Project 038 Rotorcraft Noise Abatement Procedures Development

The Pennsylvania State University/Continuum Dynamics, Inc. / Sikorsky Aircraft Corporation/AHS International

Project Lead Investigator

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- P.I.: Kenneth S. Brentner, Professor of Aerospace Engineering
- FAA Award Number: 13-C_AJFE-PSU-038, Amendment No. 22
- Period of Performance: September 2016 to August 2017
- Task(s): (during this period)
  5. Development and evaluation of noise procedure
  6. Analyze noise abatement procedures and assist in flight test planning
  7. Compare flight test data with prediction
  8. Evaluate flight test data

Project Funding Level

FAA: $150,000; In-Kind Match: (Continuum Dynamics, Inc.: $75,000 to PSU; Sikorsky Aircraft Corporation: $37,500; AHS International: $37,500)

Investigation Team

Kenneth S. Brentner, PI, The Pennsylvania State University; acoustics predictions 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 and wake integration, and CHARM coupling.
Mrunali Botre, Graduate Research Assistant, The Pennsylvania State University; primary responsibility for setting up new aircraft models, developing simulations with new helicopter types, acoustic predictions and development of flight abatement procedures, involved in all tasks.
Eric Jacobs, Industrial Partner, Sikorsky Aircraft Corporation; primary responsibility for flight test plan development, provide feedback on all aspects of project, especially related to flight test.
Paul Schaaf, Industrial Partner, AHS International; pilot and operator experience, provides guidance on abatement procedure development.

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 that is heard by the community upon takeoff, landing, and along the flight path of the helicopter. Rotor noise consists of several different noise sources including thickness noise and loading noise (together typically referred to as rotational noise), blade-vortex-interaction (BVI) noise, high-speed-impulsive (HSI) noise, and broadband noise – with each noise source having its own unique directivity pattern around the helicopter. Furthermore, any aerodynamic interaction between rotors, interaction of the airframe wake and a rotor, or unsteady, time-dependent loading generated during maneuvers typically results in significant increases in loading noise. The combination of all the potential rotor noise sources makes prediction of rotorcraft noise quite complex, even though not all of the noise sources are present at any given time in the flight (e.g., BVI noise usually occurs during descent and HSI noise only occurs in 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 preform rotorcraft noise predictions. This noise prediction system was used for developing noise abatement procedures through computational and analytical modeling. Although this noise prediction system does not contain engine noise or HSI noise prediction capability, it was thoroughly validated by comparing predicted noise levels for a Bell 430 aircraft with flight test data (Ref. 19) for several observer positions and operating conditions.

In the previous year's work in ASCENT Project 38, representative helicopters for noise abatement procedure development were recommended. These helicopters were selected to determine if it is feasible to develop noise abatement procedures for categories of helicopters, (i.e., 2 blade light, 4 blade light, 2 blade medium, etc.) or if aircraft specific design considerations will be required in the development of noise abatement procedures.

Objectives

The objective of this project is to utilize computational and analytical modeling to develop noise abatement procedures for various helicopters for various phases of flight. An extension of the project also includes predictions to support flight test planning and abatement procedure development for the flight testing.

The research team will recommend representative helicopters for which noise abatement procedures will be developed. The helicopters will be selected to determine if it is feasible to develop noise abatement procedures for categories of helicopters, (i.e., 2 blade light, 4 blade light, 2 blade medium, etc.) or if aircraft specific design considerations will be required in the development of noise abatement procedures. Noise abatement procedures will be compared to representative baseline operations. Comparisons will be made using various noise metrics (SEL, DNL, EPNL, etc.) along with the acoustic pressure time history and acoustic spectrum plots (which will be used primarily to explain what is impacting the metrics).

Note: The FAA/NASA flight test occurred late in this year (August and October 2017), so some of the activities reflect this unanticipated change in schedule.

