ASCENT Project 02

Re-Examination of Engine-to-Engine PM Emissions variability using an ARP Reference Sampling and Measurement System

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Cost Share Partner: EMPA/FOCA

Objective:

- The effect of ambient atmospheric conditions on the nvPM emissions from aircraft engines is not yet well understood. A quantitative relationship of this effect is required to develop standard day corrections for nvPM mass and number emissions. By changing the inlet conditions in a combustor rig test, this research seeks to quantify the effect of ambient conditions on the nvPM mass and number emissions.
- The research will also address the impact of fuel composition on the nvPM mass and number emissions for various inlet conditions to improve our understanding of the fuel composition effects.

Project Benefits:

- Standard day corrections for nvPM mass and number emissions that can be implemented in ICAO Annex 16 Vol.II
- Evaluation, verification and validation of cruise and performance based nvPM emissions modeling methodologies
- Improved understanding of fuel composition effects on nvPM emissions including any correlations between inlet conditions and fuel composition variability.

Research Approach:

- A series of combustor rig tests will be conducted by Honeywell at their testing facilities in Phoenix Arizona. The North American Reference System (NARS) and its ancillary equipment will be used in conjunction with Honeywell emissions testing facilities to characterize the non-volatile Particulate Matter (nvPM) emissions and develop predictive emission functions for a series of conventional and synthetic alternative jet fuels.

SCHEDULE	Q4 2021	Q1 2022	Q2 2022	Q3 2022	Q4 2022
Phase 1 Data Red.	*******	***			
Test Planning		********			
Test Execution			**		
Data Analysis			*******	*******	****
Final Report					*

Major Accomplishments (to date):

- Testing with conventional Jet A has been completed
- Analysis including development of predictive emissions functions is completed.
- Real-time size data acquired with MS&T DMS 500 analyzed and delivered to Honeywell for inclusion in predictive emissions development.
- Developed phase 2 test plan for rig testing using 3 synthetic alternative jet fuels and repeating Jet A.
- Develop fuel delivery and doping protocol.

Future Work / Schedule:

Deploy MST NARS to Honeywell and execute test plan
Analyze data and develop predictive emissions functions
Prepare final report

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Background

- 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

- Combustion system is equipped on a Mixed Turbofan engine with 7,000 lbs thrust.
  - Test data available from engine & rig testing

- 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

Data Analysis

- **Emission Indices of nvPM mass (EIm), nvPM number (EI#), NOx, CO, UHC and smoke numbers were gathered**
- **Correlating parameters** evaluated:
  - Combustor inlet pressure (P_3)
  - Combustor inlet temperature (T_3)
  - Combustor primary zone equivalence ratio (ϕ_{PZ})
  - Combustor referred flow (correlates with pressure drop, see next slide for definition)
  - Other parameters also assessed: exit temperature (T_4), overall Fuel/air ratio, residence time, primary zone temperatures
- Best fit functions developed for both EIm and EI#
  - Avoided use of polynomials (improved fit, but may be too combustor specific)

EImass (Emissions Index nvPM mass) – Curve Fits

"pressure drop" effect | pressure effect | Primary Zone equivalence ratio effect

$$EIm = 6.14 \times \left(\frac{w_{3c}}{w_{3c,100\%}}\right)^{(-30*e^{-0.5*\delta_3})} \times \delta_3{}^{(\varphi_{PZ})^{3.2}} \times (\varphi_{PZ})^{(-12.6*(\varphi_{PZ}-0.97)*(\delta_3)^{0.35})}$$

φ_{PZ} Primary Zone Equivalence ratio

$w_{3c} = w_3\sqrt{(T_3 + 460)/518.7}/(P_3/14.696)$ Combustor Corr. flow or Referred flow

