



# Project 040 Quantifying Uncertainties in Predicting Aircraft Noise in Real-world Scenarios

# Pennsylvania State University Purdue University

# **Project Lead Investigator**

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# **University Participants**

## Pennsylvania State University

- P.I.: Victor W. Sparrow, United Technologies Corporation Professor of Acoustics
- Co-PI: Philip J. Morris, Boeing/A.D. Welliver Professor of Aerospace Engineering
- FAA Award Number: 13-C-AJFE-PSU, amendment 023.
- Period of Performance: June 28, 2016 to December 31, 2017.
- Task(s):
  - 1. Assess meteorological and acoustic measurement data sets for noise propagation model validation
  - 2. Assess influence of aircraft noise sources on uncertainty in noise modeling
  - 3. Assess overall modeling uncertainty for aircraft noise prediction
  - 4. Assess usefulness of SILENCE-R dataset

#### **Purdue University**

- P.I.(s): Kai Ming Li, Professor of Mechanical Engineering
- FAA Award Number: 13-C-AJFE-PU, amendment 14
- Period of Performance: August 1, 2016 December 31, 2017
  - 5. Assess DISCOVER-AQ Acoustics data for model validation
    - 6. Assess the uncertainty due to the ground effect and source directivity for en-route aircraft

# **Project Funding Level**

FAA funding to Penn State in 2016-2017 is \$128K. FAA funding to Purdue in 2016-2017 is \$90K.

In-kind cost sharing from Vancouver Airport Authority was received for ASCENT Project 5, and additional cost sharing is likely in Project 40. The point of contact for this cost sharing is Mark Cheng, mark\_cheng@yvr.ca. Project support is in the form of aircraft noise and trajectory data, meteorology data, and consulting on those datasets.

Additional cost sharing from ANOTEC Engineering, Motril, Spain is likely in the future for ASCENT Project 40 regarding the BANOERAC data set. The point of contact for this cost sharing is Nico van Oosten, <u>nico@anotecengineering.com</u>.

Further cost sharing from National Aviation University of Ukraine (and Airbus) is possible in the future for ASCENT Project 40 regarding the SILENCE-R data set. The point of contact for this cost sharing is Sasha Zaporozhets, zap@nau.edu.ua.





# **Investigation Team**

#### Penn State

Victor W. Sparrow (PI) Philip J. Morris (Co-PI) Graduate Research Assist

Graduate Research Assistant Manasi Biwalkar (measurement data sets for noise propagation model validation) Graduate Research Assistant Harshal Patankar (uncertainty modeling for aircraft noise propagation)

# Purdue

Kai Ming Li (PI)

Graduate Research Assistant Yiming Wang (moving source investigation)

# **Project Overview**

To assess the uncertainties in aircraft noise prediction, an integrated approach will be used to understand uncertainties in the aircraft state and resulting noise levels and directivity (source), the atmospheric and meteorological conditions (propagation), and ground impedance and terrain model (receiver). This approach will include all predominant uncertainties between source and receiver. The primary focus in the current year is in validating the propagation uncertainty. In addition, a new collaborative initiative with National Aviation University of Ukraine is underway.

Reporting will be provided for tasks 1-4 of Penn State and tasks 5-6 of Purdue collectively instead of separately.

# Task #1: Assess Meteorological and Acoustic Measurement Data Sets for Noise Propagation Model Validation

# Task #2: Assess Influence of Aircraft Noise Sources on Uncertainty in Noise Modeling

# Task #3: Assess Overall Modeling Uncertainty for Aircraft Noise Prediction"

# Task #4: Assess Usefulness of SILENCE-R Dataset

The Pennsylvania State University

# **Objective(s)**

This research seeks to validate current FAA/Volpe noise modeling capabilities by comparing with measurement dataand to quantify uncertainties of both model prediction and measurement in trying to predict aircraft noise (or patterns or changes) in real world situations, particularly when meteorological conditions over various different time periods may affect prediction output.

The research will focus on four areas: (1) review and analyze available field measurement data for patterns that are influenced by the (change of) meteorological conditions; (2) identify sets of field data for specific scenarios that contain proper parameters/quality input values to validate the enhanced modeling capabilities; (3) use the enhanced modeling capabilities to understand the patterns identified in the field measurement data that are influenced by the (change of) meteorological conditions and (4) quantify uncertainties in predicting aircraft noise in real-world situations. In addition, a new collaborative initiative on aircraft noise propagation model validation will be begin with National Aviation University, Kiev, Ukraine.



