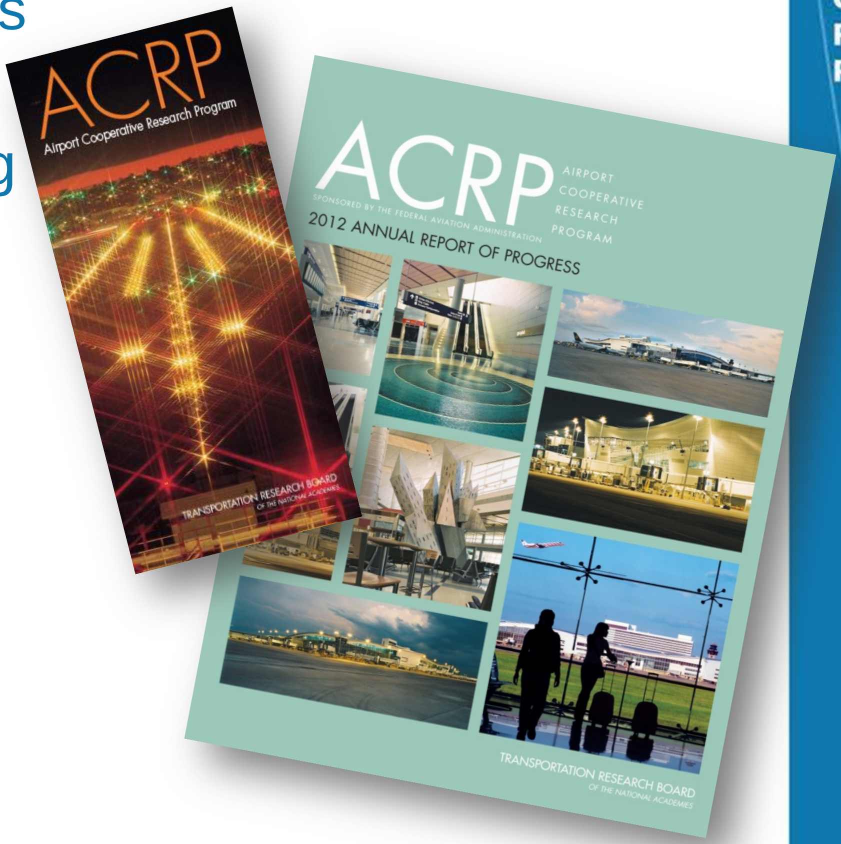
Information on ACRP

- www.TRB.org/ACRP
- Regular news and updates on:
  - o Upcoming and ongoing research projects
  - o New publications
  - o Success stories
  - o Announcements
  - o Webinars
- Find ACRP on Facebook and LinkedIn



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Upcoming ACRP Webinars

December 14, 2016

Effective Stakeholder Relationships at Airports

You can register for and learn more about upcoming 2016 webinars by visiting:

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Opportunities to Get Involved!

- ACRP's Champion program is designed to help early- to mid-career, young professionals grow and excel within the airport industry.
- Airport industry executives sponsor promising young professionals within their organizations to become ACRP Champions.
- Visit ACRP's website to learn more.

ACRP Champion

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Join us for the

Symposium on ACRP Research in Progress

…at the TRB Annual Meeting!

January 8–12, 2017

Learn more at:

http://www.trb.org/AnnualMeeting/AnnualMeeting.aspx

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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***

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Today's Speakers

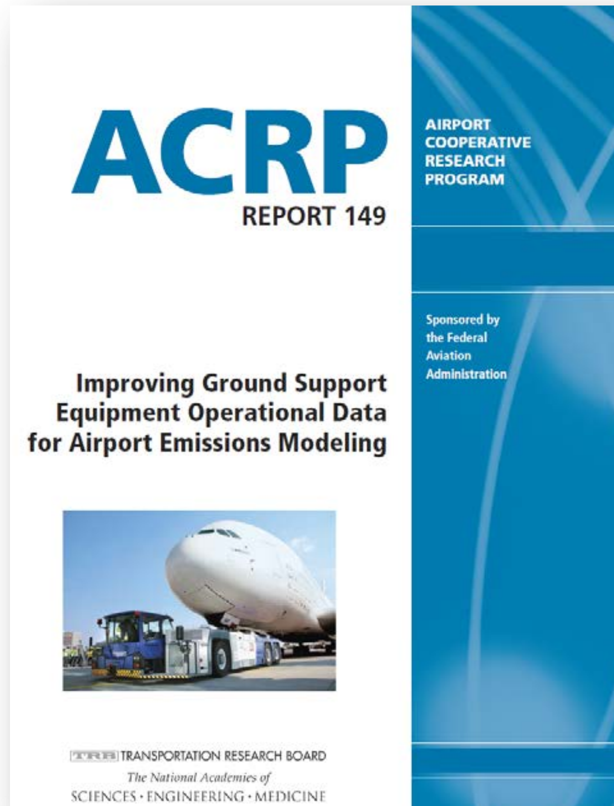
Moderated by Kris Russell
Dallas/Fort Worth International Airport

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



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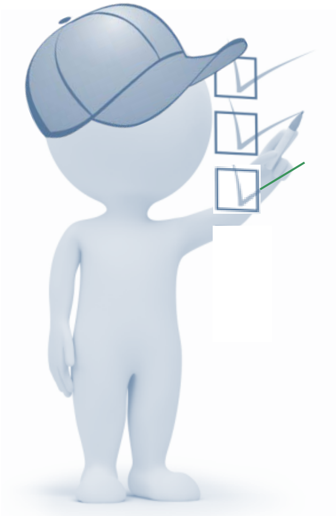
Research Objectives



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

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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

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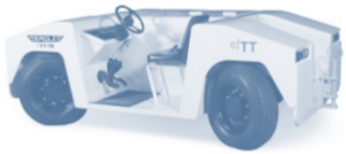
Ground Support Equipment



Aircraft Tractor

Cabin Service Truck

Belt Loader

Fuel Truck

Emergency Vehicles

Air Conditioner

Fork Lift

Deicer

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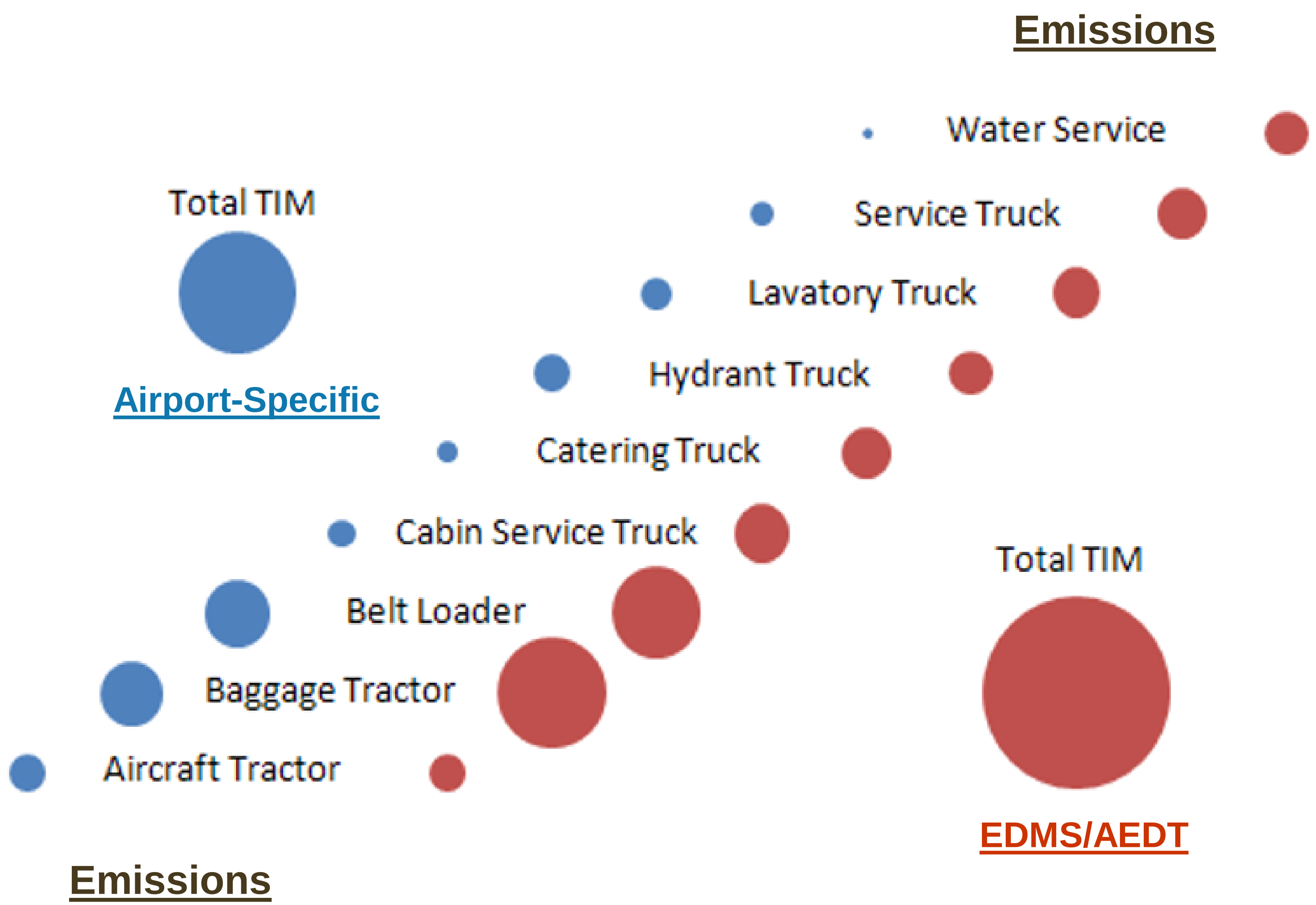
Why The Need?



