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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP RESEARCH REPORT 162

Guidebook for Assessing Airport Lead Impacts

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AIRPORT COOPERATIVE RESEARCH PROGRAM

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

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

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

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

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

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

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COOPERATIVE RESEARCH PROGRAMS

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FOREWORD

By Marci A. Greenberger
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ACRP Research Report 162: Guidebook for Assessing Airport Lead Impacts discusses two strategies that airport operators can potentially implement to minimize the impacts of lead emissions from piston-engine aircraft. These strategies are (1) making available unleaded ethanol-free motor gasoline (MOGAS) for use by aircraft that are compatible with that fuel, and (2) relocating run-up areas. The guidebook begins by educating the user on the history of lead in AVGAS (aviation gasoline), known health impacts, and EPA regulations. The strategies examine how the impact from lead emissions may be minimized, with a chapter on other factors that should be considered. A *Frequently Asked Questions* document about aviation and lead is included in Appendix A and is also available on the TRB website. The *Contractor's Final Report*, which details the research, is also available on the TRB website at www.trb.org/acrp.

Leaded fuel has been banned in almost all transportation applications except for aviation gasoline (AVGAS). For over two decades, there have been efforts to find a replacement for leaded AVGAS and progress continues. It is expected that any replacement fuel will require infrastructure (fueling) and face other airport challenges before it can be fully implemented. Until such time that there is a replacement for leaded AVGAS, airports may be able to implement practices to reduce baseline lead emissions and/or exposure in order to mitigate lead impacts.

Sierra Research, as part of ACRP Project 02-57, built on their previous research that resulted in *ACRP Report 133: Best Practices Guidebook for Preparing Lead Emission Inventories from Piston-Powered Aircraft with the Emission Inventory Analysis Tool*. Their research effort conducted air quality modeling at three airports and was used to identify the potential effectiveness of the two strategies. This information can be used to help airport operators and managers understand lead impacts at their facilities and in determining if one or both of the two strategies outlined in this guidebook can be safely implemented at their airport.

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CHAPTER 1

Background

1.1 Health Impacts from Lead Exposure

Exposure to lead (also known by its chemical symbol Pb) can lead to a variety of adverse health impacts, including neurological effects in children that lead to behavioral problems, learning deficits, and lowered IQ (U.S. EPA 2011). Lead accumulates in the body in blood, bone, and soft tissue because it is not readily excreted. As a result, lead affects the kidneys, liver, nervous system, and blood-forming organs; the EPA also considers lead to be a probable human carcinogen.

Human exposure to lead occurs primarily through inhalation and ingestion, with the health effects being same regardless of the route of exposure. People can be exposed to aircraft lead emissions from both the inhalation pathway and from ingestion of aircraft lead that deposits to surfaces and is inadvertently transferred by hand-mouth activity.

The concentration of lead in blood (PbB) is the metric generally used to define exposure to lead. Research has shown that PbB is significantly associated with mean ambient lead concentrations (Bierkens et al. 2011, Brunekreef 1984). Historical studies have shown that the use of leaded gasoline accounted for more than 50 percent of PbB in children and that the concentration of lead in gasoline was directly proportional to PbB (Hayes et al. 1994, Schwartz and Pitcher 1989). The Centers for Disease Control and the World Health Organization have identified PbB concentrations of 10 micrograms per deciliter or higher as a “level of concern” to human health (Centers for Disease Control 1991, World Health Organization 1995). CDC has also introduced a new reference level, which is set at 5 micrograms per deciliter (Centers for Disease Control 2012).

1.2 Addition of Lead to Gasoline

The use of lead, primarily in the form of tetraethyl lead (TEL), as a gasoline additive began in the 1920s. TEL increases the octane rating of gasoline (Midgley and Boyd 1922). The availability of higher octane gasoline allows for the design of high compression ratio engines which provide greater power and fuel efficiency compared to engines with lower compression ratios. Use of TEL as a gasoline additive was transformative to the transportation engine and fuel industries during the twentieth century (Additive Technical Committee 2013). Using a gasoline with a lower octane rating than the engine was designed to use causes improper combustion—commonly known as “knock”—which can result in engine damage or failure.

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CHAPTER 2

Regulation of Airborne Lead in the United States

2.1 U.S. Standards for Airborne Lead Concentrations

Concerns regarding adverse health effects associated with exposure to airborne lead resulted in lead being classified as an air pollutant pursuant to the Clean Air Act in 1976, followed by the requisite enactment of a health-based National Ambient Air Quality Standard (NAAQS) for lead by the EPA in 1978, which was set at 1.5 micrograms per cubic meter based on a measured quarterly-average concentration.

In October 2008, the EPA promulgated a revised lead NAAQS that lowered the acceptable level by an order of magnitude, to 0.15 micrograms per cubic meter based on a rolling 3-month average concentration. In December 2014, the EPA issued a proposed rulemaking in which it reaffirmed its position that the existing lead NAAQS of 0.15 micrograms per cubic meter is set appropriately to protect public health (U.S. EPA 2015b).

2.2 Elimination of Lead from Gasoline Used in Cars and Trucks

Concerns regarding ambient lead concentrations and the adoption of vehicle emission standards necessitating the use of catalytic converters, which are poisoned by lead, resulted in the EPA's promulgation of regulations requiring the phase-out of lead from gasoline used in on-road vehicles (which is known as motor gasoline or "MOGAS") beginning in the mid-1970s. These regulations required major gasoline retailers to begin selling at least one grade of unleaded MOGAS by July 1, 1974 (U.S. EPA 2000b).

Vehicle engines required redesign to accommodate the elimination of lead from gasoline, and special gasoline nozzle and vehicle fill-pipe designs were needed to prevent the introduction of lead-containing gasoline into vehicles designed for use with unleaded fuel.

By 1988, the amount of lead consumed in MOGAS in the United States was reduced by 99 percent (U.S. EPA 2000a). Leaded MOGAS was completely phased out by 1990 in Canada and by 1996 in the United States. Although leaded gasoline continued to be used in racing applications in the United States, strictly speaking those are not on-road motor vehicles. As a result, in highly populated areas such as California, ambient lead levels dropped rapidly in the late 1970s and early 1980s as lead began to be eliminated from gasoline, as shown in Figure 1.

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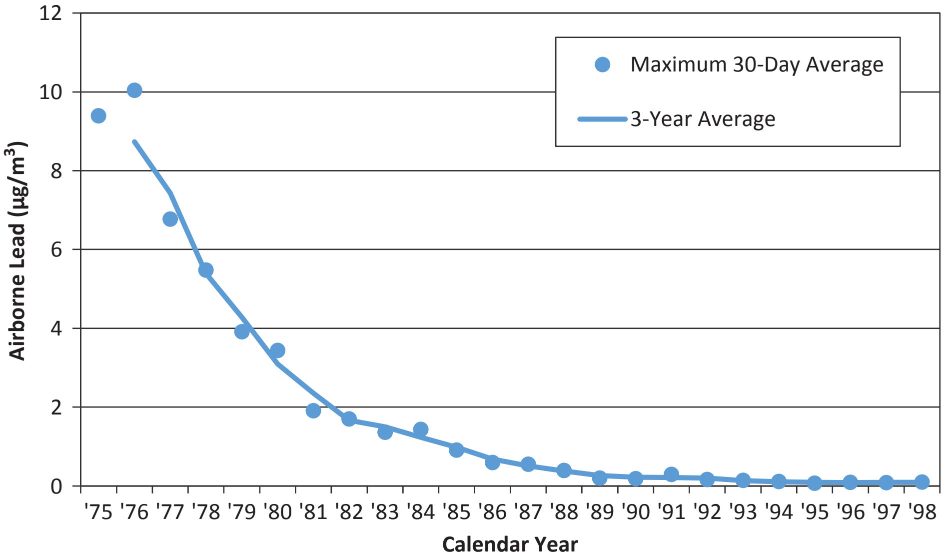

Source: Sierra Research, Inc., *CVS News*, October 1993.

