Project 022 Evaluation of FAA Climate Tools: Aviation Portfolio Management Tool (APMT)

University of Illinois at Urbana-Champaign

Project Lead Investigator
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University Participants

University of Illinois at Urbana-Champaign
PI: Dr. Donald Wuebbles
- FAA Award Number: 13-C-AJFE-UI-029
- Period of Performance: October 1, 2022 to September 30, 2023 (project started February 5, 2020)
- Tasks:
    1. Examine effects of fleets of supersonic aircraft on ozone and climate using the state-of-the-art Whole Atmosphere Community Climate Model (WACCM), a global climate-chemistry model.
    2. Analyze emissions provided to us for fleets of proposed supersonic aircraft designs.

Project Funding Level
Support from the FAA over this time period was about $200,000, with an additional $200,000 in matching in-kind support from the DLR, Germany.

Investigation Team
Dr. Donald Wuebbles (PI), All Tasks
Swarnali Sanyal and Dharmendra Singh (postdocs), responsible for conducting studies and performing analyses using the Community Earth System Model (CESM) WACCM, a 3-dimensional (3D) atmospheric climate-chemistry model

Task 1 - Revisiting High-speed Civil Transports and Their Potential Effects on Ozone and Climate
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Major Goals
This project utilizes state-of-the-art modeling and technical knowledge to analyze the potential global environmental effects of aircraft and to perform analyses that underpin the development of analytical tools that can assess the costs and benefits to inform decision-making on technology development. The studies rely on state-of-the-art models of the earth system that can provide useful scientific input for considerations by decision-makers. The analyses in the project will aid decision-making by translating complex models into simpler tools for use in cost-benefit analyses.

Objectives

To quantify the costs and benefits of using advanced aircraft and engine technologies, FAA uses tools that are underpinned by state-of-the-art technical knowledge. These tools are used to inform decision-making by providing the benefits and costs of various options that could enable technology development. The overall objective of this project is to enhance our understanding of the relationships between subsonic and proposed supersonic aircraft and the atmospheric state, and the development and evaluation of the capabilities, limitations, and uncertainties of metrics and simple models (e.g., APMT) to assist decision-makers. This project will use state-of-the-art geophysical models of the earth system that fully represent tropospheric and stratospheric processes to evaluate the costs and benefits of technologies that could advance subsonic aviation and enable supersonic aviation. Specific project goals include the following: (1) science-based evaluation of analytical tools used by the FAA; (2) development of ideas and concepts for the next-generation treatment of aviation's effects on the earth system; (3) updated evaluation and analyses of the science of aviation effects on atmospheric composition; and (4) evaluation of potential environmental effects from assumed fleets of supersonic commercial and business jet aircraft to compare with their benefits in terms of decreased time for air travel.

Research Approach

The study will use the WACCM of the CESM, developed by the National Center for Atmospheric Research (NCAR). This model has 66 layers from the ground to the middle of the mesosphere and provides a comprehensive treatment of tropospheric and stratospheric chemical processes. WACCM is one of the most advanced models worldwide for studying atmospheric processes and one of the few with a complete representation of stratospheric and mesospheric processes and higher; for example, it is one of very few models to represent the quasi-biennial oscillation that is important to stratospheric ozone. This makes it ideal for the study of the environmental impacts from supersonic and subsonic aircraft.

Results and discussion

In 2022, we completed analyses for a journal paper that was submitted to the journal *Earth's Future*. This study examined a high-altitude emissions scenario for a supersonic commercial aircraft designed and evaluated for emissions of a mature fleet of these aircraft by Georgia Tech University under project A10. Our analyses used the latest version of the climate-chemistry WACCM model. Evaluated effects were developed for changes in atmospheric composition (e.g., ozone, water vapor, particles) and for the radiative forcing on climate. This paper was published in spring 2023.

