Project 038 Rotorcraft Noise Abatement Procedures Development

The Pennsylvania State University/Continuum Dynamics, Inc.

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. 37
- Period of Performance: September 2017 to August 2018
- Task(s): (during this period)
  9. Analyze noise abatement procedures flown in flight test program
  10. Compare flight test noise results with predicted results
  11. Assist in the initial evaluation of flight test data to determine effectiveness of noise abatement procedures

Project Funding Level

FAA: $150,000; In-Kind Match: (Continuum Dynamics, Inc.: $150,000)

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.

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 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. Aircraft models were set up for the following aircraft: Bell 430, Sikorsky S-76C+ and S-76D, Bell 407 and 206L, Airbus EC130 and AS350, and Robinson R-66 and R44 aircraft. Predictions were made before the FAA/NASA noise abatement flight test to provide guidance for the flight test.

Objectives

The objective of the continuing project is to utilize computational and analytical modeling to develop noise abatement procedures for various helicopters for various phases of flight. The extension of the project also includes prediction to support analysis of previous flight test data and planning for a potential new noise abatement procedure flight test. Comparison of predictions with flight test data provides further validation of the noise prediction system and deeper understanding of the impact of noise abatement procedures on the noise directivity and amplitude. Comparisons have been made using various noise metrics (SEL, DNL, EPNL, etc.) along with the acoustic pressure time history and acoustic spectrum plots.

Task 9- Analyze Noise Abatement Procedures Flown in Flight Test Program.

The Pennsylvania State University

Objective(s)

The objective of this task is to analyze noise abatement procedures performed in the FAA/NASA noise abatement flight test program. Comparison of predictions and measured data will be used to assess the importance of each flight procedure in the flight test plan. This task will also continue to assess the fidelity of input data required for accurate noise predictions.

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 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. By comparing the predictions with flight test data of different aircraft, deficiencies of the noise predictions can be determined. The noise abatement procedures will be compared to standard procedures through comparison of several different acoustic metrics. Finally, the noise from the various flight procedures can be analyzed more thoroughly by investigating the physics in the noise prediction.

Milestone(s)

The milestones for this task include: 1) analysis of noise abatement procedures performed in the flight test for the flight test aircraft; 2) begin comparison of the predicted data and flight test data to evaluate; and 3) further validate the noise abatement procedures and the noise prediction system. This task will also provide any needed support for the pre- and post-flight test planning and analysis.

Major Accomplishments

Through comparing the noise predictions and flight test data (L_A vs. time plots and SEL contours), it was discovered that there was an underprediction in the noise when broadband noise was a major contributor to the SEL values, but in cases where the loading noise was comparable or higher than broadband noise the SEL underprediction was not as evident. This is underprediction was related to the fact that the broadband noise model in PSU-WOWPOP did not include ground reflection. All the other noise components were increased due to reflection from a hard ground.

Once this deficiency was understood, the PSU-WOPWOP code was modified to change the way in which the reflections were computed – to include broadband noise reflection. Two representative comparisons are shown in Figure 9.1 for a 80 kts, level flight case. On the left in the figure is the SEL contour data for the Robinson R66 and on the right is data for Bell 407. The top figure in each column is the measured data, the middle figures are the predicted SEL contours without the broadband noise reflection from the ground plane, and the bottom figures in each column are the SEL contours when the broadband noise is properly reflected by the ground plane. The particular cases shown here are chosen because for the Robinson R66 broadband noise is a dominant component of the SEL (higher than loading noise), but for the Bell 407, loading noise and broadband noise contribute approximately equally to the SEL values. Notice that the prediction with broadband noise reflection is significantly closer to the measured data for the Robinson R66 than for the Bell 407. This is due to the fact that the SEL values in the Bell 407 case are set largely by loading noise, but for the R66 the SEL values are set by broadband noise. The corrected broadband noise values for the Bell 407 are slightly overpredicted and the Robinson R66 was slightly underpredicted – but much less so than without broadband noise reflection.

