# APPENDIX K DEVELOPMENT OF THE ANSI SLEEP STANDARD

The Origins of the Methods Described in the ANSI Standard

Years of sleep disturbance research and then synthesis of those research results provided a practical method to compute number of people awakened from a full night of aircraft operations. That practical method eventually led to development of the current version of the ANSI Standard. [17]

Sleep Disturbance Research

Night time aircraft noise can awaken people living near an airport, and there have long been efforts to quantify the circumstances that produce such awakenings.   Such research has involved documenting the reactions of sleeping subjects to measured noise levels, either in a laboratory or in "field studies" in their homes.   The subjects are sometimes attached to instrumentation that measures such things as heart rate, brain activity and physical movement, or they may be asked to simply press a button on a computer next to their bed or on a bracelet whenever they awaken. Noise events may be played through speakers, or may be a result of aircraft flying over their homes. In general, the results of such studies are summarized in a form similar to Figure K-1.

Figure K-1 Typical Experimentally Determined Relationship between Indoor SEL and Percent of Population Awakened
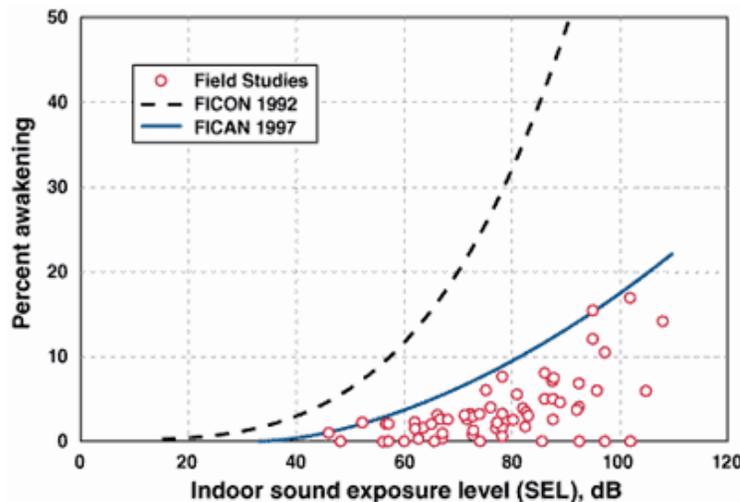
Curves like those plotted in Figure K-1 mathematically represent the summation of the results, showing what percent of the people who experienced the various sound levels were awakened. In the figure, the FICAN 1997 curve shows, for example, that for an indoor Sound Exposure Level of 80 dB, a maximum of about 10 percent of those who experience it are likely to be awakened.

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[17] American National Standard, ANSI / ASA S12.9-2008 / Part 6, "Quantities and Procedures for Description and Measurement of Environmental Sound — Part 6: Methods for Estimation of Awakenings Associated with Outdoor Noise Events Heard in Homes." This Standard is available for purchase at: http://webstore.ansi.org/.

But the issue with most night time noise is not what percent will be awakened by a single event, but what percent or number of people will be awakened by the full night of events. The answer to the second question is much more practical, particularly in assessing changes in night time noise or ways to reduce the effects of night time noise.

Putting Sleep Research Results to Practical Use

In 2007, a pragmatic approach for using sleep research results was proposed. [18] This approach used the awakening data on each of 84 subjects who lived around Los Angeles International (31 subjects), Denver International Airport (29 subjects) and Castle Air Force Base (24 subjects). The U.S. Air Force provided these data, which were previously obtained by Dr. Sanford Fidell and his co-workers under contract to the U.S. Air Force and NASA and were previously reported. [19,20,21,22] The data on each subject included the time and level of each aircraft noise event as measured in the sleeping room, and whether the subject awoke or not.

First Analysis Result – New Awakening Relationships

The first level of analysis provided by Anderson and Miller developed two primary equations that gave the probability that an average person would awaken dependent on the indoor Sound Exposure Level (SEL). One equation gave the probability independent of when during the night the aircraft noise event occurred, while the second one included the time of night. The results for the second equation showed that the later in the night an event occurred, the more likely a person is to awaken – probability of awakening depends on time of night.

