Project 049 Urban Air Mobility Noise Reduction Modeling

The Pennsylvania State University, Continuum Dynamics, Inc.

Project Lead Investigator

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University Participants

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- PI: Kenneth S. Brentner, Professor of Aerospace Engineering
- FAA Award Number: 13-C-AJFE-PSU-049, Amendment No. 52
- Period of Performance: February 5, 2020 to February 4, 2021
- Tasks:
    1. Update the flight simulation component of the noise prediction system for urban air mobility (UAM)/ electric vertical takeoff and landing (eVTOL) aircraft.
    2. Update the coupling of the new flight simulation software with Comprehensive Hierarchical Aeromechanics Rotorcraft Model (CHARM) and PSU-WOPWOP noise prediction software.
    3. Evaluate broadband noise models appropriate for UAM/eVTOL aircraft.
    4. Develop and test trim strategies for notional UAM/eVTOL vehicles.
    5. Evaluate the computational algorithm to ensure it is efficient enough for many rotors and noise generating bodies.

Project Funding Level

FAA provided $280,000 in funding. The Pennsylvania State University (PSU): $147,454 faculty academic year cost sharing; $102,000 equipment cost sharing.

Investigation Team

- Kenneth S. Brentner, PI, The Pennsylvania State University; acoustic prediction lead on all tasks.
- Eric Greenwood, Co-PI, The Pennsylvania State University; acoustics prediction/analysis supporting acoustic tasks.
- Joseph F. Horn, Co-PI, The Pennsylvania State University; flight simulation lead supporting flight simulation tasks.
- Daniel A. Wachspress, Co-PI, Continuum Dynamics, Inc.; responsible for rotor loads, wake integration, and CHARM coupling.
- Ze Feng (Ted) Gan, Graduate Research Assistant, The Pennsylvania State University; primarily responsible for developing PSU-WOPWOP noise prediction software and performing acoustic predictions (Tasks 2, 3, 5).
- Bhaskar Mukherjee, Graduate Research Assistant, The Pennsylvania State University; primarily responsible for software coupling, establishing new aircraft models, developing simulations for new aircraft types, performing acoustic predictions, and developing flight abatement procedures (Tasks 1, 2, 4).

Project Overview

A wide variety of unconventional configurations for UAM and eVTOL aircraft, with many electrically driven propellers and lifting rotors, have been proposed and are currently under development by companies worldwide. These novel configurations make up a new category of aircraft that will need to be certified and especially for acceptable noise levels, given their urban operations. Furthermore, the noise of UAM and eVTOL vehicles is expected to be one of the determining factors for community and passenger acceptance. Therefore, first principles noise predictions of these aircraft will be important for providing information that is independent from manufacturers for the FAA, and before manufacturer flight test or certification noise data is available.

In ASCENT Project 38, the helicopter noise prediction system initially developed in ASCENT Project 6 was successful in accurately predicting the noise of 6 helicopters (usually within 1-3 sound exposure level (SEL) dBA), when comparing the predictions to flight test results from a FAA/NASA rotorcraft noise abatement flight test that was carried out in August and October of 2017. Sound exposure level contours from the flight test were compared with predictions for several flight procedures. This noise prediction system developed in Project 38 consisted of the PSUHeloSim flight dynamics simulation code coupled to the Comprehensive Hierarchical Aeromechanics Rotorcraft Model (CHARM) aeromechanics modeling software and the PSU-WOPWOP noise prediction code. This coupling with the flight simulation code was demonstrated to be important for noise predictions, which improved noticeably when the simulation was modified to track the time dependent aircraft position, velocity, and attitude flown in the individual run, rather than the nominal flight path.

To build upon the success of ASCENT Project 38, an analogous approach of coupling a flight simulation code with CHARM and PSU-WOPWOP is taken in this ASCENT Project 49. In this project, the PSUHeloSim flight simulation component of the noise prediction system used in Project 38 is replaced with DEPSim, a flight simulation code designed for many electrically driven rotors and the unique control strategies to fly such vehicles effectively. Coupling of DEPSim with CHARM was done in work outside of ASCENT, but the DEPSim-CHARM coupling with PSU-WOPWOP will be performed in this project.

The goal of this project is to develop a noise prediction system with the initial capability to analyze the noise from UAM and eVTOL vehicles with unique configurations under any flight conditions. This will enable the FAA, manufacturers, and related entities to investigate how this new class of vehicles—and their noise—might be integrated into the national airspace. Emphasis is placed on modeling the unique features of UAM and eVTOL configurations not commonly seen in conventional rotorcraft, such as variable rotation speed rotors and complex unsteady aerodynamic interactions between the many rotors and airframe. UAM vehicles will likely have lower tip speeds to achieve acceptable noise levels, so broadband noise is expected to become the dominant rotor noise source; accordingly, fast, accurate modeling of rotor broadband noise is a goal of this project. Another goal of this project is to use the noise prediction system developed in this project to provide guidance on how to fly these vehicles in a quiet manner through flight operations. Since the analysis and computations are based on fundamental physics, noise abatement procedures for novel new vehicles can be developed.

(Note: This is the first year of Project 49, which was authorized in February 2020. This report reflects approximately 7 months of effort).

Task 1 – Update the Flight Simulation Component of the Noise Prediction System for UAM/eVTOL Aircraft

The Pennsylvania State University

Objectives

This task will leverage the new flight simulator DEPSim to replace the PSUHeloSim component of the noise prediction system developed in ASCENT Projects 6 and 38. The DEPSim flight simulator will need to be tested for a variety of notional UAM and eVTOL configurations with distributed electric propulsion. For expediency, nominal configurations proposed by NASA will be used as example cases (Ref. 1.1). The trim envelope will be explored for these configurations in order to evaluate potential strategies for tailoring acoustics of these aircraft (as further explored in Task 4 below).

