Project 004(B) Estimation of Noise Level Reduction

University of Washington

Project Lead Investigator

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- P.I.: Mitsuru Kurosaka, Professor, William E. Boeing Department of Aeronautics and Astronautics
- FAA Award Number: 13-C-AJFE-UW-002, 003, and 004.
- Period of Performance: August 18, 2014 to December 23, 2015.
- Tasks:
    1. Construct an isotropic speaker and phased array of microphones
    2. Conduct tests of a test house by ASTM E 966-10 (speaker outside, microphone inside) and by the UW method (speaker inside, microphone outside). Compare the two results to demonstrate the validity of the UW method.

Project Funding Level

$60,000 from the FAA to the University of Washington.
Non-Federal cost share total $ 60,105 consisting of (a) in-kind share of $ 24,125 from the University of Washington, and (b) in-kind cost share of $35,980 from Optinav,1414 127th Pl, NE #106, Bellevue, WA.

Investigation Team

Mitsuru Kurosaka, ,P.I., professor, Robert P. Dougherty, affiliate associate professor, Tessa L. Robinson, graduate student. Dan Ablog and Ben Turner, undergrads

Project Overview.

To improve measurement & modeling technology for characterizing Noise Level Reduction (NLR) of houses.

Task: Estimate of Noise Level Reduction-Assessment of Phased Array of Microphones

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Objective

The objective of this activity is to assess the use of phased array of microphones for Noise Level Reduction (NRL) measurements, which can potentially make an improvement on the current ASTM standards E 966-10.

Research Approach

For housing near the airports, the eligibility criteria for the FAA funded Residential Sound Insulation Program (RSIP) are twofold:(1) the exterior noise exceeds 65 dB Day-Night-Average-Sound Level (DNL) and (2) the interior noise exceeds 45 dB DNL. The interior noise is a difference between the exterior noise and the noise level reduction (NLR). The NLR measurement method is based on the ASTM E-966-10, ref. 1, which specifies in detail the use of an artificial sound source placed outside of the house and a set of microphones positioned both outside and inside of the house. The difference between the outside and inside microphone data forms the basis of NLR. The use of a speaker outside of the house, which emits high-intensity sound for a prolonged time, would disrupt and annoy the neighbors. To alleviate this drawback, the goal of the UW efforts is to place a speaker inside of the house and microphone outside, which is the reverse of the ASTM guides. The interior placing of the speaker could substantially reduce the sound level perceived outside of the house and lessen the disturbances to neighbors. From the reciprocity principle of acoustics, the NRL obtained by this reverse arrangement should be equivalent to the one from the conventional ASTM method.

1. Construction of an isotropic speaker and phased array of microphones

Strictly speaking, the reciprocity principle upon which the UW method based, is applicable for a simple source. Therefore, as an approximated point source, an isotropic speaker is constructed.

Fig. 1 (left) isotropic speaker inside the bedroom, (right) phased array of speakers outside.

The isotropic speaker is a quasi-spherical, where twelve 6.5 inch, 100 W ceiling loudspeakers (On-Q/Legrand) were mounted in 9 inch pentagons made of ¾ inch plywood. The resulting dodecahedron loudspeaker (Fig. 1, left) was driven with a Dayton Audio MA1240a Multi-Zone 12 Channel Amplifier that can provide up to 40 W per channel with potentially independent inputs and gain control. A General Radio 1382 random noise generator was connected to all of the amplifier inputs, after splitting into the left and right banks. The amplifier gains were all set to about 2/3 of maximum to prevent the smoke that was observed at full power due to evident overheating. The RMS output of the random noise generator was usually set to 2 V. For some runs, the power was reduced by 10 dB by reducing the amplifier input voltage to 0.63 V. Driving all of the loudspeakers was intended to produce an isotropic source. For some runs, the leads for the six loudspeakers on one side of the dodecahedron were disconnected to produce an anisotropic sound source, intended to have directivity that is more representative of a commonly available loudspeaker.

