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Computing Number of People Awakened by Aircraft Operations Noise

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The acoustics literature documents a number of field studies in which aircraft noise was measured in people's bedrooms while their awakening was simultaneously monitored. Nearly all the field studies produced a dose-response relationship between noise and an awakening response. These dose-response relationships generally show good agreement with each other. Virtually without exception, however, these relationships pertain to (1) the indoor noise dose produced by a single aircraft flyover and (2) the chances that the noise dose will awaken an average person. These dose-response relationships are too limited for application to a full night of operations and to a realistic population of varying individual sensitivities to noise-induced awakenings. The relationships do not account for multiple aircraft exposures during the night or for person-to-person variation in how soundly different people sleep. This paper first briefly reviews a method previously reported for applying the study data to a full night of operations, accounting for time of night and for individual sensitivity to awakening. It then compares percent of population awakened for realistic situations, using three different dose-response relationships, two of which are presented and discussed in a working group final draft ANSI Standard S12.9, Part 6.

1 The Basic Method

A recently published [1] pragmatic application of sleep awakening data has been incorporated in part in a working group final draft ANSI standard [2]. The application uses a dose-response relationship and computes the number of people or percent of a population likely to be awakened at least once during a night of aircraft noise events (ANE) [3].

Essentially, the method uses a dose-response relationship to determine first the probability that a single event will produce an awakening, and then converts this probability into one of NOT being awakened (1 minus the probability of being awakened). Next, the probability of NOT being awakened all night by multiple events is computed as the joint probability of not being awakened by any of the nighttime events. Finally, the probability of being awakened at least once by any of the nighttime events is one minus the probability of not being awakened at all. Eq. (1) expresses this approach.

$$\begin{aligned} p_{awake\ once,\ multiple} &= 1 - p_{sleep\ thru,multiple} \\ &= 1 - \prod_{a=1}^{N} \left(p_{sleep\ thru,single} \right)_a \\ &= 1 - \prod_{a=1}^{N} \left(1 - p_{awake,single} \right)_a , \end{aligned} \tag{1}$$

Where:

N = index across all noise events during the night, and

$p_{awake,single}$ is the probability of being awakened by the *nth* single event.

2 3 Dose-Response Relationships

The three different dose-response relationships used in this paper to compute awakenings all have the same fundamental form:

$$p_{awake,single} = \frac{1}{1 + e^{-Z}} \tag{2}$$

Where

$$Z = \beta_0 + \beta_L L_{AE} + \beta_T T_{retire} + \beta_S S_{sensitivity} \tag{3}$$

And

$\beta_0, \beta_L, \beta_T, \beta_S$ = Constants

L_{AE} = Indoor SEL

T_{retire} = Time since retiring, minutes

$S_{sensitivity}$ = Sensitivity for population segment

The sensitivity variable represents a distribution, with the population divided into a range of sensitivities based on logistic regression applied to many different subjects and their awakening responses to aircraft noise events. (This distribution of sensitivities to awakening is found to closely approximate a Gaussian distribution. [1])

The values of the constants for each of the three dose-response relationships are given in Table 1.

Awakening Dose-Relationship	β_0	β_L	β_T	β_S
ANSI (1)t	-6.8884	0.04444	0	0
ANSI (2)	7.594	0.04444	0.00336	0
W/SENS	-10.723	0.08617	0.00402	Multiple [1]

Table 1 Eq. (3) Constants for the 3 Different Relationships

In Table 1, ANSI (1) is the relationship identified in the ANSI working group final draft standard as Equation (1). It provides probability of awakening as a function of only the indoor SEL. ANSI (2) is Equation (2) of the draft standard and includes time of night in the probability of awakening. W/SENS is discussed in reference [1] and includes sleeper sensitivity to awakening. Reference [1] documents derivation and all the sensitivity constants as a function of percent of population with each level of sensitivity.

Direct comparison of these three relationships is confounded because they each apply to a different set of variables. Fig. 1, however, provides a limited comparison by selecting specific values for each variable. The figure compares the relationships at 1 hour after retiring for ANSI (2) and W/SENS and for the median sensitivity for W/SENS. It should be noted that ANSI (1) and ANSI (2) are identical when the time since retiring equals 210 minutes or 3.5 hours, one half the seven hours that adults sleep on average [2].

