

ACRP

REPORT 133

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PROGRAM

Best Practices Guidebook for Preparing Lead Emission Inventories from Piston-Powered Aircraft with the Emission Inventory Analysis Tool

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**Best Practices Guidebook for
Preparing Lead Emission
Inventories from Piston-Powered
Aircraft with the Emission
Inventory Analysis Tool**

Jeremy Heiken
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AIRPORT COOPERATIVE RESEARCH PROGRAM

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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). The ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. It is modeled after the successful National Cooperative Highway Research Program and Transit Cooperative Research Program. The ACRP undertakes research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration. The ACRP provides a forum where airport operators can cooperatively address common operational problems.

The 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) the 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 Academies formally initiating the program.

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FOREWORD

By Marci A. Greenberger
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ACRP Report 133: Best Practices Guidebook for Preparing Lead Emission Inventories from Piston-Powered Aircraft with the Emission Inventory Analysis Tool will assist airport operators at general aviation airports with piston-powered aircraft in developing emission inventories at their airports. The methodology used in the guidebook and the tool are enhancements to the current Federal Aviation Administration/Environmental Protection Agency (FAA/EPA) methodology. The use of airport-specific data is encouraged to ensure a more precise estimation of the emission inventory; however, the tool allows for the use of default data from either the FAA/EPA or data collected as part of ACRP Project 02-34, “Quantifying Aircraft Lead Emissions at Airports.”

EPA standards for lead emissions have become increasingly stringent over the last 35-plus years based on lead’s known health impacts. Regulations and EPA standards have required more general aviation airports to monitor for lead because of assumptions that were not necessarily based on airport-specific information.

Sierra Research, Inc. as part of ACRP Project 02-34, developed an inventory methodology, best practices guidebook, and a companion tool to assist airports in quantifying aircraft lead emissions at airports. It collected data at a number of different airports that was used as an input to, and to validate, its methodology. Information on how the project was conducted can be found in the contractor’s research report, *ACRP Web-Only Document 21: Quantifying Aircraft Lead Emissions at Airports*, available on the TRB website (www.trb.org). The guidebook and tool (on the accompanying CD-ROM) will be useful to airport managers and specifically air quality practitioners for general aviation airports.



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Summary

This guidebook and its companion Emission Inventory Analysis Tool (EIAT) have been developed as part of the Airport Cooperative Research Program (ACRP) Project 02-34, “Quantifying Aircraft Lead Emissions at Airports.” They encompass a series of best practices and guidance for estimating airport lead emissions from piston-powered aircraft fueled with aviation gasoline [or 100 grade “low lead” (100LL)] containing tetraethyl lead.

The best practices identified herein are intended to supplement (and not replace) the current Federal Aviation Administration (FAA) and Environmental Protection Agency (EPA) default methods for lead inventory preparation. EPA must approve any lead inventory methods used for regulatory purposes.

The EIAT allows users to select either FAA/EPA defaults or average site-specific results from ACRP 02-34 for inventory development or provide airport-specific inputs. At a minimum, the user must supply airport-specific annual operations data in order to estimate annual lead emissions.

FAA/EPA default methods are consistent with those utilized in the EPA’s triennial National Emissions Inventory (NEI). At the most basic level, the EIAT replicates the NEI method. However, the primary purpose of the EIAT is to allow inventories to be based on the enhanced inventory methodology developed as part of ACRP 02-34. Although two sets of default data are available, it is recommended that airport-specific data be obtained and used as input to the EIAT whenever feasible. The EIAT allows users to incrementally modify the inventory methodology—incorporating additional details or airport-specific data in place of default data and assumptions. The most significant recommendations for inventory development are summarized as follows:

1. Piston aircraft lead inventory development needs to incorporate the emissions occurring during flight-check run-up procedures (i.e., the magneto test). High lead concentrations were observed in the ACRP 02-34 air quality modeling specifically in the run-up areas. This guidebook provides a method and supporting data such that this inventory element can be addressed with no additional user input.
2. Currently, there is no reliable data source for airport-level piston operations, whereas total airport operations are widely available. The piston engine share of aircraft activity is poorly quantified by publicly available data and current methods. It is recommended that airport collection of activity-based aircraft tail numbers be completed for purposes of (1) calculating the piston-engine share of aircraft operations and (2) improving the accuracy of fleet-average aviation gasoline consumption rates (based on the locally observed fleet). The EIAT is designed to incorporate these piston fleet data, if collected, into the inventory analysis method.
3. It is recommended that airport sampling of aviation gasoline be completed to determine typical, local lead content of fuel dispensed. Current inventory methods model lead content as the maximum allowable, whereas the limited data available show that there is considerable

variation in lead content from airport-collected gasoline samples. The EIAT allows for modeling with airport-specific gasoline lead content.

4. The standard modes of operation included in existing inventory methods are not adequate to address commercial flight school activities, which are common at many general aviation airports. For the three airports of study in ACRP 02-34, “continuous” operations (i.e., those associated with training procedures) accounted for about 40 percent of all piston operations. The emissions characteristics of continuous modes are distinct and not modeled adequately by current inventory methods. The EIAT can address these modes of operation; however, the frequency of occurrence will be airport specific and should be based on locally collected data.
5. The amount of time spent in each mode, termed “time in mode” (TIM), is variable and depends on the airport configuration and the individual piston-engine aircraft. Local collection of TIM data is a means to improve the airport-specific inventory, and the EIAT facilitates the incorporation of TIM data into the inventory method.
6. 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 average fuel consumption rates from ACRP 02-34 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.

Background

Lead 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 lead 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 lead 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 lead 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 (U.S. EPA 2008).

Because general aviation airports represent a significant source of lead emissions, ACRP Project 02-34 was initiated with the objective of reviewing and improving existing methodologies to quantify and characterize aircraft-related lead emissions at airports with significant populations of aircraft that use leaded aviation gasoline. This guidebook was 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 *ACRP Web-Only Document 21*, the unpublished contractor’s report for ACRP Project 02-34 (Heiken et al. 2014).

This guidebook and the companion Emission Inventory Analysis Tool (EIAT) on the accompanying CD-ROM encompass a series of best practices for estimating airport lead emissions from piston-powered aircraft. The EIAT calculates annual airport lead emissions based upon user-selected options and input data sources. The guidebook and the EIAT are designed to be used concurrently.

The remainder of this background chapter describes the (1) current FAA/EPA default methods, (2) inventory improvements included in the EIAT, and (3) recommended use of the EIAT.

2.1 FAA/EPA Default Methods

Both the 2008 lead NAAQS and the 2010 ambient lead monitoring rulemakings declare EPA’s NEI as the default source for airport lead emission inventories. The NEI is a triennial national emissions inventory prepared by EPA; the most current published version—also known as the 2011 NEI (U.S. EPA 2013b)—is for calendar year 2011. In the 2010 rule, EPA added regulatory language stating that the facility-level lead inventory determination, which factors into the monitoring requirements, is “based on either the most recent [NEI] or other scientifically justifiable methods and data (such as improved emissions factors or site-specific data) taking into account logistics and the potential for population exposure” (U.S. EPA 2010).

This guidebook supplements the existing FAA/EPA default methods for estimating airport lead emission inventories. Use of the EIAT requires familiarity with current agency methods and resources, as agency default parameters and assumptions are incorporated into the EIAT. At the most basic level, the EIAT will simulate the 2011 NEI approach, replicating the current agency default methods.

Two references, described below, make up the FAA/EPA default methods that are cited in this guidebook. It is recommended that copies of these documents be obtained and used, as needed, in developing inventories using the EIAT.

1. The *2011 NEI documentation* specific to lead emissions from airports (U.S. EPA 2013b) provides the foundation for the default methods in this guidebook. This one document is hereinafter referred to as the “2011 NEI documentation.” The 2011 NEI documentation provides the default methods for airport operations, fuel consumption rates, determination of aircraft fleet characteristics and specification of aviation gasoline parameters. This reference is available at ftp://ftp.epa.gov/EmisInventory/2011/doc/2011nei_AircraftLead_20130827.pdf.
2. The *1992 EPA emission inventory (EI) guidance* document (U.S. EPA 1992)—which reflects the last time the agency issued official emission inventory guidance for the mobile source sector—remains relevant for key inventory elements. This document, referred to hereinafter as the “1992 EPA EI guidance,” is directly referenced in the 2011 NEI documentation; it provides additional background and details behind specific modeling assumptions, which have been carried forward over time. Relevant to this guidebook, the 1992 EI guidance further documents the default time spent in each operating mode (termed “time in mode” or TIM) that is defined for the typical landing-takeoff (LTO) cycle. This reference is available at <http://www.epa.gov/otaq/models/nonrdmdl/r92009.pdf>.

It should also be noted that since 1993, the FAA’s Emissions and Dispersion Modeling System (or EDMS) has been EPA’s preferred guideline model for emission inventory and air quality evaluations of airports (FAA 2013a). EDMS does not model lead emissions or report fuel consumption in a manner suitable for estimating lead inventories from piston-powered aircraft. While these limits to EDMS preclude its direct use in airport lead inventory development, the 2011 NEI documentation and this guidebook do refer to the EDMS when applicable, and the 2011 NEI methods and data input intentionally have considerable overlap with those of EDMS.

The ability of the EIAT to replicate the results from the 2011 NEI is summarized in Table 1. Although the EIAT uses the same default input data, the EIAT processes the calculations at

Table 1. Comparison of EIAT results using FAA/EPA default parameters to 2011 NEI.

Source	Fixed-Wing Fleet-Average Fuel Consumption (Gal./LTO)	Fixed-Wing Fleet-Average Gasoline Lead Content (Gram/LTO)	Rotorcraft Average Gasoline Lead Content (Gram/LTO)
2011 NEI Documentation	3.46 ^a	7.34 ^a	6.60 ^b
EIAT Estimate Using FAA/EPA Defaults ^c	3.35	7.10	6.49
% Difference vs. 2011 NEI	-3%	-3%	-2%

^a U.S. EPA (2013b), p. 17.

^b U.S. EPA (2013b), p. 18.

^c LTOs are not used in EIAT; reported values are estimated by assuming 1 LTO = 2 operations in the EIAT.

a more detailed level (e.g., by individual operating mode) as necessitated by the inventory enhancements. The EIAT rounds off only at the final step, and the EIAT uses a more precise Microsoft® Excel function to convert between imperial units and metric units. The differences between the 2011 NEI and the EIAT parameter estimates are 3 percent or less for the comparable results shown in Table 1.

2.2 Inventory Enhancements Available with the EIAT

The inventory methodologies available in the EIAT include several enhancements to the current FAA/EPA defaults. Before reviewing these enhancements, it should be understood that EPA acknowledges the limitations of the current default methodology; the 2011 NEI documentation includes “Section 7. Improving Airport-Specific Lead Emissions Estimates,” which outlines the following three areas for improving lead inventories:

1. Regular collection of airport-specific data on the proportion of operations by piston-engine aircraft;
2. Collection of airport-specific data on the time spent in each operation mode, and an assessment of the engine run-up procedures currently unaddressed in the default method; and
3. Determination of the airport-specific lead content in aviation gasoline dispensed, including seasonal variation.

