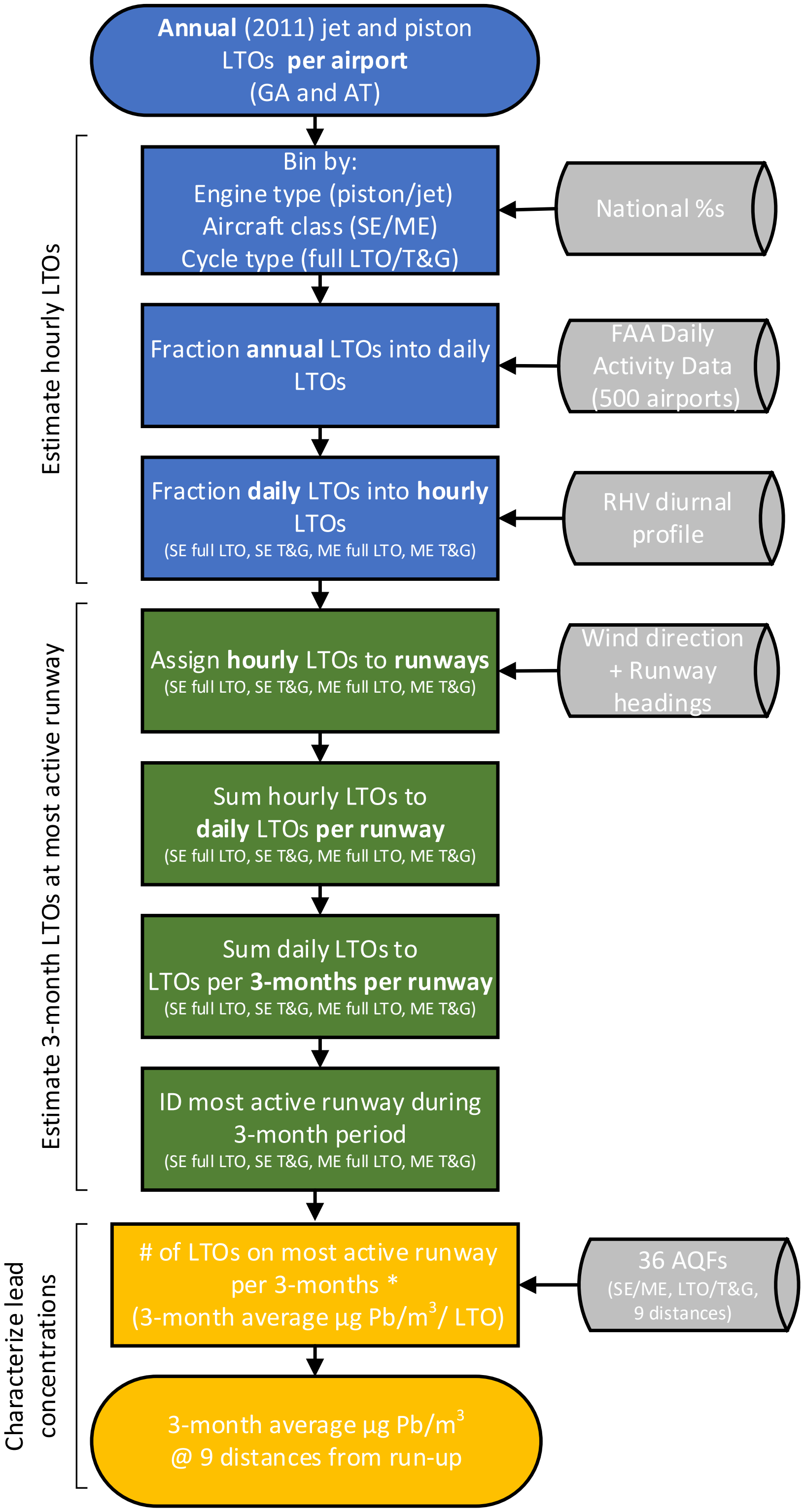

Figure 2. Overview of method to estimate piston-engine aircraft activity at airports nationwide. Center rectangles represent main calculation steps, while colors denote different spatial granularity. Grey cylinders represent input datasets. See Table 2 for details.

With the number of piston-engine LTOs (categorized as SE full LTO, SE T&G, ME full LTO, ME T&G) per hour at each airport, the next step was to assign LTOs to specific runway ends at each airport. Hourly LTOs were assigned to the runway end at which piston-engine activity would occur based on wind direction data since piston-engine aircraft take-off and land into the wind (See Appendix B for additional information on runway assignment and wind direction data).[206] Hourly LTOs per runway end were then summed to daily and, subsequently, rolling 3-month totals (aircraft class and cycle-type categories were maintained when aggregating up to 3-month LTOs). The total piston-engine LTOs per runway end in a 3-month period was then used to identify the most active runway at each airport. Next, the number of 3-month LTOs on the most active runway is multiplied by the appropriate AQF (e.g., number of 3-month SE full LTOs x SE full LTO AQF at maximum impact site) (Figure 3). As depicted in Equation 2, summing across the products from each of the four aircraft class and cycle-type categories provides a 3-month average, model-extrapolated concentration of lead in the maximum impact area and eight downwind locations for each of the approximately 13,000 airports. These model-extrapolated 3-month average lead concentrations are: 1) attributable to aircraft using leaded avgas, and 2) located at each of the nine specified distances at each US airport.

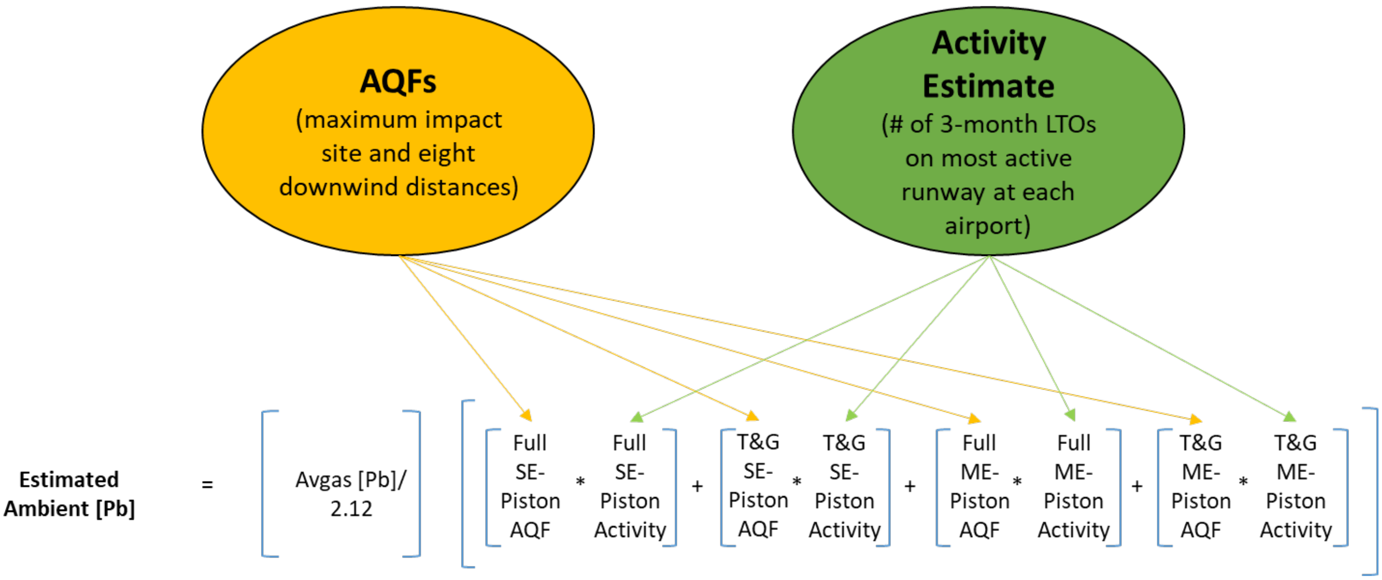

Figure 3. Visualization of approach for calculating extrapolated lead concentrations by multiplying emission factors (AQFs) by activity estimates for each airport nationwide using Equation 2.

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[206] While piston-engine aircraft may conduct run-up and take-off on an alternative runway (i.e., not one facing into the wind) due to activity levels, weather, noise restrictions, or other airport operational considerations, wind is the primary driver of active runway selection Lohr, G. W. and D. M. Williams (2008). *Current practices in runway configuration management (RCM) and arrival/departure runway balancing (ADRB)*. NASA/TM-2008-215557 NASA. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090010329.pdf. Therefore, prevailing wind direction is an appropriate indicator for identifying which runway and direction piston-engine aircraft conduct take-off and landing operations. Runways are built to allow the maximum possible days of flying by taking into account the dominant wind direction(s) experienced at the airport; thus, the runway end(s) predominantly used for piston-engine aircraft take-off can be identified.

While several meteorological, geographical, and operational parameters may vary from conditions at the model airport or from the national default parameters used across the national analysis described above, wind speed is one meteorological parameter that clearly affects local concentration profiles of atmospheric aerosols. The model-extrapolated concentrations at and downwind of the maximum impact site as characterized in the approach above can be adjusted to better consider meteorological conditions by using inverse wind speed data over the 3-month maximum period. Specifically, the near-field concentration of a non-reactive pollutant scales with $<\boldsymbol{u}^{-1}>$, where $\boldsymbol{u}$ is wind speed and angled brackets imply a time average (Barrett and Britter 2008). If the wind speed at the model airport is $\boldsymbol{v}$ and the wind speed at a specific airport is $\boldsymbol{u}$, then the wind-adjusted concentration would be the model-extrapolated concentration estimated by the methodology detailed above multiplied by the ratio of average inverse wind speeds $<\mathbf{v}^{-1}>/<\mathbf{u}^{-1}>$. If the wind speed at the specific airport is, in general, higher than the wind speed at the model airport where the AQFs were derived, then $<\mathbf{v}^{-1}>$ would be less than $<\boldsymbol{u}^{-1}>$ resulting in a lower concentration per activity at the specific airport than the AQF. Utilizing the same wind data that was used to assign operations to specific runways, model-extrapolated concentrations at airports nationwide can be adjusted for wind-speed, thereby appropriately characterizing concentrations at airports with significantly higher or lower wind speeds than the model airport. For the wind speed adjustment, wind speeds from 6am to 11pm[207] were averaged over the entire year at the model airport and for the 3-month maximum activity period at each US airport. As the inverse of wind speed tends toward infinity as wind speed tends toward zero, 0.5 m/s is chosen as a minimum allowable wind speed; this choice also aligns with ASOS station wind detection limits. Further details of the wind-adjustment approach are provided in Appendix A.

Results of the national analysis method and wind speed adjustment described here, and detailed in Table 2, are provided in Section 4. Additional quantitative and qualitative assessments of uncertainty from other potentially influential parameters, such as avgas lead concentration and seasonality of operational profiles are discussed in Section 3.4.

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[207] These are the modeled hours from opening through one hour past closing for each airport, reflecting the times when atmospheric lead concentrations are expected to be highest.

Table 2. Steps to Calculate Airport Facility Specific Piston-Engine Aircraft Lead Concentrations

Step #	Step[208]	Description	Rationale	Data Source[209]
Steps 1 – 7 Objective: Estimate how much piston-engine activity occurred at each U.S. airport on an hourly basis, by engine, and operation type.				
1	**Estimate how much activity is conducted by piston-engine aircraft annually**	Estimate the annual number of piston-engine LTOs[210] in defined categories (i.e., GA and AT)	Only piston-engine aircraft use leaded avgas, thus we needed to estimate how much of the total activity at an airport was specific to piston-engine aircraft, rather than turbine-engine aircraft. While several data sources provide airport-specific aircraft activity data (separately for General Aviation (GA) and Air Taxi (AT) activity), none specifically identify the number of *piston-engine*	2011 NEI GA and AT piston-engine annual LTOs[211] (USEPA 2011)

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[208] Each step in this table was carried out for the 13,153 airports in the US. Heliports and rotorcraft activity at airports were not included in this analysis; see Appendix B for additional information. For each of the 13,153 airports included in the analysis, calculations were completed for each day of 2011 and January – February 2012; however, annual estimates of piston-engine specific LTOs were only available for 2011, and thus estimates of piston-engine aircraft LTOs from January – February 2011 were used as surrogate activity data in the first two months of 2012. Based on the 2010 FAA Terminal Area Forecast (TAF), GA activity levels were similar between 2011 and 2012 (5% lower activity in 2012 than 2011) (https://taf.faa.gov/).

[209] Additional information on available FAA data sources is presented in Appendix B.

[210] An aircraft operation is defined as any landing or takeoff event, therefore, to calculate LTOs, operations are divided by two. Most data sources from FAA report aircraft activity in numbers of operations. Our air quality factors (AQFs), described in step 13, are in units of concentration per LTO, therefore for the purposes of this analysis, operations need to be converted to LTO events.

[211] The EPA 2011 NEI estimates annual GA and AT piston-engine LTOs that occur at each airport nationwide. These estimates were the starting point for this national analysis of lead concentrations at and downwind of maximum impact sites at airports nationwide. The general approach to estimate piston-engine aircraft LTOs in the 2011 NEI is briefly outlined here with more details are available in Sections 1, 3, 4, and 6a of the NEI documentation USEPA. (2011). "2011 National Emissions Inventory (NEI) Data." 2017, from http://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-data. In particular, the 2011 NEI used based aircraft, reported as single- or multi-engine, to develop more airport-specific piston-engine LTOs at airports with the potential for lead air emissions inventories greater than 0.50 tons per year. In the national analysis, based aircraft are similarly used to develop more airport-specific results for airports with model-extrapolated concentrations in the upper range of those nationwide (see Section 3.3 for details).

Step #	Step[208]	Description	Rationale	Data Source[209]
			aircraft LTOs that occur at each U.S. airport facility.	
1a	For GA activity	The national average percent of GA activity that was conducted by piston-engines (72%), according to the 2010 FAA GAATA report, was multiplied by total GA LTOs at each airport.	Multiplying GA LTOs at an airport by the national average of GA LTOs conducted by piston-engine aircraft was necessary to estimate the annual number of GA *piston-engine* LTOs that occurred at each airport.	2011 NEI GA piston-engine annual LTOs & FAA GAATA, 2010 (FAA 2010)
1b	For AT activity	The national average percent of AT activity that was conducted by piston-engines (23%), according to the 2010 FAA GAATA report, was multiplied by total AT LTOs at each airport.	Multiplying AT LTOs at an airport by the national average of AT LTOs conducted by piston-engine aircraft was necessary to estimate the annual number of AT *piston-engine* LTOs that occurred at each airport.	2011 NEI AT piston-engine annual LTOs & (FAA 2010)
Result: **Annual** number of GA piston-engine LTOs and AT piston-engine LTOs at each U.S. airport				
2	**Estimate how much of the annual piston-engine aircraft activity is conducted by each piston-engine aircraft class, performing**	Estimate the number of total annual piston-engine LTOs that are conducted by specific aircraft classes (i.e., SE and ME for specific cycle-types (i.e., Full LTO and T&G) at each airport.	Different aircraft classes and cycle-types have different fuel consumption rates, and therefore different quantities of lead emissions.	

Step #	Step[208]	Description	Rationale	Data Source[209]
	different cycle-types			
2a	For GA piston-engine LTOs	Multiply the annual number of GA piston-engine LTOs (from Step 1a) by the national fraction of annual GA activity conducted by each aircraft class and cycle-type (i.e., SE Full LTO, SE T&G, ME Full LTO, ME T&G).	Fractioning GA piston-engine activity into 4 combinations of aircraft and cycle-types (i.e., 68% SE Full LTO, 23% SE T&G, 8% ME Full LTO, 2% ME T&G) allows us to categorize LTOs by sub-type of GA piston-engine activity which is important since each sub-type impacts the resulting concentrations differently.	Step 1a & (FAA 2010)(Table 1.4)[212]
2b	For AT piston-engine LTOs	Multiply the annual number of AT piston-engine LTOs (from Step 1b) by the national fraction of annual AT activity conducted by each aircraft class and cycle-type (i.e., SE Full LTO, SE T&G, ME Full LTO, ME T&G).	Fractioning AT piston-engine activity into 4 combinations of aircraft classes and cycle-types (i.e., 57% SE Full LTO, 0% SE T&G, 43% ME Full LTO, 0% ME T&G) allows us to categorize LTOs by sub-type of AT piston-engine activity, which is important since each sub-type impacts the resulting concentrations differently.	Step 1b & (FAA 2010) (Table 1.4)
Result: <u>**Annual**</u> number of piston-engine LTOs at each U.S. airport categorized as: 1) GA SE Full LTO, 2) GA SE T&G, 3) GA ME Full LTO, 4) GA ME T&G, 5) AT SE Full LTO, 6) AT SE T&G, 7) AT ME Full LTO, 8) AT ME T&G.				
3	**At the U.S. towered airports,**	Approximately 500 airports have air traffic control towers (i.e., are	Steps 1 – 2 provide <u>annual</u> piston-engine activity; however, aircraft activity varies	ATADS

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[212] The 2011 FAA GAATA report was not published, therefore the 2010 FAA GAATA report was used for this step. Based on a comparison of the 2010 and 2012 FAA GAATA reports, engine and operation type splits were very similar between 2010 and 2012 (<1% difference in any category between 2012 than 2010) (https://www.faa.gov/data_research/aviation_data_statistics/general_aviation/). See Section 4 for additional discussion on uncertainty and variability in data used in this analysis. The full LTOs and T&Gs fractions were based on the number of hours flown for GA or AT activities where T&Gs were defined as the percent of "instructional" hours and full LTOs were defined as the percent of all remaining hours (e.g., total GA hours flown – instructional hours). The amount of instructional activity will vary by airport. For instance, T&G activity was 4.5 to 29% and 0 to 35% of total SE and ME LTOs, respectively at airports for which EPA has conducted onsite observational surveys (see Appendix C for survey details).

Step #	Step[208]	Description	Rationale	Data Source[209]
	estimate what fraction of annual activity occurred on each day of the analysis (separately for GA and AT) [213]	"towered airports") and therefore have daily activity counts (separate for GA and AT). At each of these airports we developed separate GA and AT daily activity profiles, or fractions of annual activity that occurred during each day of the analysis. These daily activity profiles will later be applied to all U.S. airports (see Step 5).	by month, day, and hour. Because of this temporal variability, identifying the maximum 3-month period of activity necessitates that we apportion the annual activity data to daily activity (this step) and subsequently (in the following steps) further apportion daily data to each hour of the day.	
3a	For GA LTOs	At each towered airport, divide daily GA LTOs for each day included in the analysis by annual GA LTOs to reach the daily fraction of GA LTOs at each towered airport.	Dividing daily by annual GA activity produces a daily GA activity profile for each towered airport.	ATADS
3b	For AT LTOs	At each towered airport, divide daily AT LTOs for each day included in the analysis by annual AT LTOs to reach the daily fraction of AT LTOs at each towered airport.	Dividing daily by annual AT activity produces a daily AT activity profile for each towered airport.	ATADS
Result: <u>**Daily**</u> Activity Profiles, separately for GA and AT activity, at each towered airport for each day in the analysis.				
4	**For each non-towered U.S. airport, identify**	Use latitude/longitude data and a distance formula to determine the closest towered airport to each non-towered U.S. airport.[214] These data	Data to develop daily activity profiles are only available for airports that report daily activity data (i.e., towered airports). To apportion each airport's annual	FAA 5010

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[213] For example, the number of GA operations at each towered airport on January 1, 2011 (from ATADS dataset) were divided by each airport's respective total number of GA operations in 2011. All operational data were converted to LTOs by dividing by two (i.e., two operations is one LTO).

[214] For two airports with (latitude, longitude) pairs of (LatA, LongA) and (LatB, LongB), the distance between them will be:
distance (km) = R*arccos[cosd(LatA)*cosd(LatB)*cosd(LongB-LongA)+sind(LatA)*sind(LatB)] where R is the radius of the spherical approximation of Earth.

Step #	Step[208]	Description	Rationale	Data Source[209]
	its closest towered airport	will be used in combination with the daily activity profiles calculated in step 3 to estimate daily piston activity at each U.S. airport.	activity to individual days, we apply the daily profile from the towered airport closest in distance to the non-towered airport. To do so, we first determine the closest towered airport for each non-towered U.S. airport. [215]	
Result: Identification of the closest towered airport for each non-towered airport in the U.S.				
5	**Estimate the number of daily piston-engine** LTO**s at all U.S. airports**	Multiply each airport's annual activity (step 2) by the daily activity profile (step 3) for its closest towered airport. This is done separately for GA and AT.	The GA and AT daily activity profiles (step 3) allow us to apportion annual activity into daily activity.	
5a	For GA LTOs	Multiply each airport's annual piston-engine GA activity (for each of the 4 types: 1) GA SE Full LTO, 2) GA SE T&G, 3) GA ME Full LTO, 4) GA ME T&G) by the GA daily activity profile for its closest towered airport.	Daily activity data are only available for the combined set of all GA aircraft engine & operation types (i.e., SE Full LTO, SE T&G, ME Full LTO, ME T&G), thus, we use the same GA daily activity profile for each of the 4 subsets of GA activity at all airports.	Steps 2a & 3a
5b	For AT LTOs	Multiply each airport's annual piston-engine AT activity (for each of the 4 types: 1) AT SE Full LTO, 2) AT SE T&G, 3) AT ME Full LTO, 4) AT	Similar to GA, daily activity data are only available for all types of AT aircraft engine & operation types (i.e., SE Full LTO, SE T&G, ME Full LTO, ME T&G) combined,	Steps 2b & 3b

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[215] Airport towers at the 500 most active airports in the U.S. report the number of total operations on each day, which are recorded in the FAA ATADS database. For airport facilities without ATADS data, we used activity data from the nearest ATADS facility as a surrogate for the airport facility without daily activity data (distances between ATADS facility and surrogates: Mean 64 km, Max 672 km, 25th % 28 km, 75th % 79 km, 90th % 128 km, 95th % 169km, 99th % 292 km). The closest towered airport to a towered airport will be itself. Note that primary airports (i.e., airports with mainly commercial jet activity) were not used as surrogates since these airports likely have a distinctly different activity profile than GA airports. (See Appendix B for additional details on the ATADS database.)

Step #	**Step[208]**	**Description**	**Rationale**	**Data Source[209]**
		ME T&G) by the AT daily activity profile for its closest towered airport.	thus, we use the same AT daily activity profile for each of the 4 subsets of AT activity at all airports.	
Result: Number of **daily** piston-engine LTOs at each U.S. airport categorized as: 1) GA SE Full LTO, 2) GA SE T&G, 3) GA ME Full LTO, 4) GA ME T&G, 5) AT SE Full LTO, 6) AT SE T&G, 7) AT ME Full LTO, 8) AT ME T&G.				
6	**Sum the number of daily** LTO**s by aircraft engine type & operation mode**	Sum the daily number of GA and AT LTOs across aircraft engine and operation type (i.e., SE Full LTO, SE T&G, ME Full LTO, ME T&G).	The concentration of lead emissions is related to the type of aircraft engine and operation type, thus there is no distinction in terms of emissions between a SE Full LTO conducted as GA vs. AT. Understanding levels of GA vs. AT activity was necessary to appropriately apportion annual GA and AT activity into specific piston engine and operation types.	Step 5
6a	For SE full LTO	Sum the # of GA SE full LTOs & # of AT SE full LTOs for each day at each airport.		
6b	For SE T&G	Same as Step 6a but for SE T&G.		
6c	For ME full LT0	Same as Step 6a but for ME full LTO.		
6d	For ME T&G	Same as Step 6a but for ME T&G.		
Result: Number of **daily** piston-engine LTOs at each U.S. airport categorized as: 1) SE Full LTO, 2) SE T&G, 3) ME Full LTO, 4) ME T&G				
7	**Estimate the number of** LTO**s that occurred during each hour of each day (i.e., the distribution of** LTO**s across**	For each day at each U.S. airport, multiply the number of daily piston-engine LTOs (separated into 1) SE Full LTO, 2) SE T&G, 3) ME Full LTO, 4) ME T&G) by the corresponding hourly activity profile (i.e., % of daily aircraft LTOs that occurred during	Step 6 results in daily piston-engine activity; however, aircraft activity varies by month, day, and hour. Because of this temporal variability, identifying the maximum 3-month period of activity necessitates that we apportion the daily activity data to hourly activity (this step).	Model airport (see Section 2 & Appendix

Step #	Step[208]	Description	Rationale	Data Source[209]
	facility operational hours of the day)	each operational hour) from the model airport. There are separate profiles for each engine type (1) SE Full LTO, 2) SE T&G, 3) ME Full LTO, 4) ME T&G) by weekday/weekend status.[216] (e.g., If 30% of SE Full LTOs occurred during Hour 5 on a weekday at the representative facility, and 10 SE Full LTOs occurred at a given facility on Day 1 (a weekday) of the analysis, then 3 SE Full LTOs would be assigned to Hour 5 of Day 1 at the given facility).	Subsequently (in the following step), we use wind direction data to apportion the hourly data to specific runway ends at each airport.	A) & Step 6
7a	For weekdays		Since data we collected suggests that the distribution of piston-engine aircraft activity can vary between weekend and weekdays, we used an activity distribution representative of weekday activity, and separately, an activity distribution for weekend activity.	Appendix A & Step 6
7ai	For SE Full LTO	Multiply % of SE Full LTOs that occurred in each operational hour of a weekday at a representative		

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[216] For more information on the distribution of LTOs over operational hours at the model airport see Appendix A. We characterize the influence of using a different distribution of LTOs across the day on estimates of ambient lead in Appendix B.

Step #	**Step[208]**	**Description**	**Rationale**	**Data Source[209]**
		facility by the number of daily SE Full LTOs for each facility in the analysis; repeat for each day in the analysis.		
7aii	For SE T&G	Repeat Step 7ai for SE T&G.		
7aiii	For ME Full LT0	Repeat Step 7ai for ME Full LT0.		
7aiv	For ME T&G	Repeat Step 7ai for ME T&G.		
7b	For weekends	Repeat Steps 7ai – 7aiv using the distribution of LTOs across operational hours on a weekend day.		Appendix A & Step 6
Result: Number of **hourly** piston-engine LTOs that occurred on each day of the analysis at each U.S. airport, categorized as: 1) SE Full LTO, 2) SE T&G, 3) ME Full LTO, 4) ME T&G				
Steps 8 – 12 Objective: Estimate how much piston-engine activity occurred on each runway end over each rolling 3-month period.				
8	**Identify the runway end at which aircraft activity likely occurred for each hour of each day in the analysis**	Use wind direction data for each hour that an airport is open (i.e., operational hours)[217] to identify the runway end on which piston-engine aircraft LTOs were conducted; repeat for each day in the analysis.	Piston-engine aircraft take-off into the wind, thus wind direction dictates the runway end that is used; wind direction can change throughout the day so we evaluate hourly wind direction[218] to identify the runway end used predominantly for each hour.	ASOS wind tower with shortest distance to airport

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[217] Operational hours were defined as 6 a.m. to 10 p.m. for all airport facilities in the analysis. While some airport facilities may have slightly different operational hours (e.g., open 6 a.m. to 11 p.m.), the operational hours selected for the analysis are likely representative of most airport facilities based on review of operational hours at numerous airports (www.airnav.com).