Research Approach

Analogous to the PSUHeloSim system, the DEPSim flight simulator has been coupled with the CHARM Rotor Module (Ref. 1.2). This enables the flight simulator to capture necessary interactional effects between several moving components reasonably. Using DEPSim, a variety of control schemes will be explored to study the trim envelope. Based on experience from noise abatement strategies developed in ASCENT Project 38, control schemes with potential for noise reduction will be studied further. The impact of variable revolution per minute (RPM) and variable collective pitch control schemes is expected to be an important factor. Realtime flight unsteadiness, such as gust (Ref 1.3), will also be included to study its impact on noise.

Milestones

The milestones for this task include 1) selecting a generic eVTOL configuration for preliminary study, 2) implementing a control scheme of choice (variable RPM, variable collective, variable RPM + collective), 3) studying trim envelope, and 4) studying the impact of control scheme choice on noise.

Major Accomplishments

A generic eVTOL configuration (Figure 1) previously developed (Ref. 1.2) was chosen for expediency. This configuration has four lift rotors and one cruise propeller along with a wing and other control surfaces included in the aerodynamic modeling.

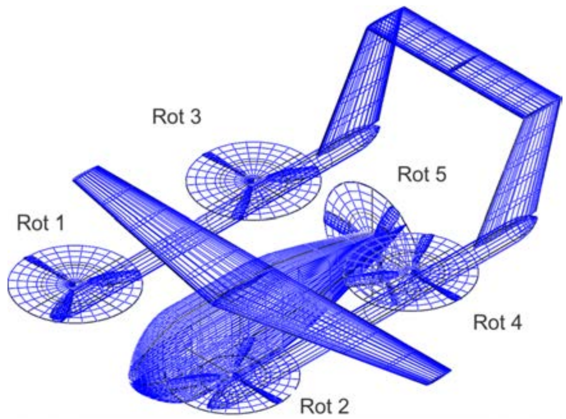


Figure 1. Generic eVTOL configuration for preliminary study.

The generic configuration shown in Figure 1 was simulated through the following maneuvers: hover, double doublet, and cruise (see Figure 2). The variable RPM fixed collective pitch control scheme was selected to trim the rotors for the entirety of this flight simulation.

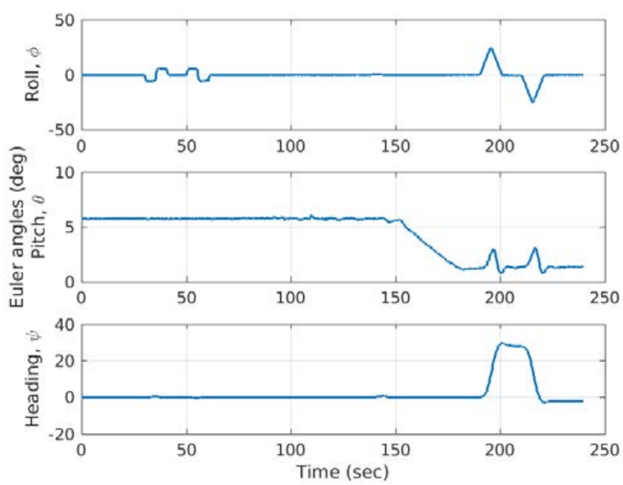


Figure 2. Aircraft Euler angles for entire flight trajectory.

Based on the maneuver commands, the variation in rotor angular velocity was studied (see Figure 3). The lifting rotors transition to zero angular velocity as the aircraft transitions to cruise and the wing provides the lift. The double doublet maneuver seems to have caused steep spikes in rotor RPM. A closer examination of Rotor 1 RPM reveals these spikes in greater detail (see Figure 4). These sudden spikes in rotor RPM are expected to have a strong impact on noise and will be an important focus in future work.

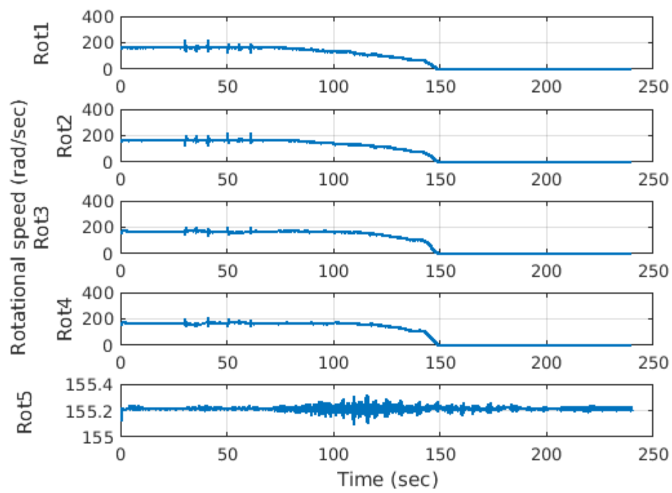


Figure 3. Rotor RPM response with respect to time.

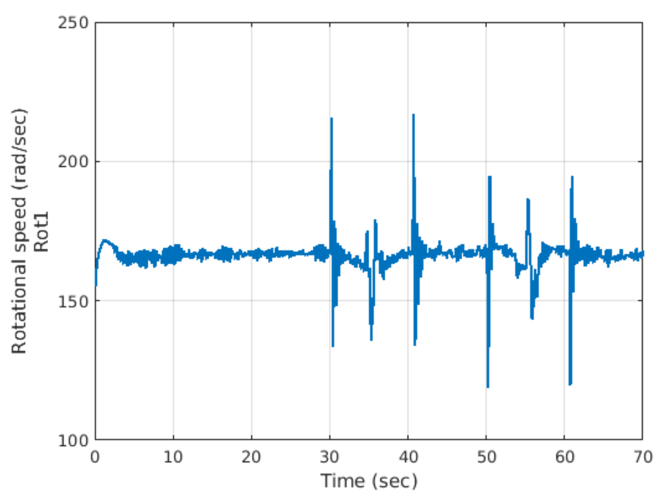


Figure 4. Rotor 1 RPM response during the double doublet maneuver.