The following enhancements relate to (1) improving the fuel consumption rate method; (2) improving operating mode modeling; and (3) facilitating the incorporation of facility-specific data.

2.2.1 Fuel Consumption Rate Method

The enhanced methodology makes use of the following for developing airport piston-fleet-average fuel consumption estimates:

1. An expanded database of piston-engine fuel consumption rates;
2. An improved method for fuel rate assignment based on engine efficiency (i.e., brake-specific fuel consumption, or BSFC);
3. Rotorcraft (RC, i.e., helicopter) engine load defined by operation mode; and
4. The capability to estimate activity-weighted fleet-average fuel rates for fixed-wing (FW) aircraft and RC.

Lead is emitted in the exhaust from gasoline-powered piston engines, as most aviation gasoline consumed still contains “low-level” lead (added to fuel in the form of tetraethyl lead). Given this, fuel consumption rates are obviously key to aircraft lead emission inventories, and the accuracy of the inventory method depends, in part, on the robustness of the piston-engine fuel consumption database.

The default FAA/EPA lead inventory approach, which is based on fuel consumption data for 6 piston-powered aircraft engines, has been enhanced by adding fuel consumption data for 29 piston-powered aircraft. Moreover, the enhanced method also uses BSFC, an efficiency metric based on fuel consumed per unit of work performed instead of volume of fuel consumed at different engine power levels, as the means for developing fuel consumption rates that factor the engine size into the final result. BSFC data are also grouped by engine/fuel metering technology, such that “default” efficiencies can be used by engine technology to map to engines not covered by the database.

The enhanced method options for assessing fleet-average piston-engine fuel consumption rates are discussed in part of Chapter 4, “Aircraft Fleet Data,” of this guidebook.

2.2.2 Operating Mode Modeling

The enhanced methodology makes two significant improvements in how operating modes are defined and applied in the inventory development:

1. The emissions associated with the magneto-test run-up procedures are addressed and
2. Additional modes of operation and modeling parameters are included so that “continuous” operations, as defined below, are addressed.

The current FAA/EPA default includes the standard four operating modes (taxi/idle, takeoff, climb-out, approach) for FW aircraft and three modes (taxi/idle, climb-out, approach) for RC. Moreover, the FAA/EPA default assumes that every two operations consist of a standalone landing and a standalone takeoff. These two operations combined are termed a “landing-takeoff cycle,” and agency inventory methods are derived and reported on a per-LTO basis with the underlying presumption that every two operations consist of a standalone takeoff and a standalone landing.

The first improvement is to address magneto-test run-up procedures, which fall outside the default modes of operation. Whereas the magneto-test run-up portion of the inventory is moderate (it adds only 5 percent more emissions to the inventory under FAA/EPA defaults), ACRP 02-34 showed that the run-up activities can result in significant airborne lead concentrations, as the emissions occur only within prescribed areas.

The second improvement addresses the finding that the standard LTO cycle approach was inadequate for evaluating the site-specific activity data collected at three airports in ACRP 02-34. A significant proportion of “continuous” operation—i.e., multiple operations executed in series such that the engine is not turned off—was observed, predominantly because of commercial flight school activity. Two distinct types of continuous operation, described below, are handled in the enhanced methodology: the “touch-and-go” and the “taxi-back.”

- **Touch-and-go operations** for FW 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 in a manner similar to 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 FW aircraft consist of a standard approach, landing, and taxiing 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 is typically omitted.

These two types of continuous operation represented approximately 40 to 50 percent of the piston-powered aircraft activity observed at the three airports during the field studies conducted. Correctly addressing the continuous operation was critical to the inventory development for these airports and will be equally important for any other facility with significant flight training operations.

The enhanced method options for defining operating mode options are discussed in Chapter 5, “Operation Mode Data,” of this guidebook. Note that because the standard LTO cycle is not representative of all piston craft operations of interest in this methodology, the fuel consumption and emission results are not expressed on a per-LTO basis; instead, the results (when reported as per unit of activity) are expressed on a per-operation basis.

Table 2. Modeling input/parameters for which facility-specific data can be used.

Modeling Input/Parameter	Guidebook Chapter	EIAT Worksheet
Annual airport operations data	Chapter 3	Worksheet 3.1
Daily airport operations data	Chapter 3	Worksheet 3.1
Distribution of operations between FW and RC	Chapter 4	Worksheet 4.1
Piston-engine share of FW aircraft operations	Chapter 4	Worksheet 4.1
Piston-engine share of RC operations	Chapter 4	Worksheet 4.1
Activity-weighted piston-engine FW aircraft fleet	Chapter 4	Worksheet 4.3
Activity-weighted piston-engine RC fleet	Chapter 4	Worksheet 4.4
Run-up occurrence frequency	Chapter 5	Worksheet 5.1
Frequency of continuous operation modes	Chapter 5	Worksheet 5.1
Time-in-mode data	Chapter 5	Worksheet 5.2
Aviation gasoline parameters	Chapter 6	Worksheet 6.1

2.2.3 Incorporation of Facility-Specific Data

By design, this enhanced methodology facilitates the incorporation of facility-specific modeling input for each of the inventory modeling parameters. Table 2 summarizes the modeling input for which facility-specific data may be used in conjunction with the inventory development. Also listed in Table 2 are the chapter of this guidebook and the worksheet of the EIAT in which the parameter enters into the analysis.

While the primary recommendation of this guidance is that facility-specific data be used whenever feasible for the parameters shown in Table 2, the approach is flexible in that screening values (e.g., FAA/EPA default modeling assumptions) are also included. The only modeling parameter for which no screening value is present in the enhanced methodology is airport operations data, which must be supplied by the user.

The approach is also flexible in that composite results from the three ACRP 02-34 airports are provided for evaluation in the EIAT for additional illustrative/screening purposes. Again, the recommended approach for inventory development is the use of locally collected, facility-specific data when feasible.

2.3 Recommended Use of the Guidebook

The guidebook/EIAT encompasses a series of best practices for estimating airport lead emissions from piston-powered aircraft.

2.3.1 Who Should Use This Guidebook

The guidebook is geared towards airport managers and air quality personnel responsible for environmental assessments. Candidate airports are any category of general aviation airports nationally, as the EIAT can perform a full range of inventory assessments from the most basic (i.e., using current FAA/EPA defaults) to the more complex (i.e., incorporating facility-specific data collection). Considerations regarding the applications of the enhanced methodology and use of the EIAT for the end-user are as follows:

1. The EIAT allows for the addition of the magneto-test run-up mode to the FAA/EPA default method without any additional user input.

2. Airports with annual lead emissions, following NEI methods, near or within the range of annual emission thresholds that trigger monitoring requirements, may apply this guidance to improve the accuracy of the inventory estimates.
3. Airports with significant flight school activities may choose to use this guidance to improve the ability to model emissions associated with continuous operations typical of training procedures.
4. Airports with lead design values close to the NAAQS may choose to apply this guidance to improve the accuracy of the inventory for air quality planning purposes.
5. The guidance may be used to evaluate the impact of modeling variables on the inventory so that the potential impact of facility data collection can be evaluated prior to developing and implementing a data collection plan.

2.3.2 How to Use This Guidebook

As mentioned, the EIAT and the guidebook are designed to be used concurrently.

The guidance contains two levels of pre-existing screening information for key inventory modeling parameters: FAA/EPA defaults and average site-specific results from ACRP 02-34. These screening data allow the methods to be applied with minimal user input. At a minimum, the user must supply airport-specific annual operations data in order to estimate annual lead emissions. However, it is recommended that facility-specific data be obtained and used whenever feasible and when airport conditions warrant.

Table 3 summarizes the guidebook structure and the corresponding EIAT worksheets. Chapters 3 through 8 of the guidebook correspond to specific EIAT worksheets as summarized in Table 3. The EIAT is designed to go through the worksheets in sequential order. The guidebook also contains two additional chapters not shown in Table 3—Chapter 9, “Implications/Limitations,” and “References.”

Further notes on the EIAT worksheet organization are provided below; these notes are also included in the “OVERVIEW” worksheet of the EIAT.

1. Worksheets of the same tab color originate from the same chapter of the guidebook.
2. The first numeric value in the worksheet name equals the chapter number of the guidebook; the second numeric value in the worksheet name is simply a sequential counter. For example, there are four worksheets related to Chapter 3 of the guidebook. These worksheets include 3.1, 3.2, 3.3, and 3.4 in the worksheet name. The worksheet title text describes the inventory element covered by the worksheet.
3. Cell A1 of each worksheet contains a comment that provides an overview of the function of the worksheet.
4. A color scheme is used to denote individual worksheet cells; the shading of specific cells is described as follows:
 - a. Grey shading denotes areas of the worksheet in which specific inventory options are summarized and implemented by the user. The user is requested to select a methodological approach option from a specific list of choices.
 - b. Green shading denotes where user input occurs. All user input will occur in green-shaded cells.
 - c. Red shading is selectively applied to highlight cell locations that should not be modified. This color coding is applied to reference values and/or specific formula, for emphasis purposes. More generally, only green-shaded cells should be modified in applying this tool.
 - d. Yellow shading is selectively used to highlight cells that include specific “comments” that provide additional information and/or clarification. Note that not all cells with comments are shaded yellow. For example, each worksheet contains a comment in Cell A1 that provides an overview of that worksheet.

Table 3. Interrelation between guidebook chapters and EIAT worksheets.

Guidebook Chapter	EIAT Worksheet	User Input?	Summary of Worksheet Function
3 – Airport Activity Data	3.1 Annual Operations	Yes	Airport-specific activity data input, select daily or annual input option
	3.2 Temporal Profiles	No	Calculates normalized profiles
	3.3 Day Chart	No	Day-of-week temporal profile chart
	3.4 Month Chart	No	Monthly profile chart
4 – Aircraft Fleet Data	4.1 Aircraft Fleet	Yes	Selection of approach option for fleet apportionment data, input of fleet apportionment data
	4.2 Piston Fuel Rates	Yes	Selection of fuel rate assignment options
	4.3 FW Piston Fleet	Yes	Optional user input of detailed piston-engine fleet for FW aircraft
	4.4 RC Piston Fleet	Yes	Optional user input of detailed piston-engine fleet for RC
	4.5 Piston BSFC Data	No	BSFC database
	4.6 Example Piston Aircraft	No	ACRP 02-34 unique set of piston-engine aircraft and BSFC assignment
5 – Operation Mode Data	5.1 Mode Definitions	Yes	Selection of mode options, input of mode frequency parameters
	5.2 Time in Mode	Yes	Selection of TIM options and data input
6 – Aviation Gasoline Data	6.1 Gasoline Parameters	Yes	Definition of gasoline parameter assumptions
7 – Inventory Calculations	7.1 Calculations	No	Series of calculations to support inventory results reporting
8 – Inventory Results	8.1 Inventory Results	Yes	Inventory results presentation; input of inventory descriptors



CHAPTER 3

Airport Activity Data

3.1 Overview

There are four worksheets denoted with orange-shaded tabs in the EIAT for the input and processing of airport activity data.

