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Noise Level Reduction Measurement Methods for Sound-Insulated Structures

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ABSTRACT

Hundreds of FAA-sponsored sound insulation projects have been completed for residences, schools and places of worship around U. S. airports over the past twenty years, and many more are starting or continuing. As a quality control procedure the Federal Aviation Administration (FAA) requires pre- and post-construction acoustical testing to ensure that noise level reduction standards are met[1]. Several methods have been established for this field testing using both aircraft flyover noise and artificial noise sources. The various procedures are described, their conformance to acoustical standards is assessed, and their relative merits are discussed. The effects of signal-to-noise ratio and the results from the various test methods on a single residential structure are presented and evaluated.

1. INTRODUCTION

While no recognized standard exists for measuring the A-weighted 'Noise Level Reduction' (NLR) of buildings, commonly-used guidelines are the ASTM guides for field measurements of airborne sound insulation of building facades and façade elements[2,3]. These guides allow for measurement by a) an artificial sound source, or b) by the transportation source. The guides and an ANSI standard[4] address alternative measurement techniques and adjustments to measurement results for various geometries and proximities of the sound source to the building. Both methods compute the NLR by subtracting the interior measurement value(s) from the concurrent exterior measurement value(s). This is therefore an insertion loss measurement incorporating the effects of the relative area and transmission loss properties of all building elements, and the room factor effects of incident area and acoustical absorption. The interior DNL value required by the FAA is obtained by subtracting the NLR from a previously established exterior DNL at that location (usually generated by computer modeling of the aircraft noise environment with the FAA's Integrated Noise Model).

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2. LOUDSPEAKER METHOD

For the loudspeaker method the speaker is typically elevated above the ground, oriented in the direction from the most commonly used aircraft flight track(s), and set back at least twenty feet from the structure to maximize coverage to all façade surfaces. Either calibrated recordings or direct on-site measurements can be made. When feasible, the loudspeaker is mounted on a hydraulic lift ‘bucket truck’ to orient the speaker from the direction of the predominant aircraft flyover activity.

The loudspeaker method has the logistic advantages of repeatable results, more control over the measurement environment, a shorter measurement period (with less homeowner disruption) and no reliance on airport operations. Additionally, this method allows for isolation of building elements during the testing, providing information on the relative transmission loss properties of individual elements. The major disadvantage is technical in that the method measures the noise reduction principally of a single façade which may not closely emulate that of the aircraft flyover sound emission. This method assumes that the sound incident on the structure from the loudspeaker is similar to that from the far-more-distant aircraft. In some cases the loudspeaker method is the only option, such as for structures located in future aircraft noise-impact areas, or where aircraft operations are otherwise not extant when measurements may be made.

This method also allows adjustment of the sound spectrum to maximize the signal-to-noise ratio of the measurement. It also facilitates spectral measurement (instead of only A-weighted measurement) which allows for more diagnostic information and adjustment for noise floor measurement issues. Spectral measurement allows for the possibility of tailoring the measurement spectrum to the average annual (DNL) flyover spectrum reflecting aircraft types, percent takeoffs and landings, climb profiles, etc. However, we know of no studies where this has been attempted.

3. AIRCRAFT FLYOVER METHOD

The transportation source method uses actual aircraft noise from typical operations as the sound source. Synchronized digital programmable sound level meters are placed concurrently outside and inside the building to simultaneously record a number of flyover events at the outdoor location and in each of two rooms. These meters typically record the A-weighted sound level simultaneously and use software to interrogate the data file, identify and correlate events, and compute the SEL of each event at each location. Calibrated recordings may also be made with this method if spectral data is required. However, the volume of such information is large and this is rarely done.

The aircraft source method has the logistic advantages of unattended monitoring and often louder sound sources for better signal-to-noise ratio results. However, A-weighted NLR results typically vary by several decibels among events due to differences in source spectra among aircraft and due to room acoustics. The lack of repeatability should not be viewed as a measurement error because the NLR being measured is an average of various aircraft events. Other acoustical measurements, such as transmission loss testing, require a moving microphone or multiple microphone measurement locations in the receiving room[3]. The aircraft flyover method has the advantage of allowing statistical quantification of the measurements; the measurement series enables computation of certainty intervals at probability levels.

