Project 038 Rotorcraft Noise Abatement Procedure Development

The Pennsylvania State University, Continuum Dynamics, Inc.

Project Lead Investigator

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University Participants

The Pennsylvania State University (Penn State)

- PI: Kenneth S. Brentner, Professor of Aerospace Engineering
- FAA Award Number: 13-C_AJFE-PSU-038, Amendment No. 53
- Period of Performance: February 5, 2020 to February 4, 2021
- Tasks (during this period):
  14. Continue evaluating flight test data to determine the effectiveness of noise abatement procedures
  15. Evaluate and refine noise abatement procedure development strategy
  16. Demonstrate the potential of refined noise abatement procedures
  17. Continue effort to develop noise abatement flight procedures for various helicopter classes

Project Funding Level

FAA provided $150,000 in funding. In-kind matching funds of $150,000 were provided by Continuum Dynamics, Inc. and Penn State provided $30,617 in faculty academic year cost sharing.

Investigation Team

- Kenneth S. Brentner, PI, The Pennsylvania State University; acoustic prediction lead on all Tasks.
- Joseph F. Horn, Co-PI, The Pennsylvania State University; flight simulation lead supporting all Tasks.
- Daniel A. Wachspress, Co-PI, Continuum Dynamics, Inc.; responsible for rotor loads, wake integration, and Comprehensive Hierarchical Aeromechanics Rotorcraft Model (CHARM) coupling.
- Damaris R. Zachos, Graduate Research Assistant, The Pennsylvania State University; primarily responsible for establishing new aircraft models, developing simulations for new helicopter types, performing acoustic predictions, and developing flight abatement procedures; involved in all Tasks.

Project Overview

Rotorcraft noise consists of several components, including rotor noise, engine noise, gearbox and transmission noise, etc. Rotor noise is typically the dominant component of rotorcraft noise to which the community is exposed upon takeoff and landing and along the flight path of the helicopter. Rotor noise consists of multiple noise sources, including thickness noise and loading noise (typically combined as rotational noise), blade-vortex-interaction (BVI) noise, high-speed-impulsive (HSI) noise, and broadband noise. Each noise source has its own unique directivity pattern around the helicopter. Furthermore, aerodynamic interactions among rotors, interactions between the airframe wake and a rotor, and unsteady time-dependent loading generated during maneuvers typically result in significant increases in loading noise. The combination of all potential rotor noise sources makes the prediction of rotorcraft noise highly complex, even though not all noise sources are present at any given time in the flight (e.g., BVI noise usually occurs during the descent, and HSI noise only occurs during high-speed forward flight).

In ASCENT Project 6, "Rotorcraft Noise Abatement Operating Conditions Modeling," the project team coupled a MATLAB-based flight simulation code with CHARM and PSU-WOPWOP to perform rotorcraft noise prediction. This noise prediction system was used to develop noise abatement procedures through computational and analytical modeling. Although this noise prediction system cannot predict engine noise or HSI noise, it was thoroughly validated via a comparison between predicted noise levels for a Bell 430 aircraft and flight test data (Ref. 19) for several observer positions and operating conditions.

In previous work for ASCENT Project 38, representative helicopters were recommended for noise abatement procedure development. These helicopters were selected to enable a determination of whether noise abatement procedures could be developed for various categories of helicopters, (i.e., 2-blade light, 4-blade light, 2-blade medium, etc.) or whether aircraft-specific design considerations would be required. Aircraft models were established for the following aircraft: Bell 430, Sikorsky S-76C+ and S-76D, Bell 407 and 206L, Airbus EC130 and AS350, and Robinson R66 and R44. Predictions were made before the 2017 FAA/NASA noise abatement flight test to provide guidance for the flight test. After the flight test, a comparison of L_A time histories and sound exposure level (SEL) contour plots revealed a problem in the broadband noise prediction, which was subsequently corrected. Initial validation comparisons demonstrated that the simulations were within a few dBA of the flight test data; however, some discrepancies in the simulations (simplifications) remained, requiring a detailed examination.