- Worksheet 3.1 is where the annual airport operations data source option is selected and the corresponding data are entered. These are the only data entry items for Chapter 3.
- Worksheet 3.2 estimates monthly and day-of-week temporal profiles. Worksheets 3.3 and 3.4 are charts of the resulting day-of-week and monthly temporal profiles, respectively. The temporal profiles are useful for inventory processing; however, these data do not impact the annual inventory estimates reported by the EIAT.

3.2 Annual Operations: Worksheet 3.1

The annual operations are the only facility-level input to the EIAT for which no pre-existing default exists; the user must supply the annual activity data. Two commonly available format options of annual data maintained by FAA are supported for input into the EIAT: the Terminal Area Forecast (TAF) and the Air Traffic Activity Data System (ATADS) standard report.

There are two required actions for this worksheet:

1. Select the approach option for the format of the annual data and
2. Input annual airport operations data in the format of the selected option.

There are no optional actions for this worksheet.

Table 4 summarizes the inventory options for entering annual operations data; this table also appears in Worksheet 3.1. The user must select either the standard ATADS report (daily) or TAF-formatted data for entering the airport annual operations. Selection is completed with a pull-down menu.

FAA's ATADS database includes 515 facilities for calendar year 2013; TAF covers approximately 3,400 facilities for 2013. For those facilities not covered by ATADS or TAF, the 2011 NEI documentation (U.S. EPA 2013b) should be consulted for alternative methods for estimating annual emissions, and those results can be readily adapted and entered into the EIAT through the TAF-formatted option in Worksheet 3.1.

The ATADS is the preferred resource for annual airport operations because the data can be reported in daily format, which also supports the preparation of temporal profiles. The format of ATADS incorporated into the EIAT is daily reporting within the standard report covering an entire year. There are no restrictions on which calendar year's data may be entered. Date-specific

Table 4. Inventory options for annual airport operations.

Inventory Option	Title	Description
Facility Specific 1	Facility Data, Standard ATADS Report (Daily)	User input of FAA ATADS standard airport report (daily operations) for any calendar year.
Facility Specific 2	Facility Data, User-Supplied TAF Format Operations	User-supplied total annual operations (FAA's Terminal Area Forecast).

operations should always begin in Row 9 and continue to Row 373 or Row 374 (depending on leap year).

The ATADS airport operations standard report can be downloaded electronically at the Airport Operations page of the ATADS website: <http://aspm.faa.gov/opsnet/sys/Airport.asp>. The format for the standard report directly used by the EIAT calls for the user to select the following reporting options:

Range: <any annual period>
 Grouping: Date
 Facility: <user selected facility>
 Display: Standard Report
 Show Itinerant: Yes
 Show Local: Yes
 Format: Excel
 Filters: <no filters>

Use of TAF data is the second preference for the entry of an airport's annual operations. The TAF covers historic years as well as future-year forecasts. These data are available at FAA's TAF website: <http://aspm.faa.gov/apowtaf/>. It should be noted that caution should be exercised when using future-year forecasts, and that reasonableness of future-year TAF data should be verified using information from other sources.

Additional comments and remarks on the use of Worksheet 3.1 are as follows.

1. The operations data are reported for four aircraft operations classes individually (air carrier, air taxi, general aviation, military). For completeness, it is recommended that all four classes of aircraft be included even though the vast majority of piston-engine aircraft will fall under the air taxi and general aviation classes. Some military applications are powered by piston engines; it is not expected to find piston-engine aircraft classified as "air carrier."
2. Columns AO to BI of Worksheet 3.1 contain the 2013 ATADS data for all 515 facilities reporting in that year. These are used to estimate national average, default temporal profiles. These national data should not be modified in normal use of the EIAT.

3.3 Temporal Profiles: Worksheets 3.2, 3.3, and 3.4

There are three purposes for calculating and reviewing the temporal variation of the operations:

1. The NAAQS design value is the maximum rolling 3-month (i.e., calendar month) average over a 3-year period; it is necessary for air quality planning to know the variation in activity by month.
2. If an airport data collection plan is developed, it is important to capture a representative fleet and representative activity. In developing that plan, it is important to understand the temporal variation in sources in order to ensure that the data collected are representative data.

Table 5. Default national day-of-week temporal profile.

Day	Percentage of Weekly Operations	
	General Aviation	Air Taxi
Sunday	11.8%	12.5%
Monday	13.7%	14.6%
Tuesday	14.5%	14.9%
Wednesday	15.4%	15.3%
Thursday	15.1%	15.5%
Friday	15.4%	15.6%
Saturday	14.1%	11.5%

3. Because temporal variation is observed to be regional and airport specific, the use of a default national average is less precise. Northern regions tend to have peak activity in the summer; southern regions tend to have peak activity in the winter. Some general aviation airports are busier on weekdays and some on weekends.

Worksheet 3.2 calculates facility and national default temporal profiles from the daily ATADS data supplied in Worksheet 3.1. If airport-specific ATADS data are not supplied by the user, the facility temporal data are not computed. Worksheets 3.3 and 3.4 present the day-of-week and monthly profile charts, respectively.

There are no user inputs to Worksheets 3.2, 3.3, and 3.4: the calculations are based on the activity data from Worksheet 3.1 and will represent the year of data supplied in that worksheet.

There are no user actions needed (required or optional) to complete the temporal profile calculations.

The national default temporal profiles for day-of-week and monthly activity variation, based on 2013 data, are presented in Tables 5 and 6, respectively. Examples of day-of-week and monthly profile charts from the EIAT are presented in Figures 1 and 2, respectively.

Table 6. Default national day-of-week temporal profile.

Day	Percentage of Monthly Operations	
	General Aviation	Air Taxi
January	10.02%	9.65%
February	9.05%	7.76%
March	9.77%	8.92%
April	10.15%	8.32%
May	9.84%	8.56%
June	7.62%	7.37%
July	9.06%	8.97%
August	8.21%	9.94%
September	6.70%	8.70%
October	7.79%	9.03%
November	5.73%	6.50%
December	6.06%	6.26%

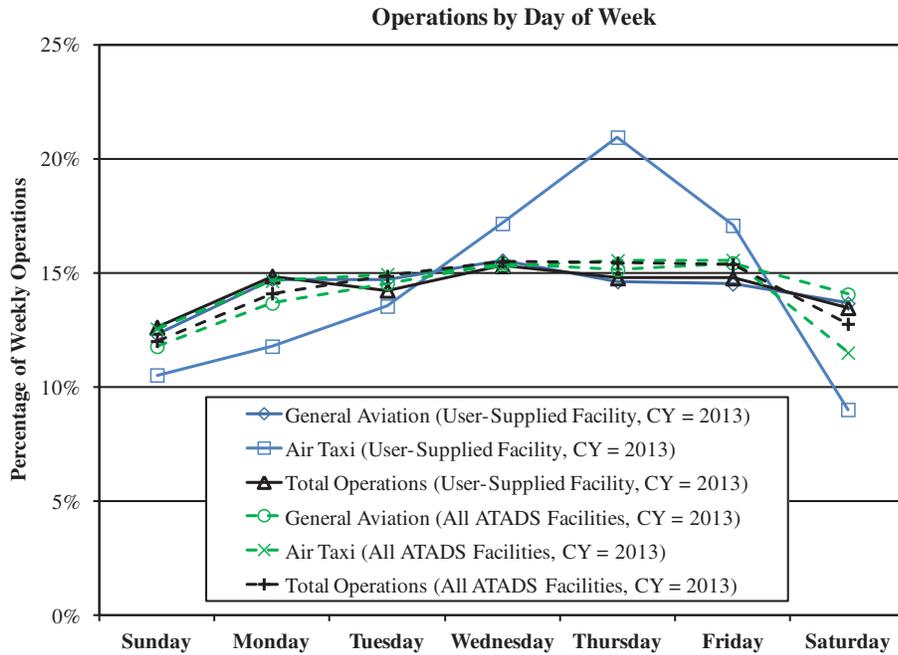


Figure 1. Example day-of-week temporal profile.

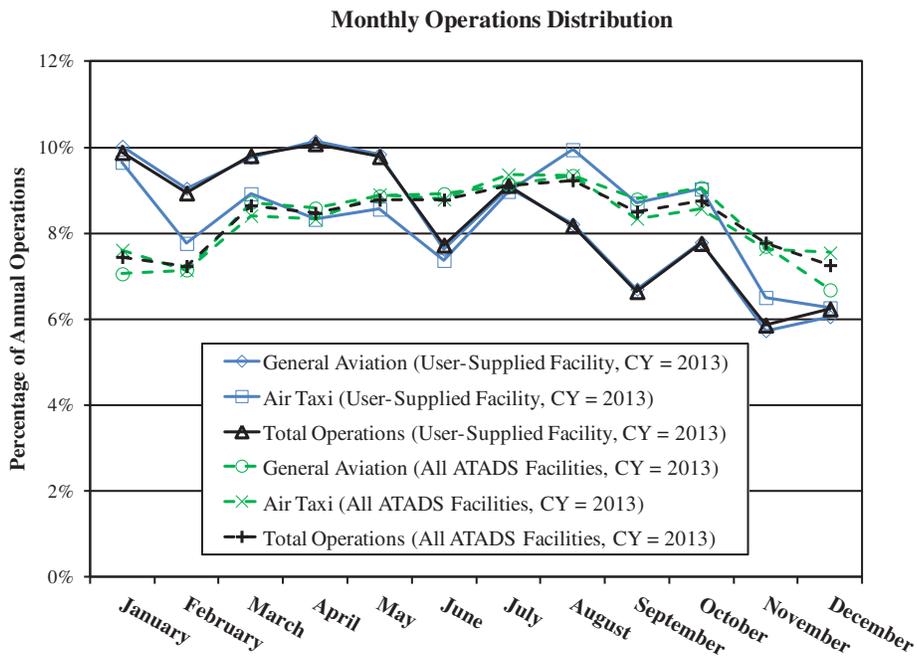


Figure 2. Example monthly temporal distribution.



CHAPTER 4

Aircraft Fleet Data

4.1 Overview

There are six worksheets denoted with green-shaded tabs in the EIAT for the input and processing of aircraft fleet data. These data define the proportion of operations by fixed-wing aircraft and rotorcraft and the proportion of piston engines within those two aircraft types. Moreover, the user has the option to input detailed piston-powered aircraft data to determine airport-specific aviation fuel consumption rates.

- Worksheet 4.1 establishes the proportions of operations from FW aircraft, the FW operations conducted by piston engines, and the RC operations by piston engines for the inventory.
- Worksheet 4.2 assigns fuel consumption rates based on a user-selected approach.
- Worksheets 4.3 and 4.4 define the airport-specific piston-engine fleets to support the option of incorporating facility-specific, piston-engine fuel consumption rates.
- Worksheets 4.5 and 4.6 contain data on fuel consumption rates and example piston aircraft information to support the application of the enhanced methodology using facility-specific aircraft data (Worksheets 4.3 and 4.4).

4.2 Aircraft Fleet: Worksheet 4.1

Worksheet 4.1 is where the data are input; these data are needed to apportion the total operations (supplied by the user from Worksheet 3.1) into FW and RC shares and into piston-engine shares of both aircraft types. Proportions are to be based on observed operations (i.e., activity based).