$w_{3c,100\%}$ Corrected flow at 100% LTO thrust

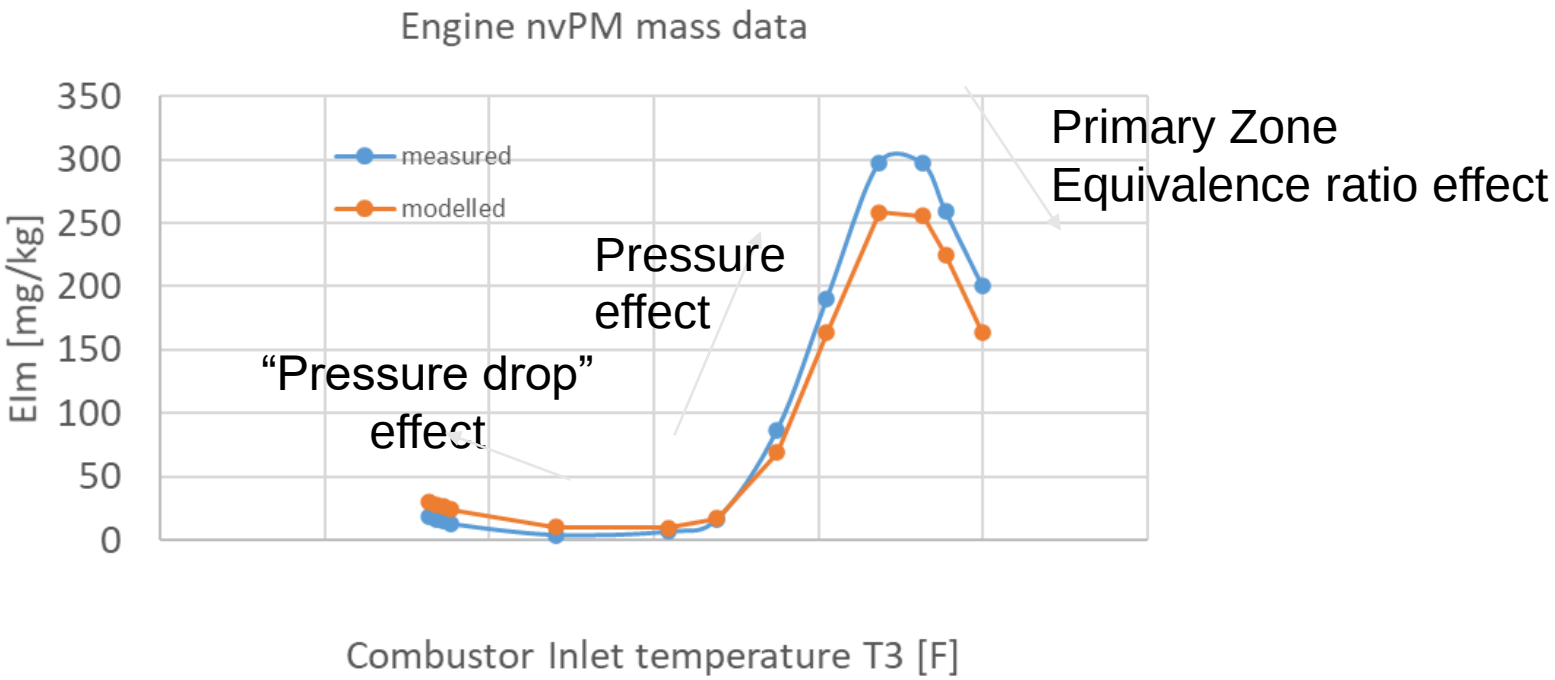
$\delta_3 = (P_3/14.696)$ Pressure Ratio

T_3 Combustor inlet temperature [F]

P_3 Combustor inlet pressure [psia]

w_3 Combustor airflow [lb/s]

Turbofan Engine test data comparison (EImass)



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

EI Number (Emissions Index nvPM number) – Curve Fits

"pressure drop" effect | pressure effect | Temp. effect | Primary Zone Equiv. ratio effect

$$EI\# = 1.8025 \times 10^{15} \times \left(\frac{w_{3c}}{w_{3c,100\%}}\right)^{(-5*e^{-0.2*\delta_3})} \times e^{0.1083\times\delta_3} \times \theta_3{}^{-2.17} \times e^{-\left(\frac{(\ln(\varphi_{PZ})-0.06)^2}{2\times 0.22^2}\right)}$$

φ_{PZ} Primary Zone Equivalence ratio

$w_{3c} = w_3\sqrt{(T_3+460)/518.7}/(P_3/14.696)$ Combustor Corr. flow or Referred flow