The objective of this continuing project is to utilize computational and analytical modeling to develop noise abatement procedures for various helicopters in different phases of flight. The extension of this project also includes predictions aiming to analyze various flight procedures to determine their effectiveness in noise reduction. Comparisons of predictions and flight test data provide further validation of the noise prediction system and allow a deeper understanding of the impact of noise abatement procedures on noise directivity and amplitude. Emphasis is given to more complicated flight procedures (turns with deceleration or descending turns) and validation of the noise prediction system for these complex procedures. The predictions help to explain the details of the noise generated in various procedures, which will aid in the design of refined noise abatement flight procedures. New flight test data from NASA became available in August 2020. This data included new aircraft data for a Bell 205, Leonardo AW139, Sikorsky S76D, and a Eurocopter MH-65. These aircraft are of a heavier class than the aircraft tested in 2017 and may have different acoustic characteristics, not present in lighter class helicopters. The extension of this project aims to evaluate the noise sources of these larger aircraft and determine if noise abatement procedures defined by aircraft size are appropriate. If new flight procedures are necessary, this project aims to assist FAA/NASA in developing these procedures following a similar approach used for the 2017 flight test aircraft.

Task 14 – Determine the Effectiveness of Noise Abatement Procedures by Class of Helicopter Using the 2017 and 2019 Flight Test Data

The Pennsylvania State University

Objective

In this Task (Task 8.1 in the 2019 proposal), helicopter models representing the aircraft in the 2019 FAA/NASA flight test will be developed from publicly available sources. Several of the noise abatement procedures flown during the flight test will be simulated with the noise prediction system. Using both the noise predictions and measured data, the noise abatement procedures will be analyzed. The effectiveness of the procedures for the heavier helicopters in the 2019 flight test will be compared to that for the lighter helicopters in the 2017 test.

Research Approach

The noise prediction system developed in ASCENT Projects 6 and 38 will be used and updated as necessary. The PSU-WOPWOP code will be used for noise prediction and will be coupled with a PSUHeloSim flight simulator and CHARM to form a rotorcraft noise prediction system. The flight test data will be examined, and the measured and predicted results will be compared to help explain any significant details of the noise measurements. This evaluation can also identify the primary and secondary noise sources involved in each flight procedure and can clarify how the noise abatement was achieved (which can lead to generalized procedures for other helicopter categories, weights, etc.). After validation of the prediction system with 2019 flight test aircraft, comparison between similar aircraft of the 2017 flight test and the 2019 flight test will be developed.

Identical maneuver cases will be developed for comparable aircraft and various noise metrics will be evaluated for signs of significant differences in noise sources between the heavier and the lighter designs. The results of this study will provide guidance on the importance of aircraft weight in the development of noise abatement procedures and determine if separate procedures are necessary for aircraft in different weight classes.

Milestones

The milestones for this Task include (a) validation of predictions for aircraft flown in the 2019 flight test and (b) comparison of noise metrics between the two predictions. This Task will examine various predicted noise sources and will investigate which sources are important in the flight test data (for several different microphones). Dissimilarities between comparable aircraft with differences in weight will be used to determine the use of noise abatement procedures to reduce noise.

Major Accomplishments

A significant number of the parameters required to model the Bell 205 and S-76D have been collected. These parameters include blade, airframe, and aerodynamic properties for each helicopter. Engineering judgment has been used to populate some of the parameters for these aircraft. Validation with other experts is underway, which will improve the flight simulation solutions. Careful documentation of the sources used for the input parameters has been maintained to ensure validation and repeatability of the predictions.

The late release of the 2019 flight test data in August of 2020 delayed significant progress on this Task to date, but data is now available at Penn State and validation of the predictions against measured data will begin soon. As a new student, Damaris R. Zachos needed to learn the prediction system. She was able to generate identical flight maneuver predictions as her predecessor for the Bell 206 and Bell 407 for multiple flight test cases (Figure 1 and Figure 2). NASA corrected the acoustic pressure in the flight test to remove ground reflections; hence, the predictions were free-field predictions. Atmospheric absorption was accounted for in the predictions. Some new flight test cases from the 2017 flight tests, previously unassessed, were also evaluated. The capability to output MaxdBA contours was added to PSU-WOPWOP during this period, and the predicted MaxdBA contour plots for the Bell 206 and Bell 407 were generated.