There is one required action for this worksheet: select the approach option for the source of the fleet apportionment data. There are two optional actions for this worksheet where the user supplies additional data if “current FAA/EPA default” or “facility-specific approach” options are selected.

Table 7 summarizes the options for entering annual operations data; this table also appears in Worksheet 4.1. The preferred approach is that facility-specific data are collected and entered. In the absence of this, the user must specify the use of one of two screening approaches: current FAA/EPA defaults or ACRP 02-34 results.

The option selected then defines the source of values for the following three parameters: the percentage of operations from FW aircraft, the share of FW operations by piston engines, and the share of RC operations by piston engines. The parameters assigned for the two screening inventory options are presented in Table 8. Note that the *percentage of operations from RC* in the methodology is equal to 100 percent minus the percentage of operation from FW aircraft.

Table 7. Inventory options for apportioning operations by aircraft and engine type.

Inventory Option	Title	Description
Screen 1	FAA/EPA Default	EPA default assumptions for apportioning total annual operations between FW aircraft and RC and for piston shares by aircraft type. Additional user input may be required.
Screen 2	ACRP 02-34 Data	ACRP 02-34 data (average over three airports) for apportioning total annual operations between FW aircraft and RC and for piston shares by aircraft type.
Facility Specific	Facility Data, User Supplied	User-supplied, facility-specific data for apportioning annual operations between FW aircraft and RC for piston shares by aircraft type. Additional user input is required.

An important clarification must be made regarding which FAA/EPA default method is applied in the enhanced methodology for defining the piston-engine share of FW aircraft operations. The 2011 NEI documentation employs two methods: use of airport-based aircraft data from FAA Form 5010 (Airport Master Record), and use of national default survey data for airports without based aircraft data (U.S. EPA 2013b). The enhanced methodology uses the latter—national default survey data—estimating that 21.8 and 72.1 percent of air taxi and general aviation operations, respectively, were from piston-powered aircraft (as reported in Table 8).

For the following reasons, the enhanced methodology does not incorporate the 2011 NEI methodology based on the use of FAA Form 5010 based aircraft population data to approximate the piston share of FW aircraft operations:

1. The 2011 NEI documentation mistakenly states that the Form 5010 reporting for airport aircraft populations for single-engine and multi-engine aircraft represents piston-powered aircraft only. It was confirmed with the FAA that these values (both single-engine and multi-engine) are the combination of piston-engine and turboprop-engine airplanes as reported in Form 5010, and turboprop engines are not piston engines.
2. The study that the 2011 NEI documentation claims validates this approach also does not distinguish between piston and turboprop engines (Louis Berger Group 2010); therefore, this specific population-based approach has not been validated with piston-only operations.

Table 8. Aircraft/engine apportionment parameters for screening inventory options.

Inventory Option	Parameter	Activity-Based Proportions by Aircraft Class			
		Air Carrier	Air Taxi	General Aviation	Military
FAA/EPA Default	% of Operations from FW ^a	100.00%	100.00%	100.00%	100.00%
	% of FW Operations by Piston Engines	0.00%	21.80%	72.10%	0.00%
	% of RC Operations by Piston Engines	0.00%	2.00%	35.80%	0.00%
ACRP 02-34 Data	% of Operations from FW	100.00%	98.99%	98.99%	100.00%
	% of FW Operations by Piston Engines	0.00%	80.98%	80.98%	0.00%
	% of RC Operations by Piston Engines	0.00%	37.36%	37.36%	0.00%

^a Note that the FAA/EPA defaults assume one of two cases—100 percent operation by FW aircraft or 100 percent operation by RC, depending on whether the facility is listed as “airport” or “heliport,” respectively, in FAA Form 5010 (Airport Master Record), which requires the user to input these values based on the facility type under evaluation. The values shown here are reflective of airports.

3. An aircraft population-based approach for determining the piston-engine share should be made only if (1) exclusively piston-powered aircraft populations are known and (2) airport operations are predominantly private only or commercial only (but not a mixture of both, as the usage rates are significantly different by ownership types).

The preferred approach option is to collect and implement facility-specific data and modeling parameters. The recommended approach for implementing this option is to capture operation-based aircraft tail number data. Correlating these data with the FAA tail number registry will produce a breakdown of operations by piston and non-piston engines, RC, and FW aircraft. Additionally, the use of tail number data and FAA registry data is the resource for Section 4.4 of this guidebook under the discussion of detailed piston fleet data used to support the development of average-fleet piston-engine fuel rates.

The approach and setup for capturing aircraft tail number data are described in *ACRP Web-Only Document 21* (Heiken et al. 2014). Aircraft tail numbers are matched to the specific airframe and engine parameters through the data contained in FAA's Aircraft Registry database. The downloadable database (http://www.faa.gov/licenses_certificates/aircraft_certification/aircraft_registry/releasable_aircraft_download/) contains a compressed file with several comma-delimited text files. The MASTER.txt file is the tail number registry (i.e., N-number registry). If the tail number is not found, the user should also search the Dereg.txt file (i.e., deregistered planes file) for the tail number. The tail number record is combined with the data in files ACFTREF.txt (aircraft reference file) and ENGINE.txt (engine reference file) to produce the fleet data needed for this evaluation. The following four engine types in the registry data are piston engines: reciprocating, 2-cycle, 4-cycle, and rotary.

Note that turboprop-powered aircraft have propellers, and it is important to understand that the mere presence of propellers is not the sole indicator of a piston engine (albeit most propeller aircraft are equipped with piston engines). Accurate visual differentiation between turboprop propellers and piston propellers while collecting facility data is not probable, and tail number identification should be employed for obtaining operations data by engine type.

Note that ACRP 02-34 researchers evaluated whether the use of airport-specific aircraft data recorded in FAA's Traffic Flow Management System Counts (TFMSC)—previously known as ETMSC—could provide a resource of airport piston proportions and piston fleet details. It was determined that a sampling bias in the subset of aircraft captured made the Traffic Flow Management System Counts inaccurate and unusable for estimating airport-specific piston fleets and their proportions to total airport activity (Heiken et al. 2014). It is strongly recommended that this resource not be utilized in lead emission inventory development from piston engines.

4.3 Piston Fuel Rates: Worksheet 4.2

Worksheet 4.2 is where the fuel rate assignment options are set and where the screening values for fleet-average, piston-engine fuel consumption rates enter into the EIAT. Separate options for assigning fuel rates can be implemented for FW aircraft and RC. Fuel consumption rates are specific to each individual operating mode (the modes of operation are discussed in Chapter 5 of this guidebook).

There are two required actions for this worksheet:

1. Select the approach option for piston-engine FW aircraft fuel rates and
2. Select the approach option for piston-engine RC fuel rates.

Tables 9 and 10 summarize the options for fuel rate assignment for FW aircraft and RC, respectively. If the user selects facility-specific rates (for either aircraft type), the data input and

Table 9. Options for assigning piston-engine FW aircraft fuel rates.

Inventory Option	Title	Description
Screen 1	FAA/EPA Default	EPA default fuel consumption rates for piston-powered FW aircraft.
Screen 2	ACRP 02-34 Data	Activity-weighted average fuel consumption rates observed for three airports.
Facility Specific	Facility Data, User Supplied	Fuel consumption rates estimated from detailed aircraft fleet data supplied by user. User data entered in Worksheet 4.3.

Table 10. Options for assigning piston-engine RC fuel rates.

Inventory Option	Title	Description
Screen 1	FAA/EPA Default	EPA default fuel consumption rates for piston-powered RC.
Screen 2	ACRP 02-34 Data	Activity-weighted average fuel consumption rates observed for three airports.
Facility Specific	Facility Data, User Supplied	Fuel consumption rates estimated from detailed aircraft fleet data supplied by user. User data entered in Worksheet 4.4.

calculations occur elsewhere in Worksheets 4.3 and 4.4, and no further data entry is required in this worksheet. If the user selects either screening approach (for either aircraft type), those screening values are presented in this worksheet.

Table 11 presents the fleet-average, piston-engine fuel consumption rates for the two screening inventory options. The FAA/EPA defaults shown were determined by extracting modal fuel consumption rates from EDMS and following the documented weighting factors in the 2011 NEI. FAA/EPA defaults for the “run-up” and “touch-and-go ground roll” modes do not exist in EDMS and were estimated. These “default” modal values were calculated from the same set of engines used for the remaining FAA/EPA default values, using the procedures and assumptions specific to these operation modes. This addition to the FAA/EPA default fuel consumption rates was completed so that the full range of operating modes could be assessed with FAA/EPA default fuel rates, if such a scenario were selected by the EIAT user.

Table 11. Modal gasoline consumption rates for piston engines (lb/hr) by screening approach option.

Operation Mode	FAA/EPA Default		ACRP 02-34 Data	
	Fixed-Wing Aircraft	Rotorcraft	Fixed-Wing Aircraft	Rotorcraft
Takeoff	147.6	n/a	117.3	n/a
Climb-out	112.7	101.1	92.5	115.0
Approach	62.0	55.0	52.4	72.4
Taxi/Idle	14.2	12.6	15.4	40.4
Run-up	66.5 ^a	70.6 ^a	55.7	62.5
Touch-and-Go Ground Roll	80.9 ^a	n/a	66.35	n/a

^a Note that FAA/EPA default values for “run-up” and “touch-and-go ground roll” operating modes were estimated from the aircraft engine data used by EPA to define defaults for the remaining modes.

Tables 12 and 13 present additional information on the number of engines and the underlying distribution of engines used to develop the screening fuel consumption rates for the FAA/EPA and ACRP 02-34 screening options, respectively. Table 12 presents the proportional mix of six engines used to calculate the FAA/EPA default fuel consumption rates; these are based on the 2011 NEI documentation. Table 13 presents the engines and weighting used for the ACRP 02-34 screening values; there are 28 gasoline-powered piston engines and 23 unique emission rates estimated by the ACRP 02-34 methodology. The ACRP 02-34 weighting factors are activity based across the three airports evaluated.

Additional comments and remarks on the use of Worksheet 4.2 are as follows:

1. If screening-based fuel consumption rates are used in an inventory analysis, it is recommended that the values from ACRP 02-34 be used as the underlying data because its fuel rate method and weighting assumptions are improvements over the methods used to create the FAA/EPA defaults.
2. Engine load assumptions for RC differ by approach option selected in Worksheet 4.2 (see Table 10). For the “FAA/EPA default” option, the RC engine load assumptions do not differ from the engine load assumptions for FW aircraft (for the same mode)—a notably poor assumption. Conversely, for the two options of “ACRP 02-34 Data” and “Facility Data, User Supplied,” the enhanced method includes the RC-specific recommended load points from the Swiss FOCA (Switzerland Federal Office of Civil Association 2009). Loads of 20, 60, and 95 percent are assumed for idle/taxi, approach, and climb-out, respectively, based on the detailed FOCA study of helicopter operations and emissions.
3. There is a compression-ignition (CI) category of piston engines in the enhanced methodology (as shown in Table 13). These engines are similar to diesel-powered automotive engines, and aircraft CI engines burn jet fuel rather than aviation gasoline. In the enhanced method, the CI piston engines (observed about 1 percent of the time in ACRP 02-34) are assigned a gasoline consumption rate of zero, as these engines do not consume aviation gasoline. With the zero-level fuel consumption rate, these engines are then treated as any other piston engine in the inventory analysis.

