Emissions Research Activities

Presented To: REDAC E&E Subcommittee

By: Ralph Iovinelli & S. Daniel Jacob

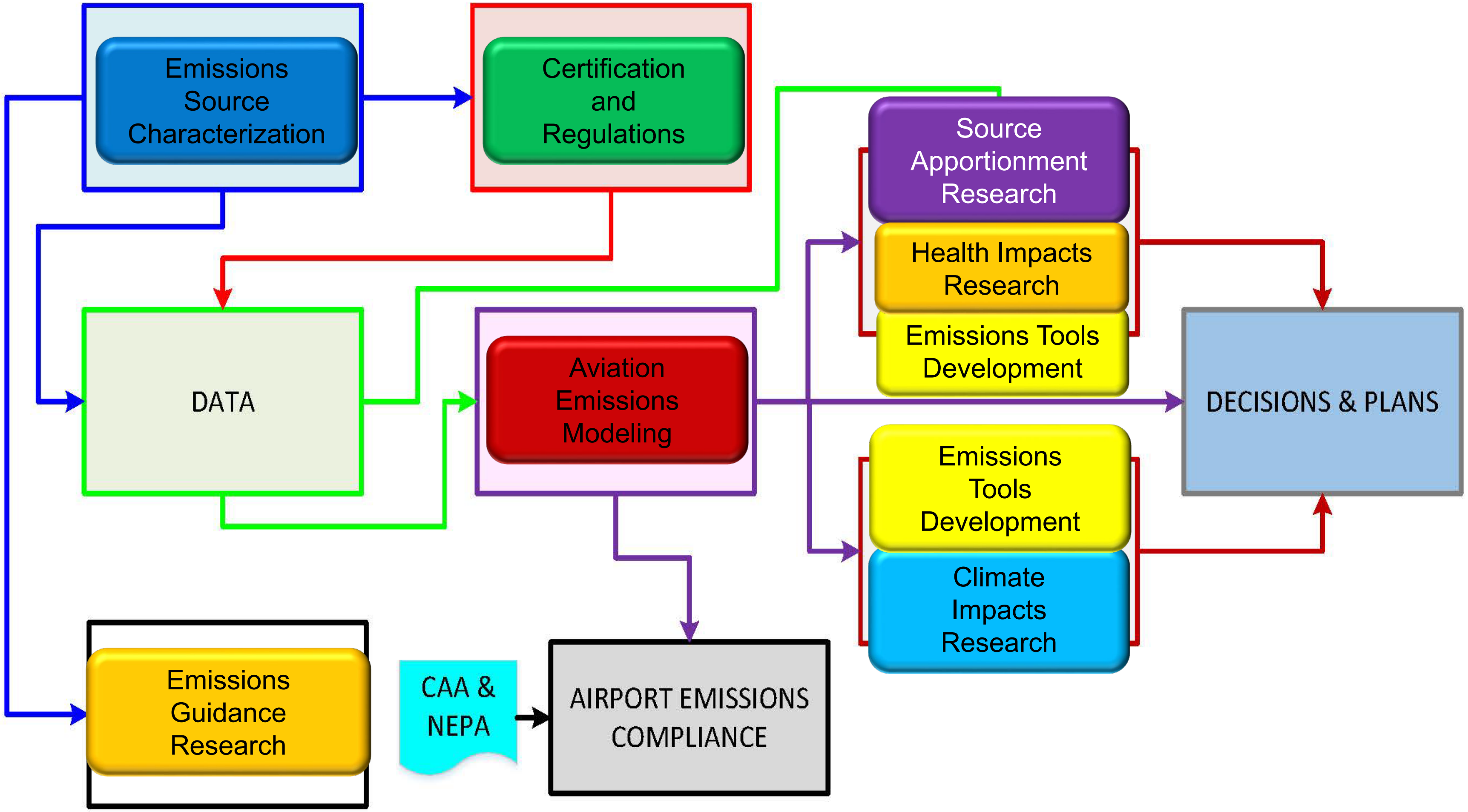
Date: 23 March 2022

Federal Aviation Administration

Outline

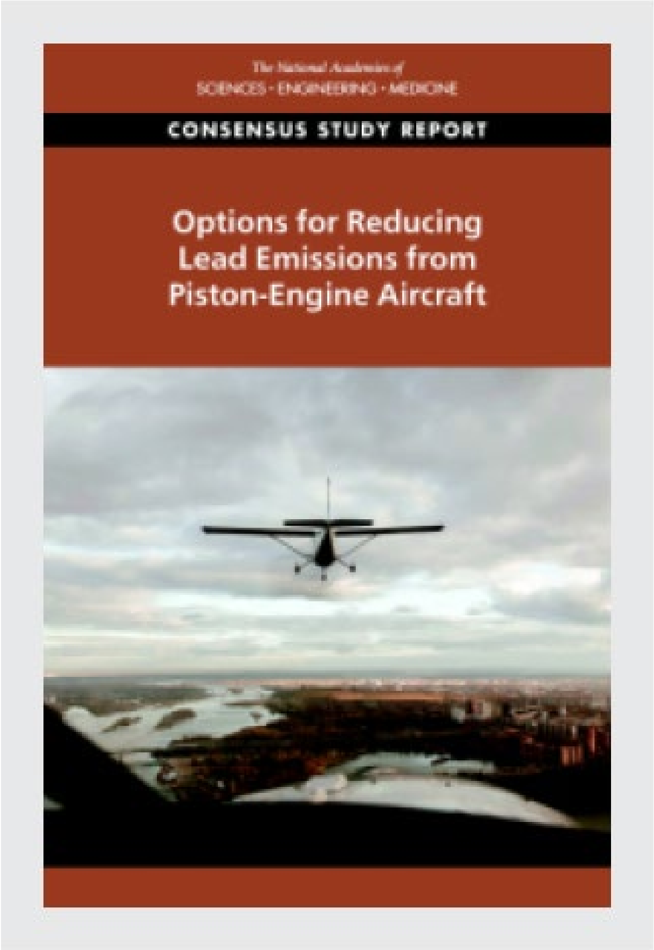
- Emissions Research Roadmap
- Eliminate Aviation Gasoline Lead Emissions (EAGLE)
- Research Updates