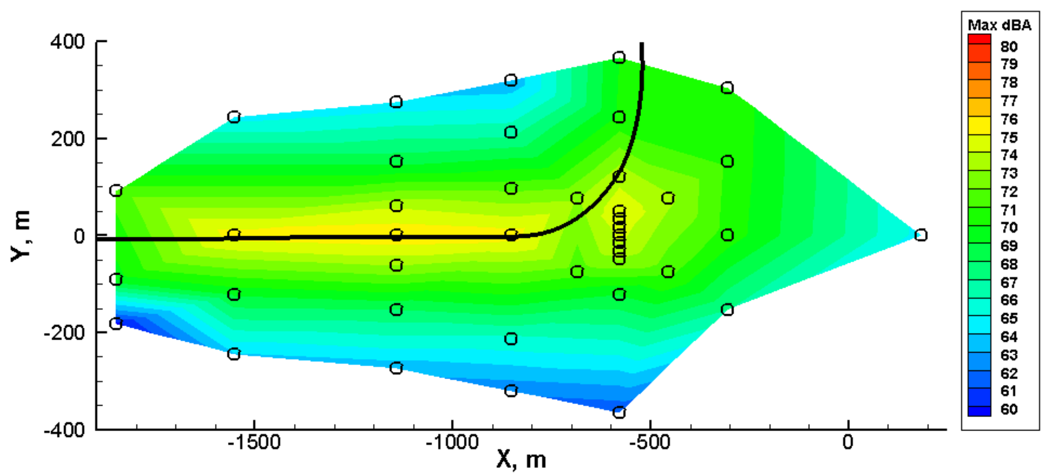

Figure 1. Predicted MaxdBA contours for Bell 407, Run 283122.

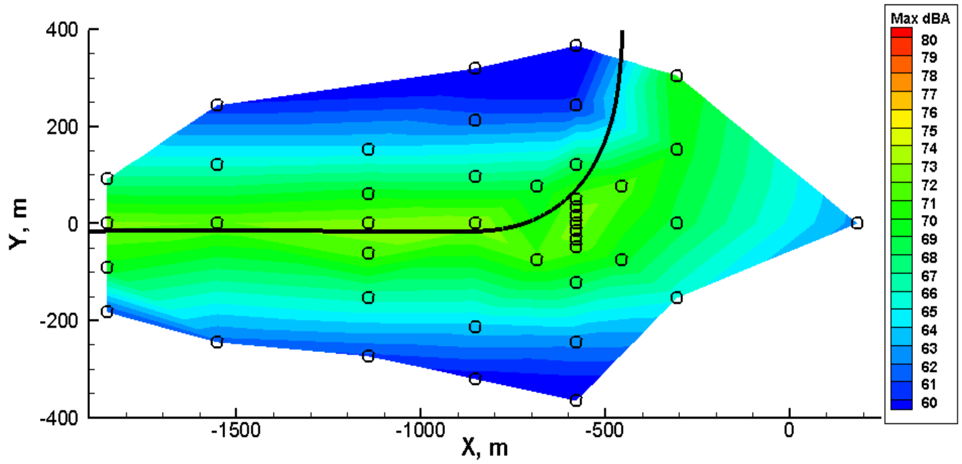

Figure 2. Predicted MaxdBA contours for Bell 206, Run 278208.

Publications
N/A

Outreach Efforts
N/A

Awards
None

Student Involvement
Damaris R. Zachos, a graduate assistant currently working toward her master's degree at Penn State, gathered the data for the Bell 205 (2019 flight test), modified PSU-WOPWOP to generate MaxdBA contours, and simulated Bell 206 and Bell 407 cases, including MaxdBA contours.

Plans for Next Period
During the next period, helicopter models representing the remaining aircraft in the 2019 FAA/NASA flight test will be developed from publicly available sources. Several of the noise abatement procedures executed during the flight test will be simulated with the noise prediction system. Based on both the noise predictions and measured data, the noise abatement procedures will be analyzed. The effectiveness of these procedures for the heavier helicopters in the 2019 FAA/NASA flight test will be compared to that for the lighter helicopters in the FAA/NASA 2017 test, which will indicate the need and feasibility of developing noise abatement procedures based on the helicopter size, type, and weight.