Task #5: Development and Evaluation Of Noise Abatement Procedures

The Pennsylvania State University

Objective(s)

The object of this task is to continue the development various noise abatement procedures and to determine the noise the procedures common across various helicopter categories (weight, number of main rotor blades, tail rotor configuration, technology generation, etc.). This will help to determine the fidelity required for designing the abatement procedure. The helicopters used for flight test will be used to do the analysis and consequently will design the flight procedure.

Research Approach

For this effort, the noise prediction system developed in ASCENT Project 38 will be used and updated as necessary. The PSU-WOPWOP code will be used for noise prediction, and will be coupled with a MatLab flight simulator and CHARM (Comprehensive Hierarchical Aeromechanics Rotorcraft Model) to form a rotorcraft noise prediction system. Limited validation of the system through comparison with the NASA/Bell flight test has demonstrated that the system is reasonably accurate with very reasonable computational cost. The initial procedure considered is a decelerating decent case, which should reduce or eliminate BVI noise during decent. Other flight procedures will be considered after that, including turns and descending turns – which often occur in urban settings. The noise abatement procedures will be compared to standard procedures through comparison of several different acoustic metrics.

Milestone(s)

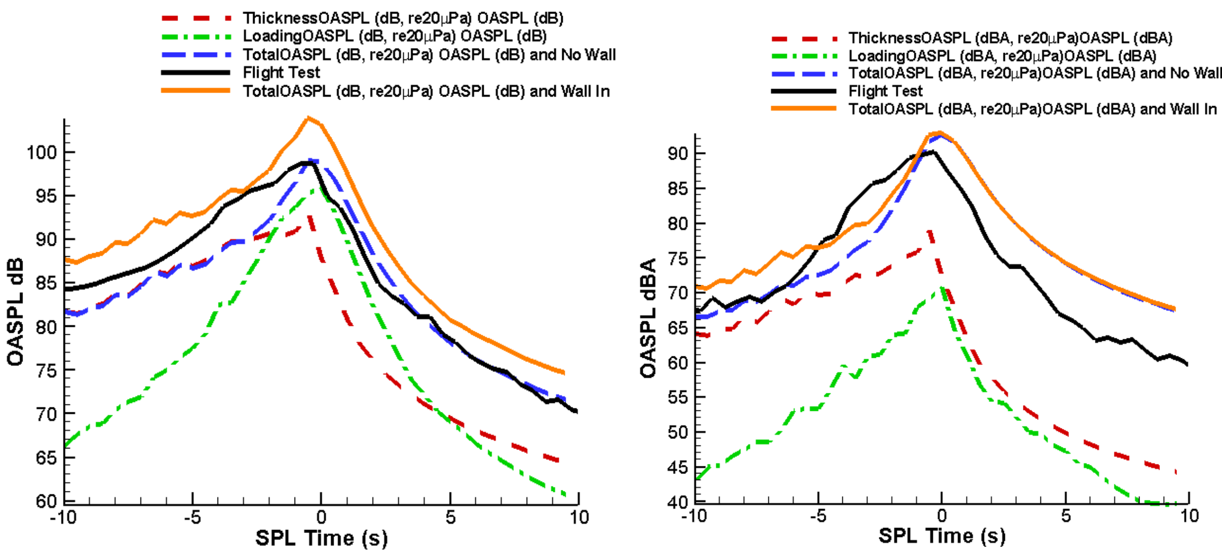
Evaluation of noise abatement flight procedures for a variety of helicopter categories.

Major Accomplishments

While evaluating noise prediction of unsteady aircraft motion (like decelerating decent) an error was found in the noise prediction system. This error was related to the reconstruction of the rotor wake in the Charm rotor module that is done to provide high-resolution airloads for the noise prediction. In particular, after the high-resolution airloads were output, the module restores the wake geometry to its original low resolution and then continues the flight simulation until the next time when high-resolution airloads need to be saved. The process of restoration added a small error that accumulated after several reconstruction/restoration cycles. To debug this problem, the code was run multiple times with only reconstruction (no restoration), but the code was run to different times. Once the source of the problem was identified, it was fixed and computations of decelerating flight were resumed.