Figure 1. Maximum 30-day average lead levels in California (1973–1998).

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CHAPTER 3

Use of Lead in Aviation Gasoline

Key design considerations for piston engines used in aircraft include maximizing the work performed per volume of fuel consumed and optimizing the power-to-weight ratio of the engine—both of which are aided by higher compression ratio engines, which in turn necessitate the use of high octane gasoline. As a result, aviation gasolines (AVGAS) have long contained lead in the form of TEL, which is added to boost octane rating, and most piston-engine aircraft have and continue to use AVGAS. However, some piston-engine aircraft can use unleaded MOGAS, provided that the fuel does not contain ethanol or diesel/jet fuel.

Despite the continued use of leaded AVGAS, lead emissions related to AVGAS use have declined over time for two reasons: the first is the introduction of 100 octane “low-lead” (100LL) fuel, which halved the maximum allowable lead content from 4.22 to 2.11 grams of lead per gallon; the second is the decline in AVGAS consumption over time. That decline is depicted in Figure 2, which shows the trend in domestic AVGAS consumption product supplied (i.e., consumption) reported by the U.S. Energy Information Administration (EIA) (U.S. Energy Information Administration 2015). While these data show a 61 percent reduction in AVGAS consumption since 1981, EIA forecasts AVGAS consumption will remain at approximately 4.4 million barrels per year for the foreseeable future.

Research focused on the development of unleaded AVGAS has been underway for years. Currently, the FAA is continuing with an evaluation program to identify a suitable lead-free replacement for 100LL that addresses both gasoline quality and flight safety needs (Esler 2015, Federal Aviation Administration 2016b). Multiple phases of aircraft testing have been proposed, and a 2018 timeframe for publishing ASTM specifications for the unleaded replacement gasoline is estimated. However, it should be noted that the adoption of unleaded AVGAS specifications does not ensure that the fuel will be available in a timely manner or at a price that is competitive with leaded fuel. Although there are specifications for a 100 octane “very low lead” (VLL) AVGAS that lowers the allowable lead content by about 20% relative to 100LL, it appears that 100LL will be the dominant AVGAS until an unleaded AVGAS becomes commercially available.

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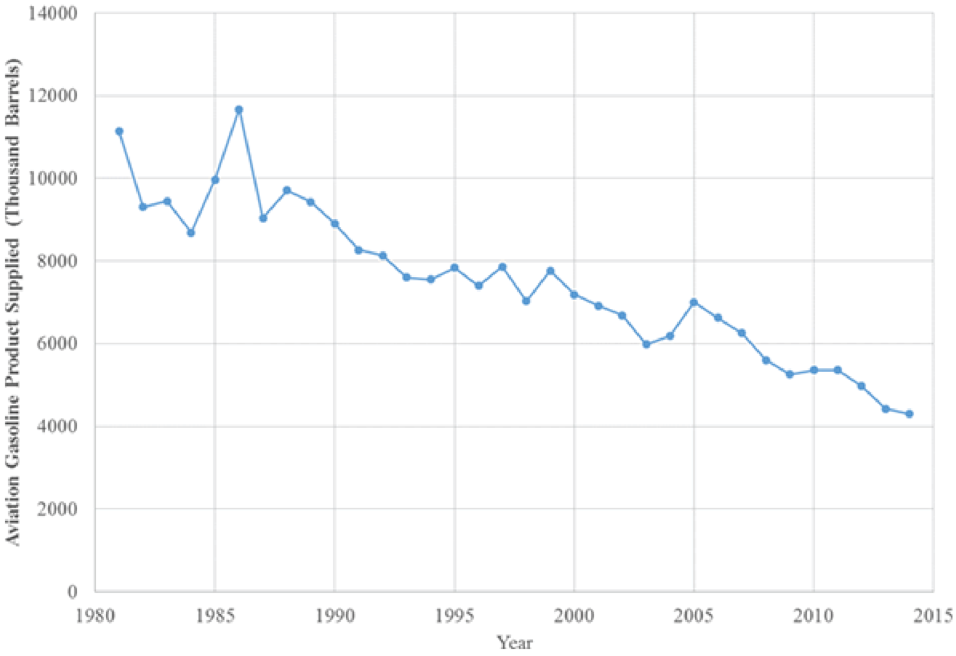

Source: U.S. Energy Information Administration 2015.

Figure 2. U.S. aviation gasoline consumption.

CHAPTER 4

Current Sources of Airborne Lead in the United States

With the elimination of lead from MOGAS, the relative contribution to total lead emissions from the remaining lead sources changed dramatically. The contribution of lead emissions from general aviation aircraft operating at airports where leaded AVGAS remains in use to total lead emissions in the United States can be evaluated through data available from the EPA's National Emission Inventory (NEI) program. The NEI is a comprehensive and detailed estimate of air emissions of criteria pollutants, criteria pollutant precursors, and hazardous air pollutants. It is released by the EPA every 3 years based primarily upon data provided by state, local, and Tribal air agencies for sources in their jurisdictions and supplemented by data developed by the EPA. Table 1 summarizes the lead emission inventory results by emissions based on the most recent NEI data available (calendar year 2011). Emissions from general aviation aircraft operating at airports are currently estimated to be the largest source of lead emissions in the United States.

Changes in the relative contribution of general aviation aircraft operations operating at airports to U.S. lead emissions over time are presented in Table 2. Aircraft emissions increased from less than 1% of U.S. lead emissions in 1970 to 60% in 2011. This trend, combined with the revised assessment of the health impacts of lead that resulted in the 2008 revision of the NAAQS, has increased concerns related to aircraft lead emissions.

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Table 1. Total U.S. lead inventory for 2011 (tons/year).

Sector	Lead Emissions
Aircraft	486.08
Industrial Processes	224.87
Electric Generation	39.68
Industrial Boilers	32.99
Waste Disposal	10.71
Commercial/Institutional Fuel Combustion	6.39
Solvent Use	3.32
Residential Fuel Combustion	3.11
Locomotives	2.23
Commercial Marine Vessels	1.65
Bulk Gasoline Terminals	0.83
Miscellaneous Industrial (NEC)	0.71
Agricultural Field Burning	0.45
Gas Stations	0.37
Non-Road Diesel Equipment	0.01
Total	813.40
Aircraft Share	***60%***

Source: U.S. EPA National Emission Inventory Program. www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data

Table 2. Airport lead contribution to total U.S. lead inventory (tons/year).