Similar predictions and comparisons with measured data were made for all of the flight test aircraft and for several different flight conditions. The results are very similar to this. This example demonstrates how the comparisons can be used to determine that one component of the noise is more important relative to the others by examining the noise predictions. The example also shows that the predictions can be improved by understanding the differences between the prediction and the data. In this case the direct and reflected broadband noise signals were assumed to be incoherent, which is typically the case for random noise sources. Actually, for a microphone on a ground board – like was used in the experiments – the two broadband noise signals should be coherent and the broadband noise levels would be raised even higher. More work needs to be done to investigate if the broadband noise prediction model consistent overpredicts the broadband noise (and hence, may need to be modified).

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 to develop and implement the broadband noise reflection capability in PSU-WOPWOP.

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. In particular, the broadband noise prediction model will be more thoroughly investigated and validated.

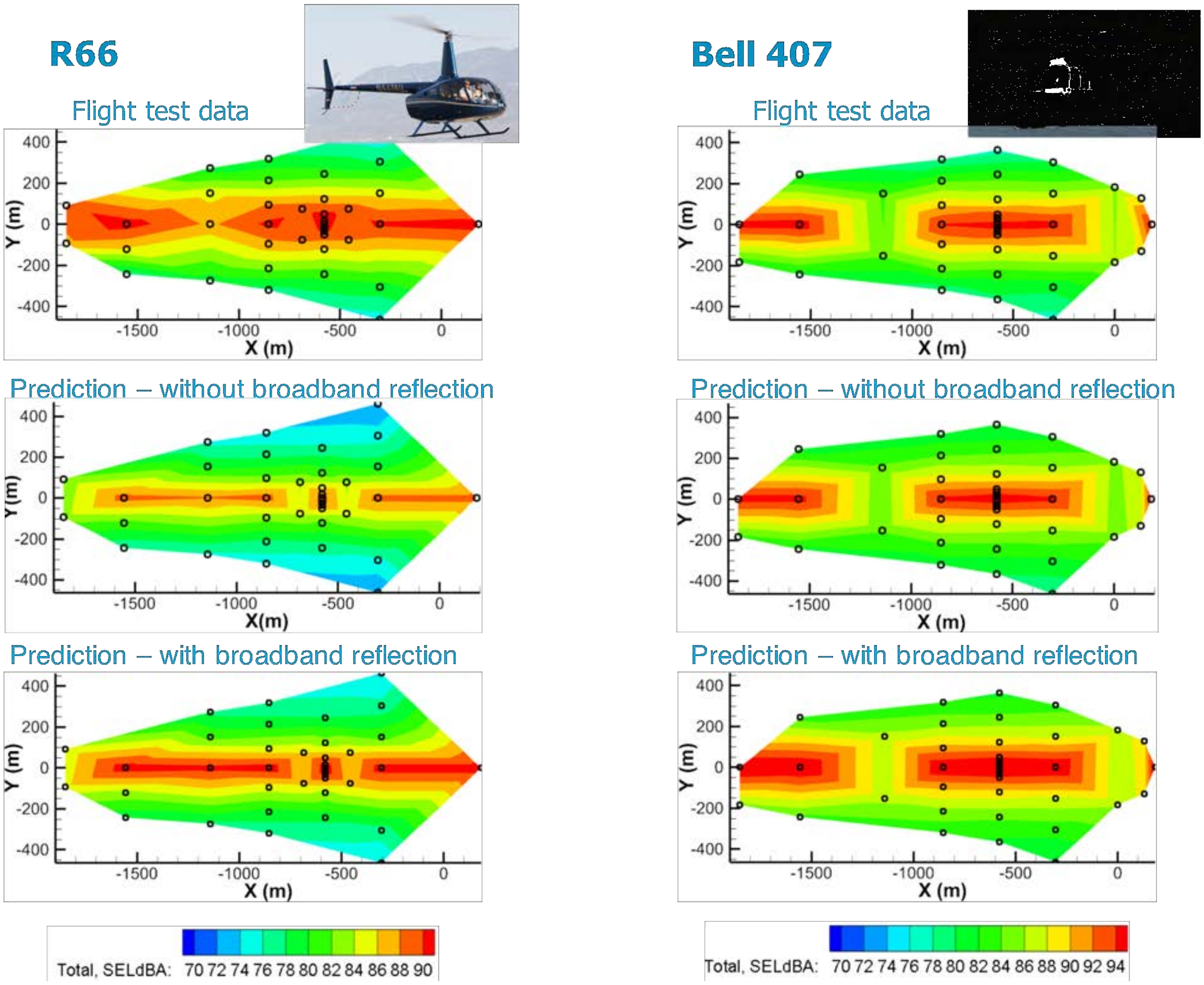

Figure 9.1. Comparison of measured data and predictions (with and without broadband noise ground reflection) for two aircraft; 80 kts, level flight.