[218] The hourly wind direction data used in this analysis is the result of 1-min wind data having been processed by EPA's AERMINUTE into hourly wind data (see section 4.6 of AERMINUTE User's Guide for averaging method: https://www3.epa.gov/ttn/scram/7thconf/aermod/aerminute_userguide.pdf

Step #	Step[208]	Description	Rationale	Data Source[209]
8a	For each U.S. airport, determine its closest ASOS station	Use latitude/longitude data and distance formula[219] to determine the closest ASOS station to each U.S. airport.[220]	Hourly wind direction data was available at the 938 ASOS stations, most of which are located at airports.[221] To determine runway usage based on wind direction data, we first determined the closest ASOS station to each U.S. airport.	ASOS and FAA 5010 (See Appendix B for details)
8b	Use the hourly wind direction data from an airport's closest ASOS station to determine which runway end was used for each hour of the analysis	See Appendix B for details.	In order to appropriately estimate the location of the maximum lead concentration from piston-engine activity, we use wind direction data to identify where activity occurred (i.e., which runway end).	
Result: Location (i.e., runway end) of aircraft activity at each U.S. airport during each hour of each day in the analysis				
9	**Determine number of** LTOs **that occurred on each runway end on an hourly basis**	Assign piston-engine aircraft LTOs in each hour (Step 7) to the runway end that was active during each hour (Step 8); repeat for each day in the analysis.	Merging information regarding the *number* of hourly LTOs (Step 7) with our assessment of hourly *runway usage* (i.e., which runway end was used during each hour) allows us to quantify the hourly number of LTOs that occurred on each runway end at each U.S. airport for each day of the analysis.	

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[219] See footnote 30 for distance formula.

[220] The closest ASOS station to an airport with an ASOS station will be its own station.

[221] ASOS & Climate Observations Fact Sheet. November 2012. U.S. NOAA

Step #	Step[208]	Description	Rationale	Data Source[209]
9ai	For SE Full LTO	Assign SE Full LTOs in each hour (Step 7) to the runway end that was active during each hour (Step 8); repeat for each day in the analysis.		Steps 7 & 8
9aii	For SE T&G	Repeat Step 9ai for SE T&G.		
9aiii	For ME Full LT0	Repeat Step 9ai for ME Full LT0.		
9aiv	For ME T&G	Repeat Step 9ai for ME T&G.		
Result: Number of piston-engine LTOs that occurred during each hour on each runway end during each day of the analysis at each U.S. airport, categorized as: 1) SE Full LTO, 2) SE T&G, 3) ME Full LTO, 4) ME T&G				
10	**Determine the number of** LTOs **that likely occurred on each runway end on a daily basis**	For each runway end at each airport, sum the number of aircraft LTOs that occurred during all operational hours for a given day; repeat for each day in the analysis.	To estimate the number and type of LTOs that occurred at an airport on each runway end over an entire day, we sum the hourly LTOs, by runway end. In subsequent steps we use this daily information to estimate activity over 3-month time periods, which corresponds to the lead NAAQS averaging period.	
10ai	For SE Full LTO	For each runway end at each airport, sum the number of SE Full LTOs that occurred during all operational hours for a given day; repeat for each day in the analysis.	Summing all of the SE Full LTOs at an airport that occurred at each runway end during each operational hour of a day allows us to estimate the number of SE Full LTOs that occurred on each day of the analysis at each runway at an airport.	Step 9
10aii	For SE T&G	Repeat Step 10ai for SE T&G.		
10aiii	For ME Full LT0	Repeat Step 10ai for ME Full LT0.		
10aiv	For ME T&G	Repeat Step 10ai for ME T&G.		

Step #	Step[208]	Description	Rationale	Data Source[209]
Result: Number of piston-engine LTOs that occurred during each day on each runway end at each U.S. airport, categorized as: 1) SE Full LTO, 2) SE T&G, 3) ME Full LTO, 4) ME T&G				
11	**Sum daily # of** LTO**s estimated to have occurred on each runway end by rolling 3-month period**		We estimate the number and type of LTOs that occurred on each runway end at each airport over a rolling 3-month period using the daily information generated in Step 10, since the averaging time for the lead NAAQS is a rolling 3-month averaging period (e.g., January – March, February – April, March – May).[222]	
11ai	For SE Full LTO	For each runway end at each airport, sum the number of SE Full LTOs that occurred during each day of a 3-month period; repeat for each rolling 3-month period included in the analysis.		Step 10
11aii	For SE T&G	Repeat Step 11ai for SE T&G.		
11aiii	For ME Full LT0	Repeat Step 11ai for ME Full LT0.		
11aiv	For ME T&G	Repeat Step 11ai for ME T&G.		
Result: Number of piston-engine LTOs that occurred during each rolling 3-month period on each runway end at each U.S. airport, categorized as: 1) SE Full LTO, 2) SE T&G, 3) ME Full LTO, 4) ME T&G				

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[222] At some airports available data suggest that the sum of LTOs in the 3-month period is less than one; this is predominantly due to the airport having fewer than 5 LTOs per year, but in some cases, may be due to missing data (e.g., runway end identifiers). Low activity or a lack of data resulted in 2,095 out of the 13,000 airports nationwide with less than one LTO in the 3-month period. Model-extrapolated concentrations at these airports are thus less than 0.0075 ug/m^3 (see Section 4.1 for results). Additional analyses outside the scope of this report would be needed to evaluate airborne lead concentrations at these individual airports.

Step #	Step[208]	Description	Rationale	Data Source[209]
12	**Identify the runway end with the highest estimates of piston-engine aircraft activity during any 3-month period at each airport**		Piston-engine aircraft activity is a first-order determinant of lead concentrations in the maximum impact area in monitoring and modeling studies, as described in Section 2, and thus the period of maximum activity is assumed to represent the period of maximum concentration. [223]	Step 11
12a	For each runway end, sum the number of total piston aircraft LTOs that occurred during each 3-month period for all engine & operation types; repeat for each rolling 3-month period included in the analysis	Sum Steps 11ai – 11aiv by runway and by 3-month period for each U.S. airport.	In addition to understanding how much piston-engine aircraft activity of specific engine class & cycle types occurred at each runway end over rolling 3-month periods (which will be used in Step 13), we to need identify the runway end at which the most piston aircraft activity of any type was conducted over a rolling 3-month period. Identifying the runway end used most frequently by piston-engine aircraft allows us to estimate ambient concentrations at the location (i.e., runway end) with the most piston-engine activity, and in turn the highest lead emissions.	Step 11
12b		Review number of piston-engine LTOs conducted at each runway end		Step 12a

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[223] In some instances, meteorological parameters (e.g., low mixing height) may result in maximum concentrations during relatively lower activity periods. Uncertainty and variability in meteorological parameters is discussed further in Section 4.3.

Step #	Step[208]	Description	Rationale	Data Source[209]
		during each rolling 3-month period included in the analysis and identify the runway end with the most total piston-engine LTOs during any 3-month period; repeat for each airport facility in the analysis.		
Result: Identification of the most active runway during any 3-month period at each airport facility included in the analysis				
Steps 13 – 15 Objective: Estimate maximum 3-month lead concentrations from Piston-engine aircraft at each U.S. Airport				
13	**Estimate ambient lead concentrations from piston-engine aircraft lead emissions at the runway end most frequently used by piston-engine aircraft during the most active rolling 3-month period**	Multiply the number of LTOs that occurred on the runway end most frequently used by piston-engine aircraft during the most active 3-month period by corresponding air quality factors; repeat for each facility in the analysis.	In Steps 1 – 12 we estimate piston-engine aircraft activity (i.e., how many LTOs of which engine class and cycle type that occur when and where) at each airport facility included in the analysis. We then combine our activity estimates with estimates of lead concentrations associated with each type of LTO in order to calculate total maximum 3-month lead concentrations from piston-engine aircraft. To do so, we use AQFs that are specific to each engine class and cycle type (SE Full LTO, SE T&G, ME Full LTO, ME T&G).	
13ai	For SE Full LTOs at the most active runway during the most active 3-month period	Multiply the following: 1) the number of SE Full LTOs that occurred at the runway end most frequently used by piston-engine aircraft during the most active 3-month period, by 2) the AQF for SE	As described in Section 3.1, AQFs are the relationship of lead concentration per unit of aircraft activity (with distinct AQFs for each aircraft engine and operation type) and having units of average 3-month µg Pb/ m^3/ LTO. By multiplying	Steps 11&12; Model airport (see Section 2

Step #	Step[208]	Description	Rationale	Data Source[209]
		Full LTOs at the max impact site; repeat for each facility in the analysis.	each AQF by the level of activity we estimate the lead concentration (µg Pb/ m^3) associated with the number of LTOs we estimated in Steps 1 – 12.	& Appendix A)
13aii	For SE T&G	Repeat Step 13ai for SE T&G.		
13aiii	For ME Full LT0	Repeat Step 13ai for ME Full LT0.		
13aiv	For ME T&G	Repeat Step 13ai for ME T&G.		
13av	For all piston-engine activity	Sum Steps 13ai – 13aiv.	We need to understand <u>total</u> lead concentrations from all types of piston-engine activity, which is the sum of Steps 13ai-13aiv.	
13avi	Scaled by the lead concentration in avgas	First, divide the ASTM standard for Pb concentration in avgas (2.12 g Pb/gal) by the avgas Pb concentration at the model airport (2.16 g Pb/gal). Second, multiply the ratio of 2.12/2.16 by the sum of lead concentration from all types of piston-engine activity (Step 13av).	The AQFs were generated at a model airport with a concentration of Pb in avgas that is different from the ASTM maximum specification for this fuel. Thus, we scale the lead concentrations at each airport by the ratio of the ASTM standard lead concentration to the avgas lead concentration at the facility used to develop AQFs.[224]	
Result: Ambient lead concentration estimates at the max impact site at the most active runway end during the most active 3-month period for each airport facility included in the analysis				
14	**Estimate ambient lead concentrations at**	Repeat Step 13 with the appropriate AQFs for the 8 locations further downwind of the max impact site	As discussed in Section 3.1, in addition to developing AQFs at the max impact site, we also developed AQFs at 8 locations	Model airport (see

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[224] We examine the influence that using the ASTM standard for avgas lead concentration has on our ambient lead concentration estimates in Section 4.

<table>
<tr><th>Step #</th><th>Step[208]</th><th>Description</th><th>Rationale</th><th>Data Source[209]</th></tr>
<tr><td></td><td>locations further downwind from the runway end</td><td>(50, 100, 150, 200, 250, 300, 400, 500 m); repeat for each facility included in the analysis.</td><td>downwind of the max impact site (i.e., where piston-engine aircraft conduct run-up checks) in order to provide estimates of how lead concentrations change with distance. Similar to Step 13, we need to combine each respective AQF with activity estimates in order to estimate concentrations of ambient lead at each distance for each airport included in the analysis.</td><td>Section 2 & Appendix A)</td></tr>
<tr><td colspan="5">Result: Ambient lead concentration estimates at 8 locations downwind of the max impact site at the most active runway end during the most active 3-month period for each airport included in the analysis</td></tr>
<tr><td>15</td><td>Estimate wind-adjusted ambient lead concentrations using average inverse wind speed</td><td>Scale the model-extrapolated ambient lead concentrations by the ratio of the average inverse wind speeds at the model airport to the average inverse wind speeds recorded at the nearest ASOS wind tower.</td><td>As discussed in Section 3.2, wind speed has a consistent and well-characterized impact on the near-field concentration of a passive tracer under dispersion. Therefore, scaling model-extrapolated lead concentrations to consider wind speed will better characterize local concentrations at airports nationwide, particularly those airports where wind speeds during the maximum activity period differ significantly from those observed at the model airport.</td><td>Appendix A and ASOS wind tower with shortest distance to airport</td></tr>
<tr><td colspan="5">Result: Ambient wind-adjusted lead concentration estimates at and downwind of the max impact site at the most active runway end during the most active 3-month period for each airport included in the analysis</td></tr>
</table>

3.3 Evaluation of Airports for Potential Lead Concentrations Above the Lead NAAQS

The national analysis methods described in Section 3.2 provided estimates of 3-month average model-extrapolated lead concentrations in the maximum impact area and locations downwind out to 500-meters for 13,153 airports. Within this large set of model-extrapolated concentrations, we identified the subset of airports where lead concentrations were estimated to potentially approach, within 10%, or to be above the lead NAAQS.[225] To do this, we first identified airports where model-extrapolated concentrations were above the NAAQS. Next, we ran a series of sensitivity analyses to identify any additional airports where model-extrapolated concentrations may be above or approach the NAAQS when considering the major drivers of airport-to-airport variability and uncertainty. For this subset of airports, we then identified additional, airport-specific data that could refine the estimates of piston-engine aircraft activity. Finally, for this subset of airports we considered additional airport-specific criteria, such as the unrestricted access within 50 meters of the maximum impact location. An overview and rationale for the approach is provided in Section 3.3.1 followed by a description of how we adjusted activity estimates for the identified subset of airports using airport-specific data in Section 3.3.2. The full methodology for considering concentrations using airport-specific activity data and additional criteria is presented in Section 3.3.3.

3.3.1 Sensitivity Analysis of Airport-Specific Parameters that Influence Potential for Lead Concentrations to be Above the NAAQS

The first step to identify airports at which model-extrapolated concentrations are potentially above the lead NAAQS was to evaluate which airport-specific parameters may result in uncertainty or bias that would lead to underestimates in model-extrapolated concentrations from the national analysis methods presented in Section 3.2. There is potential uncertainty and/or bias from using national defaults for: 1) percentages of piston aircraft at an airport, 2) percentages of piston operations performed by single- versus multi-engine aircraft, and 3) assigning piston operations to runway ends. To address these sources of uncertainty and to identify airports where lead concentrations may approach or be above the NAAQs, but would not be identified by using national defaults, we conducted a series of sensitivity analyses. These sensitivity analyses expand the number of airports that would be within 10% of the NAAQs by using different assumptions for each of the three parameters outlined above that used national defaults in the national analysis.

For the first two parameters, we accounted for the possibility that the percentage of activity conducted by piston-engine aircraft and/or the percentage of piston-engine aircraft activity conducted by multi-engine aircraft at each airport might be underestimated by national averages. We did so by evaluating a scenario in which all GA and half of AT activity was conducted by piston-engine aircraft at each airport (i.e., we substituted 100% and 50% for the national average percentages of 72% and 23% piston-engine aircraft of total GA and AT,

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[225] The current NAAQS for lead is 0.15 µg/m^3 as a 3-month rolling average. For this analysis, “approaching” the lead NAAQS is defined as within 10% of the current standard, or 3-month average model-extrapolated concentrations ≥0.14 µg/m^3.

respectively; see Step 1 of Table 2).[226] Because AT operations are more often conducted by ME aircraft, this sensitivity analysis impacts both the estimates of piston-engine aircraft activity and the predominance of ME or SE piston-engine aircraft at an airport. We then identified airports that had 3-month average model-extrapolated lead concentrations that were within 10% of the lead NAAQS after accounting for the possibility that national averages might be under-representations of piston-engine activity at some airports.

An additional sensitivity analysis was performed on the percentage of operations that occur at the most-utilized runway during the maximum activity period (Step 12 of Table 2). Two factors contribute to this percentage: the seasonal profile of operations and the allocation of operations to different runways based on wind direction. For the airports that were identified as having maximum 3-month concentrations above or approaching 0.15 µg/m^3 through the national analysis method presented in Section 3.2, the average percentage of annual activity occurring at the maximum period runway end is 20%. However, this percentage ranges from <6% at some airports, up to 45% at others. Reasons why an aircraft could take-off or land on a runway end other than the one assigned in the extrapolation, or be active during another 3-month period, include that the airport's seasonal profile of piston operations differs from that of the nearest ATADS airport, or the airport has two runways with similar headings, such that the dominant wind direction bisects them. These effects could bias estimates of operations and therefore concentrations either high or low. To better understand if some airports could have concentrations approaching or above the NAAQs that were not identified in the initial nationwide analysis due to a runway assignment bias, a sensitivity analysis was performed; airports that had less than 20% of their operations occurring at their maximum utilized 3-month period runway end were changed to having 20% of operations occur at that runway during that period.[227]

Additional sources of uncertainty in operational data that could impact the national analysis results are discussed in Section 4.4 of this report. For example, there may be uncertainty in the annual GA operations counts that underlie the piston operations data. However, changing the total annual GA operations count effects the resulting maximum concentrations in the same way that changing the percentage of GA operations that are conducted by piston aircraft effects the maximum concentration (i.e., increasing total GA operations by 10% would be analytically equivalent to keeping GA operation counts constant and increasing the percentage performed by piston aircraft by 10%). Thus, the sensitivity analyses performed above may be

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[226] The parameters presented in these sensitivity analyses, such as the 100% GA and 50% AT activity conducted by piston-engine aircraft, were only used to identify airports for additional analysis; neither these parameters nor the resulting maximum 3-month concentrations were used in the airport-specific activity analysis described below and presented in Section 4.2.

[227] This sensitivity analysis may not identify all airports where maximum concentrations have been under- (or over-) estimated due to the operational profile and runway assignment methodology. For example, an airport that the national analysis identifies as having 21% of operations occurring at the maximum runway end may in practice have 35% of operations occurring at that runway end. However, initial analysis showed that model-extrapolated concentrations estimated to be above the level of the lead NAAQS were mostly insensitive to operational shifts of this scale. This suggests that the national analysis methodology is appropriate for identifying airports with the potential for model-extrapolated concentrations to be above the lead NAAQS even considering this operational uncertainty.

interpreted to account instead, at least in part, for independent uncertainty from these other sources.

The airports identified in the national analysis or sensitivity analyses as having maximum 3-month concentrations above or approaching the NAAQS were the focus of a more refined assessment of piston-engine aircraft activity, as described below.

3.3.2 Airport-Specific Activity Data

The objective of the sensitivity analyses described above was to identify additional airports at which it would be informative to evaluate airport-specific piston-engine aircraft activity data, rather than national average data. The above sensitivity analyses applied alternative default assumptions for two parameters to all 13,000 airports, while the analyses in this section apply airport-specific data to the subset of airports identified through the sensitivity analyses and the national analysis. The objective of the analyses in this section is to account for the fact that national average activity estimates may potentially be improved by using airport-specific activity surrogates. As described in Section 3.2, piston-engine aircraft activity is not reported for individual airports, thus estimates of activity specific to piston-engine aircraft were calculated using national averages for the fraction of total GA and AT LTOs conducted by piston-engine aircraft. Similarly, national average fractions were used to estimate piston-engine LTOs conducted by SE versus ME aircraft. Both of these parameters (piston-engine aircraft activity and SE versus ME activity) particularly influenced monitored and modeled lead concentrations attributable to piston-engine aircraft in previous analyses conducted by EPA and others (Fine et. al. 2010, Carr et. al. 2011, Heiken et. al. 2014, Feinberg et. al. 2016). In these analyses, piston-engine aircraft activity had a direct impact on lead concentration, where more piston-engine aircraft activity (i.e., more LTOs) generally correlated with higher lead concentrations (Figure 4 provides one example of this relationship at Palo Alto Airport (PAO), which was included in EPA NAAQS lead surveillance monitoring network).

Additionally, sensitivity analyses conducted at two GA airports (RHV and SMO), showed that the amount of activity conducted by multi-engine piston aircraft had a disproportionately larger impact on lead concentrations compared with single-engine aircraft activity (see Appendix B; (Carr et. al. 2011)). [228] Based on the important influence of these two parameters in previous analyses, additional, airport-specific information was gathered to further characterize total piston-engine aircraft activity and the percentage of activity conducted by single- versus multi-piston-engine aircraft at each of the airports included in this refined, airport-specific activity analysis.[229]

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[228] Multi-engine (ME) piston aircraft have a higher fuel consumption rate compared to single-engine (SE) piston aircraft; thus, LTOs conducted by ME aircraft result in higher lead concentrations.

[229] Total landing and take-off counts, the percentage split between piston and non-piston aircraft, and the runway assignment method may also each contribute to uncertainty in counts of piston-engine aircraft LTOs at a given runway end. The runway assignment method and its impact on LTO counts is discussed in Appendix B.

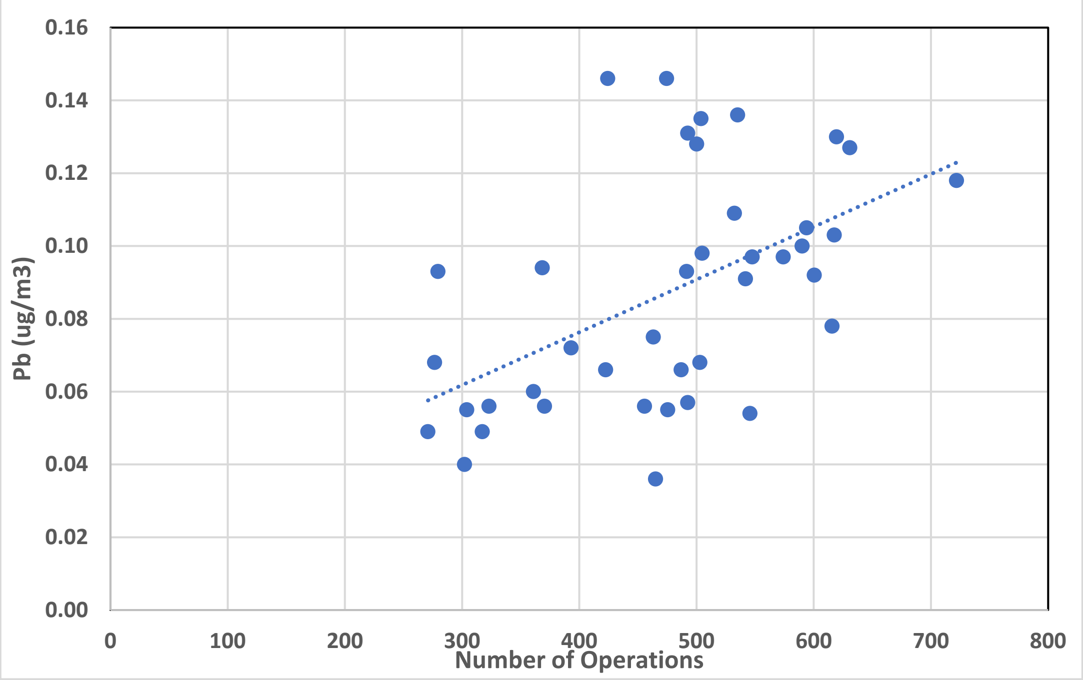

Figure 4. Example of the relationship between monitored lead concentrations and piston-engine aircraft activity.[230]

Specifically, based aircraft data (i.e., the number and class of aircraft that are parked at an airport) were collected for airports included in this airport-specific activity analysis. Data from previous EPA studies at six airports showed agreement within 10% between the number of SE and ME aircraft based at an airport and onsite observations of piston-engine aircraft activity at the airport (see Appendix B for study details).[231] As such, the number and class of aircraft based at each airport included in this airport-specific activity analysis was used to refine the national average percentages for estimating the number of LTOs specific to piston-engine aircraft, and then SE versus ME piston aircraft.

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[230] The relationship between monitored lead concentrations and piston-engine aircraft activity is impacted by several parameters including distance of the monitor from the area where aircraft conduct run-up checks, wind speeds, the type of aircraft (multi-engine or single-engine), and the type of operation (full landing and take-off versus touch-and-go. This figure does not analyze each of these influencing variables but is illustrative of the general relationship between activity and lead concentration at a general aviation airport).

[231] SE and ME aircraft based at an airport were considered piston-engine aircraft. While some SE and ME aircraft based at an airport may be turboprop or other non-piston-engine aircraft, comparisons with onsite activity counts suggest based aircraft data provide reasonable, airport-specific data and FAA considers based aircraft data to be a reliable indicator of activity at small airports (FAA 2015).

For each airport included in this analysis, the number of aircraft based at that airport was collected from available data sources.[232] Next, for each airport, the percent of total operations conducted by piston-engine aircraft was calculated using the number of SE and ME aircraft over the total number of aircraft based at the airport (i.e., sum of SE and ME based aircraft over total SE, ME, turboprop, jet, and helicopter based aircraft multiplied by 100). Similarly, the percent of piston-engine operations conducted by SE versus ME aircraft was calculated using the numbers of SE versus ME aircraft based at the airport (e.g., SE based aircraft over sum of SE and ME based aircraft multiplied by 100). Table 3 presents a summary of the percent of LTOs allocated to piston-engine aircraft, and separately SE versus ME piston aircraft, in the national analysis compared to the allocation using data for aircraft based at the airports included in this airport-specific activity analysis.

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[232] A search was conducted for airport master plans or onsite studies on piston-engine aircraft activity, and in the absence of such information, based aircraft data were used from airport master plans or Airnav.com.