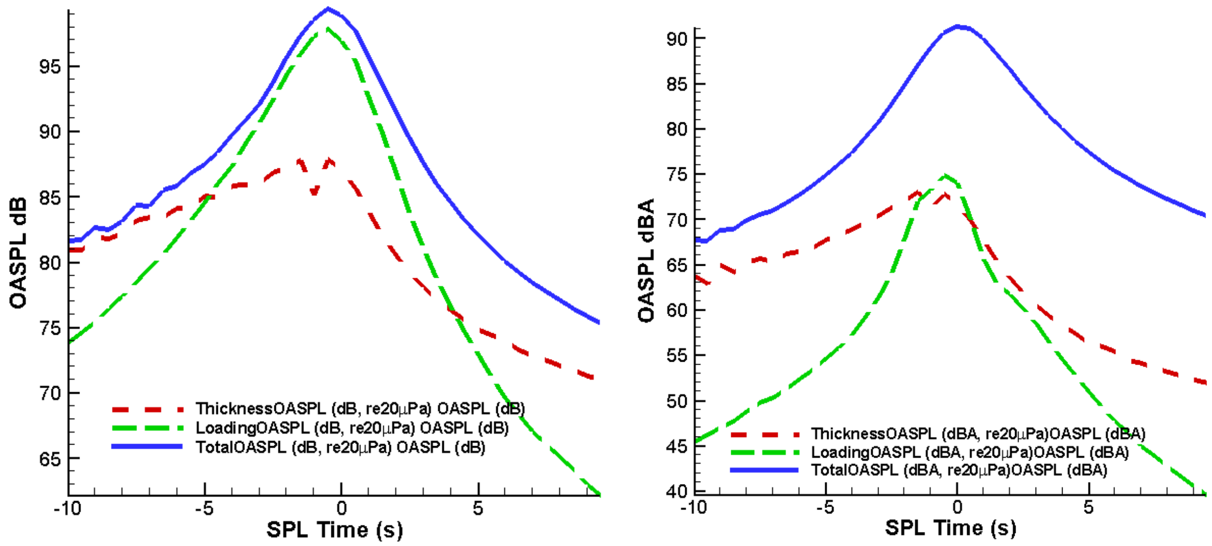
Another accomplishment during this task, is related to validation of the noise prediction system. For more direct comparisons with flight test data, a tool was written that takes the acoustic pressure measure in the flight test and puts it into a format that PSU-WOPWOP can read. In this way, noise predictions and flight test data are post processed in exactly the same manner – both using the post processing procedures in PSU-WOPWOP.

One of the accomplishments of this task is the simulation of different flight conditions and comparing the noise with flight test data. The validation of the noise prediction system in both level flight and a blade-vortex-interaction flight conditions is a significant achievement for the project. The agreement between the predicted and measured results is quite reasonable for fidelity of these tools and it demonstrates that the tools are able to predict the significant physical noise sources that must be modified to achieve noise abatement. This validation enables the noise prediction system to be used for the other tasks in the project with a degree of confidence. Figure 1 shows the prediction for a 95 kts level flight case. The noise components and total noise are shown in terms of OASPL and A-weighted OASPL as a function of the helicopter time (0 sec. is the time with the helicopter is overhead). Note that the flight test data (black line) includes a ground reflection on a hard ground. The noise predictions labeled "Total …. – No Wall" are free-field noise prediction, while the "Total … - Wall in" include the effect of a hard ground; hence, the "wall in" prediction should be compared with the flight test data (Run 273126). In Fig. 2, the predicted noise for a 0.05g deceleration along 6 deg. descent is shown. During this flight procedure, the aircraft velocity reduces from 100 kts to approximately 68 kts.



