# Best Practices for Preparing Lead (Pb) Emission Inventories from Piston-Powered Aircraft

Jeremy G. Heiken
Sierra Research, 1801 J Street, Sacramento, CA 95811
jheiken@sierraresearch.com

## ABSTRACT

Lead (Pb) is a well-known air pollutant that can lead to a variety of adverse health impacts, and in October 2008, the EPA promulgated a new Pb NAAQS that lowered the acceptable level by an order of magnitude. Because general aviation airports represent a significant source of lead emissions, the Airport Cooperative Research Program initiated project ACRP 02-34 – *Quantifying Aircraft Lead Emissions at Airports*, with the objective of reviewing and improving existing methodologies to quantify and characterize aircraft-related Pb emissions due to the use of leaded aviation gasoline. A product of this project was the preparation of "best practices" guidance for the preparation of Pb emission inventories from piston-powered aircraft[1]*.

The best practices guidance advances the science of piston aircraft inventory methods by expanding the database of aircraft fleet fuel consumption rates, refining methods for fuel rate assignment, expanding the types operating modes modeled and creating methods specific to rotorcraft. The guidance is supplemented with locally collected modeling inputs representing the aggregate of 3 candidate general aviation airports studied in ARCP 02-34. These inputs are provided for demonstration purposes as the airport-to-airport variation is significant. The generalized airport-level impacts in Pb emission inventory (3-airport aggregate) are estimated for the incremental changes in the inventory methods developed. For all inventory improvements collectively, the resultant changes in airport Pb inventory were -39 percent for the at-ground modes (taxi, idle, takeoff and run-up) and -37 percent for all modes (at-ground and aloft modes combined).

## INTRODUCTION

Lead (Pb) is a well-known air pollutant that can lead to a variety of adverse health impacts. Concerns regarding the adverse health effects of exposure to airborne Pb resulted in its classification 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 Pb in 1978—set at 1.5 micrograms per cubic meter of air based on quarterly average concentration. Thirty years later, in October 2008, the EPA promulgated a new Pb NAAQS that lowered the acceptable level by an order of magnitude, to 0.15 micrograms per cubic meter based on a rolling three-month average concentration[2].

General aviation airports currently produce a majority of the total national lead emission inventory for the sole reason that aviation gasoline still contains added lead. USEPA estimates 60 percent of national lead emissions originated from these facilities in calendar year 2011 (the

* Project documentation includes the Final Project Report and the *Best Practices Guidebook for Preparing Lead (Pb) Emission Inventories from Piston-Powered Aircraft.*

most recent year reported)[3,4]. Because of this significance, the Airport Cooperative Research Program (ACRP) sponsored project ACRP 02-34 – *Quantifying Aircraft Lead Emissions at Airports*, with the objective of reviewing and improving existing methodologies to quantify and characterize aircraft-related Pb emissions at airports with significant populations of aircraft that use leaded aviation gasoline. An emission inventory "best-practices" guidebook and emission inventory spreadsheet tool were prepared to allow for the incorporation of key project results from ACRP 02-34 into emission inventory development for airports with significant piston-powered aircraft operations and is separate from the ACRP 02-34 project report[1].

It requires stating that the results of ACRP 02-34 represent supplemental emission inventory guidance. The final authority on emission inventory methods from aircraft lies jointly with the FAA and USEPA. With that context understood, aircraft emission inventory methods development over the last 40 years has focused on the commercial aircraft sector – for good reason – as commercial aviation represents a greater proportion of criteria pollutant emissions. For general aviation aircraft, however, neither methods nor supporting data for estimating emission inventories have changed since their original development in the 1970's (i.e., "AP-42"); moreover, current, requisite aircraft emission inventory modeling software (i.e., EDMS and AEDT) simply do not estimate lead emissions from aviation gasoline consumption. In short, existing methods and resources are not inadequate for accurate lead emission inventory development from the consumption of aviation gasoline.