Task 10- Compare Flight Test Noise Results with Predicted Results.

The Pennsylvania State University

Objective(s)

The objective of this task is to assess and validate the effectiveness of the prediction system, determine the significance of noise sources not currently modeled, and evaluate the effectiveness of noise abatement flight procedures performed in the FAA/NASA noise abatement flight test program.

Research Approach

For this effort, the noise prediction system developed in ASCENT Projects 6 and 38 will be used to perform the noise predictions and to process the acoustic pressure data from the FAA/NASA noise abatement flight test. 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. Validation of the predicted noise abatement is achieved by comparing the predicted noise abatement to that measured in the flight test – for a range of helicopters. Incidentally, it will also be important to determine if the limited information about the helicopters we have (i.e., incomplete data with some estimates to fill in the gaps) is sufficient to agree with the flight test data, or if more detailed data is needed for accurate prediction (and what that data is).

Milestone(s)

The milestones for this task are: 1) analysis and validation of the predicted noise through comparison with flight test data; and 2) consideration of more complete/complex procedures than were possible in the flight test by combining segments of the flight test into more comprehensive results

Major Accomplishments

Noise predictions were made to compare with the FAA/NASA noise abatement flight test. First the flight test will be described, and then representative examples of the noise comparison will be presented.

The FAA and NASA performed a series of noise abatement flight tests for six different helicopters during the fall of 2017. The six helicopters tested were chosen for comparison of key features and availability. The first two aircraft, the Robinson R44 and R66, are aircraft with similar weight, but the R44 has a piston engine and the R66 has turbine engine. Both the R44 and R66 have two bladed main rotors and tail rotors, but the main rotor blade chord and twist are different. The next two aircraft, the Bell 206L and 407, are similar aircraft, but different generations. The 206L has a two bladed main rotor, while the newer 407 has a four bladed main rotor and is slightly heavier. The final two aircraft, the Airbus AS350 and Airbus EC130 are also very similar aircraft, but the EC130 is newer. The Airbus helicopters have three bladed main rotors that operate in the clockwise direction (instead of counterclockwise when viewed from above – like the other aircraft). The EC130 also uses a different antitorque device (a fenestron) as compared to the two bladed main rotor of the AS350.

Sound exposure level (SEL) predictions are compared to flight test data in Figure 10.1 for the six test aircraft. The acoustic pressure measured at the test microphones was processed with the PSU-WOPWOP code so that all the post processing is identical for the predictions and measurements (eliminating any uncertainty due to differences in acoustic post processing). The black dots represent the microphone locations in the flight test. Predictions were made at the same microphone locations that were available for each test condition – and if any data was missing during the test at a microphone location, the prediction data for that microphone location was also excluded (which is why some of the black dots are apparently missing). The predictions shown in Figure 10.1 are for an 80 kts, 6 deg. descent case, which is a strong BVI condition. It is apparent in the figure that the peak SEL values and the contour shapes agree within about 2 dBA or less for all of the aircraft, except for the EC130. This agreement is very good. In fact, the subtle changes in noise directivity found when comparing one aircraft to another are also predicted quite well (i.e., compare the R44 vs the R66 or the Bell 206L and the Bell 407). Notice that a subtle skew in the contours to the right (positive y values) is observed for the aircraft with counter-clockwise main rotor rotation. This skew shifts to the left (negative y values) for the two Airbus helicopters, which have clockwise main rotor rotation. The fact that such subtle changes are predicted is very encouraging and a good validation of the noise prediction system. The EC130 prediction is lower than the measured data by 5 to 6 dB. This is likely because the Fenestron duct/shroud is not modeled in the prediction. (Other predictions for previous research has shown that the shroud is expected to increase the noise levels, which is consistent with underprediction here.) Also note that while the engine noise is different for the R44 and R66, little difference is seen in the measure noise levels due to the engine - and the predictions do not include engine noise.

