Project 048 Analysis to Support the Development of an Engine nvPM Emissions Standard

Massachusetts Institute of Technology

Project Lead Investigator

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University Participants

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- P.I.: Prof. Steven Barrett
- Co-PI: Dr. Raymond Speth
- FAA Award Number: 13-C-AJFE-MIT, Amendment No. 027
- Period of Performance: July 8, 2016 to Aug. 31, 2017 (Reporting here with the exception of funding level and cost share only for the period July 8, 2016 to September 30, 2016).
- Tasks:
    - Task 1: Write a detailed scientific background of the APMT-I tools suite
    - Task 2: Map emissions from a short-list of representative engines to all engine/airframe combinations
    - Task 3: Evaluate metrics from the CAEP/WG3/PMTF for evaluating an engine's nvPM performance
    - Task 4: Verify technology response provided by engine manufacturers
    - Task 5: Evaluate proposed fuel sensitivity corrections and ambient conditions corrections
    - Task 6: Evaluate the current nvPM modeling approaches available to CAEP and assess uncertainty contributions

Project Funding Level

$150,000 FAA funding and $150,000 matching funds. Sources of match are approximately $63,000 from MIT, plus 3rd party in-kind contributions of $87,000 from University College London.

Investigation Team (all MIT)

Principal Investigator: Prof. Steven Barrett
Co-Principal Investigator: Dr. Raymond Speth
Co-Investigators: Prof. John Hansman, Dr. Jayant Sabnis, Dr. Brian Yutko
Graduate Students: Akshat Agarwal

Project Overview

This projects aims to provide support to the FAA Office of Environment and Energy (OEE) in developing an emissions standard for non-volatile Particulate Matter (nvPM). The analyses will be further used to inform the International Civil Aviation Organization's Committee on Aviation Environmental Protection (ICAO-CAEP) in developing a global standard for nvPM emissions. The analyses will cover both US NAS-wide and global bases covering the costs and benefits from an economic and environmental (air quality, climate and noise) perspective. The main goals for this project include:

- Writing a scientific overview of the Aviation environmental Portfolio Management Tool's Impact (APMT-I) suite of analysis tools.
- Mapping emissions from a short-list of representative engines to a broader list of engine/airframe combinations.
- Evaluating metrics developed by CAEP Working Group 3 PM Task Force (CAEP/WG3/PMTF) important for evaluating an engine/airframe's nvPM emissions performance.
- Using the initial metrics and stringency options, independently verify the technology response provided by engine manufacturers.
- Evaluating proposed fuel sensitivity corrections and ambient conditions corrections.
- Evaluating the current nvPM modeling approaches available to CAEP, as well as investigating the potential of using number emissions to estimate health impacts. The tools will be further developed to incorporate a number of uncertainties relevant to the nvPM modeling approach.

Task 1 – Write a detailed scientific background of the APMT-I tools suite

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Objective(s)

This task involves writing a detailed overview of the scientific background and uncertainty estimations used in the noise, air quality and climate models within the APMT-I tools suite.

Research Approach

The APMT-I tools suite consists of models to analyze the noise, air quality and climate impacts of aviation emissions. Each model moves from estimated emissions or noise sources to monetized impacts in order to compare and contrast the various costs and environmental benefits of a particular policy. The papers are written to provide a detailed resource for understanding the scientific background, modeling assumptions and uncertainty analyses used within the APMT-I models. The papers will be written in 4 sections covering each of the APMT-I models (air quality, climate and noise) and an additional section on the advantages of cost-benefit analyses versus the historic use of cost-effectiveness.

Milestone(s)

Draft individual sections for the air quality, climate and noise models have been completed and are being refined in collaboration with FAA project managers. Subsequent aims include writing an overview of cost-benefit analyses and its benefits in comparison with cost-effectiveness. Collating the four sections into a single document is the final step in the process.

Major Accomplishments

None.

Publications

None.

Outreach Efforts

None.

Awards

None.

Student Involvement

Graduate student Akshat Agarwal is primarily responsible for writing the reviews.

Plans for Next Period

Finalize the first full version of the document by January 31, 2017.

Task 2 – Map emissions from a short-list of representative engines to all engine/airframe combinations

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Objective(s)

The objective of this task is to develop mappings between a short-list of representative engines that were analyzed during the measurement campaign and engine/airframe combinations currently in operation.

Research Approach

A major improvement from historic smoke/PM standards developed by CAEP is the use of a new measurement method to more precisely estimate nvPM emissions from aircraft engines. The measurement campaign will focus on a subset of all available aircraft engines. In order to estimate the emissions from other aircraft engines, a mapping between measured and available engines is required. The mapping will involve analyzing the available data provided by OEMs and map between engines of similar models and configurations as well as mapping to engine/airframe combinations for modeling purposes. Engine/airframe combinations will be provided using a 2012 base using a "growth and replacement" database.

Milestone(s)

Awaiting completion of data use agreements to gain access to the nvPM measurements.

Major Accomplishments

None.

Publications

None.

Outreach Efforts

None.

Awards

None.

Student Involvement

Graduate student Akshat Agarwal is primarily responsible for conducting the mappings.

Plans for Next Period

Develop the mappings upon acceptance of data use agreement.