A phased array, Fig. 1 (right), using 24 Panasonic WM-61 electret microphones was constructed with three 1 m arms and logarithmic element spacing on each arm with the element spacing decreasing away from the center of the array. The minimum spacing was constrained by the 2 inch foam windscreens. The arms, with integral OptiNav 8-channel preamplifiers, are removable for transportation. Data were acquired at 48 kHz using a 24-bit MOTU 24I/O audio interface. Thirty seconds of data were record for each condition. Phased array processing was performed using OptiNav Beamform Interactive software. The algorithm used was Robust Asymptotic Functional Beamforming (RAFB). This is a new method that provides quantitative results and offers much lower sidelobes, and hence higher dynamic range, than conventional beamforming. Functional Beamforming, the predecessor of RAFB, is described in Refs. 2 & 3. The robust, asymptotic extension offers improved level accuracy.

2 Description of the field tests

Tests were conducted at a two-bedroom house located at UW Center for Sustainable Forestry at Pack Forest in the Mt. Rainier National Park. Two separate tests were performed: (1) November, 4-8, 2014, and (2) April, 16-17, 2015.The façade element tested is the bedroom windows, and the test layout for the UW method is shown in Fig.2 (left). Measurements were made for the four incidence angles as shown. Selected results to be reported herein are for the 0° position.

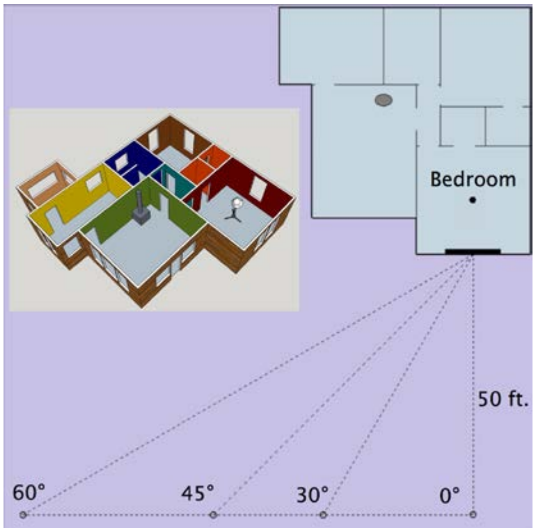

Fig. 2. (left)Test layout for the bedroom window, (right) free field calibration

The free-field test was conducted in an open field near the test house, Fig.2 (right), in accordance with ASTM E-966-10. The distance between the speaker and the microphones was 57ft. The ground reflection was removed using an analytical calculation involving the impedance of grass as given in Ref. 4. The bedroom windows were tested using both the ASTM and UW method. Some representative results obtained by the UW method are shown in Fig. 3, which displays Beamforming images at the 1/12 octave bands of 2114 and 4728 Hz; the bedroom left lower window was open, cracked, and shut. The open and cracked portion of the window are seen clearly in Fig. 3 (d) and (f). Figure 3 (c) shows that propagation thorough the window is important even when it is closed. It also shows the ground reflection and some radiation from parts of the house other than the bedroom.

