Project 044 Aircraft Noise Abatement Procedure Modeling and Validation

Massachusetts Institute of Technology

Project Lead Investigator

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University Participants

Massachusetts Institute of Technology (MIT)

- P.I.: Professor R. John Hansman
- FAA Award Number: 13-C-AJFE-MIT, Amendment Nos. 050, 057, and 073
- Period of Performance: September 1, 2018 to September 30, 2023
- Tasks:
    1. Evaluate general approaches to aircraft noise validation
    2. Develop validation approach options
    3. Develop flight test plans
    4. Perform initial experimental runs on targets of opportunity
    5. Evaluate experimental results and implications for advanced operational flight procedure noise modeling and low-noise procedures

University of California, Irvine (UCI; sub-award from MIT)

- P.I.: Professor Jacqueline Huynh
- Award Number: MIT Subaward Purchase Order No. S5171-PO 523807
- Period of Performance: September 1, 2020 to September 30, 2023
- Tasks:
    1. Evaluate general approaches to aircraft noise validation
    2. Develop validation approach options
    3. Develop flight test plans
    4. Perform initial experimental runs on targets of opportunity
    5. Evaluate experimental results and implications for advanced operational flight procedure noise modeling and low-noise procedures

Project Funding Level

The FAA provided $720,000 in funding. A total of $720,000 in matching funds was provided, approximately $125,000 from MIT and $595,000 from the Massachusetts Port Authority.

Investigation Team

- Professor R. John Hansman – P.I., MIT (Tasks 1-5)
- Professor Jacqueline Huynh – P.I., UCI (Tasks 1-5)

- Clement Li - graduate student, MIT (Tasks 1-5)
- Sandro Salgueiro - graduate student, MIT (Tasks 1-5)
- Ara Mahseredjian - graduate student, MIT (Tasks 1-5)

Project Overview

This project uses empirical noise data to develop validation methods from noise and flight surveillance datasets and improve existing noise models. Field measurements of aircraft noise on approach and departure have historically shown significant variation (on the order of 10 dB), which have traditionally been attributed to factors such as varied power settings, aircraft configuration differences, and propagation effects. Recent analyses in this and other ASCENT projects have attempted to account for these factors but have been constrained by limited detailed flight data. This project explores approaches to combine emerging sources of flight data from flight data recorders and other sources such as Automatic Dependent Surveillance-Broadcast (ADS-B) with current and emerging networks of ground noise monitors, to validate or improve aircraft noise models and to validate proposed noise abatement procedures. The rise of data mining techniques has substantially enabled new insights and modeling capabilities based on the use of large datasets without requiring full a priori knowledge of all relevant physics. The development of advanced data mining approaches applied to noise modeling is expected to provide insight into aircraft noise prediction for refining or validating noise models, and developing strategies for noise mitigation, through either new aircraft technologies or operational changes. Furthermore, improved noise modeling capabilities would enable more informed decision-making for stakeholders considering the options and consequences of operational or technological changes, thus facilitating the minimization of noise impacts on communities. Because noise is becoming an increasingly important factor in operational decisions regarding airports in the National Airspace System, an accurate understanding of noise impacts is necessary to minimize unnecessary disruptions to, or inefficiencies in, National Airspace System operations.

Task 1 - Evaluate General Approaches to Aircraft Noise Validation

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University of California, Irvine

Objectives

This goal of this task is to evaluate the different options for validation of the Aircraft Noise Prediction Program (ANOPP) source component models and to confirm noise reductions from proposed low-noise procedures. Approaches to experimental design were considered, including dedicated engineering flight trials involving parametric sweeps of velocity and aircraft configuration at various power conditions. This process would involve collaborating with airline operators, who would need to be willing to fly trials of procedures, and air traffic control, which would need to approve the procedures. A ground measurement system would need to be in place under the departure tracks.

Potential monitoring approaches will also be considered, including distributed microphone arrays or single microphone installations, as well as potential phased-array microphone configurations. In addition, alternative flight data sources will be obtained, either through airline sources or through available surveillance data. Sources of noise data from existing and emerging noise monitoring systems will be identified. Boston Logan International Airport (BOS) has agreed to provide data, and additional airports will be approached to participate in the effort. Emerging open-source and community noise monitoring systems such as those being developed under ASCENT Project 53 will also be investigated. Opportunities for collaboration will be explored, with a focus on providing correlated flight data and noise datasets.