Sector	1970	1975	1980	1985	1990	1996	1998	2008	2011
Aircraft	0.6%	0.7%	1.2%	3.0%	12.4%	13.0%	12.7%	60%	60%

Source: U.S. EPA 2015a. http://www.epa.gov/otaq/documents/aviation/420f15003.pdf

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CHAPTER 5

Assessing Lead Impacts in the Vicinity of Airports

In December 2010, the EPA established requirements for ambient lead monitoring around facilities known to have substantial lead emissions. These facilities included airports with sufficient piston-powered aircraft activity leading to estimated annual lead emissions of 1.0 ton or more, and industrial facilities with estimated annual lead emissions of 0.5 ton or more. Moreover, the EPA also completed a 1-year monitoring study of 14 additional airports with estimated annual lead emissions between 0.5 and 1.0 ton to investigate whether general aviation aircraft may have the potential to cause violations of the lead NAAQS.

Table 3 summarizes the results of the EPA airport monitoring, which was conducted at 17 airport facilities through December 2013 (U.S. EPA 2015a). The results shown are "design values" for maximum 3-month average concentrations which can be compared directly to the lead NAAQS of 0.15 microgram per cubic meter of air. There are considerable variations in the monitored ambient lead concentrations from airport to airport. However, maximum 3-month average concentrations for two California sites—McClellan-Palomar Airport south of Carlsbad and the San Carlos Airport south of San Francisco—exceed the current NAAQS level. The maximum 3-month average at a third site—Palo Alto Airport, also south of San Francisco—approached the level of the NAAQS.

These results suggest that lead emissions at general aviation airports could lead to violations of the lead NAAQS, and strategies for reducing aircraft lead emissions may need to be considered. However, to assess the need for control strategies at any particular airport, as well as to effectively develop and implement them if needed, it is vital to have a detailed understanding of the sources of lead emissions from airport activities and their impacts on ambient lead concentrations.

Based on previous research, including ACRP Project 02-34, "Quantifying Aircraft Lead Emissions at Airports," the primary sources of lead emissions associated with piston-engine aircraft operating at general aviation airports are as follows:

- Idling and taxiing before and after takeoff and landing;
- Run-up; and
- Takeoff and climb-out.

The amount of lead emitted by a given aircraft during each of these activities is determined by the fuel it consumed during each activity and the lead content of that fuel. The amount of lead emitted at an airport over any period of time depends on the number of aircraft in operation and their individual lead emissions. Ambient concentrations of lead at and around the airport depend on the temporal and spatial distributions of the lead emissions from aircraft operation as well as meteorological conditions.

A methodology to quantify lead emissions associated with aircraft operations and to assess airborne lead concentrations at and around airports through air quality modeling was developed

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Table 3. Concentration of lead at airports in 2013 (microgram per cubic meter).

Airport, State	Maximum 3-Month Average
San Carlos, CA	0.33
McClellan Pallomar, CA	0.17
Palo Alto, CA	0.12
Reid-Hillview, CA	0.10
Gillespie Field, CA	0.07
Merrill Field, AK	0.07
Auburn Municipal, WA	0.06
Van Nuys, CA	0.06
Deervalley, AZ	0.04
Brookhaven, NY	0.03
Stinson Municipal, TX	0.03
Centennial, CO	0.02
Harvey Field, WA	0.02
Oakland County International, MI	0.02
Nantucket Memorial, MA	0.01
Pryor Field Regional, AL	0.01
Republic, NY	0.01

Source: U.S. EPA 2015a /www.epa.gov/otaq/documents/aviation/420f15003.pdf
Note: Maximum 3-month average concentration in the monitoring dataset through December 2013.

as part of ACRP Project 02-34, "Quantifying Aircraft Lead Emissions at Airports." That project led to the release of an emissions inventory development tool for airports as well as a related guidance document. Furthermore, the technical report for that project, *ACRP Web-Only Document 21: Quantifying Aircraft Lead Emissions at Airports*, documented how the inventory tool could be used in combination with aircraft operations data and air quality models to develop detailed estimates of airborne lead concentrations at and around an airport, as well as the contribution of specific operating modes to those estimated concentrations.

As part of ACRP Project 02-57 that produced this guidebook, the prior study's methodology was applied to three general aviation airports. Application of the methodology required use of detailed data at each airport, including spatial and temporal aircraft activity patterns, number and types of operating aircraft, and AVGAS lead content. These data were used to create a detailed spatially and temporally resolved emissions inventory for each airport that was used as input data into an air quality model to estimate ambient lead concentrations.

Results for a general aviation airport, denoted here as airport "A," are shown in Figure 3a; Figures 3b, 3c, and 3d show the relative contributions associated with taxiway; engine test run-up (i.e., run-up); and takeoff/landing operations, respectively. Although quantitative data are generated through application of the ACRP Project 02-34, "Quantifying Aircraft Lead Emissions at Airports" methodology, the results shown in Figure 3 are qualitative and presented only for purposes of illustrating their value towards assessing airport lead impacts.

Figure 3 illustrates a number of important points related to the assessment of airport lead impacts. First, Figure 3a shows the estimated lead concentration levels both at the airport as well as in adjacent areas outside the airport footprint. This information is critical in evaluating the magnitude of impacts from piston-engine aircraft using leaded fuel, and peak estimated levels can be compared to the lead NAAQS. Second, because of the way the emissions inventory is constructed, it is possible to evaluate the contributions from different types of aircraft operations

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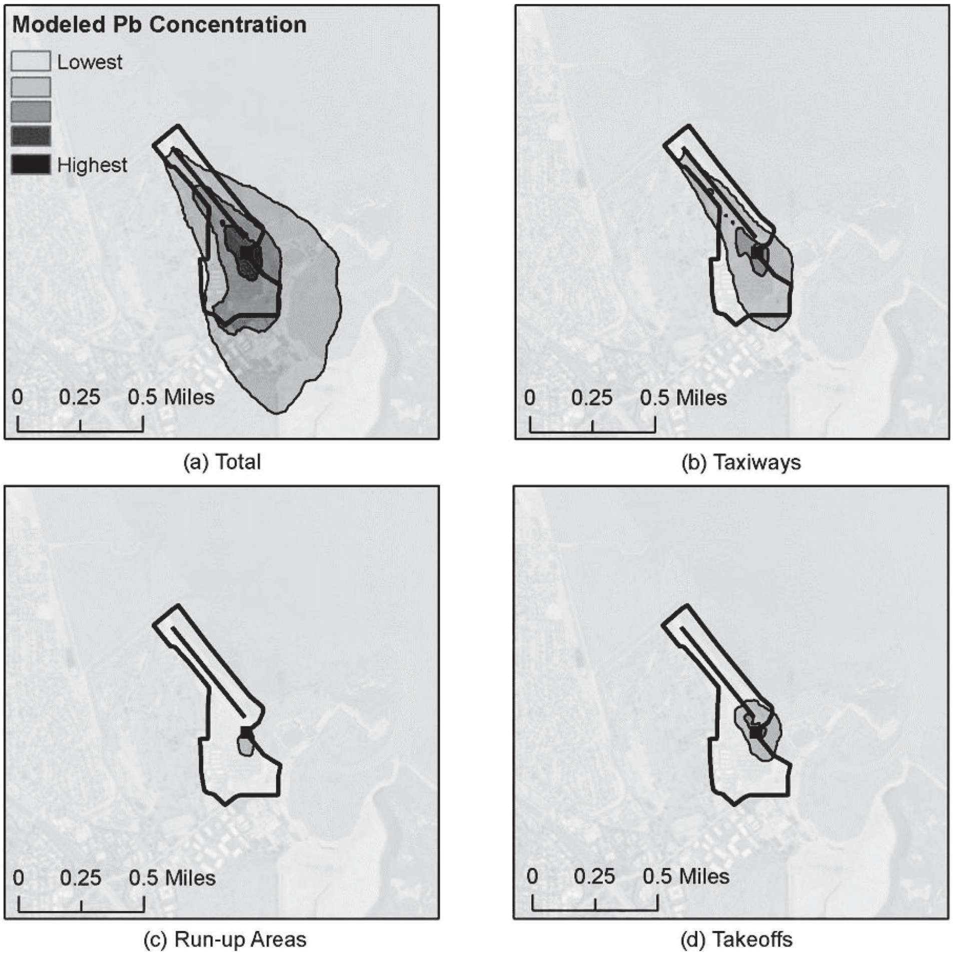

(a) Total (b) Taxiways (c) Run-up Areas (d) Takeoffs

Note: Airport property boundaries are designated by a thick black line; the dark interior line indicates the runway.