Publications

Published conference proceedings

B. Mukherjee, Z. F. T. Gan, J.-P. Theron, M. Botre, K. S. Brentner, E. Greenwood, and J. F. Horn, "A New Distributed Electric Propulsion Aircraft Simulation Tool for Coupled Flight Dynamics, Free Wake, and Acoustic Predictions,'" Vertical Flight Society 77th Annual Forum & Technology Display, May 11-13, 2021, *abstract submitted and under review*.

Outreach Efforts
N/A

Awards
None

Student Involvement
Bhaskar Mukherjee, a graduate assistant just finishing his master's degree at PSU, has worked towards gaining proficiency in using DEPSim and CHARM Rotor Module.

Plans for Next Period
The generic eVTOL vehicle in Fig. 1.1 will be studied for other flight operations. One to two more eVTOL vehicles (likely generic configurations developed by NASA) will be modeled in the coupled DEPSim/CHARM system. These aircraft models will be available for Task 2, which will include coupling of the current DEPSim/CHARM system with PSU-WOPWOP. The experience gained in this Task will support the activities of the other Tasks.

References

[1.1] Johnson, W., Silva, C., and Solis, E., "Concept Vehicles for VTOL Air Taxi Operations," AHS Technical Conference on Aeromechanics Design for Transformative Vertical Lift, San Francisco, CA, Jan. 16-19, 2018.

[1.2] Theron, J.-P., Horn, J. F., and Wachspress, D., "An Integrated Simulation Tool for e-VTOL Aeromechanics and Flight Control Analysis," 2020 VFS Aeromechanics for Advanced Vertical Flight Technical Meeting, San Jose, CA, Jan. 2020

[1.3] Theron, J.-P., Horn, J. F., Wachspress, D., and Enciu, J., "Nonlinear Dynamic Inversion Control for Urban Air MobilityAircraft with Distributed Electric Propulsion," Vertical Flight Society 76th Annual Forum & Technology Display,Virginia Beach, VA, Oct. 2020.

Task 2 – Update the Coupling of the New Fight Simulation Software with CHARM and PSU-WOPWOP
The Pennsylvania State University

Objective
The objective of this task is to couple the DEPSim flight simulation system with PSU-WOPWOP and enable noise prediction. Emphasis will be on new changes to be made to the DEPSim flight simulation system and PSU-WOPWOP in order to enable computation of noise from rotors operating with variable angular velocity (variable RPM). This will enable the noise prediction of arbitrary eVTOL configurations and different trim strategies. The general approach used for PSUHelosim will be used in this Task, but will be modified as appropriate for DEP vehicles (i.e., variable RPM, many rotors, etc.)

Research Approach
The DEPSim system is to be coupled with PSU-WOPWOP for enabling noise predictions. A schematic of the system is shown in Figure 5. The starting point for the coupling code was based of the work done for ASCENT Projects 6 and 38. The code needs modification in order to transfer time-varying rotor angular velocities to PSU-WOPWOP. High resolution blade loads are essential for noise prediction; therefore, the coupling with DEPSim and CHARM rotor module will require the azimuthal refinement of the wake and blade loads, known as reconstruction, to be passed to PSU-WOPWOP. CDI will extend the current reconstruction process to time-varying angular velocities. The new DEPSim/PSU-WOPWOP coupling will also need to extend what was previously done in PSUHelosim/CHARM/PSU-WOPWOP coupling. These changes are critical for noise prediction of UAM and eVTOL aircraft.

Milestones
Milestones achieved for this task are 1) transferring aperiodic aircraft position, velocities, rotor angular velocities, aerodynamic blade loading, and geometry to PSU-WOPWOP; 2) generating input for broadband noise models (needed for Task 3); 3) updating PSU-WOPWOP to accept input data with arbitrary timestep spacing, regardless of whether the rotor has constant or variable RPM.

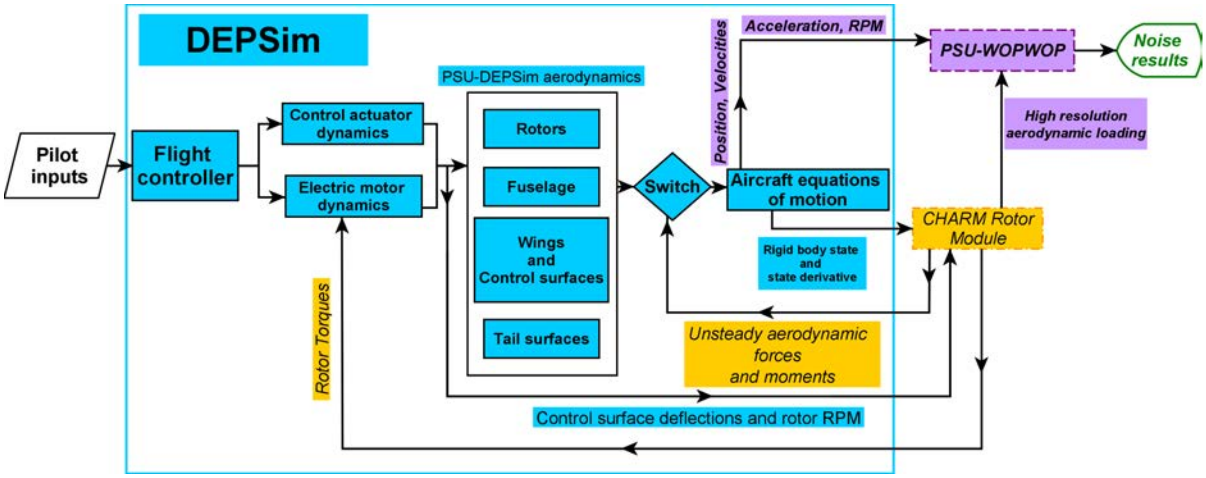


Figure 5. DEPSim system coupling schematic with CHARM rotor module and PSU-WOPWOP.