Upon completion, ACRP 02-34 has yielded substantial improvements to both inventory methods and supporting data for the estimation of lead emissions form aviation piston-powered engines. Moreover, the project results from ACRP 02-34 include a guidebook and emission inventory analysis tool (EIAT) to assist agency personnel and affected stakeholders in the preparation of lead emission inventories[1]. Those project resources should be used to supplement the inventory improvements which are the subject of this paper.

Finally, it should be noted that Airport Cooperative Research Program has initiated a follow-up project examining mitigation measures for reducing lead emissions at general aviation airports. ACRP 02-57, *Reducing the Impact of Lead Emissions at Airports*, is targeted for completion sometime in 2015[5].

This paper summarizes key emission inventory improvements developed under ACRP 02-34 and then presents the results of a unique analysis – the application of the lead inventory methods incrementally. The incremental analysis quantifies the impact of each inventory improvement individually. The remainder of this paper is divided into the topics of Methods, Results and Discussion. References are provided at the end of the paper.

## METHODS

Inventory methods were developed from the existing FAA/USEPA approach as the foundation onto which improvements were made. Moreover, 3 field studies were completed to collect facility-level data at 3 candidate airports: Richard Lloyd Jones Jr. Airport (RVS) in Tulsa, OK; Centennial Airport (APA) in Englewood, CO; and Santa Monica Municipal Airport (SMO) in Santa Monica, CA. The field studies provided an unprecedented amount of data on the operations of piston-powered aircraft engines. Substantial improvements were made to the methods defining operation modes, time-in-mode (TIM), fuel consumption rates and local Pb content in gasoline. These elements to the inventory method are described individually as follows.

**Operation Modes**

Under the standard FAA/USEPA emission inventory procedures universally applied to evaluate general aviation airports in the U.S., every two operations consist of a landing and a takeoff. These two operations combined are termed a *landing-takeoff (LTO) cycle*, and agency inventory methods are based on a per-LTO basis with the underlying presumption that every two operations consist of a standalone takeoff and a standalone landing. "Standalone" in this context signifies operation that either begins or ends with the engine off and the aircraft parked at the hanger/ramp location.

The standard LTO cycle approach was quickly deemed inadequate for evaluating the facility-specific data collected. A significant proportion of "continuous" operation—i.e., multiple operations executed in series such that the engine is not turned off—was observed. This operation is specific to the piston engine fleet. The refined methodology was expanded for the facility-specific analysis to properly address continuous operation presumably present due to commercial flight school activity (i.e., training operations). Multiple flights schools operated at each airport evaluated.

As explained below, two distinct types of continuous operation were explicitly evaluated, the "touch-and-go" and the "taxi-back."*

- Touch-and-go operations for fixed wing aircraft consist of an approach, brief ground roll (landing), an immediate takeoff, and a climb-out—all of which occur without exiting the runway. Specifically a touch-and-go operation counts as two operations in FAA procedures, because both a landing and a takeoff occur. Approach and climb-out modes for the touch-and-go were handled similarly as the procedure used for any standard landing and takeoff. However, the fuel rate for the ground-roll mode of the touch-and-go was handled distinctly as the average of the idling rate (typical for landing) and the takeoff rate.

- Taxi-back operations for fixed-wing aircraft consist of a standard approach, landing, and taxing off the runway, after which the aircraft taxis back to a runway and completes a takeoff and climb-out. The taxi/idle time on the ground is unique for this procedure (and accounted for separately in the methodology) and the run-up prior to takeoff may be omitted. A taxi-back counts as two operations (both a landing and a take-off).

