How many people will be awakened by nighttime aircraft noise?

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INTRODUCTION

Increasing demand for air travel has prompted plans by several airports around the U.S. to increase their capacity, primarily by adding new runways or by extending existing ones. These capacity-increase plans usually raise public concerns about increased noise. One common concern is increased sleep disturbance. In response to this public concern, some of the associated environmental documents attempt to address sleep disturbance. The relevant environmental regulations do not prescribe specific criteria, metrics, or computation methods for determining sleep disturbance.

Now, however, a recently published method, Anderson & Miller (2007), based on analysis of sleep awakening data has been incorporated in part in a working group final draft ANSI standard, ANSI (R2005). 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).

METHOD BASED ON PROBABILITY OF AWAKENING

The method determines the number of people or percent of the population likely to be awakened at least once from a full night of ANE. Most sleep disturbance data are reduced to a relationship of the form of a dose-response curve similar to that shown in Figure 1, from Marks et al. (2008).

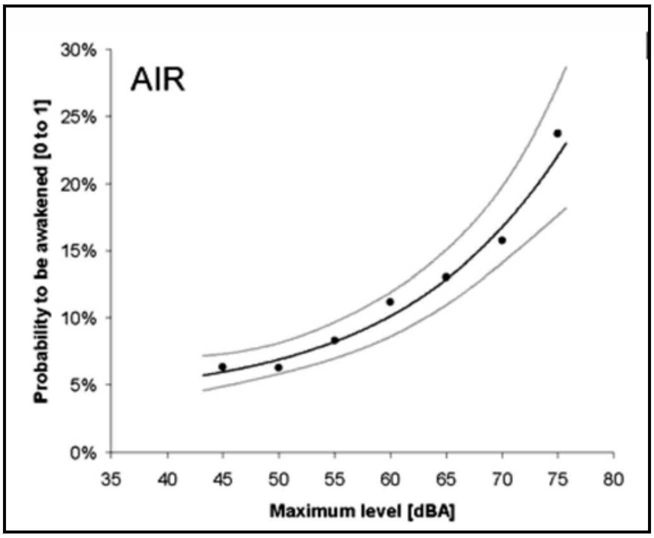

Figure 1: Representative dose-response curve derived from polysomnogram records

Such relationships cannot be applied directly to determine awakenings that may result from a full night of ANE. However, such a dose-response relationship can be used to determine first the probability that a single event will produce an awakening. This probability may then be converted into a probability 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 night time events. Finally, the probability of being awakened at least once by any of the night time events is one minus the probability of not being awakened at all. Eq. (1) expresses this approach,

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

where:

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

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

Hence, if Figure 2 gives the probability of awakening an average person by a single aircraft, then application of this method for multiple aircraft (all with the same Sound Exposure Level) gives Figure 3 which shows how the probability of awakening for this average person is affected by multiple aircraft during the night.

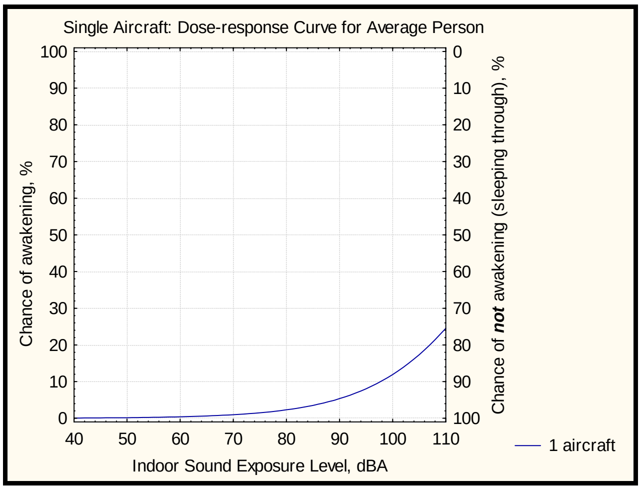

Figure 2: Dose-response curve for probability of awakening from one aircraft, average person

