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December 14, 2016
Effective Stakeholder Relationships at Airports

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Additional ACRP Publications Available on this Topic

- **ACRP Report 71**: Guidance for Quantifying the Contribution of Airport Emissions to Local Air Quality

- **ACRP Report 84**: Guidebook for Preparing Airport Emissions Inventories for State Implementation Plans

- **ACRP Report 86**: Environmental Optimization of Aircraft Departures: Fuel Burn, Emissions, and Noise

- **ACRP Report 97**: Measuring PM Emissions from Aircraft Auxiliary Power Units, Tires, and Brakes

- **ACRP Legal Research Digest 17**: State and Federal Regulations that May Affect Initiatives to Reduce Airports’ GHG Emissions

You can learn more about these publications by visiting [www.trb.org/publications](http://www.trb.org/publications)
Today’s Speakers

Moderated by Kris Russell
Dallas/Fort Worth International Airport

1) ACRP Report 149: Improving Ground Support Equipment Operational Data for Airport Emissions Modeling
   • Mike Kenney, KB Environmental Sciences, Inc.

2) ACRP Project 02-54: Measuring and Understanding Emission Factors for General Aviation (GA) Aircraft
   • Tara Yacovitch, Aerodyne Research, Inc.
ACRP Report 149:
Improving Ground Support Equipment Operational Data for Airport Emissions Modeling
Research Objectives

1. Update “Default” GSE Fleet Activity Data
2. Improve Data Collection Methods
3. Provide Guidance Documer
Research Team

- Mike Kenney, KB Environmental Sciences, Inc. (KBE)
- Carrol Fowler, KBE
- Wayne Arner, KBE
- John Pehrson, CDM-Smith
- Eric Dinges, ATAC
- James Gebhardt, GebCo.
- Michael Graham, Mosaic ATM
Oversight Panel

- Susan Fizzell, Oakland International Airport (Chair)
- Lillian A. Kerberg, United Parcel Service
- Leihong Li, Georgia Institute of Technology
- Randy J. McGill, Greater Toronto Airports Authority
- Waguih Ouess, ACA Associates
- Adam Walters, Southwest Airlines
- C. Flint Webb, SAIC

- Peggy Wade, Federal Aviation Administration
- Marianne Csaky, Airlines for America
- Katherine B. Preston, Airports Council International - North America
- Theresia Schatz, ACRP Project Coordinator
Ground Support Equipment

- Aircraft Tractor
- Cabin Service Truck
- Belt Loader
- Fuel Truck
- Emergency Vehicles
- Air Conditioner
- Fork Lift
- Deicer
Why The Need?

EDMS/AEDT

Airport-Specific

Emissions

Total TIM

Water Service

Service Truck

Lavatory Truck

Hydrant Truck

Catering Truck

Cabin Service Truck

Belt Loader

Baggage Tractor

Aircraft Tractor

EDMS/AEDT

Total TIM
Common Refrain

From my observations…it was very difficult to determine if the GSE were operating or merely parked near the aircraft with the engines turned off…therefore we just used our own judgements.

(EDMS User, April 2014)
Computing GSE Emissions

- GSE Inventory
- Utilization & Activity Data
- Emission Rates

Emissions
1. Methods & Logistics

- GSE Owner/Operator Information
- Paper & Electronic Surveys
- Personal Knowledge
- In-the-Field Surveys
- Remote Sensing
Principal Research Aims

2. Safety & Security

- Strategy
- Domain
- Resources
- Security Clearance
- Safety Plan
- Communication
3. Quality Assurance

- Data Needs
- Sample Size
- Aircraft & GSE Types
- Missing Data
- Outliers Errors & Bias
Benefits vs. Costs

- Airport Emissions
  - GSE, 7%
  - APU, 3%
  - Aircraft, 90%

- Costs
- Accuracy
- Time
Applications

- Aviation Environmental Design Tool (AEDT)
- NEPA/CEQA Support
- SIP Inventory Support
- General Conformity Determinations
- FAA VALE Grants
- Air Quality Management Plans
- GSE Replacement Strategies
- Sustainability Management Plans
- Carbon Footprint Assessments
Information

- Google - Ground Support Equipment Operational Data
- Sia Schultz (ACRP) tschatz@nas.edu
- Mike Kenney, mkenney@kbenv.com
ACRP Report 164: Exhaust Emissions from In-Use General Aviation Aircraft

Tara I. Yacovitch, Zhenhong Yu, Scott C. Herndon, Rick Miake-Lye
Aerodyne Research, Inc. Billerica, MA

David Liscinsky
United Technologies Research Center, East Hartford, CT

W. Berk Knighton
Department of Chemistry & Biochemistry, Montana State University, Bozeman, MT

Mike Kenney, Cristina Schoonard, Paola Pringle
KB Environmental, St Petersburg, FL
Tara I. Yacovitch, PhD  
Principal Investigator

- Principal Scientist, Aerodyne Research, Inc.
- Instrument Development
  - laser-based trace gas monitors
- Fieldwork
  - Air quality measurements
  - Aircraft emissions
  - Oil and gas emissions
  - Forest fire emissions… etc.
- PhD in Physical Chemistry from UC Berkeley.
Chair:
Ms. Karen A. Scott, P.E.