These two types of continuous operation represented a significant portion of the piston-powered aircraft activity observed at the three airports. Correctly addressing the continuous operation was key to the inventory development because the run-up procedures are generally omitted between

* "Stop-and-go" is a third type of continuous operation involving a landing, coming to a complete stop and taking off again all while never exiting the landing runway. There were no stop-and-go operations observed, and safety concerns may limit such activity at many facilities.

successive takeoffs (if operation is continuous) and the time spent in each operation mode is otherwise distinct from a similar standalone operation.†

The standard methods of FAA/USEPA explicitly model aircraft activity by four distinct modes of engine operation: taxi/idle, takeoff, climb-out, and approach. This study added 2 more modes (the run-up mode and the touch-and-go ground roll) and made other minor adjustments to the mode definitions as described below.

- FAA/USEPA methods omit the run-up mode. The run-up mode encompasses the magneto test completed prior to takeoff, and the estimated fuel consumption rate for this mode is specific to the magneto test.‡ Any additional time the aircraft spends at a run-up location, in excess of the magneto test time, is counted as part of the total taxi/idle time on the ground. On average, it was observed that an aircraft spends about five minutes total at the run-up locations, of which about one minute is for completing the magneto test.

- For this study, takeoff is the period from the initial ground roll to wheels up. This differs purportedly from FAA/USEPA defaults which include the time to reach a nominal altitude of 500 feet as described in the 1992 emission inventory guidance[6]§.

- For this study, the approach ends at wheels down on the runway. The landing ground roll—the period from wheels down to turning off the runway—is included as part of the approach mode in the standard FAA/USEPA modeling protocol for fixed-wing aircraft. We changed this assumption because the landing ground roll is completed specifically at engine idle, whereas for the remainder of the approach mode the engine is assumed to be operating at 40 percent load. In this method, the period of the landing ground roll is explicitly counted as part of the on-the-ground idle/taxi time in order to apply the proper fuel flow rate to the landing roll operation.

- The touch-and-go ground roll is the brief period from wheels down to wheels up again. As noted above, the fuel rate for the ground-roll mode of the touch-and-go was handled distinctly as the average of the idling rate (typical for landing) and the takeoff rate. This ground roll operation is, in effect, a distinct mode.

- Our general recommendation is that the maximum altitude included in the climb-out and approach modes is capped at the traffic pattern altitude (TPA) of each airport. The TPA, assigned by aircraft type, is typically between 500 and 1,500 feet above ground level (AGL). This is an improved assumption over the FAA/USEPA default of 3,000 feet

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† The continuous operations observed were almost exclusively completed by piston-powered aircraft; effectively no jet engines were observed in these types of training operations. On aggregate across the 3 airports, about 40 percent of piston engine operations were continuous operations. These are a significant proportion of piston-powered aircraft engine activity.

‡ The magneto run-up test is only applicable to gasoline-powered piston engines as the magneto provides the spark for ignition.

§ Inconsistencies were documented between the FAA/USEPA default TIM values for takeoff and the 500 foot elevation assumption. It is believed that the nominal 500 foot altitude assumption reported in the 1992 USEPA guidance is an error in that it does not apply to the general aviation case (it may be a valid assumption for the commercial aviation case).

AGL, which is atypical to general aviation airports. However, for the purposes of this paper, the FAA/USEPA default of 3,000 feet AGL was assumed. Thereby, the results presented herein are comparable to the standard agency defaults under an equivalent maximum altitude case of 3,000 feet AGL.

**Time-in-Mode (TIM)**

The sources of time-in-mode (TIM) data for fixed-wing aircraft were as follows.

- The facility-specific TIM data were collected and used to define the amount of time for the at-ground modes (i.e., taxi/idle, takeoff and run-up). The facility-specific TIM data represent the tracking the individual planes over the entirety of their on-the-ground movements at each airport. The TIM data collection was complete for all operation on runways and taxiways.

- The facility-specific times for the run-up mode (i.e., the magneto test) were validated against information contained in Owner's Manuals. The TIM for the magneto test was log-normally distributed; three data points—in excess of six minutes duration and more than two geometric standard deviations from the mean—were removed.** The geometric mean of the remaining data was used to define the average magneto test time for the purposes of inventory development.

