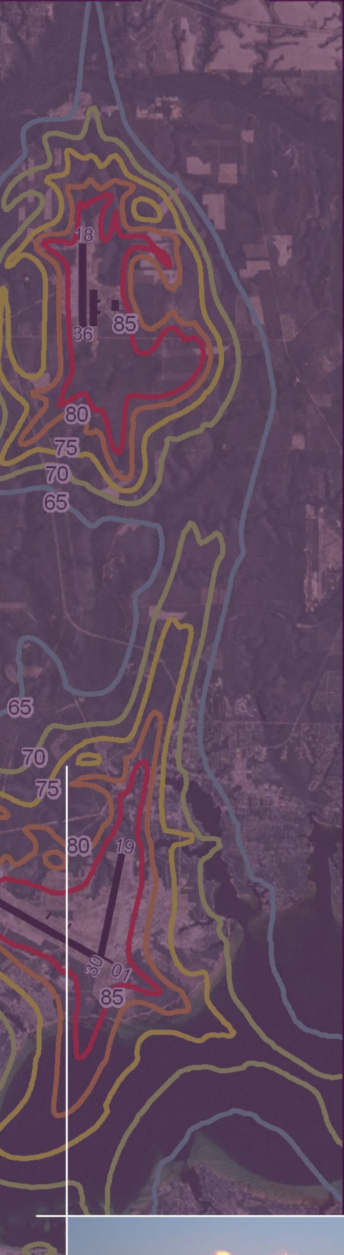


DNWG

DEPARTMENT OF DEFENSE
NOISE WORKING GROUP

TECHNICAL BULLETIN

Sleep Disturbance From Aviation Noise

December 2009

Supplementing the typical military noise exposure assessment with disclosure of aircraft noise-induced sleep disturbance will lead to better informed decisions on major operational changes and will facilitate more credible dialogue with affected communities.

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

INTRODUCTION

This *Sleep Disturbance from Aviation Noise* bulletin is one of a series of technical bulletins issued by the Department of Defense (DoD) Noise Working Group (DNWG) under the initiative to educate and train DoD military, civilian and contractor personnel, and the public on noise issues.

In compliance with the provisions of the National Environmental Policy Act of 1969 (NEPA), the DoD predicts the environmental impacts of all major proposed changes in military operations, including the effects of the noise expected from such actions on exposed communities. The Military Services execute several planning programs, such as Air Installation Compatible Use Zones (AICUZ) and Joint Land-Use Studies (JLUS), and routinely meet with the local communities to address flight operations and noise impacts in order to foster compatible land-use development in the vicinity of DoD airfields or other environments exposed to noise from military activities. The ability to convey the effects of nighttime military aircraft noise exposure, such as sleep disturbance, should facilitate both the public discussions and the environmental impact analysis process.

The loss of sleep is an irritant to the general population and is a significant component in long-term community annoyance. The most common metric used to assess military aircraft noise exposure, Day-Night Average Sound Level (DNL), includes a nighttime penalty, in part, to account for sleep disturbance potential[1]. The 10 decibel (dB) penalty added to noise levels for the period 10 PM to 7 AM (2200 hr to 0700 hr) is included to account for the increased intrusiveness of noise at night because the ambient sound level is generally lower, and more people are at home during this period than at other times of the day. Thus, the opportunities for activity interference, such as sleep disturbance, are much higher during nighttime hours, which could lead to greater annoyance. Under certain circumstances, such as operational plans that increase nighttime military aircraft flights, an estimate of the sleep disturbance effect could enhance the noise assessment.

The relationship between noise levels and sleep disturbance is complex and not fully understood. The disturbance depends not only on intrusive noise levels, but also on the depth of sleep, the previous exposure to aircraft noise, familiarity with the surroundings, the physiological and psychological condition of the recipient, and a host of other situational factors. The most readily measurable effect of noise on sleep is the number of arousals or awakenings. The findings cited in this bulletin are based on the body of scientific literature that has focused on predicting the percentage of the population that will be awakened at various noise levels.

DNWG endorses the Federal Interagency Committee on Aviation Noise (FICAN), "Effects of Aviation Noise on Awakenings from Sleep" (June 1997) recommendation to disclose potential sleep disturbance as a supplemental tool beyond the typical DNL analysis, and FICAN's December 2008 recommendation to use the July 2008 American National Standard Institute's and Acoustical Society of America's method discussed in this Technical Bulletin to predict the percent of an exposed population that may be awakened from multiple noise events at least once during a night-long period.