Major Accomplishments

The code from ASCENT Projects 6 and 38 used in PSUHelosim for transferring the temporal aircraft, rotor, and blade loading data from CHARM rotor module to PSU-WOPWOP was used as a starting point for the development of a new interface for DEPSim. This code transfers data from CHARM and DEPSim using shared memory blocks. Work is ongoing in transferring the following data in aperiodic format:

1. Aircraft position, velocity
2. Position and orientation of rotors and other aircraft components
3. Rotor angular velocity

Previously, PSU-WOPWOP was able to calculate the noise for variable RPM rotors, but only if the input data was provided at discrete timesteps with constant time interval spacing. PSU-WOPWOP was updated to accept input data with arbitrary time spacing. To validate these changes to PSU-WOPWOP, the loading noise of a single rotating blade section with linearly-increasing RPM was calculated using two kinds of input data files: 1) with constant timestep spacing (and thus variable azimuthal spacing), and 2) with constant azimuthal spacing (and thus variable timestep spacing). Loading was approximated using blade element theory. The results from the two kinds of input data files coincide (see Figure 6), thus validating PSU-WOPWOP's capability in predicting the noise of rotors with arbitrary variable rotation speed, with input data from arbitrary timesteps.

Publications

Published conference proceedings

B. Mukherjee, Z. F. T. Gan, J.-P. Theron, M. Botre, K. S. Brentner, E. Greenwood, and J. F. Horn, "A New Distributed Electric Propulsion Aircraft Simulation Tool for Coupled Flight Dynamics, Free Wake, and Acoustic Predictions,'" Vertical Flight Society 77th Annual Forum & Technology Display, May 11-13, 2021, *abstract submitted and under review.*

Outreach Efforts

N/A

Awards

None

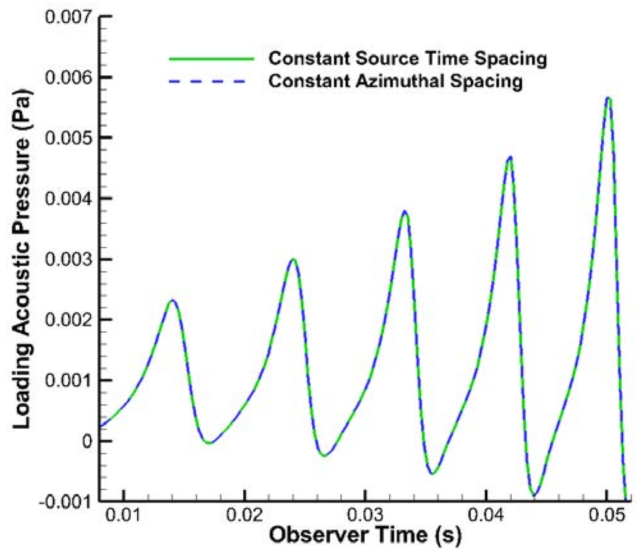


Figure 6. PSU-WOPWOP predictions for rotor with linearly increasing RPM.

Student Involvement

Bhaskar Mukherjee, a graduate assistant just finishing his master's degree at PSU, is working on the coupling of DEPSIm-CHARM and PSU-WOPWOP for this Task.

Ze Feng (Ted) Gan, a graduate assistant currently working towards his master's degree at PSU, performed the modifications to PSU-WOPWOP to enable variable RPM rotors with nonuniform time step size for this Task.

Plans for Next Period

Once the aircraft state data, such as velocities, position, and rotor trim data are transferred successfully, the focus will be on getting rotor geometry and high-resolution aerodynamic data to PSU-WOPWOP. When the coupling is complete, the system will be tested by simulating helicopters from the flight test data captured for ASCENT Project 6 and 38 and eVTOL vehicles modeled in Task 1.

Task 3 – Evaluate Broadband Noise Models Appropriate for UAM/eVTOL Aircraft

The Pennsylvania State University

Objective

The objective of this task is to predict the broadband noise of arbitrary UAM and eVTOL aircraft configurations. Broadband noise arises due to stochastic aerodynamic loading, usually due to turbulence. Broadband noise is expected to be important for UAM and eVTOL aircraft due to their complex configurations causing unsteady, turbulent aerodynamic interactions (e.g., between rotors, other rotors, and the airframe), and their low rotor tip speeds that reduce deterministic thickness and loading noise levels.

Research Approach

To balance computational costs and physics-capturing fidelity, the semi-empirical physics-based Brooks, Pope, and Marcolini (BPM) model was chosen to model the rotor broadband noise (Ref. 3.1). The BPM model for airfoil self-noise is implemented within PSU-WOPWOP via an incoherent summation of the noise sound pressure level (SPL) spectrum generated at discrete airfoil sections along each blade span under a quasi-steady assumption. This implementation of the BPM model in PSU-WOPWOP was validated with other codes and experimental data.

Existing literature typically integrates the broadband noise spectrum for a time segment on the order of a rotor period; previously this was also done in PSU-WOPWOP. However, this may average out significant temporal/azimuthal variations in broadband noise that occur over one rotor period. For example, the rotor blade sections of helicopters and UAM aircraft may experience significant variations in unsteady aerodynamic loading, due to edgewise flight or interactional aerodynamics. Therefore, PSU-WOPWOP was updated to calculate the SPL spectrum as a function of time.