- The TIM values for the aloft modes (i.e., approach and climb-out) were determined from scaling the FAA/USEPA default for 3,000 feet AGL. Slight differences between the TIM for the aloft modes for the study versus FAA/USEPA defaults exists based on minor differences in the mode definitions.

TIM data for piston-engine aircraft observed at each airport during the field studies are summarized in Table 1 alongside the FAA/USEPA default assumptions. Overall, TIM for the 3 facilities on average matched reasonably well with the agency default values.

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** Long-duration magneto tests are not feasible as it would cause the engine to overheat. However, multi-engine craft complete tests in series such that magneto test times are proportional to the number of aircraft engines.

| Table 1<br>Time-in-Mode Assumptions for Fixed-Wing Piston Aircraft (Minutes) | | |
|---|---|---|
| **Operation Mode** | **FAA/EPA Default** | **ACRP 02-34 Data<br>3-Facility Mean** |
| Idle/Taxi (Takeoff) | 12 | 9.89 |
| Run-Up | N/A | 0.96 |
| Takeoff | 0.3 | 0.33 |
| Climb-Out | 5 | 5.28 |
| Approach | 6 | 6.57 |
| Idle/Taxi (Landing) | 4 | 4.08 |
| Idle/Taxi (Taxi-Back) | N/A | 3.32 |
| Ground Roll (Touch-and-Go) | N/A | 0.28 |

Taking these data one step further – aggregating the modal TIM to the total time over a typical operation – is informative. Those results are summarized in Table 2. Times are reported on a per operation basis and each row represents 2 operations. For example, the FAA/USEPA default is a standalone takeoff and a standalone landing (termed "conventional LTO"). What is important in these data is to demonstrate how much less engine time per operation occurs for the continuous operations (i.e., taxi-back and touch-and-go operations). Whereas, the FAA/USEPA default treats all operations as a conventional LTO, this results in a significant over estimation of engine operation time for those facilities with significant continuous operations.

| Table 2<br>Total Time-in-Mode per Operation for Fixed-Wing Piston Aircraft (Minutes) | | |
|---|---|---|
| | **At-Ground Modes (Taxi/Idle, Run-up and Takeoff)** | **Total (At-Ground plus Aloft Modes)** |
| FAA/USEPA Default (Conventional LTO) | 8.2 | 13.7 |
| Facility Data (Conventional LTO plus Run-up) | 7.6 | 13.6 |
| Facility Data (Taxi-Back) | 1.7 | 7.6 |
| Facility Data (Touch-and-Go) | 0.1 | 6.1 |

## Fuel Consumption Rates

The methods and data for estimating aviation gasoline consumption rates were improved upon standard FAA/USEPA methods as follows.

- The amount of engine-specific fuel consumption data was increased from 6 engines (used in the standard FAA/USEPA methods) to 29 engines in the improved methodology.

- Whereas, the FAA/USEPA methods aggregate the engine-fuel consumption to a fleet average based on a simple average, the improved methodology determined the fleet average fuel consumption rates based on the proportion of engines observed at each facility.††

- The improved method used brake-specific fuel consumption (BSFC) – a measure of efficiency – to extrapolate fuel consumption rates to engines not coved in the database. This method factors in the engine rating into the methodology. The underlying data were separated into 6 gasoline engine technology groups in which engine efficiencies were distinct (4-stroke horizontally-opposed carbureted, 4-stroke horizontally-opposed fuel injection, 4-stroke horizontally-opposed turbocharged, 2-stroke horizontally-opposed and 4-stroke radially-opposed). Extrapolations were based on the specific engine technology.‡‡

Table 3 summarizes the fuel consumption rates of the FAA/USEPA defaults and the 3-facility mean from ACRP 02-34. Fuel consumption rates from the study are generally less than the agency default values except for the taxi/idle mode.