# Research Approach

#### Introduction

It is a challenging task to include the influences of atmospheric conditions and ground properties for the prediction of aircraft noise. However, the accuracy of these inputs are critical for the predictions. In the past three years, the research performed by Penn State and Purdue through FAA ASCENT Center research grants has informed FAA regarding the limitations of existing noise tools and helped advance the state-of-the-art in aircraft noise modeling. Appropriate models were enhanced and developed to account for the effects of meteorological conditions, atmospheric absorption, and the Doppler effect due to source motions on the propagation of aircraft noise. Field data obtained from Discover/AQ<sup>1</sup> are currently used to validate these numerical models. At the same time, Penn State and Purdue sought support from Vancouver Airport Authority<sup>2</sup>, which has kept a comprehensive set of measured terminal area noise data around the Vancouver Airport. There are plans to use this database, and other databases, to improve the accuracy of the AEDT and quantify the sensitivities in the predicted noise levels due to the variation in atmospheric conditions and ground properties. It is possible that additional data available at National Aviation University of Ukraine may be helpful for the work. In Project 40, Penn State and Purdue will continue their efforts and extend them to quantify noise prediction uncertainties, now beginning to include the effects of the noise source.

In the first few months of Project 40, documented in last year's annual report, a survey of available datasets was provided. These datasets have not changed, so the focus here will be on the dataset that was explored in detail at Penn State during the period October 1, 2016 to September 30, 2017. This is the aircraft noise and meteorology data made available by the Vancouver (Canada) airport authority. That airport was chosen because of its availability and similarity to large U.S. airports in both number of operations and aircraft fleet mix. Vancouver had available radar data, noise monitor data, and meteorology. Penn State would like to particularly thank Mark Cheng and Rachel Min from Vancouver Airport Authority for their help with and suggestions about these data.

#### Thesis of Biwalkar

The work described in the next sections is summarized from the Masters of Science Thesis by Ms. Manasi Biwalkar.<sup>1</sup> The thesis was completed in November 2017, just after the completion of the project period. That thesis will be available online in early 2018 from the website: <u>https://etda.libraries.psu.edu</u>. It is suggested to search by author using the keyword "Biwalkar".

#### NORD2000 noise model

In addition to a simplified in-house model accounting only for spherical spreading and atmospheric absorption, the project team elected to use the NORD2000 sound propagation model as it can also include the effects of atmospheric refraction in the case of simplified sound speed profiles. Including atmospheric refraction is important in the propagation of aircraft noise as the aircraft noise can be bent toward or away from the ground due to the effects of both temperature and wind variations. NORD2000 uses the effective sound speed approximation, i.e., assumes only the horizontal wind component is additive or subtractive with the temperature-dependent sound speed. The program also assumes the effective sound speed is a log-linear function of height (as an approximation) so NORD2000 uses analytical curved. This type of modeling seems sufficient for a comparison with the Vancouver Airport Authority noise data, as it provides the simplest model to include refraction in a robust and consistent way. The NORD2000 Matlab model utilized was provided by Delta (a company in Denmark), and the project team appreciates the use of their code.

#### Data processing

The different data types needed to be processed in various ways to lead to comparisons between noise monitor terminal (NMT) measured data and predicted noise levels. First, the radar data from individual flight events at Vancouver airport needed to be analyzed and processed. It took a substantial amount of time for the project team to decipher the radar data and turn it into useable flight trajectory information to ascertain the position of an individual aircraft. Once accomplished, then the processed flight tracks needed to be sorted with respect to the positions of the NMTs, see Fig. 1. Criteria were established to ascertain if NMT acoustic events corresponded to nearby aircraft. The NMTs react to all environmental sounds, so sorting which events were likely due to aviation activity was important. Once this was established, it made sense to only use aircraft flight tracks that corresponded to recordings at multiple NMTs. As an example three arrival flight tracks where multiple NMTs were involved is shown in Fig. 2 for one of the runways.