Figure K-2 and Figure K-3 present examples of how, when the time of an event is later, the probability of awakening increases. These results, however, still provide no way to account for a full night of aircraft noise events. The second analysis of the article (footnote 21), gives a method.

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[18] Anderson, G.S. and Miller, N.P., "Alternative analysis of sleep-awakening data," Noise Control Eng. J. 55 (2), 2007 March-April
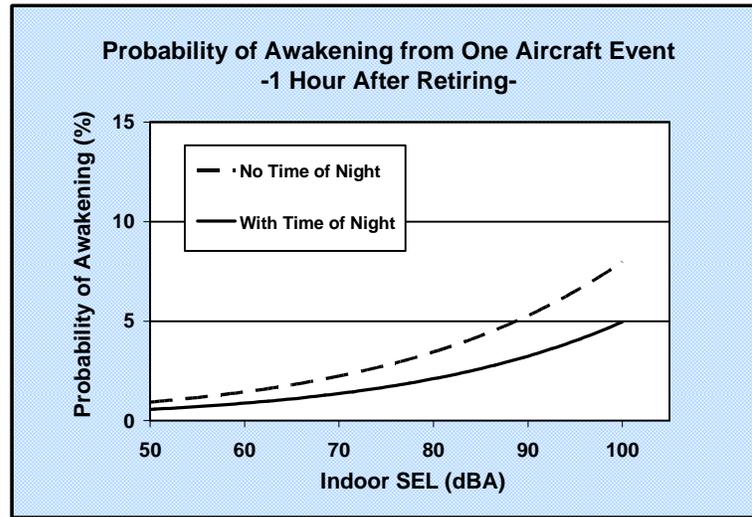
[19] S. Fidell et al, "Noise-induced sleep disturbance in residential settings," Report AL/OE-TR-1994-0131, Occupational & Environmental Health Division, Armstrong Laboratory, Wright Patterson Air Force Base, Ohio (1994).

[20] S. Fidell et al, "Field study of noise-induced sleep disturbance," J. Acoust. Soc. Am. 98(2), (1995)
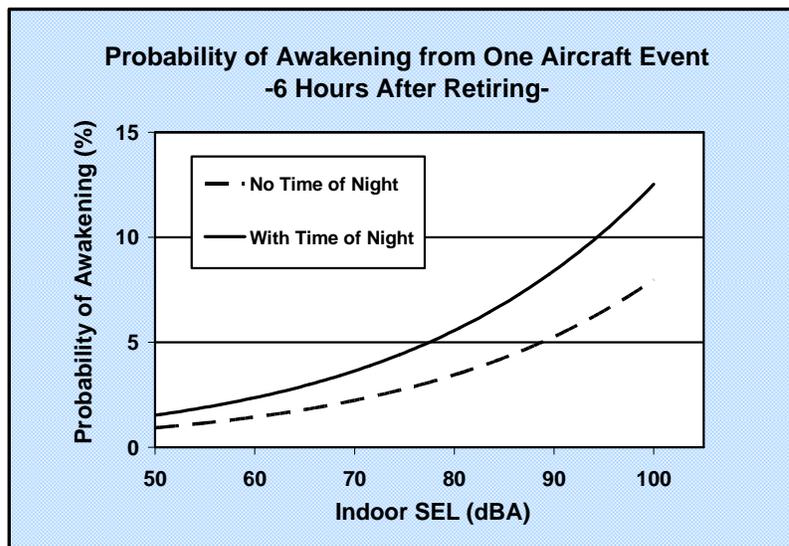
[21] S. Fidell et al, "Effects on sleep disturbance of changes in aircraft noise near three airports," J. Acoust. Soc. Am. 107(5), (2000)

[22] S. Fidell et al, "Noise-induced sleep disturbance in residences near two civil airports," NASA Contractor Report 198252, Contract NAS1-200101 (December 1995)