Table 3. Comparison of Piston-Engine Activity Estimates Using National Averages versus Airport-Specific Data

	National Analysis National Averages	**Airport-Specific Based Aircraft Data**[233]	**Data Sources**
% piston versus jet operations	GA: 72% AT: 23%	Unique to each airport (%SE & ME based aircraft of total based aircraft) GA & AT Mean: 92% GA & AT Range: 60 – 100%	National Analysis: (FAA 2010, USEPA 2011) Airport-specific: Airport Master Plans & Airport Master Record Forms 5010-1 & 5010-2
% single-versus multi-engine operations	GA SE: 90% GA ME: 10% AT SE: 57% AT ME: 43%	Unique to each airport (%SE OR ME based aircraft of SE AND ME based aircraft) GA & AT SE: Mean: 89% Range: 58 - 99% GA & AT ME: Mean: 11% Range: 0.02 – 42%	National Analysis: (FAA 2010, USEPA 2011) Airport-specific: Airport Master Plans & Airport Master Record Forms 5010-1 & 5010-2

In general, for the airports evaluated here, using the number of piston-engine aircraft based at the airports as a surrogate for activity suggests that piston-engine aircraft activity at these airports is higher than indicated by the national average fraction (Table 3). The higher percent

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[233] In the national analysis, the percent of activity attributed to piston-engine vs. jet, and separately, multi- vs. single-engine aircraft differed for GA vs. AT activity based on FAA data; however, based aircraft data do not provide information on differences between GA and AT and thus the same percentages are used for both.

of piston-engine aircraft activity at these airports is expected given that master plans and other available information (e.g., airport websites) show that these airports are predominately GA airports, which generally have higher levels of piston-engine aircraft activity compared to a national average that includes activity at commercial and other larger airports with more jet activity. For the percentage of piston-engine aircraft activity conducted by SE versus ME aircraft, the number of SE and ME aircraft based at these airports suggest similar percentages of aircraft activity are conducted by each aircraft class compared to the national average data for GA activity. Conversely, the number of ME aircraft based at these airports generally suggest ME activity is lower than the national average used to estimate ME piston aircraft activity from total AT activity (Table 3). The airport-specific activity estimates calculated using aircraft based at these airports were used to calculate refined model-extrapolated lead concentrations, per the methods described in Table 2. These refined model-extrapolated concentrations are compared with national analysis values, as well as relevant monitoring data, in Section 4.

3.3.3 Airport-Specific Criteria for Identifying Potential Lead Levels Above the NAAQS

This section summarizes the approach and rationale for selecting airports included in the airport-specific activity analysis of lead concentrations at the maximum impact area. At a high-level, this approach entails identifying airports where the maximum 3-month average model-extrapolated concentrations may be above or approach the NAAQS, characterizing model-extrapolated maximum 3-month concentrations at these airports using airport-specific, refined estimates of aircraft activity splits, and then evaluating each airport on local criteria such as the proximity of the maximum-impact site to unrestricted public access. The detailed methods for this analysis are provided in Table 4.

Table 4. Steps for Identifying Airports Where Lead Concentrations May Be Above the Lead NAAQS

Step #	Step	Description	Rationale	Data Source
Steps 1 – 3 Objective: Identify a subset of airports where, considering sources of variability and uncertainty, model-extrapolated atmospheric lead concentrations could be above or approach the NAAQS for Lead.				
1	**Identify airports with maximum model-extrapolated concentrations approaching or above the NAAQS**	Sum the contributions of single- and multi-engine T&G and LTO operations to atmospheric lead concentrations at the maximum impact site for the maximum activity period from the national analysis described in Section 3.2. Identify all airports where the maximum concentration is above or is within 10% of 0.15 µg/m^3.[234]	The primary and secondary National Ambient Air Quality Standards for Lead are 0.15 micrograms per cubic meter lead in total suspended particles as a 3-month average. Because the AQFs relate operations to average atmospheric lead concentrations over the same timescale (3 months), the results of the national analysis indicate whether or not model-extrapolated lead concentrations may approach or be above the concentrations specified in the NAAQS for lead when the inputs described in Section 3.2 are used.	National Analysis Step 14 and 40 CFR Part 50
2	**Identify airports with maximum model-extrapolated concentrations approaching or above the NAAQS when all GA and half of all AT**	Scale the contributions of single- and multi-engine T&G and LTO operations to maximum impact area atmospheric lead concentrations to characterize these concentrations if 100% GA operations and 50% of AT operations were operated by piston-engine aircraft.	As detailed in Steps 1a and 1b in the national analysis methods, the national analysis assumed that 72% of GA and 23% of AT operations are performed by piston-engine aircraft. The current step identifies airports where concentrations would be above or approach the NAAQS if piston-engine aircraft were a larger portion of activity at each airport.	National Analysis Steps 1a and 1b and GAATA Survey

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[234] Aircraft activity for the most recent year available was evaluated at this stage; airports where overall activity decreased such that estimated lead concentrations were no longer within 10% of 0.15 µg/m^3 were excluded.

Step #	Step	Description	Rationale	Data Source
	operations are assumed to be piston aircraft operations			
2a	Scale concentration contributions from T&G operations	Scale lead concentration contributions from GA operations by (1/0.72)	In the national analysis, all T&G operations are assumed to be from GA flight activity. Thus, as concentrations scale with operations, both single- and multi-engine concentrations can be scaled by the proportional change in GA piston-engine operations.	
2b	Scale concentration contributions from full flight operations	Scale full flight lead concentration contributions from AT operations by (0.5/0.23), the ratio of new operational cycles to old operational cycles for both SE and ME concentration contributions.	Both GA and AT operate SE and ME full flight operations.	National Analysis (FAA 2010, EPA 2011)
3	**Identify airports with maximum model-extrapolated concentrations approaching or above the NAAQS when at least 20% of operations occur at the most-used runway end during the**	Scale model-extrapolated lead concentrations by the ratio (0.2/X), where X is the airport-specific fraction of operations occurring at the most-used runway end during the maximum 3-month period and X < 0.2.	For the airports that are identified as potentially having lead concentrations approaching or above the NAAQs for lead at Step 1 of the airport specific analysis, the average percentage of operations occurring at the maximum period runway end is 20%. This sensitivity analysis identifies airports where operations at the most-used runway end may have been underestimated due to assumptions about wind direction, runway	Airport Specific Analysis Step 1

Step #	Step	Description	Rationale	Data Source
	maximum 3-month period		assignment, and local seasonal operational profile.	
Result: Identification of a subset of airports as having model-extrapolated lead concentrations that could be above the NAAQS for lead.				
Steps 4 – 7 Objective: Refine model-extrapolated concentrations at the subset of airports identified in Steps 1-3 using airport-specific activity data				
4	**Collect based-aircraft data for the subset of airports identified in Steps 1-3**	Designate to each airport in the airport-specific analysis counts of jet, single-engine, and multi-engine aircraft from reported based-aircraft numbers at that airport.	For the national analysis, national average splits of piston/non-piston and subsequently SE/ME operations were applied to both GA and AT operations. Because individual airports may serve different aircraft populations, an airport-specific activity assessment may provide a refined characterization of operational splits by aircraft type. This assessment uses counts of aircraft based at a particular airport as a proxy for a representative sample of the split of operations by aircraft type.	FAA Form 5010 Data
4b	Retain national average splits of operational cycles for airports with no based-aircraft data in Form 5010.	Where airports have no reported based-aircraft data[235], retain the national average splits of operational cycles by SE/ME and Full/T&G for AT and GA.	Where based-aircraft are not reported, the national average percentage of SE/ME and Full/T&G operational cycles remain the best estimates of operational characteristics at that individual airport.	National Analysis (FAA 2010, EPA 2011)

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[235] For the airport-specific analysis presented in Section 4, 5.7% of airports have no based-aircraft data.

Step #	Step	Description	Rationale	Data Source
4c	Retain national average splits of operational cycles for airports with low based-aircraft counts relative to annual operations.	Where airports have an annual-operations-to-based-aircraft ratio greater than 730[236], retain the national average splits of operational cycles by SE/ME and Full/T&G for AT and GA.	As based-aircraft numbers are self-reported, Form 5010 Data may be incomplete at some airports. Further, at busy airports with significant commercial or AT traffic, aircraft based at the airport may not be representative of all aircraft serving the airport. The lower the ratio of operations-to-based-aircraft, the more appropriate based-aircraft is expected to be a proxy for operational splits. We make the assumption that annual operations-to-based aircraft greater than 730 (2 operations per based aircraft per day), is an upper limit above which the based aircraft data are not a suitable proxy for activity at an individual airport.	
5	**Assign splits of GA and AT piston/non-piston operations from based-aircraft data**	Characterize the number of operations that would be performed by piston-engine aircraft at each airport if the non-jet aircraft based at the airport were representative of the percent of GA and AT operations performed by piston-engine aircraft at that airport.	While several data sources provide airport-specific aircraft activity data (separately for General Aviation (GA) and Air Taxi (AT) activity), none specifically identify the number of *piston-engine* aircraft LTOs that occur at each U.S. airport. In the national analysis, a default percentage representative of national averages was used to determine piston-engine aircraft operations at each airport; this analysis uses local airport-specific	FAA Form 5010 Data

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[236] For the airport-specific analysis presented in Section 4, 10.0% of airports have annual-operations-to-based-aircraft ratios above 730.

Step #	Step	Description	Rationale	Data Source
			information (namely based-aircraft) to better characterize model-extrapolated lead concentrations at those airports that could have model-extrapolated concentrations that approach, or be above the NAAQS for lead as identified in Steps 1-3.	
6	**Assign splits of ME and SE Full and T&G operations from based-aircraft data**	Characterize the percentage of piston aircraft operations that would be classified as SE Full, SE T&G, ME Full, and ME T&G	In the national analysis, default percentages of operational splits for AT and GA operations by aircraft class (SE/ME) and operational cycle type (Full/T&G) representative of national averages were used to characterize piston aircraft operations at each airport; this analysis uses local airport-specific information (namely based-aircraft) to better characterize model-extrapolated lead concentrations at those airports that could have model-extrapolated concentrations that approach, or are above the NAAQS for lead as identified in Steps 1-3.	FAA Form 5010 Data
6a	Determine operational splits for AT at each airport	The percent of AT operational cycles that are SE (or ME) full LTO matches the percent of based-aircraft that are SE (or ME).	All AT operations are considered to be full LTOs.	
6b	Determine operational splits	The percent of GA operational cycles that are SE (ME) matches the percent of based-aircraft that are SE	Both full LTO and T&G operational cycles are performed by GA aircraft.	

Step #	Step	Description	Rationale	Data Source
	for GA at each airport	(ME). Of the GA SE operational cycles, 24% are characterized as T&G consistent with the national analysis. Of the GA ME operational cycles, 20% are characterized as T&G consistent with the national analysis.		
Result: Characterization of a refined estimate of the number and type of operations performed by SE and ME piston-engine aircraft for each of the airports identified in Steps 1-3.				
7	**Refine model-extrapolated lead concentrations using updated operational splits**	For the airports identified in Steps 1-3, estimate model-extrapolated lead concentrations at and downwind of the maximum impact site using the data gathered in Steps 4 – 6 paired with the methodology described in the National Analysis (Table 2).		National Analysis Steps 3-14
Result: Lead concentration estimates at and downwind of the maximum impact site at the most active runway end during the most active 3-month period for each airport identified in Steps 1-3 using airport-specific activity data.				
Step 8 Objective: Identify whether there is unrestricted access to the area of maximum impact at airports identified at Step 7				
8	**Identify airports where there is unrestricted access to the 50 m perimeter around a maximum impact site**	For the airports that have model-extrapolated lead concentrations that are above the lead NAAQS as identified in Step 7, estimate the distance from the run-up area at the most-utilized runway end to the nearest unrestricted access using satellite imagery.	The layout and footprint of many general aviation airports is such that, aircraft run-up areas and the maximum impact site may be in close proximity to where people have unrestricted access. We sub-select airports where there was unrestricted access within 50m of the maximum impact site where lead	Satellite and street-view imagery

Step #	Step	Description	Rationale	Data Source
			concentrations were estimated as potentially above the lead NAAQS in Step 7.	
9	**Identify local airport characteristics that may influence lead concentrations at the maximum impact site**	For the airports that have model-extrapolated lead concentrations that are above the lead NAAQS as identified in Step 7, review satellite imagery and airport documentation to determine if there are any airport-specific conditions or characteristics that could influence lead concentrations at the maximum impact site.	As all airports are unique, any airport may have a layout, local characteristic, or operational pattern that may differ from the assumptions underlying the national analysis and may impact resulting atmospheric lead concentrations.	Satellite imagery, airport master plans
Result: Identification of airports that have model-extrapolated lead concentrations above the NAAQS for lead considering both airport-specific activity data and unrestricted access to the maximum impact area.				

3.4 Characterization of Uncertainty of Cross-Airport Parameters that Influence the Potential for Lead Concentrations to Be Above the NAAQS for Lead

As discussed in Section 1, the goal of this work is to characterize lead concentrations at and downwind of the maximum impact area at airports nationwide. The approach described in Sections 3.2 and 3.3 was selected because of the consistent set of ground-based parameters that are inherent to safe operation of piston-engine aircraft. Namely, that these aircraft take-off into the wind and conduct pre-flight engine checks adjacent to the take-off runway end. These parameters are consistent across airports, and thus constrain the uncertainty and variability that might be associated with results based on combining information from one model airport with activity estimates at airports nationwide. The limited set of key parameters, which influenced maximum impact area ground-level air lead concentrations in previous modeling by EPA and others, were: 1) the duration of run-up, where longer run-up times results in higher concentrations, 2) the concentration of lead in the fuel, where higher avgas lead concentrations results in higher concentrations, 3) activity, where more piston-engine aircraft activity increases lead concentrations, 4) the percent of activity conducted by ME piston-aircraft, where more ME activity results in higher lead concentrations due to the higher fuel consumption rates of these aircraft relative to SE aircraft, and 5) meteorological factors and local topography (including wind speed, wind direction, mixing height, atmospheric stability, and surface roughness) (Section 2; Appendix A) (Carr et. al. 2011, Feinberg et. al. 2016).

Parameters 3 and 4 (activity estimates and SE/ME aircraft splits) were evaluated for a subset of airports for which uncertainty in the extent to which national average fractions represented the individual airport would most influence whether or not model-extrapolated concentrations are above the lead NAAQS, as described in Section 3.3. The uncertainty from these two parameters and the fifth parameter (meteorological and other local factors) are additionally assessed qualitatively in Section 4.4.

The duration of run-up operations and the concentration of lead in avgas were both found to be highly influential in ground-level 3-month average lead concentrations in air attributable to piston-engine aircraft. Run-up emissions accounted for 82% of the 3-month average lead concentration attributable to piston-engine aircraft in EPA air quality modeling at a model facility, and was a primary contributor to emissions in modeling conducted by Feinberg et. al. (Section 2, Appendix A) (Feinberg et. al. 2016). Moreover, variation between the 5th and 95th percentiles of average run-up times observed in EPA modeling resulted in an almost 8-fold variation in concentration attributable to only run-up emissions (Appendix C). Similarly, Feinberg et. al. found greater variation in the duration of run-up than that of other modes of operation in the LTO cycle (e.g., landing and take-off time in mode), and variation in run-up time led to variation in concentrations downwind (Feinberg et. al. 2016).

Similarly, the concentration of lead in avgas has a direct impact on atmospheric lead concentrations attributable to piston-engine aircraft activity, where higher levels of lead in fuel result in greater lead emissions and hence concentrations of lead in air. The ASTM standard for the maximum lead concentration in 100LL was used in the national analysis; however, the amount of lead in the fuel can vary across fuel suppliers and by batch. The concentrations of lead in air attributable to aircraft are expected to directly scale with the concentration of lead in avgas; thus, the lead avgas concentration was used as a scalar in the calculation of model-extrapolated concentrations at airports nationwide (see Equation 2, Section 3.1). Based on the important influence of these two parameters (run-up time and avgas lead concentration) in modeling 3-month average lead concentrations attributable to piston-engine aircraft activity, additional information was gathered to further characterize each parameter in results from both national and airport-specific activity analyses.

Information on average run-up times was collected from a series of studies that observed run-up operations at five airports (Appendix C) (USEPA 2010a, Heiken et. al. 2014).[237] The average run-up time from each airport was used to develop a distribution of average run-up times.[238] This distribution of run-up times provided a way to evaluate model-extrapolated lead concentrations based on observations at a larger number of airports compared to the run-up times used in the national analysis, which were based on observations at the model airport. The distribution of average run-up time across the five airports was lognormally distributed with an average of 70 seconds, compared to the 40- or 63-seconds used for SE or ME aircraft, respectively, in the national analysis (Table 5). The relationship between variation in run-up time and concentrations of lead in air at and downwind of the maximum impact area was not characterized in the additional studies used to develop the distributions of average run-up times, and thus observations at the model airport were used to characterize how changes in run-up time impacted changes in lead concentrations in the maximum impact area and downwind (See Appendix C for details).

The distribution of average run-up times combined with an understanding of the relationship between run-up time and downwind lead concentrations attributable to piston-engine aircraft provided the necessary inputs for conducting a Monte Carlo analysis. The objective of the Monte Carlo analysis was to characterize the impact of variation in the 3-month average run-up time at a given airport on 3-month average model-extrapolated lead concentrations. Conceptually, the Monte Carlo analysis entailed repeatedly selecting a run-up time value from the distribution of average run-up times, and then adjusting the model-extrapolated lead concentration based on the difference between the selected run-up time and the run-up time used in the national analysis. For example, if an average run-up time of 70 seconds was selected from the distribution of average run-up times, then the national model-extrapolated concentration for SE piston aircraft would be adjusted up to account for the 30 second difference between the time used in the national analysis (40 seconds) and the time selected in the Monte Carlo draw. The amount of increase in concentration in this example would be based on the relationship observed between run-up time and concentration at each

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[237] One airport was included in two different studies, so while four unique airports were included in the studies referenced here, a total of five observational periods is included in the combined dataset.

[238] The use of average run-up times was selected as more representative of run-up times over a 3-month period, the time period of the model-extrapolated concentrations, than the variability observed in the raw run-up time data. For consistency with the national analysis, the median, rather than mean, run-up time at RHV was retained in the distribution of run-up times across the five airports included here.

distance downwind at the model airport, such that the concentration of lead in air would increase more at the maximum impact site than locations downwind (see Table C-1 in Appendix C). The resulting model-extrapolated concentration at each location, which accounted for the change in run-up time, would then be used to adjust the model-extrapolated concentration resulting from the national analysis. The Monte Carlo analysis used 10,000 iterations (i.e., 10,000 average run-up times were selected from the distribution and used to adjust the model-extrapolated concentration at each airport, at each downwind distance, which produced 10,000 adjusted concentrations that then provided a range of potential concentrations at each airport, at each downwind distance, based on variation in run-up time).

A similar approach was used to characterize the impact of variation in avgas lead concentrations on 3-month average model-extrapolated atmospheric lead concentrations. Available data from FAA and EPA reporting lead concentrations in avgas samples had an average lead concentration of 1.79 g/gal and were normally distributed within the range specified for 100LL (i.e., 1.70 to 2.12 g/gal) (see Appendix C for details on avgas lead data and their distribution). A Monte Carlo analysis was used to characterize variation in 3-month average model-extrapolated lead concentrations based on variation in avgas lead concentration. As with run-up time, a value was selected from the distribution of avgas lead concentrations (Table 5), and then used to scale a model-extrapolated concentration. For example, if an avgas lead concentration of 1.80 was selected from the distribution, a model-extrapolated concentration would be scaled by 0.85 (i.e., 1.80/2.12) to decrease extrapolated concentration and account for a lower concentration of lead in fuel. The Monte Carlo analysis was conducted 10,000 times. Results of the avgas lead and run-up time Monte Carlo analyses were combined per Equation 3 to provide model-extrapolated concentrations that account for variation in each parameter at and downwind of the maximum impact area at each US airport (see Appendix C for details).

Eq. 3:

$$\text{Monte Carlo Adjusted Lead Concentration, } [\text{Pb}]_{\text{MC}} = \mathrm{L_{MC}}/2.12\,\frac{\text{g Pb}}{\text{gal}}\,(\mathrm{Y_n} \times \mathrm{C_n})$$

Where:

L_{MC}= concentration of lead in avgas (g/gal) from Monte Carlo analysis of avgas lead distribution

Y_n= model-extrapolated concentration from national analysis at location n

C_n= %difference change in concentration at location n due to change in run-up time (see Equation C-1)

N= location at or downwind of maximum impact (i.e., 0, 50, 100, 150, 200, 250, 300, 400, 500 meters)

Table 5. Monte Carlo analysis inputs for characterizing variability in key AQF parameters

Variable	**National Analysis**		**Monte Carlo Analysis**				**Assumptions**
	Data Source	**Value**	**Data Source**	**Mean (SD)**	**Range**	**Distribution Shape**	
Run-up Time (seconds)	Model facility (Appendix A)	SE: 40 ME: 63	(USEPA 2010a, Carr et. al. 2011, Feinberg and Turner 2013)(Appendix A) (n=5)	SE & ME: 70 (21)[239]	Min: 49 Max: 91	Log-normal (Time in Mode)	We assume that the log-normal distribution of data from the five airports noted in text is representative of the distribution of piston aircraft run-up times nationwide since these are the only data in the literature reporting this information. We assume that bounding the distribution by one sigma above and below the logarithmic mean is representative of average run-up times over a 3-month period.
			Model Airport (Appendix A)			Exponential (distance)	The lead concentration attributable to run-up decreases as a negative power law with distance from the maximum impact site. As such, increases or decreases in run-up time compared to an average influences lead concentration more at 0 or 50 m from run-up than at 500 m meters for run-up. Our modeling suggests an exponential curve describes the relationship between run-up time and variability in lead concentration estimate (see Appendix C for details).
Avgas Lead Concentration (g/gal)	ASTM standard	2.12	EPA & FAA fuel samples (n=116)	1.79 (0.27)	Min: 1.70 Max: 2.12	Normal	We assume that the normal distribution of data from EPA and FAA fuel samples is representative of the distribution of avgas lead content at all US airports. The EPA fuel data were collected during modeling studies discussed in Section 2. FAA published a study reporting the lead concentration of avgas fuel samples which was also used in this analysis. We bounded the distribution based on the ASTM fuel specifications for 100 octane Very Low Lead avgas (100VLL) which has a lead concentration of 1.70 g/gal, and 100 Low Lead (100LL) which has a maximum lead concentration of 2.12 g/gal.

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[239] As noted in the text, the average run-up times observed in four studies were used in combination with the median run-up time observed at the model airport, and used in the national analysis, to develop a distribution of average run-up times. As such, the standard deviation here is the SD of average values.

4. Model-Extrapolated Lead Concentrations: Results and Uncertainty Characterization

In this section we present results of the national analysis and the evaluation of individual airports with the potential to be above the lead NAAQS described in Sections 3.2 and 3.3, respectively, as well as the results of our methods to characterize uncertainty and variability in model-extrapolated concentrations of lead from piston-engine aircraft operating at US airports. Section 4.1 provides results of the national analysis; we then further evaluate of the impact of the wind speed, and, separately, multi-engine aircraft activity on lead concentrations at the maximum impact site. Lastly, Section 4.1 characterizes performance of the model-extrapolation methodology through a comparison of results to monitored concentrations. Section 4.2 provides results of using airport-specific data to refine concentration estimates at airports with the potential for lead concentrations to be above the lead NAAQS, and similarly characterizes performance through comparisons of results with monitored concentrations. Section 4.3 discusses the results of the quantitative uncertainty analysis on variability in run-up durations and avgas lead concentrations. Finally, Section 4.4 discusses qualitative uncertainty analyses for results from both national and airport-specific activity analyses.

4.1 Ranges of Lead Concentrations in Air at Airports Nationwide

The national analysis methods described in Section 3.2 produced estimates of 3-month average model-extrapolated lead concentrations at and downwind of maximum impact areas at 13,153 airports nationwide. These model-extrapolated concentrations are calculated for 3-month periods of peak activity at each airport, and are attributable only to piston-engine aircraft activity.[240] Recall that model-extrapolated concentrations should decrease with increasing distance from maximum impact area, based on the AQFs used in the analysis (Table 4), and that concentrations across all sites should generally correlate with estimates of piston-engine aircraft activity given the relationship between activity and concentration described in Section 3.3.2. Table 6 shows that indeed model-extrapolated concentrations decrease as distance from the maximum impact area increases (left to right in table), and higher levels of piston-engine activity (i.e., LTOs) generally correlate with higher model-extrapolated concentrations (top to bottom in table). The decrease in model-extrapolated concentrations with increasing distance from the maximum impact area has also been observed in lead monitoring data near airports servicing piston-engine aircraft (Environment Canada 2000, Fine et. al. 2010, Anchorage DHHS 2012), as well as lead modeling work conducted by others (Feinberg et. al. 2016), and conforms to near field concentration gradients for other primary pollutants.

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[240] As discussed in Section 2, since model-extrapolated lead concentrations are attributable to piston-engine aircraft activity only, these lead concentrations may not reflect the total lead concentration (i.e., local emissions other than aircraft as well as local background lead concentrations are not included in the estimates provided in Table 6).

Table 6. Ranges of Piston-Engine LTOs and 3-month model-extrapolated lead concentrations at and downwind of maximum impact areas at airports nationwide during 3-month peak activity[241,242]

LTOs	Model-Extrapolated Concentrations of Lead (µg/m³) at and Downwind of the Maximum Impact Area								
	Max Site	50 m	100 m	150 m	200 m	250 m	300 m	400 m	500 m
3,616 - 26,816	0.155-0.475	0.038-0.116	0.018-0.054	0.013-0.040	0.011-0.032	0.009-0.027	0.006-0.019	0.005-0.014	0.003-0.010
2,579 - 8,814	0.100-0.154	0.024-0.038	0.011-0.018	0.008-0.013	0.007-0.011	0.006-0.009	0.004-0.006	0.003-0.005	0.002-0.003
1,783 - 5,728	0.075-0.100	0.018-0.025	0.009-0.012	0.006-0.009	0.005-0.007	0.004-0.006	0.003-0.004	0.002-0.003	0.0017-0.0023
1,275 - 4,302	0.050-0.075	0.012-0.018	0.006-0.009	0.004-0.006	0.003-0.005	0.003-0.004	0.002-0.003	0.0015-0.0023	0.0011-0.0017
160 - 2,889	0.0075-0.050	0.002-0.012	0.001-0.006	0.001-0.004	0.001-0.004	0.0004-0.003	0.0003-0.002	0.0002-0.0016	0.00002-0.001
<1 - 446	< 0.0075	≤ 0.002	≤ 0.001	≤ 0.001	≤ 0.001	≤ 0.0004	≤ 0.0003	≤ 0.0002	≤ 0.0002

The relationship between piston-engine aircraft activity and model-extrapolated concentrations is discussed further below; this relationship is influenced by a few key factors that include the fraction of SE and ME piston-engine aircraft, and wind speed at a given airport. Looking specifically at model-extrapolated concentrations at maximum impact areas, results show a range of <0.0075 to 0.475 µg/m³ at airports nationwide, depending on aircraft activity levels (Table 6). Inspecting the ranges of activity and model-extrapolated concentrations reveals that there is a wide range of activity that could result in model-extrapolated concentrations above the lead NAAQS. The airports with comparatively higher lead concentrations and 3-month maximum activity levels between 3,616 and 26,816 LTOs represent a mix of airports, some of which are dominated by SE aircraft activity and some of which have a mix of SE and ME aircraft activity. As noted earlier, SE activity results in lower lead concentrations per LTO compared with ME activity. Figure 5 presents a plot of the relationship between 3-month average concentrations and activity, with the relative amount of ME depicted in shades of blue. As indicated in Figure 5, more activity occurs at an airport dominated by SE aircraft to result in lead concentrations similar to those at other facilities where there is a mix of ME and SE aircraft. The mix of SE and ME activity, along with other characteristics of airports with model-extrapolated concentrations above the lead NAAQS is explored further in Section 4.2.