**Table 3**
**Fuel Consumption Rates for Fixed-Wing Piston Aircraft (lb./hr.)**

| Mode | FAA/EPA Default | ACRP 02-34 Data 3-Facility Mean |
|---|---|---|
| Takeoff | 147.6 | 117.3 |
| Climb-out | 112.7 | 92.5 |
| Approach | 62.0 | 52.4 |
| Taxi/Idle | 14.2 | 15.4 |
| Run-up (Magneto Test) | N/A | 55.7 |
| Touch & Go Ground Roll | N/A | 66.4 |

## Pb Content of Aviation Gasoline

The FAA/USEPA standard approach models the Pb content of aviation gasoline at the maximum allowable; and the FAA/USEPA assumes all aviation gasoline consumed is grade 100LL. Grade 100LL has a limit of 0.56 g/L tetraethyl lead (TEL) – the equivalent of 2.12 g/L Pb.

Grade 100LL was the only aviation gasoline encountered in the study. About 90 percent of aviation gasoline sold is estimated to be grade 100LL based on FAA survey data[7]. Aviation gasoline samples were collected and analyzed at each facility. Observations from these data are as follows.

†† Operation-weighted aircraft/engine proportions were obtained by video recording of aircraft tail number data.

‡‡ A seventh piston-engine technology group "compression-ignition piston engines" was also defined. This technology, whose frequency was about 1 percent of all piston operations, consumes jet fuel, not aviation gasoline and thereby does not produce Pb exhaust emissions. These engines are based on a platform comparable to a light-duty on-road diesel vehicle.

- The Pb content (3-facility mean) observed was 1.60 g/L. This represents a 25 percent margin and substantial reduction in Pb content (versus the default assumption of modeling the maximum limit).

- Aviation gasoline is a highly refined, batch product. The data collected are date-specific and it is not known if seasonal, temporal variation in gasoline properties is significant.

- Pb content is variable by location as observed in the data collected. Because of this variability, it is not appropriate to extrapolate the mean Pb content reported here more generally to other facilities. Adding a local Pb content assumption requires local data collection.

## RESULTS

An incremental Pb inventory analysis was completed using the spreadsheet analysis tool of the ACRP 02-34 project[1]. The results are reported on a mass per operation basis. Six modeling scenarios were completed as follows.

- Scenario 1: FAA/USEPA defaults

- Scenario 2: Scenario 1 plus adding the run-up mode

- Scenario 3: Scenario 2 plus adding local TIM (3-facility mean)

- Scenario 4: Scenario 3 plus adding local continuous modes (3-facility mean)

- Scenario 5: Scenario 4 plus adding local Pb content of gasoline (3-facility mean)

- Scenario 6: Scenario 5 plus adding local fleet-specific fuel consumption rates (3-facility mean)

The resulting Pb exhaust emissions are reported in Table 4.§§ The FAA/USEPA defaults are those of Reference 4 as evaluated in the ACRP 02-34 spreadsheet tool.*** The results are reported for the at-ground modes (taxi, idle, run-up and takeoff combined) and for all modes (at-ground and aloft modes combined). ACRP 02-34 showed that the at-ground modes were predominate in impacting facility-level Pb air quality,[1] and therefore it is informative to examine just the at-ground results as well as the airport total.

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§§ Exhaust emissions exclude the 5 percent retention of Pb in engine and engine oil. The 5 percent retention rate is a USEPA assumption.