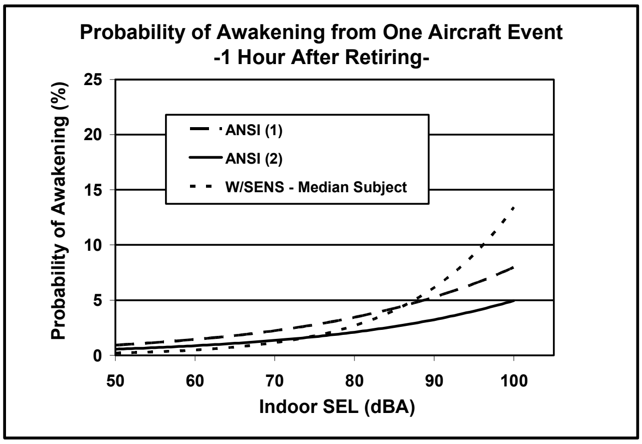

Fig.1 Comparison of the Three Dose-Response Relationships

3 Specific Scenarios Compared

For purposes of comparing the three relationships, each is applied to a specific scenario including a realistic distribution of SEL values, three different numbers of nighttime aircraft noise events (ANE), and three different outdoor-to-indoor noise reductions.

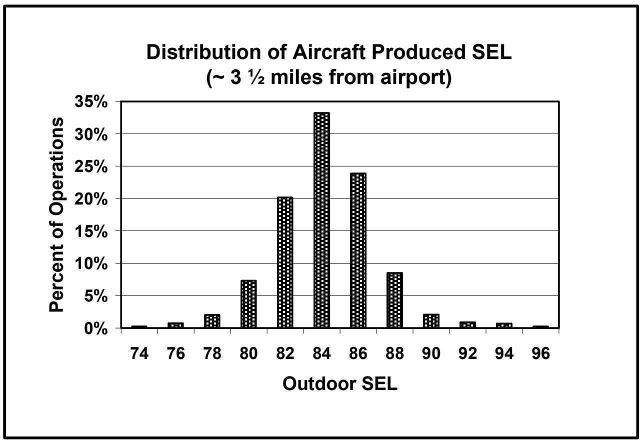

Fig.2 Outdoor SEL Distribution Used for Scenario

Fig. 2 gives a distribution of aircraft produced SEL measured by a permanent noise monitor located about 3½ statute miles from the airport (at the approximate location of the 65 dB Ldn level for that airport).

Table 2 gives the assumed distribution of nighttime ANE. For purposes of this comparison, these events are grouped into thirds of the night. Compared with distribution 1, distribution 2 and distribution 3 might both be the result of a significant increase in operations at an airport, with no increase in capacity – operations arrive later at night (distribution #2) or leave earlier in the morning (distribution 3).

Finally, awakenings are computed assuming the three different outdoor-to-indoor noise reductions listed in Table 4.

ANE by Hour			
Starting:	Dist #1	Dist #2	Dist #3
10pm 11pm Midnight	20	35	20
1am 2am 3am	5	5	5
4am 5am 6am	20	20	35
Total	45	60	60

Table 2 Assumed Distributions of Nighttime ANE

Outdoor to Indoor Noise Reduction		
15 dB	23 dB	30 dB
(Window Open)	(Window Closed)	(Sound Insulated)

Table 34 Assumed Reductions of Outdoor SEL

4 Results of the Comparisons

Fig. 3, Fig. 4 and Fig. 5 show the computed percent awakenings for the three distributions, for the three outdoor-to-indoor noise reductions. The relative percents across the three different relationships demonstrate some expected trends. All relationships show decreasing awakenings with increasing outdoor-to-indoor sound reductions, and all show increased awakenings with increased operations, except that, as expected ANSI (1) shows no difference between distribution 3 and 4, because they both have the same number of operations, but at different times of night.

Fig. 6 shows how use of the different relationships affects computed changes in awakenings due to increasing outdoor-to-indoor sound insulation from 23 dB to 30 dB. For all distributions of operations, W/SENS gives greater reductions in awakenings than do ANSI (1) or ANSI (2).