#### Calculation methodology

An initial attempt to model each aircraft as a moving omnidirectional source with a fixed sound power level eventually did not agree very well with the NMT recorded events. Ultimately what worked better was to use the databases available in the Aviation Environmental Design Tool (AEDT), and carry out similar calculations as are performed in that program.<sup>3</sup> The details of this processing are described in detail in the thesis of Biwalkar.<sup>1</sup> In summary, it was necessary to know the aircraft type for each event, use the corresponding information for that type of aircraft in AEDT's Fleet Database, particularly both its noise power distance (NPD) information and its spectral class. These adjustments were made identically, to the best of the Project team's ability, to the way they are done in AEDT. Numerous suggestions from E. Boeker of the Volpe National Transportation Systems Center and H. He of the FAA were very helpful in correcting the levels of the spectral information for the aircraft source noise. This tremendously improved the comparisons between the measured and predicted noise levels. Another thing that was found to improve the agreement was to include the effects of refraction. To do this, atmospheric conditions needed to be taken into account. In this investigation weather data from both Environment Canada and the Climate Forecast Systems Reanalysis (CFSR) were utilized. Details on the processing and use of that information are available in Biwalkar's thesis. The temperature and horizontal wind information, corresponding to the day or evening of the aircraft flights, were used as inputs to develop the sound speed profiles that were used in the NORD2000 calculations.

#### **Overall results**

In summary it was determined that including both the atmospheric data and corresponding curved-ray modeling of NORD2000 gave better agreement for these aircraft single events, compared to simply using a straight-ray model. As mentioned previously, using the correct spectrum for each individual aircraft was absolutely required, as a minimum. These results are displayed in Fig. 3. One further observation is that the predictions for takeoffs were not as good as for landings. Not having additional data to assume otherwise, the presumption was that each takeoff would be at maximum thrust. This was very likely not the case for most of the aircraft departure events, but it was assumed to provide consistency across the analysis. Additional details are available in Biwalkar's thesis.<sup>1</sup> A short overview of these analyses and results was presented at the Acoustics '17 meeting in Boston, MA, USA in June 2017.<sup>5</sup>





Figure 1: Overview of Vancouver International Airport and the surrounding noise monitors.





**Figure 2:** Three arrival flight tracks that activated multiple noise monitors. The red asterisk indicates the position of the Vancouver airport's map reference coordinate used for the radar.

Input spectrum	Input atmosphere	NMT Vs. prediction
Overall SWL Back-calculated from NMT SEL	Const Temp & No wind = Homogeneous $c(z)$	Poor agreement
1/3 <sup>rd</sup> octave SPL Correct aircraft i/p spectrum from AEDT database	Const Temp & No wind = Homogeneous $c(z)$	Satisfactory agreement
	Temp gradient & Wind data = Log-Lin $c(z)$	Overall Better Agreement

**Figure 3:** Overall results for single events at Vancouver International Airport. SWL is an abbreviation for sound power level, and SPL is an abbreviation for sound pressure level. NMT SEL stands for noise monitor terminal sound exposure level. *c(z)* is the speed of sound profile as a function of height *z*. The best overall agreement occurs when both the correct aircraft spectrum and the temperature and wind information are incorporated in the predictions.





#### Uncertainty in aircraft noise source models

To assess the overall uncertainty in an aircraft noise prediction it is necessary to understand the uncertainties in the aircraft noise sources. This is an additional task in progress at Penn State under the direction of Boeing/Welliver Professor Philip Morris. During the reporting period, two sources of aircraft noise source uncertainty were considered. The first examined issues with the prediction of fan noise and identified the effects of inaccuracies in the specification of engine conditions on the noise source predictions. Secondly, the issues related to slat noise, which is an important component of airframe noise on approach were examined. The various parameters and dimensions that are important for noise prediction of the component were identified and the relative effect of errors in them were examined.

#### Silence( R ) dataset and international cooperation

This year was very productive in beginning a discussion with National Aviation University (NAU) of Ukraine, located in Kiev, Ukraine. Dr. Sasha Zaporozhets of NAU attended both the Fall 2016 and Spring 2017 ASCENT Advisory Committee Meetings in the USA, and Dr. Victor Sparrow of Penn State visited NAU in July 2017. Each of these meetings was productive regarding a number of technical discussions related to the prediction of aircraft noise. Some of the discussions focused on the SILENCE( R ) dataset, from a large aircraft noise reduction program funded by the European commission.<sup>8</sup> Particularly the part of the dataset which focused on the certification of Airbus aircraft, the data seems potentially very useful for validation of FAA and university noise tools. Hence, discussions will continue in the next project year to see if data sharing agreements can be established between Airbus/Xnoise and both Penn State and Purdue.

## Milestone(s)

Completed initial analysis of Vancouver International Airport data set.

#### **Major Accomplishments**

Comparisons between Vancouver airport data and predictions confirm the importance of including correct aircraft noise source spectra as well as accounting for atmospheric effects such as wind and temperature gradients. Hence, it is confirmed that including atmospheric refraction effects is a required element to improve aircraft noise prediction. For the Vancouver airport data set, the research team has met the objectives of the project to analyze field data and to determine those aspects important for validating existing modeling capabilities. The both the aircraft noise source spectra and the time-dependent meteorological conditions are important.