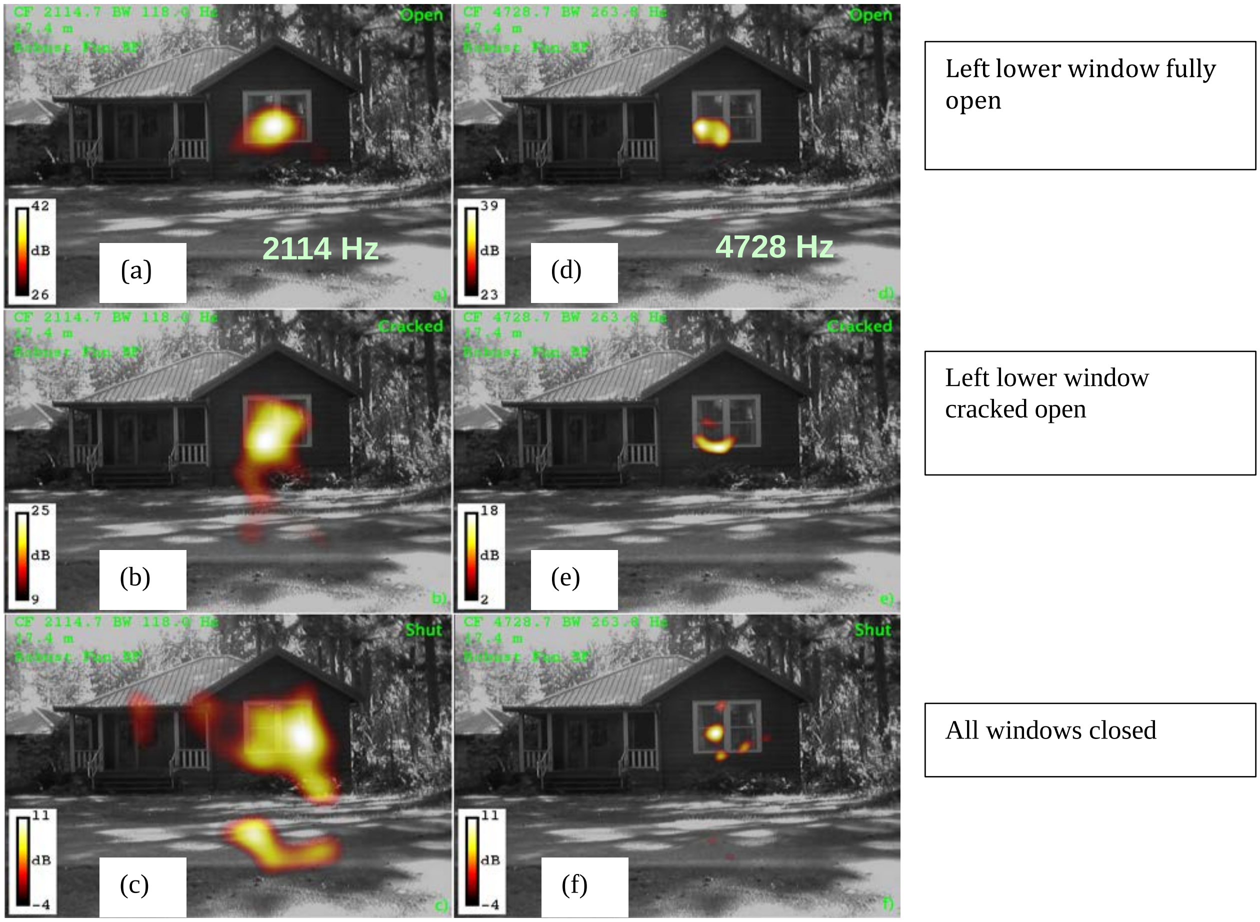

Fig 3. Images obtained by the phased array of microphone placed outside (the UW method; (a) to (c) at 2114 Hz, (d) to(e) at 4728 Hz.

3. Comparison of the UW and ASTM method

The UW method rests on the reciprocity principle and its validation is shown in Fig. 4. The cases with the left window open and cracked are shown Fig. 4a, and the case with the window shut is given in Fig. 4b. For each window position, the ASTM spectrum, measured with the loudspeaker outside, and the UW, RAFB spectrum, measured with the loudspeaker in the bedroom and the array outside, generally match. This validates the fundamental approach of using reciprocity for the measurement. The agreement is not perfect. There are several factors that can potentially cause the ASTM and UW curves to differ. These include interfering noise, which varies between runs, the placement of the loudspeaker in the bedroom for the UW method in relation to the placement of the microphones in the bedroom for the ASTM method, and the details of the array processing algorithm.

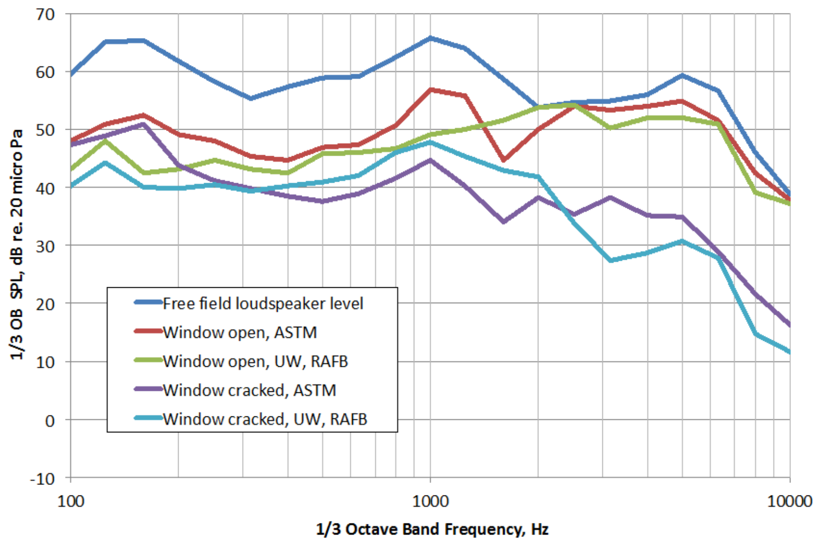

Fig. 4 a – Reciprocity check, window open and cracked.