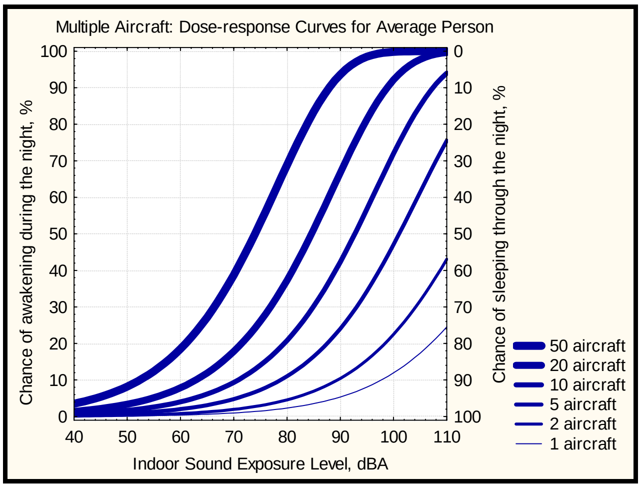

Figure 3: Dose-response curves for multiple aircraft, average person

REFINEMENT OF DOSE-RESPONSE CURVE

By applying logistic regression to raw awakening data, more variables may be included in the dose-response curves. Data for these regressions were obtained in people's homes by Dr. Sanford Fidell and his co-workers, have been previously reported in the acoustical literature, Fidell et al. (1994, 1995a, b, 2000), and were provided to HMMH courtesy Larry Finegold and Robert Lee. Data were from studies in communities around Denver International, Los Angeles International and Castle Air Force Base.

Data were of the form pictured in Figure 4. In this figure, each vertical column represents the results for one subject; subject numbers are given on the horizontal axis. For each subject, the indoor SEL of each event, its time of occurrence, and whether or not it resulted in a behavioral awakening were contained in the data set. Hence regressions could include not only SEL, but also time of night and subject.

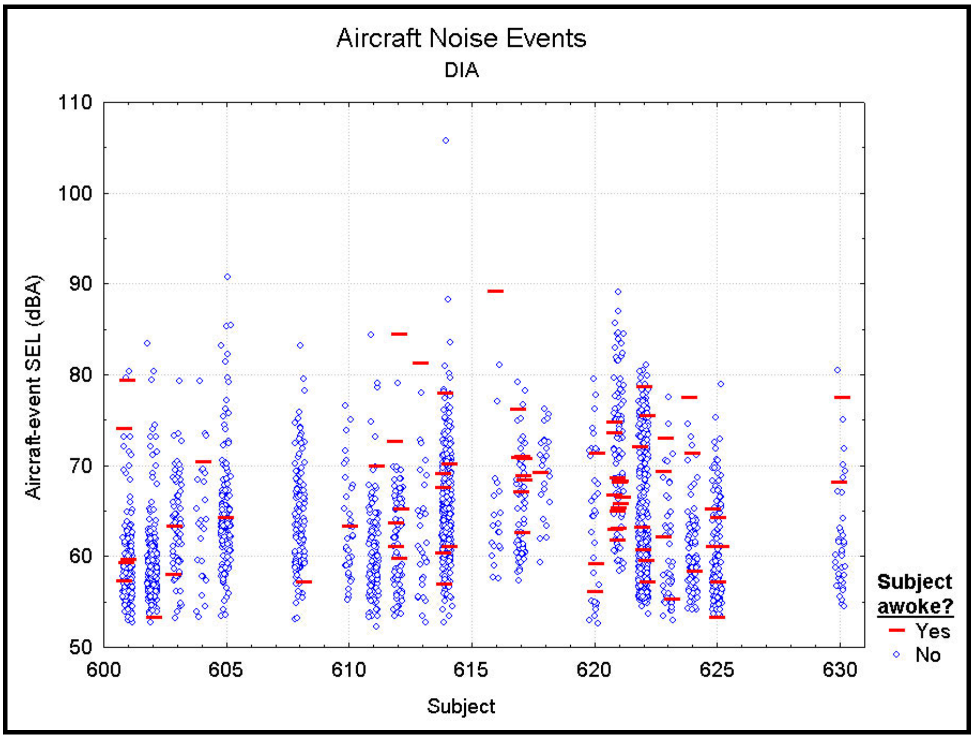

Figure 4: Aircraft noise events experienced by subjects at Denver International

The analyses of these three data sets provided results of the form:

$$p_{awake,single} = \frac{1}{1+e^{-Z}} \qquad \text{Eq. (2)}$$

where

$$Z = \beta_0 + \beta_L L_{AE} + \beta_T T_{retire} + \beta_S S_{sensitivity} \qquad \text{Eq. (3)}$$

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 ANSI working group draft provides two methods for computing the awakenings from a full night of ANE: 1) as a function of only SEL – a non-zero constant β_L, 2) as a function of SEL and time since retiring, β_T, based on Anderson & Miller (2007). For the purposes of this paper, an additional relationship is examined: inclusion as well of subject sensitivity to awakening, β_S. Table 1 lists the values of the constants for each awakening relationship. For β_S, Anderson & Miller (2007) suggest dividing the population into 33 groups with constants as in Table 2. These sensitivities are applied to populations at points where the populaton around each point experiences uniform exposure to ANE during the night. (For a detailed description of application see Anderson & Miller 2007.)