Members:
Dr. Patti J. Clark, CM
Mr. Robert D. Freeman
Mr. Samuel J. Hartsfield
Mr. Corbett Smith
Mr. Phillip Soucacos
Ms. Marci A. Greenberger AAE
Mr. Joseph J. Snell
Mr. Carl Ma
Ms. Peggy Wade
Ms. Christine Gerencher

Tetra Tech
Embry-Riddle Aeronautical University
Los Angeles World Airports
Port of Portland (OR)
Mead & Hunt
Booz Allen Hamilton
ACRP Senior Program Officer
ACRP Program Associate
FAA Liaison
FAA Liaison
TRB Liaison
Acknowledgements

Team of Researchers

Airport managers and host airports, including:
- Stephen Bourque and the users at Boire Field
- Robert Mezzetti and the Beverly Regional Airport

Pilots, flight schools, fixed base operators, charter services and companies, including:
- Joe Sarcione
- Mark Scott at Falcon Air
- Arne Nordeide at Beverly Flight Center
- Paul Beaulieu at Perception Prime Flight Instruction
- Ron Emond at Air Direct Airways
- Drew Gillett
- Sheera Kaizerman
- Brian Stoughton
- Aeroptic, LLC.
ACRP Report 164: Exhaust Emissions from In-Use General Aviation Aircraft

- Reports Emission Factors for 47 in-use aircraft
- Verifies and supplements existing data
- Shows how new results impact a hypothetical airport’s emissions
- Recommendations
- Finds large inherent variability in piston engine emissions
- Published this quarter (2016)
Why: Air Quality at Airports

Only 8 piston engines!

- Continental Motors, Inc. 6-285-B
- Curtiss-Wright R-1820
- Lycoming Engines IO-320-D1AD
- Lycoming Engines IO-360-B
- Lycoming Engines O-200
- Lycoming Engines O-320
- Lycoming Engines TIO-540-J2B2
- Lycoming Engines TSIO-360C
What: Measure Emissions Compounds

- Nitrogen oxides
  \[ \text{NOx} = \text{NO} + \text{NO}_2 \]

- Carbon Monoxide
  \[ \text{CO} \]

- Carbon Dioxide
  \[ \text{CO}_2 \]

- Total Hydrocarbons
  \[ \text{HC} = \text{methane} + \text{ethane} + \ldots + \text{benzene} + \ldots \]

- Particulate Matter
  \[ \text{PM} \]
How: Calculate Emission Indices & Burden

Indices:
amount of compound per fuel burned at defined conditions

\[ EI_x \left[ \frac{g \times X}{kg \text{ Fuel}} \right] = \frac{\Delta C_x}{AC_{totC}} \times \frac{MW_x}{44} \times Fuel \ CO_2 \]

Burden:
grams of compound for a landing-take-off cycle (sometimes multiple aircraft)

Excess CO₂, CO, HC, NOx, …

ICAO LTO Cycle Definition

Cruise

Approach

3000 ft

Final approach

Take-off

Take-off

Idle

Taxi-in

Taxi-out

Average \( D_{o/F_{180}} \) simplifies:

\[ \text{Average } D_{o/F_{180}} = \sum \left( \frac{\text{Operating Mode Emission Rate} \times \text{Time in Mode}}{\text{Seal Level Static Take-Off Thrust} \left( F_{180} \right)} \right) \]
Results: Emissions from Piston Engines are Drastically Different than from Gas Turbine Engines
Results: Emissions from Piston Engines are Drastically Different than from Gas Turbine Engines

Piston

Gas Turbine
Results: Emissions from Piston Engines are Drastically Different than from Gas Turbine Engines
Results: Emissions from Piston Engines are Drastically Different than from Gas Turbine Engines
Results: Emissions from Piston Engines are more Variable than from Gas Turbine Engines
Why So Variable?