*** Small differences in the "default" case of a few percent is observed between Reference 4 and results reported herein. This is due to round-off differences (round-off to 2 significant digits only occurs at the final end point in the calculations for the results of this paper).

| Table 4<br>Pb Exhaust Emissions (Grams per Operation) by Scenario | | | |
|---|---|---|---|
| **Scenario** | **Description** | **At-Ground Modes** | **Total** |
| 1 | FAA/USEPA defaults | 0.76 | 3.38 |
| 2 | Adding the run-up mode | 0.94 | 3.55 |
| 3 | Adding local TIM (3-facility mean) | 0.87 | 3.67 |
| 4 | Adding local continuous modes (3-facility mean) | 0.60 | 3.41 |
| 5 | Adding local Pb content of gasoline (3-facility mean) | 0.46 | 2.59 |
| 6 | Adding local fleet-specific fuel consumption (3-facility mean) | 0.46 | 2.12 |

Tables 5 and 6 present the relative incremental changes and the cumulative changes of each modeling scenario. Table 5 shows that the scenarios with the greatest impact on at-ground Pb emissions were adding the run-up mode (Scenario 2), adding continuous operations (Scenario 4) and adding local Pb content of gasoline (Scenario 5). Table 6 shows that by addressing all inventory elements combined, there is a net change in Pb emissions of -39 and -37 percent for at-ground and total modes, respectively (defined relative to the FAA/USEPA default scenario).

| Table 5<br>Incremental Change in Pb Exhaust Emissions (Percent) of Each Scenario | | | |
|---|---|---|---|
| **Scenario** | **Description** | **At-Ground Modes** | **Total** |
| 2 | Adding the run-up mode | 24% | 5% |
| 3 | Adding local TIM (3-facility mean) | -7% | 3% |
| 4 | Adding local continuous modes (3-facility mean) | -31% | -7% |
| 5 | Adding local Pb content of gasoline (3-facility mean) | -23% | -24% |
| 6 | Adding local fleet-specific fuel consumption (3-facility mean) | 0% | -18% |

| Table 6<br>Cumulative Change in Pb Exhaust Emissions (Percent) Relative to Scenario 1 | | | |
|---|---|---|---|
| **Scenario** | **Description** | **At-Ground Modes** | **Total** |
| 2 | Adding the run-up mode | 24% | 5% |
| 3 | Adding local TIM (3-facility mean) | 14% | 9% |
| 4 | Adding local continuous modes (3-facility mean) | -21% | 1% |
| 5 | Adding local Pb content of gasoline (3-facility mean) | -39% | -23% |
| 6 | Adding local fleet-specific fuel consumption (3-facility mean) | -39% | -37% |

## DISCUSSION

The following are the recommendations related to Pb inventory preparation for general aviation airports based on this analysis and the results of ACRP 02-34.

1. The run-up mode needs to be included in every airport inventory assessment; its omission is a significant flaw, and its inclusion will increase the emission inventory by approximately 5 percent overall. ACRP 02-34 includes adequate data and assumptions for modeling this mode of operation, and no local data collection is required.

2. Continuous operations needs to be at least considered for every airport inventory assessment; modeling continuous operations should be based on facility-specific activity inputs (as facility variation is significant). Continuous operations, indicative of flight training operations, exhibit significantly different operation characteristics that result in significantly less emissions per operation than the conventional LTO cycle currently assumed. Beit understood that training operations at general aviation airports are the norm not the exception. The FAA has registered approximately 600 pilot training schools the majority of which operate at multiple airports. The FAA has assessed every single general aviation airport nationally and all general aviation airport classifications applied in this assessment (national, regional, local and basic) are noted to have training operations present[8,9].†††

3. Margins with respect to locally observed Pb content of gasoline can be significant, but facility variation is significant and the temporal variation in Pb content has not yet been determined. Use of facility-specific Pb content must be based on local fuel sample analyses.

4. The amount of time spent in each mode (TIM) is locally variable and depends on the airport configuration and the individual fleet of piston engine aircraft. Local collection of TIM data is a means to improve the airport-specific inventory.

5. The primary recommendation is that the collection of local operations-based fleet data be collected to improve the accuracy of the fuel consumption rate assignments. If airport-specific fuel consumption rates are not calculated from a local aircraft fleet assessment (i.e., the primary recommendation), then the secondary recommendation is that the 3-facility average fuel consumption rates from the ACRP 02-34 project be used in place of FAA/EPA defaults. The underlying data, fuel rate assignment method, and activity weighting assumptions of the ACRP 02-34 averages are all significant improvements over the methods used to create the FAA/EPA default fuel consumption rates.

