Criteria for the Design of Sound Insulation in Homes Around Commercial Airports

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Current FAA regulations provide for FAR Part 150 funding for the noise insulation of residences, schools, hospitals, churches, and other approved noncompatible structures located within the 65-dB yearly day-night average sound level (DNL) contour. For residences located where the exterior DNL is 65 dB, a noise level reduction (NLR) of at least 20 dB is required in major habitable rooms. The requisite NLR is increased commensurate with any increase in exterior DNL above 65 dB. This is mathematically equivalent to achieving an interior DNL of 45 dB in major habitable rooms. Although the use of the DNL metric may be appropriate in determining eligibility for funding because it has been found to be correlated to the community reaction to environmental noise, experience has indicated that an individual homeowner's annoyance with the noise from aircraft overflights is more closely related to the average sound exposure level (SEL) of overflights. The relationship between DNL and SEL is examined as a function of the number of aircraft operations. It is demonstrated that, for a given value of DNL, the average value of the allowed SEL increases as the number of operations decreases. Thus the use of an interior DNL metric to determine the NLR criterion for homes around airports results in higher average interior SEL values in homes around smaller airports than in homes around large airports. An alternate SEL criterion is proposed.

Three different acoustic metrics are commonly used to describe the noise exposure from aircraft overflights:

- Day-night average sound level (DNL),
- Sound exposure level (SEL), and
- Maximum A-weighted sound level (ALM).

Each of these metrics is a sound pressure level measured in units of decibels (dB) and each deals with the A-weighted sound level. An A-weighted measurement of an acoustic signal adjusts the level to take into account the fact that the human ear is not equally sensitive to all frequencies of sound—it being most sensitive to frequencies between 1,000 and 6,000 Hz and progressively less sensitive at frequencies farther from that range.

The DNL value is a sound level corresponding to the average A-weighted sound energy that is received during an entire 24-hr period, giving a 10-dB penalty to noise occurring at night (10:00 p.m. to 7:00 a.m.). SEL and ALM are single-event metrics. The former is a level corresponding to the total A weighted sound energy that occurs during an overflight; the latter is the maximum A-weighted sound level that occurs during an overflight.

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Because SEL is the sound level that would contain, in 1 sec, the same A-weighted sound energy as did the actual overflight (which is always longer than 1 sec), the value of SEL for a given event is always greater than the value of ALM for the same event. On the other hand, because DNL contains both quiet and noisy periods in its average, the value of DNL is lower than typical SEL or ALM values for individual overflights that occur during the 24-hr period.

The physical difference between these three metrics should be clearly understood. The public is often confused by discussions of DNL values between 65 and 75 dB when they have seen exterior ALM measurements at their homes that are typically 20 dB higher and occasionally as much as 40 dB higher. The reason for the difference, of course, is that each of the metrics describes a different aspect of the noise.

DAY-NIGHT AVERAGE SOUND LEVEL

DNL is the acoustic metric that has been chosen by the FAA to determine a structure's eligibility for inclusion in a federally supported sound insulation program. The October 24, 1989, edition of the *Airport Improvement Program (AIP) Handbook* states: "Unless specifically justified by the airport sponsor in its NCP and approved by the FAA, the structure must be located within a DNL 65 dB contour." The NCP is the FAA-approved noise compatibility program for the airport.

The AIP Handbook further states: "Normally, unless extenuating circumstances dictate, noise insulation should not be considered for structures within a DNL 75 dB or greater noise contour since it is preferable to change the land use."

The FAA also uses DNL to define the minimum acoustic insulation that should be provided to a residential structure taking part in a federally supported sound insulation program. The AIP Handbook states:

> For residences located in areas where exterior noise exposure is DNL 65 dB, the requisite noise level reduction (NLR) provided by the structure should be at least 20 dB in major habitable rooms. The requisite NLR should be increased commensurate with any increase in exterior DNL above 65 dB.

This condition is mathematically equivalent to requiring an NLR that will produce an interior DNL value of 45 dB or less.

Although the normal program eligibility requirements are fixed (an exterior DNL value between 65 and 75 dB), the NLR requirement is a lower limit. Acoustic insulation that produces a greater NLR value can be provided without violating the conditions in the AIP Handbook. In fact, the Handbook goes on to state: "Since it takes an improvement of at least 5 dB in NLR to be perceptible to the average person, any residential noise insulation project will be designed to provide at least that increase in NLR."

Of course, providing a higher NLR value than the minimum required by the AIP Handbook should be justified.

The DNL metric has been used for two different purposes: (a) to define a structure's eligibility for the program, and (b) to define the minimum noise level reduction that must be provided.