This task will use a systems approach and will explore options with potential collaborators regarding experimental opportunities to validate research concepts.

Research Approach

- Evaluate the different options for validation of the ANOPP source component models, and confirm any noise reductions from proposed procedures
- Identify potential existing data sources for noise validation
- Model aircraft flight profiles by using existing surveillance (e.g., ADS-B or Airport Surface Detection Equipment, Model-X) data to generate noise estimates (Readily available surveillance data are easier and less expensive to acquire than Flight Data Recorder (FDR) data and dedicated flight tests.)
- Evaluate flight profiles to understand why some procedures are quieter than others

Milestones

- Identified Seattle–Tacoma International Airport (SEA) and Boston Logan International Airport (BOS) noise monitor networks as potential sources of noise data for validation.
- Identified the OpenSky surveillance database as a potential source of flight procedure data for noise validation.

Major Accomplishments

- Approach and departure ADS-B and noise monitoring data were collected for 2 months at Seattle–Tacoma International Airport (SEA).
- A framework was developed to generate flight profiles by using raw ADS-B and atmospheric data. Noise monitor recordings were correlated with ADS-B data.
- Flight profiles were generated from raw ADS-B data for various departures and arrivals at SEA. Flight profiles were used to identify factors potentially significantly contributing to noise measurement variation.
- Quieter flyover cases were analyzed, and trends in aircraft altitude, airspeed, and lateral position were identified.
- Sources of weather data as a function of altitude were identified to make atmospheric absorption corrections for noise modeling validation.

Publications

Published conference proceedings

Jensen, L., Thomas, J., Brooks, C., Brenner, M., & Hansman, R. J. (2017). *Analytical approach for quantifying noise from advanced operational procedures* [Presentation]. European Air Traffic Management Research and Development Seminar. Seattle, Washington.

Reynolds, T., Sandberg, M., Thomas, J., & Hansman, R. J. (2016). *Delayed deceleration approach noise assessment* [Presentation]. 16th AIAA Aviation Technology, Integration, and Operations Conference, Washington, DC.

Salgueiro, S., Thomas, J., Li., C. & Hansman, R. J. (2021). *Operational noise abatement through control of climb profile on departure* [Presentation]. AIAA Scitech 2021 Forum, Washington, DC. https://doi.org/10.2514/6.2021-0007.

Salgueiro, S., Huynh, J., Li., C. & Hansman, R. J. (2022). *Aircraft Takeoff and Landing Weight Estimation from Surveillance Data* [Presentation]. AIAA Scitech 2022 Forum, San Diego, CA. doi: 10.2514/6.2022-1307.

Thomas, J., Jensen, l., Brooks, C., Brenner, M., & Hansman, R. J. (2017). *Investigation of aircraft approach and departure velocity profiles on community noise* [Presentation]. AIAA Aviation 2017 Forum, Grapevine, TX.

Thomas, J., Yu, A., Li., C., Maddens Toscano, P., & Hansman, R. J. (2019). *Advanced operational procedure design concepts for noise abatement* [Presentation]. 13th USA/Europe Air Traffic Management Research and Development Seminar, Vienna, Austria.

Thomas, J., Yu, A., Li, C., Toscano, P., & Hansman, R. J. (2019). *Advanced operational procedure design concepts for noise abatement* [Presentation]. 13th USA/Europe Air Traffic Management Research and Development Seminar, Vienna, Austria.

Thomas, J., & Hansman, R. J. (2020). *Modeling and assessment of delayed deceleration approaches for community noise reduction* [Presentation]. AIAA Aviation Forum, Dallas, TX.

Yu, A., & Hansman, R. J. (2019). *Approach for representing the aircraft noise impacts of concentrated flight tracks* [Presentation]. AIAA Aviation Forum 2019, Dallas, TX. doi: 10.2514/6.2019-3186

Written reports

Jensen, L. & Hansman, R. J. (2018). *Data-driven flight procedure simulation and noise analysis in a large-scale air transportation system* (Report No. ICAT-2018-02). Massachusetts Institute of Technology, Cambridge, MA.

Jensen, L., O'Neill, G., Thomas, J., Yu, A., & Hansman, R. J. (2018). *Block 1 procedure recommendations for Logan Airport community noise reduction* (Report No. ICAT-2017-08). Massachusetts Institute of Technology, Cambridge, MA.