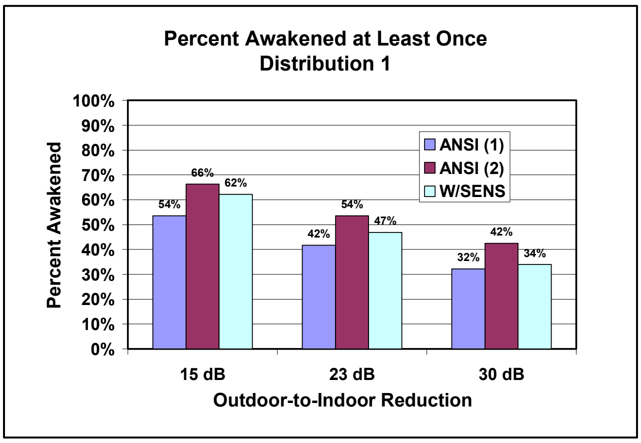

Fig.3 Results for Different Relationships, Distribution 1

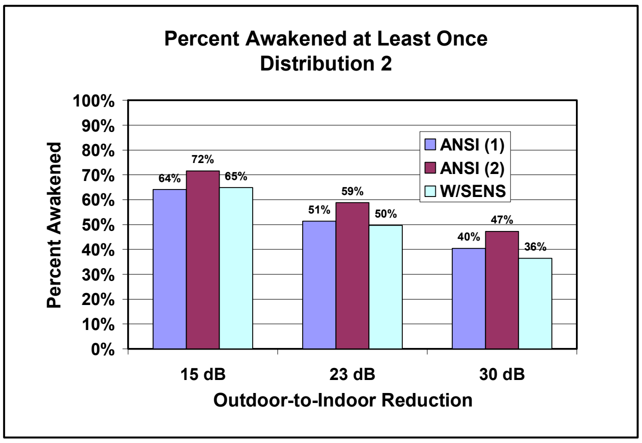

Fig.4 Results for Different Relationships, Distribution 2

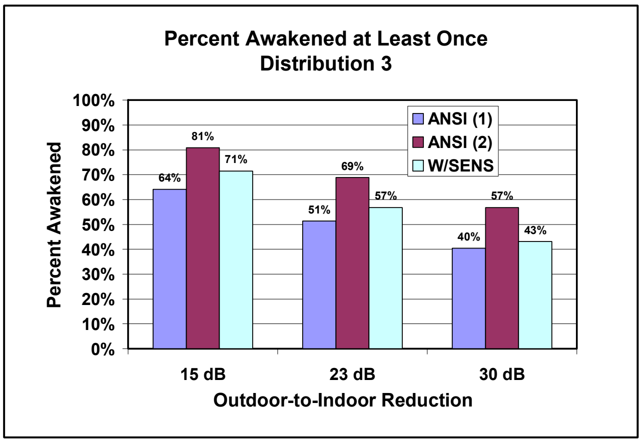

Fig.5 Results for Different Relationships, Distribution 3

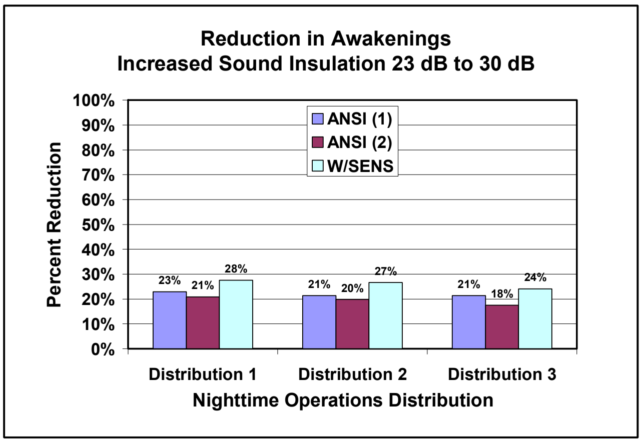

Fig.5 Reductions in Awakenings from Sound Insulation

5 Conclusions

The working group draft final ANSI standard provides a pragmatic general method for estimating the awakening effects of nighttime noise events. By applying this method to the two dose-response relationships described in the standard and the one of reference [1], this paper demonstrates the relative differences that can be expected when using these relationships.

All three relationships produce roughly similar results. However, the relationship - ANSI (1) - that uses only the indoor SEL as a variable will show no time-of-night effect – an effect that was strongly indicated ($p < 0.01$) in the regression analysis of reference [1], and has been observed by others [4]. The author judges this phenomenon important in assessing the effects likely to occur as air travel increases and nighttime operations become more likely. Inclusion of population sensitivity, though not widely researched, may provide additional analysis possibilities. Awakening responses are very complex [5] and if an additional factor such as sensitivity can be confirmed and included in predictive methods, better informed decisions might be possible regarding effects of nighttime noise on communities, sound insulation benefits, nighttime operations scheduling, nighttime runway use, etc.

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References

[1] Anderson, G.S. and N.P. Miller, "Alternative analysis of sleep-awakening data," *Noise Control Eng. J.* 55 (2), 2007 March-April.

[2] BSR/ASA S12.9-200X / Part 6 (Revision of ANSI S12.9-2000 (R2005))

[3] The application in the ANSI working group final draft has application beyond aircraft noise and is intended to apply in homes near areas of routine jet aircraft takeoff and landing operations, railroads, roads and highways.

[4] M. Brink et al., "Effects of early morning aircraft overflights on sleep and implications for policy making," EuroNoise 2006, Tampere, Finland (2006)

[5] Multiple studies have revealed this complexity. See, for example:

a. 1.K. S. Pearsons et al., "Analyses of the predictability of noise-induced sleep disturbance," Report HSD-TR-89-029, Noise and Sonic Boom Impact Technology, Human Systems Division, Air Force Systems Command, Brooks Air Force Base, Texas (1989).

b. 26.J. B. Ollerhead et al., "Report of a field study of aircraft noise and sleep disturbance," Department of Transport, Civil Aviation Authority, U.K. (1992)

c. 27.W. Passchier-Vermeer et al., "Sleep disturbance and aircraft noise exposure: Exposure-effect relationships," Report TNO 2002.027, Division Public Health, The Netherlands (2002).