Figure K-2 Analysis Results for 1 Hour after Retiring

**Probability of Awakening from One Aircraft Event
-1 Hour After Retiring-**

- - - No Time of Night
—— With Time of Night

Probability of Awakening (%)

Indoor SEL (dBA)

Figure K-3 Analysis Results for 6 Hours after Retiring

**Probability of Awakening from One Aircraft Event
-6 Hours After Retiring-**

- - - No Time of Night
—— With Time of Night

Probability of Awakening (%)

Indoor SEL (dBA)

## *Second Analysis Results – Accounting for a Full Night of Operations*

The relationships shown in Figure K-2 and Figure K-3 give probability of awakening. Figure K-4 shows how this probability is translated simply to the probability of sleeping through; i.e., of not awakening from the event. Sleeping through is simply one minus the probability of awakening. If the probability of awakening is 10%, then the probability of not awakening is 90%. If there are two events, then the probability of sleeping through both is 90% times 90% or 81% chance of not awakening.

In the same way, the probability of sleeping through any number of events can be computed. Once all the events in a night are included, then one minus the total probability of sleeping through all events is the probability of not sleeping through them all or the probability of awakening at least

once during the night. The result can be interpreted as the percent of people likely to be awakened at least once during the night since the equations of the first analysis are based on averages. The result can also be interpreted as the probability the average person will be awakened at least once during the night.

Figure K-4 Translating Probability of Awakening to Probability of Sleeping Through an Aircraft Event
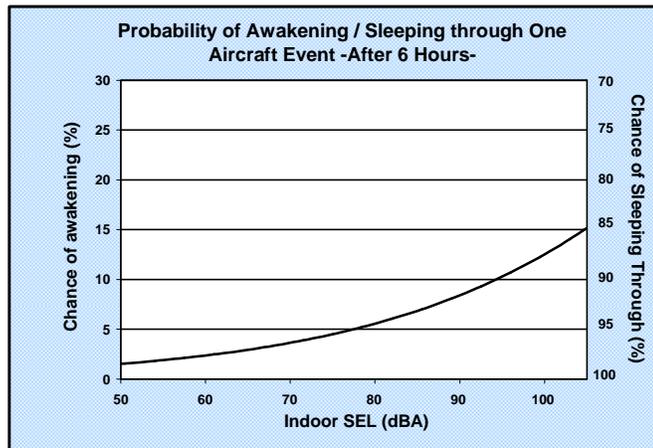
DEVELOPMENT OF THE STANDARD

The American National Standards Institute, Inc. (ANSI) has served as administrator and coordinator of the United States private sector voluntary standardization system for more than 90 years. ANSI has as its primary goal the enhancement of global competitiveness of U.S. business and the American quality of life by promoting and facilitating voluntary consensus standards and conformity assessment systems and promoting their integrity.

ANSI facilitates the development of American National Standards by accrediting the procedures of standards developing organizations. One of those standards organizations is the Acoustical Society of America, providing several ANSI accredited Standards Committees on topics related to acoustics. Specifically, Standards Committee S12 develops and revises standards related to noise.

Committee S12 recognized that since the awakening Standard was first approved in 2000, considerable additional data on sleep disturbance had become available. Following its approved operating procedures, the Working Group 15 of Committee S12 met over the course of several years, reviewing available data and methods developed by credible sleep disturbance studies, both in the U.S. and in other countries. [23]

The committee reached consensus on several important issues, including the following two. First, actual (behavioral) awakening would be the type of sleep disturbance addressed. Several European researchers suggest that physical movement ("motility") is the appropriate indicator of sleep disturbance, [24] while others consider changes in or time spent in different sleep stages the important

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[23] Note that Committee S12 has a number of working groups, each working on different aspects of noise and noise control. Working Group 15 is "Measurement and Evaluation of Outdoor Community Noise"

[24] Miedema, H.M.E., W. Passchier-Vermeer, H. Vos, "Elements for a position paper on night-time transportation noise and sleep disturbance," TNO Inro report 2002-59, 2002

measure of sleep disturbance.[25] This decision was based in part on the limited ability to relate these other measures to actual awakenings, the overall uncertainty of the relationship of any type sleep disturbance to health effects, and on the ease of communicating to a lay public the concept of increased or decreased behavioral awakenings.