Emissions Research Roadmap



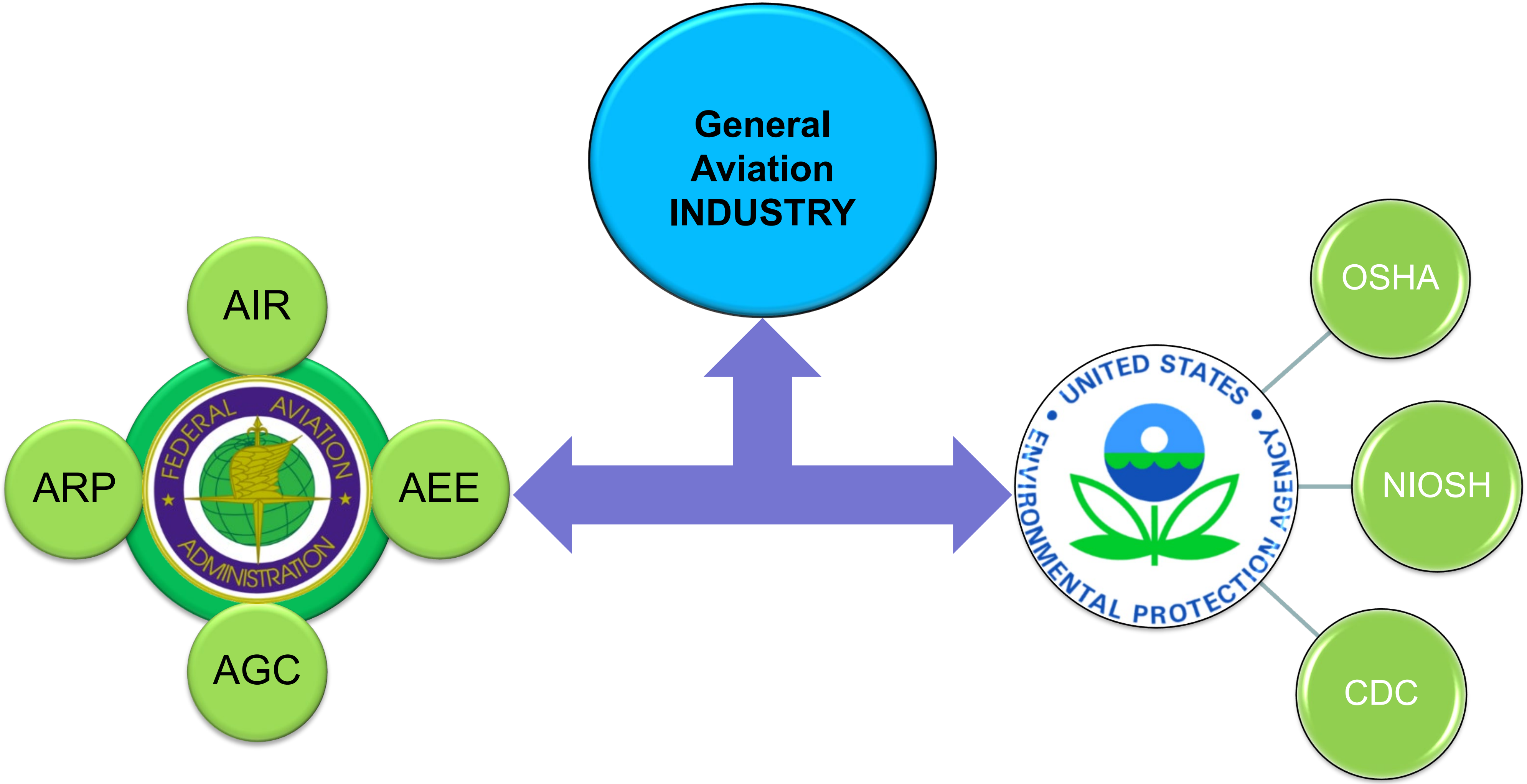
Report to Congress – *January 12, 2021*

- **Section 177 of the FAA Reauthorization Act of 2018, called on FAA to commission this study by a National Academies committee.**
- **The study considers:**
  - (a) ambient lead concentrations at and around airports where piston-engine aircraft are used,
  - (b) existing nonleaded fuel alternatives to avgas used by piston-engine general aviation aircraft; and
  - (c) mitigation measures to reduce ambient lead concentrations, including increasing the size of run-up areas, relocating run-up areas, imposing restrictions on aircraft using avgas, and increasing the use of motor gasoline.
- **Report Conclusion: the removal of leaded aviation gasoline in the United States is a combination of integrated efforts from industry, government, and Congress.**



http://nap.edu/26050

3-Tier Coordination & Collaboration



EAGLE = Eliminate Aviation Gasoline Lead Emissions

GOAL

Remove the use of leaded aviation fuels for piston-engine aircraft in the United States by the end of 2030 without adversely impacting the existing GA fleet.

Path to a Lead-Free Aviation System

Eliminate Aviation Gasoline Lead Emissions (EAGLE)

Pillar A

Business Infrastructure and Implementation

Pillar B

Research and Development

Pillar C

Unleaded Fuel Evaluation and Authorization

Pillar D

Regulation, Policy, and Programmatic Activities

- Industry-Led
- FAA-Led

AOPA your freedom to fly · AAAE · API American Petroleum Institute · EAA The Spirit of Aviation · Federal Aviation Administration · GAMA · Helicopter Association International · NATA National Air Transportation Association The Voice of Aviation Business · NBAA

EMISSIONS RESEACH ROADMAP ELEMENTS – CURRENT AND FUTURE

EMISSIONS MEASUREMENT	Emissions Characterization, Corrections Development, Fuel Composition Effects, Emissions from Advanced Technology, Rig Tests, Engine Tests, Collaboration with CLEEN, NASA, Industry and International Partners
VOLATILE PM MODELING	New methodology to model volatile particulate matter in the vicinity of airports
NVPM MASS CALIBRATION	Maturing the charged particle mass analyzer (CPMA) methodology for in-line and in situ calibration of nvPM mass instruments
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IMPACTS OF HIGH ALTITUDE EMISSIONS	Impacts of various sources of emissions in the upper atmosphere including supersonic transport, high altitude long endurance UAVs, rocket emissions
SUPERSONICS	Technology, Forecasts and Emissions in collaboration with Noise/ CLEEN Divisions
CONTRAIL PHYSICS & MITIGATION	Improved understanding of contrail formation and real-time predictability of the radiative forcing of contrails as affected by technology, fuels and operations. Mitigation of Contrails through technology, fuels and operations (Avoidance)
AVIATION CO_2 TRENDS	Examine CO_2 Emissions Trajectories for Domestic Aviation
AAM LIFE CYCLE EMISSIONS	Lifecycle benefits/disbenefits of transporting people and goods via AAM