This approach is justified by rotor broadband noise frequencies being approximately 10 to 50 times higher than the blade passage frequency. This approach assumes that the time scale of the turbulence generating the self-noise is much smaller than the rotor period, such that only a short (compared to the rotor period) acoustic pressure time history is required to construct a representative broadband noise spectrum.

Milestones

The milestones reached for this task include (1) validation of the implementation of the BPM model in PSU-WOPWOP, and (2) adding the capability to predict the time variation of broadband noise using the implementation of the BPM model in PSU-WOPWOP.

Major Accomplishments

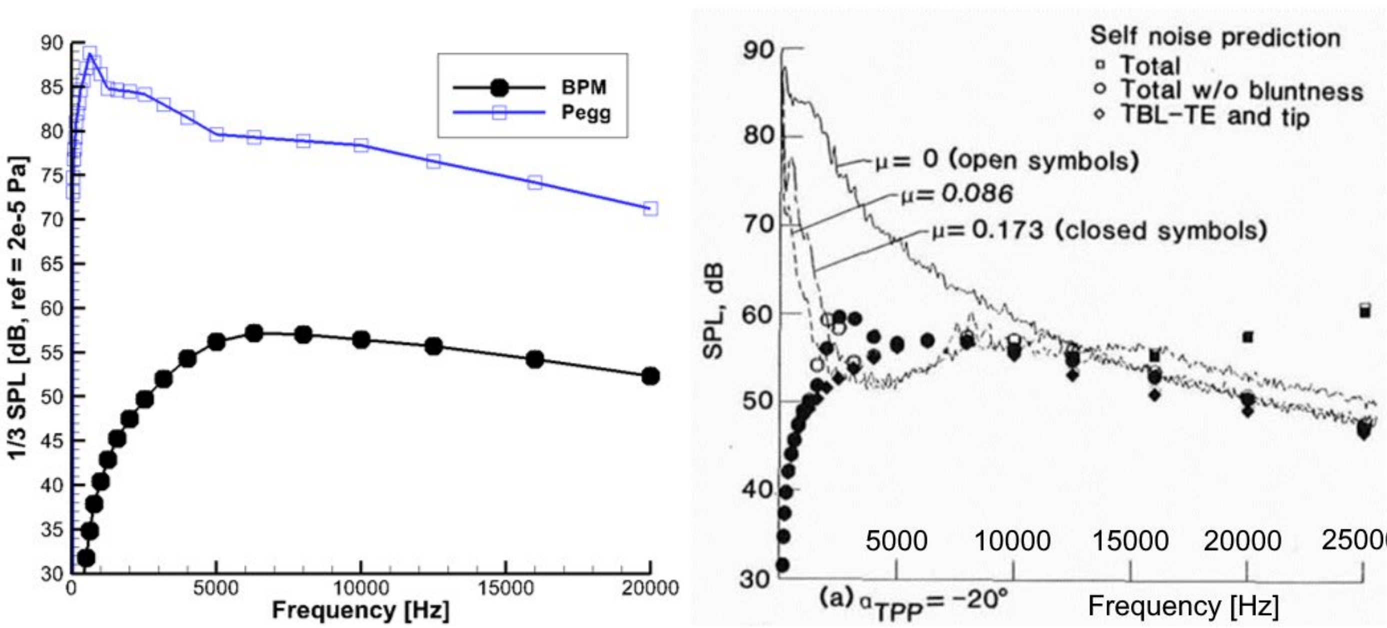
Two major activities were undertaken in this Task. The first activity was to validate the BPM model implementation in PSU-WOPWOP. Although the BPM model was available in PSU-WOPWOP, it had not been fully validated or widely used; thus, the first activity was to validate the model implementation. The second activity was to investigate the time varying nature of broadband noise in a way that has not been done previously. This is necessary before considering the broadband noise of time varying angular rotation rate of rotors. Both activities are described in more detail in the following.

Validation of the BPM Model Implemented in PSU-WOPWOP

To validate the implementation of the BPM model in PSU-WOPWOP, PSU-WOPWOP noise predictions were compared with experimental data of the higher-harmonic control aeroacoustic rotor test (HART) rotor (40% scale model BO-105 helicopter main rotor) in the DNW wind tunnel, and corresponding predictions made using the NASA ROTONET code (Ref. 3.2). The input data files required by PSU-WOPWOP were generated using CHARM, which solves for the rotor inflow.