(a) OASPL, dB (b) A-weighted OASPL, dBA

Figure 1- OASPL and A-weighted OASPL levels for Bell 430 in 94.7 kts level flight, compared with flight test data (Run 273126).



(a) OASPL, dB (b) A-weighted OASPL, dBA

Figure 2 - OASPL and A-weighted OASPL levels for Bell 430 in deaccelerating descent flight.

Publications

None

Outreach Efforts

None

Awards

None

Student Involvement

Mrunali Botre, graduate assistant currently working toward her Ph.D. at Penn State, performed the acoustic predictions and worked on debugging the problem with the error introduced by the reconstruction/restoration process.

Plans for Next Period

Validation of the system with the FAA/NASA flight test data will be an ongoing process, that will be done in parallel to “understanding” what was likely the reasons for changes in noise in the flight tests. The flight test data does not have any details about blade loadings, specific BVI information, etc., but the predictions can suggest which noise components were dominant in different parts of the flyover and at different directivity angles. For example, the predictions show that the broadband noise is dominant when the aircraft is overhead and downrange – so the broadband noise model can be validated for the different aircraft during this part of the flight profile.

Task #6: Analyze Noise Abatement Procedures and Assist In Flight Test Planning

The Pennsylvania State University

Objective(s)

This task will develop and analyze of rotorcraft noise abatement flight procedures for the aircraft used in flight test. The procedures will be used to plan flight test and the data will be used to validate the tools.

Research Approach

In support of an FAA/NASA flight test, the helicopters used in the flight test were modeled and the noise from the anticipated flight procedures (baseline and noise abatement procedures) were predicted. The aircraft selected for the flight test originally included the Sikorsky S-76C and S-76D models, but ultimately Sikorsky decided not to provide the aircraft for the flight test, so the final group of helicopters were: Robinson R-44 and R-66 (piston and turbine engines respectively); Bell 206L and 407 (2 and 4-bladed main rotors, different generation of similar aircraft); and Airbus AS 350 and EC130 (standard tail rotor and Fenestron).

While these aircraft are all generally smaller, there are subtle differences that can be compared. The research approach is to determine if the approximate modeling using in the predictions is sufficient to distinguish between the aircraft, and to determine if the difference between aircraft result in significant noise differences between related models and other manufacturers models.

Figure 3 - Helicopters used in FAA/NASA flight test and modeled in PSU predictions.

Milestone(s)

Computational models for all the flight test aircraft need were developed. Predictions on a hemisphere, 100 ft radius, were computed for all steady flight conditions in the flight test and for segments of the abatement procedures. These noise hemispheres were provided to Volpe for their noise prediction activity to explore more rapidly various noise abatement procedures.

Major Accomplishments

Prediction of the SEL contours for several of the flight conditions were performed to compare the different flight procedures to determine which procedures had the lowest noise. Much of the focus was on descent, when BVI noise can occur – and should be avoided as part of a noise abatement strategy. To show the subtle differences between aircraft that are nearly the same, Figs. 4 and 5 compare the SEL contours on the ground for 3 and 6 deg descents for the Robinson R-44 and R-66 aircraft for 3 flight speed (60, 80, and 100 kts). The size and weight of the two Robinson aircraft is nearly the same, but the engine in the R-44 is a piston engine, while the R-66 has a turbine engine. The main rotor blade on the R-66 has a different chord and twist distribution as compared to the R-44 as well, but these differences are not readily identifiable by a cursory visual inspection.

These figures show a couple of different trends, visible at both descent angles. First, flying at higher speeds in the descent tends to take the helicopter out of the BVI noise condition and the noise levels are lower. Although not shown, a steeper descent angle or deceleration can also achieve this result. A secondary observation is that although the differences in the helicopter configuration are relatively small, there are noticeable difference in the noise levels and directivity on the ground plane. A more detailed investigation is needed to determine if these small differences are significant, and when they might be significant.