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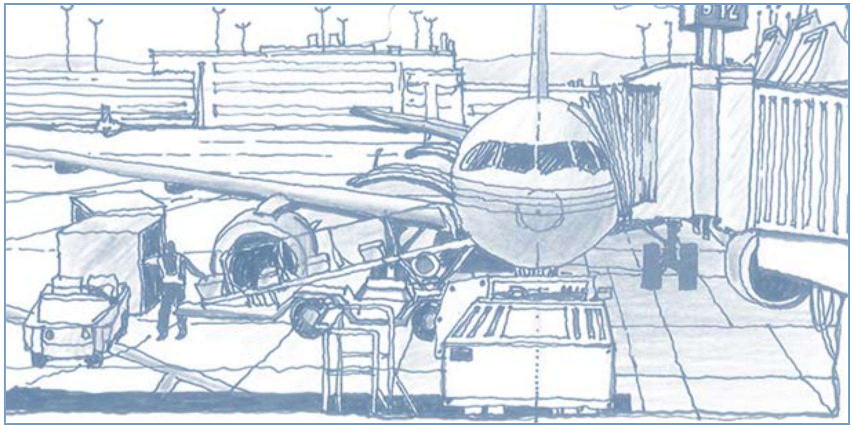
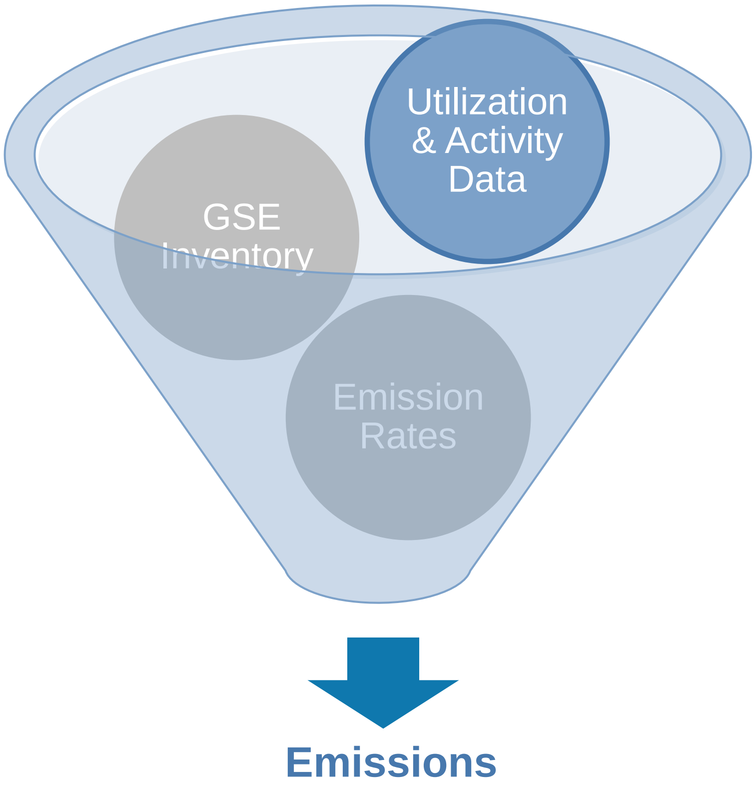
Common Refrain

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



Principal Research Aims

1. Methods & Logistics

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

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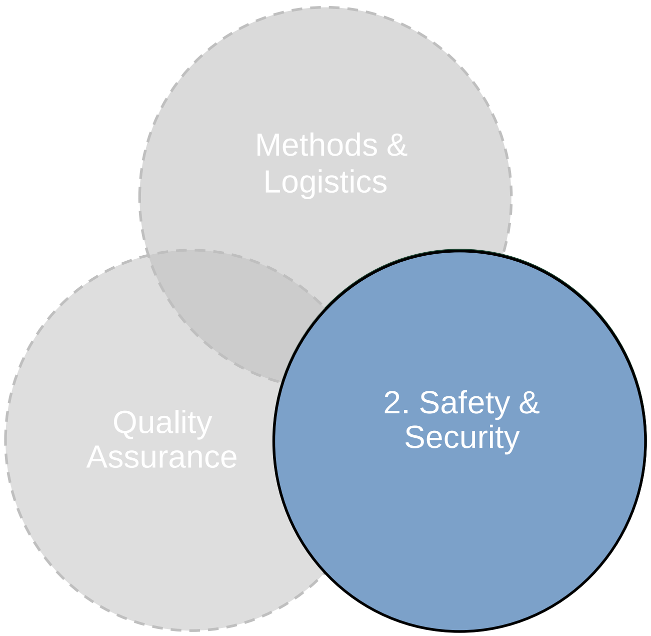
Principal Research Aims



2. Safety & Security

- Strategy
- Domain
- Resources
- Security Clearance
- Safety Plan
- Communication

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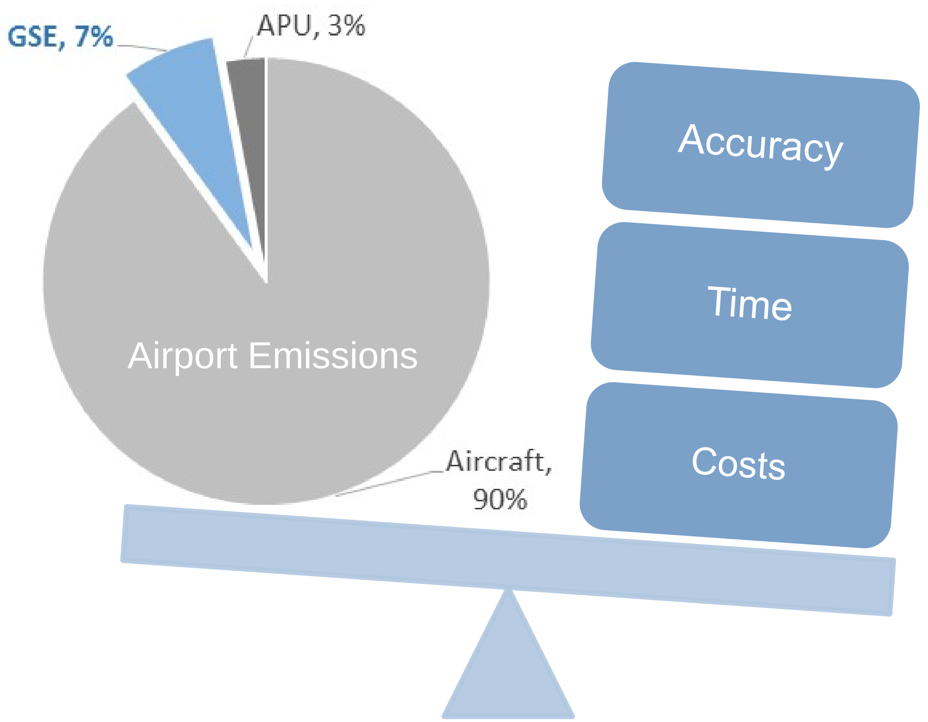
Principal Research Aims

3. Quality Assurance

- Data Needs
- Sample Size
- Aircraft & GSE Types
- Missing Data
- Outliers Errors & Bias