Task 15 – Assist in Data Analysis of 2019 FAA/NASA Acoustic Flight Test Data

The Pennsylvania State University

Objective

The goal of this Task (Task 8.2 in the 2019 proposal) is to provide continued assistance in the evaluation of the 2017 and 2019 FAA/NASA flight test data and the assessment of the effectiveness of various noise abatement procedures. This will involve evaluation of the flight test data and examination and comparison of measured and predicted results to help explain any significant unexpected differences in the noise measurements. This evaluation can also identify which noise sources are the primary and secondary noise sources involved in a flight procedure and provide understanding about how the noise abatement was achieved (which can lead to generalizing the procedure to other helicopter categories, weights, etc.).

Research Approach

Flight test data for the 2017 and 2019 FAA/NASA flight tests signal processing methods will be evaluated. Comparison between PSU-WOPWOP and NASA signal processing will indicate if there are any differences between the predictions and measured data not caused by modeling discrepancies. NASA TM-2019-220264 contains data published on the 2017 flight tests, including MaxdBA contours and hemispheres for various flight maneuvers. This Task relies on the ability to recreate these same plots using the predictions from PSU-WOPWOP to determine any modeling differences, which may indicate inaccuracy in the helicopter model or noise prediction sources. During the review of the signal processing methods, recommendations regarding different signal processing methods may be made. Examination of the processed acoustic signal at each stage of processing may indicate if a certain noise source is being attenuated or reduced via signal processing. If a particular noise source is both significant and distorted by processing, then the knowledge learned should lead to improved data analysis techniques.

Milestones

The milestones for this Task are (a) determination of the signal processing methods used on the 2017 and 2019 NASA flight test data, (b) replication of identical cases in PSU-WOPWOP, (c) comparison of the results to ensure similarity in the signal processing, and (d) potential recommendation of new signal processing methods for 2019 flight test data.

Major Accomplishments

The ability to output MaxdBA contours was not present in PSU-WOPWOP at the start of 2020. It has since been added and select 2017 flight test cases have been replicated to compare results published in NASA TM-2019-220264. Additionally, the ability to incorporate a moving average into the signal processing chain was added to PSU-WOPWOP. Insight from Kyle Pascioni (NASA Langley) provided detailed information about the signal processing methodology used to generate the MaxdBA contours published in the NASA TM, and the data processing methodology that will be published for the FAA/NASA 2019 flight test data. The NASA process used includes de-Dopplerization, which is not currently included in PSU-WOPWOP. Other signal processing methods, such as overlap and windowing, are available in both the prediction and the published results. PSU-WOPWOP also can account for atmospheric absorption and reflection from a ground plane. Figure 3 shows some preliminary results that highlight the differences in flight test data processed by PSU-WOPWOP (top) and the NASA post-processing used in NASA TM-2019-220264 (bottom).