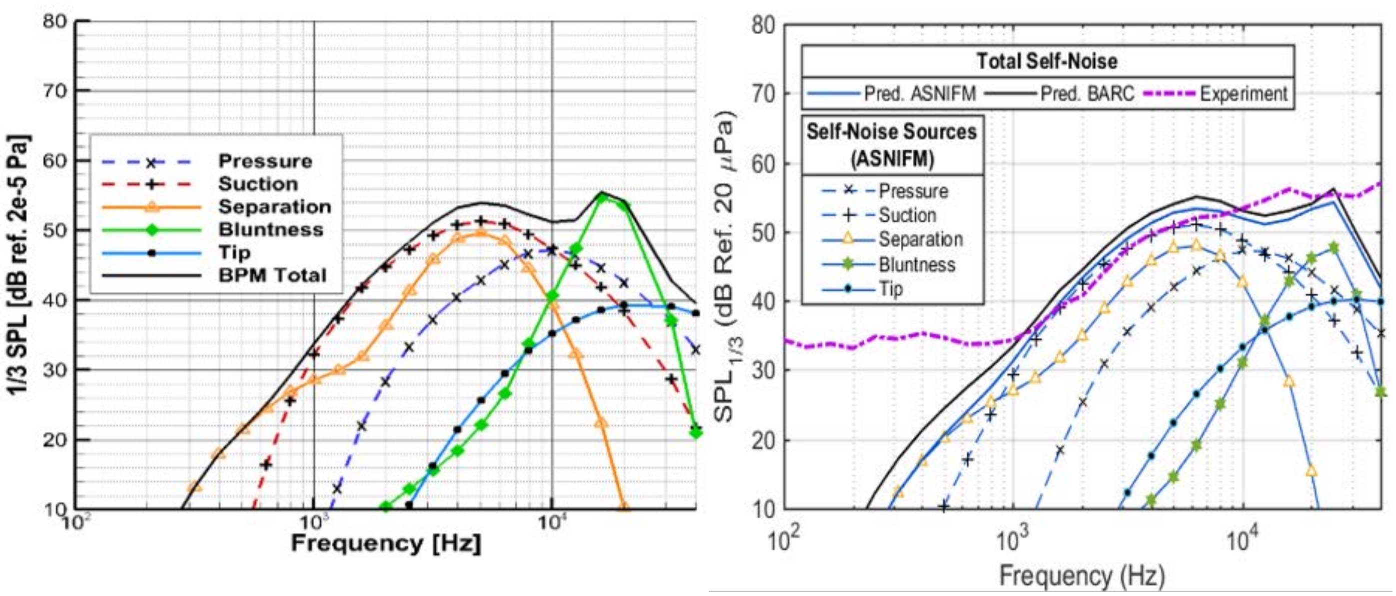
Good agreement (within ~3-5 dB above 1000 Hz, where broadband noise dominates in the absence of rotor blade passage frequency harmonics) was obtained when comparing the PSU-WOPWOP predictions made using the BPM model with the experimental data and the ROTONET predictions (see Figure 7, from Ref. 3.2). The empirical Pegg model was found to be highly inaccurate (>20 dB over-prediction) compared to the experimental data. This inaccuracy was found to persist independently of the observer location (distance and directivity). The precise reasons for the observed discrepancies are difficult to determine, as the Pegg model combines numerous physical sources that are difficult to isolate and is heavily calibrated using experimental helicopter rotor data. The primary conclusion is that purely empirical models suitable for helicopters are probably not suitable for UAM aircraft. Accordingly, physics-based models, such as the BPM model, are needed. In Figure 8, a comparison of the BPM model implementation in PSU-WOPWOP (left) and the NASA BARC and ASNFIM codes (right, Ref. 3.3) is made. The PSU-WOPWOP predicts each of the self-noise components very close to the ASNFIM results (which is a newer implementation of the Brooks, Pope and Marcolini model, Ref. 3.1). The trailing-edge bluntness noise seems to be somewhat different, but more research is needed to determine the reason for this discrepancy.

The work summarized above provides validation of the BPM model implementation in PSU-WOPWOP. This accomplishment in Task 3 impacts the rest of the project by increasing confidence in the accuracy of broadband noise predictions to be made later in this project (Project 49).



a) b)

Figure 7. Broadband noise SPL spectrum for HART rotor case, advance ratio μ = 0.173. a) PSU-WOPWOP prediction. b) Experimental data (lines) and ROTONET code predictions (symbols) (Ref. 3.2).



a) b)

Figure 8. SPL spectrum from BPM model for ideally twisted rotor. a) PSU-WOPWOP prediction. b) BARC prediction (Ref. 3.3).

Time Variation of Rotor Broadband Noise

Examples of time-varying broadband noise results are shown below for a Bell 407 helicopter main rotor (four blades, R = 5.34 m) in steady level 80 knots forward flight (advance ratio $\mu = 0.18$, advancing tip Mach number $M_{AT} = 0.8$). These sample plots demonstrate the new capabilities added to PSU-WOPWOP to analyze the time variation of broadband noise.

A spectrogram for a single observer (see Figure 9) demonstrates the time variation in the broadband noise SPL spectrum over a rotor period. At frequencies near 1 to 3 kHz, where SPL and human hearing sensitivity is highest, amplitude modulations of up to 4 dB peak-to-peak amplitude are observed. This demonstrates that averaging the SPL spectrum over a rotor period may average out important variations in the broadband noise.

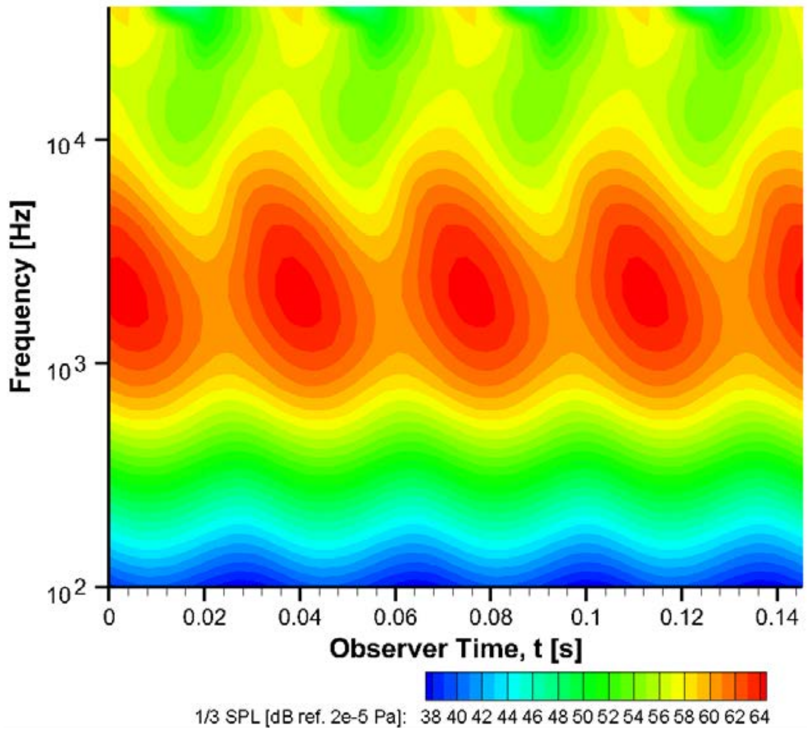


Figure 9. Spectrogram for observer located at -45° elevation relative to hub plane, 180° azimuth, and distance 11R from hub.