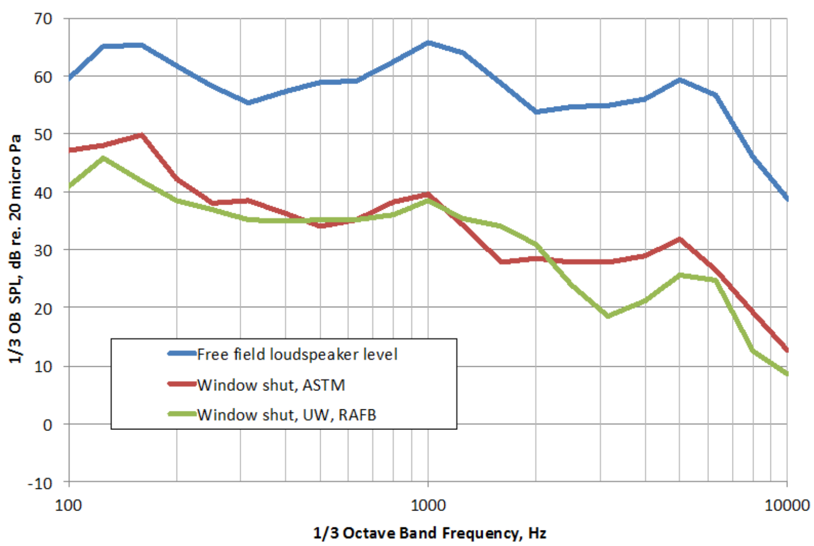

Fig. 4 b – Reciprocity check, window closed.

4. Noise Reduction Level

The 1/3 octave band noise reduction (NR) spectra are shown in Fig. 5. The noise level reduction values derived from the 1/3 OB values according to ASTM E1332-10a , ref. 5, are shown in the legend. The agreement between the NLR values from the ASTM and UW methods is perfect for the open window case. The UW method shows 1.06 dB less noise reduction for the window cracked and 2.82 more reduction for the window shut case. The UW method shows higher NR than ASTM for the window shut case at both high and low frequency. The low frequency difference carries more weight in the computation of the NLR because the NLR formula is more sensitive to changes in smaller NR values than larger ones. Starting with the UW NR spectrum and replacing the NR values for frequencies above 2 kHz with the ASTM NR values, the NLR estimate for the window shut case would drop from 23.79 dB to 23.58 dB. Alternatively, replacing the UW NR values with the ASTM NR values for frequencies below 400 Hz, the NLR for window-shut would become 20.98 dB, matching the observed ASTM result of 20.97 dB. The accuracy of the UW NR values for frequencies below

400 Hz is constrained by the size of the array tested. An array with longer arms would produce more reliable results. More loudspeaker power at low frequency would also improve the results by reducing the reliance on the beamforming at low frequency.

