inter•noise 96
25th Anniversary Congress – Liverpool

INCE: 72.5

THE MEASUREMENT OF AIRCRAFT NOISE REDUCTION IN RESIDENCES

B H Sharp & S Martin

Wyle Laboratories, Arlington, VA 22202, USA

1. INTRODUCTION

One of the popular methods for noise mitigation in communities adjacent to commercial airports is to increase the noise reduction of exposed residences, so that residents can obtain relief from high noise levels at least when they are inside. The advent of such airport sound insulation programs in the U.S. has generated an increased interest in the prediction and measurement of noise reduction in single- and multi-family residences. One of the requirements in these sound insulation programs is to measure the noise reduction of the residential structures. The following sections of this paper evaluate two common methods for measuring the noise reduction of residential structures, and introduce a third method that may be used when aircraft are not available.

2. CHARACTERISTICS OF AIRCRAFT NOISE REDUCTION

A typical example of the exterior and interior noise levels as a function of time for a residence exposed to noise from an aircraft overflight is shown in Figure 1.[1] The instantaneous difference between the exterior and interior levels – the noise reduction – is shown by the solid line in the figure. Notice that in the initial seconds, when the room is partially shielded from the aircraft by other portions of the residence, the noise reduction is very high at 52 dB. When the aircraft is level with the residence (indicated by the vertical line), the noise reduction is still nearly 50 dB. Then it decreases rapidly to a value as low as 22 dB before rising and then varying about a mean value of about 30 dB.

At first glance, it is not at all clear how the noise reduction of the residence should be defined. At the time when the exterior level is at a maximum, the noise reduction ot the residence in the above example is

48 dB. At the maximum interior level, it is 23 dB. The difference between the maximum exterior and interior levels, regardless of the time at which they occur, is 30 dB. Finally, the difference between the exterior and interior sound exposure levels (SEL) is 31 dB. Since the measurement of SEL contains information on the entire flyover event, it is generally considered to be more representative of the noise environment experienced by the occupants than any instantaneous noise measurement. However, the example clearly shows the significant and rapid variation in noise reduction with aircraft location with respect to the building.

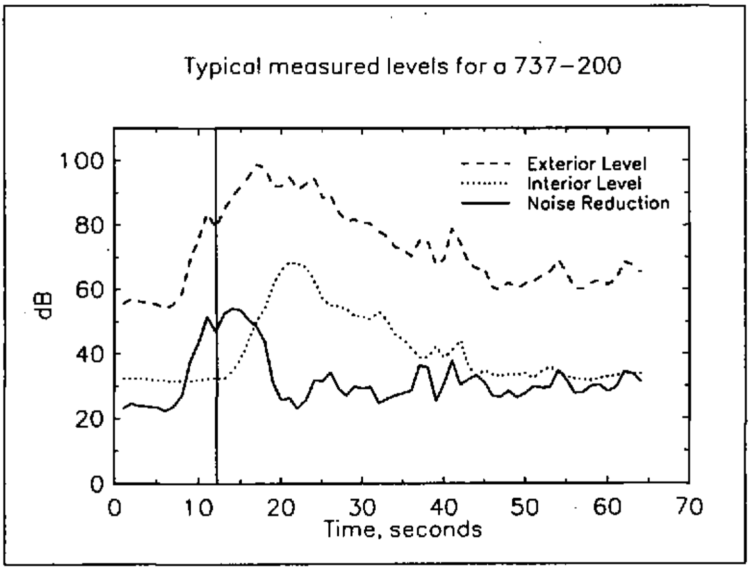

Figure 1. A-Weighted Sound Level Time History for an Aircraft Overflight.

3. EXISTING NOISE REDUCTION MEASUREMENT PROCEDURES

Aircraft Noise Source

Since aircraft are the noise source of concern in sound insulation programs, and there are usually plenty of them near airports, it would seem appropriate to use aircraft overflights for the measurement of noise reduction. This has the advantage of precisely measuring the noise exposure to the residence, and of measuring the increase in noise reduction experienced by its occupants when sound insulation modifications have been applied, provided that the measured overflights are representative of normal operations from the airport.