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 for this task. She also post-processed the flight test data for the comparison.

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 differences between the predicted and measured noise. Comparisons will be made for more flight conditions that were performed in the flight test – especially time dependent maneuvers.

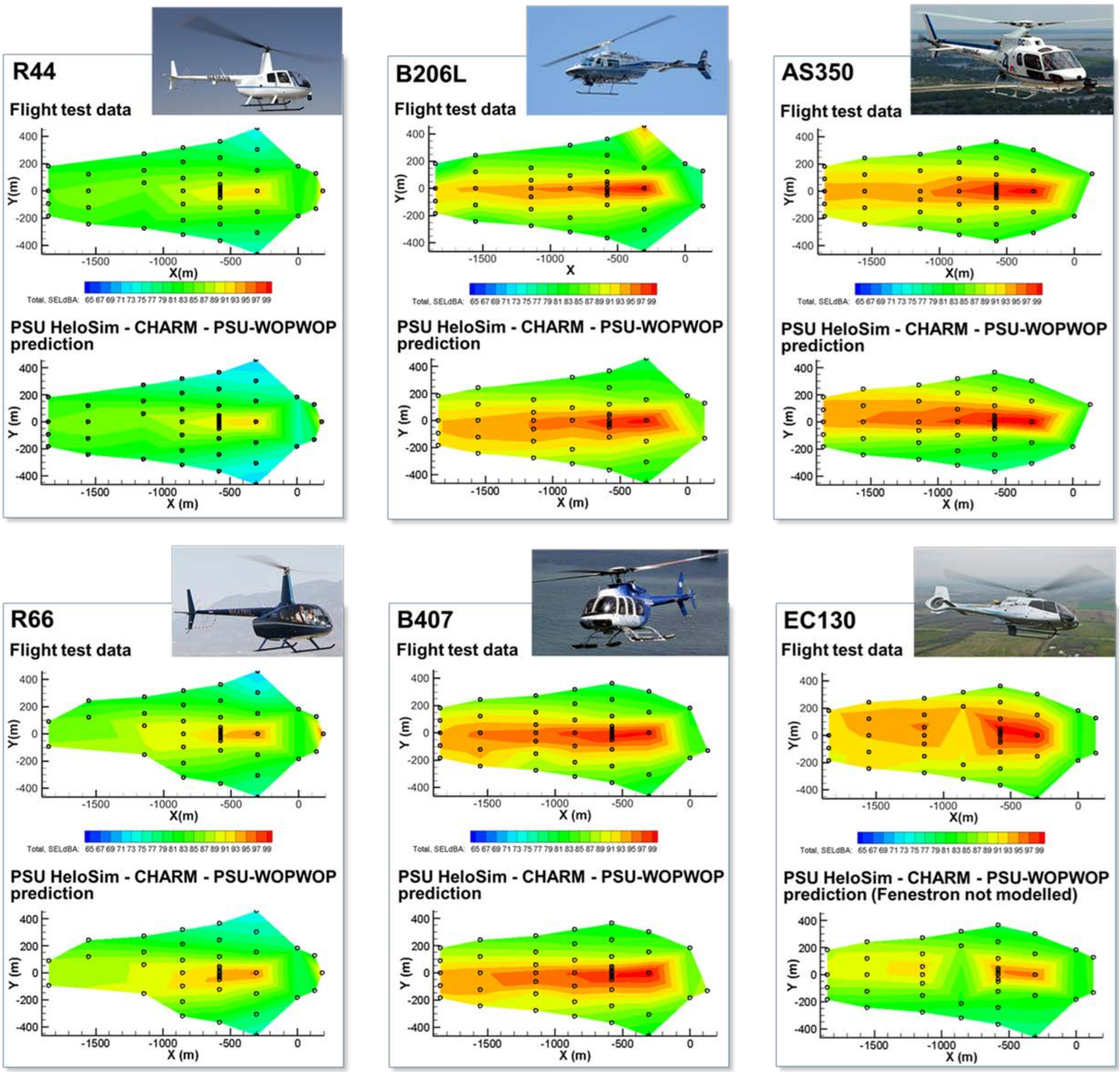

Figure 10.1 Comparison of measured and predicted Sound Exposure Level contours for 6 helicopters; 80 kts, 6 degree descent case (BVI noise condition). These comparisons are BEFORE broadband noise reflection was included.