## **Publications**

M.S. thesis of Manasi Biwalkar. Acoustics '17 abstract.

## **Outreach Efforts**

None

#### <u>Awards</u>

None.

## **Student Involvement**

Graduate Research Assistant Manasi Biwalkar has been the primary person working on this task. She will receive her M.S. in Acoustics degree from Penn State in December 2017. A new Graduate Research Assistant Harshal Patankar started working on the project in August 2017.

#### **Plans for Next Period**

Now that the utility and limitations of the Vancouver Airport Authority's data has been assessed, the project team will focus on some of the newer approaches for including uncertainty in the propagation of aircraft noise. Graduate Research Assistant Harshal Patankar already replicated a portion of the results for ground-to-ground sound propagation presented by Wilson, et al.<sup>6</sup> This approach should yield important tools that may be applicable for aircraft noise prediction. At the same time an additional dataset will be considered, BANOERAC,<sup>7</sup> which may be useful in further assessment of aircraft



noise models. Further, a complementary effort will generate a realistic noise source model in the form of a set of time dependent sound source spheres. These will serve as the starting point for the subsequent prediction of propagation effects on the uncertainty of the predicted noise at the ground.

### **References**

- <sup>1</sup>M. Biwalkar, "Single event comparisons of predicted and measured sound at Vancouver International Airport," M.S. Thesis (Graduate Program in Acoustics, Pennsylvania State University, University Park, PA, 2017).
- <sup>2</sup> M. Cheng, et al., Vancouver Airport Authority [Private Communication] (2016).
- <sup>3</sup> M. Ahearn, *et al.*, "Aviation environmental design tool (AEDT): Technical manual, Version 2c," (U.S. Dept. of Transportation Volpe National Transportation Systems Center, 2016).
- <sup>4</sup>B. Plovsing, "NORD2000: Comprehensive Outdoor Sound Propagation Model, Part 2: Propagation in an atmosphere with refraction," (Delta, Denmark, 2006).
- <sup>5</sup>M. Biwalkar and V. Sparrow, "Quantifying uncertainties in predicting aircraft noise in real-world situations," J. Acoust. Soc. Am. 141 (5, Pt. 2) 3878 (2017). This is an abstract in the program of the Acoustics '17 meeting, Boston, MA, USA.
- <sup>6</sup>D. K. Wilson, C. L. Pettit, V. E. Ostashev, and S. N Vecherin, "Description and quantification of uncertainty in outdoor sound propagation calculations," J. Acoust. Soc. Am. **136**(3) 1013-1028 (2014).

<sup>7</sup> BANOERAC Project final report, Document ID PA074-5-0, ANOTEC Consulting S.L. (2009).

<sup>8</sup> SILENCE( R ) dataset. See https://www.xnoise.eu/index.php?id=85.

# Task #5: Assess DISCOVER-AQ Acoustics Data for Model Validation Task #6: Assess the Uncertainty Due to the Ground Effect and Source Directivity for En-Route Aircraft

**Purdue University** 

# **Research Approach**

#### Background

There are significant impacts of atmospheric conditions and ground properties on accurate predictions of aircraft noise. It is well known that the accuracy of these inputs are critical for the predictions. The research performed by Penn State and Purdue through FAA ASCENT Center research grants has informed FAA regarding the limitations of existing noise tools and helped advance the state-of-the-art in aircraft noise modeling. Appropriate models were enhanced and developed to account for the effects of meteorological conditions, atmospheric absorption, and the Doppler effect due to source motions on the propagation of aircraft noise.

The Purdue project team has identified the key drivers for quantifying uncertainties in predicting aircraft noise. To assess these uncertainties, an integrated approach will be used to understand uncertainties in (a) the aircraft state and resulting noise levels and directivity (source), (b) the atmospheric and meteorological conditions (propagation), and, (c) the ground impedance and terrain model (receiver). This integrated approach will include all predominant uncertainties between the source and receiver. One of the main motivations of the current project is to guide these recent advancements for reaching a sufficient Research Readiness Level (RRL) that leads to a possible implementation in AEDT in near future.