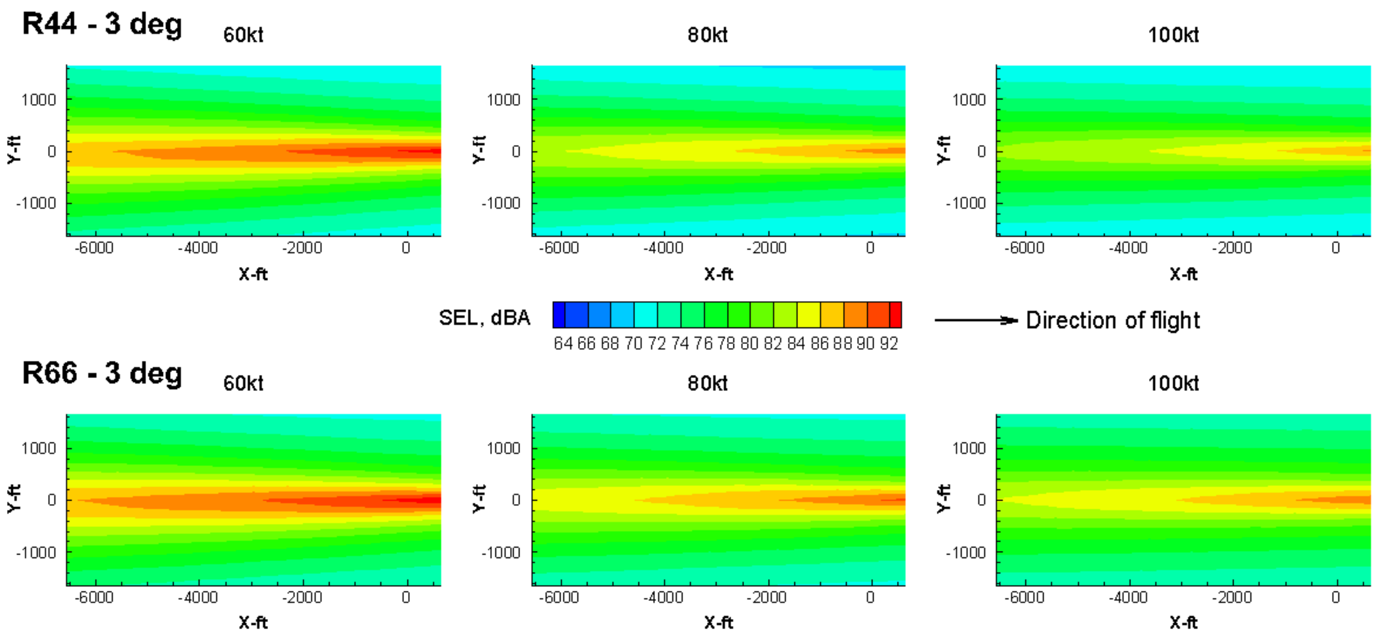


Figure 4 - Predicted SEL contours: 3 deg steady descent for different flight speeds.