Task 11- Assist in the Initial Evaluation of Flight Test Data to Determine Effectiveness of Noise Abatement Procedures.

The Pennsylvania State University

Objective(s)

The objective of this task is to provide assistance in the initial evaluation of the flight test data and the effectiveness of various noise abatement procedures.

Research Approach

In this task predictions are made to provide guidance for planning and executing the flight test and then evaluating the noise abatement procedures. This involves evaluation of the flight test data and examination and comparison of measured and predicted results to help explain any significant unexpected 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.). Prediction of noise hemispheres in advance can also be used to develop the noise abatement procedures in that are proposed and test.

Milestone(s)

Provide a more thorough comparison of flight test noise data and predicted noise. Focus analysis on the effectiveness of various noise abatement procedures and interrogate the elements of the predicted airloads, flight dynamics, and noise to understand more completely the reason for noise reduction (or lack of noise reduction) during flight test procedures.

Major Accomplishments

Noise hemispheres were computed for each of the aircraft and all of the flight procedures planned in the FAA/NASA noise abatement flight test prior to the test. These hemispheres were provided to Volpe before the test so that they could evaluate potential noise abatement procedures. SEL contours on the ground plan were also computed prior to the flight test. Figure 11.1 shows an example of the ground contour data provided to Volpe and the flight test team. Then during the flight test, the preliminary data was compared to the PSU predictions. One example of this preliminary data comparison is shown in Table 11.1. This information was used in the noise abatement part of the flight test, which used predictions and prior days test data to develop some of the procedures during the flight test.

Noise predictions for the Sikorsky S-76C+ helicopter were made for a wide range of steady flight conditions for Juliet Page at Volpe to support a test/event where she worked with operators and pilots. The noise hemispheres were used as input for fly neighborly guidance, which was given to the pilots as they carried out typical operations flying to Long Island.

Table 11.1 Preliminary during the flight test

R-44 Day 227 Run #164 3deg 60 knots

Mic # **	Measured #164	Ideal Traj Std Meteo	Actual Traj Std Meteo	Ideal Traj Actual Meto*	Actual Traj Actual Meteo*
19	95.50	95.8	95.6	95.8	95.6
23	83.79	83.3	83.3	83.1	83.2
15	82.90	81.8	81.9	81.7	81.8

* No %RH or Press available from Meteo equipment yet.
** Actual Mics used to build the sphere are TBD.
All use Sphere #164; Ideal Trajectory vs. Actual Trajectory
Standard Meteo (US 76, 70% RH) vs. Actual Meteo (78 F, 80 %RH)
* Updated PSU runs (proper height of flight path, 9/18/2017)