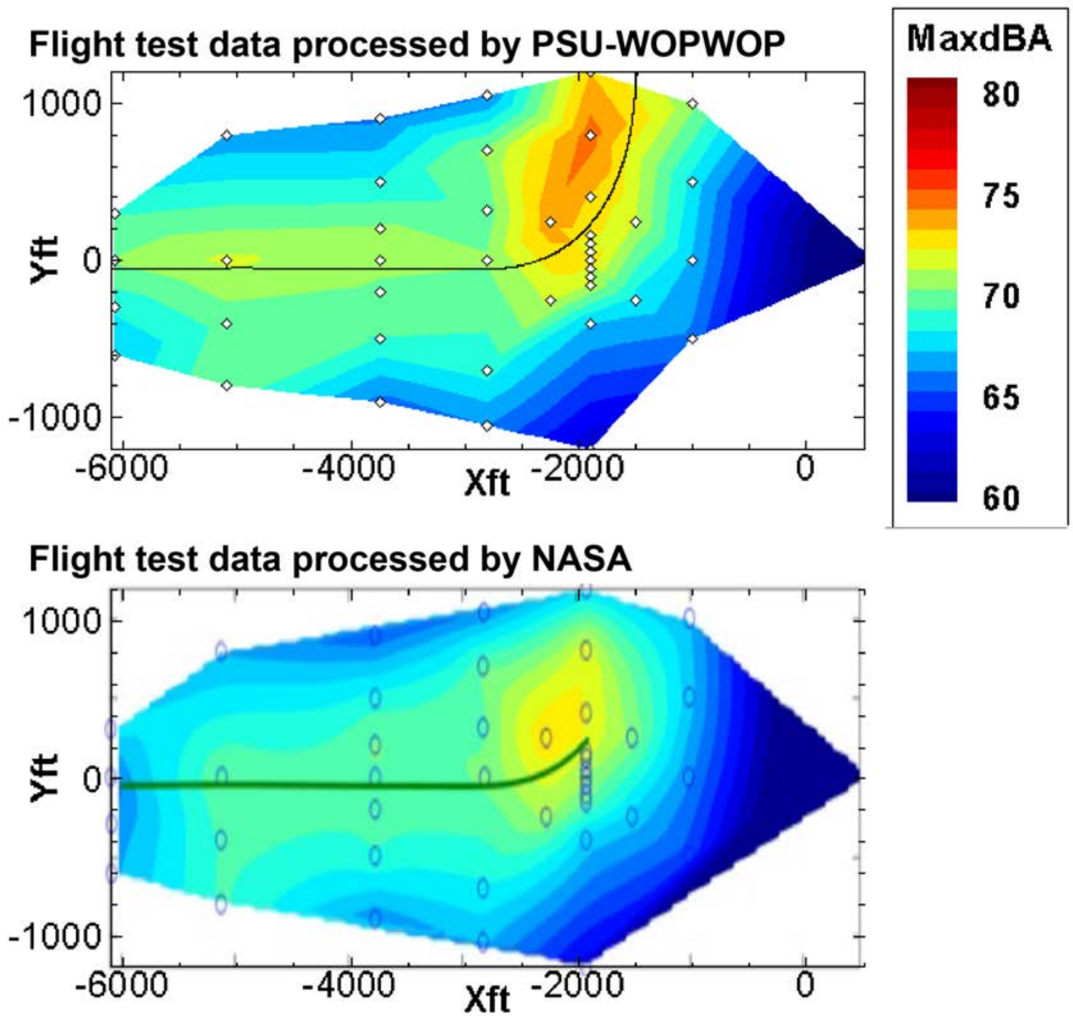

Figure 3. Comparison of MaxdBA contours for flight test data processed with PSU-WOPWOP (top) and NASA's processing in NASA TM-2019-220264 (bottom) for Bell 206 Run, 278208.

Publications
N/A

Outreach Efforts
N/A

Awards
None

Student Involvement
Damaris R. Zachos, a graduate assistant currently working toward her master's degree at Penn State, post-processed the flight test data for this Task, added the capability to output MaxdBA contours to PSU-WOPWOP, implemented moving averaging into PSU-WOPWOP, and worked with NASA to determine the signal processing methods they used.

Plans for Next Period

Evaluation of the significance of de-Dopplerization used to generate MaxdBA contours will be conducted via a comparison of predictions with and without moving observers (observers moving with the vehicle do not have Doppler shift). New plots comparing the NASA TM and PSU-WOPWOP results will be generated to ensure identical results between the two signal processing methods. Assessment of the signal processing used for these plots and the hemispheres published in NASA TM-2019-220264 will be conducted for assistance in validating transient maneuvers. Evaluation of each independent noise source and an assessment of the impact of the signal processing methods for each noise source will be performed to determine if any important information is neglected using the current NASA processing method.

Task 16 – Assessment of Noise Prediction System and Provide Potential Improvements for Broadband Noise, Engine Noise, and Improved Interface with FAA Noise Codes

The Pennsylvania State University

Objective

In this Task (Task 8.3 in the 2019 proposal), predictions of noise abatement procedures executed in the flight test will be simulated and compared to the optimal procedures developed under the new strategy. The process will be thoroughly documented and will provide the basis for future low-noise operational guideline development. Both linear flight profiles and turns will be considered, along with more complex procedures. These demonstrations will consider flight conditions both with and without BVI noise.