Benefits vs. Costs



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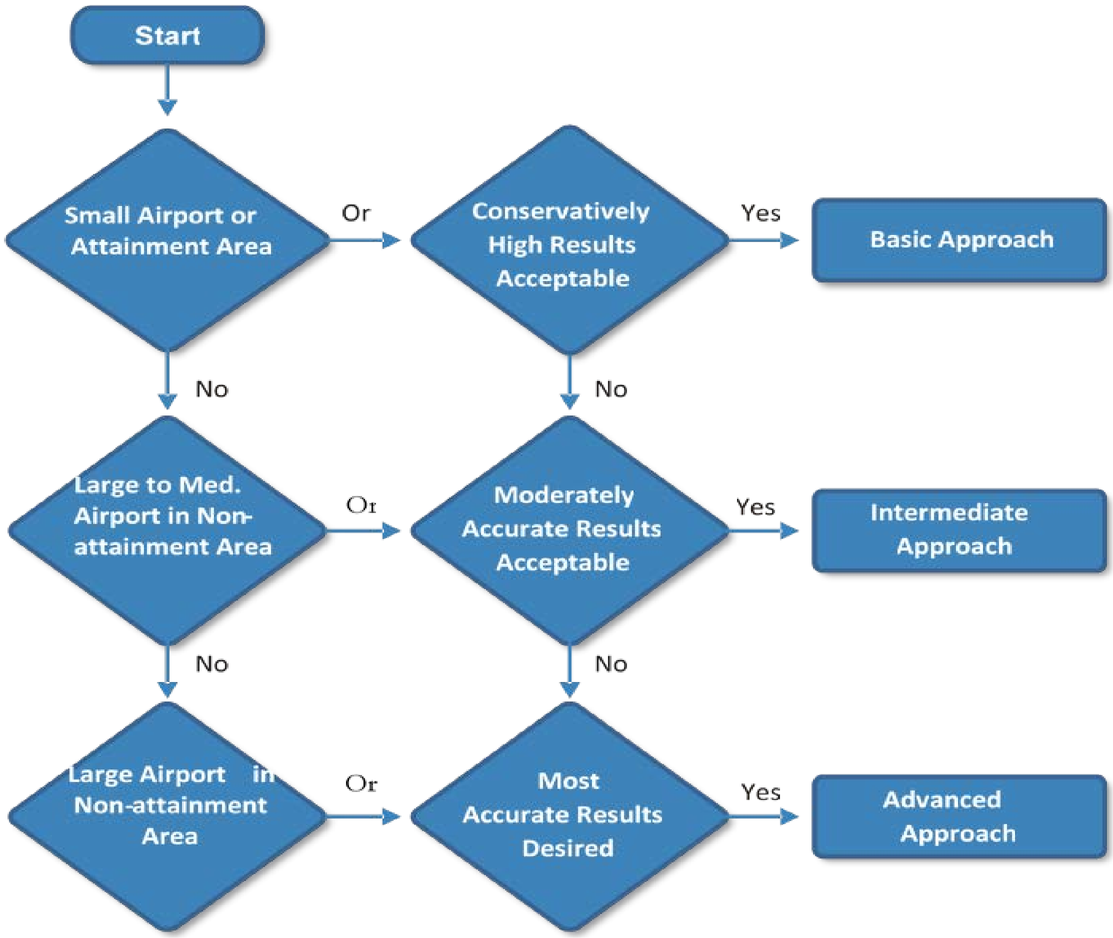
Approaches



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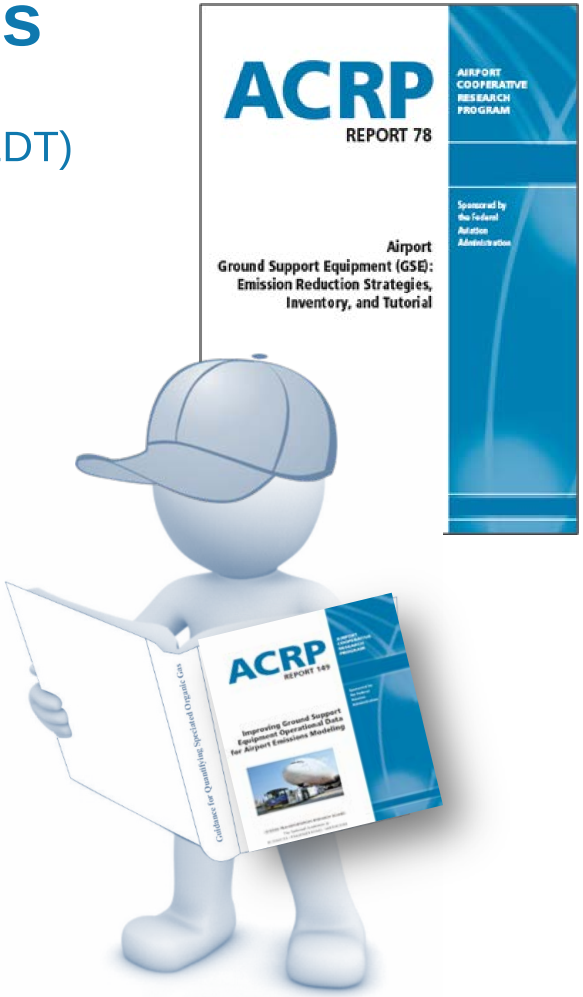
Applications

- 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

- Download Copy: *www.trb.org/main/blurbs/173715.aspx*
- 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

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Tara I. Yacovitch, PhD
Principal Investigator

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- 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.

ACRP Report 164 Oversight Panel

ACRP AIRPORT COOPERATIVE RESEARCH PROGRAM

Chair:	
Ms. Karen A. Scott, P.E.	Tetra Tech
Members:	
Dr. Patti J. Clark, CM	Embry-Riddle Aeronautical University
Mr. Robert D. Freeman	Los Angeles World Airports
Mr. Samuel J. Hartsfield	Port of Portland (OR)
Mr. Corbett Smith	Mead & Hunt
Mr. Phillip Soucacos	Booz Allen Hamilton
Ms. Marci A. Greenberger AAE	ACRP Senior Program Officer
Mr. Joseph J. Snell	ACRP Program Associate
Mr. Carl Ma	FAA Liaison
Ms. Peggy Wade	FAA Liaison
Ms. Christine Gerencher	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.

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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)

VARIABILITY

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Why: Air Quality at Airports

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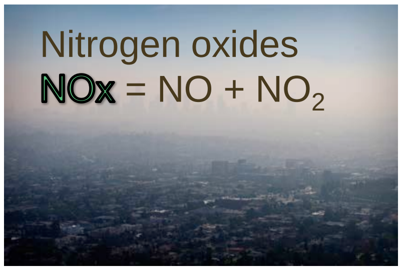
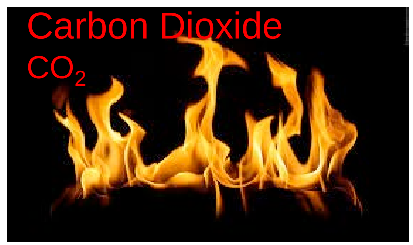
Only 8 piston engines!

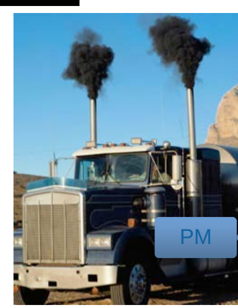
Continental Motors, Inc.	6-285-B
Curtiss-Wright	R-1820
Lycoming Engines	IO-320-D1AD
Lycoming Engines	IO-360-B
Lycoming Engines	O-200
Lycoming Engines	O-320
Lycoming Engines	TIO-540-J2B2
Lycoming Engines	TSIO-360C

What: Measure Emissions Compounds





Total Hydrocarbons
HC = methane +
ethane +
… +
benzene +
…



Particulate Matter
PM

- PM
  - number
    - volatile
    - non-volatile
  - mass
    - volatile
    - non-volatile

How: Calculate Emission Indices & Burden

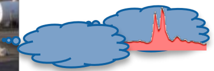
Indices:

amount of compound per fuel burned at defined conditions

$$EI_X\left[\frac{\text{g X}}{\text{kg Fuel}}\right]=\frac{\Delta C_X}{\Delta C_{TotC}}MW_X\frac{\text{Fuel } CO_2}{44}$$

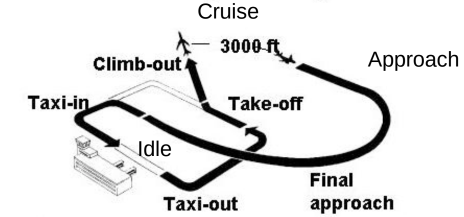
Burden:

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



Excess CO_2, CO, HC, NOx, …

ICAO LTO Cycle Definition

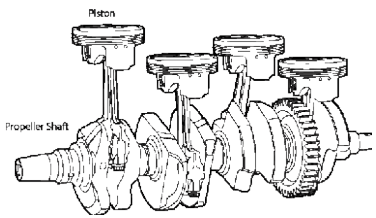


Operating mode	Power setting	Time in mode
1. Taxi / idle	7 % take-off thrust	26.0 minutes
2. Take-off	100% std day take-off thrust	0.7 minutes
3. Climb	85 % take-off thrust	2.2 minutes
4. Approach	30 % take-off thrust	4.0 minutes

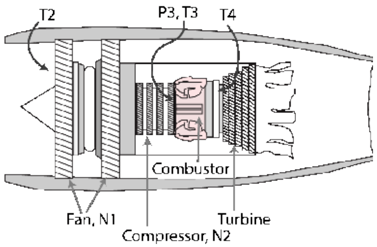
$$\text{Average } [\,Dp/F_{00}\,]^*_{\text{emittant}} = \frac{\sum \text{(Operating Mode Emission Rate)*(Time in Mode)}}{\text{Seal Level Static Take-Off Thrust } (F_{00})}$$