LEGEND

- Source
- Emissions Tools Development
- Emissions Source Characterization
- Climate Impacts Research
- Certification and Regulations
- Aviation Emissions Modeling
- Airport Emissions Compliance

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Emissions Measurements

- Lack of Standard Day (i.e. Ambient Conditions) Corrections for nvPM Emissions (CAEP)
- The role of Naphthalenes on nvPM Emissions (CAEP, Tools)
- Inform Cruise nvPM and NOx Emissions Modeling (CAEP, Tools)
- Collaboration: CLEEN Projects on nvPM Prediction Models (Tools)
- Collaboration: Emissions from Advanced Technology (NASA ASCR and Altitude Test – Technology, Tools, CAEP)
    - Advanced Rich Quench Lean
    - Lean Burn

Emissions Source Characterization

Aviation Emissions Modeling

Certification and Regulations

Emissions Measurements

Started: October 2019

June 2022 | September 2022 | December 2022

ASCENT 02: HONEYWELL RIG TEST

Jet A with 29 P3 T3 Test Points

Deliverables: Ambient Conditions Corrections Methodology and Cruise nvPM Methodology Validation

Success Criteria: Methodology applicable to all technologies
Inclusion in ICAO Annex 16 Vol.II

Reference Fuel 1

Deliverables: nvPM Emissions for Fuel 1 and Cruise nvPM Methodology Validation

Success Criteria: Usable data for emissions prediction for different fuel composition

Reference Fuel 2

Deliverables: nvPM Emissions for Fuel 2 and Cruise nvPM Methodology Validation

Success Criteria: Usable data for emissions prediction for different fuel composition

Reference Fuel 3

Deliverables: nvPM Emissions for Fuel 3 and Cruise nvPM Methodology Validation

Success Criteria: Usable data for emissions prediction for different fuel composition

T | T+1 | T+2

FUTURE MEASUREMENTS

Collaboration with NASA
- ASCR + Fuels
- Altitude Tests


ENGINE/ RIG TEST DATA & ANALYSIS

DELIVERABLES: EMISSIONS PREDICTION MODELS FOR ADVANCED TECHNOLOGY

CLEEN Collaboration

CLEEN ASCENT Projects on Emissions Prediction Models

Success Criteria: Methodology usable in AEDT for Emissions Prediction for Advanced Technology Engines

Collaborators: EPA, Transport Canada

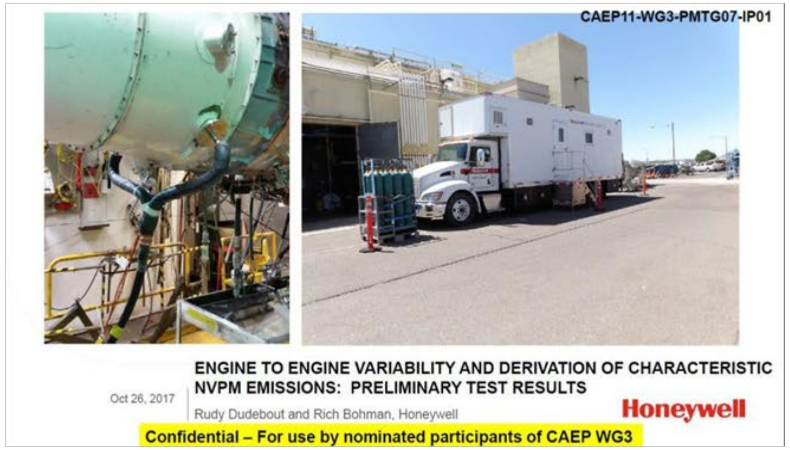
ASCENT 02

- **Honeywell has collaborated with the US FAA and MS&T under University Federal Award, 13-C-AJFE-MST to measure nvPM data in a combustor rig to assess ambient effects on nvPM emissions**

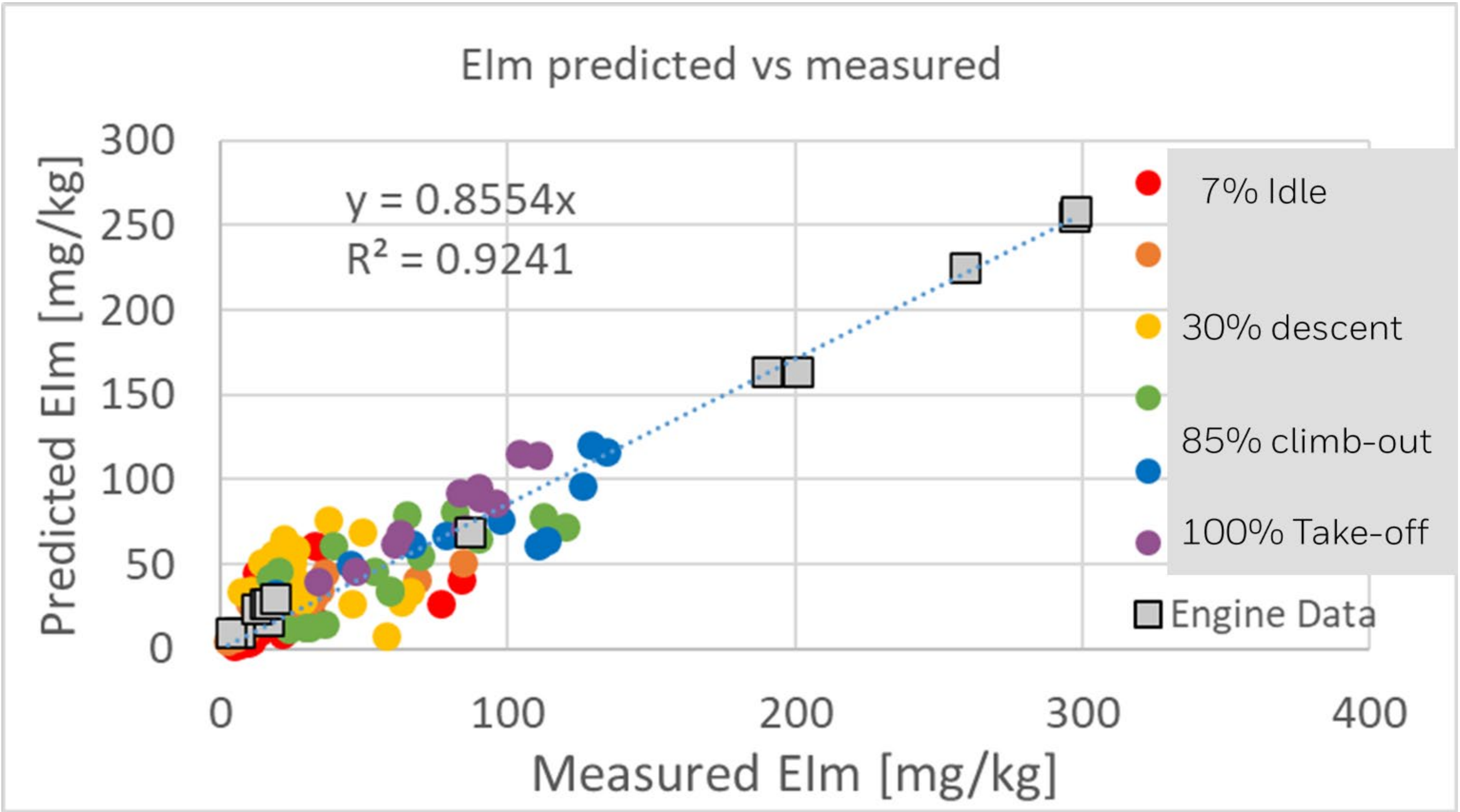
- **Combustor is the same one tested in the 25 engine test campaign (CAEP11-WG3-PMTG07-IP01) – ~7000 lbs thrust MTF engine**