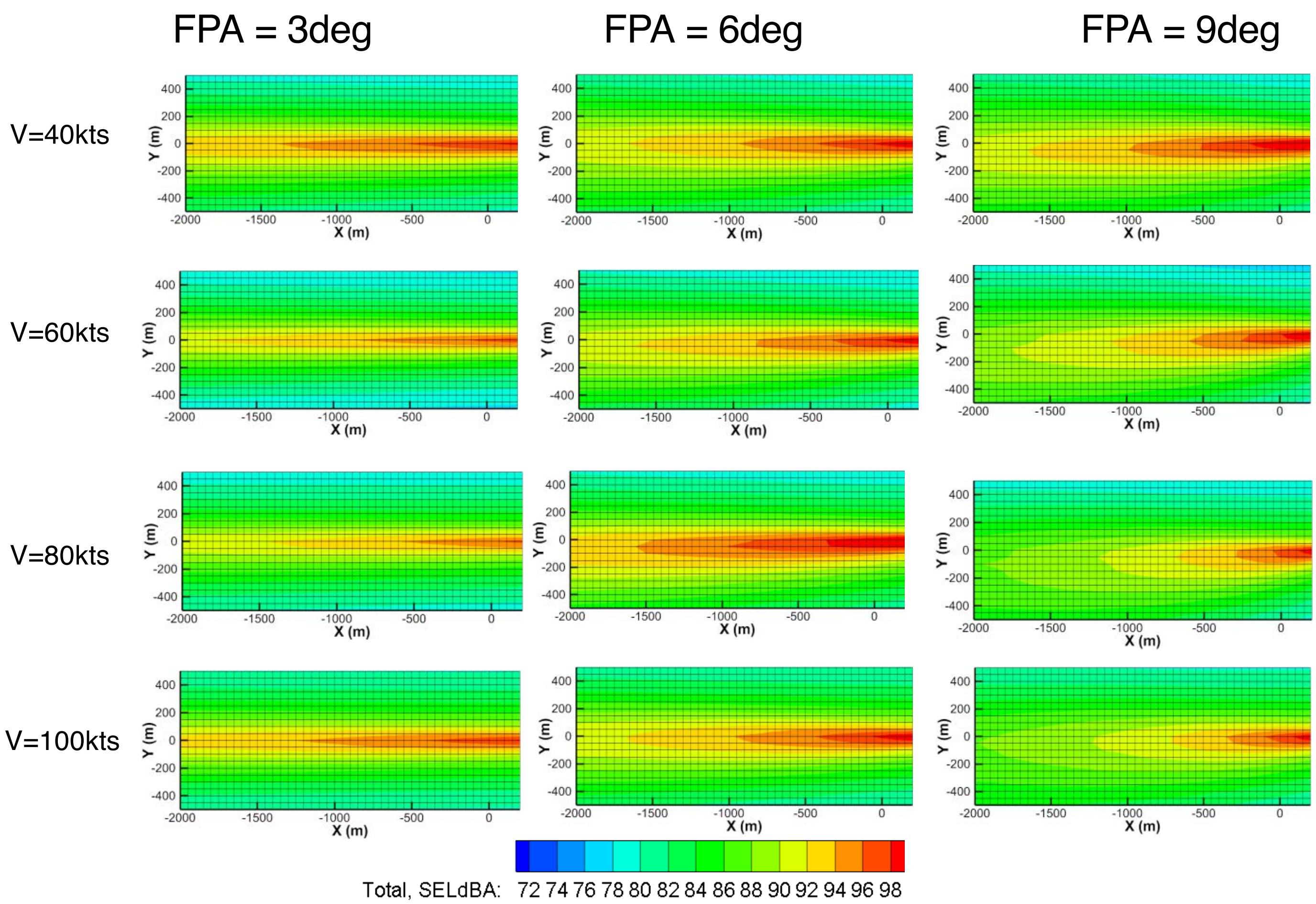

Figure 11.1. Sound exposure level ground contours for the Bell 407 aircraft. Note, when the aircraft is at $x = 0$, it is 200 ft AGL. (FPA is flight path angle)

Table 11.2 shows some key characteristics of the S-76C+ aircraft and Table 11.3 shows the matrix of flight test data provided to Volpe.

Table 11.2 Key characteristics of S-76C+ and S-76D aircraft.

	S76C+	S76D
Power (hP)	1844	2244
Weight (lb)(90 % of max takeoff weight)	10530	10688
Number of blades	4	4
Blade radius	22	22
Vtip	220	220

Table 11.3 Flight condition matrix for noise hemispheres provided to Volpe for S-76C+.

Speed	FPA								
	0.0	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12
75	X	X	X	X	X	X	X	X	X
90	X	X	X	X	X	X	X		
105	X	X	X	X	X				
120	X	X	X						
135	X								
150	X								

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 with Volpe to provide the needed predictions and any explanation of the results.

Plans for Next Period
We will support efforts by Volpe, FAA, and NASA to evaluate the flight test data and provide more understanding of the noise abatement procedures. Efforts will also extend this understand to develop new procedures and use the validated noise prediction system to assess the effectiveness of the new procedures.