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[241] As discussed in Section 3.2, model-extrapolated concentrations in Table 6 are attributable to piston-engine aircraft activity and do not include local background lead concentrations.

[242] In monitoring 3-month average lead concentrations at airports, concentrations in µg/m³ are typically presented out to two decimal places. Additional decimal places and/or significant figures are shown in this table and in select other figures either to demonstrate the trend of lead concentrations further downwind of the maximum impact location or at airports with few operations.

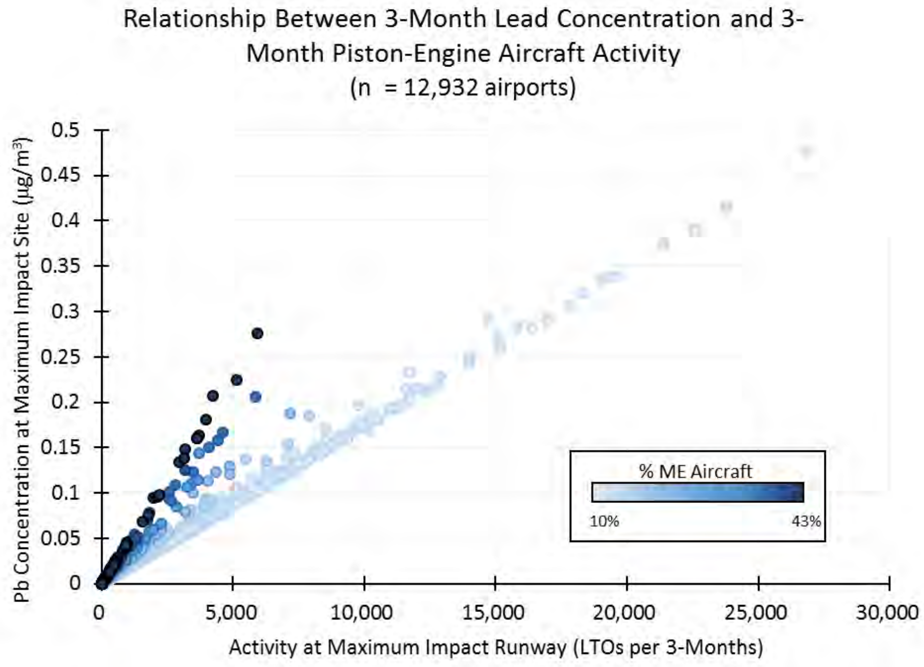

Figure 5. The relationship between 3-month average lead concentration at the maximum impact site and piston-engine aircraft activity during the same 3-months. Blue shading denotes the relative amount of multi-piston-engine aircraft activity at each airport. Air Taxi data were used to estimate the relative ME aircraft activity at each airport since this type of activity is generally dominated by ME and data specific to multi-piston-engine aircraft activity is not available across US airports. Airports with zero LTOs (n = 221) were excluded from the figure for clarity. This figure presents non-wind-adjusted concentrations using national default analysis parameters as described in Table 2 to better highlight the impact of multi-engine activity on concentration.

As described in Section 3.2 and Table 2, wind speed at each airport relative to wind speed at the model airport can also influence model-extrapolated lead concentrations, and thus the maximum impact site concentrations were adjusted to reflect wind speeds at each airport. Airports with wind speeds during the 3-months of maximum activity that are higher than wind speeds measured at the model airport will have wind-adjusted concentrations that are lower than the non-adjusted concentrations using national defaults. Similarly, airports with lower wind speeds than the model airport will, in general, have higher wind-adjusted concentrations. Results of the wind-speed adjusted lead concentrations are compared with unadjusted values in Figure 6.

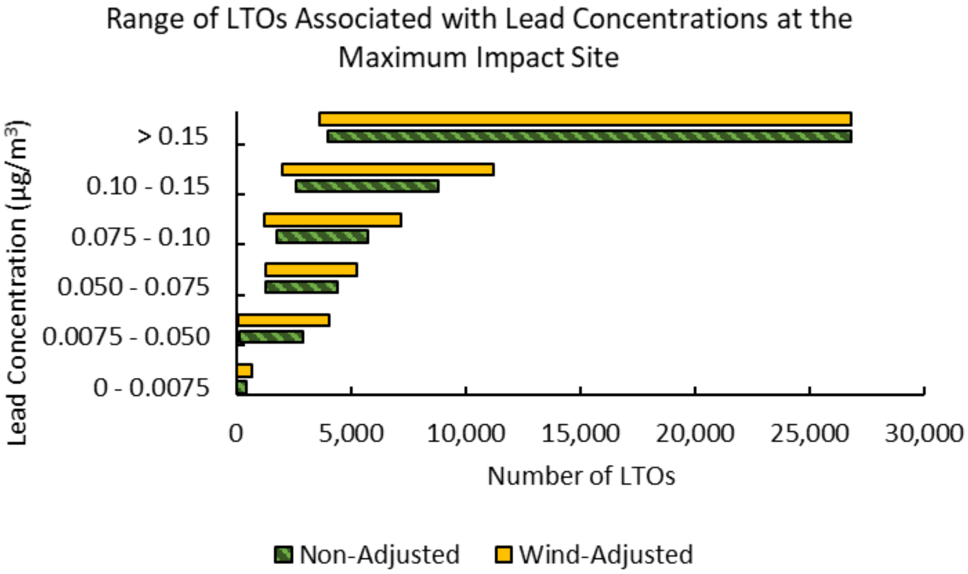

Figure 6. Average 3-month model-extrapolated concentrations versus the number of piston-engine LTOs during the same 3-month period at the maximum impact area runway end. Concentrations are generally categorized relative to the lead NAAQS (e.g., greater than the standard of 0.15 µg/m^3, less than half the standard, 0.075 µg/m^3, less than concentrations generally detected by monitors, 0.0075 µg/m^3, etc).

Across all airports, the effect of the wind adjustment ranges from a 45% decrease in concentration to a 210% increase in concentration; however, 48% of airports have concentrations that change by less than 10%. The impact of the wind adjustment on maximum impact site concentrations for all airports is shown in Figure 7. In absolute difference, the 3-month maximum concentration at the maximum impact site changes by less than 0.01 µg/m^3 at most airports. At airports with concentrations greater than half the lead NAAQS, the absolute concentration change from wind adjustment tends to be higher, from -0.06 to 0.16 µg/m^3, as shown in Figure 8. Overall, results of adjusting for wind speed show that while this parameter is influential at individual airports, it does not meaningfully impact the range of concentrations in the maximum impact area at airports nationwide. In turn, individual airports with the potential to have concentrations above the lead NAAQS are evaluated more closely in Section 4.2.

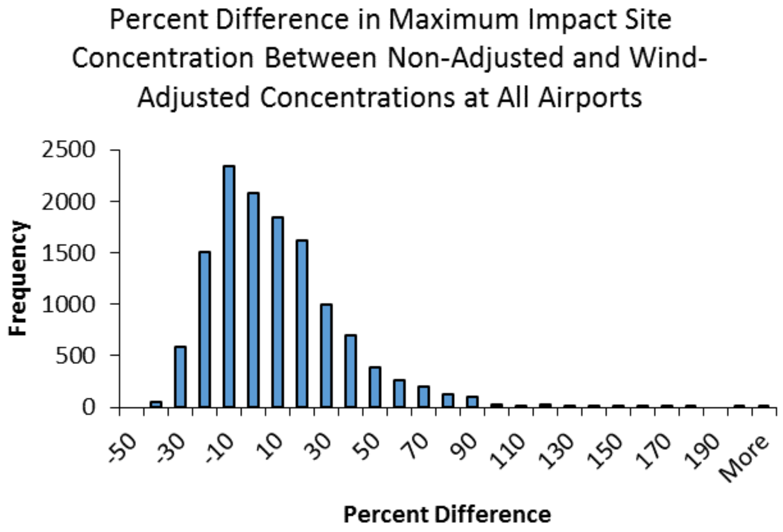

Figure 7. The percent change in 3-month maximum concentration at the maximum impact site from accounting for average inverse wind speed at all airports.

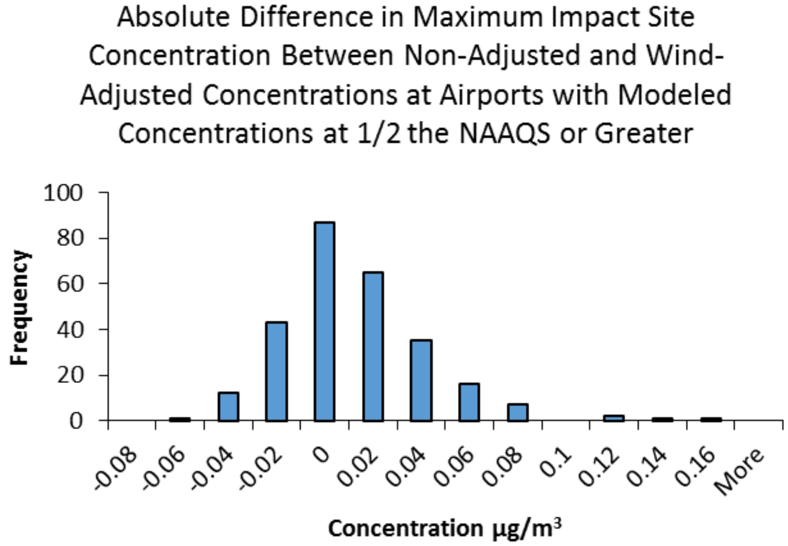

Figure 8. The absolute change in 3-month maximum concentration at the maximum impact site from accounting for average inverse wind speed at airports with concentrations greater than ½ the NAAQS for Lead.

The model-extrapolated concentrations from the national analysis presented above can be evaluated through a comparison to monitored concentrations. Such an evaluation would ideally be informed by monitored data that corresponds spatially and temporally with the model-extrapolated concentrations. However, as detailed below, monitored lead concentrations are only available at a subset of airports and none of these data are spatially and temporally consistent with model-extrapolated data.[243] Nevertheless, a coarse comparison of model-extrapolated to monitored concentrations is feasible for a subset of airports at which monitors were placed proximate to the maximum impact area, or downwind, as part of evaluating attainment of the lead NAAQS.[244] In evaluating these comparisons, it is noteworthy that in addition to spatial differences, monitored and model-extrapolated concentrations differ in temporal periods and scope. Model-extrapolated concentrations were calculated for 2011 while monitored concentrations were collected over different 1-year periods depending on the airport.[245] As described in Section 3.1, while 2011 is expected to be generally representative of piston-engine aircraft activity during monitored periods, differences in the volume and type of piston-engine activity (i.e., SE vs. ME, full LTO vs. T&G) and meteorological conditions would be expected to impact the comparisons presented here. In addition, model-extrapolated concentrations are specific to aircraft lead emissions, while monitored concentrations include background lead from other sources. Other factors could influence lead concentrations in air from year-to-year as well, and both monitored, and model-extrapolated concentrations also have inherent variability and uncertainty. With the characteristics of each dataset in mind, Figure 9 provides a coarse comparison of national model-extrapolated to monitored concentrations at three airports with monitors placed proximate to the maximum impact area or downwind locations.[246] Each panel presents the monitored NAAQS design value (i.e., maximum 3-month average concentration during monitored time period) along with model-extrapolated concentrations. Across these airports, model-extrapolated and monitored concentrations generally align when considering both the downwind gradient, and horizontal transport of lead emissions at the maximum impact area.

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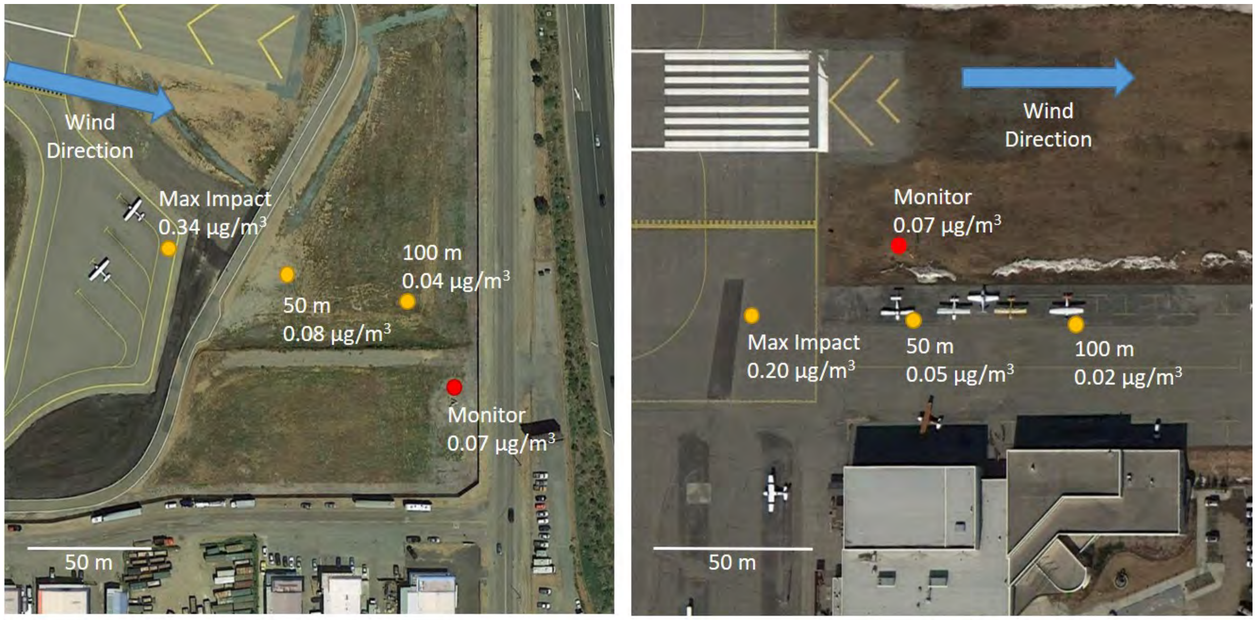
[243] The monitors were in a different physical location than that for the model-extrapolated lead concentrations and the monitoring data was collected at a different time period than that for the model-extrapolated lead concentrations.

[244] Logistical considerations (e.g., aviation safety clearance regulations for siting fixed objects near the landing and take-off area, and availability of power in these locations) typically prevented placement of lead monitors in the maximum impact area.

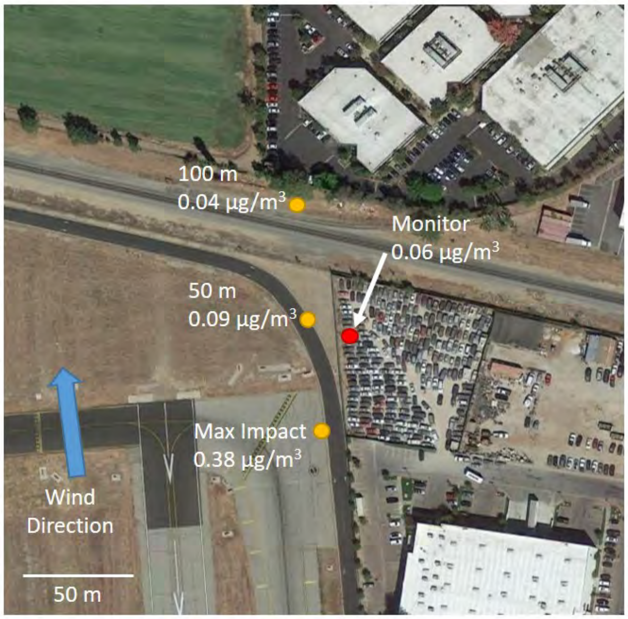
[245] Monitoring agencies were required to measure the maximum lead concentration in ambient air resulting from specific lead sources, including a subset of airports USEPA (2010b). Revisions to Lead Ambient Air Monitoring Requirements.; these monitoring data are part of the lead surveillance network that is used to evaluate attainment of the NAAQS for lead (https://www3.epa.gov/ttnamti1/pb-monitoring.html). A summary of monitored data is available on the EPA website USEPA. (2017a). "Airport Lead Monitoring and Modeling." 2017, from https://www.epa.gov/regulations-emissions-vehicles-and-engines/airport-lead-inventories-air-quality-monitoring-air.

[246] Among the 17 airports where lead surveillance monitoring was conducted, eight NAAQS monitors were sited in locations proximate to or downwind of the maximum impact area. Four are presented in this section with the remaining four presented in Section 4.3. In two instances NAAQS monitors were sited particularly close to model-extrapolated locations, which supported an extended comparison of monitored to model-extrapolated concentrations, also in Section 4.3.



Airport A

Airport B



Airport C

Satellite Image Source: Google Earth

Figure 9. Coarse comparison of monitored to model-extrapolated lead concentrations at airports with NAAQS monitors sited proximate to the maximum impact area or locations downwind. Red dots represent approximate monitor placement, while yellow dots represent approximate locations of model-extrapolated concentrations from national analysis methods (Section 3.2). Blue arrows denote the prevailing wind direction at each airport. As noted above, the year in which monitored concentrations were collected varies by airport, while model-extrapolated concentrations represent 2011. All locations are based on scientific judgment of the alignment of model-extrapolated locations from the expected maximum impact area. The max impact concentrations represented in the figure are not wind speed adjusted. The wind speed adjusted concentrations at max impact for airports A, B, C are 0.36, 0.23, and 0.44 µg/m³ respectively.

4.2 Airports with Potential Lead Concentrations Above the Lead NAAQS with Unrestricted Access Within 50 m of the Maximum Impact Site

As described in Section 3.3, a series of sensitivity tests were performed to identify a subset of airports beyond those identified in the national analysis where model-extrapolated lead concentration estimates were above the NAAQS for lead. Additional data were then identified to calculate airport-specific activity estimates for each airport in this subset.[247] Next, the airport-specific activity estimates for each airport were used to calculate updated model-extrapolated lead concentrations for that airport with a focus on concentrations in the maximum impact area. In addition, for each of these airports, satellite imagery was utilized to assess if there was unrestricted access within 50 meters of the maximum impact site. The results of this screening analysis are presented in Table 7.

Each column in Table 7 represents the outcome of analysis steps presented in Section 3.3 and described in Table 4: the first column identifies the airport, the second column indicates the lead concentration at the maximum impact site relative to the lead NAAQS using national default parameters (Section 3.2); the third column adjusts the national default concentrations based on average inverse wind speed (Section 3.2); the fourth and fifth columns present the outcomes of airport-specific parameters that influence the potential for lead concentrations to be above the NAAQS for lead; the sixth column shows the results of the airport-specific-activity analysis before adjusting for average inverse wind speed; and the seventh column shows the results using both airport-specific activity and airport-specific wind speed data. Black filled circles indicate model-extrapolated concentrations are above the NAAQS for lead and white unfilled circles indicate model-extrapolate concentrations that are more than 10% below the NAAQS for lead. The potential impacts of additional local characteristics (e.g., mixing height, local terrain) on airport-specific estimates of lead concentration are discussed qualitatively in Section 4.4.

Among the airports in Table 7, air quality monitoring has been conducted at RHV at a location approximately 60 m downwind from the maximum impact site. Lead concentrations at RHV measured 60 m downwind were above half the level of the lead NAAQS.[248]

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[247] As described in Section 3.3, airport-specific data consist of the number of SE and ME piston-engine aircraft based at an airport. Airport-specific activity estimates were calculated using the following steps. First, the number of LTOs specific to piston-engine aircraft was estimated by summing the number of SE and ME piston-engine aircraft based at an airport and dividing the sum by the total number of aircraft based at an airport, then multiplying the fraction by total LTOs at the airport. Next, the fraction of piston-engine aircraft LTOs conducted by SE piston aircraft was calculated by dividing the number of SE based aircraft by the total number of SE and ME based aircraft at an airport. The same approach was used to calculate the fraction of piston-engine aircraft LTOs conducted by ME piston aircraft. For airports where no based aircraft data were available or for where based aircraft numbers represented fewer than one aircraft for every 730 operations, national default splits were used for the airport-specific activity estimates.

[248] See the program overview titled Airport Lead Monitoring: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100LJDW.PDF?Dockey=P100LJDW.PDF

Table 7. Airports with Model-Extrapolated Lead Concentrations Potentially Above the Lead NAAQS at the Maximum Impact Area With Unrestricted Areas Within 50 Meters.

Airports[249]	**National Defaults**	**Wind Adjusted**	**% Piston Adjusted**	**Runway Shift**	**Based Aircraft**	**Based Aircraft Wind Adj.**
52F	●	●	●	●	●	●
RHV	●	●	●	●	●	●
ORS	o	●	●	o	●	●
WHP	o	o	●	o	●	●

For the airports identified in Table 7, model-extrapolated concentrations increase when using airport-specific data to estimate piston-engine aircraft activity; the magnitude of the increase varies based on the difference between the airport-specific fleet and operational characteristics compared with the national average values used for piston-engine aircraft activity. The percentage of piston-engine activity estimated as SE versus ME also influences the magnitude of change between airport-specific and national analysis results. As described previously and in greater detail in Section B.4, the use of based aircraft to estimate piston activity, as well as SE and ME splits in activity was evaluated by comparing on-site observations with based aircraft at a subset of airports and reasonable agreement was observed (within 10%) between based aircraft and on-site observations. Additional factors that influence model-extrapolated concentrations (e.g., run-up time, avgas lead concentration) are discussed in Section 4.3. Figure 10 presents the model-extrapolated lead concentrations in the maximum impact area from both the airport-specific analysis and the national analysis at individual airports where lead concentrations at the maximum impact site with unrestricted access may potentially be above the lead NAAQS.

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[249] Airport codes are commonly used to identify airports; the name and location of airports in this table is provided in Appendix B.

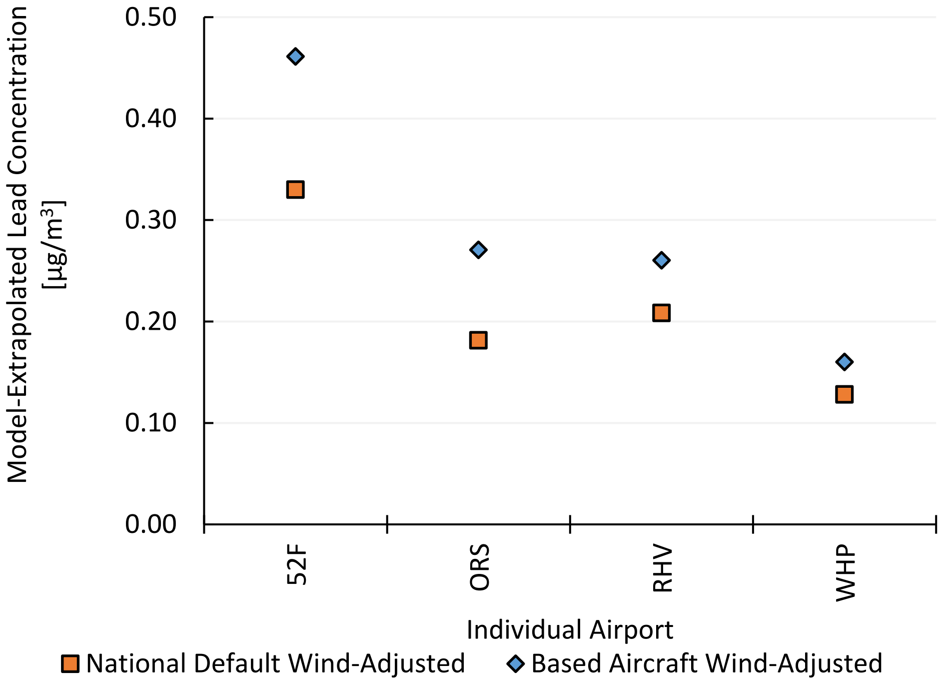
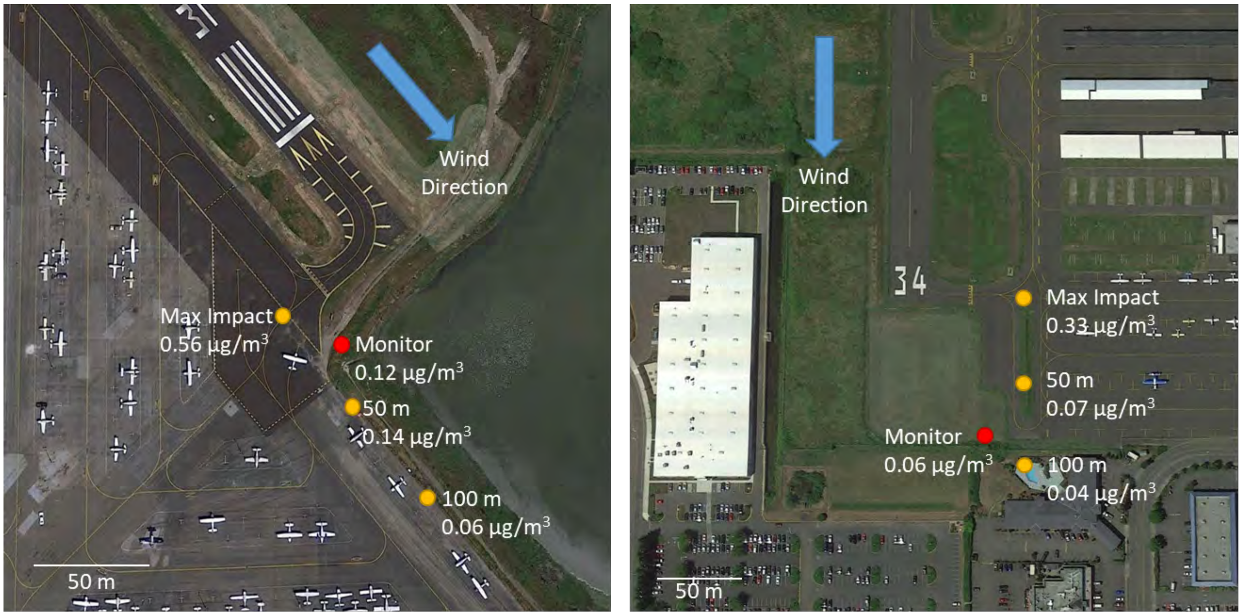


Figure 10. Comparison of model-extrapolated lead concentrations from the wind-speed adjusted national default parameters (orange squares; Section 3.2), and wind-speed adjusted airport-specific activity analysis (blue diamonds; Section 3.3) at airports that have the potential for maximum impact site concentrations to be above the NAAQS for lead with unrestricted access.