- **Rig Test Matrix**
  - 6 different temperature points (idle to 100% thrust) with variations in corrected flow, fuel to air ratio and pressures.
  - One-factor at a time perturbation enables exponents to be calculated for each control variable
  - Facility limits to about half of the 100% LTO full engine pressure

- **EIm and Ei# presented is thermophoretic loss corrected only**

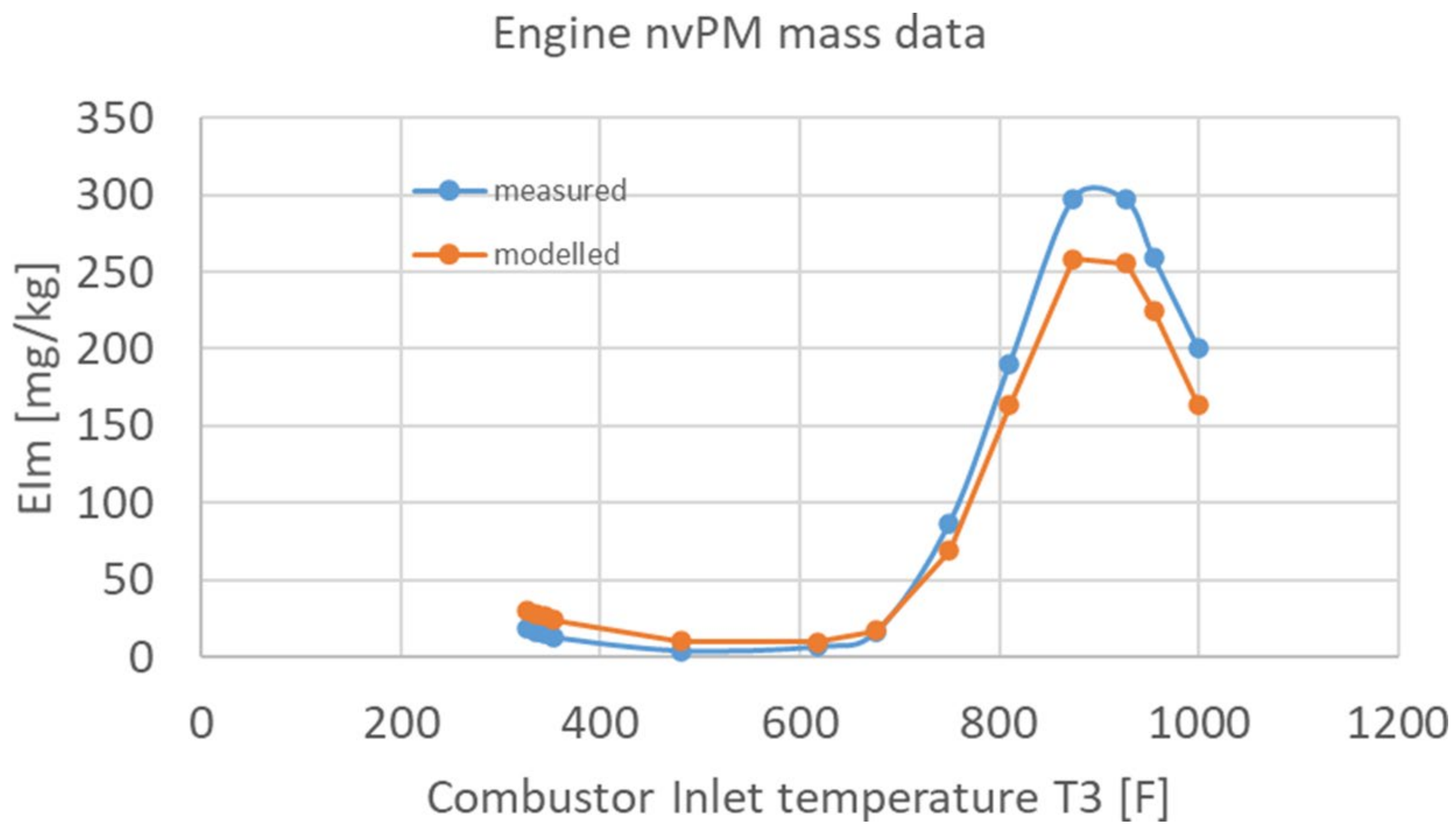


COMPARISON OF MASS MODEL TO RIG & ENGINE



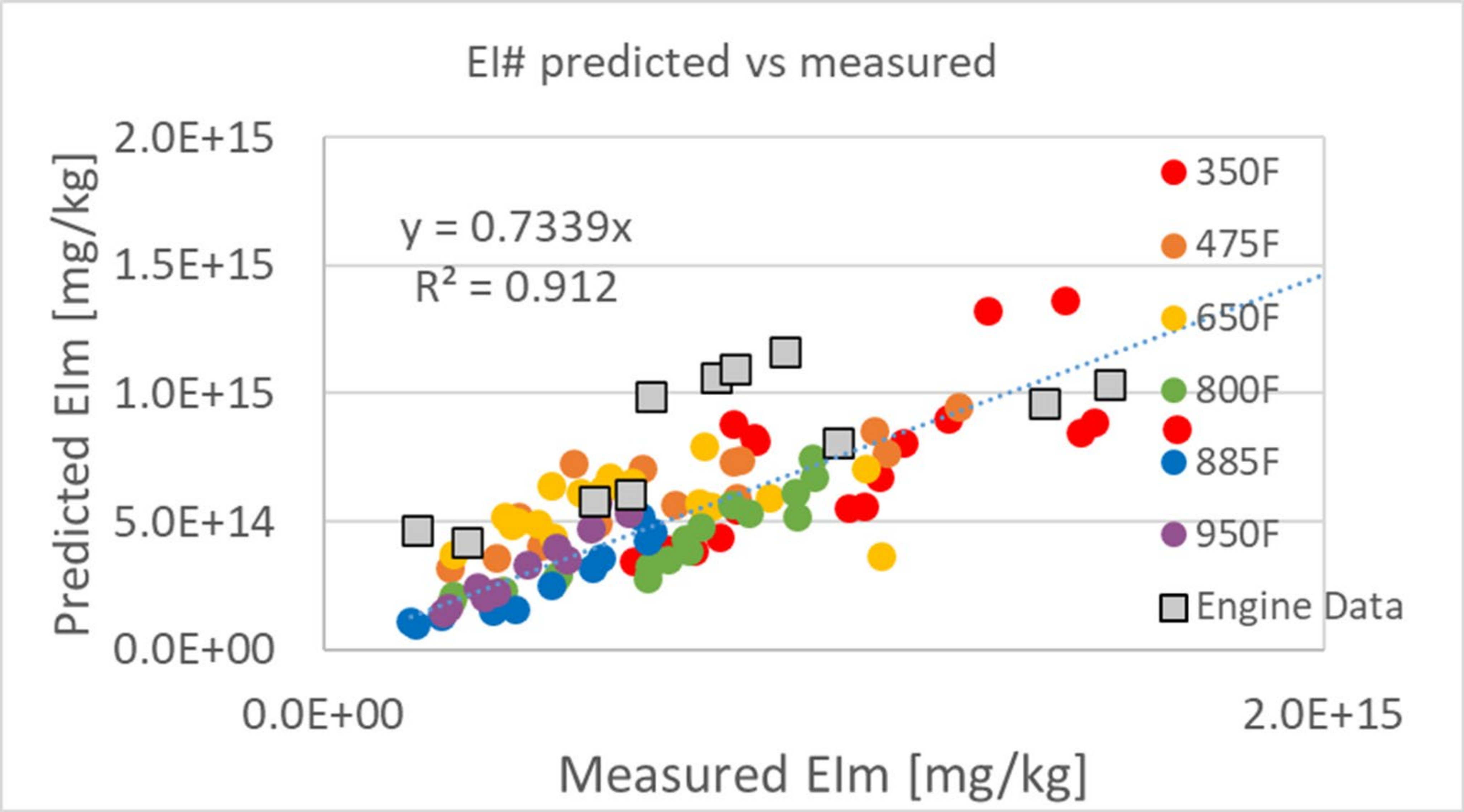
$$EIm = 6.14 \times \left(\frac{w_{3c}}{w_{3c,max}}\right)^{(-30*e^{-0.5*\delta_3})} \times \delta_3^{(\varphi_{PZ})^{3.2}} \times (\varphi_{PZ})^{(-12.6*(\varphi_{PZ}-0.97)*(\delta_3)^{0.35})}$$

TURBOFAN ENGINE TEST DATA COMPARISON (MASS)

