Project 48
Analysis to Support the Development of an Engine nvPM Emissions Standard

Lead Investigators: Steven Barrett, Raymond Speth — Project Manager: Daniel Jacob, FAA — October 9-10, 2018

Motivation

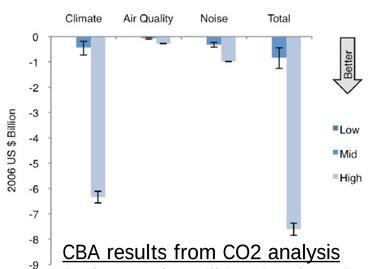
- The combustion of fuel is a source of non-volatile particulate matter (nvPM), with a size less than 2.5 µm ($PM_{2.5}$). Aircraft engines also emit "ultrafine" particles that are considered to be more harmful more toxic to humans than other sources.
- Exposure to $PM_{2.5}$ and "ultrafine" particles has been linked to health risks such as cardiopulmonary disease leading to premature mortality.
- Cruise-altitude nvPM emissions contribute to aviation's climate impact through direct black carbon radiative forcing. They also provide a surface for ice crystals to nucleate, supporting the formation of contrails.

In order to reduce these environmental impacts, ICAO-CAEP is developing a standard for nvPM mass and number emissions for aircraft engines to reduce aviation's environmental impact.

Objectives

This projects helps support the FAA decision-making process related to the development of the standard, while providing an independent assessment of the CAEP analyses. The main tasks include:

- Provide independent evaluation of candidate stringency options (SOs).
- Verify estimates of technology responses to different nvPM metrics and stringency options.
- Generate and assess mappings from representative engines to a broader set of engine/airframe combinations accounting for variations in engine technologies.
- Develop advanced, data-driven methods to estimating nvPM mass and number emissions using smoke number (SN).
- Develop tools and processes to be used in cost/benefit analyses of possible nvPM standards including economic, climate, air quality, and noise impacts.
- Conduct CBA to identify the optimum stringency options for the nvPM metrics.



CBA results from CO2 analysis
Similar results will be developed for nvPM mass

This work was funded by the US Federal Aviation Administration (FAA) Office of Environment and Energy as a part of ASCENT Project 48 under FAA Award Number: 13-C-AJFE-MIT-027. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA or other ASCENT Sponsors.

Summary

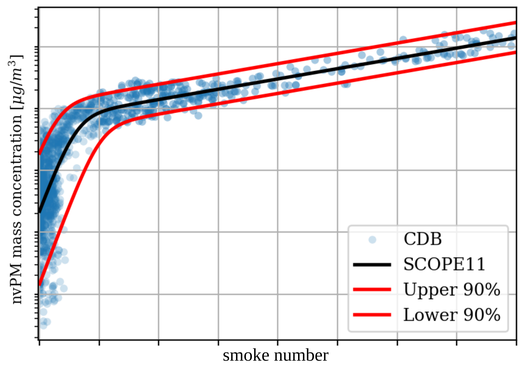
Aviation emissions contribute to air quality and climate impacts. Policies must be developed to direct the technology towards a cleaner future. In the current policy cycle, ICAO-CAEP is developing a standard for nvPM mass and number emissions.

By aiding the CAEP analyses and FAA decision-making process, we aim to identify cost beneficial nvPM regulations that can reduce aviation's environmental impact using the APMT-I tools. In the process, we aim to motivate and convince CAEP to adopt CBA in addition to cost-effectiveness analysis (CEA).

Results & Discussion

Methods to estimate nvPM mass and number emissions

- FAA and ICAO require an inventory of nvPM mass & number emissions to conduct CBA and CEA
- We have developed a correlation between SN and nvPM mass that improves upon current practice (Wayson et al. 2009[1]) by using:
  - I. A dataset of concurrent SN and nvPM mass measurements that used standardized, certification-compliant measurement systems; and
  - II. A novel relationship that can explain the trend of nvPM mass at low and high SNs.
- This correlation is referred to as the Smoke Correlation for Particle Emissions – CAEP/11 (SCOPE11) and includes upper and lower confidence intervals for uncertainty quantification.



- For number emissions, we must estimate the geometric mean diameter (GMD). Current methods assume a fixed GMD for each mode of operation. This is used to estimate a number emissions index (EI-n) as below, where $\sigma = 1.8$ is the geometric standard deviation:

$$EI_{\#} = \frac{8EI_m}{\pi\rho(GMD)^3 e^{4.5(ln\sigma)^2}}$$

- We have developed a new method using mass concentration (C_{BC}). A higher C_{BC} increases coagulation rates, and so larger GMDs, which our method attempts to model.

SCOPE11 can be used to estimate nvPM mass and number emissions knowing only the SN. The method will be used to calculate an emissions' inventory for all historic engines where nvPM measurements do not exist. This work has been submitted for peer-review publication.

Evaluation of stringency options (SOs)

- Using the agreed upon SOs (5 for mass, 3 for number), we have estimated the margins of a set of engines to each SO.
- This provides guidance on technically achievable targets to help ICAO-CAEP push manufacturers toward cleaner engines.

Replacement of SN with mass concentration limit line

- During CAEP/10, a mass concentration limit line was developed using the original SN limit line.
- ICAO-CAEP is now considering the possibility of replacing SN with the CAEP10 limit.
- The SN limit line was developed as a visibility standard in the 1980s, based on the characteristics of turbojet engines.
- We have developed an updated analysis which explores the application of the same visibility criterion to mixed and unmixed turbofan engines, in order to understand how this visibility criterion compares to both the SN and CAEP/10 limits.

Future Work

1. Complete the CBA of the nvPM stringency options. This includes using sensitivities from adjoint simulations for air quality impacts and the APMT-I climate model.
2. Provide input on the use of the SCOPE11 method for airport inventory calculations in ICAO Doc 9889.

Contributors & Collaborators:

- MIT: Akshat Agarwal, Jayant Sabnis; Carla Grobler (ASCENT Project 21); Kingshuk Dasadhikari (ASCENT Project 20)
- Aerodyne: Rick Miake-Lye (ASCENT Project 2)

[1] Wayson RL, Fleming GG, Iovinelli R. Methodology to Estimate Particulate Matter Emissions from Certified Commercial Aircraft Engines. J Air Waste Manag Assoc. 2009 Jan 1;59(1):91–100.