Similar to national analysis results, results of the airport-specific activity analysis can be evaluated through a comparison to monitored data. Of the airports included in the airport-specific activity analysis, four had NAAQS surveillance monitors located proximate to or downwind from the maximum impact area. Figure 11 presents the comparison of monitored and model-extrapolated concentrations at these airports. As discussed in Sections 3.4 and 4.1, the coarse comparison presented in Figure 11 has attendant uncertainties (e.g., spatial and temporal differences between monitor and model-extrapolated data). Despite these uncertainties, monitored data suggest that model-extrapolated concentrations which use airport-specific activity estimates generally align with monitored concentrations. A more in-depth comparison of model-extrapolated to monitored concentrations is presented in the context of additional uncertainty analysis in Section 4.4.



Airport D

Airport E

Airport F

Airport G

Satellite Image Source: Google Earth

Figure 11. Coarse comparison of monitored to model-extrapolated airport-specific lead concentrations at airports with NAAQS monitors sited proximate to the maximum impact area or locations downwind. Red dots represent monitor location, while yellow dots represent approximate locations of model-extrapolated concentrations from airport-specific activity analysis (Section 3.3). Blue arrows denote the prevailing wind direction at each airport. Locations for model-extrapolated lead concentrations depicted here were based on approximated location of the dominant run-up location. The max impact concentrations represented in the figure are not wind speed adjusted. The wind speed adjusted concentrations at max impact for airports D, E, F, and G are 0.58, 0.31, 0.26, and 0.24 µg/m^3 respectively.

4.3 Quantitative Uncertainty Analysis of Concentrations of Lead in Air at Airports: The Influence of Run-up Time and Avgas Lead Concentration

As with any analysis of this scope in which estimates of pollutant concentrations at facilities nationwide are developed using an extrapolation approach, there is inherent uncertainty and variability in the estimates. The focus here is on two key parameters that have been demonstrated in previous studies to impact lead concentrations at and downwind from the maximum impact area at airports: run-up time and avgas lead concentration. Run-up time and avgas lead concentrations are not constrained by the functional role of a given airport, but rather vary across airports independently of airport attributes. These two parameters were thus the focus of a quantitative variability evaluation using a Monte Carlo analysis, which is discussed in Section 3.4 above. Additional meteorological and local considerations may contribute to uncertainty at individual airports; the uncertainty from these parameters is discussed qualitatively in Section 4.4.

4.3.1 National Analysis and Airport-Specific Monte Carlo Results

Figure 12 shows the national analysis results with Monte Carlo bounds around each model-extrapolated concentration for the airport with the highest, and, separately, the airport with the lowest model-extrapolated concentration at the maximum impact site and downwind locations. As the Monte Carlo bounds show, variability in run-up duration and avgas lead concentrations add uncertainty to the exact range of model-extrapolated concentrations nationwide (i.e., exact value of the highest and lowest model-extrapolated concentration in the maximum impact area and downwind locations of US airports); however, the quantitative uncertainty shown in the Monte Carlo is small enough such that it does not obscure meaningful differences between model-extrapolated concentrations at different US airports.

Further, Monte Carlo results consistently show the potential for higher model-extrapolated concentrations than the national analysis results (compare black or blue dots to upper error bars in Figure 12). The potential for higher model-extrapolated concentrations is due to the difference in observed run-up times at the model airport compared to run-up times observed at airports included in the Monte Carlo analysis. As noted in Section 3.4 the deterministic national analysis used 3-month median run-up times for SE and ME, separately, which were measured at the model airport at which AQFs were developed, while the Monte Carlo analysis included observations of longer run-up times from studies at additional airports (Table 5). The increase in model-extrapolated concentrations due to the potential for longer durations of run-up at airports nationwide compared to that observed at the model airport, generally aligns with a sensitivity analysis conducted at the model airport. The sensitivity analysis showed that increasing run-up time from the 5th (16 seconds) to 95th (121 and 160 seconds for SE and ME respectively) percentiles resulted in approximately an order of magnitude increase in 3-month average modeled concentrations (i.e., 5th to 95th percentiles of 3-month average modeled concentrations increased from 0.043 to 0.322 µg/m^3 and from 0.005 to 0.035 µg/m^3 for SE and ME, respectively) (Appendices A and C). The average run-up time at a given airport may be impacted by a number of factors (e.g., the number of pilots in training); however, the use of average run-up time from airports with available data provides relevant information to characterize the potential range of concentrations at airports nationwide in a manner consistent with the approach laid out in Section 3.

While the concentration of lead in avgas is also included in the Monte Carlo analysis, this parameter influences results less than run-up duration for two reasons. First, the range of lead in avgas is smaller than the range of average run-up times used in the analysis (Table 5). Second, the impact of longer run-up durations is additive, whereas the impact of lower avgas lead concentrations is incremental (i.e., each additional second of run-up compared to the median value used in the national analysis contributes the same amount to downwind lead concentrations, whereas fuel with 2.10 g/gal lead rather than the 2.12 g/gal contributes 0.02 g/gal less to emissions). The difference in the influence of these parameters helps explain why the uncertainty analysis for model-extrapolated concentrations consistently demonstrates higher values compared with the point estimate.

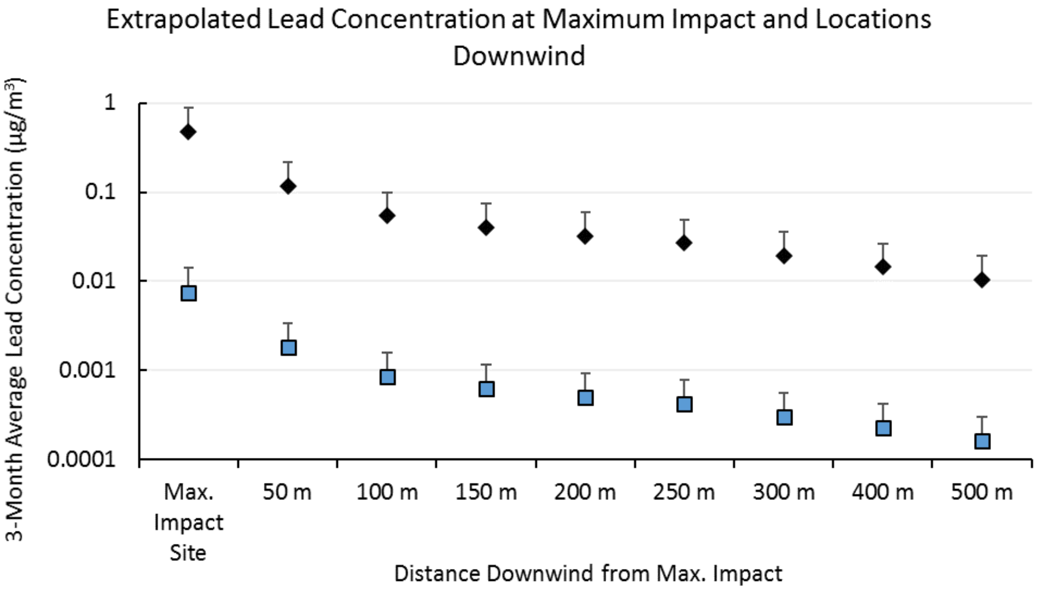


Figure 12. The range of model-extrapolated lead concentrations at and downwnind of the maximum impact area based on national analysis results. Black diamonds represent the maximum and blue squares represent the minimum model-extrapolated concentration at each location for the 13,153 airports included in the national analysis. Error bars are the concentrations at the 97.5th percentile of Monte Carlo results, which account for potential ranges in run-up time and avgas lead concentrations across airports.

Similar to the Monte Carlo bounds around national analysis results, the model-extrapolated concentrations from the airport-specific activity analysis are consistently at or near the 2.5th percentile of the Monte Carlo bounds while the 50th percentiles and 97.5th percentiles of the Monte Carlo analysis are on average 38% and 91% higher than the model-extrapolated concentrations from the airport-specific activity analysis. As discussed above, this observation is primarily the result of having used a shorter run-up time in developing the model-extrapolated lead concentrations in the national analysis compared with run-up times that have been observed at other airports, which were used in the Monte Carlo analysis (Table 5). In addition, the greater influence of run-up time versus lead concentrations in avgas on ground-based atmospheric lead concentrations, leads to changes in run-up time dominating the potential range of concentrations observed in the Monte Carlo results (ICF 2014, Feinberg et. al. 2016). The uncertainty results presented here are sensitive to the choice of input distributions for avgas lead concentration and run-up time.

4.3.2 Comparison of Model-Extrapolated Concentrations From the Airport-Specific Activity Analysis with Monte Carlo Bounds to Monitored Concentrations in the Maximum Impact Area

To evaluate the approach for calculating airport-specific model-extrapolated concentrations with Monte Carlo bounds, results from the approach were compared to relevant monitoring data. Comparisons between model-extrapolated and monitored lead concentrations are most informative when the model-extrapolated and monitor concentrations are in the same approximate location. Two airports had monitors located in close proximity to the location of the model-extrapolated concentrations; however, monitoring at each airport was conducted during different time periods than the time period of national analysis. Thus, model-extrapolated concentrations were adjusted to reflect activity and meteorological data from the monitored time periods. The same national analysis data sources were used to update activity and meteorology in model-extrapolated concentrations to monitored time periods (See Section 3.2, Table 2 for data source details). In addition, as with the airport-specific activity analysis, onsite observational survey data or data on the number and class of aircraft based at the airport were used to calculate piston-engine aircraft activity, as well as SE and ME activity at each airport.[250]

Figure 13 compares the rolling 3-month average model-extrapolated concentrations at the two airports with monitored data in similar locations.[251] At the airport in Panel A, two lead monitors were co-located proximate to the maximum impact area; the primary monitor is identified with a blue dot, the co-located monitor with a black dot, and the model-extrapolated concentrations (based on the lower run-up time estimates) are identified with green dots. Model-extrapolated lead concentrations at this facility are consistently lower than lead concentrations measured at the primary monitor with the difference ranging from 12% to 52% yet the Monte Carlo bounds reflecting potential variation in model-extrapolated values due to variability in run-up duration and avgas lead concentrations consistently include the primary monitored value. Model-extrapolated concentrations at the airport in Panel A identified the

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[250] The following percentages were used to allocate total LTOs given observational survey or based aircraft data: 70 and 86% piston-engine, 73 and 98% SE, 27% and 2% ME for each airport, respectively. See Appendix C for details on observational survey data; based aircraft data are from Airnav.com (May 2016).

[251] The time period of rolling 3-month average is used here for comparison with the lead NAAQS. Model extrapolated values presented in Figure 13 are not wind-speed adjusted.

majority of 3-month monitored concentrations that exceeded the lead NAAQS (noted by the red line).

Similarly, model-extrapolated concentrations appropriately reflect attainment of the lead NAAQS at the airport in Panel B. In this instance, both model-extrapolated (green dots) and monitored (blue dots) concentrations are below the NAAQS. In addition to providing an example of model-extrapolation performance below the NAAQS, Panel B, also provides an example of a location further downwind than the maximum impact area. At this airport, the monitor was located approximately at the 50-meter downwind model-extrapolation site, which along with activity and other parameters discussed in previous sections, explains the lower concentrations relative to the airport in Panel A.

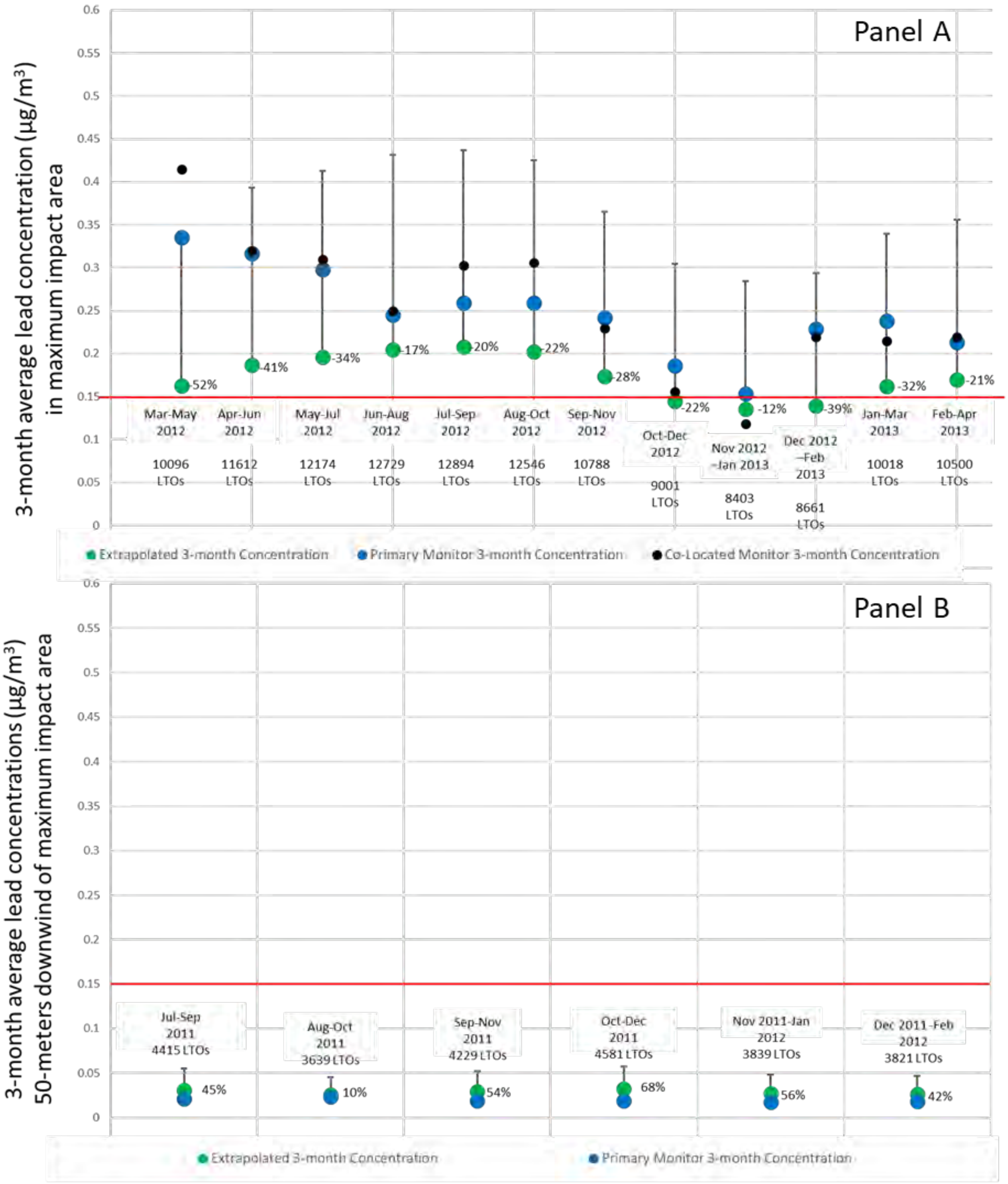

Figure 13. Comparisons of model-extrapolated (green dots) to monitored (blue and black dots) concentrations at the two airports with monitors placed proximate to model-extrapolated locations. The airport in Panel A had both a primary and co-located monitor (blue and black dots, respectively) in the maximum impact area. The airport in Panel B had a monitor approximately 50 meters downwind of the maximum impact site. The red line denotes the NAAQS for lead (i.e., rolling 3-month average of 0.15 µg/m^3).

4.4 Qualitative Characterization of Uncertainty and Variability in Model-Extrapolated Lead Concentrations from National and Airport-Specific Activity Analyses

As discussed in Sections 1 and 2, emissions from piston-engine aircraft during run-up is the single largest contributor to the maximum impact area concentrations for lead from this source, and there is consistency in how and where these run-up operations are conducted across airports. The run-up emissions are released near the surface while the aircraft is stationary, occur in a flat terrain that is required for landing and take-off, and predominately impact receptor sites nearby (i.e., up to 500 meters downwind) (Carr et. al. 2011, Feinberg et. al. 2016) (Appendix A). While the consistent nature of piston-engine aircraft run-up emissions results in a straight-forward dispersion modeling scenario that can be used to extrapolate to other airports, key parameters impart uncertainty on the model-extrapolated results. This section qualitatively discusses additional sources of uncertainty that were not addressed in previous sections, namely uncertainty from meteorological, dispersion modeling, and operational parameters.

4.4.1 Meteorological Parameters

Several meteorological parameters affect modeled concentrations that result from dispersion modeling of pollutant emissions released at surface level. These parameters include wind speed and direction, mixing height, atmospheric stability, and ambient temperature since they directly relate to conditions of atmospheric turbulence, thermal buoyancy, as well as resulting vertical and lateral dispersion.

Low wind speeds disperse emissions less rapidly compared with high wind speeds, resulting in higher concentrations near the emissions source. Conversely, higher wind speeds result in lower concentrations near the emissions source. Specifically, as discussed in Section 3.2 and demonstrated in Appendix A, the near-field concentration of a non-reactive pollutant approximately scales with $<u^{-1}>$, where u is wind speed and angled brackets imply a time average (Barrett and Britter 2008). Three-month average inverse wind speeds varied -23% to + 21% from the annual average wind speed. The range of inverse wind speeds at the model airport results in 3-month AQFs that vary +23% to -15% from the annual average.[252] Approximately 51% of airports have 3-month average inverse wind speeds during the 3-month period of maximum piston-engine aircraft activity at a single runway end that fall within the range of 3-month average inverse wind speeds at the model airport.[253] Thus, we do not expect wind speed to be a significant source of uncertainty nationwide as sensitivity to wind speed will be captured by the wind speed scaling technique applied, and 3-month AQFs were only sensitive to wind speed by approximately +/-20% at the model airport. For individual airports at the extremes of high and low wind speed, we recognize there is more uncertainty in the

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[252] As described in Section 3.2, the model-extrapolated lead concentrations were wind-speed adjusted to reflect the impact of lower or higher wind speeds at each airport compared with the model airport. As such, we do not expect variations in wind speed to impose a large uncertainty in the evaluation of the potential for airports to have model-extrapolated lead concentrations above or below the level of the lead NAAQS.

[253] Wind speed data is from the nearest ASOS station to each airport. See Appendix A for additional information on data sources.

extrapolated concentrations.[254] However, we do not expect significant GA activity during winds below 2.6 m/s or above 10.3 m/s as FAA safety recommendations state that these may be conditions under which it is particularly challenging for a general aviation aircraft to fly (FAA 2006).

At both high and low wind speeds, significant variability in wind direction can result in additional uncertainty. When wind direction shifts significantly, airport operators may or may not initially change the runway end from which piston-engine aircraft take-off due to considerations of cross-winds and operational consistency. As noted in Section 1, airports are built such that one runway-end faces directly into the predominate wind direction, which limits the likelihood of runway-end variability. Further, Section 3.3 discusses a sensitivity analysis that evaluated the impact of shifting piston-engine aircraft operations to a specific runway-end, which addresses instances such as when wind direction variability leads to differences between the active runway-end and wind direction.

Mixing height is another meteorological condition that can influence atmospheric lead concentrations both independently and in conjunction with wind conditions. When mixing heights are very low, as is often the case overnight, then pollutants released at the surface remain trapped in the shallow surface layer, resulting in higher concentrations. Higher mixing heights occur when there is substantial surface mixing, which more rapidly disperses pollution away from the surface and result in lower surface-level concentrations. An unstable atmosphere where the mixing height is changing rapidly will also affect the concentration of lead at the maximum impact site. Previous air quality modeling conducted by EPA at individual airports characterized the influence of mixing height on modeled aircraft lead concentrations (Section 2; Appendix A) (Carr et. al. 2011, Feinberg et. al. 2016). At the model airport, there is a strong relationship between the 3-month average wind speeds and mixing heights (Figure 14), making it difficult to separately calculate the influence of mixing height on the AQFs. However, because run-up is the largest contributor to lead concentrations at the maximum impact site, the AQF at the maximum impact site is not expected to be sensitive to local mixing height. Concentrations at sites downwind may be more sensitive to mixing height and atmospheric stability, particularly during long periods of atmospheric inversion or at airports that have mixing height characteristics significantly different from the model airport.

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[254] At very low wind speeds, the inverse wind speed tends toward infinity and the wind speed scaling approach is limited by the choice of modeled minimum wind speed and the resolution of the wind monitor data.

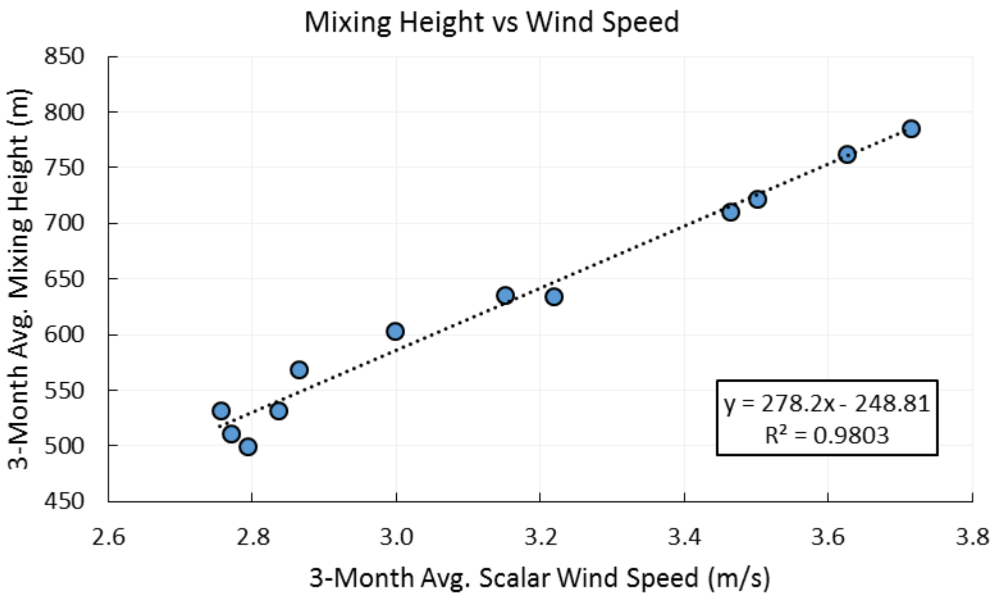

Figure 14. 3-month average mixing height at the model airport as a function of 3-month average scalar wind speed at the model airport over the same period.

Microclimate conditions and other meteorological parameters may contribute to some variability in the relationship between aircraft operations and resulting atmospheric lead concentrations. For example, near-source maximum primary pollutant concentrations have shown some dependence on ambient air temperature, but to a lesser extent than wind speed (Liang et. al. 2013). A preliminary analysis of 3-month AQFs at the model airport showed that temperature was a significant variable (p-value =0.001046) when controlling for average inverse wind speed; however, because average 3-month temperature varied by less than +/-2% at the model airport, maximum impact and downwind concentrations were not sensitive to ambient temperature. Thus, while results nationwide are not expected to be particularly sensitive to microclimate conditions and other meteorological variables, there is more uncertainty in model-extrapolated concentrations at airports that have maximum activity periods during meteorological conditions not observed at the model airport.

4.4.2 AERMOD and AERSURFACE Parameters

Modeling parameters in AERMOD may be a source of both aleatoric and epistemic uncertainty. [255] Near-field surface and geographic characteristics may have an impact on lead

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[255] Uncertainty can be classified into aleatoric uncertainty and epistemic uncertainty. Aleatoric uncertainty is often characterized as natural randomness that is often difficult to measure. Epistemic uncertainty is typically characterized as uncertainty due to the lack of data (e.g., data that could be collected but the methods may be prohibitive).

concentrations at and downwind of the maximum impact site. The calculation of AQFs included a fixed parameterization of surface roughness, Bowen Ratio, and albedo as described in Appendix A, but downwind surface characteristics may differ at airports nationwide. Other research has suggested that, at certain receptors, modelled AERMOD concentrations are sensitive to changes in surface roughness length but indifferent to albedo and Bowen Ratio variation (Grosch and Lee 2000, Karvounis et. al. 2007). Further, the modeling approach does not necessarily account for complex airflow around or near buildings and other obstructions. While these factors may cause uncertainty at downwind concentrations, their impact on variability near the maximum impact site is mitigated by requirements for on-airport characteristics and land-use immediately downwind of runways due to landing and take-off safety requirements, which results in some consistency nationwide. Where obstructions such as noise barriers or fences may impact atmospheric lead concentrations near the maximum impact site, extrapolated concentrations and their associated uncertainty should be considered on a case-by-case basis. Finally, the aircraft were modeled as volume sources with fixed horizontal and vertical plume extents, which may introduce uncertainty at airports with aircraft and engines that differ significantly from those at the model airport. Details on the modeling approach for aircraft sources, information on prior modeling work, and a comparison between piston-engine aircraft included in the model airport modeling with those active at airports nationwide is provided in Appendix A.

4.4.3 Operational Parameters

As discussed throughout the report, the availability, resolution, type, and detail of operational data available at airports nationwide can contribute to uncertainty in the estimated lead concentrations. The impact of airport-specific fleet heterogeneity (i.e., piston/turboprop split and single-engine/multi-engine split) was explored through the use of airport-specific data for a subset of airports in Section 4.2. However, other local fleet characteristics (e.g., distribution of aircraft engine types operating at the airport) are not accounted for in the analysis and may also contribute to uncertainty at specific airports that have distinct local characteristics. The nature of piston engines means that there is also a great deal of variability in their emissions, even for the same pilot operating the same airplane (Yacovitch et. al. 2016); however, the sensitivity of atmospheric lead concentrations to this variability should be minimized by averaging concentrations over a 3-month period. Similarly, the diurnal profile of aircraft activity may influence local lead concentrations over short timescales, but is not expected to be a sensitive parameter in determining 3-month average concentrations as discussed in Appendix B. Regional, local, and seasonal differences in daily operational patterns may contribute additional uncertainty to that discussed in Appendix B. However, given the insensitivity of average concentrations to different diurnal patterns in sensitivity analysis modeling, these are not expected to contribute significantly to uncertainty in extrapolated concentration estimates for airports nationwide. In modeling individual airports, national fleet and operational data should be supplemented with local data where available and feasible.