There are additional inventory elements addressed in ACRP 02-34 that were not addressed in this paper. The project resources can be consulted to further investigate the following.

††† These FAA "asset" reports includes the classification of all general aviation airports and are potentially useful inventory references for air quality planning personnel not familiar with the characteristics of an airport under evaluation.

1. Spatial variation was significant and should be addressed in the context of micro-scale air quality modeling. Activity was asymmetrically distributed in the 3 candidate airports studies. Trips originated and ended predominately at the commercial fixed base operators (FBOs); standalone operations favored more proximate runways; continuous operations favored more distant runways; meteorological conditions impacted runway selection; TIM values were runway specific due to the asymmetry in activity.

2. Temporal variation was significant and should be addressed in the context of micro-scale air quality modeling. Meteorological conditions were temporally variable; continuous operations had distinct temporal variation (i.e., occurring during normal business hours).

3. Legacy aircraft were situationally significant. A Boeing B-17 (known as the "flying fortress") was observed with activity at one airport over a 1-week period. The methodology developed handled the fuel consumption from the 4 large radially opposed piston engines; the resulting fuel consumption rates were 40 to 50 times that of a typical piston-engine aircraft.

4. Altitude was situationally significant due to reduced air density required for liftoff. The TIM for takeoff, climb-out and approach are impacted by altitude; speed, climb angle and approach angle are also impacted by altitude.

5. Rotorcraft were not a significant source at the 3 candidate airports studied. Separate methods for rotorcraft were developed for ACRP 02-34 and may be situationally important. Methods for rotorcraft are distinct from fixed-wing aircraft; existing default methods are poor for this aircraft class.

6. It is recommended that the maximum altitude of aloft modes for general aviation airports be capped at the traffic pattern altitude (TPA). The TPA is that at which approach begins and climb-out ends. Most continuous operations flying the circuit never exceed the TPA. The default assumption of 3,000 feet AGL is suitable for commercial aircraft but not general aviation. TPA for each airport is readily available as this is part of the facility characteristics posted for pilots. TIM for climb-out and approach can be scaled by the maximum altitude assumption, and no local data collection is required.

7. It was noted that the characteristics of the fleet for standalone and continuous operations were distinct. The fleet completing continuous operations tended to be lighter with proportionately more single-engine aircraft.

8. Emissions from maintenance-related, run-up operations were not fully evaluated in ACRP 02-34 and may be significant. Some accounting of these were included when observed but the analysis (both in terms of activity and fuel rates assumed) was not robust. Maintenance related run-up procedures are not the same as magneto test run-up procedures. Maintenance run-ups are longer in duration at a lower fuel consumption rate (relative to a magneto test run-up).

**REFERENCES**

**1** ACRP 02-34 project reports and emission inventory spreadsheet tools will be available at this URL (not yet posted at the time of this paper's publication): http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3035.

**2** U.S. EPA. November 12, 2008. 40 CFR Parts 50, 51, 53 and 58 – National Ambient Air Quality Standards for Lead; Final Rule. Published at 73 FR 66964.

**3** U.S. EPA. June 2012. *2008 National Emissions Inventory, Version 2: Technical Support Document (DRAFT)*.

**4** U.S. EPA. 2013b. *Calculating Piston-Engine Aircraft Airport Inventories for Lead for the 2011 National Emissions Inventory*. EPA-420-B-13-040.

**5** ACRP 02-57 project reporting will be available at this URL (not yet posted at the time of this paper's publication): http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3703.

**6** U.S. EPA. 1992. Procedures for Emission Inventory Preparation Volume IV: Mobile Sources. EPA420-R-92-009. http://www.epa.gov/otaq/models/nonrdmdl/r92009.pdf.

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