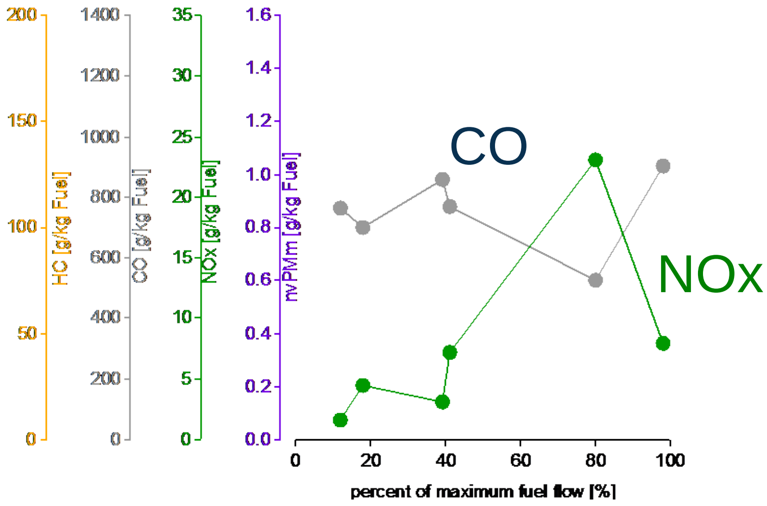
Results: Emissions from Piston Engines are Drastically Different than from Gas Turbine Engines

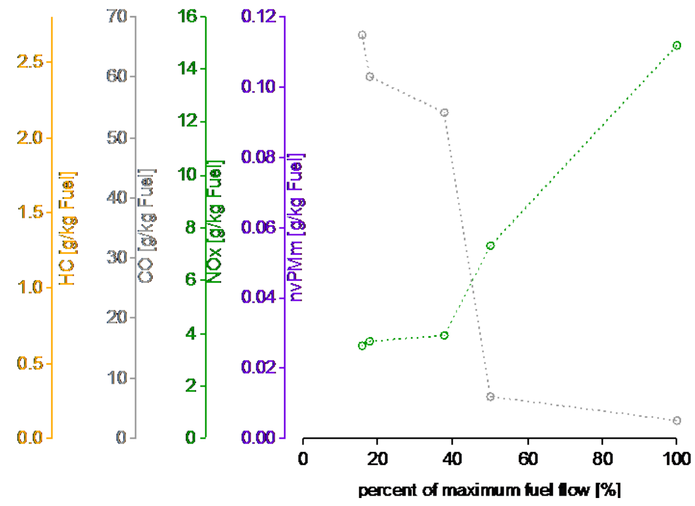
Piston



Gas Turbine







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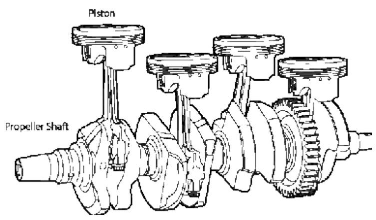
Results: Emissions from Piston Engines are Drastically Different than from Gas Turbine Engines

Piston



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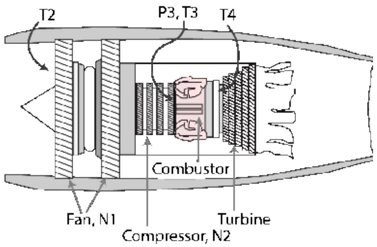

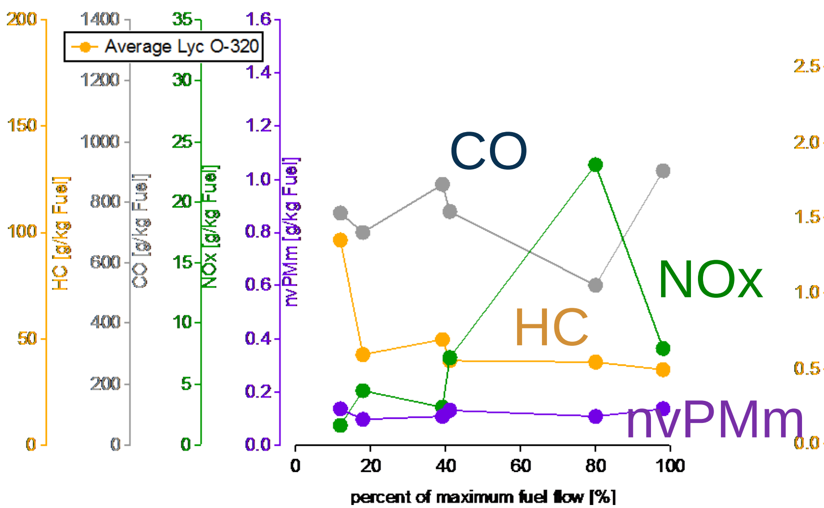

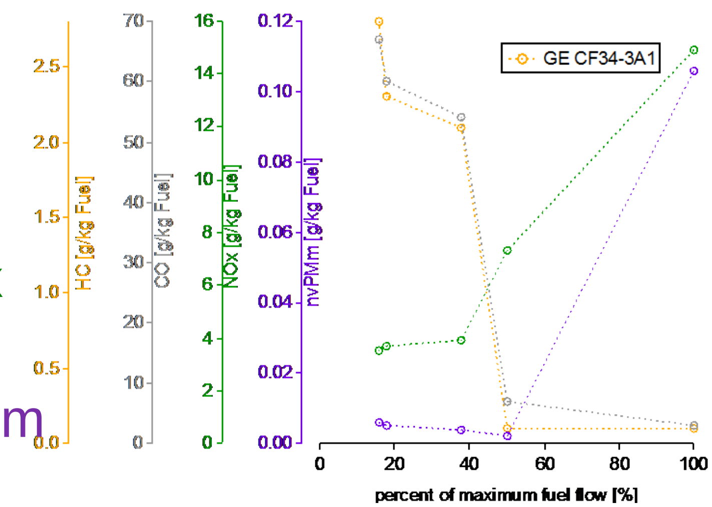

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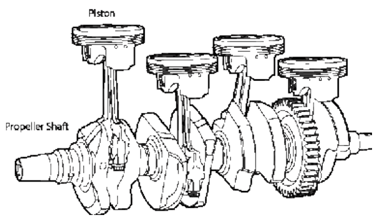
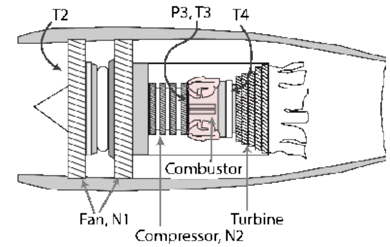
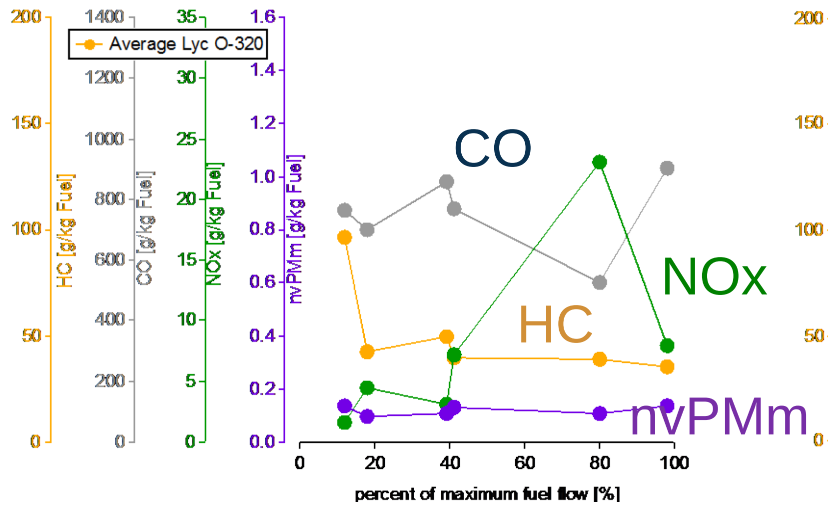
Results: Emissions from Piston Engines are Drastically Different than from Gas Turbine Engines