Research Approach

Predictions for various aircraft from 2017 and 2019 FAA/NASA flight tests will be generated using the PSUHeloSim/CHARM/PSU-WOPWOP prediction system. These results will have been validated as a result of Task 14's milestones. New flight paths will then be predicted via the same prediction system, but with a noise-optimized command input generator. Various noise metrics for these predictions will be evaluated to determine the effectiveness of these maneuvers on reduced noise generation. To assist the FAA in evaluating helicopter noise, the capability to process prediction data from PSU-WOPWOP will be streamlined for use with Advanced Acoustic Model (AAM) software.

Milestones

The milestones for this Task are (a) completion of the validation of the prediction system from Task 14, (b) evaluation of the prediction of individual noise sources, and (c) add the capability to PSU-WOPWOP to output noise files for AAM.

Major Accomplishments

Significant modifications to the internal data structures in PSU-WOPWOP have been performed to enable the additional data processing capabilities required in Task 15 and other data output. As a direct result of the internal improvements to PSU-WOPWOP, the ability to output moving averaged data was possible (see Figure 4). **Figure 1**This code revision applied changes to the signal processing hierarchy used in PSU-WOPWOP that enable addition of new post-processing methods to PSU-WOPWOP and simplify the process of writing out the data PSU-WOPWOP already computes but does not output. By evaluating flight test signals through a moving average filter, information about the presence of non-tonal noise, such as broadband noise, can be determined to better validate the prediction results. Additionally, this architecture change allows the user to evaluate the prediction results with multiple signal processing methods during one case, instead of a single processing method per run. This will significantly improve the speed at which new flight test cases can be evaluated for noise abatement flight procedures. The architecture change also lays the groundwork necessary to output files for use with AAM. Discussions with Juliet Page and Chris Cutler at the Department of Transportation's Volpe National Transportation Systems Center provided Penn State with the some of the information necessary to output files for AAM. Work is underway to update the flapping motion of the blade surface files required for noise predictions. This will improve the thickness noise predictions for all aircraft.

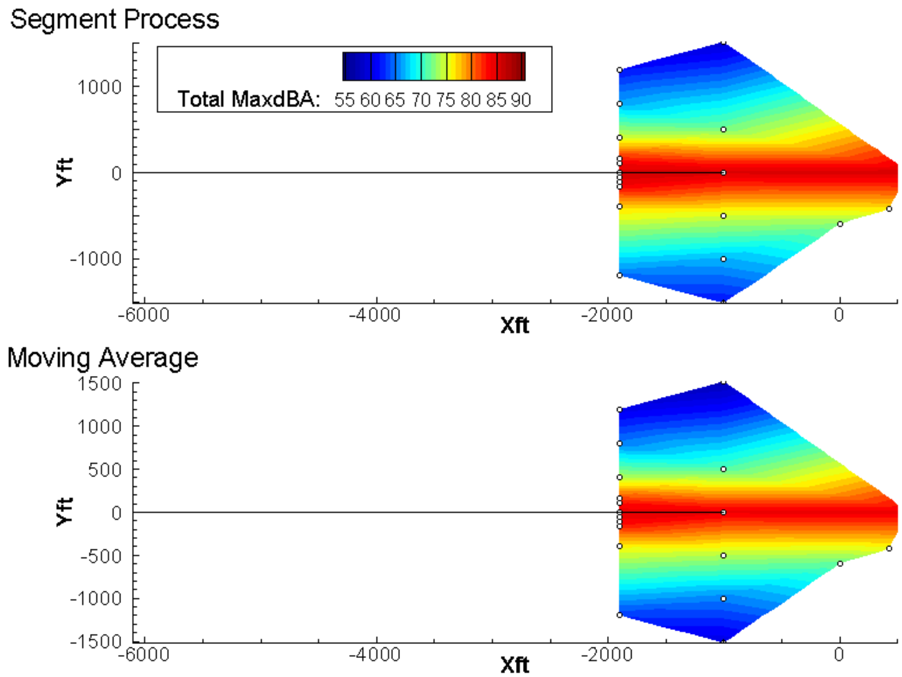

Figure 4. Comparison of results for small aircraft (Bell 206) on a level flight trajectory with legacy processing method (top) and moving average implementation (bottom). Note the decrease along the flight path line.