Table 12. Six piston engines from EDMS used to define FAA/EPA default fuel consumption rates.

Engine Manufacturer ^a	Engine Model	Engine/Fuel Metering Technology	Engine Distribution	
			Fixed-Wing	Rotorcraft
Lycoming	IO-320-DIAD	Fuel-injected, horizontally opposed, 4-stroke	15%	25%
Continental	IO-360-B	Fuel-injected, horizontally opposed, 4-stroke	15%	25%
Continental	O-200	Carbureted, horizontally opposed, 4-stroke	15%	0%
Lycoming	O-320	Carbureted, horizontally opposed, 4-stroke	15%	25%
Lycoming	TIO-540-J2B2	Turbocharged, fuel-injected, horizontally opposed, 4-stroke	20%	0%
Continental	TSIO-360C	Turbocharged, fuel-injected, horizontally opposed, 4 stroke	20%	25%

^a “Continental” refers to both “Continental Aircraft Engine Company” and “Teledyne Continental Motors”; “Lycoming” refers to both “Lycoming” and “Textron Lycoming.”

Table 13. Engine distribution used to develop ACRP 02-34 screening-case fuel consumption rates.

Technology Group	Engine Manufacturer & Model Number or Engine Displacement ^a	Engine Count for Fuel Rate Development	Engine Distribution Observed in ACRP 02-34	
			Fixed-Wing Aircraft	Rotorcraft
4-Stroke Horizontal Compression Ignition (CI)	All	n/a	0.7%	0.0%
	Default	8	16.3%	30.0%
	Lycoming 320	2	16.3%	0.0%
4-Stroke Horizontal Spark Ignition (SI), Carbureted	Lycoming 360	1	10.3%	0.0%
	Lycoming 540	1	1.3%	0.0%
	Rotax 912	2	3.5%	0.0%
	Continental 200	1	0.5%	0.0%
	Continental 6-285	1	0.0%	0.0%
4-Stroke Horizontal SI, Fuel Injection	Default	8	6.7%	0.0%
	Lycoming 320	2	0.2%	0.0%
	Lycoming 360	1	27.4%	70.0%
	Lycoming 540	2	2.1%	0.0%
	Continental 360	1	2.0%	0.0%
4-Stroke Horizontal SI, Turbocharged	Continental 550	2	3.0%	0.0%
	Default	9	0.2%	0.0%
	Lycoming 540	3	2.8%	0.0%
	Rotax 914	1	0.0%	0.0%
	Continental 360	1	1.0%	0.0%
4-Stroke Radial SI	Continental 520	1	3.7%	0.0%
	Continental 550	3	0.6%	0.0%
	Default	2	1.5%	0.0%
2-Stroke Horizontal SI	Wright 1820 ^b	1	0.0%	0.0%
	Rotax 582	1	0.0%	0.0%

^a “Continental” refers to both “Continental Aircraft Engine Company” and “Teledyne Continental Motors”; “Lycoming” refers to both “Lycoming” and “Textron Lycoming.”

^b The Wright R-1820 engine was observed at the field study conducted at the Centennial Airport (Denver, Colorado) but was omitted from this screening approach. The Boeing B-17 (known as the Flying Fortress) has four large Wright 1820 radial engines; the aircraft’s fuel consumption rates are 40 to 50 times higher than the average general aviation plane. This aircraft was present for a special event and may not be suitably representative as a screening value.

4.4 Detailed Piston Fleet Data: Worksheets 4.3 and 4.4

Worksheets 4.3 and 4.4 are where the user supplies the airport-specific piston-engine fleets to support the option of developing facility-specific, piston-engine fuel consumption rates. Both Worksheets 4.3 and 4.4 are described herein, as the format and function is nearly identical. Worksheet 4.3 is user-supplied FW aircraft data; Worksheet 4.4 is user-supplied RC data.

There are no required user actions for this worksheet.

There are two optional actions that need to be taken if the user has selected the “Facility Data, User Supplied” option for either FW aircraft or RC in Worksheet 4.2.

1. If the “Facility Data, User Supplied” option is selected for FW aircraft in Worksheet 4.2, then the aircraft data in Worksheet 4.3 must be entered.

2. If the “Facility Data, User Supplied” option is selected for RC in Worksheet 4.2, then the aircraft data in Worksheet 4.4 must be entered.

The recommended approach for acquiring fleet data, as applied in the field studies of ACRP 02-34, is to capture operation-based aircraft tail number data. Correlating these data with the FAA tail number registry will produce a breakdown of operations by piston and non-piston engines, RC, and FW aircraft. Additionally, the use of tail number data and FAA registry data is the recommended resource for Chapter 4.2 of this guidebook under the discussion of aircraft fleet apportionment data.

The approach and setup for capturing aircraft tail number data are described in *ACRP Web-Only Document 21* (Heiken et al. 2014). Aircraft tail numbers are matched to the specific airframe and engine parameters through the data contained in FAA’s Aircraft Registry database. The database (http://www.faa.gov/licenses_certificates/aircraft_certification/aircraft_registry/releasable_aircraft_download/) contains a compressed file with several comma-delimited text files. The MASTER.txt file is the tail number registry (i.e., N-number registry). If the tail number is not found, the user should search the Dereg.txt file (i.e., deregistered planes file) for the tail number. The tail number record is combined with the data in files ACFTREF.txt (aircraft reference file) and ENGINE.txt (engine reference file) to produce the fleet data needed for this evaluation. Note that the following four engine types in the registry data are piston engines: reciprocating, 2-cycle, 4-cycle, and rotary.

In Worksheets 4.3 and 4.4, the detailed aircraft fleet data entered are restricted to just the piston-engine aircraft. The following list provides the aircraft fleet defining parameters:

- Tail number
- Aircraft manufacturer
- Aircraft model
- Aircraft type
- Manufacture year
- Engine type
- Engine manufacturer
- Engine model
- Engine horsepower
- Displacement or model number
- Number of engines

Of the listed parameters, all but “displacement or model number” are found through the FAA registry. The displacement or model number is the numeric portion of the engine model, the value of which is pertinent to the BSFC database (Worksheet 4.5). Note that for Lycoming and Continental engine models, the numeric portion of the engine model is typically the engine displacement (in cubic inches).

Of the listed parameters, only the values for “engine horsepower” and “number of engines” numerically enter into the emission inventory calculations. The remaining aircraft fleet identifying parameters are useful in assigning BSFC rates and identifying the technology group (by which the BSFC data are organized).

Additional comments and remarks for entering facility-specific piston-engine aircraft data are as follows:

1. Operational counts are supplied in Column M, allowing for weighting data based on the total counts observed.
2. In Column O, the user is responsible for assigning the BSFC rate to each entry from the 23 options available. The assignment process is described in Section 4.5.
3. Worksheets 4.3 and 4.4 can handle up to 1,000 unique aircraft entries.

4. The pre-existing data in Worksheets 4.3 and 4.4 (10 FW aircraft records and 6 RC records) are random, dummy data intended to facilitate understanding of the EIAT and the data entry of these worksheets. These pre-existing data are not representative of any case and should not be used in any inventory analysis.
5. As described in *ACRP Web-Only Document 21* (Heiken et al. 2014), the calculation of fuel consumption rate from BSFC is completed according to the following formula:

$$\text{Fuel Rate}_{\text{Mode}} \left(\frac{\text{lb}}{\text{hr}} \right) = \text{BSFC}_{\text{Mode}} \left(\frac{\text{lb}}{\text{hp-hr}} \right) \times \text{Load}_{\text{Mode}} \times \text{Rated Power (hp)}$$

4.5 BSFC Data: Worksheet 4.5

Worksheet 4.5 contains the BSFC database developed in ACRP 02-34; *ACRP Web-Only Document 21* (Heiken et al. 2014) should be consulted for further information related to their compilation, if needed.

There are no required or optional actions associated with this worksheet; there are no user inputs or modifications to be completed in this worksheet.

BSFC assignment to individual user-supplied piston-engine aircraft (Worksheets 4.3 and 4.4) is performed manually by the user. The assignment requires the user to determine the technology group to which the aircraft engine belongs. The BSFC data are organized by the following six technology groups:

- 4-stroke horizontal spark-ignition (SI) engine, carbureted;
- 4-stroke horizontal SI engine, fuel injected;
- 4-stroke horizontal SI engine, turbocharged;
- 4-stroke radial SI engine;
- 2-stroke horizontal SI engine; and
- 4-stroke horizontal CI engine.

The following steps and criteria are used for BSFC assignment (pull-down menus in Column O of worksheets 4.3 and 4.4) using Worksheet 4.5:

1. Identify the technology group.
2. Within the technology group, assign the BSFC for the specific engine and model number if the engine and model number match the aircraft being assigned.
3. If the engine and model do not match, use the “default” BSFC within the technology group.

The “engine model” shown in the BSFC database is the engine model with the leading letters and suffix letters removed. For example, the Continental TSIO-520 series engine falls under the “4-stroke horizontal SI engine, turbocharged” technology group and appears in the database as “Continental 520” within that group. For Lycoming and Continental engine models, the numeric portion of the engine model is typically the engine displacement (in cubic inches).

Upon assignment of a few engines, it becomes readily apparent that the leading letters in the engine model are typically sufficient for defining the technology group. To facilitate the learning curve in assigning BSFC values, the complete set of unique aircraft identified in ACRP 02-34 field studies is provided in Worksheet 4.6. The aircraft data in Worksheet 4.6 include the BSFC assignment and can be used as a template for many common aircraft/engine combinations.

Additional comments and remarks on the use of Worksheet 4.5 are as follows:

1. The BSFC values at the RC-specific load points are determined by interpolation in Worksheet 4.5 (with the formula present in the worksheet). Fuel consumption test data obtained

in ACRP 02-34, which form the foundation of this database, did not test the RC-specific load points because these are not standard modes.

2. There is a CI category of piston engines in Worksheet 4.5 (described previously in Section 4.3 of this guidebook). The CI engines are piston engines that burn jet fuel and are assigned a BSFC value of zero in the enhanced methodology, as they do not consume aviation gasoline.

4.6 Example Piston Aircraft: Worksheet 4.6

Worksheet 4.6 contains the more than 300 unique piston-engine aircraft observed in the ACRP 02-34 site-specific data collection efforts.

There are no required or optional actions for this worksheet; there are no user inputs or modifications to be completed for this worksheet.

The purpose of including these data in the EIAT is to support the BSFC assignment process in Worksheet 4.5. These data are aircraft examples and have no function in the actual inventory calculations. The detailed aircraft parameters and the corresponding BSFC assignments are provided as searchable examples.

Note that these data are not activity weighted and therefore any composite estimated from these data is not representative of any real-world case. These data, on whole, should not be used to estimate average fuel consumption rates because of the lack of an activity-based observation frequency.

