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

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2015 International Emission Inventory Conference

April 15, 2015
Background – Air Quality

- NAAQS for Pb (1978) = 1.5 µg/m³
- 2008 NAAQS 2008 revision = 0.15 µg/m³
- 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)
- 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

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

<table>
<thead>
<tr>
<th>Mode</th>
<th>FAA/EPA Default</th>
<th>Site-Specific Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takeoff</td>
<td>147.6</td>
<td>117.3</td>
</tr>
<tr>
<td>Climb-out</td>
<td>112.7</td>
<td>92.5</td>
</tr>
<tr>
<td>Approach</td>
<td>62.0</td>
<td>52.4</td>
</tr>
<tr>
<td>Taxi/Idle</td>
<td>14.2</td>
<td>15.4</td>
</tr>
<tr>
<td>Run-up (Magneto Test)</td>
<td>N/A</td>
<td>55.7</td>
</tr>
<tr>
<td>Touch &amp; Go Ground Roll</td>
<td>N/A</td>
<td>66.4</td>
</tr>
</tbody>
</table>
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)

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

## Percent Change from Default Scenario

<table>
<thead>
<tr>
<th>Scenario (3-Site Mean), Cumulative Analysis</th>
<th>At-Ground Modes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add Run-up Mode</td>
<td>24%</td>
<td>5%</td>
</tr>
<tr>
<td>Add Time-in-Mode (TIM), Run-up</td>
<td>14%</td>
<td>9%</td>
</tr>
<tr>
<td>Add Continuous Modes, TIM, Run-up</td>
<td>-21%</td>
<td>1%</td>
</tr>
<tr>
<td>Add Pb Content, Continuous, TIM, Run-up</td>
<td>-39%</td>
<td>-23%</td>
</tr>
<tr>
<td>Add Revised Fuel Rates, Pb Content, Continuous, TIM, Run-up</td>
<td>-39%</td>
<td>-37%</td>
</tr>
</tbody>
</table>
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
Acknowledgements

- Project Team
  - Jim Lyons, Sierra Research
  - Jay Turner & Neil Feinberg, Washington University, St. Louis
  - Mike Kenny, KB Environmental Sciences

- ACRP Project Committee

- Participating Airports
Questions and Discussion