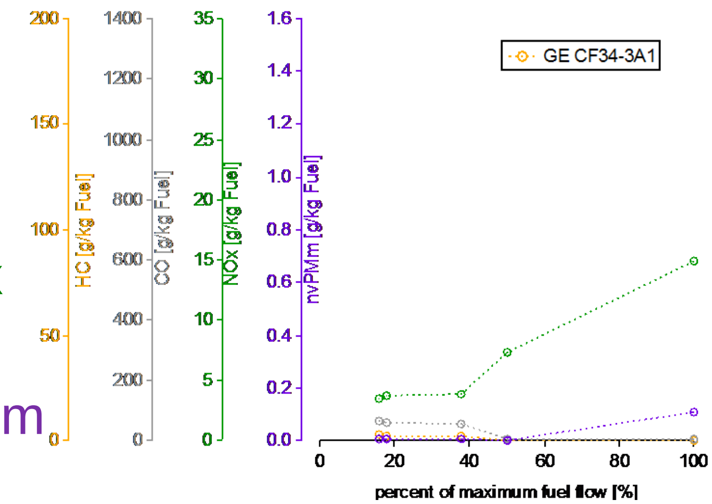
Piston



Gas Turbine

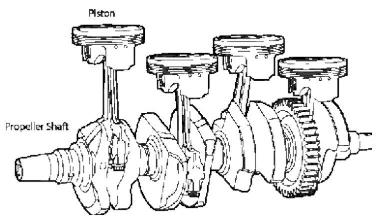




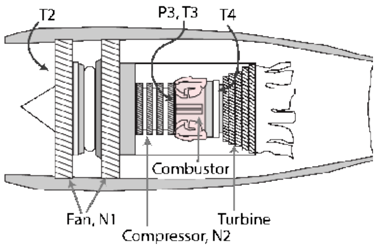


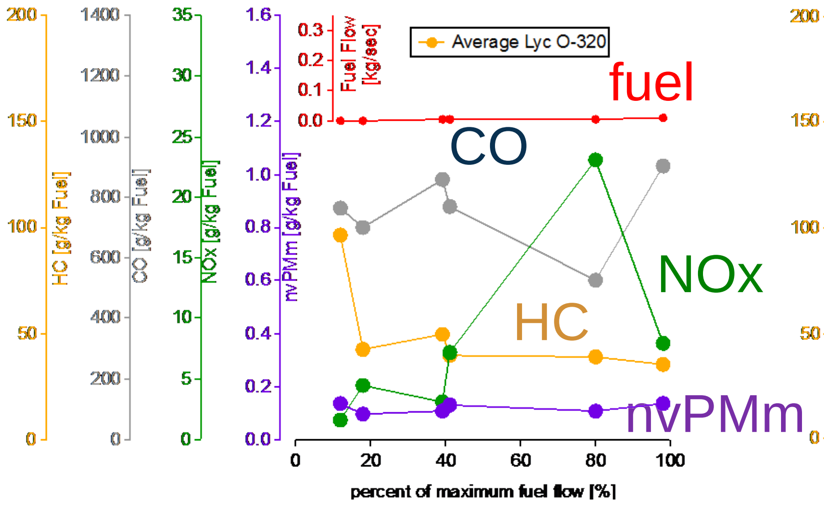
Results: Emissions from Piston Engines are Drastically Different than from Gas Turbine Engines

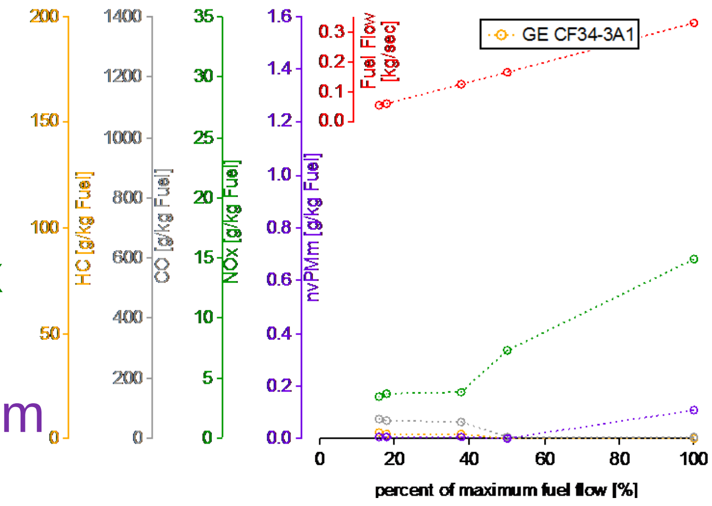
Piston



Gas Turbine







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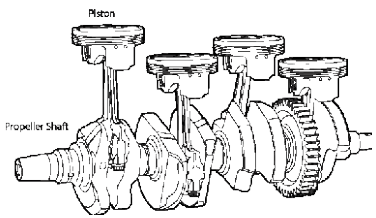
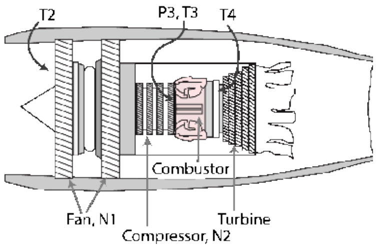
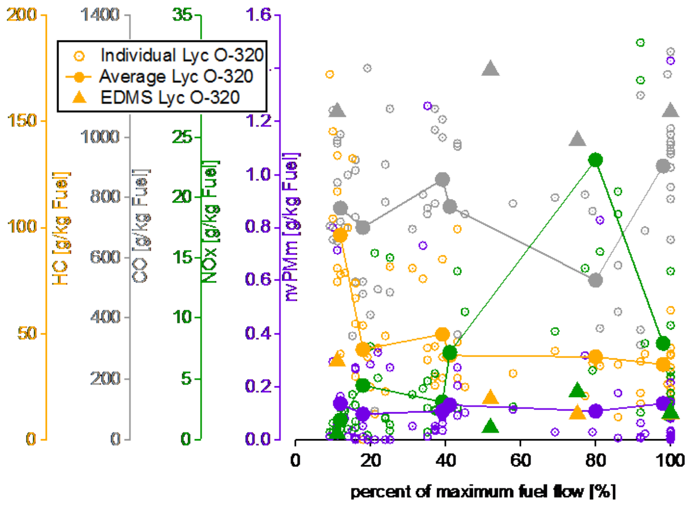
Results: Emissions from Piston Engines are more Variable than from Gas Turbine Engines

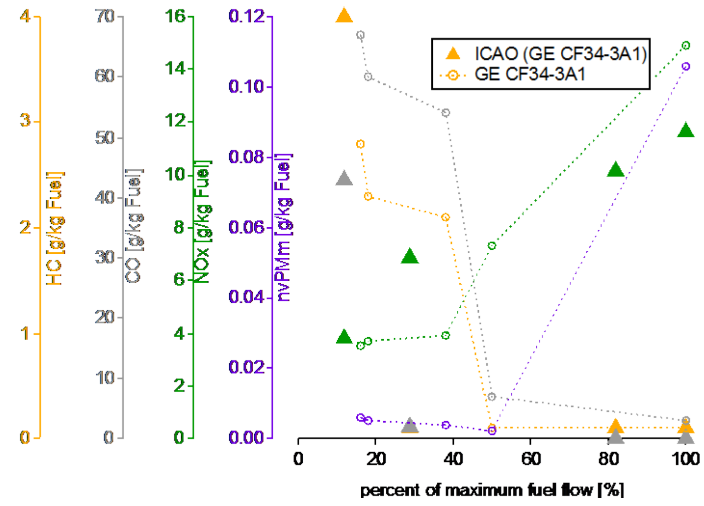
Piston



Gas Turbine







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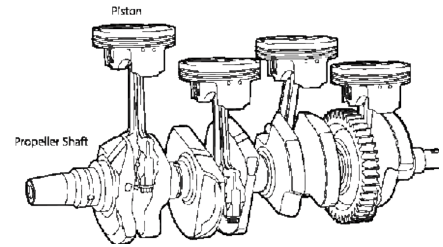
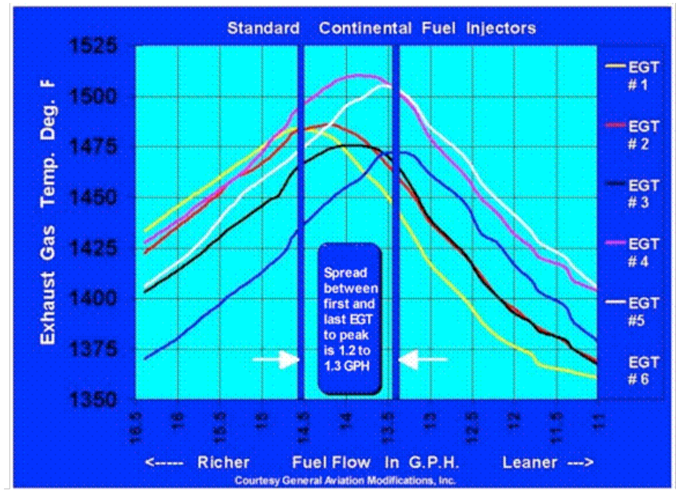
Why So Variable?

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



Each piston's temperature behaves differently



http://www.swaircraftappraisals.com/MeyersForum/Engine%20Info/Engine%20Operation/Pelican's%20Perch%20Mixture%20Magic.htm

Exhaust Gas Temp (non-standard!)

Propeller RPM

Throttle

Mixture

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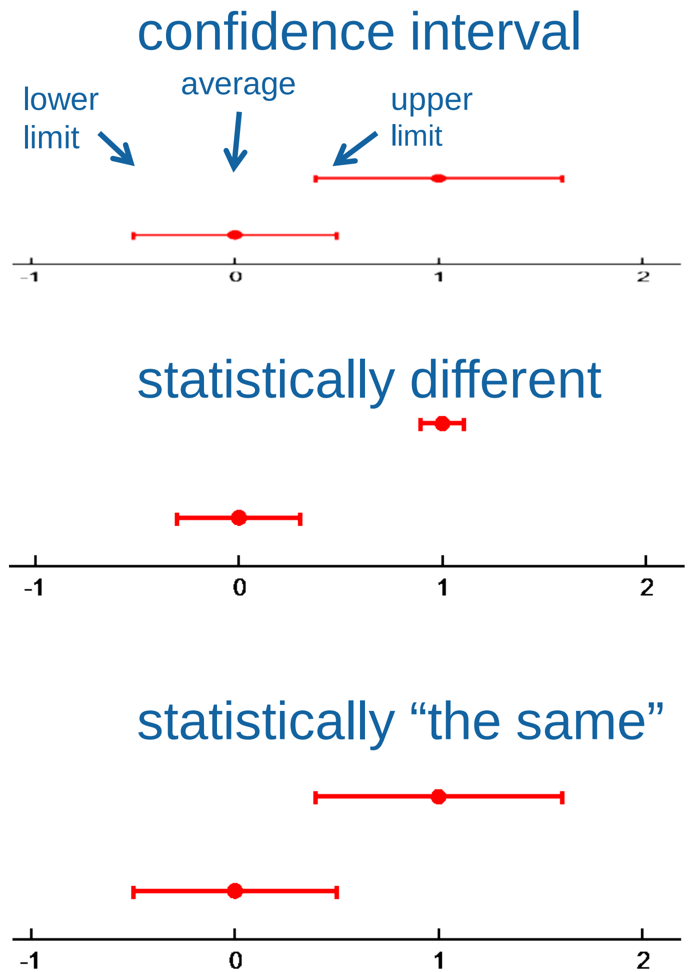
Comparing Variable Data

- 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.