Operation Mode Data

5.1 Overview

Two worksheets denoted with blue-shaded tabs in the EIAT are used for selecting inventory options for defining operating modes and TIM assumptions.

- Worksheet 5.1 is where the options for defining operating modes are selected by the user and parameter values corresponding to the approach option are set.
- Worksheet 5.2 is where the option for defining TIM is selected by the user and TIM values corresponding to the approach option are set.

5.2 Mode Definitions and Modeling Parameters: Worksheet 5.1

Worksheet 5.1 is where the user selects the options that determine model operating modes, which in turn define the set of operation modes that will be included in the inventory analysis.

There are two required actions for this worksheet: (1) select the inventory option for FW aircraft operating modes and (2) select the inventory option for RC.

There are two optional actions for this worksheet where the user supplies additional data if the facility-specific approach option is selected for either FW aircraft or RC.

Table 14 summarizes the options for defining FW aircraft operating modes; this table also appears in Worksheet 5.1. The preferred approach is that facility-specific data are collected and entered. In the absence of this, the user must specify the use of one of three screening approaches: current FAA/EPA defaults, FAA/EPA defaults with run-up included, or ACRP 02-34 data. The FAA/EPA default option includes four modes: taxi/idle, takeoff, climb-out, and approach.

Table 15 summarizes the options for defining RC operating modes; this table also appears in Worksheet 5.1. The preferred approach is that facility-specific data are collected and entered. In the absence of this, the user must specify one of two screening approaches: use of current FAA/EPA defaults or use of FAA/EPA defaults with run-up included. The FAA/EPA default option includes three modes: idle, climb-out, and approach.

Tables 14 and 15 include the options associated with the standard FAA/EPA default, both with and without the completion of the magneto test (as a pre-flight-check procedure). The magneto test is a required procedure before each leg of a flight during which the engine has been turned off. Whereas the 2011 NEI methods exclude the run-up mode, this EIAT also includes a second approach option of FAA/EPA default with the run-up magneto test included. For FW aircraft, the inclusion of the run-up procedure adds about 5 percent to the lead inventory

Table 14. Inventory options for defining FW aircraft operating modes.

Inventory Option	Title	Description
Screen 1	FAA/EPA Default	Application of the four EDMS operation modes (taxi/idle, takeoff, climb-out, approach) assuming every two operations consist of a standalone landing and a standalone takeoff.
Screen 2	FAA/EPA Default with Run-up Included	EPA/FAA default (Screen 1) updated to include performance of a magneto run-up prior to takeoff by every piston-powered FW aircraft.
Screen 3	ACRP 02-34 Data	Application of operation modes defined by the three airport-average results from ACRP 02-34. Incorporates facility-specific data to account for continuous operations and observed run-up frequencies.
Facility Specific	Facility Data, User Supplied	User-supplied input for facility.

under FAA/EPA default conditions. It is recommended that the run-up procedure be included in all inventory development, even when using FAA/EPA default operating mode assumptions.

Specific parameters are used with the enhanced methodology to define the extent to which continuous operations are observed at the facility, which are implemented based on the approach option selected. As described in Section 2.2.2 of this guidebook, there are two types of continuous operations handled in this enhanced methodology—“taxi-back” and “touch-and-go” operations:

1. The taxi-back operation is an aircraft landing and then taxiing back to a runway and taking off again without turning the engine off. A taxi-back counts as two operations: a landing and a takeoff.
2. A touch-and-go is a landing with a brief ground roll followed by an immediate takeoff, all occurring on a single runway. The touch-and-go operation counts as two operations—a landing and a takeoff—which is important to defining the touch-and-go rate of frequency (defined as a fraction of total operations).

These apply only to FW aircraft operations. Continuous operations are typical of pilot training procedures and were observed frequently during airport studies conducted during ACRP 02-34.

The FAA/EPA default for operation modes assumes that every two operations consist of a standalone landing and a standalone takeoff. These two operations combined are termed a “landing-takeoff (LTO) cycle,” and agency inventory methods are derived and reported on a per-LTO basis with the underlying presumption that every two operations consists of a standalone takeoff and a standalone landing.

Table 15. Inventory options for defining RC operating modes.

Inventory Option	Title	Description
Screen 1	FAA/EPA Default	Standard EDMS three-mode approach of idle, climb-out, and approach.
Screen 2	FAA/EPA Default with Run-up Included	EPA/FAA default of three modes (Screen 1) updated to include performance of a magneto run-up prior to departure by every piston-powered RC.
Facility Specific	Facility Data, User Supplied	User-supplied input for facility.

For FW aircraft, the approach option selected in Table 14 then corresponds to setting the values for the following four parameters within the enhanced methodology:

- Touch-and-go rate—the fraction of facility operations that are touch-and-go;
- Taxi-back rate—the fraction of FW landings that then taxi-back and takeoff again without turning off the engine;
- Run-up frequency (for a taxi-back takeoff)—the fraction of occurrence of a taxi-back operation performing a run-up test prior to takeoff; and
- Run-up frequency (for a standalone takeoff)—the fraction of occurrence of a standalone takeoff (one that begins with the engine off and is not a continuous operation) performing a run-up test prior to takeoff.

Accordingly, the values assigned for each of the three FW screening inventory options are presented in Table 16. If continuous operations are not expected to be significant, then the FAA/EPA default with run-up included is the recommended approach option. If continuous operations do occur at the facility, then the recommended approach is for the user to supply the parameter values based on local observation. Because the proportion of continuous operations will be facility specific, the ACRP 02-34 values are not recommended for inventory development, but are included here for informational purposes.

It is expected that the touch-and-go rate and the taxi-back rate would be based on local observations. Collecting a representative sample is critical, with the following considerations:

1. In collecting these data, the proportion of continuous activity can vary by time of day, day of week, and season (as the commercial instruction proportion of activity may vary temporally).
2. In collecting these data at facilities with more than one runway, the proportion of continuous activities may vary by runway. It was observed in ACRP 02-34 that facility traffic management often favored certain runways for continuous operations.

If locally observed run-up frequency rates are not collected, it is reasonable to assume no run-ups are performed for taxi-back operations and that all standalone takeoffs include a magneto-test run-up.

Finally, it should be understood that capturing continuous operations in the inventory method is a critical element because the default FAA/EPA assumption that every two operations consists

Table 16. Operating mode defining parameters by screening inventory option for FW aircraft.

Parameter	Description	Screening Inventory Option		
		FAA/EPA Default	FAA/EPA Default with Run-up Included	ACRP 02-34 Data
Touch-and-Go Rate	Fraction of total FW operations that are from touch-and-go operations	0	0	0.180
Taxi-Back Rate	Fraction of FW landings that taxied back to the runway and took off again	0	0	0.219
Run-up Frequency, Taxi-Back Takeoff	Fraction of taxi-back operations that completed a magneto-test run-up procedure before takeoff (assessed for piston-powered equipment only)	0	0	0.026
Run-up Frequency, Standalone Takeoff	Magneto-test run-up frequency per standalone takeoff (assessed for piston-powered equipment only)	0	1	0.877

of a standalone takeoff and a standalone landing significantly overestimates fuel consumption for both taxi-back and touch-and-go operations. Using the average statistics from ACRP 02-34, a FW aircraft that completes a standalone landing and takeoff (i.e., two operations) spends 15.3 minutes on the ground with the engine running and consumes 5.1 pounds of aviation gasoline (ground operation modes only). In comparison, the time and fuel consumed on the ground for a taxi-back (i.e., two operations) are 3.7 minutes and 1.5 pounds, respectively; and for a touch-and-go (i.e., two operations), 0.3 minute and 0.3 pound, respectively.

5.3 Time-in-Mode Data: Worksheet 5.2

Worksheet 5.2 is where the user selects the inventory options and values for TIM data. There is one required action for this worksheet, which is the selection of the option for defining TIM in the inventory analysis. There is one optional action for this worksheet where the user supplies additional data if the facility-specific inventory option is selected.

Table 17 summarizes the three options for defining TIM; this table also appears in Worksheet 5.2. The preferred approach is that facility-specific data are collected and entered. In the absence of this, the user must specify use of one of two screening approaches: current FAA/EPA defaults or ACRP 02-34 data. Note that the FAA/EPA default option is not valid for use in modeling scenarios that include continuous operations (as defined by the user in Worksheet 5.1), as FAA/EPA default TIM values do not exist for touch-and-go and taxi-back operations. It is the user's responsibility to ensure consistent selection of options between Worksheets 5.1 and 5.2. If continuous operations are selected as part of the inventory modeling on Worksheet 5.1, then the user must apply the ACRP 02-34 data or input facility-specific results for the TIM assumption shown in Table 17.

Table 18 presents TIM data for the two screening inventory options. The FAA/EPA defaults are applicable to the current 2011 NEI approach, but the 2011 NEI documentation does not report TIM assumptions other than to cite the 1992 EI guidance (U.S. EPA 2013b). The 1992 EI guidance should be consulted, if needed, to better understand the background behind the values (U.S. EPA 1992). For the aloft operation modes (i.e., climb-out and approach), the FAA/EPA defaults assume a maximum altitude of 3,000 feet above ground level (AGL). Comparatively, the ACRP 02-34 values for climb-out and approach are capped at the "traffic pattern altitude" or TPA of each facility. The maximum vertical extent of the aloft modes of operation is discussed further as part of the remaining discussion of how to develop and apply TIM values.

Table 17. Inventory options defining time-in-mode assumptions.

Inventory Option	Title	Description
Screen 1	FAA/EPA Default	EPA default TIM rates for piston-powered FW aircraft. ^a
Screen 2	ACRP 02-34 Data	Average TIM rates observed for three airports (FW aircraft only); RC values based on Swiss FOCA study (Switzerland Federal Office of Civil Association 2009).
Facility Specific	Facility Data, User Supplied	User-supplied input for facility.

^a The FAA/EPA default option should not be used if there are continuous operations at the facility.

Table 18. Time-in-mode values by screening inventory option.

Aircraft Type	Operation Mode	Screening Inventory Option	
		FAA/EPA Default (minutes)	ACRP 02-34 Data (minutes)
Fixed-Wing Aircraft	Idle/Taxi (Takeoff)	12.00	9.89
	Run-up	0.96	0.96
	Takeoff	0.30	0.33
	Climb-out	5.00	1.76
	Approach	6.00	2.19
	Idle/Taxi (Landing)	4.00	4.08
	Idle/Taxi (Taxi-Back)	N/A	3.32
	Ground Roll (Touch & Go)	N/A	0.28
Rotorcraft	Idle/Taxi (Departure)	3.50	4.00
	Run-up	0.96	0.96
	Climb-out	6.50	0.92
	Approach	6.50	0.67
	Idle/Taxi (Arrival)	3.50	4.00

In order to correctly collect and apply the TIM values to the inventory analysis, several key background elements need to be considered as relevant context. Five topics are covered in this remaining discussion: operating mode definitions, differences with the 1992 EPA guidance, ACRP 02-34 TIM data, maximum altitude assumptions, and other considerations for facility-specific data collection.