Publications
None

Outreach Efforts
None

Awards
None

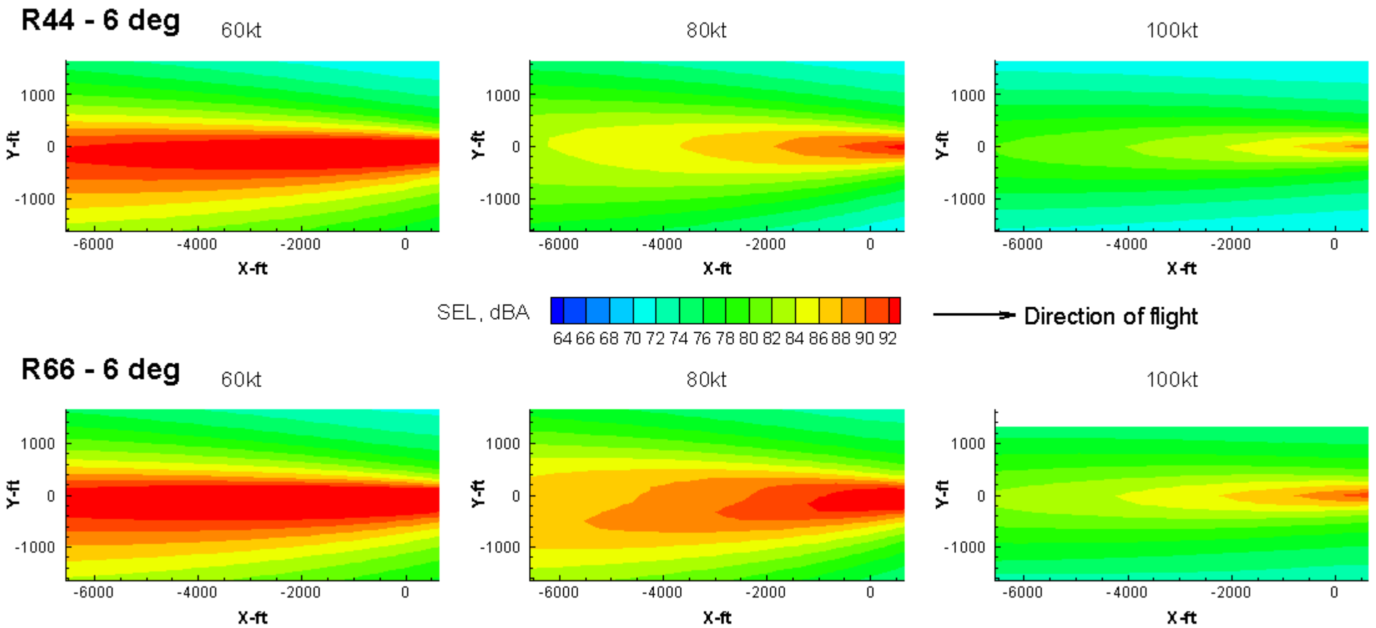


Figure 5 - Predicted SEL contours: 6 deg steady descent for different flight speeds.

Student Involvement

Mrunali Botre, graduate assistant currently working toward her Ph.D. at Penn State, led the noise prediction effort, including development of the flight test aircraft models (with the help of Dan Wachspress and the rest of the team). She performed a large number of noise predictions in a short period of time leading up to the flight test.

Plans for Next Period

The primary noise abatement procedures (or procedure element) for the flight test will be predicted with the noise prediction system. The aircraft models for the anticipated flight test aircraft will be developed.

References

None

Task #7: Compare Flight Test Noise Results with Predicted Results for the Same Aircraft for Validation and Assessment of the Noise Prediction System

The Pennsylvania State University

Objective(s)

The objective is to compare the flight test data with predicted noise levels to validate the effectiveness of the noise abatement procedures.

Research Approach

In this task, acoustic data from the flight test will compared with the noise predictions. This comparison will have two primary goals: 1) to assess and validate the effectiveness of the prediction system and to determine the significance of noise sources not currently modeled (i.e., engine noise); and 2) to evaluate and verify the effectiveness of noise abatement flight procedures. Although the flight test did not occur as early as anticipated, some preliminary flight test data was available for comparison – in the form of data extrapolated by Volpe (i.e., based on measured data). This allows comparison of predicted and interpolated/extrapolated flight test data for a few cases for the R-44 helicopter. It should be noted that the extrapolation is not thought to be accurate at distant sideline observers because the microphone array data used to form an acoustic data hemisphere for the Volpe extrapolation does not have any data near the rotor plane (zero elevation angle) because that would require very distant microphones on the ground.

Milestone(s)

Sound exposure levels for interpolated/extrapolated data and predictions have been compared for two flight conditions for the Robinson R-44 aircraft: 3 deg descent at 60 kt forward speed and 6 deg descent at 80 kt forward speed. In the flight test, the aircraft does not fly all the way down to a hover at a touchdown point and in the predictions, the simulation is stopped when aircraft reaches a minimum altitude.