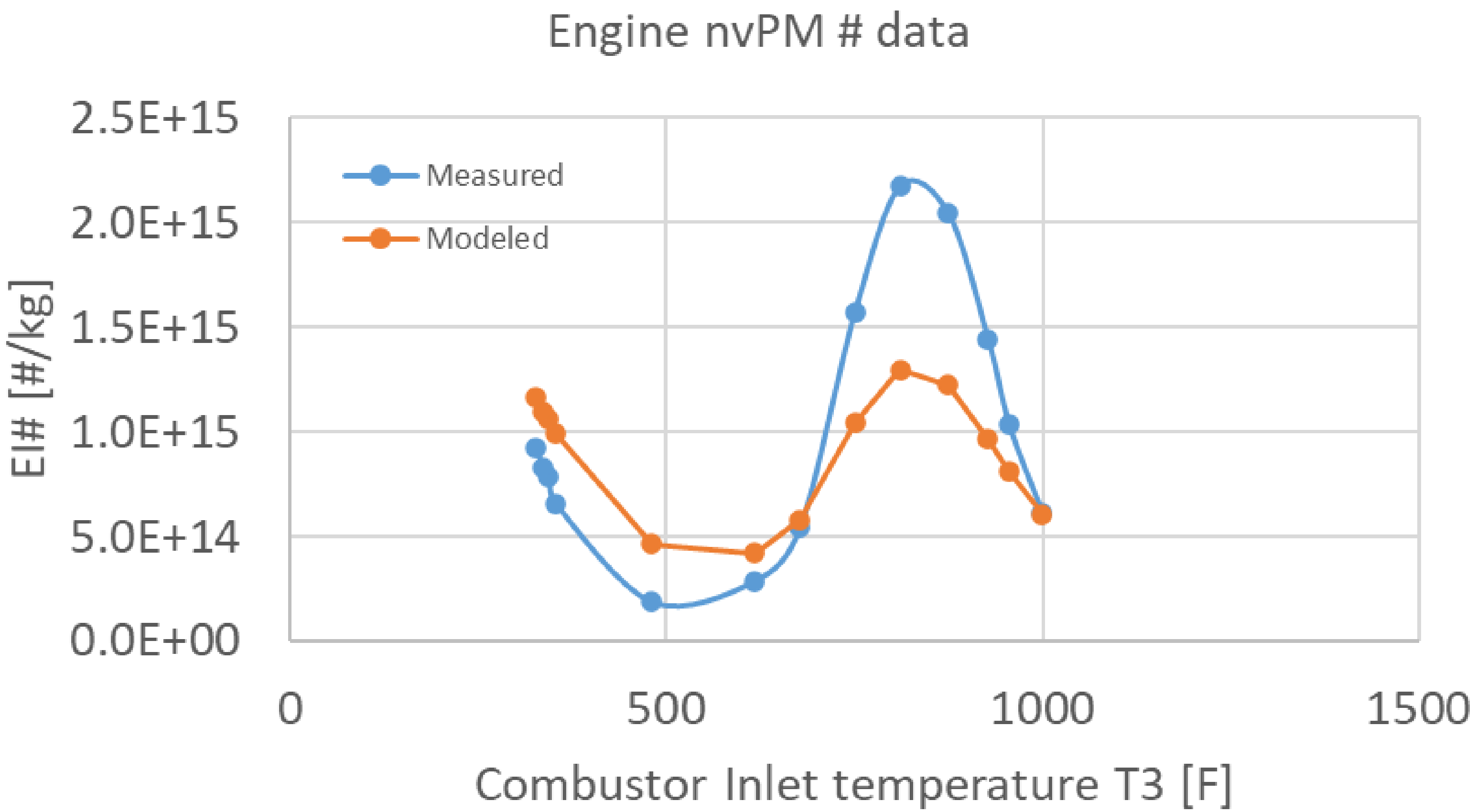


Engine test indicated a S-shaped behavior for Eim_nvPM vs T3

COMPARISON OF # MODEL TO RIG & ENGINE



TURBOFAN ENGINE TEST DATA COMPARISON (#)



Broad trends captured – but magnitudes are off

ASCENT02 Future Work

- Develop Correlations for Standard Day Corrections – Planned collaboration with MIT under ASCENT Project 48 and 83
- Perform Simultaneous Measurements with the North American Reference System (NARS)
  - ➢ The NARS has additional instrumentation to measure size distribution, contribution of volatile particulate matter and additional high sensitivity non-volatile particulate matter mass measurement
  - ➢ Use Jet A and three Sustainable Aviation Fuel Blends with varying aromatic contents

Emissions Measurements

Deliverables:

- Ambient Conditions Corrections Methodology and Cruise nvPM Methodology Validation
- nvPM Emissions for Different Fuel Specifications

Success Criteria:

- Methodology applicable to all technologies for inclusion in ICAO Annex 16 Vol. II
- A validated cruise nvPM Methodology
- Data for nvPM emissions prediction for different fuel compositions

Future Work:

- Additional work on Honeywell Rig Test not anticipated for ASCENT 02
- Research on Emissions Predictions for higher Overall Pressure Ratio engines needed

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Microphysical Modeling of Volatile Particulate Matter (vPM) – CAEP, Tools

- The non-volatile modeling methodology that is part of the First Order Approximation 4.0 was updated during the CAEP/11 cycle. The vPM modeling methodology of FOA4 is based on a single dataset. More datasets are available now that can be used to develop more representative vPM emissions estimates from aircraft engines in the vicinity of airports