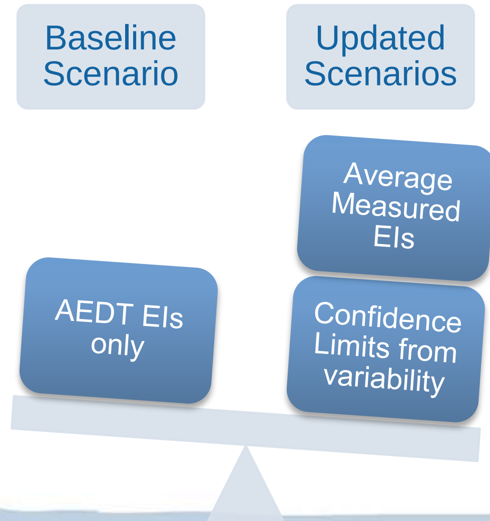
Impact of New Data on a GA Airport

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.



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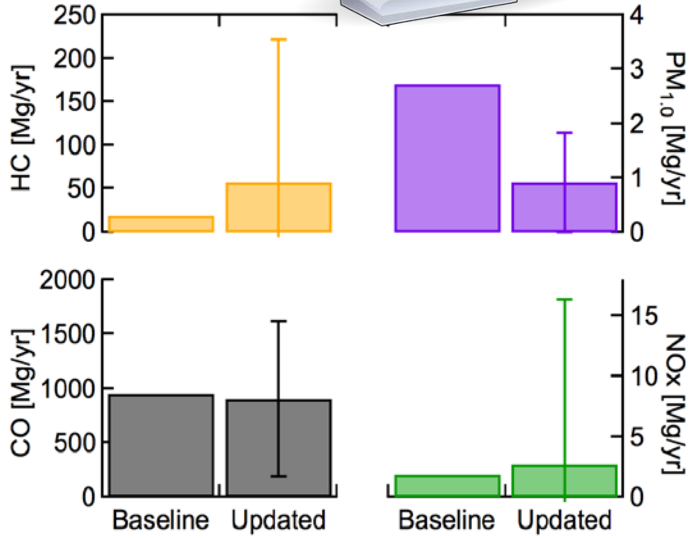
Impact: Hypothetical Airport Emissions

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

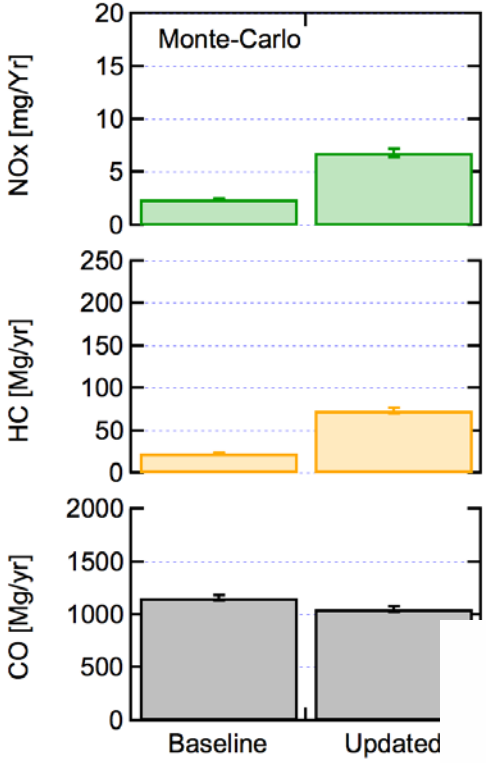
- Variability in piston engine emissions leads to enormous confidence intervals using standard procedures.

- 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)



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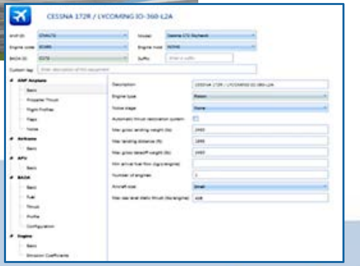
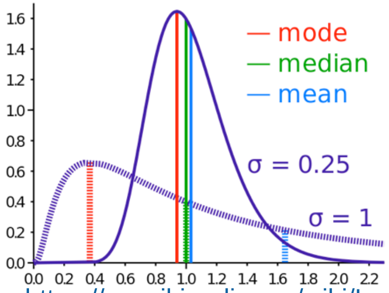
Put the Data into Action!

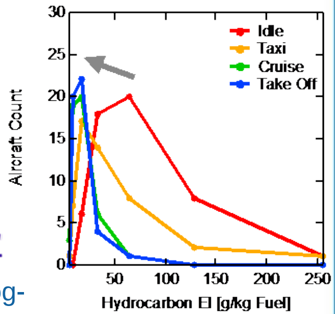
- Prepare an Environmental Impact Statement
  - **Replace** Lycoming O-320 data with new data
  - Use our methods for better **engine/airframe substitutions**

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



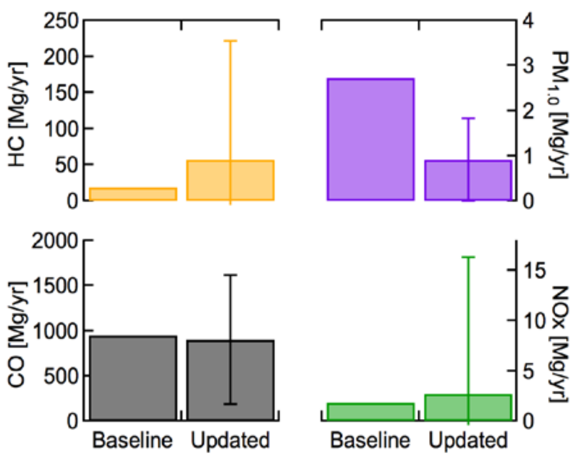


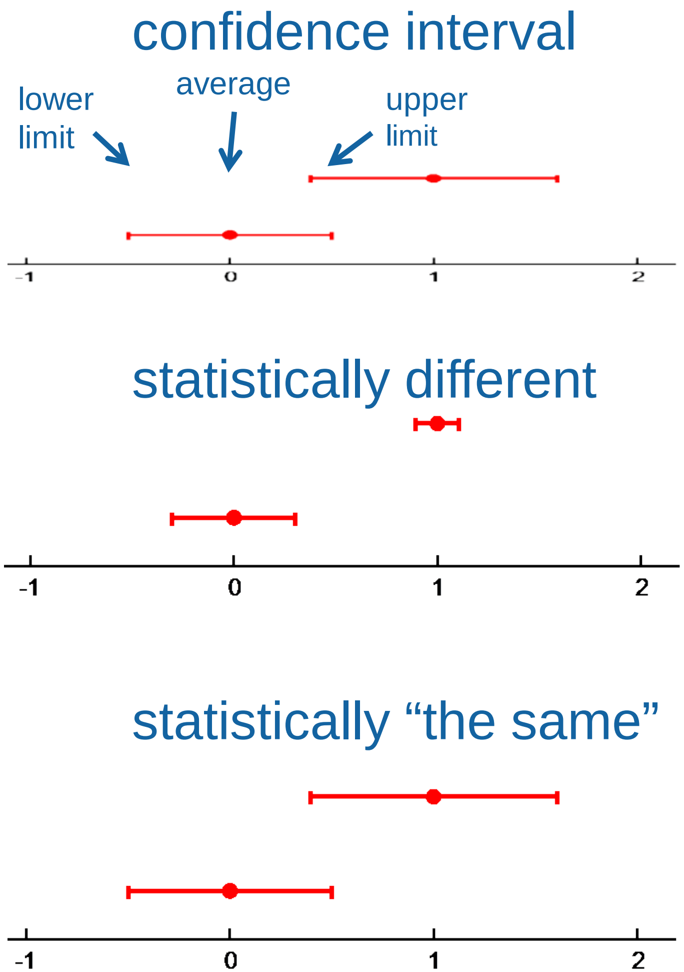
https://en.wikipedia.org/wiki/Log-normal_distribution



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?