#### Results

In the recent years, the project team has obtained measurement data from NASA/VOLPE,<sup>1</sup> and Vancouver Airport Authority.<sup>2</sup> Two more datasets: BANOERAC<sup>3</sup> and SILENCE(R)<sup>4</sup> will become available this year. These 4 datasets will form a vital part in the assessment of uncertainties in predicting aircraft noise at various atmospheric, typographic and ground conditions.

For the Purdue effort, there are 4 tasks listed below:

A. Assess experimental datasets for use in validating noise tools (propagation).





- C. Assess the impacts of geometric locations of source and receiver, the effective surface impedance and the ground topography on the accurate prediction of aircraft noise (receiver).
- D. Assess the overall uncertainty in the noise prediction (propagation+source+receiver)

Three of these 4 tasks (A, B and D) are comparable to the effort of the PSU team. Nevertheless, the Purdue team has been tasked to investigate the influence of ground effect on predicting aircraft noise (Task C). On the other hand, the PSU team has been invited to maintain an international link with National Aviation University of Ukraine for the possible use of SILENCE(R) dataset and other collaborations. Through PSU's effort, the Purdue team will be able to interact with the Ukraine team and access the relevant dataset. The achievements for each of the 4 tasks will be explained in the following sections.

#### Task A

In the past year, the Purdue team has concentrated on the analysis of the DISCOVER-AQ dataset. The full details of the scope of the DISCOVER-AQ acoustic research effort and its measured results can be found in Ref. 1. After an initial study, the Purdue team has identified that the maneuvers of Lockheed P-3B Orion (see Figure 4) contains the most relevant acoustic datasets for detail investigations. Lockheed P-3B Orion is a four-engine turboprop aircraft with a maximum gross take-off weight of 135,000 lbs. The propeller blades were manufactured by Hamilton Standard. Each of the propeller blades was driven by an Allison T56-A-14 turboprop engine delivering 4,100 shp.



Figure 4: Lockheed P-3B Orion 4-engine turboprop aircraft used in the experiment

A typical source spectrum of the noise radiated from Lockheed P-3B Orion is shown in Figure 5. For this type of propellerdriven aircraft, it is apparent that the low-frequency tonal components dominate the sound fields which is quite different from the noise spectrum for a typical jet-engine aircraft. Noise radiated from turboprop engines can travel a longer distance to the ground because the rate of atmospheric absorption of sound is typically much smaller in the low frequency regime. For ground-based receivers, it is most likely that en-route noise from turboprop aircraft is more noticeable than a jet-driven aircraft.





Figure 5: Typical Spectrum of a Lockheed P-3B Orion turboprop aircraft

From the DISCOVER-AQ dataset, event 34 was chosen to illustrate the flight trajectory of the test aircraft (see Fig. 6) and the measured time histories of A-weighted noise levels at different octave-band frequencies from 63 to 500 Hz (see Fig. 7). In Fig.7, the aircraft locations at the beginning and end points are marked. In addition, the aircraft locations at the peaks of the measured sound pressure levels (SPL) are also shown for frequencies at 63 and 500 Hz only.







Figure 7: Measured time-histories of the A-weighted SPL for different frequencies



For clarity and completeness, an aerial view (taken from the goggle map) of the test site and photographs of microphone locations are shown in Fig. 8. In the aerial view, the flight paths of Event 33 and 34 are shown with the test aircraft moving in 5 downward spiral loops and the average diameter of about 4 km.

During the test flights, temperature and wind profiles were recorded. These profiles have been presented in Fig. 9 in terms of sound speed and wind speed profiles. A close examination of Fig. 9 suggests that the sound speed gradient





was about 4 m/s per 1 km and the largest wind speed gradient was about 8 m/s per 1 km. Thus, the highest effective sound speed gradient should not be more than 12 m/s per 1 km. Given this weak effective sound speed gradient, the atmosphere may be treated as homogeneous throughout the measurement period for Lockheed P-3B Orion.







Task B



Fig. 10: Comparison of measured and predicted time histories of A-weighted noise level of the test aircraft at the frequency 63 Hz.

Measured results from DISCOVER-AQ dataset indicate that the test aircraft (noise source) has a strong directivity pattern. This is illustrated in the time history measurements at different frequencies shown in Fig. 7. Because of the effect of the source directivity, the measured peak levels for different frequencies occurred at different times. A simple assumption of an omni-directional moving source will not be adequate to model the pass-by noise levels of the test aircraft especially for the frequency below 125 Hz. Currently, the Purdue team has developed an empirical model (based on a spherical harmonic function) to estimate the directivity patterns of the test aircraft. Essentially, the measured noise levels from Event 33 were used to deduce the directivity patterns of the test aircraft. This directivity pattern was then applied to predict the time histories of other events. Figure 10 shows a comparison of the predicted and measured time histories of Event 135 for the source frequency at 63 Hz. Generally speaking, the agreement between the measured results and predictions are reasonably well.

