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

Jeremy G. Heiken

Sierra Research, Inc.

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Background – Air Quality

- NAAQS for Pb (1978) = 1.5 µg/m^3
- 2008 NAAQS 2008 revision = 0.15 µg/m^3
- US National Emission Inventory: 60% of Pb inventory is from aircraft (2011)
- General aviation: gasoline-powered piston aircraft burn leaded gasoline (100LL grade)
- USEPA established monitoring requirements at airports > 1 TPY (2010); completed special monitoring study at select airports > 0.5 TPY

Background – Emission Inventory

- AP-42 (1977)
- EDMS model (1991 – 2015)
- AEDT model (2015+)
- All aircraft rely on single method
  - Piston aircraft share of total aircraft operations = 55%
  - Piston share of VOC/NOx/PM2.5 = 9%/2%/35%
  - Piston inventory method has not changed since AP-42
  - EDMS/AEDT do not address lead emissions

Background – ACRP 02-34 Project

"Quantifying Aircraft Lead Emissions at Airports"

- Evaluate best practices for lead inventory development from piston aircraft engines
  - Literature review
  - On-site data collection (3 airports)
  - Refine inventory methods
  - Microscale modeling/validation
- Development of "Guidebook" and "Emission Inventory Analysis Tool"

Emission Inventory Improvements

- Operation modes
  - Magneto run-up test (new)
  - Continuous operations (new)
  - Site-specific time-in-mode
- Fuel consumption rates
  - Expanded database
  - Assignment to fleet based on efficiency
  - Site-specific fleet proportions
- Local Pb content of gasoline

Operation Modes – Magneto Run-up

- Currently omitted in standard inventory approach
- Specific to SI piston engines
- 1 minute test – moderately high fuel flow rate
- 5 minutes total time in run-up area
- Incrementally small portion of inventory (~5%)
- Significant portion of at-ground emissions occur in run-up area (~37%)

Operation Modes – Continuous Operations

- Standard inventory approach: every 2 operations consist of 1 landing and 1 takeoff (termed LTO cycle)
- Continuous operations not addressed:
  - **Touch-and-go**: Aircraft lands and departs on a runway without stopping or exiting the runway.
  - **Stop-and-go**: Aircraft lands and comes to a full stop on the runway, then takes off from that point.
  - **Taxi-back**: Aircraft lands, exits the runway, and taxis to the departure end for takeoff.

Operation Modes – Continuous Operations

- Touch-and-go and taxi-back operations significant at 3 airports (~40 percent of piston operations)
- Continuous operations have significant impact:
  - Magneto run-up test skipped
  - Reduced at-ground operation

	Minutes per Operation (3000 Ft. AGL Max. Altitude)	
	At-Ground	Total
FAA/EPA Default (Conventional LTO)	8.2	13.7
Site Data (Conventional LTO+Run-up)	7.6	13.6
Site Data (Taxi-Back)	1.7	7.6
Site Data (Touch-and-Go)	0.1	6.1

Fuel Consumption Rates

- Pb emissions a function of fuel consumption and lead retention rate (5%)
- New methods:
  - Expand fuel consumption database from 6 to 29 engines
  - Group by engine technology and define default rates by technology
  - Assign rates to all engines observed based on BSFC (efficiency)
  - Aggregate overall rates in proportion to observed operations

Fuel Consumption Rates

Mean operation mode fuel consumption rates (lb/hr)

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

Aviation Gasoline Parameters

- Standard approach models Pb content at maximum allowable (0.56 g/L TEL = 2.12 g/L Pb)
- Site-specific data collected (density and Pb content)
  - Density not variable (matched expectation)
  - Pb content variable by location
  - Pb content (3-site mean) = 1.60 g/L, 25% margin
  - Do not extrapolate Pb content outside the locations collected

Results

Mean Exhaust Rates

(Grams of Pb per Operation, 3000 Ft. AGL Max. Altitude)

Scenario (3-Site Mean), Cumulative Analysis	At-Ground Modes	Total
FAA/EPA Defaults	0.76	3.38
Add Run-up Mode	0.94	3.55
Add Time-in-Mode (TIM), Run-up	0.87	3.67
Add Continuous Modes, TIM, Run-up	0.60	3.41
Add Pb Content, Continuous, TIM, Run-up	0.46	2.59
Add Revised Fuel Rates, Pb Content, Continuous, TIM, Run-up	0.46	2.12

Results

Percent Change from Default Scenario

Scenario (3-Site Mean), Cumulative Analysis	At-Ground Modes	Total
Add Run-up Mode	24%	5%
Add Time-in-Mode (TIM), Run-up	14%	9%
Add Continuous Modes, TIM, Run-up	-21%	1%
Add Pb Content, Continuous, TIM, Run-up	-39%	-23%
Add Revised Fuel Rates, Pb Content, Continuous, TIM, Run-up	-39%	-37%

Conclusions

- Run-up mode significant to ground-level emissions
- Continuous operation activities have substantially different emissions; standard LTO cycle not representative
- Airport Pb content of fuel may be significantly below maximum allowable (must be locally determined)
- Significant enhancements to TIM and fuel consumption rates yielded moderate impact on Pb inventory results

Final Remarks

- For more information
  - ACRP 02-34 project report
  - Guidebook of “best practices”
  - Emission Inventory Analysis Tool (EIAT)
- Additional topics
  - Altitude impacts
  - Traffic pattern altitude
  - Legacy aircraft
  - Rotorcraft

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Questions and Discussion