Major Accomplishments

The Robinson R-44 helicopter was modeled and flown in several different flight conditions. In particular, two descent conditions, 3 deg descent at 60 kts and 6 deg descent at 80 kts were compared with flight test data. The predictions included both main rotor and tail rotor noise sources, including thickness noise, loading noise, and broadband noise. Engine noise was not modeled in the simulation. The ground reflection was included in the discrete frequency noise sources (thickness and loading), but the noise prediction system is not currently able to model ground reflection for broadband noise. The ground reflection model is for a perfectly hard ground, which is not completely representative of the flight test. Atmospheric attenuation of the noise was also modeled, but the specific relative humidity was not used in these preliminary comparisons. It should be noted that the flight test data interpolation/extrapolation is thought to be representative of the flight test over the region where microphones were placed on the ground (± 0.5 SELdBA), but once the flight test is complete, the data processing needs to be reviewed to ensure that the data is correct. Then refinements to the predictions can also be considered.

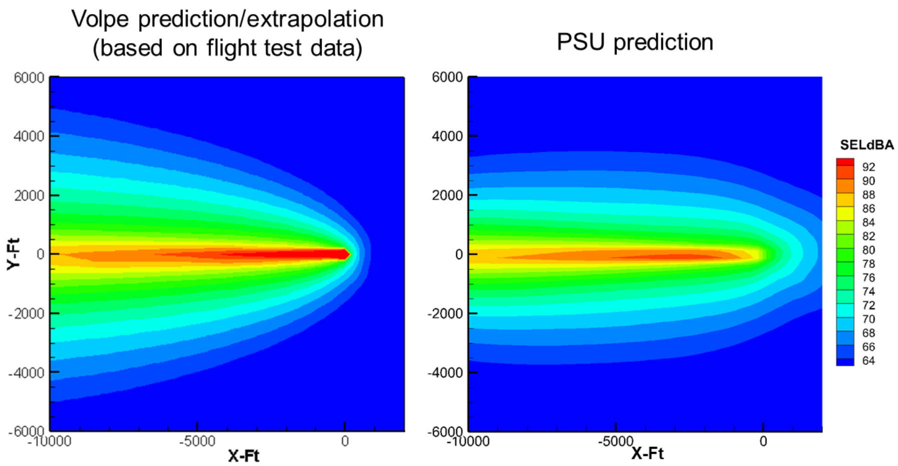


Figure 6 - Comparison of SEL flight test data (interpolation/extrapolation) with PSU prediction for Robinson R-44 helicopter in 3 deg descent at 60 kt.

In Fig. 6, the helicopter flight path is from left to right along the y axis. The target touchdown point is at x = 0 ft. The SEL values along the flightpath and within the first 1500 ft to each side are very similar to those of the flight test. For a more direct comparison, without the interpolation and extrapolation of the flight test data, comparison of the SELdBA values were made at three microphone locations at x = -1900 ft, along the flight path and 400 ft to either side. The measure data and predicted values are shown in Table 1. At this location, the SELdBA value is within 0.5 SELdBA along the flightpath and

3 SELdBA on each side. Further investigation is needed to understand if this agreement can be improved and if there is a reason why the levels at the sideline locations are too low (although not accounting for ground reflection of the broadband noise is likely to raise all the levels by a few SELdBA).

In Fig. 7, a similar comparison of flight test data and PSU prediction is made for the Robinson R-44 for a 6 deg descent at 80kt. There the prediction seems to predict higher SEL values farther away from the target touchdown point. It is not clear if there this has something to do with an actual difference in the flight path angle (intended vs. what was flow, or due winds), but this difference will need to be investigated further. Nonetheless, at x = - 1900 ft where the actual data is compared with the prediction, the SELdBA values are all within 2 SELdBA or less, as shown in Table 1.