Publications
N/A

Outreach Efforts
N/A

Awards
None

Student Involvement
Damaris R. Zachos, a graduate assistant currently working toward her master's degree at Penn State, made the code architecture changes to PSU-WOPWOP and added the capability for moving average post-processing. She also initiated communication with Volpe on the needs for AAM output file generation.

Plans for Next Period
Changes to PSU-WOPWOP are still needed to output the files needed for AAM. Once completed, the documentation on how to use PSU-WOPWOP with that capability will be generated. Regarding prediction improvements, a scaling factor may need to be added to the Pegg broadband noise model to account for inaccuracies in that method during a maneuver. Thickness noise predictions will also be improved upon the completion of the blade flapping motion integration in PSUHeloSim.

Task 17 – Continue Effort to Develop Noise Abatement Flight Procedures for Various Helicopter Classes

The Pennsylvania State University

Objective

This Task (Task 8.4 in the 2019 proposal) will continue the development of noise abatement procedures. The noise abatement procedures demonstrated in the FAA/NASA acoustic flight test will be simulated and compared to the best procedures that can be developed with the new strategy. The strategy for developing noise abatement procedures will be evaluated/demonstrated for various helicopter classes (light to medium weights). The process will be thoroughly documented and provide the basis for future low noise operational guideline development.

Research Approach

Following the validation of noise predictions with the 2019 FAA/NASA flight test data (Task 14), the prediction system will have been authenticated for multiple maneuvers. Using both predicted and experimental data, a flight path optimizer tool will be created to develop flight paths with the lowest noise. Optimal flight paths will be tested in the noise prediction system to verify the noise is minimized. Predictions from these generated flight paths will yield new insight about noise abatement procedures for different class size aircraft. Evaluation of the noise results from these optimized flight paths will be compared against flight path recommendations from the Fly Neighborly guide to update the guidance as needed.

Milestones

The milestones for this Task are (a) creation of a noise-optimized flight trajectory generator, (b) evaluation of the noise metrics for fully simulated flight test cases, and (c) the recommendation of noise abatement flight maneuvers for aircraft.

Major Accomplishments

A flight path generation code which follows user input waypoints was created in August 2020. This code adapted the strict trajectory following command input design used for validation runs into a more lenient waypoint following code that more readily utilized the helicopter dynamics modeled in PSUHeloSim. This code set the groundwork for the noise-optimized trajectory generator which will be used to determine optimal noise abatement maneuvers. Preliminary work, which will incorporate the ability to turn in this command generation code, was also started.

Revisions to the MATLAB-based simulation code, PSUHeloSim, have been made to improve the helicopter simulation utilized in the predictions. These changes removed erroneous trim conditions which may have flown the simulated aircraft in an unrealistic manner. The combination of the waypoint following method described above and these changes improved the pilot control outputs. The significance of the pilot inputs in noise generation could be evaluated during this Task with these results. The improvements also enhanced the accuracy of the helicopters modeled. The improvement caused by allowing the simulated model to fly according to its dynamics instead of the trajectory following method, indicate that improvements to the simulated trajectory may be inherent in the noise-optimizer tool design.

Publications

N/A

Outreach Efforts

N/A

Awards

None

Student Involvement

Damaris R. Zachos, a graduate assistant currently working toward her master's degree at Penn State, created the preliminary trajectory following command program and worked with Professor Horn on improvements to the PSUHeloSim code to better predict the command outputs.

Plans for Next Period

Further development of the waypoint trajectory generator will be needed to perform more complicated maneuvers and to add the capability to optimize the flight path based on noise results. An in-depth analysis of the changes in noise sources during each point in a maneuver is also required to determine which sound sources may be causing the high noise levels. This information should be included in an optimizer tool for determining low noise flight maneuvers. Evaluation of the effects of pilot commands on the noise generated may also be assessed.