$w_{3c,100\%}$ Corrected flow at 100% LTO thrust

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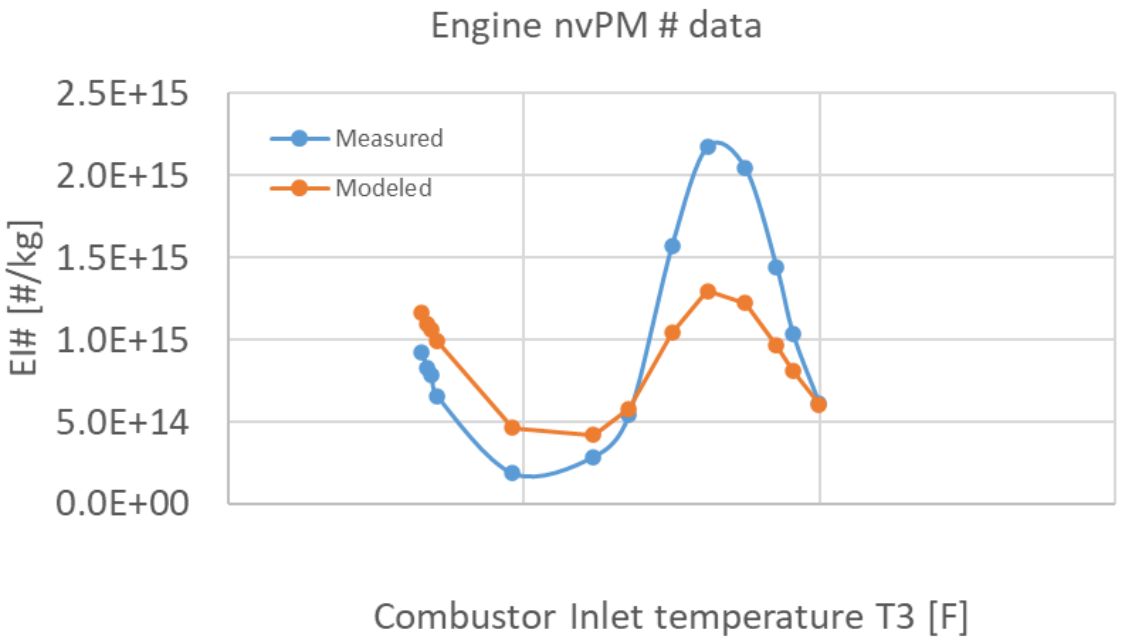
Turbofan Engine test data comparison (EInumber)



- Similar trends as EIM – but magnitudes are off for EI# model

Conclusions and Go-Forward

- Eim and EI# nvPM Models has been developed that have good predictive capability, including capturing non-monotonic behaviors
- The model also appears to capture trends observed in various different Turbofan engines that could be associated with design and operating conditions
- Next steps:
  - Further data analysis (including using other pollutants as correlating parameters)
  - Develop Standard Day Corrections for nvPM mass and number emissions
    - Communicate to ICAO CAEP WG3 for evaluation for different combustor technologies
  - Inform Cruise Emissions Modeling
  - Follow-on testing planned for Q2-3 2022
    - include Jet-A, as well as 3 blends of SAF with varying levels of aromatics
    - to be conducted with HON and North American Reference System in parallel

Outreach and Participants

Outreach:

- This work has been presented to ICAO CAEP WG3
  - nvPM combustor rig test 1 – Preliminary Correlations for the Honeywell nvPM Rig test", CAEP12-WG3-ECTG7-IP01 presented Sept 9, 2021 at the 7th meeting of the ICAO CAEP working group 3

- This work will be presented at Coordinating Research Council (CRC) Aviation Meeting 4-5 May 2022 in the session on Properties and Emissions
  - ASCENT Project 002: to characterize the non-volatile Particulate Matter (nvPM) emissions and develop predictive emission functions for a series of conventional and synthetic alternative jet fuels.

