Project 4A
Estimation of Noise Level Reduction
Executive Summary

Georgia Institute of Technology and University of Nebraska - Lincoln
FAA Award Number: 13-C-AJFE-GIT-005

Team of Investigators
Georgia Institute of Technology (GT)
- P.I.(s): Kenneth Cunefare, Professor of Mechanical Engineering
  Javier Irizarry, Associate Professor of Building Construction

University of Nebraska – Lincoln (UNL)
- P.I.(s): Erica Ryherd, Associate Professor of Architectural Engineering

Two primary graduate students assisted in this project. René Robért (GT) was the lead graduate research assistant on this project. Hyun Hong (UNL) was a graduate research assistant who contributed to the model simulations portion of the project. Multiple students from the GT College of Architecture and Building Construction Program assisted in the test house construction. The GT Team also collaborated with the Mitsuru Kurosaka and Robert Dougherty from the University of Washington (UW), Victor Sparrow from the Pennsylvania State University (PSU), and Alan Hass and Eric Seavey from Landrum & Brown on various aspects of the project.

Bill He was the FAA Project Manager. The team participated in the three bi-annual ASCENT meetings during the project period. The Advisory Committee and other attendees at these meetings provided many useful suggestions and comments that were incorporated into the project. These discussions helped facilitate directions of P4A.

Project Overview
The specific goal of Project 4A was to better understand and improve the outdoor loudspeaker methods of estimating the noise level reduction (NLR) performance of buildings exposed to aircraft noise. Measurements and modeling were conducted on a test house located outdoors with a loudspeaker placed at an array of spatial positions to simulate angular coverage of aircraft flyover in both vertical and lateral directions. Results were used to evaluate and compare various NLR estimating approaches.

Project Summary

Task 1: Conduct Field NLR Study
<u>Task 1A: Test House Construction, Iterations, and Deconstruction</u>
A test house was constructed to allow for direct measurement of NLR outdoors under semi-controlled conditions. Subtasks included securing and preparing a construction site, estimating construction materials, material procurement, material delivery, student training, test house construction, and test house iterations. The test house was a single-room structure of approximately 90 ft^2. It was constructed to be typical of the mixed-humid climate region in Atlanta, GA, with fiber-cement siding, an asphalt-shingled roof, and a single hung vinyl window [1,2]. The test house was constructed on the GT campus in an open green space. Two construction iterations were implemented: a) window type, and b) window condition. For the window type iteration, two windows with differing acoustical performance were measured (STC 25 and STC 31). For the window condition iteration, three positions were measured (closed, ½ open, and fully open). The test house was deconstructed after acoustic NLR measurements (Task 1B) were completed.

<u>Task 1B: Acoustic NLR Measurements</u>
NLR was directly measured in accordance with industry best practices and ASTM E966 [3, 4]. To summarize, a loudspeaker was located outside of the test house playing pink noise, a standard noise reduction measurement signal. Sensors located both inside and outside the test house captured NLR performance data. Three instrumentation iterations were implemented: a) source vertical location, b) source horizontal location, and c) sensor location.

The vertical and horizontal location iterations were included to investigate an array of spatial positions that simulate angular coverage of real aircraft flyover in both vertical and lateral directions. Two mounting methods were used to achieve a range of vertical locations: i) tripod mounting (3.4' and 7'), and ii) lift mounting (15', 20', and 30'). The range of horizontal angles was achieved by moving the source along fixed radial and linear increments.

Three sensor locations were included: i) fixed near, ii) fixed flush, and iii) moving. In the fixed near method, microphones were placed at a distance from the exterior façade surface. In the fixed flush method, microphones were located flush to the exterior façade surface. In the moving method, the microphone was dynamically swept along a path. The moving method was identified as one commonly used by industry practitioners. Guidance was provided by Landrum & Brown on appropriate implementation of this method.

In total, 197 construction and instrumentation iterations were measured, using a combination of the following iteration variables:

- Source vertical location
  - 3.4', 7', 15', 20', 30'
- Source horizontal location
  - 0°, ±15°, +30°, -35°, ±45°, +60°, +75°
- Sensor location
  - fixed near, fixed flush, moving
- Window type
  - STC 25, STC 31
- Window condition
  - closed, ½ open, fully open

Task 2: Evaluate NLR Estimation Approaches

NLR estimation approaches were evaluated by: a) analyzing differences in field-measured NLR for the various construction and instrumentation iterations, and b) comparing a subset of the field-measured NLR to model simulations.

Task 2A: Analyze Differences in Field-Measured NLR Iterations

The field-measured NLR results were compiled and analyzed using Excel software. Averages, confidence intervals, and graphical inspection techniques were used to compare results across various combinations of iterations. Extensive analyses were conducted to analyze the differences in the 197 field-measured NLR iterations. Examples are shown below.

Repeatability and Reproducibility Analysis

An analysis of the repeatability and reproducibility of the three sensor iterations (fixed near, fixed flush, and moving) was conducted. The repeatability test compared the results of a single test configuration multiple times. It therefore revealed the within-test variability, or the ability of a specific test to be implemented multiple times with comparable results. The reproducibility test compared the results of different test configurations. It therefore revealed the between-test variability, or the ability for various test configurations (allowed within the standard) to yield comparable results.