Second, rather than use a cumulative noise metric such as the Day-Night Average Sound Level, DNL, or the equivalent night-time level, Lnight (as proposed in the reference of footnote 24), the method of Anderson and Miller would be used to compute the percent of populations likely to be awakened at least once during the night as a result of a stated distribution of aircraft SELs. It was noted that the metric of Lnight has been shown to have no correlation with awakenings.[26]

The resultant Standard, after detailed review, comments and changes by Working Group 15, was approved by Committee S12 and approved in July 2008 by the American National Standards Institute, Inc. Later that year, the Standard was reviewed by the Federal Interagency Committee on Aviation Noise (FICAN) and recommended for use in predicting awakenings from aircraft noise; see FICAN Recommendation, Appendix L.

APPLICATION OF THE STANDARD TO CHANGES IN NIGHT OPERATIONS

This section provides the technical detail on use of the Standard to estimate the percent or number of people awakened by nighttime operations at an airport.

The Equation

The relationship that predicts the probability of awakening from a single event is given by Equation K-1.

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

Equation K-1

In this equation, the variable Z is expanded in **Error! Reference source not found.**.

$$Z = \beta_0 + \beta_L L_{AE} + \beta_T T_{retire}$$

Equation K-2

Where:

$$\beta_0, \beta_L, \beta_T = \text{Constants}$$

$$L_{AE} = \text{Indoor SEL}$$

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[25] Griefahn, B., S. Robens, P. Bröde, M. Basner, "The sleep disturbance index – a measure for structural alterations of sleep due to environmental influences," Proceedings ICBEN 2008, Foxwoods, CT, U.S.A

[26] Ibid, Fidell, 1994

$$T_{retire} = \text{Time since retiring (minutes)}$$

Table K-1 gives the values of the constants. The constants are different depending on whether or not the times of night of the aircraft noise events (which are translated to time since retiring) are known.

Table K-1 Values of Equation Constants for Calculating Probability of Awakening
Source: ANSI SI12.9-2008

Determine Awakenings Using:	Values of the Constants		
	β_0	β_L	β_T
SEL values only	-6.8884	0.04444	0
SEL and Time Since Retiring	-7.594	0.04444	0.00336

The Method

Define a Grid of Points about the Airport

The Standard is used by computing percent awakened at individual points around the airport. Each point should be associated with a population number. Using census block centroids is one useful means to identify the grid of points. Alternatively, a regular grid of points may be defined, but then the population values need to be associated with the closest or most appropriate grid point.[27]

Run INM to Compute Distribution of SEL Values at each Point

The FAA's Integrated Noise Model (INM) is particularly useful because it can provide (by setting up a "detailed grid point analysis") a complete list of SEL values at each grid point. When accounting for time of night (as done in the Part 161 study) the computations are run once for the operations in each third of the night: 10:00 p.m. to 01:00 a.m., 01:00 a.m. to 04:00 a.m., and 04:00 a.m. to 07:00 a.m.

Determine Outdoor-to-Indoor Noise Level Reductions

In the sleep research, indoor SEL values that are less than about 50 dB have generally been determined to awaken few if any subjects. Hence, any indoor SEL's less than 50 dB may be eliminated from the calculations. (The Standard states that "…the probability of awakening shall be set to zero for any [SEL] that is less than 50 dB."). Because the INM computes outdoor sound levels, an outdoor-to-indoor noise level reduction needs to be selected for each grid point. For some airports, this reduction can be different for the areas where the homes have received sound insulation.[28] Adjust all computed SEL values by the outdoor –to-indoor reduction and eliminate any resulting SEL less than 50 dB.