References

Anchorage DHHS (2012). *Merrill Field Lead Monitoring Report*. Municipality of Anchorage Department of Health and Human Services. Anchorage, Alaska. December 2012. http://www.muni.org/Departments/health/Admin/environment/AirQ/Documents/Merrill%20Field%20Lead%20Monitoring%20Study_2012/Merrill%20Field%20Lead%20Study%20Report%20-%20final.pdf.

ASTM International (2016). *Standard Specification for Leaded Aviation Gasolines, D910*.

Barrett, S. R. H. and R. E. Britter (2008). Development of algorithms and approximations for rapid operational air quality modelling. *Atmospheric Environment,* 42 (34), 8105-8111. DOI: http://doi.org/10.1016/j.atmosenv.2008.06.020.

Carr, E., M. Lee, K. Marin, C. Holder, M. Hoyer, M. Pedde, . . . J. Touma (2011). Development and evaluation of an air quality modeling approach to assess near-field impacts of lead emissions from piston-engine aircraft operating on leaded aviation gasoline. *Atmospheric Environment,* 45 (32), 5795-5804. DOI: http://dx.doi.org/10.1016/j.atmosenv.2011.07.017.

Chang, J. and S. Hanna (2004). Air quality model performance evaluation. *Meteorology and Atmospheric Physics,* 87 (1), 167-196.

Environment Canada (2000). *Airborne Particulate Matter, Lead and Manganese at Buttonville Airport.* Conor Pacific Environmental Technologies for Environmental Protection Service. Ontario.

FAA (2010). General Aviation and Part 135 Activity Surveys - CY 2010. F. A. Administration.

FAA (2012). *General Aviation Airports: A National Asset*

FAA (2014). General Aviation and Part 135 Activity Surveys - CY 2014. F. A. Administration.

FAA (2015). General Aviation and Part 135 Activity Surveys - CY 2015. F. A. Administration.

FAA (2017). FAA Form 5010, Airport Master Record.

Feinberg, S. and J. Turner (2013). Dispersion Modeling of Lead Emissions from Piston Engine Aircraft at General Aviation Facilities. *Transportation Research Record: Journal of the Transportation Research Board,*(2325), 34-42.

Feinberg, S. N., J. G. Heiken, M. P. Valdez, J. M. Lyons and J. R. Turner (2016). Modeling of Lead Concentrations and Hot Spots at General Aviation Airports. *Transportation Research Record: Journal of the Transportation Research Board,* 2569, 80-87. DOI: 10.3141/2569-09.

Fine, P., A. Polidori and S. Teffera (2010). *General Aviation Airport Air Monitoring Study*. South Coast Air Quality Management District.

Grosch, T. G. and R. F. Lee (2000). Sensitivity of the AERMOD air quality model to the selection of land use parameters.

Heiken, J., J. Lyons, M. Valdez, N. Matthews, P. Sanford, J. Turner and N. Feinberg (2014). *Quantifying Aircraft Lead Emissions at Airports*. ACRP Report 133. http://www.nap.edu/catalog/22142/quantifying-aircraft-lead-emissions-at-airports.

ICF (2014). *Final Report: Modeling Analysis of Air Concentrations of Lead from Piston-engine Aircraft*. ICF International.

Karvounis, G., D. Deligiorgi and K. Philippopoulos (2007). On the sensitivity of AERMOD to surface parameters under various anemological conditions.

Liang, M. S., T. C. Keener, M. E. Birch, R. Baldauf, J. Neal and Y. J. Yang (2013). Low-wind and other microclimatic factors in near-road black carbon variability: A case study and assessment implications. *Atmospheric environment (Oxford, England : 1994),* 80, 204-215. DOI: 10.1016/j.atmosenv.2013.07.057.

Lohr, G. W. and D. M. Williams (2008). *Current practices in runway configuration management (RCM) and arrival/departure runway balancing (ADRB)*. NASA/TM-2008-215557 NASA. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090010329.pdf.

Luecken, D., W. Hutzell and G. Gipson (2006). Development and analysis of air quality modeling simulations for hazardous air pollutants. *Atmospheric Environment,* 40 (26), 5087-5096.

National primary and secondary ambient air quality standards for lead (40 CFR 50.12). Amended Nov. 12, 2008.

USEPA (2010a). *Development and Evaluation of an Air Quality Modeling Approach for Lead Emissions from Piston-Engine Aircraft Operating on Leaded Aviation Gasoline*. EPA-420-R-10-007. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1007H4Q.PDF?Dockey=P1007H4Q.PDF.

USEPA (2010b). Revisions to Lead Ambient Air Monitoring Requirements.

USEPA. (2011). "2011 National Emissions Inventory (NEI) Data." 2017, from http://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-data.

USEPA. (2016a). "2014 National Emissions Inventory (NEI) ", from http://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data.

USEPA (2016b). Review of the National Ambient Air Quality Standards for Lead EPA–HQ–OAR–2010–0108; FRL–9952–87–OAR.

USEPA. (2017a). "Airport Lead Monitoring and Modeling." 2017, from http://www.epa.gov/regulations-emissions-vehicles-and-engines/airport-lead-monitoring-and-modeling.

USEPA. (2017b). "Learn About Lead Designations." 2018, from http://www.epa.gov/lead-designations/learn-about-lead-designations#process.

Yacovitch, T., Z. Yu, S. C. Herndon, R. Miake-Lye, D. Liscinsky, W. Knighton, . . . P. Pringle (2016). Exhaust Emissions from In-Use General Aviation Aircraft (ACRP Report No. 164).

Appendix B:

National Analysis of the Populations Residing Near or Attending School Near U.S. Airports

FINAL REPORT

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Table of Contents

1.0 Introduction

According to Federal Aviation Administration (FAA) records, there are approximately 20,000 airport facilities[1] in the U.S.[2] At the vast majority of these landing facilities, setbacks for residential development and recreational activity can be less than 50 meters (m) from aircraft operations.[3, 4] By contrast, commercial airports (defined by FAA as those with at least 2,500 passenger boardings each year), typically have a large spatial footprint which provides greater distance between aircraft activity and residential or recreational spaces compared with other airport facilities. There are approximately 500 commercial airports in the U.S.[5]

This report focuses on estimating the number of people who live and attend school near airports for the purposes of characterizing the magnitude of people potentially exposed to lead in air from piston-engine aircraft operations at airports. For the purposes of this report we are considering the population to be near an airport if they live in a census block that intersects the 500 m buffer of a runway or the 50 m buffer of a heliport. We also evaluated educational facilities that intersects the 500 m buffer of an airport runway. These buffer distances were selected due to results of air quality modeling and monitoring data for lead at and near airport facilities and one study reporting a statistically significant increase in children's blood lead for children living within 500 meters of an airport.[6] EPA and local air quality management district studies indicate that over a 3-month averaging time (the averaging time for the EPA National Ambient Air Quality Standard for Lead), the impact of aircraft lead emissions at highly active airports, extends to approximately 500 m downwind from the runway.[7, 8] These same studies suggest that on individual days, the impact of aircraft lead emissions can extend to almost 1,000 m downwind from the runway of a highly active airport (i.e., hundreds of take-off and landing events by piston-engine aircraft per day). The horizontal and lateral dispersion of the lead plume from aircraft emissions depends on several variables, including: wind direction, wind speed, the amount of aircraft activity (i.e., the number of take-off and landing operations), and the time spent by aircraft in specific modes of operation that have been demonstrated to greatly impact the magnitude of the ground-based lead concentrations (i.e., emissions occurring during pre-flight engine safety checks).

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[1] In this paper 'airport facility' refers to airports, balloonports, seaplane bases, gliderports, heliports, STOLports, and ultralight facilities.

[2] FAA Office of Air Traffic provides a complete listing of operational airport facilities in the National Airspace System Resources (NASR) database available at: http://www.faa.gov/airports/airport_safety/airportdata_5010/.

[3] U.S. FAA, 2012. General Aviation Airports: A National Asset. Available at: http://www.faa.gov/airports/planning_capacity/ga_study/media/2012AssetReport.pdf.

[4] ASTM International (2005) ASTM F2507 – 05 Standard Specification for Recreational Airpark Design.

[5] FAA National Plan of Integrated Airport Systems 2013-2017. Available at: http://www.faa.gov/airports/planning_capacity/npias/reports.

[6] Miranda, M., Anthopolous, R., Hastings, D. (2011) A geospatial analysis of the effects of aviation gasoline on childhood blood lead levels. Environmental Health Perspectives 119:1513-1519.

[7] Carr, E., Lee, M., Marin, K., Holder, C., Hoyer, M., Pedde, M., Cook, R., Touma, J. (2011) Development and evaluation of an air quality modeling approach to assess near-field impacts of lead emissions from piston-engine aircraft operating on leaded aviation gasoline. Atmos Env 45: 5795-5804.

[8] South Coast Air Quality Management District (2010) General Aviation Airport Air Monitoring Study Final Report.

Section 2.0 describes the data and methods used to quantify the number of people living near an airport runway and/or heliport where piston-engine aircraft operate, as well as the number of children attending school in this environment. Section 3.0 provides the resulting population demographics for the population, by race, living near an airport runway and/or heliport. This section also provides the results of the number of children attending school near a runway and/or heliport by race and free or reduced-price school lunch eligibility (a proxy for socioeconomic status of the population located in close proximity to airports) as well as the number of children attending preschool near a runway and/or heliport. A discussion of the sources of uncertainty in the methods applied is presented in Section 4.0.

2.0 Data and Methods

In order to quantify the population living near an airport runway and/or heliport, we first developed layers[9] to represent the location of all airport facilities (referred to here as the 'airport layer') using ArcGIS 10.0.[10] For airports with available data, the airport layer is represented by the location of the runway(s) at the airport and is more specifically referred to as the 'runway layer.' For airport facilities where data are not available to identify the location of the runways, the airport facility centroid represents the facility in the airport layer and is more specifically referred to as the 'facility layer.' The airport centroid is the approximate geometric center of all usable runways.[11] We then developed buffers around each layer element that extend out to 500 m from the airport runway and 50 m from heliport centroids. We intersected the resulting buffers with 2010 U.S. Census data (at the block level[12]) and data identifying the location of public and private schools and preschools. In this section we describe the methods used to create airport layers, airport buffer layers, a census block population layer, education facility layers and the intersection analysis of airport buffer layers with population and educational facility layers. A detailed description of the data sources is described below.

2.1 Creation of Airport Layers

The availability of airport runway data that can be used to create airport layers varies among the almost 20,000 airport facilities in the U.S. Therefore, depending on the data elements available, different data sources and methods were used to generate the U.S. airport layers. There are seven methods used to create the airport layers, that are focused on seven categories of airports based on data availability as described below.

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[9] A layer is "the visual representation of a geographic dataset in any digital map environment. Conceptually, a layer is a slice or stratum of the geographic reality in a particular area and is more or less equivalent to a legend item on a paper map. On a road map, for example, roads, national parks, political boundaries, and rivers might be considered different layers." (from: https://support.esri.com/en/other-resources/gis-dictionary/term/ba1e96e7-4cae-4714-875a-a7e3488b8bb9).

[10] ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

[11] U.S. Department of Transportation (2004) FAA Advisory Circular 150/5200-35, 5/20/2004, 'Submitting the Airport Master Record in Order to Activate a New Airport.'

[12] Census blocks "are statistical areas bounded by visible features, such as streets, roads, streams, and railroad tracks, and by nonvisible boundaries, such as selected property lines and city, township, school district, and county limits and short line-of-sight extensions of streets and roads." (from: http://www.census.gov/geo/reference/gtc/gtc_block.html).

The first method uses geospatial linear runway data produced by the FAA Research and Innovative Technology Administration's Bureau of Transportation Statistics (RITA/BTS), which is part of the National Transportation Atlas Databases (NTAD) 2010 data. These data are referred to in this report as the FAA geospatial data. This geographic dataset of U.S. runways contains information on runway geometry and is derived from the FAA's National Airspace System Resource Aeronautical Data Product.

The remaining method categories (II-VII) were applied to airport facilities for which FAA geospatial data were not available. The data used in these categories came from FAA's Office of Air Traffic which provides a complete list of operational airport facilities in the National Airspace System Resources (NASR) database, which is partly populated by airport submissions of Airport Master Record (5010) forms. The electronic NASR data report can be generated from the NASR database and is available for download from the FAA's website.[13] Reports are available both at the runway level (referred to here as the "5010 runway data report"), and the airport facility level (referred to here as the "5010 airport data report"). Both reports are updated every 56 days with any newly available information.[14] For some airports, tabular runway data in the 5010 runway data report were provided that included fields for the latitude and longitude coordinates of the runway base end and for the runway reciprocal end (opposite to the base end) or just one runway end. The base end of a runway is the runway end located to the west of the north-south line and the reciprocal end is the runway end located to the east of the north-south line. Base runway ends have a magnetic heading of 10 to 180 and reciprocal runway ends have a magnetic heading of 190 to 360 degrees. These data from the 5010 runway data report were used to create runway layers in methods II and III, as described below. For airports without runway end coordinate data, data from the 5010 runway data report were supplemented with airport centroid latitude and longitude data from the 5010 airport data report to create runway layers in methods IV and V, as described below. For airports without relevant runway data, we used the airport centroid latitude and longitude from the 5010 airport data report to create the facility layers in methods VI and VII. Appendix Table A-1 provides the summary of airport and population data by method.

Methods Used to Create Airport Layers

I. Runway layers were created directly from FAA geospatial data for 6,090 runways at 4,146 facilities. This dataset was downloaded in March 2011[15] and contained information for 6,159 runways, however, we excluded runways at airport facilities that are closed[16] as well as runways at facilities in U.S. territories since the U.S. Census data used in this analysis does not provide complete coverage of the U.S. territories.[17] In total, 69 runways were excluded from this dataset.

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[13] "Airport Data & Contact Information" at http://www.faa.gov/airports/airport_safety/airportdata_5010/.

[14] This analysis used the 5010 airport and runway data reports downloaded on March 5, 2012.

[15] National Transportation Atlas Databases. Washington, D.C.: U.S. Department of Transportation, 2010. (accessed at: http://www.bts.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_atlas_database/2013/polyline.html).

[16] Determined by comparing the geospatial data with the February 7, 2012 and September 25, 2013 versions of the FAA 5010 facility data report, which indicates if an airport is open, closed indefinitely, or closed permanently.

[17] U.S. Census Bureau (Revised 2012). 2010 Census Summary File 1 – Technical Documentation.

II. For 414 runways at 385 facilities, the latitude and longitude coordinates of the runway base end and runway reciprocal end were provided in the 5010 runway data report. The runway layer was created using the ‘points to line’ tool in ArcGIS to connect the reciprocal and base end coordinates to generate a line representing the runway.

III. For 4 runways at 4 facilities, latitude and longitude data for only one runway end – either base or reciprocal end - were provided in the 5010 runway data report. The magnetic heading of the runway and the runway length were also provided in the FAA database for these facilities. The coordinates for the runway end without available longitude and latitude data were calculated using equations 1 and 2 in Figure 1 below. Equations 1 and 2 use trigonometric functions to determine the runway location given either the base end latitude and longitude or the reciprocal end latitude and longitude. The constants in the denominator of both equations convert the changes from meters to degrees. The conversion constants were calculated by dividing the circumference of the earth in meters by 360 degrees to determine the length of one degree latitude and longitude at the equator. Multiplying by cos X_1 in the denominator of equation 2 accounts for the fact that the distance of one degree of longitude decreases significantly as the point moves closer to one of the earth’s poles.[18] The runway length (designated as ‘RunwayLength’ in the FAA 5010 runway data report) was represented by l. Where the reciprocal end coordinates were available, they were designated as X_1 for the reciprocal end latitude, and Y_1 for the reciprocal end longitude in equations 1 and 2. Using the information provided for the length of the runway and the reciprocal end coordinates, the base end of the runway was calculated. The latitude of the base end of the runway was designated as X_2, and the longitude of the base end of the runway was designated as Y_2. For the runways with available base end data (i.e., X_2, Y_2 coordinates in equations 1 and 2), and the equations were used to solve for the reciprocal runway end latitude and longitude designated as X_1, and Y_1, respectively. The runway identification data (designated as ‘runway ID’ in the FAA 5010 runway data report) is provided by FAA in the 5010 runway data report and is defined by FAA as the whole number nearest the one-tenth of the magnetic azimuth of the direction to which the runway is pointing (measured clockwise, with 0^o at due north). These runway IDs were used to calculate θ as follows: the base end runway ID was converted to an angle using Table A-2. For purposes of the equation, θ is measured in degrees, counterclockwise from due east, with due east having a value of 0 degrees. A runway pointing due east has a magnetic heading of 90 as defined by FAA (runway designation marking of 09), with the reciprocal runway end having a magnetic heading of 270 (runway designation marking of 27). A conversion chart in Table A-2 in the appendix links runway magnetic headings with the value of θ

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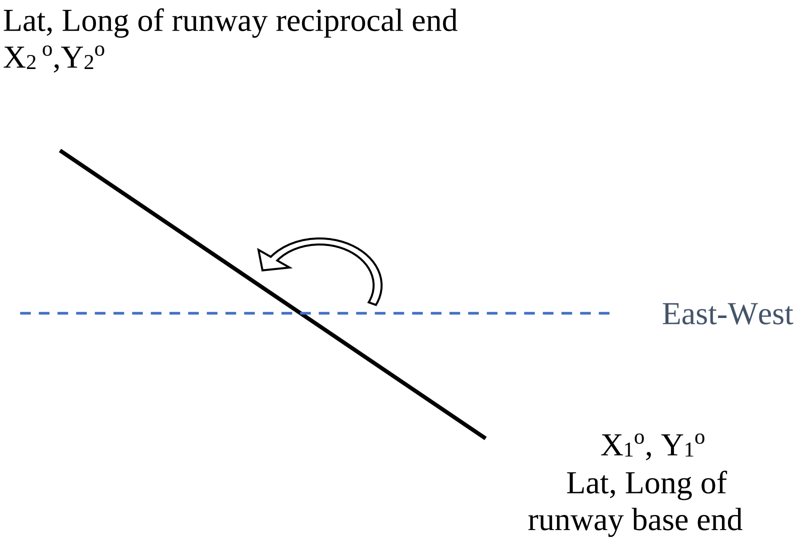
[18] The data for these conversion constants were obtained from http://oceanservice.noaa.gov/education/tutorial_geodesy/geo02_hist.html and The National Center for Geographic Information and Analysis.

used in this equation. This value of θ was adjusted using magnetic declination of the closest 15-arc minute declination contour.[19] The runway layer was created using the 'points to line' tool in ArcGIS to connect the reciprocal and base end coordinates to generate a line, representing the runway.



$$X_2^0 = X_1^0 + \frac{l\sin\theta}{111{,}112} \tag{1}$$

$$Y_2^0 = Y_1^0 + \frac{l\cos\theta}{111{,}112\cos X_1^0} \tag{2}$$

Figure 1. Calculation of Runway Latitude and Longitude Coordinates for Category III

Where X_1 and Y_1 are the latitude and longitude of the reciprocal end of the runway, respectively; X_2 and Y_2 are the latitude and longitude of the base end of the runway, respectively; theta (θ) is the runway angle from the east-west line.

IV. For 8,597 runways at 8,597 airports, the airport centroid (which is the center of the runway on the runway centerline) was used to create the runway layer.[20] The coordinates for the runway ends were calculated in a similar manner to those in category III. Both the base and

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[19] The magnetic declination data were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center World Magnetic Model 2010 at http://www.ngdc.noaa.gov/geomag/data.shtml (follow links to: 'maps and shape files,' 'wmm2010,' 'shapefiles,' and 'WMM2010_Shapefile_15min_for_NGA.zip').

[20] U.S. Department of Transportation (2004) FAA Advisory Circular 150/5200-35, 5/20/2004, 'Submitting the Airport Master Record in Order to Activate a New Airport.'

reciprocal runway end coordinates were calculated from the reference point of the centroid (coordinate pair X_3, Y_3 in Figure 2). Base end coordinates, X_2, Y_2, were calculated using equations (3) and (4), which uses the distance of half the runway length ($l/2$) since the centroid bisects the runway. The reciprocal end coordinates, X_1, Y_1, were solved for using equations (5) and (6), again with the distance of $l/2$. In both sets of runway end calculations the runway identification data (designated as 'runway ID' in the FAA 5010 runway data report) were used to calculate θ as follows: the base end runway ID was converted to an angle using Table A-2.[21] Runway IDs are based on the magnetic heading[22] of each runway end, therefore magnetic declination data from the NOAA National Geophysical Data Center World Magnetic Model 2010 were obtained[23] and the angle resulting from the use of Table A-2 was adjusted by the magnetic declination of the closest 15-arc minute declination contour to calculate the value of θ used in equations (3) through (6). The runway lines for these facilities, which comprise the runway layer, were then generated in ArcGIS using the 'points to line' tool to connect the calculated runway end latitude and longitude pairs.

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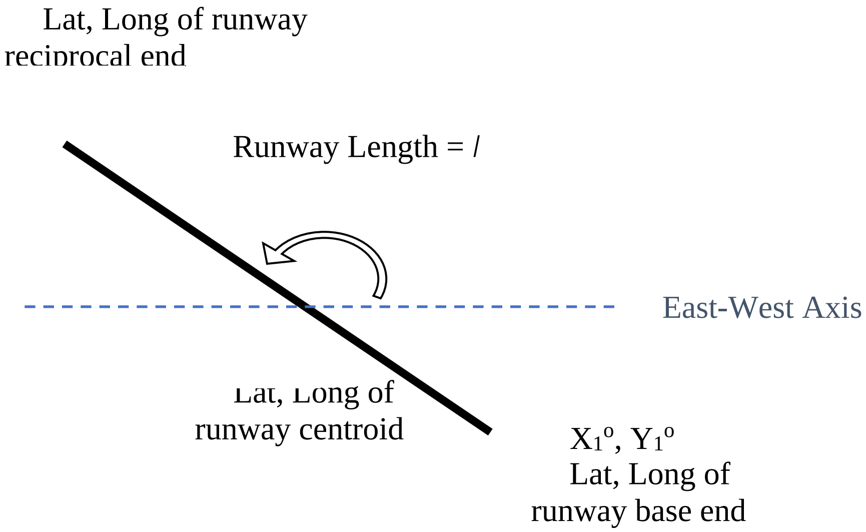
[21] θ is measured in degrees, counterclockwise from due east.

[22] The runway designation is the whole number nearest the one-tenth of the magnetic azimuth of the direction to which the runway is pointing (measured clockwise, with 0° at due north).

[23] http://www.ngdc.noaa.gov/geomag/data.shtml (follow links to: 'maps and shape files,' 'wmm2010,' 'shapefiles,' and 'WMM2010_Shapefile_15min_for_NGA.zip').



$$X_2^0 = X_3^0 + \frac{(l/2)\sin\theta}{111{,}112} \tag{3}$$

$$Y_2^0 = Y_3^0 + \frac{(l/2)\cos\theta}{111{,}112\cos X_3^0} \tag{4}$$

$$X_1^0 = X_3^0 + \frac{(l/2)\sin\theta}{111{,}112} \tag{5}$$

$$Y_1^0 = Y_3^0 + \frac{(l/2)\cos\theta}{111{,}112 cos X_2^0} \tag{6}$$

Figure 2. Calculation of Runway Latitude and Longitude Coordinates for Category IV

V. For 41 runways at 41 facilities, the runway ID in the 5010 runway data report was “ALL/WAY” (i.e., the runways were not identified with a runway magnetic heading because aircraft can take off and land in many directions). An additional facility had an ALL/WAY runway and a helipad. These facilities were all designated as seaplane bases and ultralight[24] facilities. The 5010 runway data report contained data on the length and width of each runway. Assuming the facility latitude and longitude was located at the center of the ALL/WAY runway and using the runway length and width data, coordinates for the four vertices of a rectangle were calculated[25]: the rectangle was assumed to be

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[24] Ultralight facilities have activity by ultralight vehicles, The parameters defining an ultralight vehicle are set forth in 14 CFR 1.1. Among other limitations, ultralight vehicles are used or intended for use by a single occupant, weigh less than 155 pounds, if unpowered (254 pounds, if powered), and have a fuel capacity not exceeding 5 U.S. gallons (http://www.ecfr.gov/current/title-14/part-103).

[25] In this analysis these facilities were modeled with a rectangular runway area since the dimensions of the runway area that were given were length and width.

oriented such that the four sides ran north-south or east-west and that the two hypotenuses of the rectangle represented ℓ in Figure 1. The runway length was assigned from East to West and the runway width was assigned the distance from North to South. The method described in III above was then used to calculate the two latitude/longitude pairs for the ends of each hypotenuse, after geometrically determining the angle, θ, between each hypotenuse and the east-west mid-line of the rectangle (based on the given length and width). The four latitude/longitude pairs were calculated and connected with the ‘minimum bounding geometry’ tool (using the convex output type option) in ArcGIS to generate a rectangular polygon, which represented the possible landing and take-off paths at these facilities.[26] The rectangular polygons comprised the runway layer for these facilities.

VI. For 1,881 runways at 856 multi-runway facilities, the 5010 airport data report provided the airport centroid coordinates, which were used to create the facility layer for these facilities.[27] These facilities had runways which were in a parallel configuration at some airports, while others had runways that intersected at varying angles or were perpendicular or some combination of these configurations. Additionally, some of these facilities had one or more helipad. Therefore, the centroid coordinates could not be used to calculate the coordinates of the runway ends as was done for category IV facilities. Instead, the coordinate points comprised the facility layer for these facilities.

VII. There were 5,387 heliports[28] with only one helipad and 202 heliports with more than one helipad. The heliport centroid coordinates from the 5010 airport data report were the only location data available, and this centroid location was used to create the facility layer for heliports. For heliports with one helipad, these centroid coordinates provide a reliable identification of the helipad location. For heliports with multiple helipads, visual inspection of a subset of the 202 multi-helipad facilities (using Google Earth software) suggested that there is no standard layout for the location of helipads at airfields with multiple helipads and they were largely removed from densely populated areas by significant setbacks or because the facility is in a rural area. The centroid provided in the 5010 report was used for this small subset of facilities as the best available data.