Spectrograms can be extended to show the acoustic spectrum generated by each blade segment as a function of observer time. Such diagrams will be referred as "spatial spectrograms", which show the contribution from each blade segment for an observer time at a single observer location. Figure 10 shows the SPL spectrum from each radial segment for four observer time "snapshots". These four observer times correspond to an approximately 1/4 revolution of the blade. Figure 10 shows that noise frequency and amplitude generally increase for radial stations approaching the blade tip.

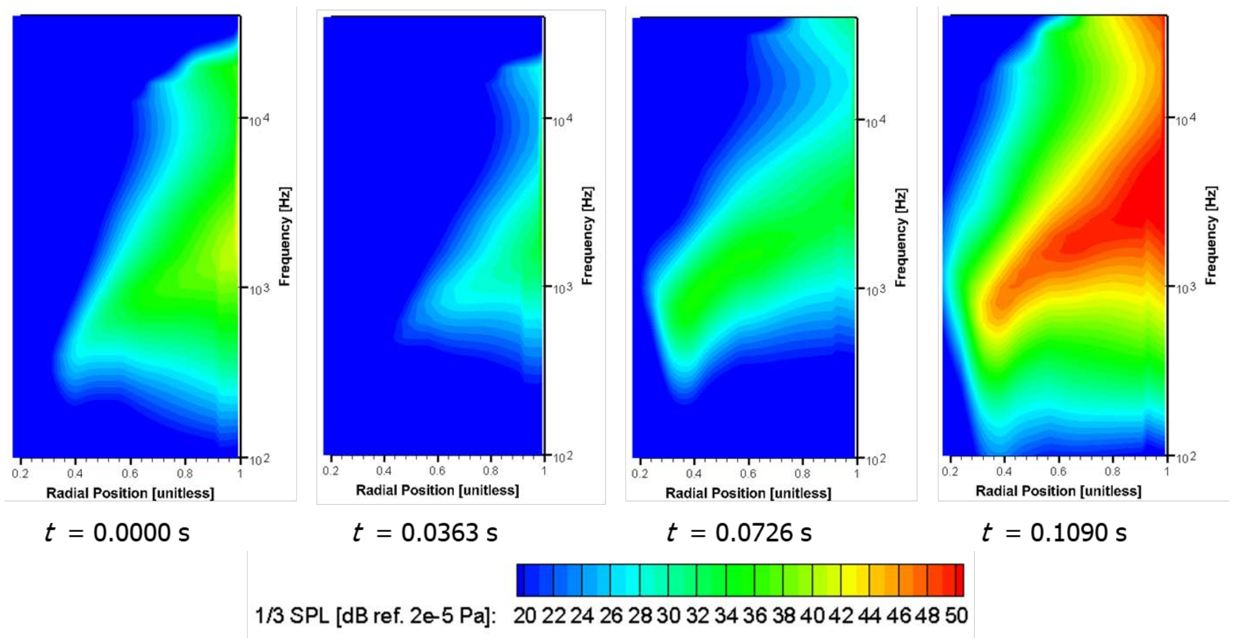


Figure 10: Observer time snapshots of spatial spectrogram of one rotor blade, for the same observer as Figure 9.

The time variation of the broadband noise directivity can be quantified using overall sound pressure level (OASPL). The noise levels (OASPL) are generally highest on the advancing side of the rotor due to convective amplification (see Figure 11). The broadband OASPL varies not only around the azimuth, but there is approximately a 3 dB OASPL difference between a single observer time (t = 0 sec) and the observer time average, again for an observer on the advancing side and to the front of the rotor.

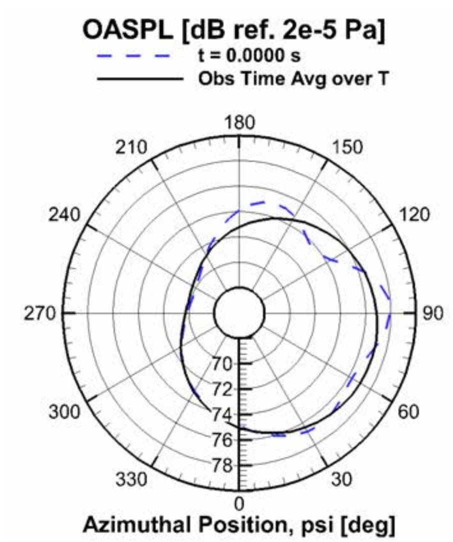


Figure 11. Broadband noise directivity in azimuthal plane, for observers located 45° below the tip-path-plane of the rotor, at a distance of 11*R* from hub.

The impact of this work on the rest of the project consists of the development of new tools for calculating, visualizing, and analyzing time-varying broadband noise. This unique viewpoint may lead to better understanding of the physics of broadband noise, and improved prediction methodologies and metrics.

Publications

Published conference proceedings

Z. F. T. Gan, K. S. Brentner, and E. Greenwood, "Time Variation of Rotor Broadband Noise,'" Vertical Flight Society 8th Annual Electric VTOL Symposium, Jan. 26-28, 2021, *accepted for presentation*.