Table 1: Values of Eq. (3) constants for the three methods used to compute awakenings

Awakening Dose-Response Relationships	β_0	β_L	β_T	β_S
ANSI (1)	-6.8884	0.04444	0	0
ANSI (2)	7.594	0.04444	0.00336	0
W/SENS	-10.723	0.08617	0.00402	(Table 2)

Table 2: Values of β_S in Eq. (3)

Population group number	Sensitivity (β_S in Eq. 1)	Fraction of population
1	-4.00	0.000984848
2	-3.75	0.001666667
3	-3.50	0.002727273
4	-3.25	0.00430303
5	-3.00	0.006590909
6	-2.75	0.009757576
7	-2.50	0.013924242
8	-2.25	0.019227273
9	-2.00	0.025621212
10	-1.75	0.033015152
11	-1.50	0.041075758
12	-1.25	0.049393939
13	-1.00	0.057378788
14	-0.75	0.064393939
15	-0.50	0.069818182
16	-0.25	0.073136364
17	0.00	0.074015152
18	0.25	0.072378788
19	0.50	0.068378788
20	0.75	0.062409091
21	1.00	0.055030303
22	1.25	0.046878788
23	1.50	0.038590909
24	1.75	0.030681818
25	2.00	0.023575758
26	2.25	0.0175
27	2.50	0.012545455
28	2.75	0.00869697
29	3.00	0.005818182
30	3.25	0.003757576
31	3.50	0.002348485
32	3.75	0.001424242
33	4.00	0.000833333

APPLICATION TO REALISTIC SCENARIOS

By using the probability of awakening method and the three different dose-response relationships defined by Eq. (2) and Eq. (3), the percent of people awakened can be computed for different realistic scenarios. For this paper, the awakenings are computed at a single point with assumed distributions of ANE. The assumptions include a realistic distribution of SEL values, three different numbers of nighttime aircraft noise events (ANE), and three different outdoor-to-indoor noise reductions.

Figure 5 gives the assumed distribution of aircraft produced outdoor SEL. This distribution was measured by a permanent noise monitor located about 3½ statute miles from the airport (at the approximate location of the 65 dB L_{dn} level for that airport).

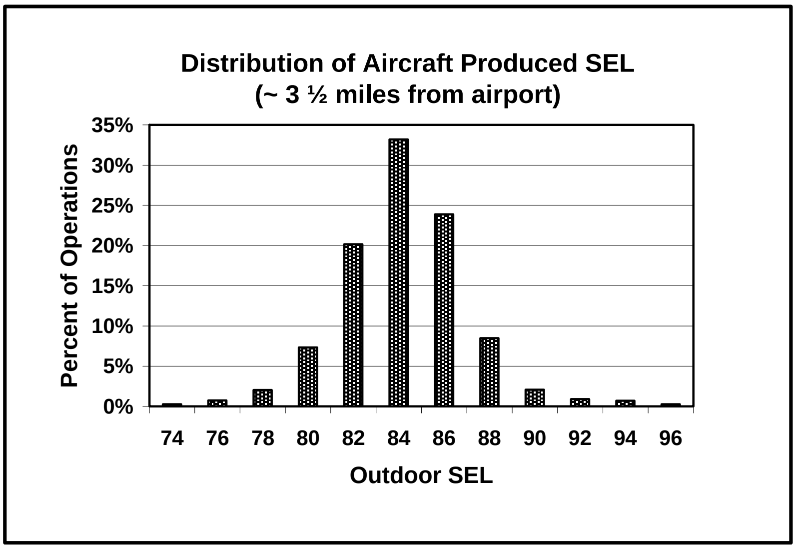

Figure 5: Assumed distribution of outdoor SEL values

Two different distributions of nighttime ANE are assumed, Table 3. For purposes of this comparison, these events are grouped into thirds of the night. These distributions are intended to represent what might occur when increases in operations are not matched by increases in airport capacity. If distribution 1 represents an existing condition, then distribution 2 and distribution 3 might both be the result of a significant increase in operations at the airport, with no increase in capacity – operations arrive later at night (distribution #2) or leave earlier in the morning (distribution 3).