Thomas, J., & Hansman, R. J. (2017). *Modeling performance and noise of advanced operational procedures for current and future aircraft* [S. M. thesis, Massachusetts Institute of Technology]. DSPace@MIT. https://dspace.mit.edu/handle/1721.1/108937

Thomas, J., & Hansman, R. J. (2020). *Systems Analysis of Community Noise Impacts of Advanced Flight Procedures for Conventional and Hybrid Electric Aircraft* [Ph.D. thesis, Massachusetts Institute of Technology]. DSpace@MIT. https://dspace.mit.edu/handle/1721.1/125995

Thomas, J., & Hansman, R. J. (2020). *Evaluation of the impact of transport jet aircraft approach and departure speed on community noise* (Report No. ICAT-2020-03). Massachusetts Institute of Technology, Cambridge, MA.

Yu, A., & Hansman, R. J. (2019). *Aircraft noise modeling of dispersed flight tracks and metrics for assessing impacts* [S. M.

thesis, Massachusetts Institute of Technology]. DSpace@MIT. https://hdl.handle.net/1721.1/122382

Mahseredjian, A., Huynh, J., & Hansman, R. J. (2022). *A Data-Driven Approach to Departure and Arrival Noise Abatement Flight Procedure Development* [S. M. thesis, Massachusetts Institute of Technology]. DSpace@MIT. https://hdl.handle.net/1721.1/144311

Outreach Efforts

- September 28, 2021: presentation to Stanford
- Collaborated with Port of Seattle to obtain noise data for arrivals and departures over several months
- Biweekly teleconferences and meetings with FAA Technical Monitors
- In-person outreach and collaboration with Massport, operator of BOS, and ASCENT Advisory Board members
- Presentations at the biannual ASCENT Advisory Board meetings

Awards

None

Student Involvement

Graduate students have been involved in all aspects of this research in terms of analysis, documentation, and presentation.

Plans for Next Period

The next phase of the project will continue outreach to other projects using noise monitor data in airport noise validation research.

Task 2 – Develop Validation Approach Options

Massachusetts Institute of Technology

Objectives

On the basis of the results of Task 1 and initial discussions with potential collaborators (measurement experts, model developers, manufacturers, operators, and test locations), one or more validation options will be identified. Targets of opportunity will be explored in which noise measurements may supplement other planned flight trials. For each option, the potential advantages and disadvantages will be identified, and preliminary flight test plans will be developed in coordination with the identified collaborators and in consultation with subject-matter experts such as NASA. Potential advantages include the willingness of operators or collaborators to participate and provide test resources, including aircraft and measurement systems. Other factors include measurement system resolution and the discrimination of noise sources. Timing and location may also be considered. On the basis of this analysis, recommendations for the next steps will be made.

Research Approach

- Identify methods to correct variations in modeled noise due to flap setting, aircraft weight, and ambient atmospheric conditions; apply these methods to approaches at BOS and SEA
- Acquire ADS-B data from the OpenSky Network and atmospheric data from NOAA High-Resolution Rapid Refresh; use these data to estimate weight from true airspeed and atmospheric attenuation from relative humidity
- Model noise at various flap configurations to identify the noise impact of high-lift devices

Milestones

- Noise was modeled at various flap configuration settings for several approach procedures.
- Developed method to relate OpenSky surveillance operational data to atmospheric data and noise monitor data at particular time stamps.

Major Accomplishments

- Demonstrated the impacts of aircraft configuration and relative humidity on modeled and measured noise over noise monitors of interest at SEA
- Developed a data-driven approach to understanding departure noise as a function of various operational, weather, and carrier factors

- Presented data driven approach results at the 2022 InterNoise conference and in a 2022 Journal of Aircraft manuscript
- Demonstrated the noise benefit of delayed-deceleration approaches using empirical data; analyzed flyovers of various monitors at BOS and SEA, and demonstrated a correlation between the fastest flyovers, flying at indicated airspeeds consistent with clean or almost-clean flap configurations, and the quietest noise monitor recordings

Publications

Peer-reviewed journal publications

Thomas, J., & Hansman, R. J. (2019). Framework for analyzing aircraft community noise impacts of advanced operational flight procedures. *Journal of Aircraft*, *6*(4), 1407-1417. doi: 10.2514/1.C035100

Huynh, J., Mahseredjian, A., & Hansman, R. J. (2022). Delayed Deceleration Approach Noise Impact and Modeling Validation. *Journal of Aircraft*, *59*(4), 992-1004. doi:10.2514/1.C036631

Published conference proceedings

Mahseredjian, A., Thomas, J., & Hansman, R. J. (2021). *Advanced procedure noise model validation using airport noise monitor networks* [Presentation]. Inter-Noise 2021, Washington, DC. doi: 10.3397/IN-2021-2842.