Figure 3. Average lead concentrations at a general aviation airport A.

to ambient lead concentrations at and around the airport. At this particular airport, taxi operations (Figure 3b) have the largest impact, followed by takeoffs (Figure 3d) and run-up (Figure 3c). Furthermore, these figures show that impacts from these three types of activities tend to be co-located and therefore contribute to the magnitude of the peak lead concentration; although at this airport the contributions from run-ups are relatively low.

The results for a different general aviation airport, denoted as airport "B," are shown qualitatively in Figure 4. Again, total lead concentrations from all airport activities are shown in Figure 4a, with the contributions from taxiways, run-up areas, and takeoffs shown in Figures 4b, 4c, and 4d, respectively. In this case, the contribution of run-up area activity to peak lead concentrations is much greater than at airport A, and the contributions from the other activities are relatively less important. Overall, the key observation from the comparison of Figure 3 to Figure 4 is that results tend to be airport specific—conclusions or observations drawn from one airport may not apply to another airport.

In addition to its utility in assessing airport lead impacts, the ACRP Project 02-34, "Quantifying Aircraft Lead Emissions at Airports" methodology allows the impact of potential lead mitigation strategies to be evaluated. During the course of the project, a literature review identified two potential approaches for lowering peak lead concentrations at and around general aviation

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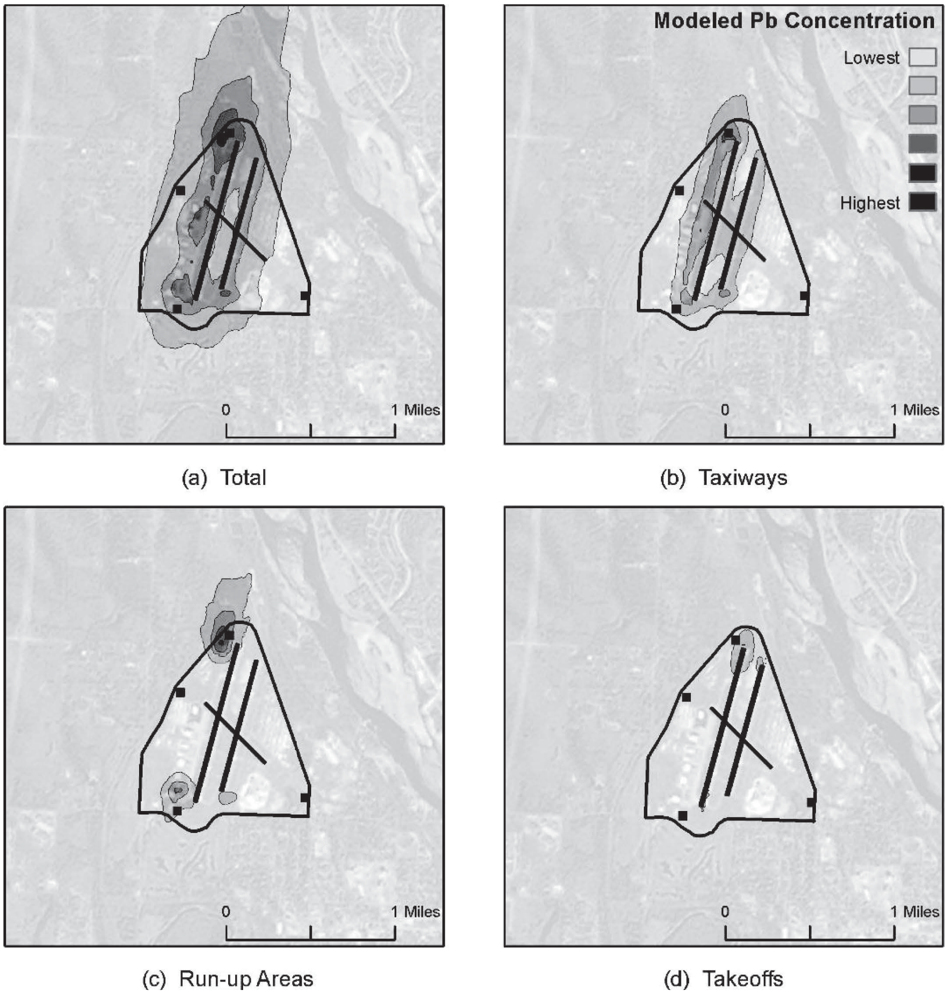

(a) Total (b) Taxiways

(c) Run-up Areas (d) Takeoffs

Note: Airport property boundaries are designated by a thick black line; the dark interior line indicates the runway.

Figure 4. Average lead concentrations at a general aviation airport B.

airports, in addition to the availability of the unleaded AVGAS sought through the FAA research program described previously:

- Relocation of run-up areas to reduce the magnitude of lead concentration hot spots; and
- Use of unleaded MOGAS in aircraft for which it is a suitable substitute for 100LL AVGAS.

Each of these was evaluated, along with the combination of both strategies. The MOGAS strategy was evaluated based on the assumption that it would be used in all aircraft for which it would be suitable, meaning that maximum impacts were assessed.

The two strategies and their combined implementation were evaluated for airports A, B, and a third airport denoted as airport "C." In addition, a detailed assessment of other factors that should be considered in the design and potential implementation of these strategies at a particular airport is presented in the following section of this guidebook.

The observed impact of implementing either strategy or both strategies at each of the three airports is summarized in Figure 5 as the percentage reduction in peak lead concentration compared to the base case value (i.e., no mitigation). The impacts of implementing either strategy or both varied considerably from airport to airport, with run-up area relocation reducing the