Task 3 – Evaluate metrics from the CAEP/WG3/PMTG for evaluating an engine's nvPM performance

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Objective(s)

The third task's objective involves independently evaluating the metrics developed by the PM Task Force of CAEP Working Group 3 (CAEP/WG3/PMTF). The aim is to identify the key issues relevant to describing nvPM emissions performance.

Research Approach
Following on from task 2, metrics must be developed in order to describe the performance of aircraft engines based on nvPM emissions. The metrics will initially be developed by the CAEP/WG3/PMTG and we will suggest alternatives to the FAA and also to CAEP/WG3 in collaboration with FAA management. Alternative metrics will be developed and tested using a data analysis process ensuring they include aircraft and engine properties such as maximum takeoff weight, payload-range capability, cabin floor area, passenger capacity, maximum takeoff thrust, thrust-specific fuel consumption, and nvPM mass and number emissions over the LTO cycle. The metrics will also be considered to satisfy evaluation criteria akin to those used for developing the CO_2 standard. These metrics allowed for differentiation among technology generations to reflect improvements in fundamental design elements and the capabilities of various aircraft/engine architectures.

The metrics are crucial as they may impact the potential of prospective policy and stringency options. Thus, we will also investigate the influence of the metrics on these options. In addition, we will consider the effect of interdependencies with other emissions similar to the tradeoff with efficiency and reducing NO_x emissions. Finally, the role of uncertainties in understanding these interdependencies and how uncertainty is propagated through technology and fleet projections under different metrics and stringencies will also be investigated.

Milestone(s)
None.

Major Accomplishments
None.

Publications
None.

Outreach Efforts
None.

Awards
None.

Student Involvement
Graduate student Akshat Agarwal is primarily responsible for conducting the mappings.

Plans for Next Period
We expect to complete this task by April 30, 2017.

Task 4 – Verify technology response provided by engine manufacturers
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Objective(s)
The objective of this task is to independently verify the technology response provided by the engine manufacturers and assist the FAA in developing consensus.

Research Approach
For the initial metrics and stringencies developed as part of Task 3, we will independently verify the proposed technology responses suggested by the engine manufacturers.

Milestone(s)
None.

Major Accomplishments
None.

Publications
None.

Outreach Efforts
None.

Awards
None.

Student Involvement
Akshat Agarwal is primarily responsible for conducting the mappings.

Plans for Next Period
We aim to complete this task by May 31, 2017.

Task 5 – Evaluate proposed fuel sensitivity corrections and ambient conditions corrections
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Objective(s)
The fifth task for this project involves conducting an independent evaluation of the proposed fuel sensitivity corrections and ambient conditions corrections.

Research Approach
nvPM emissions tests are conducted using Jet A fuel, which can vary in its molecular content. We will evaluate the sensitivity of the nvPM emissions to various fuel content factors such as the aromatic or naphthalene content, validating the proposed corrections as well. The emissions tests have also been conducted at sea-level static conditions, however this can vary between tests conducted on different days and at multiple locations. We will evaluate the sensitivity to ambient conditions, validating the proposed corrections as well.

Milestone(s)
None.

Major Accomplishments
None.

Publications
None.

Outreach Efforts
None.

Awards
None.

Student Involvement
Graduate student Akshat Agarwal is primarily responsible for conducting the analyses.

Plans for Next Period
We expect to complete this task before June 30, 2017.

Task 6 – Evaluate the current nvPM modeling approaches available to CAEP and assess uncertainty contributions
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Objective(s)
The objectives for this task involve assessing the modeling capabilities available to CAEP for estimating the environmental impacts of aviation (air quality, climate and noise) and their potential for incorporating additional measurements available from the new nvPM measurement system. In addition, we aim to include additional uncertainties from the new measurement system that have previously not been included.

Research Approach
In the final task, we not only aim to quantify the environmental impact of an nvPM emissions standard, but also attempt to quantify the various uncertainty contributions due to the new measurement methods. The nvPM emissions tests are conducted at ground level because of their ease in comparison to high-speed, cruise-altitude measurements. However, in order to evaluate the effects of cruise-altitude emissions on other atmospheric processes, e.g. contrail formation, these ground level test data must be mapped to cruise conditions. This has been addressed in historic models such as the FOX model (Stettler et al. 2013a) for nvPM emissions, who used a correlation developed by Dopelheuer and Lecht (1998). In this task, we will evaluate the applicability of these models for the new method of measuring nvPM emissions, quantifying the uncertainty of the measurements.

The next part of this task involves ensuring the advanced nvPM measurement capabilities can be used to model the environmental impacts of an nvPM emissions standard. The new nvPM measurement system allows for the estimation of number emissions. These are important for estimating the health impacts of nvPM exposure and will be incorporated in addition to the mass-based exposure response functions that are currently used. We will also take into account the uncertainties associated with the differential toxicity between the various types of PM species. Finally, we will also incorporate the uncertainties in the climate model due to the direct black carbon warming impact and the warming due to contrails.

These tasks will be done in collaboration with the team at the Pennsylvania State University led by Prof. Randy Vander Wal.

Milestone(s)
None.

Major Accomplishments
None.

Publications
None.

Outreach Efforts
None.

Awards
None.

Student Involvement

Graduate student Akshat Agarwal is primarily responsible for conducting the analyses.

Plans for Next Period

We aim to complete this task by August 31, 2017.