The fixed flush method was found to be the most repeatable— that is, it provided the most precise results when implementing identical tests. The repeatability 95% confidence interval (CI) for the fixed flush method was calculated to be ±0.3 dB. However, it was determined that the moving method provided the most reproducible results with a 95% confidence interval (CI) of ±0.5 dB. Reproducibility is a better metric of precision as it is the precision for a procedure rather than a specific test; thus, it was concluded that the moving method was the most precise procedure.

Differences Across Iterations

The variation in NLR measurements caused by the source location was measured with a loudspeaker mounted on a tripod and man lift with an STC 25 window. With the loudspeaker mounted on a tripod and altered on the radial locations at an angle of incidence of 75°, the NLR values decreased likely due to the side façade affecting the measurement of the front façade since the speaker was approaching grazing. The locations of the tripod were also varied linearly such that the source variations were on the same plane at an equal offset from the façade. These locations resulted in a measured NLR an average of 1 dB less than the average NLR measured for the radial locations. This was expected since the speaker was nearly forty feet away from the center of the façade for the loudspeaker at the 75° angle of incidence linear location. The average moving test across all angles of incidence was 1 dB less than the average measured by the fixed near and fixed flush methods.

The testing performed with the speaker mounted on the man lift was used to evaluate the vertical angle of incidence as well as the symmetry of the measurements, but no clear angular dependency was observed. It was determined that the measurements were not symmetric for the test house, as the NLR values were not consistently similar across either side of normal incidence. The lack of symmetry in NLR measurements is likely due to flanking paths present in the construction. Once again, the moving method measured NLR values about 1 dB less than the fixed flush method. When comparing the measurements between the tripod and lift testing, it was determined that the tripod mounted testing resulted in NLR values that were less than the lift mounted testing.

Testing was also completed with two construction iterations: the acoustic performance of the window and window condition. In addition to the testing performed with the STC 25 window, NLR of the test house with an STC 31 window was also measured. The changing of the window offered minimum changes in NLR. The minimal changes were likely due to flanking paths present in the walls of the test house. Application of expanding foam to minimize flanking paths resulted in an average increase of 3.4 dB NLR; however, there was still no clear angular dependency after applying the foam.

<u>Task 2B: Compare Field Measurements and Model Simulations</u>
A subset of iterations were modeled in composite sound transmission software (IBANA-Calc) and compared to the field-measured results. In total, 27 iterations were modeled, using the following iteration variables:

- Source vertical location
  - 3.4', 7', 15', 30'
- Source horizontal location
  - 15°, 45°, 75°
- Sensor location
  - fixed near, fixed flush, moving
- Window type
  - STC 25, STC 31
- Window condition
  - closed, ½ open, fully open

The difference between measured and modeled predictions was calculated using two measures: a) $|\Delta NR|$, and b) $|\Delta TL|$. Both measures were averages of the differences between measured and modeled predictions across the frequency range 315 – 5000 Hz. The $|\Delta NR|$ was a direct measure of the difference between measured and modeled results. The $|\Delta TL|$ was found by accounting for the horizontal angle of incidence. Results showed that the difference between measured and modeled was less than 3-5 dB for approximately 57% of the iterations ($|\Delta NR|$) and 83% of the iterations ($|\Delta TL|$) depending on the metric evaluated.

Task 3: Synthesize Findings and Future Steps

A variety of NLR estimation approaches were compared and evaluated. Overall, changes in NLR were observed across all of the measurements, but the measurements did not exhibit consistent angular dependency. It is suggested to implement the moving method for NLR measurements with the loudspeaker test as it was the most reproducible. Future testing should examine the correction factor for the moving method, as the average NLR for the radial locations test with both windows and the lift mounted tests was at least 1 dB less than the fixed flush method. Additionally, correction factors should be considered when measuring NLR with a tripod mounted speaker rather than an elevated source or when altering the source locations linearly rather than radially. A set procedure to measure NLR with a loudspeaker would also be beneficial in reducing variations allowed currently.

Comparisons between the loudspeaker and aircraft flyover method should be examined further, including the overall accuracy of each method. Currently, the measurements do not appear to be similar due to the characteristics of the sources; a fixed point source and a time varying line source are used as equivalent methods of testing a spectrum dependent method. The artificial noise source method may be better suited to perform measurements to determine the acoustic performance of a building before and after modifications, as is stated as the primary goal of these measurements for the FAA in ASTM E966-10. In other words, the artificial noise method may be better suited for comparative rather than absolute measurements.

References

1. U.S. DOE (2004)"Introduction to building systems performance: Houses that work II", NREL/SR-550-345-85, *Building America*, http://www.nrel.gov
2. Building Science Corporation, "Building Profiles", *Enclosures That Work*, (2010). http://www.buildingscience.com
3. Landrum & Brown (2013), "Study of Noise Level Reduction (NLR) Variation," *FAA Technical Directive Memorandum 0017.*
4. ASTM E966-10 (2011): Standard guide for field measurements of airborne sound attenuation of building facades and façade elements, *ASTM International*.