5.3.1 Operating Mode Definitions for Time in Mode

The modes of operation to which the TIM data apply must be clearly defined, as shown in Table 18. It is recommended in applying the enhanced methodology that the following specific operating mode definitions, corresponding to each TIM value, be determined.

- **Idle/taxi time (takeoff)**—aircraft time spent from engine-on to the initiation of takeoff, except for the time of the magneto-test run-up.
- **Run-up**—time needed strictly to perform the high RPM magneto test (because the fuel consumption rate assignment to this mode is reflective only of the magneto test). During the ACRP 02-34 field studies, the average aircraft spent about 5 minutes in the run-up area, of which about 1 minute was spent performing the magneto test. The remaining time in the run-up area (about 4 minutes) related to other preflight checks (or for waiting on runway clearance) is included as part of the taxi/idle time (takeoff).
- **Takeoff**—time from the initial runway ground roll to the wheels leaving the ground.
- **Climb-out**—time aloft from 0 feet AGL (i.e., airport level) to the maximum altitude tracked.
- **Approach**—time aloft (on approach) from the maximum altitude tracked down to the wheels-down event at the airport.
- **Idle/taxi (landing)**—time from the landing ground roll, including all subsequent taxiing and idling time, until the engine is turned off.
- **Idle/taxi (taxi-back)**—time from the landing ground roll, including all subsequent taxiing and idling time, until reaching the head of the runway for takeoff.
- **Ground roll (touch-and-go)**—time on the ground for a touch-and-go operation.

5.3.2 Differences Between Guidebook Modes and EPA Guidance

It should be noted that three of the operating mode definitions described above differ from the 1992 EI guidance, as follows:

1. There is a difference in the point at which the transition between takeoff and climb-out assumption is applied. There is an error in the 1992 EI guidance as it describes the takeoff mode, which it describes as including the climb-out to 500 feet AGL (U.S. EPA 1992). This is an error because it is physically impossible for an FW piston aircraft to include both a takeoff and a 500-foot climb-out in 0.3 minute, followed by a 5-minute period to complete the remaining 2,500 climb-out—the 500-foot climb-out can be approximately scaled and would take 1 minute. The 1992 EI guidance transition elevation of 500 feet between takeoff and climb-out may be accurate for commercial jet engines, but it is not for FW piston aircraft takeoff.

A review of piston aircraft operations manuals, which provide fuel use and rate of climb data, was completed as part of ACRP 02-34 and the default EPA TIM values for takeoff and climb-out are typical for a single-engine, carbureted piston aircraft assuming a transition point at the wheels-up moment. This transition definition is also consistent with how the terminology is applied in aircraft manuals (for the purposes of fuel management strategies). The transition from takeoff to climb-out at the wheels-up moment is recommended for piston aircraft inventories, and that is the transition assumption applied in the enhanced methodology.

2. The time during which the aircraft is completing the landing ground roll is assigned to different modes. Under the FAA/EPA default, the landing ground-roll time is part of the approach mode; in the enhanced methodology, the landing ground-roll time is part of the taxi/idle (landing) mode. This is a small correction, but it is one that is made because the engine is idling during the landing roll. The enhanced method thereby assigns the correct fuel consumption rate to the landing roll.
3. FAA/EPA default assumptions do not include the run-up mode; the run-up data from ACRP 02-34 were assumed in Table 18 under the FAA/EPA option as a reasonable extrapolation. This was done so that the FAA/EPA default case with run-up could be included as a modeling option (see Worksheet 5.1). The run-up mode TIM is not highly variable (the procedures are standardized and specific). It should be noted that the FAA/EPA default value for run-up is strictly a construct for the enhanced methodology and is not an agency-assumed value.

5.3.3 ACRP 02-34 Time-in-Mode Data

It is noteworthy to document additional assumptions behind the ACRP 02-34 (Heiken et al. 2014) TIM values shown in Table 18.

1. The ground-level modes of takeoff, taxi/idle (takeoff), taxi/idle (landing), taxi/idle (taxi-back), touch-and-go ground roll, and magneto-test run-up for FW aircraft were determined by on-site data collection.
2. The RC TIM values (except run-up) were taken from the Swiss FOCA study of helicopters (Switzerland Federal Office of Civil Aviation 2009).
3. The run-up TIM was measured only for FW aircraft. The same value of 0.96 minute was assumed to apply to RC.
4. The aloft modes of climb-out and approach were capped at the TPA. The TPA varies by airport and equipment. RC was 500 feet AGL at all three airports; FW piston aircraft varied from 1,000 to 1,500 feet AGL. FW aircraft climb-out and approach TIM values used in ACRP 02-34 were FAA/EPA defaults (for 3,000 feet AGL) scaled to the TPA.

5.3.4 Maximum Altitude of Aloft Modes

It is important to understand the different maximum altitude assumptions for the aloft modes of climb-out and approach that impact the TIM values for these modes.

FAA/EPA defaults include the assumption of 3,000 feet AGL maximum altitude. The FAA/EPA default allows for scaling the maximum altitude based on mixing height. Mixing height is the height of the ground-level air layer in which pollutants will be dispersed and is temporally variable. The 1992 EI guidance includes methods for scaling the TIM aloft (for climb-out and approach) based on the average mixing height. This is pertinent to air pollution studies because the emissions occurring at or below the mixing height will become dispersed, impacting ground-level pollutant concentrations. Incorporating mixing height into annual inventory development is problematic because mixing height is temporally variable, and EPA guidance does not specify how this variable can be treated on an annual timescale.

For ACRP 02-34, the TPA of each airport was used as the maximum altitude for the aloft modes of climb-out and approach. The use of a pattern at airfields is for air safety management (i.e., consistent flight patterns) and is specific to the type of aircraft (e.g., rotorcraft, single-engine piston, etc.). The TPA defines the altitude for initial climb-out and final approach at the airport. Significant local operations may be flying a circuit at the TPA, such as touch-and-go operations.

Although use of the TPA is recommended to achieve the most accurate result, use of 3,000 feet AGL may be required for inventories being submitted to EPA.

For ACRP 02-34, climb-out and approach TIM for FW aircraft were estimated by scaling the FAA/EPA default TIM by the ratio of the airport-specific TPA to the FAA/EPA default assumption of 3,000 feet AGL maximum altitude, as follows:

$$\text{TIM}_{\text{airport}} (\text{min}) = \text{TIM}_{\text{FAA/EPA default}} (\text{min}) \times \frac{\text{TPA}_{\text{airport}} (\text{feet AGL})}{3,000 \text{ feet AGL}}$$

In the above equation, the FAA/EPA default TIM values are 5.0 minutes for climb-out and 6.0 minutes for approach. Airport-specific TPA can be obtained from sources such as airport directories or the Aircraft Owners and Pilots Association database (<http://www.aopa.org/airports/>).

5.3.5 Considerations for Facility-Specific Time-in-Mode Data Collection

Local data collection of TIM should consider the following elements:

1. Data collection can focus on the modes that are most likely to be locally variable, and thereby a combination of local data and screening values could be implemented by the user. Moreover, it is not readily possible to get TIM of aloft modes from on-the-ground observations. The idle/taxi modes are the ones most likely to be locally variable; run-up (magneto test) is the least likely to vary locally. Takeoff times can vary with the altitude of the facility.
2. TIM of idle/taxi modes will have temporal and spatial variability, and effort needs to be applied to get a representative sample. Congestion and use are temporally variable; traffic patterns at facilities are not symmetrical, and runway assignments are based on meteorological conditions.
3. A typical ground speed of 20 mph for taxiing was observed, which can be used to approximate taxiing times (if the distance is known) or validate taxiing time measurements [as part of quality assurance/quality control (QA/QC)].



CHAPTER 6

Aviation Gasoline Data

6.1 Overview

There is a single worksheet, denoted with a purple-shaded tab in the EIAT, used for selecting options for defining gasoline properties. The two aviation gasoline properties that factor into the inventory analysis are lead content and density.

Worksheet 6.1 is where the option for defining aviation gasoline is selected by the user and parameter values are set.

6.2 Gasoline Parameters: Worksheet 6.1

Worksheet 6.1 is where the method and data for aviation gasoline parameters are set for the inventory analysis. Of the two fuel parameters, gasoline density exhibits little variation but gasoline lead content is variable and a key modeling assumption.

There is one required action for this worksheet: the selection of the approach option for the source of the gasoline parameter data. There is an optional action to supply the gasoline parameter data if the facility-specific approach option is selected.

Please note that in this guidance method, the lead content is strictly defined as the amount of lead in gasoline and not the amount of tetraethyl lead (TEL) in gasoline, which is a different metric.

Table 19 summarizes the options for gasoline parameter data; this table also appears in Worksheet 6.1. The preferred approach is that facility-specific data be collected and entered. In the absence of this, the user must specify use of one of two screening approaches: current FAA/EPA defaults or ACRP 02-34 results.

The gasoline parameters for the screening inventory options are presented in Table 20. The FAA/EPA default models lead content at the maximum allowable for 100 grade “low lead” (i.e., 100LL) and does not provide a citation for density (U.S. EPA 2013b). The ACRP 02-34 value is the average over the three locations’ locally collected gasoline samples. The ACRP data show a margin with respect to the maximum of about 75 percent, but the data by location were highly variable. The FAA/EPA default assumes only 100LL gasoline used in all facilities nationally; the ACRP 02-34 project found only 100LL gasoline available at the three facilities studied.

FAA survey data for 2012 show that piston engines consume predominantly, but not exclusively, 100LL gasoline (FAA 2013b). The national consumption data are summarized in Table 21. Grade 100 aviation gasoline has a maximum lead limit twice that of 100LL, and on-road motor gasoline (MOGAS) has no lead. Nearly all aircraft can use 100LL (Coordinating Research Council

Table 19. Options for defining aviation gasoline properties.

Option	Title	Description
Screen 1	FAA/EPA Default	Lead content modeled as maximum allowable; density as 2011 NEI.
Screen 2	ACRP 02-34 Data	Average observed in sampling at three locations as part of ACRP 02-34.
Facility Specific	Facility Data, User Supplied	User-supplied values for lead content and density.

Table 20. Gasoline parameter data for screening inventory options.

Gasoline Parameter	Screening Inventory Option	
	FAA/EPA Default	ACRP 02-34 Data
Lead Content (g/gallon)	2.12	1.60
Gasoline Density (lb/gallon)	6.00	5.95

Table 21. National gasoline consumption by grade in piston aircraft.

Gasoline Grade	U.S. Consumption (Thousand Gallons)
100LL	168,232
100	15,207
MOGAS	2,440
Other grades ^a	114

^a Includes 91 grade aviation gasoline, which has the same maximum lead limit as 100LL.
Source: FAA (2013b)

2011), and some aircraft are designed to operate on a range of fuels that includes MOGAS (Rotax 2009). At the facility level, if additional grades (other than 100LL) are dispensed, then an assessment of the proportions of fuel dispensed would be necessary to determine the appropriate overall lead content to use in the inventory method. FAA Airport Master Record data (i.e., Form 5010) provides a listing of fuels dispensed by airport; a cursory look shows that Grade 100 gasoline may be available in Hawaii and Utah.