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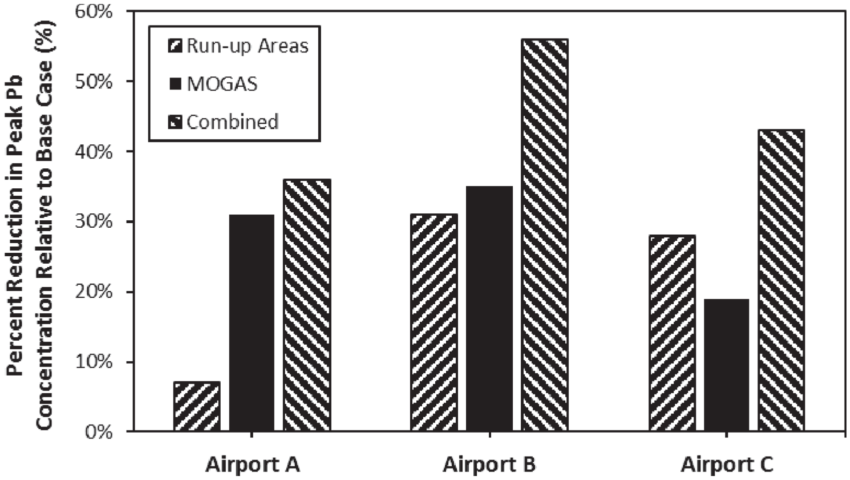
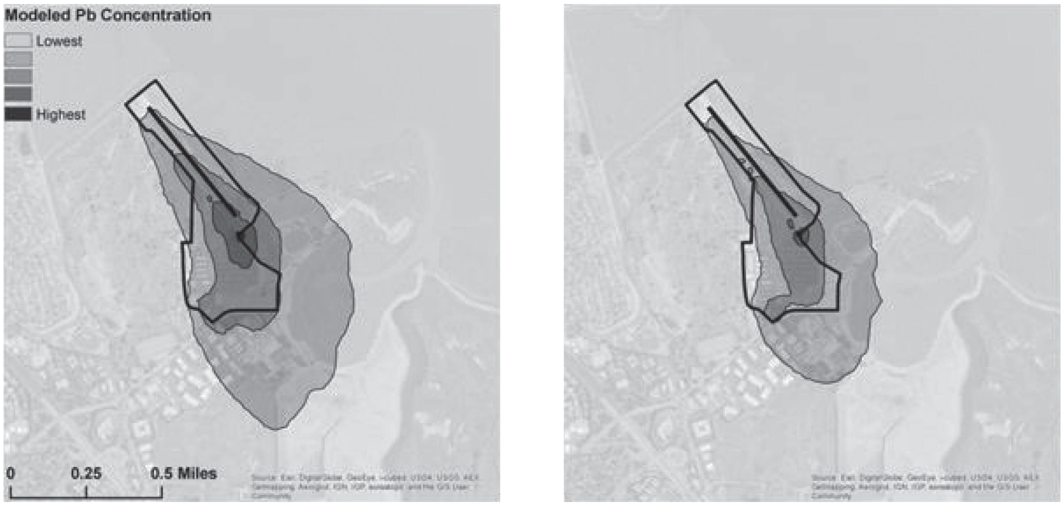


Figure 5. Impacts of control strategies on peak lead concentrations at three general aviation airports.

peak lead concentration by 7% to 31%, use of MOGAS by 19% to 35%, and the combination of the two by 36% to 56%. These findings again underscore the fact that results from one airport should not be generalized to other airports and highlight the need for conducting an airport-specific analysis using the ACRP Project 02-34, "Quantifying Aircraft Lead Emissions at Airports" methodology, or a similar approach, when considering implementation of general aviation aircraft lead control strategies.

In addition, the impacts on peak concentrations at and around the airports were evaluated. Figures 6, 7, and 8 show qualitative modeled base case lead concentrations (a) and concentrations reflecting the implementation of both control strategies (b) at airports A, B, and C, respectively. As expected, these figures show not only reductions in peak lead concentrations but also



(a) (b)

Note: Airport property boundaries are designated by a thick black line; the dark interior line indicates the runway.

Figure 6. Modeled lead concentrations at airport A for the base case* (a) *and combination of run-up area relocation and MOGAS use* (b)*.

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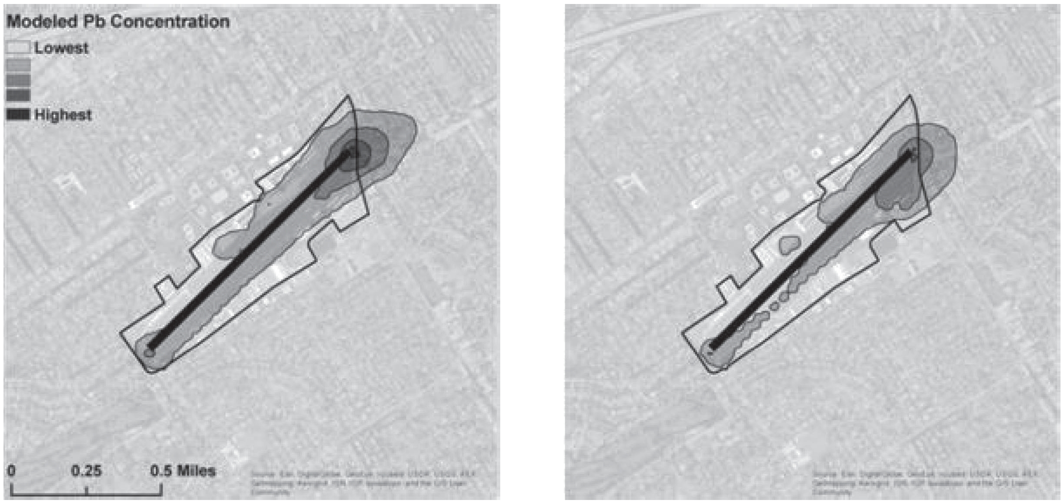
(a) (b)

Note: Airport property boundaries are designated by a thick black line; the dark interior line indicates the runway.

Figure 7. Modeled lead concentrations at airport B for the base case (a) ***and combination of run-up area relocation and MOGAS use*** (b)*.*



(a) (b)

Note: Airport property boundaries are designated by a thick black line; the dark interior line indicates the runway.

Figure 8. Modeled lead concentrations at airport C for the base case (a) ***and combination of run-up area relocation and MOGAS use*** (b)*.*

reductions in the size of impacted areas. Again, the different impacts from implementing both strategies at the different airports underscore the need for airport-specific analyses. Also, it must be stressed that the benefits modeled for the unleaded MOGAS strategy reflect the maximum impact of that strategy because MOGAS was assumed to be used in all aircraft for which it would be suitable; this might not occur in practice and would reduce the effectiveness of the strategy.

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CHAPTER 6

Other Factors to Consider When Evaluating Potential Strategies to Reduce Lead Impacts at General Aviation Airports

ACRP Project 02-57 assessed two potential strategies to reduce piston-engine aircraft lead impacts besides the availability of unleaded AVGAS: (1) use of unleaded MOGAS in aircraft for which it is suitable, and (2) relocation of run-up areas. While each strategy offers the potential to reduce lead concentrations, there are other factors that should be considered before making a decision to implement either or both strategies. These factors are addressed in this chapter.

6.1 Unleaded MOGAS

The vast majority of general aviation airports offer only a single gasoline grade for sale (100LL AVGAS) that can be used in all gasoline-powered, piston-engine aircraft. However, many general aviation aircraft can operate on unleaded ethanol-free MOGAS, which could potentially be made available at some airports. As discussed herein, there are several issues that should be considered before proceeding with efforts to make MOGAS available.

6.1.1 Confirming the Availability and Estimated Price of MOGAS

The first step in evaluating the potential of the MOGAS strategy is to determine whether suitable fuel is commercially available and, if so, what the approximate price differential is compared to AVGAS. Approaches to finding an ethanol-free MOGAS distributor include using online research/resources (Billing 2013), contacting local refineries and fuel distributors, and contacting other proximate airports that already distribute MOGAS.

The grade of MOGAS that will be dispensed (87 or 91 AKI MOGAS) should also be considered: 91 AKI MOGAS can be used in a greater proportion of the piston-engine fleet (increasing the lead reduction potential), while 87 AKI MOGAS is expected to be less expensive (providing a greater financial incentive). Currently, over half of airports selling MOGAS dispense 91 AKI.