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)

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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

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Supplemental Slides

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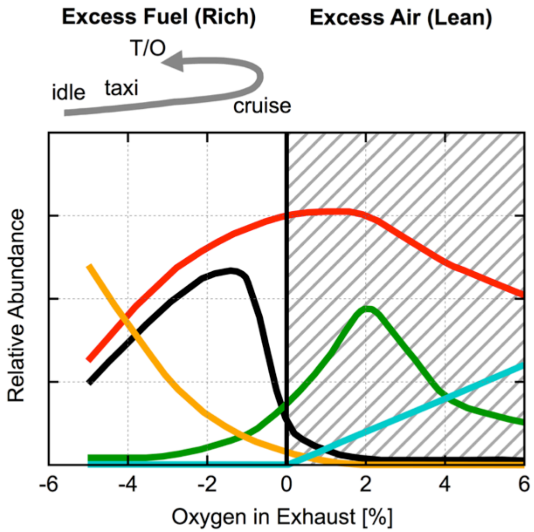
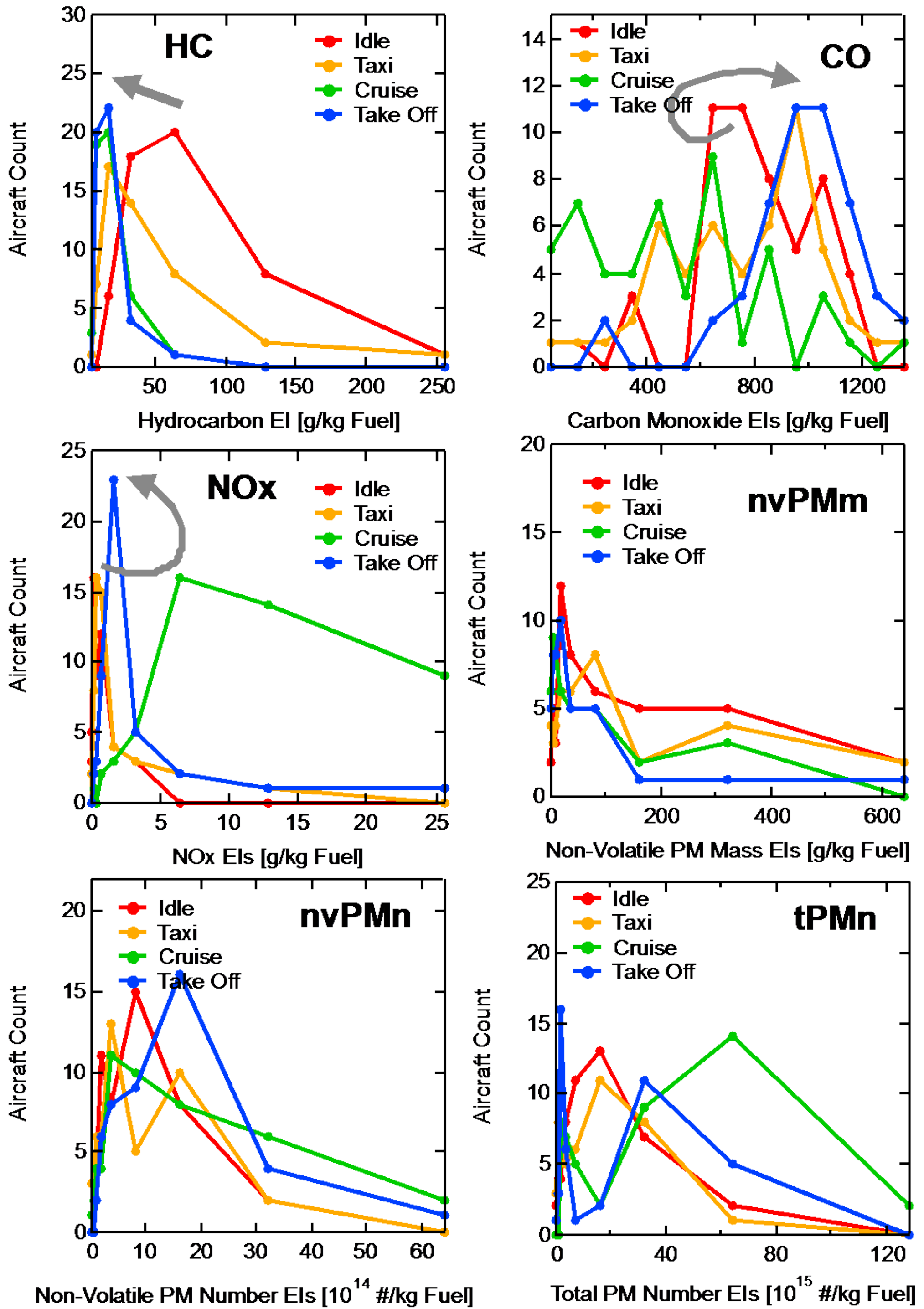
Results: Overall Trends

GA Piston Engines	GA Gas Turbines
CO very high	CO is very low
NOx is low (usually)	NOx is higher (usually)
HC is high and mostly unburned fuel	HC is low and partially combusted
volatile PM dominate	volatile PM dominate
PM size is <20nm	PM size is 10-70 nm
Fuel flow is very low	Fuel flow is relatively high
High inherent variability	Low inherent variability



Distributions of Piston Engine Emissions Show Trends with Power State

- linear axes



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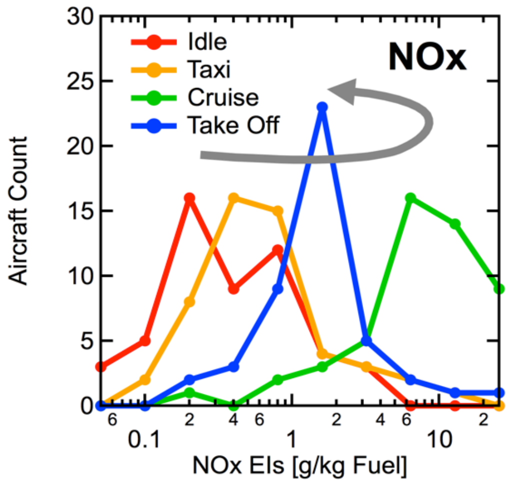
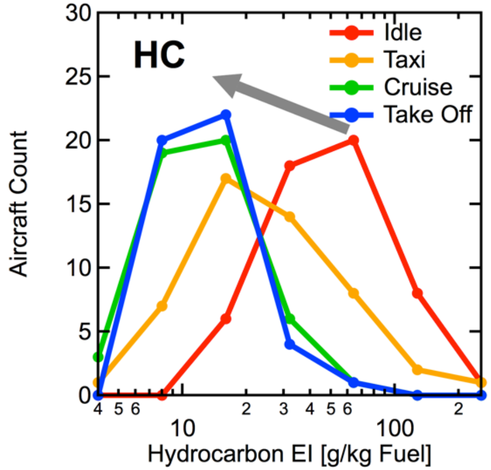
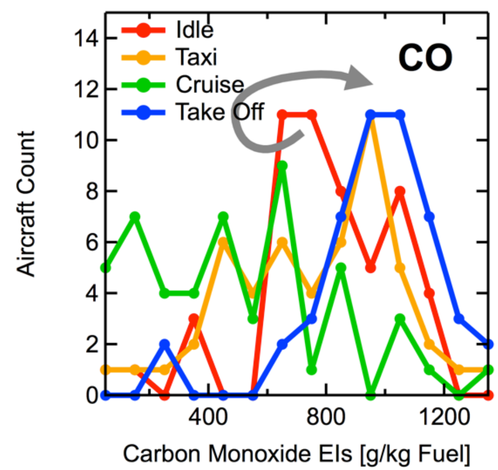
Distributions of Piston Engine Emissions Show Trends with Power State

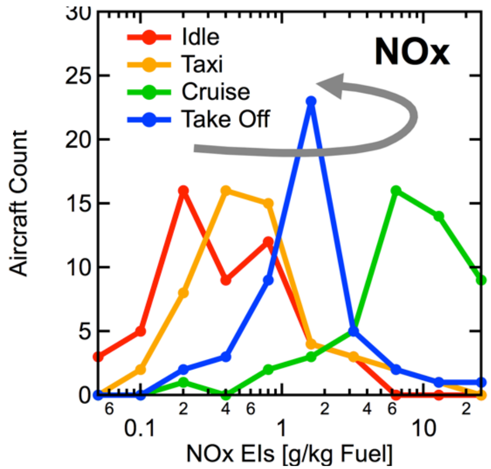
- note logarithmic axis! (except for CO)

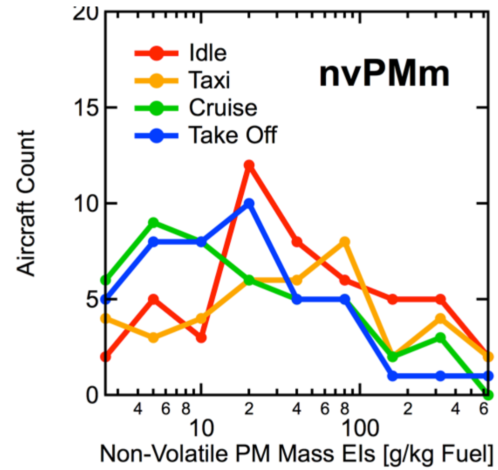
NOx peaks at cruise power
the leaner the fuel/air mixutre,
the higher the NOx