However, the aircraft noise source cannot be considered a controlled source, and there are situations that do not lend themselves to this simple approach to noise reduction measurement. For example, if the building lies directly under the nominal flight path, the normal dispersion of aircraft tracks may result in some rooms being shielded from the direct sound for some of the flights, but not for others. The average measured noise reduction then becomes meaningless. Also, when there are only occasional flights from a given runway, as may occur near small airports, the time to acquire data for a sufficient number of flights may become excessive. Under these conditions, measurements must be conducted using an artificial noise source, such as a loudspeaker.

Artificial Noise Source

The obvious approach to using an artificial source, such as a loudspeaker, is to position it so as to generate an external sound field similar to that of an aircraft overflight event. The advantage is that of a controlled noise source. The disadvantage, however, is that it is impossible to exactly simulate the sound field of a moving aircraft with a stationary source.

A review of the data presented in Figure 1 shows that the measured noise reduction will be strongly dependent on the positioning of the source with respect to the residence. Thus the method must be used with caution, and perhaps is really only suitable for measuring differences in noise reduction before and after treatment, and even this difference may not always be representative of the real noise situation.

There is another, non-technical, reason for not using this procedure, and this relates to the annoyance caused in the local community by the continuous noise produced by the test loudspeaker.

4. INDOOR–OUTDOOR MEASUREMENT PROCEDURE

Details of the Proposed Procedure

An alternative method of measuring noise reduction with an artificial source, without the disadvantages noted above, is to place the source inside the room. Noise levels are then measured inside the room and at the exterior wall surface. To be consistent, the noise spectrum generated inside the room must be characteristic of aircraft noise. Both interior and exterior measurements are conducted using an integrating sound level meter. The average interior sound level is obtained from a three-dimensional spatial scan over the room volume. The average exterior sound level is measured by a two-dimensional scan over the exterior surface of the wall at a constant distance of about 0.3m. The difference between the interior and exterior average sound levels is then a measure of the indoor-outdoor noise reduction that can be related to the outdoor-indoor noise reduction of aircraft noise.

The advantage of this method is that, like the method employing an external loudspeaker, it is a controlled method that does not require the presence of aircraft. However, unlike the external loudspeaker method, the measured values of noise reduction are not sensitive to source placement, and, in fact, are very consistent when repeated. One condition that does have to be met, of course, is that the exterior ambient sound level must be at least 6 dB less than the exterior level from the interior noise source. The method also has the advantage that the contribution to the overall noise reduction from different elements – windows, doors, etc. – can be estimated. Finally, an internal loudspeaker causes no complaints from nearby residents.

Relationship to Aircraft Noise Reduction Measurements

For the proposed method to be useful, it is necessary to develop a relationship with values of noise reduction measured using an aircraft noise source. The process of sound propagation from a directional, moving source, through a wall exhibiting directional transmission loss characteristics, is very complex. As a result, many generalizations will be used to develop the approximate relationships in this section.

For a stationary exterior sound source, and a reverberant receiving room, the noise reduction, $NR_{r,\theta}$, of the exterior wall is given by the expression:[2]

$$NR_{r,\theta} = TL_\theta - 10 \log (S \cos \theta / A) - 6 \text{ , dB} \quad (1)$$

where $NR_{r,\theta}$ and TL_θ are the noise reduction and transmission loss, respectively, of the wall at angle θ, S is the area of the exposed building element, and A is the absorption inside the room.

For a moving noise source, such as an aircraft, θ can vary over a range that depends on the configuration of the residence with respect to the flight track. However, as shown in Figure 1, the maximum noise energy is transmitted into the room just after the aircraft has passed the 0 degree angle (assuming the exterior surface is parallel to the flight track), and it is this energy that contributes most to the interior SEL. In practice, the maximum interior level occurs at an angle of about 30 degrees. With this assumption, Equation (1) can be rewritten as:

$$NR_r \approx TL_{30} - 10 \log (S/A) - 5.5 \text{, dB} \quad (2a)$$

where NR_r is the noise reduction of the wall for an aircraft event, and TL_{30} is the transmission loss of the wall at an angle of 30 degrees.