With respect to prices, Figure 9 shows recent AVGAS and MOGAS price information as published online by *airnav.com.* Price spreads and differentials between MOGAS and AVGAS vary widely. However, it is important to understand the likely price differential—if both fuels are available, it is unlikely that MOGAS would be used over AVGAS unless there is a cost savings. There may also be costs related to recovering the capital investment associated with the new refueling infrastructure.

6.1.2 Determining the Potential for MOGAS Use

The proportion of aircraft approved for MOGAS operation will be facility-specific and facility variation in fleets (the number of aircraft that can operate on MOGAS vs. AVGAS) is significant,

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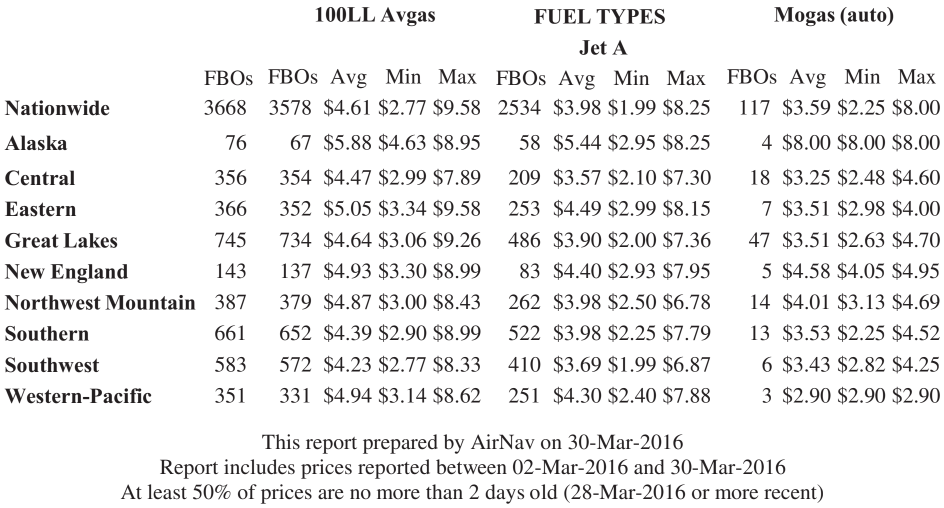

		100LL Avgas				FUEL TYPES Jet A				Mogas (auto)			
	FBOs	FBOs	Avg	Min	Max	FBOs	Avg	Min	Max	FBOs	Avg	Min	Max
Nationwide	3668	3578	$4.61	$2.77	$9.58	2534	$3.98	$1.99	$8.25	117	$3.59	$2.25	$8.00
Alaska	76	67	$5.88	$4.63	$8.95	58	$5.44	$2.95	$8.25	4	$8.00	$8.00	$8.00
Central	356	354	$4.47	$2.99	$7.89	209	$3.57	$2.10	$7.30	18	$3.25	$2.48	$4.60
Eastern	366	352	$5.05	$3.34	$9.58	253	$4.49	$2.99	$8.15	7	$3.51	$2.98	$4.00
Great Lakes	745	734	$4.64	$3.06	$9.26	486	$3.90	$2.00	$7.36	47	$3.51	$2.63	$4.70
New England	143	137	$4.93	$3.30	$8.99	83	$4.40	$2.93	$7.95	5	$4.58	$4.05	$4.95
Northwest Mountain	387	379	$4.87	$3.00	$8.43	262	$3.98	$2.50	$6.78	14	$4.01	$3.13	$4.69
Southern	661	652	$4.39	$2.90	$8.99	522	$3.98	$2.25	$7.79	13	$3.53	$2.25	$4.52
Southwest	583	572	$4.23	$2.77	$8.33	410	$3.69	$1.99	$6.87	6	$3.43	$2.82	$4.25
Western-Pacific	351	331	$4.94	$3.14	$8.62	251	$4.30	$2.40	$7.88	3	$2.90	$2.90	$2.90

This report prepared by AirNav on 30-Mar-2016
Report includes prices reported between 02-Mar-2016 and 30-Mar-2016
At least 50% of prices are no more than 2 days old (28-Mar-2016 or more recent)

Source: www.airnav.com/fuel/report.html

Figure 9. Fuel price report summary of fuel prices at 3,668 fixed base operators (FBOs) nationwide.

depending on geography, airport size, and aircraft types in operation. A survey of MOGAS sales at airports that already sell both MOGAS and AVGAS indicates that MOGAS sales are between 3 and 55 percent of total gasoline sales, with typical sales around 10 percent of the facility's gasoline total (KB Environmental Sciences 2014).

Because new refueling infrastructure would be required for an airport that does not already have MOGAS, the potential of the local aircraft fleet to use MOGAS should be evaluated to assist both in assessing the potential value of the strategy as well as in designing the new refueling infrastructure.

This evaluation can be performed in one of two ways: through an examination of the airport-based aircraft inventory, or through an examination of actual airport operations conducted by observation of aircraft tail numbers. The operations-based approach provides a more accurate reflection of facility activity but is more labor intensive. If an examination of the airport-based aircraft inventory is completed, the primary focus should be on the portion of the fleet used for commercial operations (e.g., flight schools), as the usage rates of these aircraft are significantly higher than for other aircraft. FAA databases of TCDSs (Type Certificate Date Sheets) and STCs (Supplemental Type Certificates) will provide information on the approved gasoline types for the identified aircraft. In either case, the data collected can be used to estimate the proportion of piston-engine aircraft suited for MOGAS consumption. Furthermore, the methodology as described in *ACRP Report 133* and *ACRP Web-Only Document 21* can estimate the proportion of AVGAS use that could be displaced by MOGAS.

Another factor to be considered is whether incentives could be offered to specific aircraft or aircraft fleets, such as those operated by flight schools, to use MOGAS. Conversion to MOGAS, when possible, by aircraft that disproportionately contribute to lead emissions will increase the benefits of the MOGAS strategy.

6.1.3 Infrastructure Costs

At most airports AVGAS is typically stored in double-walled underground tanks; however, aboveground tanks, which do not require excavation and any associated monitoring for leakage, may be less expensive options for making MOGAS available. Based on data available from other airport projects, the cost of installing infrastructure for storing about 5,000 gallons of MOGAS and dispensing it is approximately $100,000.

There may, however, be additional costs required to address requirements of the National Environmental Policy Act (NEPA) and state laws related to modifications made to airport facilities. Such modifications are often required to be shown on the airport's Airport Layout Plan, constituting a federal action requiring compliance with NEPA. If an airport makes modifications to its fueling facilities, FAA Orders 1050.1F and 5050.4B require compliance with NEPA, which may require the airport to perform other studies to support NEPA compliance. Given this, the actual environmental requirements as well as time and cost associated with compliance also need to be assessed.

6.1.4 Outreach and Review of Safety Protocols

Consideration needs to be given to conducting public outreach to aviators, fixed base operators, and the local community. This outreach should address not only the availability and benefits of MOGAS, but also the safety hazards of misfueling aircraft that require AVGAS.