The DNL value is an appropriate metric to use for these purposes because it has been shown to correlate fairly well with community reaction to environmental noise (*1,2*) and it is related to the total acoustic energy received throughout a 24-hr period. As a result, the DNL value takes into account both the sound level of typical overflight events and the number of events that occur. A structure experiencing a large number of overflights in a 24-hr period will have a higher DNL value than a structure experiencing a small number of similar events in that period.

SINGLE-EVENT METRICS

Although the DNL value correlates with community reaction to noise, the relation is statistical in nature, not causal (*1,2*). That is, an individual's annoyance is caused by the interference of specific noise events with some human activity, such as speech or sleep. Questionnaires administered by Wyle Laboratories to residents of homes before their acoustic insulation have indicated the most disturbing aspects of aircraft overflight noise to be interference with radio and television listening and with telephone and general conversation. These activities are followed by interference with general relaxation and concentration and by sleep disturbance.

Whether or not activity interference will occur is best determined by a single-event metric. Because the DNL value does depend on both the sound level of a typical overflight event and the number of events, it is not a good estimator of single-event sound levels.

In order to clarify this statement, note that the relation between the DNL at a given point and the daily mean value of SEL for aircraft overflights at that point is

$$\text{DNL} = \langle\text{SEL}\rangle + 10 \log (N_{eff}) - 49.4$$

where

$\langle\text{SEL}\rangle$ = mean value (on an energy basis) of SEL, and
N_{eff} = number of effective daily operations = $N_d + 10N_n$.

Here N_d is the number of daytime operations and N_n is the number of nighttime operations. (Multiplying the number of nighttime operations by a factor of 10 is equivalent to penalizing nighttime sound levels by adding 10 dB.)

For a given value of exterior DNL, the corresponding value of exterior <SEL> will increase as the number of effective daily operations decreases, as presented in Table 1. Thus, while a structure located on the DNL 65 dB contour around

TABLE 1 AVERAGE SEL AS A FUNCTION OF DNL AND N_{eff}

Exterior DNL (dB)	N_{eff}	Exterior <SEL> (dB)	Minimum NLR (dB)	Interior <SEL> (dB)
65	500	87.5	20	67.5
	100	94.5	20	74.5
	50	97.5	20	77.5
70	500	92.5	25	67.5
	100	99.5	25	74.5
	50	102.5	25	77.5
75	500	97.5	30	67.5
	100	104.5	30	74.5
	50	107.5	30	77.5

a large airport might experience a mean exterior SEL value of 87.5 dB, a structure located on the same DNL contour around a smaller airport might experience a mean exterior SEL value that is 5 to 10 dB higher. Providing the minimum required NLR in each of these situations results in mean interior SEL values from 67.5 dB at large airports to 77.5 dB at small airports.

The physical interpretation of this is as follows. Because of the larger number of operations on a given runway at a large airport than at a smaller airport, a given DNL contour is farther from that runway at the large airport than it is at the smaller airport. Thus, for an average overflight at the larger airport, the aircraft is farther from a point on that DNL contour than it would be for a similar point on the corresponding DNL contour at a smaller airport. As a result, the mean value of SEL for the overflight at the larger airport is less than the mean value of the SEL for the overflight at the smaller airport.

Clearly, if the goal of the sound insulation program is to prevent activity interference by maintaining an interior value for a single-event metric that is independent of the size of the airport, the structure near the smaller airport should receive more acoustic insulation than does the structure near the larger airport. This would occur if a single-event metric is used for the criterion for acoustic insulation modification designs. It would not occur if the DNL metric is used for this purpose.

This argument also applies to homes near lesser-used runways at large airports. A home situated on a given DNL contour adjacent to such a runway will be exposed to single-event noise levels that are higher than those experienced at a home on the same DNL contour adjacent to the main runway. Thus, to achieve the same interior value for a single-event noise metric in both homes, more acoustic insulation would be required in the home near the lesser-used runway than would be required in the home near the main runway.

A criterion based on a single-event metric does not conflict with the present AIP Handbook as long as it leads to acoustic insulation designs that provide at least the minimum NLR value discussed earlier.

Which, then, is the best single-event metric for the purpose, SEL or ALM, and what is the appropriate value for that metric? As will be discussed in the following paragraphs, both metrics have advantages and disadvantages.

ALM is the maximum sound level during an overflight. Thus, in general, the interior ALM value is easy to measure above the background sound level inside the home, even when the structure has been well insulated and the overflight does not occur directly overhead. However, the ALM value corresponds to the level at a single instant of time. As a result, it is subject to wide variations from overflight to overflight of the same type of aircraft at the same distance because of the varying effects on sound propagation of atmospheric turbulence.