Table 3: Assumed distributions of nighttime ANE

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

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

Table 4: Assumed Distributions of Nighttime ANE

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

RESULTS

Figures 6, 7 and 8 give the percent of the population awakened at least once for all scenarios. The 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 2 and 3, because they both have the same number of operations, but at different times of night.

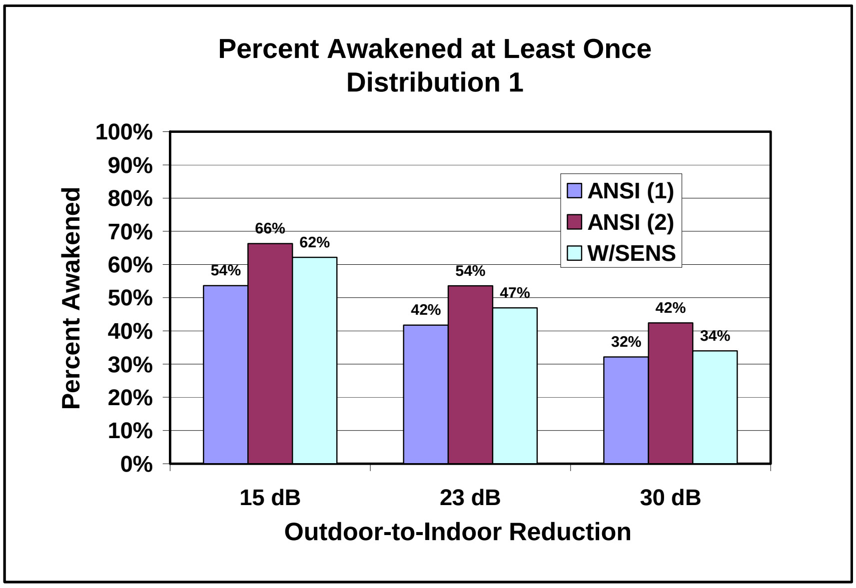

Figure 6: Results for different relationships, distribution 1

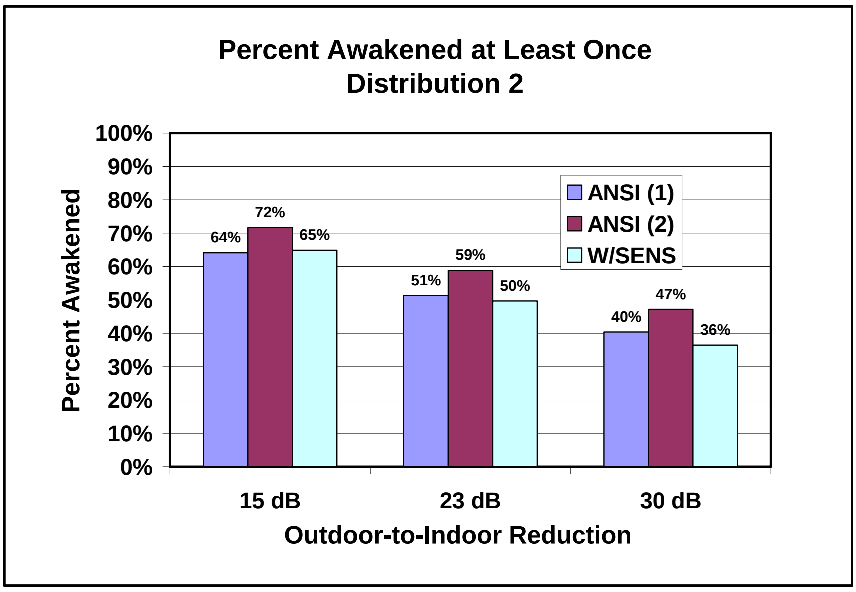

Figure 7: Results for different relationships, distribution 2

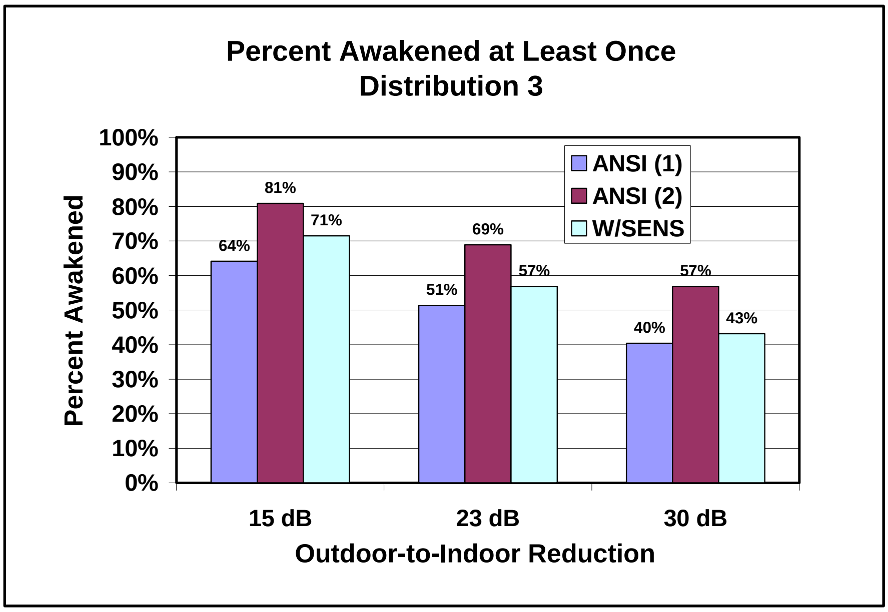

Figure 8: Results for different relationships, distribution 3

Interestingly, when sensitivity is included, the benefits in reduced awakenings produced by sound insulation are greater than those shown by either of the other two methods, Figure 9. Heuristically this result makes sense because sound insulation lowers the distribution of ANE and for ANSI (1) and ANSI (2) this is equivalent to moving down a single dose-response curve, whereas for W/SENS, this lowering means some people (those less sensitive) will drop out of the computations – their probability of awakening becomes relatively smaller or approaches zero.

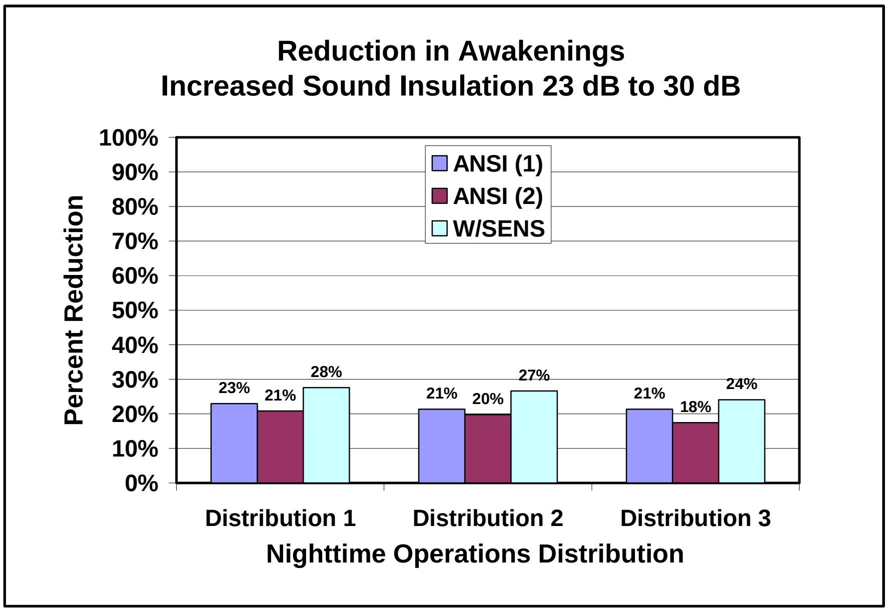

Figure 9: Reductions in awakenings produced by sound insulation as computed by the three methods

CONCLUSIONS

The working group draft final ANSI standard provides a pragmatic general method for estimating the awakening effects of night time noise events. By applying this method to the two dose-response relationships described in the standard and the one of Anderson & Miller (2007), 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 Anderson & Miller (2007), and has been observed by others, Brink et al. (2006). The author judges this phenomenon important in assessing the effects likely to occur as air travel increases and night time operations become more likely.

Without the inclusion of population sensitivity, though not widely researched, it appears over estimation of awakening may occur. Awakening responses are very complex, see for example Passchier-Vermeer et al. (2002), and if this additional factor of sensitivity can be confirmed and included in predictive methods, better informed decisions might be possible regarding effects of night time noise on communities, sound insulation benefits, night time operations scheduling, night time runway use, etc. In any event, any of these methods will provide more information about the likely effects of night time ANE than do cumulative measures such as Day-Night Average Sound Level, which have shown no useful predictive association with sleep disturbance, Fidell et al. (1995a).

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