#### Task C

In the past year, the Purdue team has examined theoretically the uncertainties in the prediction of aircraft noise due to the ground effect. In essence, the ground effect of the predicted/measured sound fields is caused by the interference of the direct and reflected waves arriving at the receivers. The intrinsic variability in the predictions depends on a host of factors including the source/receiver geometry, source frequency, atmospheric turbulence, acoustic characteristics of the ground surface, and, terrain profile. Figure 11 shows a comparison of the predicted attenuation due to the ground effects for source frequencies of 250 and 500 Hz. The prediction according to the AEDT model is shown in 'gold' solid line. The predicted attenuation at different sideline distances are shown for snow-covered (blue) and grass-covered (red) grounds with frequencies at 250 Hz (solid line) and 500 Hz (dashed line). The Delaney and Bazley (D-B) model<sup>5</sup> is used to predict the effective impedance of the ground surface in Fig. 11. We can see that the discrepancy in predicting the attenuation can be as high as 6 dB between the AEDT and (D-B) models.

In fact, the D-B model has been used in the predictions showed in Fig.10 that lead to a better agreement between the measured data and numerical prediction except for the region towards the end of the event. This apparent disagreement may be explained by the fact that the test aircraft was very close to the ground during this period of measurements. In this situation, the effects of ground impedance, shielding by obstacles and ground typography may play an important role that introduce uncertainties in predicting the aircraft noise. The development of a more accurate model to account for these uncertainties will be explored in our next stage of study.





Fig. 11: Comparison of AEDT ground model with a more precise ground impedance model

#### Task D

The Purdue team has conducted an initial analysis on the overall uncertainties on the DISCOVER-AQ data set. Event 33 was chosen for illustration here. Figure 12 shows the improvement on the prediction of the A-weighted sound pressure level (SPL). The agreement between the field data and our current prediction scheme using a better directivity pattern (gold) is much better than the prediction using the monopole model (red), especially, at the location of the first peak.



Fig. 12: Comparison of predictions and field data for A-weighted SPL for event 33



Figure 13 shows that the errors of the prediction with directivity model decreased obviously, however, lager error still exists when the distance is short and elevation angle is small. Future work should focus on the analysis of ground effects since most measurement sites are located not far away from forest and many aircraft paths are above water-covered region.





# Milestone(s)

Several Discover-AQ acoustic events were reviewed and analyzed. The current models, which have been used in AEDT, have been used to compare with the measured data. Particularly, the uncertainty due to the ground effect for an en-route aircraft has been assessed. An empirical model for evaluating the source directivity of a propeller-driven aircraft (P3-Orion) has been developed and used to assess a fly-by aircraft.

## **Major Accomplishments**

In coordination with Penn State University, the Purdue research team has focused on the analysis of the experimental data retrieved from the Discover-AQ dataset. The quality of field data, which offers real world situations, allows the uncertainties of both model prediction and measurement in predicting aircraft noise to be identified and quantified. It has been shown that the source directivity has played an important role in predicting aircraft noise. The uncertainty in the ground vegetation can lead to significant variations in the measured aircraft noise levels. Enhanced model capabilities have been used to investigate the difference in the noise levels due to an approaching and a receding aircraft.

## **Publications**

Acoustics '17 abstract.



# **Outreach Efforts**

None

## <u>Awards</u>

None.

## **Student Involvement**

Graduate Research Assistant Yiming Wang has been the primary person working on this task.

## **Plans for Next Period**

Continue the current work, particularly, we shall examine,

- The impact of Doppler-shift in source frequency on the overall A-weighted noise levels
- The shielding effects due to ground vegetation.
- The uncertainties in predicting the noise levels in upward refracting medium where the receiver is located at the shadow boundaries.

#### **References**

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- <sup>4</sup> SAE-AIR-5662 "Method for Predicting Lateral Attenuation of Airplane Noise" (2012).
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- <sup>6</sup> C. G. Fleming, J. Burstein, A. S. Rapoza, D. A. Senzig, and J. M. Guilding. "Ground effects in FAA's integrated noise model," Noise Control Engineering Journal **48**, 16-24.
- <sup>7</sup> C. Hobbs, Interim Report on ACRP 02-52: Improving AEDT noise modeling of ground surfaces (2016).