Mahseredjian, A., Huynh, J., & Hansman, R. J. (2022). *Analysis of community departure noise exposure variation using airport noise monitor networks and operational ADS-B data* [Presentation]. Inter-Noise 2022, Glasgow, Scotland.

Outreach Efforts

- Biweekly teleconferences and meetings with FAA Technical Monitors
- In-person outreach and collaboration with Massport, operator of BOS, and ASCENT Advisory Board members
- Presentations at the biannual ASCENT Advisory Board meetings

Awards

None

Student Involvement

Graduate students have been involved in all aspects of this research in terms of analysis, documentation, and presentation.

Plans for Next Period

The next phase will involve determining additional methods and data for evaluating aircraft noise variation, such as procedure type (RNAV versus ILS approaches, for example).

Task 3 - Develop Flight Test Plans

Massachusetts Institute of Technology
University of California Irvine

Objectives

For the recommended validation options identified in Task 2, detailed flight test plans will be developed. Flight test plans for dedicated engineering flights would involve detailed planning of the speed, configuration, and thrust of each trial. Test plans for flight trials in collaboration with airline operators would focus on documenting the flown profiles to analyze the associated data measurements. Opportunity exists in both types of trials to validate not only the expected effects of aircraft speed versus noise in the analysis models but also the expected noise impacts of procedures, including delayed deceleration approaches, steeper approaches, and continuous approaches.

Research Approach

- Develop flight test plans, where appropriate, for the validation of low-noise procedures
- Collaborate with airline operators and industry to determine appropriate data collection for trial flight tests

Milestones

- Sought partnerships with operators for FDR data (MIT was unable to obtain FDR data because of operator restrictions on the sharing of flight data.)

Major Accomplishments

- Determined that validation for low-noise flight procedures, such as the delayed deceleration approach, can be performed by using available surveillance and noise monitoring data, if reasonable assumptions regarding the weight, flap and slat configuration, and atmospheric attenuation are made
- Examined additional lower-noise departure procedures in 2 months of noise monitoring data from SEA

Publications

None

Outreach Efforts

- Biweekly teleconferences and meetings with FAA Technical Monitors
- In-person outreach and collaboration with Massport, operator of BOS, and ASCENT Advisory Board members
- Presentations at the biannual ASCENT Advisory Board meetings

Awards

None

Student Involvement

Graduate students have been involved in all aspects of this research in terms of analysis, documentation, and presentation.

Plans for Next Period

The next phase of this project will evaluate the departure and arrival noise of various aircraft at SEA from a full year of noise monitor recordings from Boeing 737-800, Airbus A320, and Boeing 777 flights.

Task 4 - Initial Experimental Runs on Targets of Opportunity

Massachusetts Institute of Technology
University of California Irvine

Objective

If targets of opportunity are identified in Task 2 that would occur within the period of performance of this proposed research, initial experimental runs will be conducted after consultation with the FAA Office of Environment and Energy and other relevant parties.

Research Approach

- Document procedural recommendations to enable flight trials
- Meet with airline technical pilots and representatives from aircraft manufacturers to discuss operational constraints and test opportunities
- Develop test plans and protocols for potential flight trials
- Develop test plans and protocols for potential noise measurement campaigns
    - Specific flight test locations
    - Operational field measurements

Milestones

- Conventional and delayed deceleration approach procedures were observed in surveillance data at BOS and SEA and were identified as sufficient for noise analysis instead of dedicated flight test plans.

Major Accomplishments

- Instead of using dedicated flight test plans, approach flights from the surveillance data were grouped by altitude and analyzed with varied speed, configuration, and thrust. The noise monitor readings from these flights were then compared. For departures, measured noise levels versus weight, thrust, speed, altitude, weather factors, and airlines were examined in 2D correlations.
- For approach procedures, flights for which the speeds were more likely to have been in the clean configuration when they flew over the monitors were shown to correlate with lower recorded noise levels than flights that were more likely to have been in a dirty configuration when they flew over the monitors.
- For departure procedures, aircraft that achieved higher altitudes early in the flight profiles were found to correlate with lower measured noise levels.