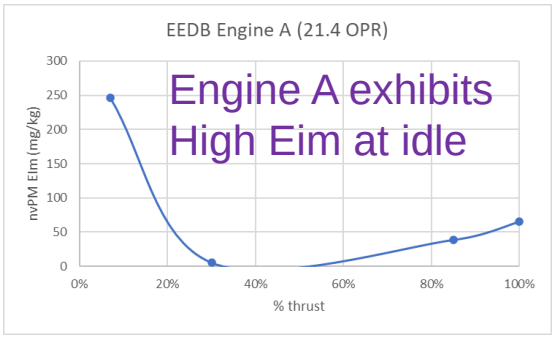
Participants:

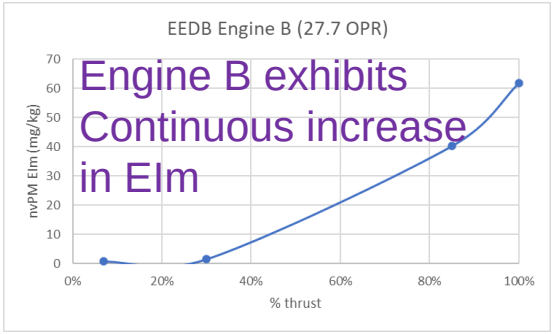
Rudy Dudebout, Rich Bohman, David Christie and Paul Yankowich (Honeywell)
Rick Miake-Lye (Aerodyne Research Inc).
Edwin Corporan (AFRL Wright Patterson AFB)
Phil Whitefield and Steven Achteberg (Missouri S&T)
Daniel Jacob (FAA)

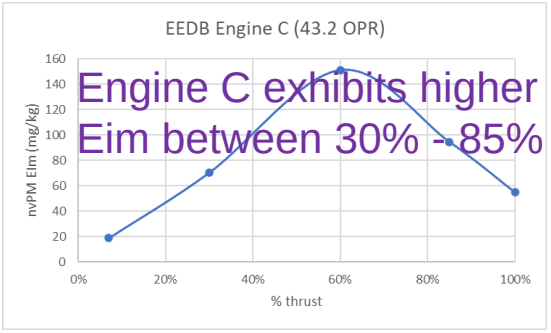
Back Up slide(s)

Evaluating "what-ifs" in model parameters

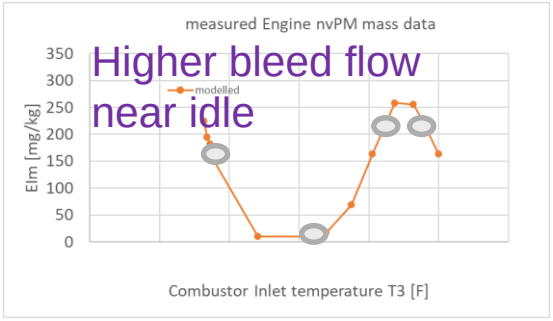
Engine data in the ICAO Engine Emissions databank (EEdb):

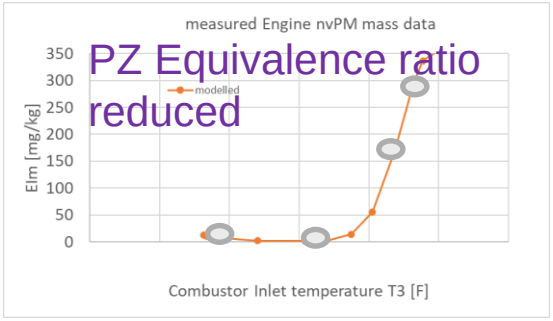


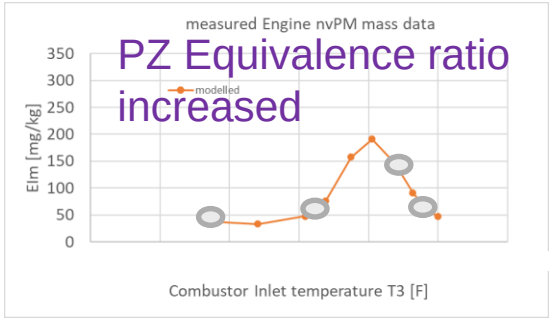




Small perturbations to the nvPM model
(no change to cycle, hypothetical changes to combustor and bleeds)







The model appears to be predictive of nvPM mass trends over the LTO cycle, depending on model inputs