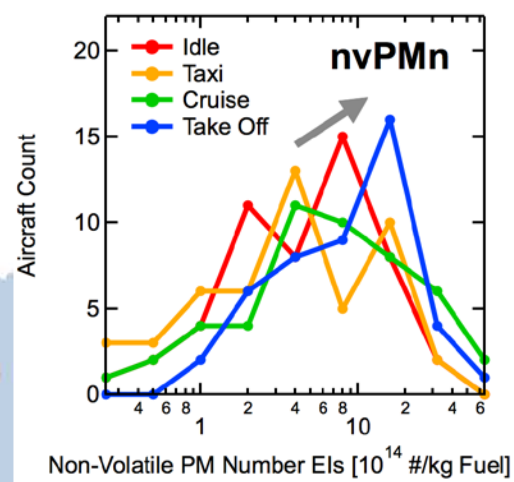


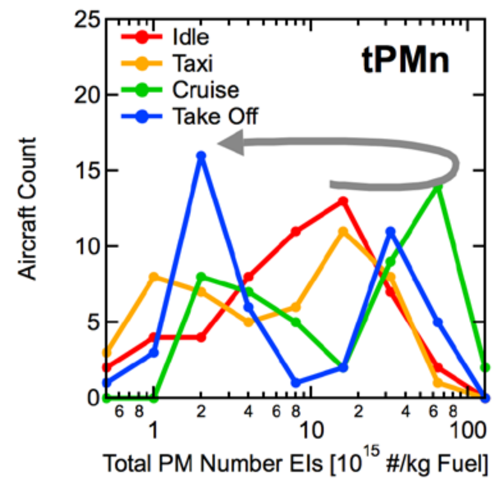












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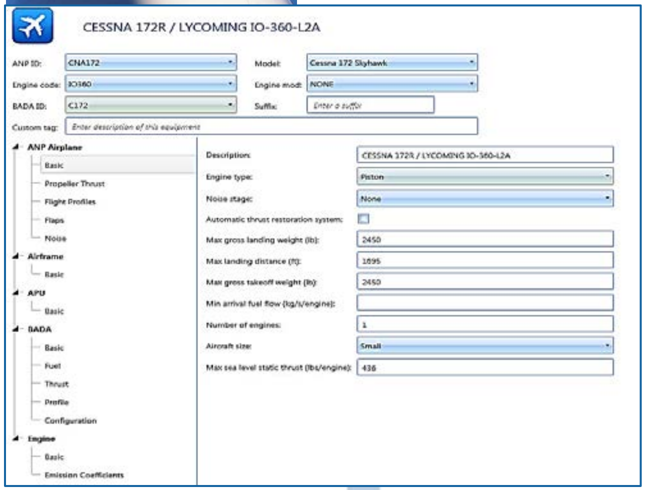
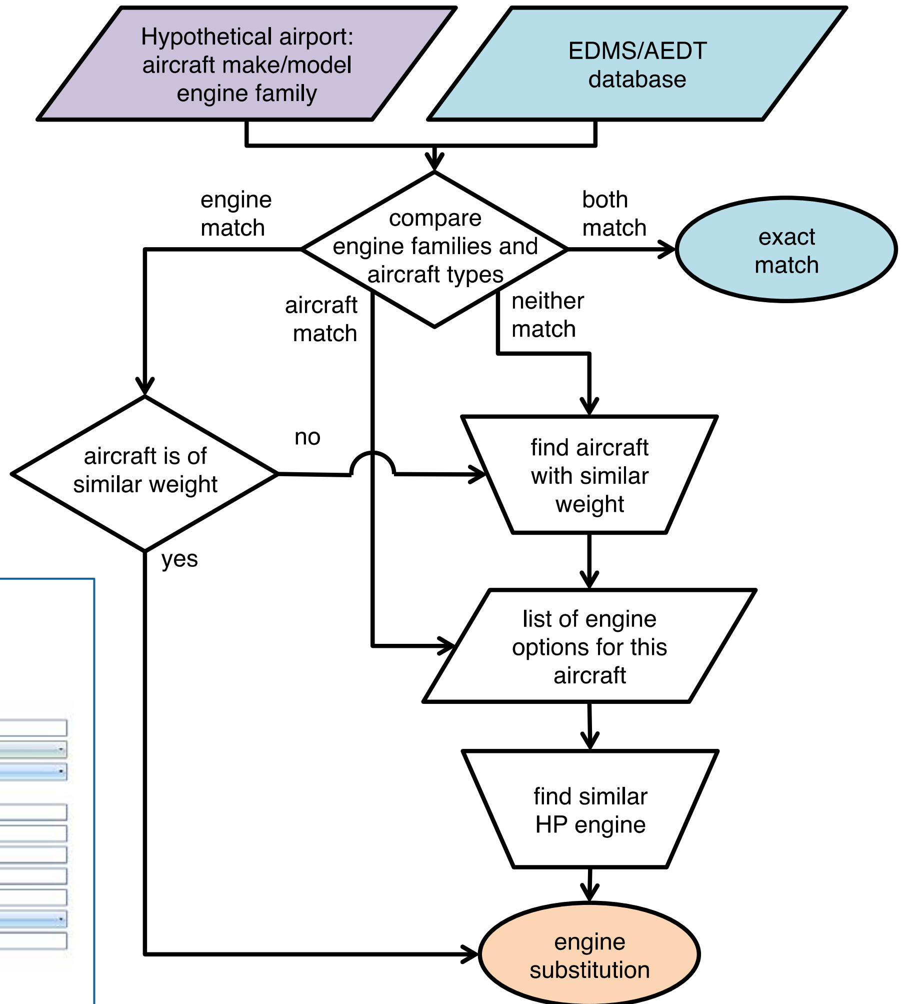
Engine Substitution Method

Use with EDMS/AEDT software for modeling airport emissions

Use "user-defined aircraft" option





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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

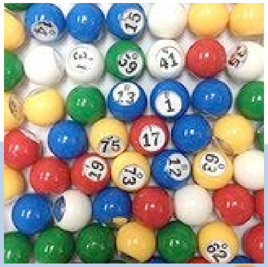
random draw from engine matches

Sample Data Pool
EI, fuel flow, times in mode

61.1	61.1	35.8	81.7	81.7	29.6	116.8
28.9	28.9	43.5	36.5	44.3	0.0	78.7
18.8	18.8	16.7	29.8	29.8	23.0	100.1
--	--	--	43.3	76.2	54.4	80.5
26.4	26.4	22.0	24.6	34.0	40.4	74.3
21.3	21.3	31.1	39.0	39.0	66.6	104.6
40.7	40.7	35.0	37.9	81.1	24.6	132.3
39.8	39.8	20.6	29.1	28.9	38.8	145.2
24.0	24.0	36.8	41.8	85.2	54.0	78.0
40.6	40.6	40.7	43.5	43.5	73.8	172.0
33.8	33.8	45.9	--	--	--	48.8
--	--	99.3	--	--	--	--
--	--	--	--	--	45.5	111.2
37.9	37.9	39.0	42.5	47.3	44.5	53.1
66.7	66.7	81.9	57.7	57.7	70.8	91.4
43.0	43.0	33.6	43.9	46.6	45.1	63.7
30.8	30.8	56.4	27.8	50.0	59.7	69.7
30.7	30.7	23.3	34.0	34.0	29.6	129.7
41.3	41.3	31.5	35.0	45.8	52.6	50.1

Emissions Burden per LTO
EI x fuel flow x times

Weekly Airport Emissions



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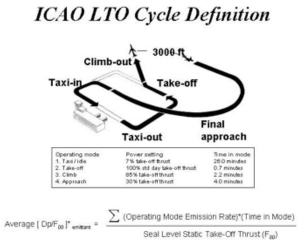
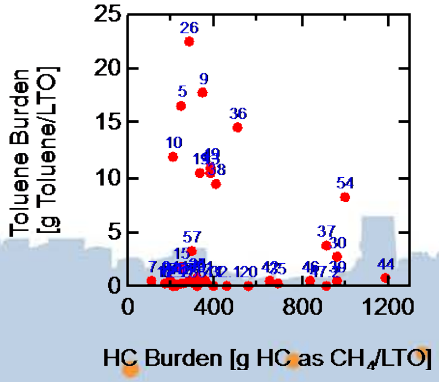
Future Research Opportunities

Representative fleet, operations and times-in-mode

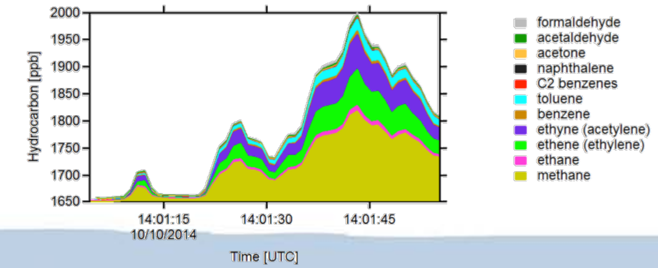


Large dataset collection of emission indices

Fuel additives



Partitioning of emissions (eg. HC to VOCs)



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Question Ideas

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?

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