January 2020 | January 2021 | September 2021

VOLATILE PM MODELING

SCOPING

DATA COMPILATION

Parametric Analysis Using Aerodyne Dynamic Simulation Code

Updated vPM Modeling Methodology and Validation

Available Datasets: APEX I, II and III, AAFEX I and II, ND-MAX/ ECLIF2 and EU AVIATOR

Status: Methodology is complete. Further evaluation by stakeholders in CAEP/13 for inclusion in to ICAO DOC 9889 and AEDT

Source Apportionment/ Health Impacts Research

Emissions Tools Development

Aviation Emissions Modeling

Microphysical Modeling of Volatile Particulate Matter (vPM)

Deliverables:

- Update to First Order Approximation 4 (FOA4) Volatile Particulate Matter Modeling Methodology that can be included in ICAO Doc 9889 and implemented in AEDT and final reports documenting the methodology
- Contrail microphysics modeling and validation

Success Criteria:

- Demonstrated improvement over the current vPM prediction methodology
- Enhanced understanding of contrail microphysics in the near field.

Future Work:

- Methodology may need refinement as newer measurement datasets become available

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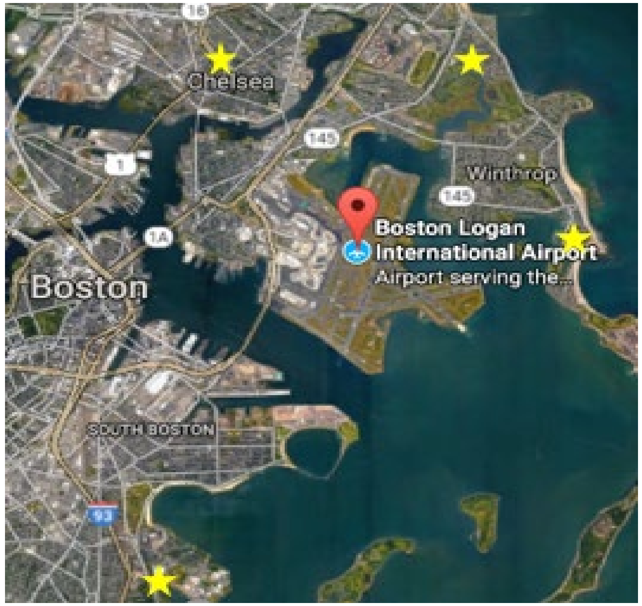
A18: Airport Monitoring: Status

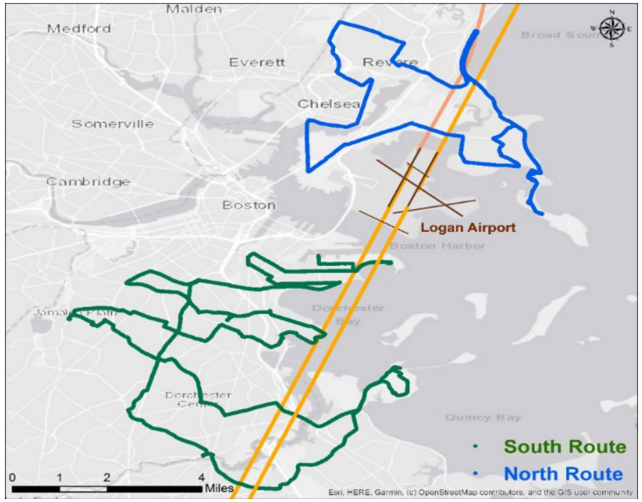
Stationary Sites

1. Monitors setup Chelsea (April 2020), Revere (July 2020), Winthrop (August 2020), and UMASS (Feb 2021)
2. **~93 million records of 1-second PNC data at each site**
3. ~ only 4% of data removed during QAQC
4. Minute and hourly aggregated data for analysis