[1] California uses the Community Noise Equivalent Level (CNEL) which is interchangeable with DNL for the purposes of this bulletin.

BACKGROUND

The effect of aviation noise on sleep is a long-recognized concern of those interested in addressing the impacts of noise on people. The scientific literature has postulated three different kinds of sleep disturbance effects: (1) interference with the sleep process itself, (2) short-term after-effects which include, for example, daytime sleepiness and annoyance, and (3) possible long-term health effects.

A good night's rest is considered vital to the recovery of a person's physical, mental, and emotional well-being. The overall sleep quality is dictated not only by total sleep duration throughout the night, but also by the quality of sleep during each sleep stage. The human body and mind cyclically move through various stages of sleep, all with varying degrees of sleep depth. In general, sleep transitions from being awake to lighter sleep to deeper sleep to progressing toward wakefulness, all occurring in various cycles over the course of a night. These sleep stages are classified by the medical community into "Awake", "Rapid Eye Movement (REM) sleep", and "non-REM sleep". Non-REM sleep is further sub-divided into sleep stages ranging from light sleep to deep sleep. People are more easily awakened during light sleep than deep sleep.

There have been numerous research studies that have attempted to quantify the complex effects of noise on sleep, but there is no current scientific evidence for establishing a direct relationship between nighttime noise from aircraft or other sources and irreversible long-term health effects (particularly stress-induced illnesses such as cardiovascular disease). Sleep disturbance from nighttime aircraft operations at intrusive noise levels is considered a major cause of annoyance for the public.

Most of the research studies attempt to measure the interference with the sleep process since the after-effects (sleepiness, annoyance, etc.) are considered consequences of this interference. The traditional method for monitoring sleep is electroencephalography or 'sleep-EEG' in which brainwaves are measured by electrodes attached to the scalp. The sleep-EEG data provides a record of sleep stage changes including light, deep, REM and wakefulness. Since this method is complex and expensive, most EEG work has been performed in laboratory situations using relatively small numbers of subjects. Field (in-home) studies comprise other sleep monitoring methods. Some field studies have been performed with activity monitors called "actimeters" to measure fine limb movements, usually of the wrist, which are indicative of sleep disturbance to an arousal state. Actimeters are small, relatively inexpensive devices, worn like a wrist watch, and easily used in the home without supervision. Another field study data collection technique is to measure behavioral awakening by requiring the test subject to physically acknowledge an awakening by button-pushing or with a verbal response.

The Federal position on aircraft noise-induced sleep disturbance has evolved as the science has advanced. The initial studies of the 1960s and 1970s focused on sleep disturbance experiments conducted in laboratories. The EPA "Levels Document" of 1974 (official title, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety"), which is regarded as the foundation for the U.S. community noise criteria, reviewed the state of sleep disturbance research and cautioned on drawing conclusions based on laboratory studies. As discovered in later research, there is a large disparity between how subjects react in the laboratory and how residents react at home. Reasons include the artificiality of the laboratory as a sleeping environment and the role of habituation in the home setting.

In 1992, the Federal Interagency Committee on Noise (FICON) published the "Federal Agency Review of Selected Airport Noise Analysis Issues." FICON recommended the use of an interim dose-response curve (dashed line in Figure 1 below) to predict the percent of the exposed population expected to be awakened (% awakening) as a function of the single event noise level expressed in terms of A-weighted Sound Exposure Level (SEL). This curve was based on research conducted by the U.S. Air Force (USAF). FICON identified this relationship as interim guidance, because it was based on a review of laboratory studies. Additional field research was already underway when FICON published its review. Based on field studies rather than laboratory research, the Federal Interagency Committee on Aviation Noise (FICAN) updated the FICON sleep disturbance guidance in 1997 with its finding, "Effects of Aviation Noise on Awakenings from Sleep."