Low Combustion Efficiency
Simple Analog Controls
Limited Diagnostics
Rugged Old Technology
Pilot mindset

Each piston’s temperature behaves differently

Comparing Variable Data

- The variability of an average emission can be measured using 95% confidence intervals.
- A confidence interval = upper limit & lower limit.
- We are 95% sure that the true average emission falls between these limits.
- Existing data is considered invalid (statistically different) if it falls outside this confidence intervals.
Impact of New Data on a GA Airport

Sensitivity Analysis on a Hypothetical Airport:

- fleet characteristics based on national registry
- 40 aircraft
- ~97K airport operations per year
- 37 pistons (99% of ops)
- 3 gas turbines (1% of ops)

Simulation choices:

- default time-in-mode
- substitutions based on engine HP, airframe, etc.
Impact: Hypothetical Airport Emissions

- GA airport emissions are higher than previously thought for HC and NOx, similar for CO.

- Variability in piston engine emissions leads to enormous confidence intervals using standard procedures.

- Monte-Carlo methods have the potential to reduce these uncertainties, but require large datasets of emissions that are representative of real operations.
Alternate Method: Monte-Carlo

- Despite variability, yearly inventory can be pinned down
- Good, plentiful data is crucial
  - need more!
- Assumptions should be verified
  - Full distribution measured
  - GA times-in-mode
  - Fleet use (flight schools vs individual-owned)
Put the Data into Action!

- Prepare an Environmental Impact Statement
  - Replace Lycoming O-320 data with new data
  - Use our methods for better engine/airframe substitutions

- Think of General Aviation differently than Commercial Aviation
  - Piston engine emissions are variable
  - The average emission is not always the most common emission

https://en.wikipedia.org/wiki/Log-normal_distribution
Put the Data into Action!

- Make decisions using confidence intervals:
  - **how well** do we know an airport’s emissions?
  - what are the **worst and best-case** scenarios?

![Confidence Interval Diagram]

- **Confidence Interval**
  - lower limit
  - average
  - upper limit

- **Statistically different**

- **Statistically “the same”**
Policy Implications

• Research impact of lean(er) operation
  • idle and taxi for less risk
  • HC vs NOx
  • changes in pilot fuel-use strategies can have real impact

• Pinning down GA airport emissions is possible if:
  • large sample sizes of representative data available
  • entire variable distribution considered (e.g. Monte-Carlo methods)

“full rich at all times”

“lean it out”
For additional information:

ACRP Report 164: *Exhaust Emissions from In-Use General Aviation Aircraft*

http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3700

http://www.trb.org/Publications/PubsACRPProjectReports.aspx

• Tara Yacovitch
  ○ tyacovitch@aerodyne.com
Supplemental Slides
## Results: Overall Trends

<table>
<thead>
<tr>
<th>GA Piston Engines</th>
<th>GA Gas Turbines</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO very high</td>
<td>CO is very low</td>
</tr>
<tr>
<td>NOx is low (usually)</td>
<td>NOx is higher (usually)</td>
</tr>
<tr>
<td>HC is high and mostly unburned fuel</td>
<td>HC is low and partially combusted</td>
</tr>
<tr>
<td>volatile PM dominate</td>
<td>volatile PM dominate</td>
</tr>
<tr>
<td>PM size is &lt;20nm</td>
<td>PM size is 10-70 nm</td>
</tr>
<tr>
<td>Fuel flow is very low</td>
<td>Fuel flow is relatively high</td>
</tr>
<tr>
<td>High inherent variability</td>
<td>Low inherent variability</td>
</tr>
</tbody>
</table>

![Graph showing relative abundance of emissions](image)
Distributions of Piston Engine Emissions Show Trends with Power State

- linear axes
Distributions of Piston Engine Emissions Show Trends with Power State

- note logarithmic axis! (except for CO)

NOx peaks at cruise power, the leaner the fuel/air mixture, the higher the NOx.
Engine Substitution Method

Use with EDMS/AEDT software for modeling airport emissions
Use “user-defined aircraft” option
Alternate Method: Monte-Carlo

Use a sample to simulate a population

Confidence intervals based on real measured distributions (no assumptions on their shape)

Hypothetical Airport
engine types, operations

Sample Data Pool
EI, fuel flow, times in mode

random draw from engine matches

Emissions Burden per LTO
EI x fuel flow x times

Weekly Airport Emissions
Future Research Opportunities

Representative fleet, operations and times-in-mode

Large dataset collection of emission indices

Fuel additives

Partitioning of emissions (eg. HC to VOCs)
Why is there a divide in pilot mindset and how does it impact your results?

How do piston engine emissions change between idle and take-off?

What more do we need to research in order to pin down general aviation emissions?