Outreach Efforts

N/A

Awards

None

Student Involvement

Ze Feng (Ted) Gan, a graduate assistant currently working towards his master's degree at PSU, performed the modifications to PSU-WOPWOP, and the generation and analysis of the results for this Task.

Plans for Next Period

Validation of the BPM model implemented in PSU-WOPWOP will continue, with diverse cases comprising a variety of flight conditions.

Future work will consist of parametric studies of the time-varying broadband noise spectrum. Parameters to vary include: number of blades and rotors, tip Mach number, advance ratio, and observer position (distance and directivity). These parametric studies will help determine conditions for which time variation of the broadband noise spectrum is important, which will in turn help determine how to incorporate knowledge of this spectrum time variation into UAM vehicle analysis and design. Both helicopter and UAM aircraft cases will be studied, including a Bell 407 helicopter in steady 6° descent, and a notional generic eVTOL aircraft. The relative contributions of the noise source mechanisms of the BPM model at different blade positions will be studied using spatial spectrograms. The correlation between deterministic and broadband loading noise will also be investigated. Some correlation is expected, as broadband noise is physically a type of loading noise, but at higher frequencies. This correlation will be investigated using the time-variation of contour plots and/or iso-surfaces of noise levels (e.g., acoustic pressure, OASPL). This work would help develop a deeper understanding of the underlying physics, enabling improved noise prediction. The impact of time varying rotor rotation rate on broadband noise will also be considered. The prediction of broadband noise for time-varying rotor rotation rate may require further noise prediction system implementation changes.

References

[3.1] T. F. Brooks, D. S. Pope, and M. A. Marcolini, "Airfoil self-noise and prediction," Tech. Rep. 1218, National Aeronautics and Space Administration, 1989.
[3.2] T. F. Brooks, M. A. Marcolini, and D. S. Pope, "Main rotor broadband noise study in the DNW," Journal of the American Helicopter Society, vol. 34, no. 2, pp. 3-12, 1989.
[3.3] N. A. Pettingill and N. S. Zawodny, "Ideally Twisted Rotor Testing and Predictions," presented at NASA Acoustics Technical Working Group, 2020.

Task 4 – Develop and Test Trim Strategies for Notional UAM/eVTOL Vehicles

The Pennsylvania State University

Objectives

UAM/eVTOL vehicles have significant control redundancy inherent in their design. This includes not only multiple propellers and rotors, but also lifting surfaces, such as wings and tail surfaces. As a result, the trim of the vehicle is not unique; hence, some strategies to determine an "optimal" trim will be required. In this Task, alternative trim approaches will be developed and demonstrated. Baseline performance oriented trim strategies will be compared with trim for maximum noise reduction. These trim strategies and their use in anticipated flight operations will be evaluated in the PSU flight simulation facility to test feasibility for practical UAM operations.

Research Approach

The development of trim strategies requires a thorough understanding of the correlation of interactional aerodynamics and fundamental acoustic mechanisms. Traditionally constant RPM rotors have discrete frequency peaks often corresponding to multiples of their blade passage frequency. Variable RPM rotors, however, are expected to introduce additional discrete frequencies whose characteristics will potentially be impacted by how the RPM will vary with time. The importance of parameters such as angular acceleration will need to be studied further in the context of acoustics.

Milestones

This task has not yet been started, as correlating trim strategies with noise requires completing Task 2 first. The first milestone will be to demonstrate satisfactory trim with multiple trim approaches, and then to compare the acoustic field for each of the equivalent (in the sense of satisfying trim) trims. This will provide an example of how noise can be improved with a proper trim strategy for eVTOL aircraft. The next milestone will be to determine which aspects of the higher noise level trims are most important. A final milestone will be to develop new acoustically optimal trim strategies to reduce the noise. The new trim approach will be demonstrated/validated in the noise prediction system.

Major Accomplishments

None

Publications

None

Outreach Efforts

N/A

Awards

None

Student Involvement

Bhaskar Mukherjee, a graduate assistant just finishing his master's degree at PSU, will perform this Task.

Plans for Next Period

This Task will be initiated after the completion of Task 2, using the planned research approach.

Task 5 – Evaluate the Computational Algorithm to Ensure it is Efficient Enough for Many Rotors and Noise Generating Bodies

The Pennsylvania State University

Objective

The objective of this Task is to ensure that the computational algorithms used in the noise prediction software PSU-WOPWOP remain efficient for UAM aircraft, which generally have many rotors and noise-generating airframe components with significant aerodynamic interactions. This objective serves the more general goal of developing noise prediction that is fast but is also accurate in capturing the key underlying physics that generate the noise.

Research Approach

The research approach taken will be to first use a code profiler to identify which parts of the computational algorithm serve as bottlenecks for noise prediction of UAM and eVTOL aircraft. These computational bottlenecks will be the focus of efforts to make the code more efficient, including techniques to make the code parallel. The eVTOL aircraft design attributes will also be considered as part of the study on the computational algorithm, with the goal of using appropriate knowledge of the number of noise-producing components (rotors, wings, etc.), as part of the algorithm design of the noise predictions system in order to reduce computational bottlenecks.

Milestones
This task has not yet been started because Task 2 must be completed first. The milestones for this task will be to 1) investigate where any bottlenecks show up in the noise predictions system, both for configurations with low number of rotors and eVTOL configurations with up to 10 rotors, and other noise generating surfaces; 2) review the configuration components and assess whether the computational algorithms can be improved by taking the aircraft configuration into account, especially in developing parallel processing strategies.

Major Accomplishments
None

Publications
None

Outreach Efforts
None

Awards
None

Student Involvement
Ze Feng (Ted) Gan, a graduate assistant currently working towards his master's degree at PSU, will perform this Task.

Plans for Next Period
This task will be initiated after the completion of Task 2, using the planned research approach.