Table 1. Comparison of measured and predicted SEL values at 3 locations; 6 deg descent at 80 kt.

Location	Measured #156 (SELdBA)	PSU prediction (SELdBA)
X= - 1900 ft, Y = 400 ft	82.4	80.0
X = -1900 ft, Y = 0 ft	87.4	88.8
X = -1900 ft, Y = -400 ft	83.3	81.1

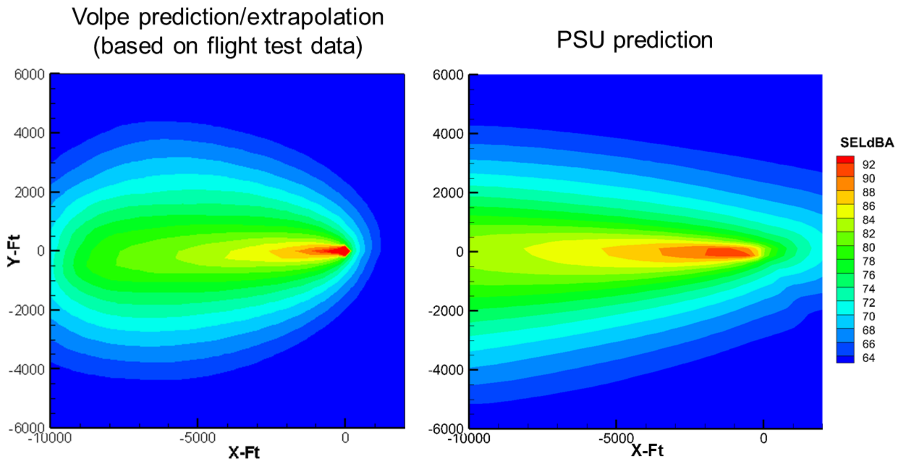


Figure 7 - Comparison of SEL flight test data (interpolation/extrapolation) with PSU prediction for Robinson R-44 helicopter in 6 deg descent at 80 kt.

Publications
None

Outreach Efforts
None

Awards
None

Student Involvement
Mrunali Botre, graduate assistant currently working toward her Ph.D. at Penn State, has performed the comparison of predicted results with flight test data.

Plans for Next Period
Many more flight conditions will be considered for the various aircraft flown in the FAA/NASA flight test. Investigation into the details of different comparisons can be made to understand more deeply the differences between the predictions and flight test data. In particular, it will be important to determine if the prediction is uniformly accurate for all aircraft classes or is better for some more than others. This information will be important in considering the noise abatement procedure predictions.

References
None

Task #8: Assist In Initial Evaluation of Flight Test Data to Determine Effectiveness of Noise Abatement Procedures
The Pennsylvania State University

Objective(s)
This task will support the flight test team to determine the effectiveness of the noise abatement procedures.

Research Approach
This task for this extended project is to provide assistance in the initial evaluation of the flight test data and 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 noise measurement. 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.).

Milestone(s)
The flight test has just been completed at two different sites. The PI attended the R-66 testing at Eglin AFB and was able to review some of that data as the test was taking place, but most of the data has not been received by Penn State yet.

Major Accomplishments
This task has just begun looking at the limited flight test data available. Based on the flight test, some work has begun on developing better ways to generate noise abatement procedures and an abstract for a paper has been prepared for the 2018 AHS Forum Acoustics Session. Once the data becomes available, which is expected in before the end of the calendar year 2017, and then more work can be done on this task.

Publications
None

Outreach Efforts
None

Awards
None

Student Involvement
Mrunali Botre, graduate assistant currently working toward her Ph.D. at Penn State, will assist in this effort.

Plans for Next Period

During the next period analysis of the flight test data for each of the 6 aircraft will be performed and analysis of the abatement procedures will begin. Comparisons with predicted results will also be used to guide the analysis.

References

None