It is important to note that (1) TEL is present in aviation gasoline for critical performance criteria (i.e., to improve anti-knock properties) and (2) aviation gasoline is a highly refined product produced in batches (Chevron 2006). Recent Coordinating Research Council 100LL gasoline samples collected at airport fixed-based operations (89 samples covering eight refineries) showed an average lead level that was 85 percent of the maximum, but the range observed included the maximum allowable limit (Coordinating Research Council 2011).

Based on the available information, it is highly recommended that lead content be modeled based on local airport data collection due to the variability of this parameter. Data sources include (1) fuel drop certificates provided to the FBOs or (2) direct sample collection with laboratory analysis. It should be noted that data should be collected from all FBOs with different fuel suppliers, and that lead content will vary over time. In the absence of airport-specific information, the secondary recommendation is that the maximum allowable lead content be modeled in the EIAT. As such, the ACRP 02-34 average results are reported here (for informational purposes), but these are not recommended for use in inventory calculations.



CHAPTER 7

Inventory Calculations

7.1 Overview

There is a single worksheet, denoted with a yellow-shaded tab in the EIAT, where intermediary calculations are performed and displayed. The final inventory results are presented in Worksheet 8.1.

Worksheet 7.1 contains the intermediary inventory calculations. These data may be of interest to further document the inventory results or to provide QA/QC checks of the inventory analysis.

7.2 Calculations: Worksheet 7.1

Worksheet 7.1 performs the aircraft operations, fuel consumption, and inventory calculations. There are no required actions or optional actions. There is one inventory modeling parameter set in this worksheet—the “Pb [lead] retention rate.”

The Pb retention rate in the analysis is assumed by the 2011 NEI documentation, which was updated in the context of the 2008 NAAQS rulemaking. The Pb retention rate is the amount of fuel Pb that ends up on engine hardware or in engine fuel (and thereby is not emitted as exhaust). The Pb retention rate assumed is 5 percent. It is not a parameter that would vary locally or would be examined locally. As such, it is not a variable likely to be modified in the inventory analysis.

Overall, the Pb inventory calculations also follow those of the 2011 NEI documentation. The general inventory equation employed by the EIAT is as follows:

$$\text{Pb Emissions (grams)} = (1 - \text{Pb Retention}) \times \frac{\text{TIM (min)}}{60 (\text{min/hr})} \times \text{Fuel Rate (lb/hr)} \times \frac{\text{Pb Content (g/gal)}}{\text{Density (lb/gal)}}$$

Emission inventory calculations are expressed in grams or tons, where tons reported in this method are always U.S. short tons (i.e., 1 ton = 2,000 pounds). Microsoft Excel conversion functions are used to convert between grams and tons.

The calculations are performed incrementally in the following 11 distinct steps. These steps are shown separately for review and reporting from the EIAT.

1. Aircraft Operations, Annual
2. Piston Operations by Landing/Takeoff Mode, Annual
3. Modal Events per Year (Piston Aircraft)

4. Total Piston Hours by Mode
5. Aviation Gasoline Emission Rate by Mode (pounds/hour)
6. Aviation Gasoline Consumption (gallons)
7. Aviation Gasoline Consumption (gallons per piston operation)
8. Lead Inventory (tons)
9. Pb Emission Rate (grams per total piston operation)
10. Pb Emission Rate (grams per piston operation by aircraft type)
11. Pb Emission Rate (grams per total operations)



CHAPTER 8

Inventory Results

8.1 Overview

A single worksheet (Worksheet 8.1), denoted with a red-shaded tab in the EIAT, presents a one-page summary of the final inventory results.

Worksheet 8.1 pulls data from Worksheet 7.1, but generally does not contain the inventory calculations.

This is the final worksheet of the EIAT.

8.2 Inventory Results: Worksheet 8.1

Worksheet 8.1 provides a one-page summary of the lead inventory results and analysis assumptions. Although there are no required actions, there is an option to add a descriptive inventory title to the tabulated results shown.

Figure 3 presents an example output of Worksheet 8.1. There are four distinct areas of reporting in this summary as follows:

1. The “Summary of Input Option Selections” lists the eight worksheets where user selection of the approach option is required and then indicates which option was incorporated into the inventory results.
2. The “Operations Summary” tabulates the total operations by aircraft class and the piston share of those operations based on the inventory options selected and the data provided.
3. The “Pb Inventory Results” contains the annual lead emissions reported for two categories: (1) aircraft class and (2) aircraft type and operation mode. Inventory results are reported in tons and grams per piston operation. In this context, “piston operation” is the sum of both FW and RC piston operations.
4. The final reporting element is the “Overall Pb Emission Rate” reported on the basis of total operations (piston and non-piston operations). This metric provides a lead emission rate that can be combined with overall operations data to produce lead emissions if the conditions of the inventory development match those to which the calculations apply.

Inventory Title: Example Inventory of Anywhere Airport		
Year: 2013		
Summary of Input Option Selections		
Worksheet	Approach Option	
3.1 Annual Operations	<i>Facility Data, Standard ATADS Report (Daily)</i>	
4.1 Aircraft Fleet	<i>ACRP 02-34 Data</i>	
4.2 Piston Fuel Rates, Fixed-Wing	<i>ACRP 02-34 Data</i>	
4.2 Piston Fuel Rates, Rotorcraft	<i>ACRP 02-34 Data</i>	
5.1 Mode Definitions, Fixed-Wing	<i>FAA/EPA Default, With Run-Up Included</i>	
5.1 Mode Definitions, Rotorcraft	<i>FAA/EPA Default, With Run-Up Included</i>	
5.2 Time-in-Mode	<i>FAA/EPA Default</i>	
6.1 Gasoline Parameters	<i>FAA/EPA Default</i>	
Operations Summary		
Aircraft Class	Total Operations	Piston Operations (%)
Air Carrier	13,024	0.0%
Air Taxi	1,192	80.5%
General Aviation	255,659	80.5%
Military	308	0.0%
Total	270,183	76.6%
Pb Inventory Results		
Aircraft Class	Pb Emissions per Year (Tons)	Pb Emission Rate (Grams per Piston Operation)
Air Carrier	0.0000	0.0000
Air Taxi	0.0033	3.1156
General Aviation	0.7073	3.1163
Military	0.0000	0.0000
Total	0.7106	3.1163
Aircraft Type, Mode	Pb Emissions per Year (Tons)	Pb Emission Rate (Grams per Piston Operation)
Fixed-Wing, Idle/Taxi (Takeoff)	0.1173	0.5145
Fixed-Wing, Run-Up	0.0339	0.1489
Fixed-Wing, Takeoff	0.0223	0.0980
Fixed-Wing, Climb-Out	0.2936	1.2877
Fixed-Wing, Approach	0.1996	0.8753
Fixed-Wing, Idle/Taxi (Landing)	0.0391	0.1715
Fixed-Wing, Idle/Taxi (Taxi-Back)	0.0000	0.0000
Fixed-Wing, Ground Roll (Touch&Go)	0.0000	0.0000
Rotorcraft, Idle/Taxi (Departure)	0.0004	0.0019
Rotorcraft, Run-Up	0.0002	0.0008
Rotorcraft, Climb-Out	0.0022	0.0098
Rotorcraft, Approach	0.0014	0.0062
Rotorcraft, Idle/Taxi (Arrival)	0.0004	0.0019
Total	0.7106	3.1163
Overall Pb Emission Rate (Grams per Total Operation): 2.39		

Figure 3. Example of inventory results worksheet.



CHAPTER 9

Implications and Limitations

9.1 Implications

The primary implications and recommendations arising from this guidance are summarized below.

1. Piston aircraft lead inventory development needs to incorporate the emissions occurring during flight-check run-up procedures (i.e., the magneto test). High lead concentrations were observed in the ACRP 02-34 air quality modeling, specifically in the run-up areas. The guidance provides a method and supporting data such that this inventory element can be addressed with no additional user input.
2. Currently, there is no reliable data source for airport-level piston operations, whereas total airport operations are widely available. The piston-engine share of aircraft activity is poorly quantified by publicly available data and current methods. It is recommended that airport collection of activity-based aircraft tail numbers be completed for purposes of calculating the piston-engine share of aircraft operations and improving the accuracy of fleet-average aviation gasoline consumption rates (based on the locally observed fleet). The guidance is designed to incorporate these piston fleet data, if collected, into the inventory analysis method.
3. It is recommended that airport sampling of aviation gasoline be completed to determine typical, local lead content of fuel dispensed. Current inventory methods model lead content as the maximum allowable, whereas the limited data available show that there is considerable variation in lead content from airport-collected gasoline samples. This guidance allows for modeling with airport-specific gasoline lead content.
4. The standard modes of operation included in existing inventory methods are not adequate to address commercial flight school activities, which are common at many general aviation airports. For the three airports of study in ACRP 02-34, “continuous” operations (i.e., those associated with training procedures) accounted for about 40 percent of all piston operations. The emissions characteristics of continuous modes are distinct and not modeled adequately by current inventory methods. The guidance can handle these modes of operation; however, the frequency of occurrence will be airport specific and should be based on locally collected data.
5. 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, and the guidance facilitates the incorporation of TIM data into the inventory method.
6. 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 average fuel consumption rates from ACRP 02-34 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.

9.2 Limitations

The following list discusses some noteworthy limitations of this guidance methodology:

1. Airport extrapolation—General aviation airports are not homogeneous—there is considerable variation in the uses and characteristics of these facilities. Caution should be applied in extrapolating results across facilities. FAA recently completed an assessment and classification of all general aviation airports nationally, which provides a benchmark for grouping facilities by common criteria. Of the three facilities studied in ACRP 02-34, two fell under the “national” and one under the “regional” classification. In extrapolating the results of ACRP 02-34 to other airports, it is advisable to take these categorizations into consideration (FAA 2012, FAA 2014).
2. Other modes of operation—Additional modes may be possible locally beyond those included in this enhanced methodology (e.g., military training procedures may differ from the civilian practices observed). Along those lines, “maintenance run-ups” are separate run-up procedures that are not coupled with a takeoff event and are often completed in conjunction with engine maintenance for specific testing purposes. Airports have guidelines where maintenance run-ups are to occur. The field studies completed as part of ACRP 02-34 did not comprehensively evaluate the frequency/duration of maintenance run-ups, but maintenance run-ups were observed. This may be an important local source of lead emissions not accounted for in the enhanced methodology. Note that fuel consumption rates of maintenance run-ups would not be the same as documented herein for the magneto-test procedure (fuel consumption rates would be less).
3. The EIAT is limited to a single user-supplied, detailed FW piston aircraft inventory (input through Worksheet 4.3). It is possible that detailed, separate aircraft fleet data can be obtained for subsets of the piston fleet at a given airport. Examples include (1) differentiating “general aviation” from “air taxi” piston fleets and (2) differentiating piston aircraft by mode (continuously operating modes versus standalone modes). ACRP 02-34 did determine that the piston share and the type of craft used in continuous operations were distinct. This level of detail could be handled in the EIAT by creating separate spreadsheet versions for each distinct piston fleet. The final airport inventory would be the sum of the individual EIAT models.

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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAAE	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
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRRP	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
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