6.1.5 Future Availability of Unleaded AVGAS

The MOGAS strategy would be rendered moot if 100 octane unleaded (100UL) AVGAS becomes available. As noted previously, the FAA is continuing to research the development of 100UL, with 2018 being the estimated timeframe for publishing ASTM specifications (FAA 2016b). However, publication of ASTM specifications does not mean commercial fuel production will immediately follow (for example, ASTM specifications for 82UL AVGAS were published in the late 1990s, and commercial fuel development has not yet commenced), and it is not clear at present what mechanisms, if any, would be employed to mandate use of the fuel.

6.2 Relocation of Run-Up Areas

Piston-engine preflight run-ups can generate significant ground-level lead emissions. These operations occur in prescribed, confined run-up areas; have high emissions density (high emissions per unit surface area); and, depending on the characteristics of the airport, contribute significantly to peak lead concentrations. There are three primary options to reduce the peak lead concentration through managing run-up activities, as listed herein.

- Relocate the run-up location to increase the distance between run-up and takeoff operations (at the busiest runway), thereby reducing the likelihood of overlapping plumes of emissions.
- Use multiple run-up locations to serve the busiest runway, in effect redistributing run-up emissions to multiple locations and reducing the emissions density associated with run-up operations.
- Increase the size of the run-up area to increase capacity. This increases the surface area over which the emissions occur, potentially minimizing unnecessary idling that may otherwise occur due to traffic congestion.

The primary focus of this strategy addresses the preflight run-up activities (i.e., the magneto test); a secondary focus is on engine maintenance run-up activities which should also be considered when developing an overall run-up management strategy for an airport.

6.2.1 Evaluation of Options

As noted, there are three primary options to evaluate: run-up area relocation, run-up area activity redistribution, and run-up area expansion. The first step in implementation is to define each option and to determine all suitable candidate scenarios for further evaluation in subsequent air quality modeling.

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Several assessments may be needed to completely characterize strategy options and define multiple candidate scenarios. Current conditions at the airport must be assessed (operations data, preflight run-up data, temporal distributions, and spatial distributions), as well as the meteorological data needed to calculate typical rolling 3-month period conditions (wind direction, wind speed, total hours at stable conditions, etc.). Candidate areas suitable for a new run-up location need to be identified. Two forms of run-up area activity redistribution should be considered: (1) if congestion is present, multiple run-up areas can be active simultaneously for a single runway; or (2) if congestion is not present, then run-up areas serving a single runway can be alternated. All options should be carefully considered to ensure that a substantial increase in taxi movements does not occur from adding or moving run-up sites, as this has the potential to offset the reduction(s) being sought. Time spent in run-up areas should be assessed to determine if congestion impacted the time spent in the run-up area and/or time spent waiting to enter the run-up area. Congestion levels should also be considered in determining whether larger run-up areas would be beneficial.

From the assessments and data collection described herein, a set of strategy scenarios should be identified for the subsequent air quality analysis. Engineering judgment should be applied to determine if there could be changes in taxiing/idling times for a candidate scenario relative to current conditions. The time spent in taxi/idle mode may vary because of changes in travel distances, changes in congestion, and pilot instruction for the case of flight school operations.

6.2.2 Safety Considerations

The primary safety concern is the interaction of this strategy with traffic control and management of aircraft movement. Adding complexity to aircraft movements around the airport may increase the potential for conflicts/collisions. In terms of safety, the simplest of the strategy scenarios would be preferable. The simpler strategy options include (1) moving an existing run-up location to a new location; (2) alternating run-up locations based on the day of the week; and (3) increasing the size of run-up areas. More complex scenarios, such as the simultaneous use of multiple run-up areas, would require more pilot and traffic control interaction.

6.2.3 Noise Considerations

Because run-up operations can be a significant source of noise for nearby residents, this strategy has the potential to affect noise planning efforts. Unexpected changes in the spatial distribution of noise at the facility may impact the facility's local surroundings and may also necessitate a review of the existing Federal Aviation Regulation Part 150 Airport Noise Compatibility Plan. The confounding influences of noise requirements may complicate implementation of this strategy.

6.2.4 Costs

Based on a review of the literature, existing costs for run-up area relocation and/or construction were found to vary from about $100,000 to $500,000 depending on the size of the run-up area as well as the need for noise containment structures.

6.2.5 NEPA Consideration

There are potential consequences under the NEPA and state laws related to modifications made to an airport layout. If an airport makes modifications to its fueling facilities, FAA Orders 1050.1F and 5050.4B require compliance with NEPA, which may require the airport to perform an Environmental Assessment or other studies. Given this, the actual environmental requirements, as well as time and cost associated with compliance, need to be assessed.

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CHAPTER 7

Data Collection at Airports

As demonstrated in Chapter 6, the efficacy of control strategies is airport specific. Maximum lead emission reductions realized by providing MOGAS depend on the active fleet and its operations. For example, airports with flight schools tend to have a disproportionately large number of operations from a small number of aircraft which may or may not be approved to use MOGAS. The impact on peak lead concentrations from moving run-up areas is more complex because it depends on the contribution of run-up areas to current peak concentrations and, as found in this study, this can vary widely across airports. Estimates of control strategy efficacy can be refined by collecting on-site activity data and, in this case of moving run-up areas, by conducting air quality modeling. The important aspects of the data collection process are described in this chapter.

Data collection descriptions with examples are provided in *ACRP Web-Only Document 21: Quantifying Aircraft Lead Emissions at Airports.* That project used video recordings and still photography when practicable. Activity data can also be collected manually through visual observation.

7.1 Aircraft Fleet Inventory

Landing and takeoff operations (LTOs) are a good indicator of overall airport operations and can be used to assess the active fleet. Tail ID numbers are recorded for a representative subset of operations, and these data are processed using the FAA registry (http://registry.faa.gov/aircraftinquiry) to determine the aircraft models and engine types. For the MOGAS option, these data can be matched to lists of MOGAS-suitable aircraft to develop an activity-weighted estimate of the maximum fraction of the fleet that could make the fuel switch.

Tail ID numbers of aircraft conducting LTOs can be manually recorded from visual observations, photographed for later review, or videotaped for later playback if the Tail ID numbers are legible. Data should be collected over a range of hours of the day as well as days of the week to ensure a representative sample. For example, flight school operations often follow a training schedule which should be proportionately captured in the data. Each recorded operation by Tail ID number should be time-stamped. While the time stamps are not strictly needed to construct the activity-weighted inventory, they provide insights into fleet operations and can be used to gauge data representativeness. Furthermore, for air quality modeling, these data can be used to allocate LTOs by hour of the day and, if warranted, by day of the week. In this case it is helpful to also record the runway and whether the operation is a conventional landing, conventional takeoff, touch-and-go (TGO), or taxiback.

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7.2 Activity Data

Air quality modeling is most robust when activities are allocated by hour and to their locations at the airport. Video cameras can be used to continuously record aircraft activity by runway; care must be taken to ensure the viewing angles are appropriate to resolve touch-and-go and taxiback operations from conventional takeoffs and landings. Video playback of continuously recorded data can be very time consuming—in this case, a representative subset of hours can be reviewed; alternatively, LTO operations can be visually recorded. One opportunity for efficiency is to combine the LTO data collection with the aircraft fleet inventory (Tail ID) data collection. Tail ID numbers can also be used to filter out jets, which do not use AVGAS and therefore do not contribute to airborne lead concentrations. Regardless of the collection method, it is important these data are time-stamped so they can be processed to generate hourly time-of-day distribution of total aircraft activity, as well as to determine the fraction of total activity resulting from LTOs, TGOs, and taxibacks.

