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

Massachusetts Institute of Technology

Project Lead Investigator

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- FAA Award Number: 13-C-AJFE-MIT, Amendment Nos. 027, 036, and 045
- Period of Performance: July 8, 2016 to Aug. 31, 2019 (Reporting here with the exception of funding level and cost share only for the period October 1, 2017 to September 30, 2018).
- Tasks:
    - Task 1: Develop and evaluate policy and stringency options
    - Task 2: Verify technology response provided by engine manufacturers
    - Task 3: Evaluate proposed fuel sensitivity corrections and ambient conditions corrections
    - Task 4: Map emissions from a short-list of representative engines to all engine/airframe combinations
    - Task 5: Conduct the cost-benefit analysis

Project Funding Level

$350,000 FAA funding and $350,000 matching funds. Sources of matching funds are approximately $105,000 from MIT, plus 3rd-party in-kind contributions of $87,000 from University College London and $158,000 from Oliver Wyman Group.

Investigation Team

Principal Investigator: Prof. Steven Barrett
Co-Principal Investigator: Dr. Raymond Speth
Co-Investigators: Dr. Jayant Sabnis
Graduate Students: Akshat Agarwal

Project Overview

The Federal Aviation Administration's Office of Environment and Energy (FAA-AEE) is working with the international community to establish an international aircraft engine non-volatile particulate matter (nvPM) standard for engines of rated thrust > 26.7 kN. The proposed nvPM standard will influence the development of future engine technologies resulting in reduction of nvPM emissions from aircraft engines. A reduction in nvPM emitted by aircraft engines will lead to improved human health and climate impacts of aviation. To this end, the FAA needs to understand and quantify how an nvPM standard might impact the total nvPM emissions for the National Air Space (NAS) as well as the globe, including overall system-wide environmental and monetary costs and benefits.

The objective of this project is to provide support for FAA decision-making related to the nvPM certification standard by analyzing scenarios involving different emission metrics, stringency options, and assumptions about technology and fleet evolution. The analyses being conducted include economic, climate, air quality, and noise impact assessments on both global and NAS-wide bases. Activities executed for this project year focus on identifying and evaluating nvPM metrics and stringency options, analyzing and developing methods to correct measurements based on fuel properties and ambient conditions, developing emissions inventories based on estimated technological responses to proposed regulations, and conducting cost/benefit analyses of proposed regulations. This research is also contributing to the understanding of how an nvPM standard may influence future engine development, fleet evolution, and associated fleet-wide nvPM emissions.

Task 1- Develop and Evaluate Policy and Stringency Options

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Objective(s)

Aid the FAA and WG3 in developing potential stringency options that can be tested to identify and evaluate potential costs and benefit of nvPM mass and number regulation.

Research Approach

To develop reasonable stringency options, we must account for current technological capabilities and the difficulties faced by engines which are used in different aircraft. As such, we developed a variety of potential limit line shapes, which were presented to WG3 [CAEP11-WG3-PMTG6-WP11]. These options were updated based on feedback from WG3 and aided in developing consensus on a set of stringency options for both mass and number emissions.

Milestone(s)

Stringency options were accepted by WG3. Our analysis helped the group in defining suitable characteristics of the options. Thereafter we helped in processing the stringency options and presenting them in an overview to the group.

Major Accomplishments

Task complete

Outreach Efforts

A series of papers were presented to WG3 and several discussions held with members of the group to improve the options.

Student Involvement

Graduate student Akshat Agarwal was primarily responsible for conducting the analysis and presenting the work.

Plans for Next Period

Task complete

Task 2- Verify Technology Response Provided by Engine Manufacturers

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Objective(s)

Independently verify the technology response provided by the engine manufacturers and assist the FAA in developing consensus.

Research Approach

OEMs supplied technology responses to WG3, which include the predicted cost to OEMs of reducing nvPM mass or number by a certain amount and also present potential emissions' trade-offs with other species. We used our expertise to evaluate the extent to which these responses are justified and provided feedback to the FAA on how to improve these responses. We used the range of data available in the ICAO emissions data bank (EDB) to compare how historic NO_x standards have led to adoption of combustor technologies affecting other emissions, in particular the smoke number (SN) which has been shown to be well correlated with nvPM mass emissions. Thus, we can identify changes in SN due to improvements in combustor technology that lead to a reduction in NO_x emissions.

Milestone(s)
EDB data has been analyzed and results shared with the FAA in November 2017.

Outreach Efforts
None

Student Involvement
None

Plans for Next Period
Task complete

Task 3- Evaluate Proposed Fuel Sensitivity Corrections and Ambient Conditions Corrections
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Objective(s)
Conduct an independent evaluation of the proposed fuel sensitivity corrections and ambient conditions corrections.

Research Approach
Since nvPM emissions are a function of both engine and fuel characteristics, the development of an engine emissions standard requires methods for correcting for variations in nvPM emissions due to changes in fuel composition. We began this process using in-house expertise (Speth et al. 2015), with presentations to WG3 of an approach that correlated emissions to fuel aromatics content. We have since worked with other members of WG3 to reconcile this approach with other approaches based on using the fuel hydrogen content. This collaborative work led to an additional modeling approach which we also presented to WG3. We have continued to provide feedback on the hydrogen-content based approach which has been accepted by the group.