The updated FICAN-recommended dose-response curve is depicted as the lower (solid) curve in Figure 1. The small circles in this figure represent the individual data points from the various field studies. Since the updated curve represents the upper end rather than the average of the range of data points, the relationship is conservative. The relationship shown by this newer curve benefited from additional field studies, including a UK Civil Aviation Authority (CAA) study in 1992, a USAF-sponsored study at Castle AFB and Los Angeles International Airport in 1993, and a NASA-sponsored study near the Denver airports in 1995.

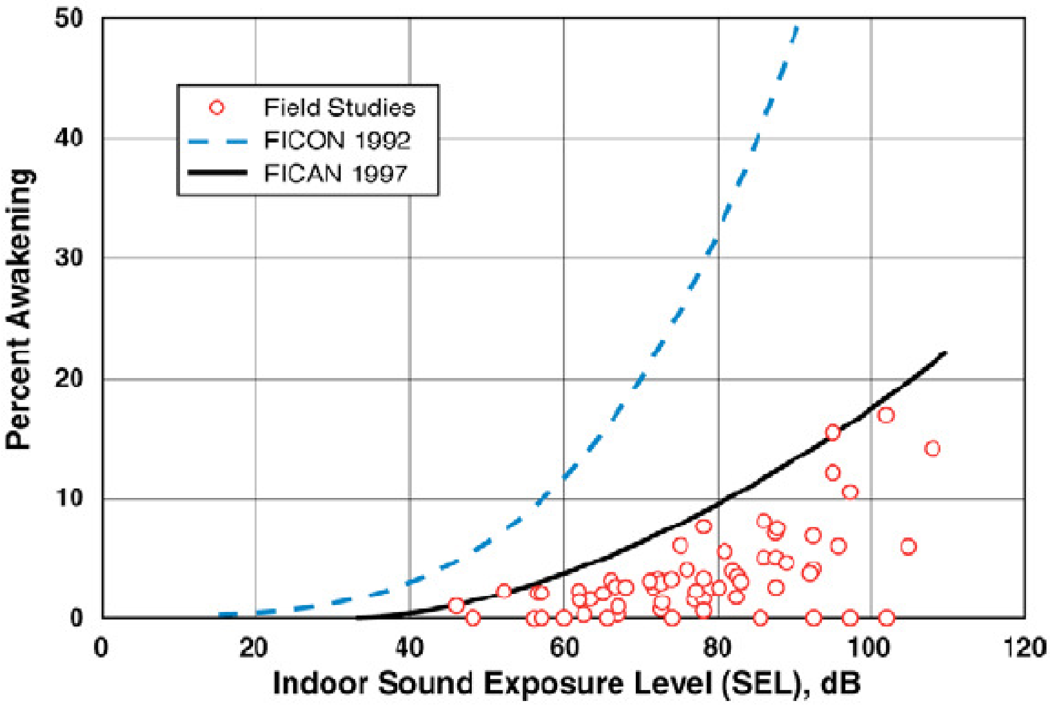


Figure 1. FICAN Recommended Sleep Disturbance Dose-Response Relationship

The first reaction the members of the public have in seeing curves like those presented in Figure 1 is disbelief at the low percentage of awakenings to fairly high noise levels. People think they are awakened by a noise event, but usually the reason for awakening is otherwise. For example, the 1992 UK CAA study found the average person was awakened about 18 times per night for reasons other than exposure to an aircraft noise – some of these awakenings are due to the biological rhythms of sleep and some to other reasons that were not correlated with specific aircraft events.

In recent years, there have been studies and proposals that attempted to determine the effect of multiple aircraft events on the number of awakenings. The German Aerospace Center (DLR) conducted an extensive study published in July 2004, focused on the effects of nighttime aircraft noise on sleep and other related human performance factors. The DLR study was one of the largest studies to examine the link between aircraft noise and sleep disturbance, and involved both laboratory and in-home field research phases. The DLR investigators developed a dose-effect curve that predicts the number of aircraft events at various Maximum A-weighted Sound Level values, which would be expected to produce one additional awakening over the course of a night. The dose-effect curve was based on the relationships found in the field studies. However, the DLR work has not yet been studied and approved by the scientific community and is simply a proposal only to be used with caution at this time.