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[26] It was assumed that the runway length represented the distance from East to West and the width represented the distance from North to South.

[27] U.S. Department of Transportation (2004) FAA Advisory Circular 150/5200-35, 5/20/2004, ‘Submitting the Airport Master Record in Order to Activate a New Airport.’

[28] A heliport is a facility with only helipads, so these facilities are separate from airports with runways that also have a helipad (which we have characterized in categories IV – VI in this document). For airport facilities that also have a helipad, we are not separately evaluating the population in a buffer around the helipad since the buffer around the runway would include the helipad at an airport facility.

2.2 Creation of Airport Buffer Layer

For runways in categories I – IV above (15,156 runways at 13,183 facilities), 500 m round-end buffers, termed 'whole perimeter buffers' in this analysis, were created around each element in the runway layer using the ArcGIS 'buffer' tool. As described in the air quality modeling and monitoring studies by Carr et. al., 2011 and Feinberg, et. al., 2016,[29] the maximum impact area for ground-based lead emissions from piston-engine powered aircraft occur at a standardized location at or near each runway end where preflight run-up checks and take-off operations occur. In order to identify the population most highly exposed to ground-based emissions from aircraft during preflight run-up checks and take-off operations, an end-of-runway buffer was created. This was accomplished by first creating 500 m flat-end buffers around each runway line using the ArcGIS buffer tool. The 'symmetrical difference' tool was then used to subtract the 500 m flat-end buffers from the 500 m round-end buffers, creating 'end-of-runway buffers.' The end-of-runway buffers are effectively two semicircles with a 500 m radius, with centers at each end of a runway (Figure 3).

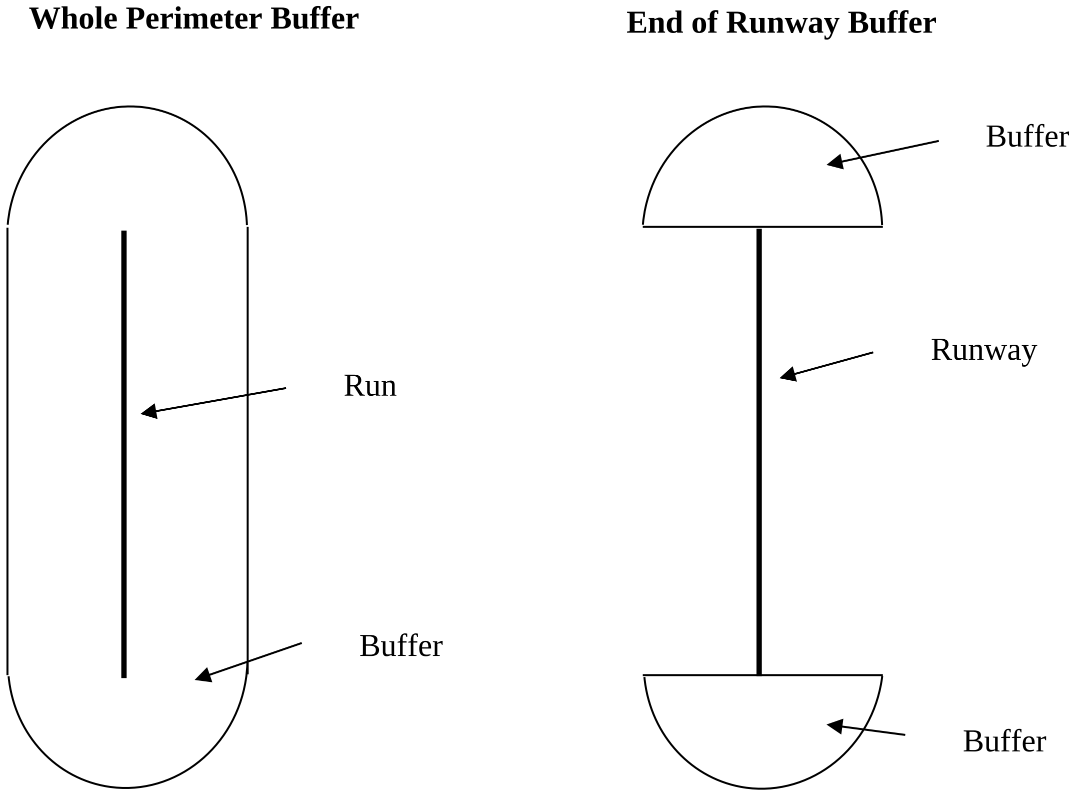

Figure 3. Whole Perimeter Buffer and End-of-Runway Buffer

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[29] Feinberg, S., Heiken, J., Valdez, M., Lyons, J., Turner, J. (2016) Modeling of lead concentrations and hot spots at general aviation airports. *Transportation Research Record: Journal of the Transportation Research Board, No. 2569,* Transportation Research Board, Washington, D.C., 2016, pp. 80–87.

For the category V runways (42 facilities), which are the "ALL/WAY" facilities, 500 m buffers were created around each rectangle runway shape in the runway layer using the ArcGIS buffer tool (Figure 4). Since aircraft can take off in any direction from these runways, no 'end-of-runway buffer' was created.

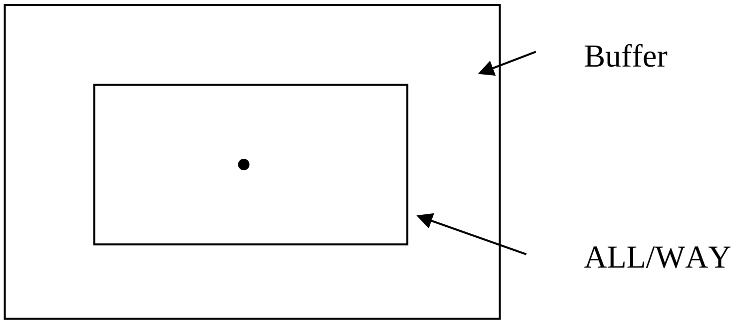

Figure 4. Buffer around ALL/WAY Airport Facilities in Category V

For the category VI runways (856 facilities), the only data available from which to determine the size of the buffer layer were the length of the runways. We calculated the average length of the runways at these facilities (737 m) and chose to generate a 1,000 m radius circular buffer around each facility centroid coordinate pair in the facility layer (Figure 5[30]). In section 4 we discuss the resulting uncertainties inherent in this approach.

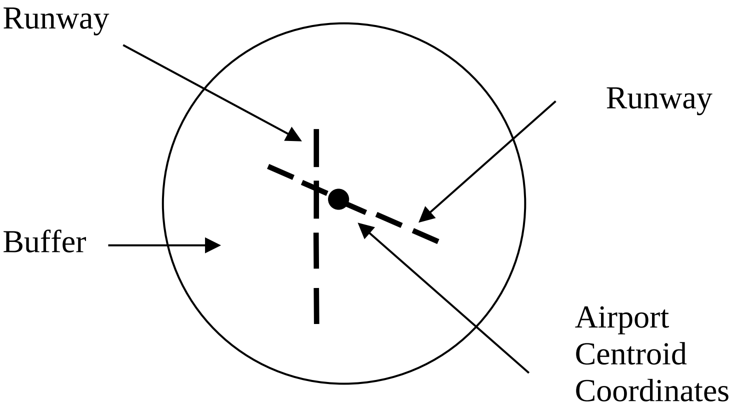

Figure 5. Buffer for Facilities with Multiple Runways and Only Airport Centroid Coordinate Data Available for Category VI

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[30] Note that the geographic location of runways in category VI are not available; the runways drawn in this figure are hypothetical and for illustrative purposes only.

For the category VII helipads at heliports (5589 facilities), 50 m buffers around the heliport centroid coordinate pairs in the facility layer were generated using the buffer tool in ArcGIS (Figure 6).

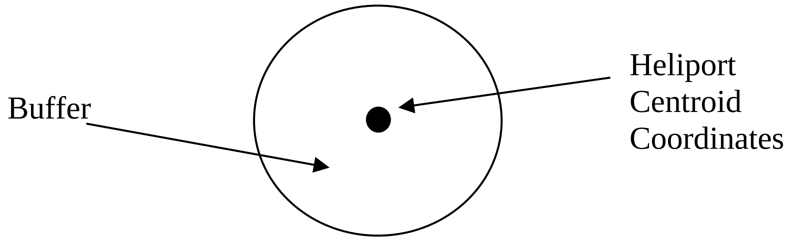

Figure 6. Buffer Layer for Heliports with One or More Helipad for Category VII

2.3 Creation of U.S. Census Block Population Layer

Using ArcGIS 10.0, 2010 U.S. Census Summary File 1[31] tabular data at the block level was joined with the 2010 U.S. Census TIGER/Line Shapefiles[32] geospatial data at the Census block level to create the population layer used in this analysis.

2.4 Creation of Education Facility Layers

Public and private school data for grades kindergarten through twelfth grade (K-12th grade) were obtained from the U.S. Department of Education's Institute of Education Sciences National Center for Education Statistics.[33, 34] At the time this analysis was conducted, the most recent public school data available were for the academic year 2010 – 2011 and the most recent private school data available were for academic year 2009 – 2010. The public school and private school databases contained latitude and longitude coordinates of the reported school physical addresses,[35,36] which were imported into ArcGIS as point data.

Data for the location of all Head Start facilities (including Head Start, Early Head Start, and Migrant and Seasonal Head Start facilities) were obtained from the Department of Health and Human Services, Office of Head Start. The data contained latitude and longitude coordinates for each facility. Facility enrollment data were not available.

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[31] 2010 Census Summary File 1 [United States]/prepared by the U.S. Census Bureau, 2011 (accessed from: http://mcdc.missouri.edu/cgi-bin/uexplore?/pub/data/sf12010).

[32] Accessed from: http://www.census.gov/cgi-bin/geo/shapefiles2010/main.

[33] http://nces.ed.gov/ccd/bat/.

[34] http://nces.ed.gov/surveys/pss/pssdata.asp.

[35] https://nces.ed.gov/ccd/CCDLocaleCode.asp.

[36] http://nces.ed.gov/pubs2011/2011322.pdf.

2.5 Intersection Analysis

Whole Perimeter Analysis

The 500 m ‘whole perimeter’ buffers for runways in categories I - IV, as well as the buffers for the category V - VII facilities were intersected with the population and education facility layers. Census block populations were included in the final population count if any part of a census block intersected the airport buffer. People living in census blocks that intersected the buffers of more than one facility or runway were included only once. The total population, by race, and the population of children 5 and younger in census blocks that intersected the 500 m whole perimeter buffers were calculated.

End-of-Runway Only Analysis

The 500 m ‘end-of-runway’ buffers for runways in categories I – IV were intersected with the population and education facility layers. As with the whole-perimeter analysis, census block populations were included in the final population count if any part of a census block intersected the airport buffer; and, as with the whole perimeter analysis, people living in census blocks that intersected more than one facility or runway buffer were included only once. The total population, by race, and the population of children 5 and younger in census blocks that intersected the 500 m end-of-runway buffers were calculated. End-of-runway buffers could not be created for category V – VII facilities because the precise location of the runway at these facilities was not known.

3.0 Results

Data comparing the population residing near an airport runway and/or heliport with the total U.S. population are shown in Tables 1 and 2 for the entire population and those 5 years of age and under, respectively. These data indicate that 5,179,000 people live in census blocks that intersected the 500 m whole perimeter buffers, 363,000 of whom are children age 5 and under.

Table 1: 2010 U.S. Population, by Race, Residing in Census Blocks that Intersect 500-meter Whole-Perimeter Buffers and 2010 U.S. Total Population, by Race

	Total Population	**White, alone**	**Black or African American, alone**	**American Indian or Alaska Native, alone**	**Asian, alone**	**Native Hawaiian or Other Pacific Islander, alone**	**Some Other Race, alone**	**Two or More Races**
U.S. Population Residing in Airport 500 m Whole-Perimeter Buffers	5,179,000	4,134,000 (79.8%)	463,000 (8.9%)	78,000 (1.5%)	154,000 (3.0%)	8,000 (0.2%)	215,000 (4.2%)	127,000 (2.5%)
Entire U.S. 2010 Population	308,746,000	223,553,000 (72.4%)	38,929,000 (12.6%)	2,932,000 (1.0%)	14,674,000 (4.8%)	540,000 (0.2%)	19,107,000 (6.2%)	9,009,000 (2.9%)

Table 2: Number of Children 5 Years and Under, by Age, Residing in Census Blocks that Intersect 500-meter Whole-Perimeter Buffers and U.S. Total Population 5 Years and Under, by Age

	Total Population 5 years and under	**Under 1 year**	**Age 1 year**	**Age 2 years**	**Age 3 years**	**Age 4 years**	**Age 5 years**
U.S. Population 5 Years and Under Residing in Airport 500 m Whole-Perimeter Buffers	363,000	58,000 (16.0%)	59,000 (16.3%)	61,000 (16.8%)	62,000 (17.1%)	61,000 (16.8%)	62,000 (17.1%)
Entire U.S. 2010 Population 5 Years and Under	24,258,000	3,944,000 (16.3%)	3,978,000(16.4%)	4,097,000 (16.9%)	4,119,000 (17.0%)	4,063,000 (16.8%)	4,057,000 (16.7%)

Data comparing those residing in census blocks that intersect the 500 m end-of-runway buffers with those residing in census blocks that intersect the 500 m whole-perimeter buffers are compared in Tables 3 and 4 for the entire population and those 5 years of age and under, respectively. This analysis indicates that 3,630,000 people live in census blocks that intersected the 500 m end-of-runway buffers (89% of the population that lives in census blocks that intersected the 500 m whole-perimeter buffers at the same set of airports). Among this population, 261,000 were children age 5 and under.

Table 3: 2010 U.S. Population, by Race, Residing in Census Blocks that Intersect 500-meter End-of-Runway Buffers and Whole-Perimeter Buffers (category I – IV facilities only)[37]

	Total Population	**White, alone**	**Black or African American, alone**	**American Indian or Alaska Native, alone**	**Asian, alone**	**Native Hawaiian or Other Pacific Islander, alone**	**Some Other Race, alone**	**Two or More Races**
U.S. Population Residing in Airport 500 m End-of-Runway Buffers	3,630,000	2,955,000 (81.4%)	302,000 (8.3%)	57,000 (1.6%)	82,000 (2.3%)	5,000 (0.1%)	143,000 (3.9%)	85,000 (2.3%)
U.S. Population Residing in Airport 500 m Whole-Perimeter Buffers	4,078,000	3,281,000 (80.4%)	344,000 (8.4%)	68,000 (1.7%)	107,000 (2.6%)	7,000 (0.2%)	171,000 (4.2%)	100,000 (2.5%)

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[37] End-of-runway buffers were not able to be generated for category V, VI, or VII airport facilities, therefore the population which resides in census blocks that intersect the 500 m whole-perimeter buffers from only category I – IV airport facilities is shown in row two in order to enable comparison of the results of the two buffer types across the same set of airports.

Table 4: Number of Children 5 Years and Under, by Age, Residing in Census Blocks that Intersect 500-meter End-of-Runway Buffers and Whole-Perimeter Buffers (category I – IV facilities only)[38]

	Total Population 5 years and under	**Under 1 year**	**Age 1 year**	**Age 2 years**	**Age 3 years**	**Age 4 years**	**Age 5 years**
U.S. Population 5 Years and Under Residing in Airport 500 m End-of-Runway Buffers	261,000	41,000 (15.7%)	42,000 (16.1%)	43,000 (16.5%)	45,000 (17.2%)	45,000 (17.2%)	45,000 (17.2%)
U.S. Population 5 Years and Under Residing in Airport 500 m Whole-Perimeter Buffers	293,000	46,000 (15.7%)	48,000 (16.4%)	49,000 (16.7%)	50,000 (17.1%)	50,000 (17.1%)	51,000 (17.4%)

The total number of schools (K-12th grade) and student enrollment, by race/ethnicity, of public and private schools that intersected the 500 m whole-perimeter buffers is shown in Table 5, below. This analysis indicates that 163,000 K-12th grade students attend the 573 public and private schools that intersected the 500 m whole-perimeter buffers. The bottom half of the table provides private and public school and enrollment data for the entire U.S.

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[38] Similar to Table 3 and as described in footnote 40, Table 4 presents data for only category I – IV airport facilities in order to enable comparison of the two buffer types across the same set of airports.

Table 5: Number of Schools (Public and Private) and Enrollment, by Race/Ethnicity, at Schools that Intersect 500-meter Whole-Perimeter Buffers and at All U.S. Schools (Public and Private)[39]

	Number of Schools	**Total Student Enrollment**	**White Students**	**Black Students**	**American Indian/ Alaska Native Students**	**Asian/ Native Hawaiian/ Pacific Islander Students**[40]	**Hispanic Students**	**Two or More Races Students**
Private Schools within 500 m Whole-Perimeter Buffers	115	15,000	10,000 (66.7%)	1,000 (6.7%)	Less than 100 (0%)	1000 (6.7%)	2,000 (13.3%)	Less than 500 (2%)
Public Schools within 500 m Whole-Perimeter Buffers	458	147,000	92,000 (62.6%)	16,000 (10.9%)	5,000 (3.4%)	5,000 (3.4%)	26,000 (17.7%)	4,000 (2.7%)
TOTAL	**573**	**163,000**	**101,000**	**17,000**	**5,000**	**6,000**	**28,000**	**4,000**
Total Private School Population	28,000	5,013,000	3,104,000 (61.9%)	397,000 (7.9%)	20,000 (0.4%)	249,000 (5.0%)	416,000 (8.3%)	119,000 (2.4%)
Total Public School Population	100,000	49,049,000	25,704,000 (52.4%)	7,812,000 (15.9%)	560,000 (1.1%)	2,442,000 (5.0%)	11,326,000 (23.1%)	1,153,000 (2.4%)
TOTAL	**128,000**	**54,062,000**	**28,808,000**	**8,209,000**	**579,000**	**2,690,000**	**11,742,000**	**1,272,000**

The total number of schools (K-12th grade) and student enrollment, by race/ethnicity, of public and private schools that intersected the 500 m end-of-runway buffers are shown in the top half of Table 6. This analysis indicates that 77,938 K-12th grade students attend the 254 public and private schools that intersected the 500 m end-of-runway buffers (compared to the 120,892 K-12th grade students who attend the 383 schools that intersected the whole-perimeter buffers at the same set of airport facilities).

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[39] End-of-runway buffers were not able to be generated for category V, VI, or VII airport facilities, therefore the total number of schools (K-12th grade) and student enrollment, by race/ethnicity, of public and private schools that intersected the 500 m whole-perimeter buffers from only category I – IV airport facilities is shown in the bottom portion of the Table 6 in order to enable comparison of the results of the two buffer types across the same set of airports.

[40] The public school data had a race/ethnicity category labeled 'Asian and Pacific Islander Students' while the private school data had a race/ethnicity category labeled 'Asian Students' and a separate category labeled 'Native Hawaiian and Pacific Islander Students.' In order to combine the results of the private and public school analysis, in this table the 'Asian/Native Hawaiian/Pacific Islander Students' column contains results from the public school data that correspond to the 'Asian and Pacific Islander Students' category and from the private school data that correspond to the sum of the counts from the 'Asian Students' and 'Native Hawaiian and Pacific Islander Students' categories.

Table 6: Number of Schools (Public and Private) and Enrollment, by Race/Ethnicity, at Schools that Intersect 500-meter End-of-Runway Buffers and Whole-Perimeter Buffers (category I – IV facilities only)[41,42]

	Number of Schools	**Total Student Enrollment**	**White Students**	**Black Students**	**American Indian/Alaska Native Students**	**Asian/ Native Hawaiian / Pacific Islander Students**[43]	**Hispanic Students**	**Two or More Races Students**
Private Schools within 500 m End-of-Runway Buffers	48	5,443	3,564 (65%)	254 (5%)	17 (<1%)	242 (4%)	480 (9%)	48 (1%)
Public Schools within 500 m End-of-Runway Buffers	206	72,495	44,656 (62%)	8,463 (12%)	973 (1%)	2,503 (3%)	14,310 (20%)	1,590 (2%)
TOTAL	**254**	**77,938**	**48,220**	**8,717**	**990**	**2,745**	**14,790**	**1,638**
Private Schools within 500 m Whole-Perimeter Buffers	92	11,568	7,211 (62%)	812 (7%)	49 (0%)	580 (5%)	1,273 (11%)	207 (2%)
Public Schools within 500 m Whole-Perimeter Buffers	383	120,892	75,717 (63%)	12,065 (10%)	3,711 (3%)	4,517 (4%)	21,815 (18%)	3,067 (3%)
TOTAL	**475**	**132,460**	**82,928**	**12,877**	**3,760**	**5,097**	**23,088**	**3,274**

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[41] End-of-runway buffers were not able to be generated for category V, VI, or VII airport facilities, therefore the total number of schools (K-12th grade) and student enrollment, by race/ethnicity, of public and private schools that intersected the 500 m whole-perimeter buffers from only category I – IV airport facilities is shown in the bottom portion of the Table 6 in order to enable comparison of the results of the two buffer types across the same set of airports.

[42] End-of-runway buffers were not able to be generated for category V, VI, or VII airport facilities, therefore the total number of schools (K-12th grade) and student enrollment, by race/ethnicity, of public and private schools that intersected the 500 m whole-perimeter buffers from only category I – IV airport facilities is shown in the bottom portion of the Table 6 in order to enable comparison of the results of the two buffer types across the same set of airports.

[43] The public school data had a race/ethnicity category labeled 'Asian and Pacific Islander Students' while the private school data had a race/ethnicity category labeled 'Asian Students' and a separate category labeled 'Native Hawaiian and Pacific Islander Students.' In order to combine the results of the private and public school analysis, in this table the 'Asian/Native Hawaiian/Pacific Islander Students' column contains results from the public school data that correspond to the 'Asian and Pacific Islander Students' category and from the private school data that correspond to the sum of the counts from the 'Asian Students' and 'Native Hawaiian and Pacific Islander Students' categories.

In addition to evaluating a potential in racial disparity among the children attending schools near airports, this analysis would ideally inform whether there is a socioeconomic disparity among the children attending schools near airports compared with the US school population generally. There are minimal data available in the U.S. Census at the block level to evaluate this question; data regarding free and reduced-price school lunches was used as a surrogate here for potential socioeconomic disparity. The total number of students (K-12th grade) eligible for free or reduced-price school lunches who attend public schools that intersected the 500 m whole-perimeter and end-of-runway only buffers is shown in Table 7. This analysis indicates that at the public schools that intersected the 500 m whole-perimeter buffers, 67,000 of the K-12th grade students were eligible for free or reduced-price school lunches. The bottom half of Table 7 indicates that at the public schools that intersected the 500 m end-of-runway buffers, 34,000 of the K-12th grade students were eligible for free or reduced-price school lunches (equal to 51% of the K-12th grade students who were eligible for free or reduced-price school lunches at schools that intersected the 500 m whole-perimeter buffers at the same set of airports).

Table 7: Number of Free and Reduced-Price School Lunch Eligible Students at all U.S. Public Schools and at Public Schools that Intersect 500-meter Whole-Perimeter Buffers and End-of-Runway Buffers[44]

	Number of Students Eligible for Reduced-price School Lunches	**Number of Students Eligible for Free School Lunches**	**Total Number of Students Eligible for Free or Reduced- Price School Lunches**
Total U.S. Public School Population	3,400,000 (7%)	20,082,000 (41%)	23,483,000 (48%)
Public Schools within 500 m Whole-Perimeter Buffers (all airport categories)	11,000 (8%)	56,000 (38%)	67,000 (45%)
Public Schools within 500 m End-of-Runway Buffers (only category I – IV facilities)	5,000 (8%)	29,000 (40%)	34,000 (47%)
Public Schools within 500 m Whole-Perimeter Buffers (only category I – IV facilities)	9,000 (8%)	47,000 (39%)	56,000 (47%)

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[44] End-of-runway buffers were not able to be generated for category V, VI, or VII airport facilities, therefore the total number of students (K – 12th grade) eligible for free or reduced-price lunches who attend public schools that intersected the 500 m whole-perimeter buffers from only category I – IV airport facilities is shown in the bottom portion of Table 7 in order to enable comparison of the results of the two buffer types across the same set of airports.

The intersection of the Head Start preschool facilities with the 500 m whole perimeter buffers showed that 92 out of the 16,794 Head Start Facilities (including Head Start, Early Head Start, and Migrant and Seasonal Head Start facilities) were located within the 500 m whole-perimeter buffers.[45] The analysis of end-of-runway buffers identified 37 Head Start Facilities (compared to 84 for the whole-perimeter buffers for the same set of airport facilities) within the 500 m end-of-runway buffers.

4.0 Discussion

This section describes data limitations and sources of uncertainty in the demographic analysis method provided for airports in this report. We first describe the portion of the total populations reported in Table 1 that are derived from each of the methods used to create airport layers, I-VII, described above (this information is also summarized in Table A-1). We then discuss the uncertainty in population included as living near a runway in urban versus rural areas and lastly, we describe uncertainty in the precise location of educational facilities.

4.1 Uncertainties in Developing Runway Layers

Geospatial data were available for 4,146 airport facilities, which are typically the busiest airports in the U.S.; method I was used for these facilities. The majority of these facilities are at airports that FAA considers significant to national air transportation and are therefore listed in the FAA National Plan of Integrated Airport System (NPIAS). These airports tend to be located in more densely populated areas of the country compared with the other roughly 15,000 airport facilities in the U.S. The population residing near the 4,146 facilities accounts for 35% of the population residing near any U.S. airport facility (Table A-1), as calculated in this analysis. For methods II, III and IV, the data provided in the 5010 airport data report and 5010 runway data report were assumed to provide an accurate record of the data elements needed to draw the runway line. Uncertainty in the creation of these runway layers is limited to the accuracy of the data provided to FAA for runway length, base and/or reciprocal end coordinates, airport centroid coordinates, and magnetic heading. The approach applied in methods II, III and IV accounts for 44% of the population reported in this analysis. Collectively, the most robust data available for developing runway layers (i.e., methods I through IV) accounted for 79% of the population residing near 13,132 airport facilities (approximately 68% of all U.S. airport facilities).