Milestone(s)
- Presented the potential use of fuel aromatics content instead of fuel hydrogen content as correlating parameter.
- Collaborated with other WG3 members to develop an alternative modeling approach using fuel hydrogen content and presented this approach to WG3.

Publications
CAEP11-WG3-PMTG5-IP03, Fuel sensitivity corrections for nvPM measurements.
CAEP11-WG3-PMTG6-WP14, Fuel sensitivity corrections factors for nvPM mass and number.

Outreach Efforts
Regular presentations have been made to the FAA and the Metrics ad-hoc group within PMTG. These efforts are aimed at disseminating preliminary results, engaging in discussions about the approach and receiving feedback from WG3.

Student Involvement
Graduate student Akshat Agarwal is collaborating on the data analyses for this task.

Plans for Next Period
Task complete

Task 4- Map Emissions from a Short-list of Representative Engines to All Engine/Airframe Combinations

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Objective(s)

Develop mappings between the set of representative engines that were analyzed during the measurement campaign and engine/airframe combinations currently in operation. This mapping will be used to develop projected nvPM emissions inventories for different policy options.

Research Approach

A major improvement from historical smoke standard developed by CAEP is the use of a new measurement method to more precisely estimate nvPM emissions from aircraft engines. The measurement campaign in support of developing an nvPM standard focused on a subset of all available aircraft engines. However, to model the effect of an emissions standard on the current fleet of aircraft, or a projected future fleet, it is crucial to have estimates of nvPM emissions from the full range of engines in use in such a fleet. This requires a mapping between measured and available engines.

We have developed the mapping iteratively, based on consultation with engine manufacturers communicating their own mappings, and MIT has been responsible for ensuring this mapping is reasonable, providing scientific and data-driven justifications. This mapping has now been completed, verified by OEMs, MIT and the FAA. The final step in this process is calculating the nvPM emissions (mass and number) for each of the “modeled” engines and ensure that they lie in the range that is expected. This process will allow for the use of these engines in understanding OEM responses to stringency options.

Milestone(s)

The mapping process has been completed and agreed upon by all parties involved.

Major Accomplishments

The mapping process has been completed and agreed upon by OEMs and the FAA. We have estimated the nvPM emissions from the mapped engines and presented results to WG3 in an information paper to PMTG7 [CAEP11-WG3-PMTG7-IP04]. With feedback from WG3 and PMTG, this was improved upon and presented to FAA and WG3 in February 2018.

Publications

Agarwal, A., Speth, R.L, “Metric values for the GRDB”, 2018, CAEP11-WG3-PMTG7-IP04

Student Involvement

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

Plans for Next Period

Task complete

Task 5- Conduct the Cost-Benefit Analysis

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Objective(s)

Estimate the climate and health impacts of the emissions, and the associated uncertainties, caused by each stringency option defined under Task 1. This task culminates in a report to the FAA to be presented to ICAO-CAEP as an information paper.

Research Approach

This task involves using various tools developed at MIT under the ASCENT projects. This include the APMT-Impacts Climate model developed by under ASCENT Project 21 and the APMT-Impacts Air Quality tool developed by under ASCENT Project

20. The climate model has been continuously improved upon since Marais et al. (2008) and allows us to rapidly estimate the climate impacts due to aviation, along with the uncertainty in this estimate. It has previously been used in the CAEP/8, CAEP/9 and CAEP/10 cycles. The air quality model employs a computationally-efficient adjoint approach to estimate the air quality impacts due to a set of emissions, requiring only multiplication of the pre-computed sensitivities with 3-D emissions (latitude x longitude x altitude). In all estimates, we quantify the uncertainty attributable to the concentration response functions that relate a change in concentration with a change in premature mortalities. In addition, for full-flight emissions, we also estimate the uncertainty due to ammonia emissions. Finally, high-resolution adjoint sensitivities have also been calculated for certain regions (North America and Asia-Pacific) and we use these sensitivities to estimate regional air quality impacts in addition to the global results.

Both the climate and global air quality models are able to compute not only the physical impacts (temperature change and premature mortalities respectively), but also to monetize these impacts for use in a cost-benefit analysis. This aggregate global environmental impact can be combined with estimates of the industry costs to give a net cost-benefit result. If the benefits are greater than the costs, then the regulation is cost-beneficial and vice-versa if the costs outweigh the benefits.

Milestone(s)

Emission datasets from Volpe were provided in July 2018 for all cases. This has allowed us to convert the input to a format that can be used by both models. Preliminary runs of the models have been conducted and regular updates have been provided to FAA project managers.

Outreach Efforts

We have presented our preliminary results to the FAA and will continue to update them as we work through our modeling chain.

Student Involvement

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

Plans for Next Period

A paper describing the cost-benefit analysis results will be prepared for submission as an IP to the CAEP/11 meeting.

References

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Speth, Raymond L., Carolina Rojo, Robert Malina, and Steven R. H. Barrett. 2015. “Black Carbon Emissions Reductions from Combustion of Alternative Jet Fuels.” *Atmospheric Environment* 105 (Supplement C): 37–42. https://doi.org/10.1016/j.atmosenv.2015.01.040.

Stettler, Marc E. J., Adam M. Boies, Andreas Petzold, and Steven R. H. Barrett. 2013. “Global Civil Aviation Black Carbon Emissions.” *Environmental Science & Technology* 47 (18): 10397–404. https://doi.org/10.1021/es401356v.