Various companies and academic institutions have been actively considering the designs of such supersonic aircraft. As these new designs are developed, the environmental impact on ozone and climate of these realistic fleets needs to be explored. This study examines one such proposed supersonic fleet that is projected to fly at Mach 2.2, corresponding to cruise altitudes of 17–20 km, and that would burn 122.32 Tg of fuel each year and emit 1.78 Tg of NOx. Our analyses indicate that this proposed fleet would cause a 0.74% reduction in global column ozone (~2 Dobson Units), which is mainly attributed to the large amounts of nitrogen oxides released in the atmosphere from the supersonic aircraft. The maximum ozone loss occurs at the tropics in the fall season, with a reduction of 1.4% in the total column ozone regionally. The stratospheric-adjusted radiative forcing on climate from this fleet was derived based on changes in atmospheric concentrations of ozone (59.5 mW/m^2), water vapor (10.1 mW/m^2), black carbon (-3.9 mW/m^2), and sulfate aerosols (-20.3 mW/m^2), resulting in a net non-CO_2, non-contrail forcing of 45.4 mW/m^2, indicating an overall warming effect.

In summer 2023, we received emissions for two different supersonic commercial aircraft designs and associated mature fleets from the Massachusetts Institute of Technology (aka MIT). Model runs for these emissions are now complete, and the analysis of findings is almost completed. However, the comparison of MIT's results with our results was delayed because the student involved in the study was on an internship. We are currently interacting closely with MIT to compare our analyses. Initial findings show some differences that we are still trying to explain.

A review of current modeling capabilities in treating the climate effects of contrails has been completed, and the resulting paper has been submitted for journal publication (Singh et al., 2023).

Milestones

- Journal paper published this year by the journal *Earth's Future*. This paper, Zhang et al. (2023), examines the potential impacts on ozone and climate for a projected fleet of supersonic aircraft based on an aircraft design made by Georgia Tech University.

- New studies are completed and being evaluated for comparison with similar modeling studies made by MIT for the potential impacts on ozone and climate of several fleets of supersonic aircraft based on aircraft designs made by MIT.
- These studies provide important context for the studies of actual projected fleets that we will be examining next in our studies.

Publications

Zhang, J., D. Wuebbles, D. Kinnison, J. Holger Pfaender, S. Tilmes, and N. Davis, 2023: Potential Impacts on Ozone and Climate from a Proposed Fleet of Supersonic Aircraft. *Earth's Future*, 11, https://doi.org/10.1029/2022EF003409.

Singh, D. K., S. Sanyal, and D. J. Wuebbles, 2023: Understanding the role of contrails and contrail cirrus in climate change: A global perspective. *Atmospheric Chemistry and Physics*, submitted.

Outreach Efforts

- Presentations at ASCENT Meetings in May 2023 and October 2023.
- Presentation made at FAA AEC Roadmap meeting in May 2023.
- Presentation made at the FAA REDAC meeting in March 2023, based on slides we sent to the FAA.
- Biweekly meeting with project manager.
- ICAO Impacts and Science Group (ISG) meetings (monthly) for Dr. Wuebbles.

Awards

None.

Student Involvement

Two postdocs, Swarnali Sanyal and Dharmendra Singh, were responsible for the analyses and modeling studies within the project and leading the initial preparation of the project reports. A prior graduate student, Jun Zhang, did most of the research for the Georgia Tech University supersonic aircraft analyses.

Plans for Next Period

- Complete and publish studies based on the emission inventories developed by ASCENT Project 10 to consider specific designs of supersonic transports (SSTs) from MIT and compare those results to model analyses done by MIT for the same scenario plus their similar analyses of the Georgia Tech SST fleet.
- Use the results from this study to inform the development of Aviation Portfolio Management Tool – Impacts Climate (APMT-IC) for supersonic impacts (ASCENT Project 58).
- Perform additional sensitivity analyses of potential supersonic aircraft fleets to enhance understanding of the envelop of potential impacts on ozone and climate from such aircraft.

References

Zhang, J., D. Wuebbles, D. Kinnison, J. Holger Pfaender, S. Tilmes, and N. Davis, 2023: Potential Impacts on Ozone and Climate from a Proposed Fleet of Supersonic Aircraft. *Earth's Future*, 11, https://doi.org/10.1029/2022EF003409.

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