Facilities for which method V was used are largely seaports where aircraft are landing and taking off from water in a near-shore environment, and we introduced uncertainty in the population counts by assuming that the landing and take-off areas were rectangles oriented with the reported length along the due east-west axis and the reported width along the due north-south axis. If the landing and take-off areas were rotated around the north-south axis or if the length and width were switched, the specific census blocks included in the population count could vary, resulting in either an under- or over-estimate of the population. This method was used for 41

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[45] Enrollment data are not available for the Head Start facilities.

facilities and accounts for 1% of the total population reported in this analysis. While alternative assumptions could be made regarding runway orientation, it is expected that since the population living near these facilities is limited to onshore locations, different runway orientations with the requisite buffer would likely include the relevant census block(s). In addition, given the small number of facilities characterized using this method, we anticipate that the assumptions made do not impart a significant source of uncertainty in the overall results of the population analysis presented in this report. When conducting an analysis of potentially impacted populations near a specific seaport, data could be collected regarding dominantly used landing and take-off patterns.

The method used to create airport layers for category VI facilities creates uncertainty in the population estimates since buffers were drawn relative to the centroid of the airport facility instead of relative to the actual runways. The approach applied using this method accounts for 7% of the population reported in this analysis. As described above, for the method applied to these facilities we generated a 1,000 m radius circular buffer around the facility centroid. On average, the runway length at all of these facilities was 737 m with a minimum runway length of 61 m and a maximum runway length of 3,200 m.[46] Therefore, the method used and the selected 1,000 m distance led to instances when the population included in the demographic count was from an area more distant than 500 m from the runway end and in other cases where the runway length extended beyond the 1,000 m buffer and the relevant population was therefore not included. Of the 856 facilities in this category, 789 (92%) are in areas defined as rural by the U.S. Census Bureau and therefore have low population densities.[47] We expect that the method used to estimate people living near these facilities is a reasonable approach for the purpose of conducting a national estimate of people living near airport facilities.

Beyond the specific methods used to create runway buffer layers, it is worth noting that for category I - IV facilities, runways were treated as lines.[48] In actuality, runways are rectangles with a width element. If the buffers had been drawn relative to the edges of the runway rectangle instead of the centerline, the buffers would have extended farther and in some instances would have intersected additional census blocks. In the March 5, 2013 version of the FAA 5010 runway data report the runways at airports had an average width of 92 feet.[49] Therefore on average, the buffers would have extended an additional 14 m in all directions if they had been drawn relative to the edges of runway polygons as opposed to the runway centerline.

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[46] As noted earlier, some of these facilities had one or more helipad and, in these cases, the “runway” length is the width of the helicopter landing area.

[47] The U.S. Census Bureau defines urban areas as densely settled core areas of census tracts with a density of more than 1,000 persons per square mile (ppsm) as well as census tracts that are contiguous to the core area and that have a population density of at least 500 ppsm; all remaining territory not included within an urban area is classified as rural. (from: “Urban Area Criteria for the 2010 Census” Department of Commerce Bureau of the Census, 76 FR 53030 – 53043 (August 24, 2011)).

[48] As described in section 2.0, buffers for category VI and VII facilities were drawn relative to the facility centroid point, therefore this uncertainty does not apply to those facilities. Buffers for category V facilities were drawn in a manner that incorporated the length and width elements, therefore this uncertainty does not apply to these facilities.

[49] Runways specifically at airports were analyzed by limiting the runway records to only those where the ‘Site Number’ variable ended in an ‘A,’ which is the identifier used by the FAA for airports. Runway records where the Site Number variable, for example, ended in an ‘H’ belonged to heliports and were therefore excluded.

Uncertainty related to the category VII facilities (heliports), is attributable to the relative scale of the buffers used around these facilities (50 m) and the much larger size of census blocks (which vary with population density). As a result, we anticipate that in general, the analysis conducted may overestimate populations that live within 50 m of a helipad. In contrast, the method used to create airport layers for the 202 heliports with more than one helipad is expected to result in an underestimate of the population in this analysis because the selection of a single centroid may exclude relevant helipad locations and nearby populations from this analysis. This underestimate is likely mitigated by the fact that several of these heliports have significant setbacks between helipads and populated areas.

4.2 Uncertainty Associated with the Estimate of Population Living Near a Runway

Uncertainty is associated with the estimate of people living near a runway because census block populations were included in the total population count if any part of a census block intersected the 500 m airport/runway buffer. Census blocks are the smallest geographic unit that contains demographic data such as total population by age, sex, and race.[50] The U.S. Census Bureau describes census block size as follows[51]: "Generally, census blocks are small in area; for example, a block in a city bounded on all sides by streets. Census blocks in suburban and rural areas may be large, irregular, and bounded by a variety of features, such as roads, streams, and transmission lines. In remote areas, census blocks may encompass hundreds of square miles."

Since census block sizes differ greatly from urban to rural areas and airports are found in both urban and rural areas, we evaluated uncertainty in the population classified as living near a runway separately for urban and rural airports. We analyzed a subset of California airports: those categorized in Section 2.0 as method I airports (which provides a representative sample of airports in urban areas) and method IV airports (which represent mostly airports in rural areas). We selected California for this evaluation because this state has the second largest number of airport facilities among states in the US (965 airport facilities). Airports were classified as urban or rural based on US Census Bureau urban-rural classification boundaries.[52] The U.S. Census Bureau defines urban areas as densely settled core areas of census tracts with a density of more than 1,000 persons per square mile (ppsm) as well as census tracts that are contiguous to the core area and that have a population density of at least 500 ppsm; all remaining territory not included within an urban area is classified as rural.[53]

For this analysis we calculated the sum of the area for all census blocks intersecting each of the 500 m buffers around the California method 1 and 4 airport runways. We made the simplifying assumption that the total area of the census blocks intersecting the runway buffer is equidistant from the runway.[54] This simplifying assumption allows us to estimate the

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[50] https://www.census.gov/newsroom/blogs/random-samplings/2011/07/what-are-census-blocks.html.

[51] http://www.census.gov/geo/reference/gtc/gtc_block.html.

[52] "Urban Area Criteria for the 2010 Census" Department of Commerce Bureau of the Census, 76 FR 53030 – 53043 (August 24, 2011).

[53] "Urban Area Criteria for the 2010 Census" Department of Commerce Bureau of the Census, 76 FR 53030 – 53043 (August 24, 2011).

[54] This assumption is more valid in urban areas than in rural areas.

approximate distance that the population included in this analysis could live from a runway. The total area of a 500 m buffer around a 1,000 m runway is 1.79 km^2. If the summed census block area for a typical airport with a 1,000 m runway is 3.57 km^2, and if the area is equidistant from the runway, then people living in these census blocks reside up to 794 m from the runway. For the analysis presented here, actual runway lengths and their associated buffer areas were used.

Among the 103 airports in urban areas (from method 1 in California), the average summed census block area for those census blocks intersecting 500 m runway buffers is 2.9 times larger than the area of the 500 m buffers around the runways at these airports. Making the simplifying assumption that the total area of the census blocks intersecting a runway buffer is distributed equidistant around the runway, this average summed census block area suggests that people in these census blocks live within 1,005 m of the runway. This suggests that in urban areas, the method described in this report captures the relevant population living near airports that may potentially experience an increase in lead concentration from aircraft emissions.

Among the 229 rural runways in California (method IV), the average summed census block area for those census blocks intersecting 500 m runway buffers was 23.3 times larger than the area of the 500 m buffer around these runways. Making the simplifying assumption that the total area of the census blocks intersecting a runway buffer is distributed equidistant around the runway, this average summed census block area suggests that people in these census blocks live within 2,441 m of the runway. This suggests that in rural areas, the method used is including people who live beyond the distance at which direct emissions from aircraft emissions may cause elevated concentrations of lead. Since these rural census blocks are sparsely populated, we expect that the misclassification of people imparts a small bias in the analysis. For example, in California, the airport runway that intersected census blocks with the largest summed area contributed 19 people to the analysis results (compared to an average of 1,372 to 1,675 people per runway in the urban airports in methods I and IV, respectively).[55] While there are a large number of rural airports at which the method described in this report might include people who live distant from an airport, comparisons with an alternative approach described below (i.e., dasymeteric data), indicate the approach used here appropriately estimates the number of people who live in rural areas near a runway.

Methods exist to estimate the number of people residing only in the portion of a census block intersecting a runway buffer. For example, one could assume that population density is constant throughout each census block and include only the fraction of a census block population equal to the fraction of the area of the census block that intersected the buffer. An alternative approach for estimating the population near an airport is to include the population of a census block only if the centroid of the block falls within the 500 m buffer. We elected not to use these methods, in part due to the computational burden, but also in recognition that there are multiple approaches to achieve the results desired for the purpose of conducting a national estimate of the population residing near airports.

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[55] This analysis was based only on California airports in Method IV. At this particular airport the census blocks that intersected the runway buffer had a total area 758 times larger than the airport's runway buffer; the census blocks had an average density of 0.014 people per km^2.

A second approach for this assessment was evaluated as a sensitivity analysis; this approach involved the use of more spatially refined population data developed by EPA's Office of Research and Development (ORD). EPA's ORD has applied the dasymetric geospatial population mapping technique to 2010 U.S. census block level data by distributing census block population to 30 m square areas based on land cover, slope, and ownership data.[56] These data were created for use in EPA's EnviroAtlas[57] which has been externally peer reviewed. In order to further understand the potential uncertainty in population counts using the method described in this report, we conducted a sensitivity analysis using dasymetric data for method I airports (described in Section 2.0) for California. We analyzed the population near airports in urban areas separately from those in rural areas and compared the results to the population counts using the method described in this report.

Using the dasymetric data, we summed the population in California for method I urban airports using a runway buffer area of approximately 700 m. This summed population of 193,000 people compares closely with the 194,000 people residing in census blocks intersecting the 500 m buffer for method 1 urban airports. However, the two methods differ somewhat in the residences that are counted as being near a runway beyond the 500 m buffer; the analysis using the dasymetric data estimated the population in discreet 30 meter buffer zones from a runway, while the method described in this report includes residences throughout irregularly shaped census blocks, some of which may occupy area that is more than 1,000 m from a runway. One advantage of using the census block data for the purposes of this analysis is the availability of demographic characteristics by census block. The dasymetric data do not include age or racial characteristics of the population.

Using the dasymetric data, the summed population in a runway buffer area of approximately 950 m provided a population estimate equivalent to that from our method for rural Method I California runways (45,484 people using dasymetric and 45,851 people using our method). Given the analysis described above, at rural runways in California method I the total census block areas were on average 16 times larger than the 500 m buffer area, which suggests that the population in rural areas with a runway tend to live in the portions of census blocks that are in closer proximity to the runway. This sensitivity analysis suggests the method described in this paper provides a reasonable approach for estimating the rural population living near runways.

4.3 Uncertainty Associated with Census Data and School Point Data

In addition to uncertainty in the methods used in this report, there is uncertainty associated with the input datasets. The US Census Bureau recognizes uncertainties inherent to US Census Data reported and US Census Bureau researchers explore approaches to improve accuracy and reduce uncertainty. Sources of error in the census total count and demographics and include omissions, duplications, erroneous enumerations, and errors of geography and demographic

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[56] The method incorporated the National Land Cover Dataset (NLCD) with the assumption that individuals will not live in areas that are classified as open water, ice/snow, or wetlands. Additionally, public lands and areas with slopes greater than 25% were also considered uninhabitable. Other vegetated and developed areas were considered habitable and were assigned population density probabilities based on land cover class. (from: https://www.epa.gov/enviroatlas/dasymetric-toolbox).

[57] http://enviroatlas.epa.gov/enviroatlas/.

characteristics. The Census Bureau employs approaches to measure error including dual-systems estimation and demographic analysis.[58] These uncertainties are not expected to have a significant impact on the results presented in this report.

Since children are a highly susceptible population to the uptake and impacts of lead, we included an evaluation of the proximity of schools and preschools to airport runways. U.S. public and private K-12th grade school data and Head Start preschool data were only available as point data (i.e., represented by a single latitude/longitude pair), which was intersected with the airport buffer layers. However, many school campuses have multiple sports fields and/or playground areas and can cover large areas of land. The results of the intersection analysis, therefore, are subject to uncertainty since inclusion of a K-12th grade school or Head Start preschool is dependent on where the school coordinates fall within the school's actual campus.

In addition, the Head Start preschool data represent only a subset of early education and care programs that serve children and infants. There are additionally the center-based, school-based and in-home preschool facilities for which there is no national database available for this analysis. The absence of information regarding proximity of these facilities to aircraft lead emissions may significantly underestimate this potentially exposed, susceptible population.

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[58] National Academy of Science, Engineering and Medicine (2007) Research and plans for coverage measurement in the 2010 Census. National Academy Press, available at: www.nap.edu/download/11941.

APPENDIX

Table A-1: Airport and Population Data by Method of Analysis

	Number of Runways	Number of Facilities	Description of Available Data and Method of Airport Facility Layer Generation	Description of Buffer Layer Generation	Population[59]
Method I	6,090	4,146	FAA GIS data.	500 m buffer around runway line	1,809,131 (35%)
Method II	414	385	FAA 5010 runway report had latitude/longitude coordinates for both the runway base and reciprocal ends.	500 m buffer around runway line	98,113 (2%)
Method III	4	4	FAA 5010 runway report had latitude/longitude coordinates for either the runway base or reciprocal end. Runway length, the available runway end coordinates, and the magnetic heading of the runway were used to calculate the latitude/longitude coordinates of the opposite runway end.	500 m buffer around runway line	624 (0.01%)
Method IV	8,597	8,597	FAA 5010 runway report did not have latitude/longitude coordinates for either the runway base or reciprocal end. These are facilities with only one runway so runway length, facility centroid coordinates, and the magnetic heading of the runway were used to calculate the latitude/longitude	500 m buffer around runway line	2,195,125 (42%)

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[59] Numbers in this column do not sum to the analysis total of 5,179,455 people from Table 1 since the population from a census block that intersects more than one airport buffer is only included once in the Table 1 result but here, the population from a census block that intersects more than one airport buffer is included in the total for each method type in the column 'Population' to which it applies.

			coordinates of both runway ends.		
Method V	41	41	FAA 5010 runway data report identified the runway ID as “ALL/WAY.” Centroid coordinate along with the runway width and length were used to calculate the four coordinate pairs of the rectangle representing this runway area.	500 m buffer around runway rectangle polygon	65,124 (1%)
Method VI	1,881	856	These facilities are multi-runway facilities with no runway specific coordinates. The facility centroid coordinates were used to create this layer.	1000 m buffer around facility centroid	361,577 (7%)
Method VII	5,978	5,589	These facilities are heliports. The heliport centroid coordinates were used to create this layer.	50 m buffer around facility centroid	740,486 (14%)

Table A-2: Conversion from Runway Designation Markings to θ (degrees)

Runway Designation Marking	**θ (in degrees)**
01	260
02	250
03	240
04	230
05	220
06	210
07	200
08	190
09	180
10	170
11	160
12	150
13	140
14	130
15	120
16	110
17	100
18	90
19	80
20	70
21	60
22	50

23	40
24	30
25	20
26	10
27	0
28	350
29	340
30	330
31	320
32	310
33	300
34	290
35	280
36	270
NW	135
SE	315
NE	45
SW	225
N	90
S	270
E	180
W	0

Program Update

Appendix C

Airport Lead Monitoring

This Program Update provides a summary of the data currently available on concentrations of lead measured at 17 airport facilities in the U.S.

Concentrations of Lead at Airports

Outdoor concentrations of lead have greatly declined over the past few decades, in large part due to regulations that removed lead from fuels used in cars and trucks. However, lead continues to be emitted into the air from certain sources, such as ore and metal processing and aircraft that use leaded aviation gasoline (avgas). These aircraft are typically used for activities including business and personal travel, instructional flying, aerial surveys, agriculture, firefighting, law enforcement, medical emergencies, and express freight. Lead is not contained in jet fuel, which is used by commercial aircraft.

To protect the public from harmful levels of lead in outside air, EPA has established a National Ambient Air Quality Standard (NAAQS) for lead. In late 2008, EPA substantially strengthened this standard, revising the level from 1.5 micrograms per cubic meter (µg/m^3), to 0.15 µg/m^3, for a 3-month average concentration of lead in total suspended particles. This revised standard improves health protection for at-risk groups, especially children.

In conjunction with strengthening the lead NAAQS, EPA improved the existing lead monitoring network by requiring monitors to be placed in areas with sources such as industrial facilities and airports. State and local air quality agencies are now required to monitor near industrial facilities with estimated lead emissions of 0.50 tons or more per year and at airports with estimated emissions of 1.0 ton or more per year, as well as, on a case-by-case basis in locations where information indicates a significant likelihood of exceeding the standard. EPA required a 1-year monitoring study of 15 airports with estimated lead emissions between 0.50 and 1.0 ton per year in an effort to better understand how these emissions affect the air at and near airports. Airports for this 1-year monitoring study were selected based on factors such as the level of piston-engine aircraft activity and the predominant use of one runway due to wind patterns, in order to help evaluate airport characteristics that could lead to ambient lead concentrations that approach or exceed the lead NAAQS.

EPA United States Environmental Protection Agency

Office of Transportation and Air Quality
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As a result of these requirements, lead monitoring has been conducted at 17 airports. As of May 2013, states and local air authorities have collected and certified lead concentration data for at least 3 months from the 17 airports. The certified data are available in the table below. EPA anticipates having a full year of certified data from all 17 airports by May 2014, at which time the airport study will be complete.

Concentrations of Lead at Airports

Airport, State	Lead Design Value,* µg/m^3
Auburn Municipal Airport, WA	0.06
Brookhaven Airport, NY	0.03
Centennial Airport, CO	0.02
Deer Valley Airport, AZ	0.04
Gillespie Field, CA	0.07
Harvey Field, WA	0.02
McClellan-Palomar Airport, CA	0.17
Merrill Field, AK	0.07
Nantucket Memorial Airport, MA	0.01
Oakland County International Airport, MI	0.02
Palo Alto Airport, CA	0.12
Pryor Field Regional Airport, AL	0.01
Reid-Hillview Airport, CA	0.09
Republic Airport, NY	0.01
San Carlos Airport, CA	0.33
Stinson Municipal, TX	0.03
Van Nuys Airport, CA	0.06

*The design value for lead is the maximum value of three-month average concentrations measured at that location.

Two airports have monitored lead concentrations that exceed the lead NAAQS. Fact sheets specific to these airports have been developed and are available at the EPA Region 9 webpage provided below. Supplemental sampling is being conducted at these two airports to evaluate lead concentrations at additional locations at and near the airport. Information from other airports that have previously been studied in greater detail indicates that air lead concentrations decrease within short distances from aircraft emissions.

EPA's Actions Regarding Lead Emissions from Aircraft Operating on Leaded Fuel

EPA is currently conducting the analytical work, including modeling and monitoring, to evaluate under section 231 of the Clean Air Act whether lead emissions from the use of leaded avgas in piston-engine aircraft cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare. Any proposed determination with regard to endangerment would be subject to public notice and comment, and we estimate the final determination will be in mid-to-late 2015. Additional details regarding EPA's evaluation are available in the Advance Notice of Proposed Rulemaking on Lead Emissions From Piston-Engine Aircraft Using Leaded Aviation Gasoline, and the associated public docket (links provided below).

If EPA makes a final positive endangerment finding (i.e., EPA finds that lead emissions from general aviation cause or contribute to air pollution which may reasonably be anticipated to endanger), the agency would initiate rulemaking to establish standards concerning lead emissions from piston-engine aircraft. FAA would then be required to prescribe regulations to ensure compliance with such standards, and prescribe standards for the composition of aircraft fuel to control or eliminate certain emissions.

For Additional Information

For more information regarding monitoring at the San Carlos Airport and San Diego airports (McClellan-Palomar and Gillespie Field), please visit:

www.epa.gov/region9/air/airport-lead/

For more information on EPA's actions regarding the endangerment evaluation, please visit:

www.gpo.gov/fdsys/pkg/FR-2010-04-28/pdf/2010-9603.pdf and
www.epa.gov/otaq/aviation.htm

For access to the rulemaking docket containing documents relevant to EPA's evaluation, please visit:

www.regulations.gov and enter EPA-HQ-OAR-2007-0294

For information on the Federal Aviation Administration's actions to eliminate leaded aviation fuels, please visit:

www.faa.gov/news/

For information on the Federal Aviation Administration’s actions to reduce lead concentrations at airports, please visit:

www.faa.gov/airports/environmental/

For more information on how you can reduce your family’s risk of lead exposure, please visit:

www.epa.gov/lead/parents.html#

For more information on lead in air, please visit:

www.epa.gov/airquality/lead/

Contact

Marion Hoyer
U.S. Environmental Protection Agency
Office of Transportation and Air Quality
2000 Traverwood Drive
Ann Arbor, MI 48105
734-214-4513,
E-mail: hoyer.marion@epa.gov

Or:

Meredith Pedde
U.S. Environmental Protection Agency
Office of Transportation and Air Quality
2000 Traverwood Drive
Ann Arbor, MI 48105
734-214-4748
E-mail: pedde.meredith@epa.gov

Appendix D

Airport Lead Monitoring

Program Overview

This Program Summary provides a full year of lead concentration data measured at 17 U.S. airport facilities through December 2013.

Concentrations of Lead at Airports

Outdoor concentrations of lead have greatly declined over the past few decades, in large part due to regulations that removed lead from fuels used in cars and trucks. However, lead continues to be emitted into the air from certain sources, such as ore and metal processing and aircraft that use leaded aviation gasoline (avgas). These aircraft are typically used for activities including business and personal travel, instructional flying, aerial surveys, agriculture, firefighting, law enforcement, medical emergencies, and express freight. Lead is not contained in jet fuel, which is used by commercial aircraft.

To protect the public from harmful levels of lead in outside air, the U.S. Environmental Protection Agency (EPA) has established a National Ambient Air Quality Standard (NAAQS) for lead. In late 2008, the EPA substantially strengthened this standard, revising the level from 1.5 micrograms per cubic meter ($\mu g/m^3$), to 0.15 $\mu g/m^3$, for a 3-month average concentration of lead in total suspended particles. This revised standard improves health protection for at-risk groups, especially children.

In conjunction with strengthening the lead NAAQS, in 2010 the EPA improved the existing lead monitoring network by requiring monitors to be placed in areas with sources such as industrial facilities and airports. State and local air quality agencies are now required to monitor near industrial facilities with estimated lead emissions of 0.50 tons or more per year and at airports with estimated emissions of 1.0 ton or more per year, as well as, on a case-by-case basis, in locations where information indicates a significant likelihood of exceeding the standard. The EPA required a 1-year monitoring study of 15 airports with estimated lead emissions between 0.50 and 1.0 ton per year in an effort to better understand how these emissions affect the air at and near airports. Airports for this 1-year monitoring study were selected based on factors such as the level of piston-engine aircraft activity and the predominant use of one runway due to wind patterns, in order to help evaluate airport characteristics that could lead to ambient lead concentrations that approach or exceed the lead NAAQS.

United States Environmental Protection Agency

Office of Transportation and Air Quality
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January 2015

As a result of these requirements and those finalized in 2008, lead monitoring has been conducted at 17 airports, and states and local air authorities have collected and certified lead concentration data for at least one year at the 17 airports. The certified data are summarized in the table below. For all but one airport (the Reid-Hillview airport) the design value is unchanged from the EPA's 2013 Program Update on Airport Lead Monitoring, either because no more data were collected or because higher concentrations were not measured. As a result of the concentrations measured, four airports will continue monitoring for lead. Additional information is available at the EPA Region 9 webpage provided below.

Concentrations of Lead at Airports

Airport, State	Lead Design Value,* μg/m^3
Auburn Municipal Airport, WA	0.06
Brookhaven Airport, NY	0.03
Centennial Airport, CO	0.02
Deer Valley Airport, AZ	0.04
Gillespie Field, CA	0.07
Harvey Field, WA	0.02
McClellan-Palomar Airport, CA	0.17
Merrill Field, AK	0.07
Nantucket Memorial Airport, MA	0.01
Oakland County International Airport, MI	0.02
Palo Alto Airport, CA	0.12
Pryor Field Regional Airport, AL	0.01
Reid-Hillview Airport, CA	0.10
Republic Airport, NY	0.01
San Carlos Airport, CA	0.33
Stinson Municipal, TX	0.03
Van Nuys Airport, CA	0.06

* Maximum three-month average concentration in the monitoring dataset

The EPA's Actions Regarding Lead Emissions from Aircraft Operating on Leaded Fuel

The EPA is currently conducting the analytical work, including modeling and monitoring, to evaluate under section 231 of the Clean Air Act whether lead emissions from the use of leaded avgas in piston-engine aircraft cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare. Any proposed determination with regard to endangerment would be subject to public notice and comment. Additional details regarding the timing and next steps of the EPA's evaluation are available at: www.epa.gov/otaq/aviation.htm.

If the EPA makes a final positive endangerment finding (i.e., the EPA finds that lead emissions from general aviation cause or contribute to air pollution which may reasonably be anticipated to endanger), the agency would initiate rulemaking to establish standards concerning lead emissions from piston-engine aircraft. The FAA would then be required to prescribe regulations to ensure compliance with such standards, and prescribe standards for the composition of aircraft fuel to control or eliminate certain emissions.

For Additional Information

For more information regarding monitoring at the San Carlos Airport and San Diego airports (McClellan-Palomar and Gillespie Field), please visit:
www.epa.gov/region9/air/airport-lead/

For more information on the EPA's actions regarding the endangerment evaluation, please visit:
www.gpo.gov/fdsys/pkg/FR-2010-04-28/pdf/2010-9603.pdf
and www.epa.gov/otaq/aviation.htm

For access to the rulemaking docket containing documents relevant to the EPA's evaluation, please visit:
www.regulations.gov and enter EPA-HQ-OAR-2007-0294

For information on the FAA's actions to eliminate leaded aviation fuels, please visit:
www.faa.gov/about/initiatives/avgas/
and www.faa.gov/news/

For information on the FAA's actions to reduce lead concentrations at airports, please visit:
www.faa.gov/airports/environmental/

For more information on how you can reduce your family's risk of lead exposure, please visit:
www.epa.gov/lead/parents.html#

For more information on lead in air, please visit:
www.epa.gov/airquality/lead/

Contact

Marion Hoyer
U.S. Environmental Protection Agency
Office of Transportation and Air Quality
2000 Traverwood Drive
Ann Arbor, MI 48105
734-214-4513 E-mail:
hoyer.marion@epa.gov

Or:
Meredith Pedde
U.S. Environmental Protection Agency
Office of Transportation and Air Quality
2000 Traverwood Drive
Ann Arbor, MI 48105
734-214-4748
E-mail: pedde.meredith@epa.gov