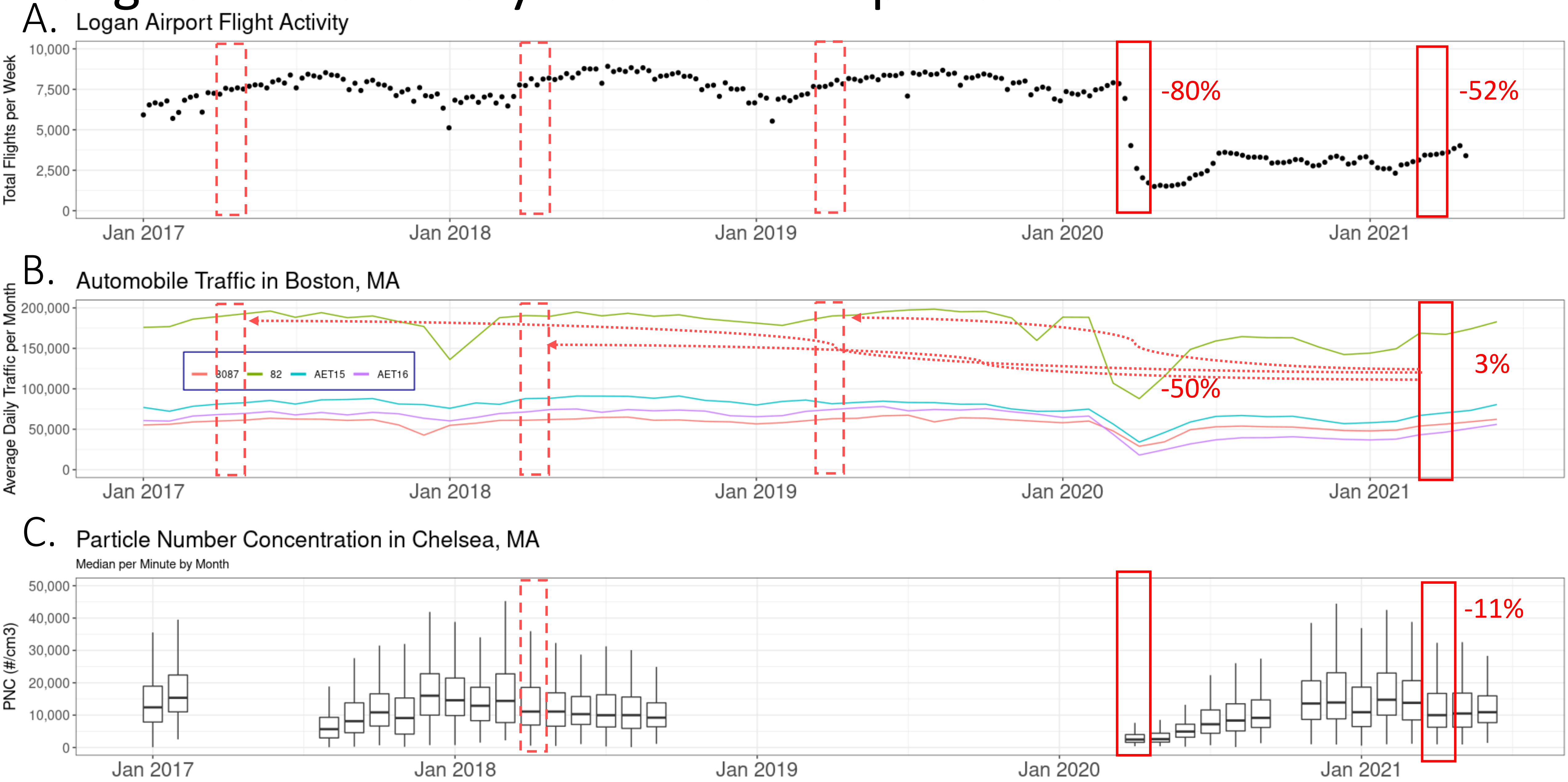


Mobile Monitoring

1. North and South Routes developed spring and launched summer monitoring 2020
2. Since August 2020 we have collected **over 700 hours of air pollution data on 228 days until December 2021** (North Route = 121 days; South Route = 107 days) including every season and month while covering a wide variation in time of day (i.e. daytime, nighttime, and overnight), weekday/weekends; and holidays (i.e. New Years day, July 4th).



Long-term Stationary Monitor PNC patterns



Airport Monitoring

Deliverables:

- Demonstration of measurement concepts for long-term spatial and temporal UFP, BC and NOx around BOS that can be extended to other airports
- Data for statistical and mathematical model development and validation purpose
- Data sharing protocol and platform with other ASCENT and non- ASCENT projects

Success Criteria:

- Spatial and temporal data; data ready for model development and validation and for use by A19
- Source attribution from aviation emissions
- Airport monitoring guidance & best practices

Future Work:

- Additional airport monitoring campaigns for model validation (A19/UNC);
- Development of ambient UFP prediction model around airports;
- UFP and Health impact studies - Epidemiological model and field campaign; and
- Joint Emission and Noise study design and health studies

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Dispersion Model Development (A19) and Monitoring Study (A18) Research

- **Challenge: Address artificial model exceedances of 1-hour NO_2 National Ambient Air Quality Standard**
  - Delays National Environmental Policy Act (NEPA) review of Federal actions at airports
- **Research Solutions:**
  - Compare performance of regulatory models to real-world monitor values (@ LAX, ORD, etc.)
  - Collaborate with EPA to improve AERMOD dispersion analyses for aviation-specific emission sources
  - Develop a validated aviation-specific emissions dispersion model
- **Expected Outcomes – A more accurate aircraft-specific model to demonstrate airport air quality compliance that is acceptable to EPA.**
  - Improved aircraft source characterization and plume rise in EPA's AERMOD for aircraft emissions
  - A new model reflecting the best science and algorithms
  - Short and long-term monitoring around airports for modeled-monitoring comparison study and model validation
  - Better characterization of AQ impacts on communities surrounding airports through modeling and monitoring study

Proposed Schedule and Deliverables: A19 – Aircraft-Specific Dispersion Model Development and AERMOD Improvement Plan