The effects of incidence are well known for transmission loss testing. Tangential incidence causes stronger bending waves in panels, thereby reducing the transmission loss effects and yielding lower measured noise reduction than that from sound at normal incidence. This can have a significant effect on results when an artificial sound source is used for measuring a wall and a picture window. By using actual aircraft flyovers a relatively uniform sound field is integrated across all building surfaces for a typical duration of 30 seconds or more.

4. METHODS COMPARISON

Before comparing the two methods it is important to review what is being measured. The aircraft flyover method measures what is actually heard by the homeowner in the rooms measured. This may be dominated by the ambient background sound level in the room, particularly in the higher frequencies where the noise reduction is greatest. Often, good sound insulation in a room with a moderate interior noise environment will reduce the high frequency sound to below that of the ambient. Therefore, high frequency ambient interior noise (perhaps from a refrigerator) will exceed the post-retrofit noise level of the intruding aircraft noise. However, the loudspeaker method typically measures the sound spectra of the exterior, interior and NLR of the structure; this allows the NLR to be extrapolated down in the high frequencies to measure that actual NLR or the structure without the limitation from the interior sound environment.

A comparison test was made of a home in the noise impact area of San Diego International Airport in January 2008 using the loudspeaker and aircraft flyover test methods. Continuous noise monitoring of 47 aircraft flyovers was conducted over a period of two hours during which time a loudspeaker test was also conducted on a single bedroom. The loudspeaker measurement method recorded an NLR of 23.8 dB while the aircraft flyover method recorded an NLR of 24.9 dB. The standard deviation of the aircraft measurement was 1.7 dB, somewhat greater than typical. For this measurement the entire measurement duration was recorded in one-third octave bands at one-second intervals for the nearly two-hour duration. These results were first pared to octave band levels and the SEL values, in octaves, was computed for the individual flyover events. This enable comparison of measurement results as shown in Figure 1.