Time in Mode data for run-up activities should include the magneto test duration and idling time in the run-up area. These data are best collected by manual recording of visual observations. Data collection must capture a range of conditions (time of day, day of week) and include the time spent by the aircraft in a run-up area (by visual observation), the duration of the magneto test (by audible changes in engine noise during run-up), and the aircraft Tail ID. Some planes bypass the run-up area prior to takeoff, and such instances should be recorded.

Time in Mode data should be collected for other activities including taxiing, takeoffs, and landings. These data can be collected by tracking individual aircraft and recording the time and location of each activity. For example, a taxiback would consist of the following data: landing time (time on runway between wheels-down and turning onto taxiway); time taxiing and idling on each taxiway; and takeoff time (time on the runway between starting rollout and wheels-up). The location along the runway for wheels-up and wheels-down should also be recorded; the wheels-up locations will typically be different for TGOs than other types of LTOs.

7.3 AVGAS Lead Concentrations

AVGAS samples can be collected from either fixed base operators (FBOs) selling AVGAS at the airport (preferred), or from planes based at the airport. AVGAS lead concentrations can also be collected from the fuel delivery certificates.

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CHAPTER 8

Public Outreach Regarding Lead

Public concerns and questions surrounding lead emissions from piston-engine aircraft operating at general aviation airports are addressed in the FAQ document provided in Appendix A. This document is intended for the general public who seek to be aware of the facts, the consequences, and the control measures necessary to address lead emissions from general aviation.

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APPENDIX A

Suggested Public Outreach Document

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ACRP AIRPORT COOPERATIVE RESEARCH PROGRAM

Aviation and Lead

Frequently Asked Questions FAQs

Q: What are the health effects of lead?

Answer: Too much lead can harm both children and adults. Once in the body, lead is rapidly absorbed into the bloodstream and can affect many organ systems. Lead poisoning can damage developing nervous systems in young children, including neurological effects that lead to behavioral problems, learning deficits, and lowered IQ. In adults, lead can cause high blood pressure and kidney damage, among other health problems.

Q: How is lead in the air measured or quantified?

Answer: The United States Environmental Protection Agency (USEPA) has developed national ambient air quality standards for six pollutants, including lead, to protect public health and welfare. The standard adopted by the USEPA for lead is 0.15 micrograms per cubic meter measured as a rolling 3-month average (i.e., the average measurements during a 3-month period such as June through August). These measurements are taken by capturing the total suspended particulates in the air and then determining the portion that consists of lead.

Q: How do I know if there is too much lead in the air?

Answer: There are several places to check. First, the USEPA designates areas where measured emissions have exceeded the national standards designed to protect public health and welfare. The map to the right shows the locations where lead has been found to exceed the USEPA standards; 21 locations in the United States have exceeded the lead standard in the past. In most cases, industrial processes have caused the standards to be exceeded. These sites are further described at http://www3.epa.gov/airquality/greenbook/mnc.html.

Finally, your state and/or local air quality agency can provide information about measurements that they take in your local community and if lead is a concern.

Q: Why is lead in general aviation aircraft fuel?

Answer: General aviation (GA) refers to all flying except scheduled passenger airlines, commuters, and military. GA as a category of airport operations includes recreational flying, package delivery, emergency medical evacuation, sightseeing, crops dusting, and police and traffic helicopter activity. Because of the need for high performance piston engines, many GA aircraft were designed to use a very high octane leaded gasoline, called aviation gasoline (AVGAS). The octane boost provided by lead in AVGAS prevents improper combustion or "knock" that can lead to engine failure, which is catastrophic in flight.

It is the need for high octane that has prevented the elimination of lead from AVGAS, whereas car and truck engines have been designed for lower octane unleaded motor gasoline (MOGAS) in order to avoid poisoning the catalytic converters. As a result, use of leaded MOGAS ended in the 1990s.

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Q: Why can't general aviation aircraft use unleaded fuel?

Answer: Although it is estimated, based on FAA-sponsored research, that between 40% to 50% of GA aircraft can operate on lower octane unleaded fuel, known as MOGAS, as well as AVGAS, the remaining 50% to 60% of GA aircraft were designed to operate only on AVGAS and can operate safely only on that fuel. At this time, only leaded fuel is commercially available as AVGAS.

Q: What has been and is being done to remove lead from general aviation fuels?

Answer: Despite the continued use of AVGAS, lead emissions related to GA have declined over time for two reasons: (1) the introduction of low-lead AVGAS with less than half the lead content of older AVGAS, and (2) a decline in the use of AVGAS in GA. In addition, much research has been conducted over the past two decades focused on finding a safe replacement for leaded AVGAS. The FAA has established the Fuels Program Office to help meet the Agency's goal of making an unleaded fuel available for the existing fleet of piston-engine aircraft. The FAA is working with the USEPA, the aviation industry, fuel producers, academia, and others to identify a replacement for leaded AVGAS by 2018. More information is available at http://www.faa.gov/about/initiatives/avgas/.

Q: Are there ways an airport can reduce leaded fuel impacts?

Answer: The Airport Cooperative Research Program (ACRP) has conducted several research efforts associated with lead at airports. ACRP Project 02-57 examined two potential options to reduce lead emissions from GA activity:

1. Based on research sponsored by the FAA, it has been determined that approximately 40% to 50% of the U.S. GA fleet could potentially operate with unleaded MOGAS. Thus, making unleaded MOGAS available as an alternative to leaded AVGAS for use in aircraft that can safely operate with that fuel could reduce lead emissions.

2. Relocating engine test (run-up) areas or redistributing the use of existing run-up areas may lead to lower maximum lead concentrations in the air.

   This study found that maximum lead concentrations could be reduced by 19% to 56% with the implementation of one or both of the recommendations at the three airports that were evaluated.

The results showed the following reductions in maximum lead concentrations:

- Making MOGAS available for the aircraft that could operate using it: 19% to 35% reduction
- Relocating the engine test run-up areas: 7% to 31% reduction
- Both MOGAS availability and relocating run-ups: 36% to 56% reduction

The magnitude of the reduction that can be achieved at any one airport is dependent on the number of aircraft that would actually use MOGAS and the availability of alternative engine test run-up locations. A guidance document developed to assist airports in considering these strategies can be found at www.trb.org/ACRP.

Q: Can my airport use these lead reduction actions?

Answer: Each airport is different, and not every airport may be able to implement one or more of these actions. In all cases, careful study by the airport is recommended to avoid potential adverse impacts on safety, noise, and other important factors.

Q: How can my airport use the results of this study?

Answer: The role of the airport operator today is to address lead emissions on a voluntary basis, as there is currently no regulatory mandate for airports to take any action. However, the USEPA reported that in 2017 it intends to issue a finding on whether aviation lead emissions represent a sufficient public hazard so as to warrant regulation.

Airport operators may choose to begin formulating plans to address lead either as part of a State Aviation System Plan, an individual airport master plan, or an airport sustainability plan. The results of this ACRP study would aid airports in being proactive through their planning process to identify (1) the aircrafts that require AVGAS, versus those that could operate on MOGAS, and the quantities of fuel consumed; and (2) locations where ground run-ups could be conducted to reduce off-airport concentrations of lead. Armed with this information, an airport operator could implement one or more of the findings of this ACRP study in advance of being required to take action if regulations are subsequently adopted.

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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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