Use of SEL minimizes some of these problems because it measures the energy in the entire overflight (defined as the interval between the time at which the sound level is initially 10 dB below the ALM value for the overflight and the time at which the sound level is again 10 dB below that ALM value). Thus, rapid temporal variations in instantaneous sound level caused by atmospheric turbulence are averaged out. In addition, an NLR value defined as the difference between measured exterior and interior SEL values is more closely representative of an average for the entire structure than is the difference between the exterior and interior ALM values.

However, practically speaking, if the house has been well insulated and if the overflight does not occur directly overhead, the two 10-dB-down points for the overflight may be below the background sound level inside the house. Thus it may be difficult to measure accurately the interior SEL after the structure has been acoustically insulated.

On balance, although it may require more effort to measure the interior SEL value of an acoustically insulated structure than to measure the interior ALM value, the SEL value is superior for use in a criterion for the design of acoustic insulation modifications.

DESIGN CRITERION

What, then, should be the interior SEL goal for the design of acoustic insulation modifications? Studies (*3*) have shown that essentially 100 percent sentence intelligibility is achieved indoors with an A-weighted background level of 52 dB. Thus, if the interior ALM for an overflight is below this level, speech interference will be minimal.

In order to relate this ALM value to an interior SEL value, the FAA's Integrated Noise Model (INM), Version 3.9, was used in a grid-point analysis to obtain SEL values for departures and arrivals of several Stage 2 and Stage 3 aircraft. At the same time, the data base within INM was examined to determine corresponding ALM values for these flight operations.

Figure 1 shows the results of this analysis for a narrowbody Stage 2 aircraft (727), a narrowbody Stage 3 aircraft (737-300), and a widebody Stage 3 aircraft (L-1011). Data have been included for thrusts corresponding to takeoff and to approach. It is seen that all of the data points lie within a 5-dB band.

Figure 1 also shows the least squares linear fit to these data for which ALM is given as a function of SEL by the expression

$$\text{ALM} = 1.17\ \text{SEL} - 24.5 \quad \text{dB}$$

Alternately, SEL is given as a function of ALM by the expression

$$\text{SEL} = 0.85\text{ALM} + 20.9 \quad \text{dB}$$

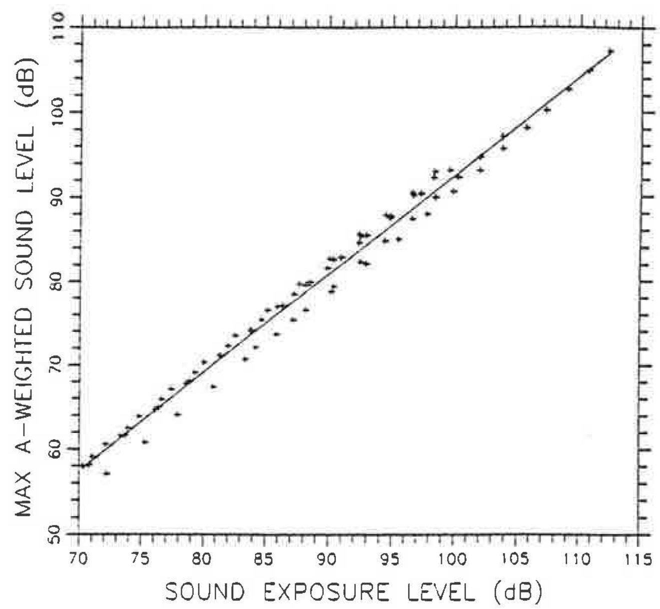

FIGURE 1 Relation between maximum A-weighted sound level (ALM) and sound exposure level (SEL).

Using this relationship, an ALM value of 52 dB corresponds roughly to an SEL value of 65 dB.

Thus, the criteria proposed to be used in developing acoustic insulation modification designs are as follows:

- In all major habitable rooms, provide sufficient acoustic insulation so that the more stringent of the two following interior levels is achieved: DNL = 45 dB and <SEL> = 65 dB, where <SEL> is the mean value, on an energy basis, of the sound exposure levels of all overflights during a 24-hr period.
- In all rooms for which the above criterion indicates that sound insulation modifications are required, increase the NLR by at least 5 dB.

Because the mean value of the daily sound exposure levels is used in these criteria rather than the maximum value, there will still be occasional overflights during which some speech interference occurs. However, past experience has indicated that use of the maximum SEL value, rather than the mean SEL value, as a design criterion leads to NLR goals that are impossible to achieve with commercially available sound insulation materials.

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