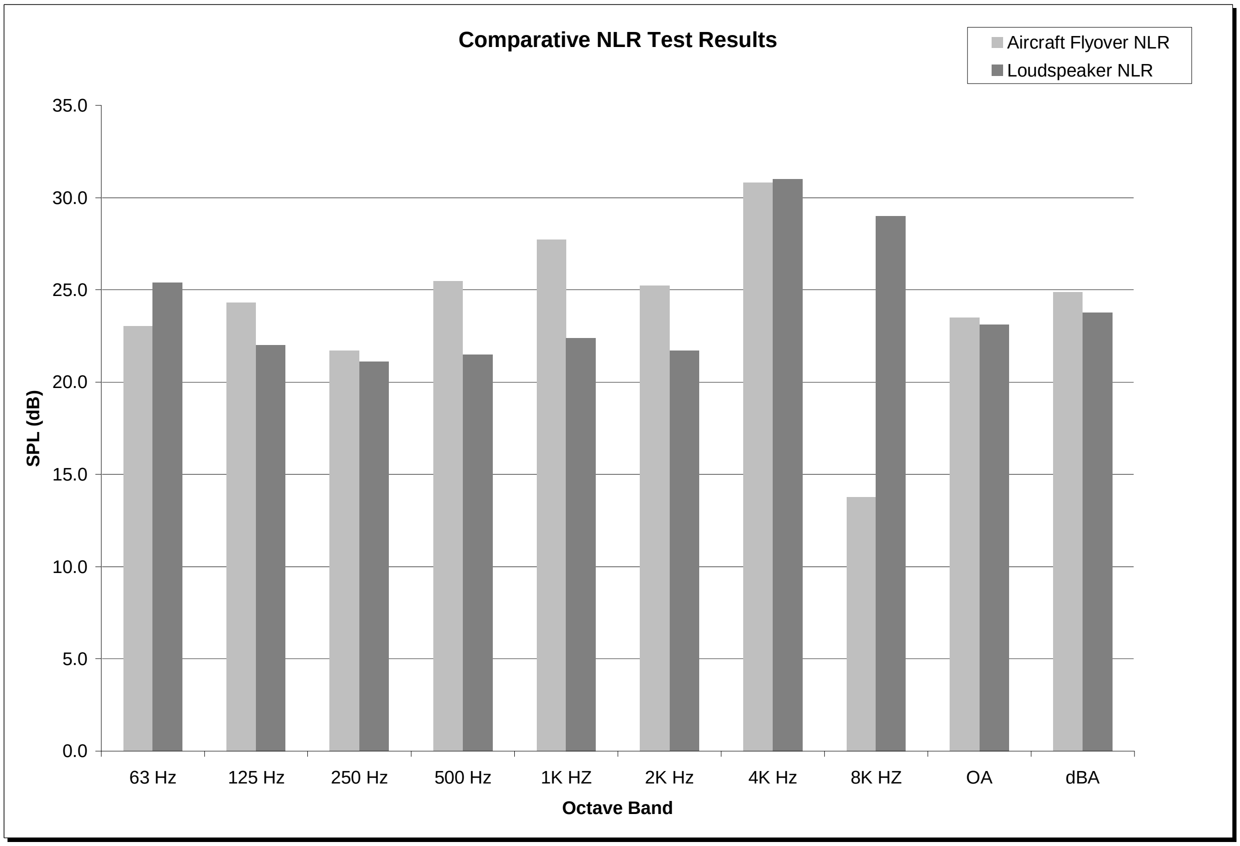

Figure 1: Comparison of Loudspeaker and Aircraft Flyover Results.

For this comparison test the interior level of the aircraft flyover test was within 5 dB of the background noise at 4 KHz and within 2 dB at 8 KHz. With the loudspeaker method, however, the high frequency sound source was adjusted to maintain good signal-to-noise in the high frequencies. Thus the loudspeaker was a better measurement of the NLR properties of the structure while the aircraft method may have better measured the noise environment of the occupants.

5. THE INTERIOR LOUDSPEAKER METHOD

Recently another test method has been employed for residential sound insulation measurement. This method uses a loudspeaker within the structure and measures the NLR as the difference between the interior noise and the exterior noise measured in a fashion unknown to the authors. This method touts the advantage, over the conventional loudspeaker methods, of minimizing disruption to neighbors during testing. This method follows no known measurement standards, but warrants some discussion.

The conventional loudspeaker and aircraft flyover methods measure incident exterior sound from a distant diffuse source, and the interior sound in the reverberant field of the room. The interior loudspeaker method measures a reverberant source and the receiver from radiating exterior building elements. The propagation properties of radiating panels are well known: point sources attenuate at 6 dB per distance doubling, line sources at 3 dB per doubling and an infinite plane does not attenuate with distance. In an acoustically untreated building structure certain elements, such as non-sound-rated windows, have significantly inferior sound attenuation properties and therefore tend to act as radiating rectangular panels (when measured inside from an exterior source or when measured outside from an interior source). Therefore the near-field sound level measured adjacent a non-sound-rated window will be substantially greater than that measured adjacent a high sound-attenuating façade. The attenuation with distance from a finite size rectangular panel is given in Rathe Theory[5] and depends upon the dimensions of the rectangle and distance from the radiating plane. The near-field radiation effects are eliminated by measuring a special average in the receiving room from an exterior source, whereas they are not when the source is within the room.

6. CONCLUSIONS

Both the loudspeaker and aircraft flyover methods may provide a good measure of the noise level reduction of structures. The loudspeaker method affords more control over the measurement environment, may compensate for signal-to-noise problems, may provide the best measure of the noise level reduction properties of the structure and minimizes testing time. The aircraft flyover method provides the best sound incidence on the structure allows for a statistical assessment of the measurement method and may provide the best measure of the actual interior noise environment. All methods require attention to signal-to-noise level issues in the receiving room as this is known to effect measurement results. The interior loudspeaker method is new and poses questions as to the validity of measurement results.

REFERENCES

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