Late 2019/Early 2020 | 2021 | 2022 | 2023 | 2024 | 2025

Task	Deliverable	Success Criteria
Develop schedules, protocols based on requirements	Detailed model design document (Completed)	Meets design implementation document, and approved by stakeholder(s)
Overall Model Architecture for ADM	General Model Architecture Development and documentation (Completed)	Source code should meet V&V and design document criteria; updated source treatment in AERMOD of aircraft emissions
Develop plume rise method in EPA's AERMOD	Tested and validated plume rise code, test results with measured data and document the results (Ongoing)	Source code should meet V&V and tested; and ready for inclusion into AERMOD
FAA-EPA Collaboration on AERMOD Improvement	Improved plume rise model implementation in AERMOD (Ongoing)	Proper characterization of plume rise and source characterization for aircraft sources in EPA's AERMOD and ready for application
Develop physical and chemical processes module in the ADM model	Test and validate source codes for physical process and chemistry, test results and documentation (Ongoing)	Improvement in jet plume model, wakes, vortices improvement and 1-hr NO2 predictions for ADM
Perform model testing and evaluation	Validate ADM against measured data with documentation (Ongoing)	Source code should meet V&V and design document criteria; and Model should exceeds present model AERMOD & meets robustness and accuracy criteria
Develop reports, user guide and manuscripts, and Appendix W inclusion	Final guidance from FAA and EPA for regulatory applications	A new and an improved aircraft-specific dispersion model (ADM) for regulatory applications

EPA – FAA Coordination on AERMOD Improvement Tasks

- Coordination with EPA - technical exchanges on the performance of dispersion models (UNC's Aviation Specific Dispersion Model - ADM, AERMOD and LASPORT) and comparison with data from LAX (Summer 2021)
- Monthly coordination meetings
- EPA Suggestion: Implementation of UNC's ADM plume rise algorithm in AERMOD
  - Paused ADM development
  - AERMOD update initiated with a detailed schedule to meet Appendix W update by November 2022 (Updated AERMOD would be released in 2023)
  - Weekly Technical Coordination Meetings

➢ Effective coordination between UNC, EPA and FAA to implement the plume rise algorithm in AERMOD

Development of Aviation-Specific Dispersion Model (ADM) and AERMOD Update: FAA-EPA Joint Task Group

- ❑ Primary focus of AERMOD science improvement specific to airport/aircraft modeling to incorporate plume rise (PR) treatment
- ❑ Enhance source characterization for aircraft sources in AEDT (area volume sources, and/or RLINE sources)
- ❑ Regulatory update to the EPA's *Guideline on Air Quality Models* focused on science improvements to the aircraft emission modeling in AERMOD Modeling System - Appendix W Update

Ongoing timeline for needed deliverables to meet Appendix W update target date

MAR 2020 — SEP 2021 — NOV 2021 — JAN 2022 — MAR 2022 — MAY 2022 — JULY 2022 — SEP 2022 — NOV 2022

MODEL DEVELOPMENT & APPENDIX W UPDATE

MODEL FRAMEWORK DOCUMENTATION

WHITE PAPER TO EPA

DRAFT PR ALGORITHM TO EPA

DRAFT CODE TESTING (EPA) & AEDT UPDATE (FAA)

MODEL EVALUATION DOCUMENTATION

MANUSCRIPTS, PUBLICATIONS

Aviation Specific Dispersion Model Development

Deliverables:

- Improved AERMOD dispersion model with better source characterization
- Fully validated new aviation dispersion model that is ready for AEDT implementation, and incorporates improved physical and chemical processes

Success Criteria:

- Updated source characterization of aircraft emissions code
- Updated jet plume model that takes into account wakes + vortices
- Improved NO_2 chemistry in 1-hr NO_2 predictions and code that meets design document criteria

Future Work:

- Utilize airport monitoring campaigns data for model validation;
- An improved meteorological model and state-of-science algorithms; and
- Implementation of a better performing model in AEDT for regulatory compliance demonstration.

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Improving Policy Analysis Tools to Evaluate Higher-Altitude Aircraft Operations

Deliverables:

- ASCENT 22 & 58: Radiative Forcing and Climate Impacts for high altitude Emissions Scenarios for APMT Implementation (Two Climate Models and Two Inventories)
- ASCENT 58: Air Quality Impacts Tool for High Altitude Emissions
- ASCENT 58: Climate Impacts Tool for High Altitude Emissions
- ASCENT 22: Evaluation of APMT-I Climate and Air Quality Tools

Success Criterion:

- APMT-I Climate and Air Quality Tools that can be used in operational Costs Benefits Analyses to include high altitude emissions

Future Work:

- Tools update and evaluation based on latest scientific knowledge

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ASCENT 78: DECISION SUPPORT TOOL FOR CONTRAIL AVOIDANCE

Recap: Objectives A78

Develop a **decision support tool** which allows evaluation of the **likely costs and benefits** of operational contrail avoidance measures

Integrate these capabilities into a **tool** which can be evaluated under real-world conditions.

A78 research needs for successful contrail avoidance

1. **Contrail forecasting module**
   Predict where contrails form and persist so that they can be avoided
2. **Contrail radiation module**
   Quantify how much climate benefit would result from avoiding the contrail
3. **Trajectory optimization module**
   Quantify how much climate penalty would result from the additional fuel burn
4. **Contrail identification module**
   Perform empirical verification of the effectiveness of the action

Mitigation of AIC Climate Impacts

Deliverables:

- Identification of data and science gaps and development of approaches to address gaps to predict real-time contrail formation at flight by flight resolution and impacts of potential mitigation actions to identify effective mitigation solutions – Resulting Action: Research to Address Gaps
- Development of tools to predict warming contrails and changes in fuel use using operations, technology, and fuel composition to assess the practicability of avoiding warming contrail formation. Validate using existing and future airborne data
- Real time tool with appropriate data stream that can predict formation of warming contrails
- Evaluation of optimal flight routing to minimize climate impacts of aviation

Success Criteria:

- Real time predictability of warming contrails
- Decision support tools that could be used by airlines to inform flight routing. Needs to determine means of warming contrail avoidance, increased fuel burn, and other climate impacts in real time

Future Work:

- Implement an integrated research program that would identify approaches that could be used by industry to cost effectively mitigate the overall climate impacts of aviation via contrail mitigation

Summary

- **Comprehensive Emissions Research Portfolio**
- **Research needs based on:**
  - Characterizing emissions of current and future engine technologies and fuels
  - Impacts reduction
  - Tools development
  - CAEP / domestic policy needs
- **Establishing internal and external collaborations**
- **Successful outreach through Annual AEC Roadmap Meeting**