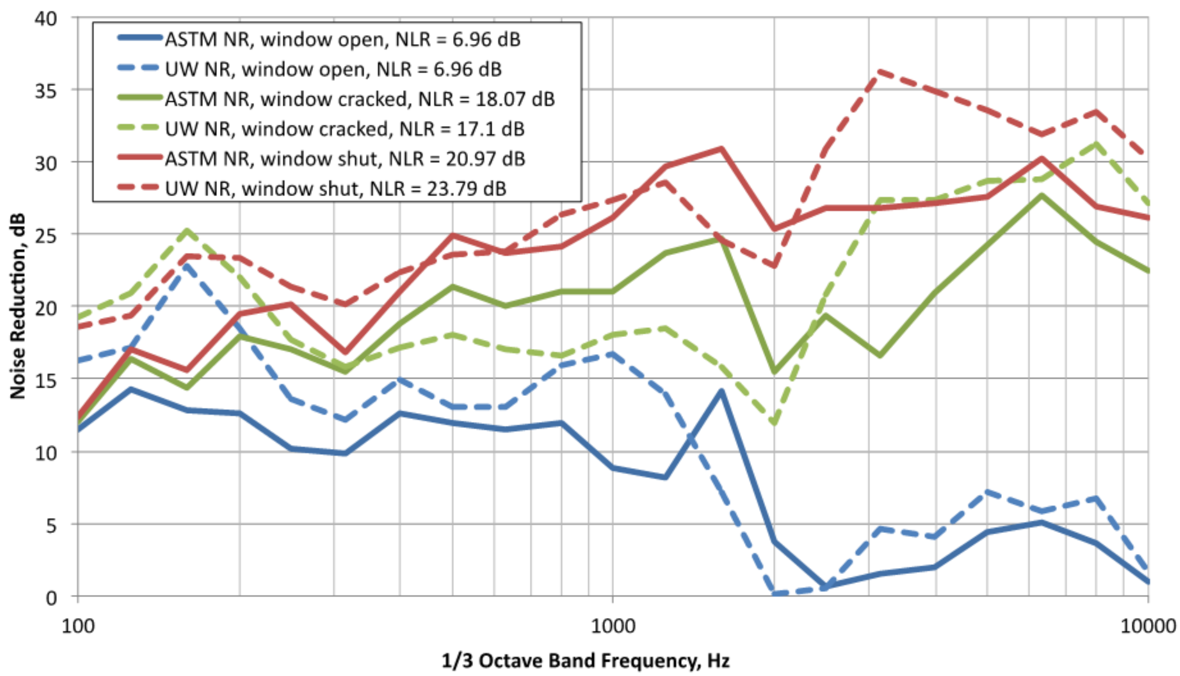

Fig. 5. Noise Level Reduction for several window conditions and measurement methods

Milestone(s)

All tasks were successfully completed with minor variations in the milestones

Major Accomplishments

The validity of the reciprocal measurement technique, the UW method, is proven. The combination of the phased array and the advanced beamforming technique more than compensates for the noise floor disadvantage of moving the microphones outside in the upper part of the frequency range. At low frequency, the ASTM method has higher dynamic range than the UW method with the tested array, processing technique, and indoor and outdoor background noise. The UW method requires further development to be effective at low frequency. Changes that would improve the low frequency performance include use of a larger phased array and a loudspeaker with more low frequency output. The array technique provides detailed images of the portions of the house that transmit sound.

Publications

"Improved Method for Estimating Noise Level Reduction of Residential Houses", by R. P. Dougherty, T.L. Robinson, and M. Kurosaka, INTER-NOISE and NOISE-CON Congress and Conference Proceedings, InterNoise15, San Francisco, CA, pp. 2063-2074.

Outreach Efforts

Presented a poster and made a table top demonstration at the 'Research+Industry' symposium held at the Mary Gates Hall, UW, on November 21, 2014, and hosted by the William E. Boeing Department of Aeronautics and Astronautics.

Awards
None

Student Involvement
(a) Tessa L. Robinson, a graduate student and supported as a RA by this project for Autumn quarter 2014, and participated in the construction of the isotropic speaker and two field tests.
(b) Dan Ablog and Ben Turner, undergrads, who volunteered to participate in the field tests.

Plans for Next Period
None

References

1. ASTM E 966-10 "Standard Guide for Field Measurements of Airborne Sound Attenuation of Building Façade and Façade Elements", (2011)
2. R.P. Dougherty, "Functional Beamforming", Berlin Beamforming Conference, BeBeC 2011, (2014)
3. R.P. Dougherty, "Functional Beamforming for Aeroacoustic Source Distributions", AIAA Paper 2014-3066, (2014)
4. T.F.W. Embleton, J.E. Piercy, and N. Olson, "Outdoor sound propagation of ground of finite impedance", *J. Acoust. Soc. of Am.*, **59**(2). (1976)
5. ASTM E1332-10a "Classification for Rating Outdoor-Indoor Sound Attenuation", (2014)