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[27] For example, if population is concentrated away from the centroid, a grid point more closely associated with the actual distribution may be selected.

[28] In realistic applications of the Standard, sound insulation reduces the number of awakenings by 20% to 25%.

Adjust Number of Operations for Seven Hours of Sleep

The Standard recognizes that the nighttime used in the U.S. is nine hours long from 10 p.m. to 7 a.m. yet average U.S. adults sleep seven hours a night. Hence, the number of operations at each SEL value is multiplied by seven-ninths.

Compute the Number or Percent of People Awakened

The computation may be thought of as iterative across grid points and step-wise for each grid point:

- At a grid point, for each SEL value in each of the three night time periods, Equation 1 and Equation 2 with the second row of constants in Table 1 are used to compute the probability of awakening from each SEL; time since retiring that should be used for each third of the night is:

    o For events between 10:00 p.m. to 01:00 a.m. – 70 minutes

    o For events between 01:00 a.m. to 04:00 a.m. – 210 minutes

    o For events between 04:00 a.m. to 07:00 a.m. – 350 minutes

- Compute the probability of not awakening for each SEL by subtracting the probability of awakening from one

- Multiply the probability of not awakening times every other probability of not awakening during the entire night

- Subtract the resulting entire night probability of not awakening from one

- Multiply the entire night probability of not awakening by the population for that grid point

- Repeat the calculation for each grid point

- If desired, the numbers of people awakened at all grid points may be summed to yield:

    o Total number of people awakened

    o Percent of all people awakened

The following tables provide an example calculation at one point with population of 1000.

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		Distribution of Indoor SEL and Number of Aircraft Operations at Each SEL 2200-0100											
	Indoor SEL	59	61	63	65	67	69	71	73	75	77	79	81
Probability of not Awakening 2200-0100	Number of Ops, each SEL	1	2	3	2	1	2	3	2	1	2	3	2
	Tretire	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00
	7/9 * Ops	0.777778	1.555556	2.333333	1.555556	0.777778	1.555556	2.333333	1.555556	0.777778	1.555556	2.333333	1.555556
0.69489806	Prob Not Awake	0.99131	0.98111	0.969232	0.977497	0.987646	0.973208	0.95648	0.968121	0.982464	0.962096	0.938669	0.954973

		Distribution of Indoor SEL and Number of Aircraft Operations at Each SEL 0100-0400											
	Indoor SEL	59	61	63	65	67	69	71	73	75	77	79	81
Probability of not Awakening 0100-0400	Number of Ops, each SEL	1	2	1	2	0	1.5	1	2	1	2	3	0
	Tretire	210.00	210.00	210.00	210.00	210.00	210.00	210.00	210.00	210.00	210.00	210.00	210.00
	7/9 * Ops	0.777778	1.555556	0.777778	1.555556	0	1.166667	0.777778	1.555556	0.777778	1.555556	2.333333	0
0.67343872	Prob Not Awake	0.986163	0.97002	0.983515	0.964344	1	0.968051	0.976642	0.9497	0.972224	0.940357	0.904227	1

		Distribution of Indoor SEL and Number of Aircraft Operations at Each SEL 0400-0700											
	Indoor SEL	59	61	63	65	67	69	71	73	75	77	79	81
Probability of not Awakening 0400-0700	Number of Ops, each SEL	1	1	2.5	2	1	0	3	0	1	2	1	3
	Tretire	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00	350.00
	7/9 * Ops	0.777778	0.777778	1.944444	1.555556	0.777778	0	2.333333	0	0.777778	1.555556	0.777778	2.333333
0.50453709	Prob Not Awake	0.978034	0.976041	0.935955	0.943837	0.968947	1	0.893415	1	0.95627	0.907063	0.948203	0.840324

For Entire Night

Population at Point	Probability of not Awakening	Probability of Awakening	Number Awakened
1000	0.236109	0.763891	763.8911

Percent Awakened or Chance Average Person Awakened	76.38911