Publications

Peer-reviewed journal publications

Thomas, J., & Hansman, R. J. (2021). Modeling of delayed deceleration approaches for community noise reduction. *Journal of Air Transportation, 29*(3), 127-136. doi: 10.2514/1.D0237

Outreach Efforts

- Biweekly teleconferences and meetings with FAA Technical Monitors
- In-person outreach and collaboration with Massport, operator of BOS, and ASCENT Advisory Board members
- Presentations at the biannual ASCENT Advisory Board meetings

Awards

- 2021, 2020 AIAA Air Transportation Systems Best Student Paper Award “Modeling, Assessment, and Flight Demonstration of Delayed Deceleration Approaches for Community Noise Reduction” (AIAA-2020-2874) by Jacqueline L. Thomas and R. John Hansman

Student Involvement

Graduate students have been involved in all aspects of this research in terms of analysis, documentation, and presentation.

Plans for Next Period

In the next phase, the validation approaches developed in the previous phase applied to one year’s worth of noise measurements and operations data will be assessed. A main goal of the upcoming work is to understand the causes of variation in both measured departure and arrival noise. The approach to understanding noise level variation uses a data-driven analysis framework for examining the impacts of various operational, weather, and airline factors on noise levels. Flight profiles and noise models will be generated for these cases of interest. Different data-mining approaches such as multivariate correlations, clustering, and machine learning will be applied to the data to examine trends in variables affecting aircraft noise, including those due to aircraft weight, thrust, distance to monitor, airspeed, ambient atmospheric conditions, and compounding factors.

Task 5 - Evaluate Experimental Results and Implications for Advanced Operational Flight Procedure Noise Modeling and Low-Noise Procedures

Massachusetts Institute of Technology
University of California Irvine

Objectives

Contingent on data availability from Task 4 or other data identified as part of the experimental approach and discussions with collaborators, this task, in coordination with NASA, will involve the following:

- Evaluating Advanced Operational Flight Procedure Noise Modeling relative to experimental results
- Identifying discrepancies requiring correction
- Determining whether the results and data are sufficient to improve discrepancies, or whether continued validation and testing are required

The implications for Advanced Operational Flight Procedure Noise Modeling from the data will be evaluated.

Validation of procedures, such as delayed deceleration approaches, will also create opportunities for the development of further low-noise procedures.

Research Approach

- Treat noise monitoring data from SEA and BOS as experimental data, which could serve as a benchmark for comparison against ANOPP component-based noise models
- Model departure noise for various departures from SEA, and identify the characteristics of the quietest departures; determine whether learning could be applied to future departure noise abatement procedure designs

Milestones

- Noise monitor recordings versus modeled results were determined to be acceptable approaches for comparing measured noise data to noise models when weather factors and operational factors were taken into account.

Major Accomplishments

- Noise models demonstrated similar trends to monitor recordings for approach procedures when proper assumptions regarding flap configuration were made. Both speed and configuration were shown to influence the noise model results.
- Aircraft weight and thrust levels were shown to influence the noise modeling results for approach procedures.
- Aircraft altitude and thrust levels were found to have the strongest correlations with measured noise for the procedures examined.
- Weather factors such as relative humidity, temperature, and wind magnitude and direction were found to have some correlations, albeit weaker, with the measured noise levels on departure.

Publications

Published conference proceedings

Thomas, J., Mahseredjian, A., & Hansman, R. J. (2021). *Delayed deceleration approach procedure noise modeling validation using noise measurements and radar data* [Paper presentation]. AIAA Aviation 2021 Forum, Virtual Meeting. doi: 10.2514/6.2021-2135.

Outreach Efforts

- Biweekly teleconferences and meetings with FAA Technical Monitors
- In-person outreach and collaboration with Massport, operator of BOS, and ASCENT Advisory Board members
- Presentations at the biannual ASCENT Advisory Board meetings

Awards

- 2018 Department of Transportation/FAA COE Outstanding Student of the Year Award to Jacqueline Thomas

Student Involvement

Graduate students have been involved in all aspects of this research in terms of analysis, documentation, and presentation.

Plans for Next Period

The next phase of this project will evaluate how different variables identified in the previous tasks influence aircraft noise and will inform the design of future advanced flight procedures intended to reduce aircraft noise.