Equation (2a) is strictly only valid when the sound field in the room is diffuse – and this is certainly not the case in a typical residential room. If, in the extreme, it is assumed that the room surfaces are totally absorbing, then the sound will be propagated into the room as a progressive wave, and the noise reduction, NR_f becomes:

$$NR_f = TL_{30} \quad (2b)$$

The relationship between NR and TL will in actuality lie somewhere in between the values determined from Equations (2a) and (2b). As a first approximation, it might be assumed that:

$$NR = TL_{30} - 5 \log (S/A) - 3, \text{ dB} \quad (3)$$

The proposed indoor-outdoor measurement technique requires a loudspeaker to be placed inside the room. If it is assumed that the sound field in the room is diffuse, then the difference, NR', between the interior reverberant sound level and that measured close to the exterior wall can be expressed as:[2]

$$NR_r' = TL_r + 6 \text{ dB} \quad (4a)$$

where TL_r is the transmission loss of the wall as measured in the laboratory between two reverberant rooms. To convert from TL_r to TL_{30}, a conversion factor of 3.5 dB is introduced, assuming that the TL obeys a 20 log (cosθ) relationship, and that $TL_r = TL_0 - 5$ dB.[3] Therefore, Equation (4a) can be written as:

$$NR_r' = TL_{30} + 2.5 \text{ dB} \quad (4b)$$

If the room is totally absorbent, then the interior sound field will be a progressive wave, and the noise reduction, NR_i', will be:

$$NR_i' = TL_\phi \quad (4c)$$

where ϕ is the angle of incidence of the interior sound wave on the exterior wall. If the loudspeaker is placed in a comer facing the exterior wall of a typical room, the value of ϕ will vary from 0 degrees to about 60 degrees, with an average of about 30 degrees. As a result, $TL_\phi = TL_{30}$. Proceeding as before, it might be assumed that a typical value of the noise reduction would lie in between the values given by Equations (4b) and (4c), namely:

$$NR' \approx TL_{30} + 1.5 \text{ dB} \quad (5)$$

With all of these assumptions and approximations, the relationship between the noise reduction as measured with aircraft and that measured using the indoor-outdoor method is as follows:

$$NR' - NR = \Delta \quad (6)$$

where $\Delta = 5 \log (S/A) + 4.5$, dB.

Procedure Validation

To test the validity of the many assumptions used in developing Equation (6), field tests were conducted on a total of 22 rooms in apartment units located close to a major airport. At least one exterior wall surface of each unit faced the airport, but other walls were partially shielded from the overflights. The noise reduction, NR, of the A-weighted sound level was measured for each room using the average of a number of aircraft overflights. A single exterior microphone was located away from reflecting surfaces, and two microphones were used to measure interior levels.

The indoor-outdoor procedure was also implemented in each unit, as described above, with the exception that the surface of each element of the exterior surface, i.e., wall, window, and door, was scanned separately to obtain data on the individual contributions to the overall noise reduction. Appropriate shielding factors were then applied to the noise reduction for each element before combining them on an area basis to provide an overall noise reduction, NR', for the entire unit. The interior absorption in each unit was determined by measuring the reverberation time for the decay of an aircraft-type spectrum.

The absorption data was used to calculate the value of Δ from the expression in Equation (6). The difference between the noise reduction as measured by the two methods, $\Delta NR = NR' - NR$, was also calculated for each of the 22 units. The mean difference for the 22 units between the values of Δ and ΔNR for each unit was determined to be 0.9 dB, with a standard deviation of 2.0 dB. Thus, it appears that the expression in Equation (6) is valid, provided that a correction factor of 0.9 dB is applied. Thus the relationship between the two methods of measuring noise reduction can be restated as follows:

$$NR' - NR = 5 \log(S/A) + 3.5 \text{ dB} \qquad (7)$$

The spread in the difference in noise reduction values is a little higher than one would like, but was determined largely the results from only 4 of the 22 units.

5. CONCLUSIONS

Existing methods for measuring the noise reduction of residences exposed to aircraft noise are not always applicable in all situations. The method of using aircraft as the noise source is the one most applicable to the situation, but is uncontrollable, and can result in errors unless special precautions are taken. These precautions sometimes require extensive measurement time. The method of using an exterior artificial noise source is prone to errors due to the sensitivity of the results to source location, and is annoying to nearby residents. An alternative procedure that overcomes these disadvantages by using an interior source has been shown to provide data that can be related to aircraft noise measurements. Additional validation measurements are needed to further develop this procedure.

References

[1] B.H. Sharp, "25 Years of Airport Sound Insulation Programs", *Proceedings of NOISE-CON 94*, Ft. Lauderdale, 1994.

[2] L.L. Beranek, *Acoustics* (McGraw-Hill, New York, 1954).

[3] L.L. Beranek (Ed.), *Noise and Vibration Control* (McGraw-Hill, New York, 1988).