Recognizing the need to devise a method to assess sleep disturbance to overcome concerns with the DLR study described above, in July 2008 the American National Standards Institute published ANSI/ASA S12.9-2008/Part 6: *Methods for Estimation of Awakenings with Outdoor Noise Events Heard in Homes,* which provides a method to estimate the percent of the exposed population that will be awakened by multiple aircraft noise events based on statistical assumptions about the probability of awakening (or not awakening). This approach, which relies on probability theory rather than direct field research/experimental data, was developed by and gained consensus among the subject experts who comprise ANSI's Accredited Standards Committee S12, Noise.

Figure 2 depicts the sleeping awakening data and equations that form the basis of ANSI S12.9-2008. The curve labeled 'Eq. (B1) - FICAN 1997' is the relationship between noise and awakening endorsed by FICAN in 1997. The ANSI recommended curve labeled 'Eq. (1) - ANSI 2008' quantifies the probability of awakening for a population of sleepers who are exposed to an outdoor noise event as a function of the associated indoor SEL in the bedroom. This curve was derived from studies of behavioral awakenings associated with noise events in "steady state" situations. The data points in Figure 2 come from these studies. Unlike the FICAN curve, the ANSI 2008 curve represents the average of the field research data points.

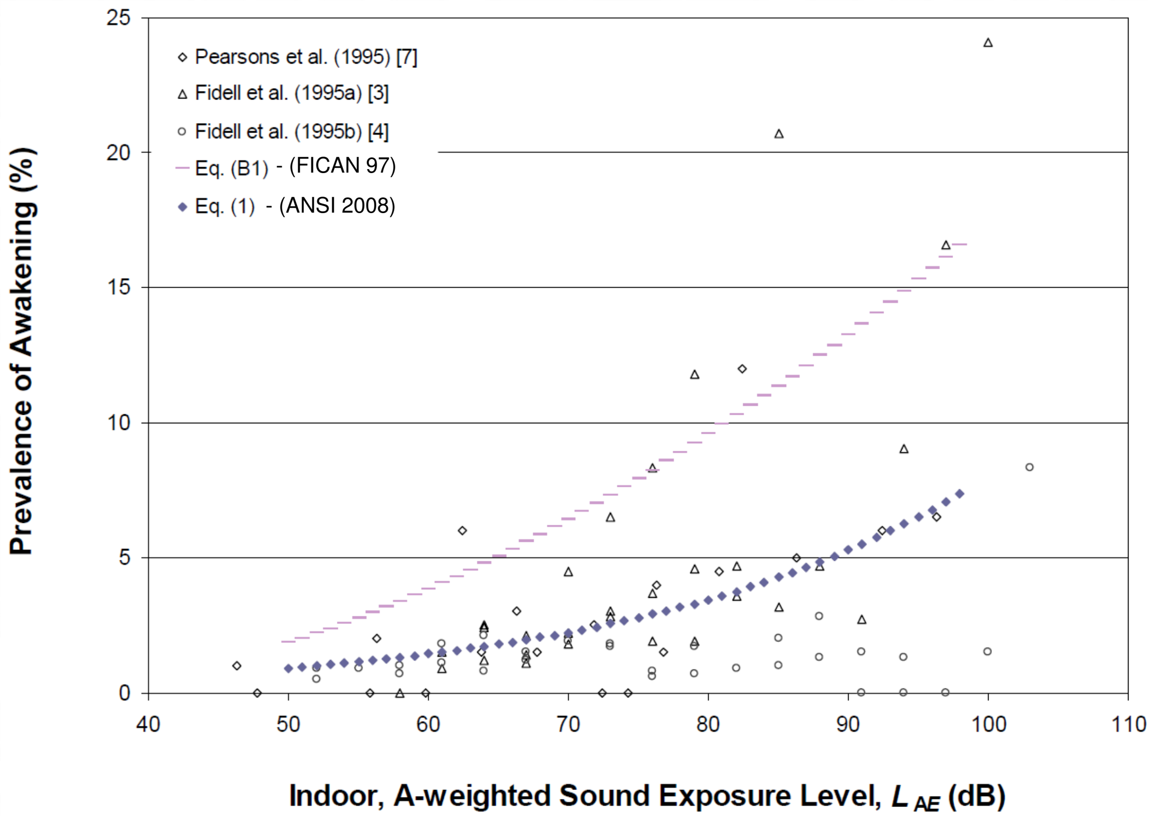


Figure 2. ANSI S12.9-2008 Plot of Sleep Awakening Data versus indoor SEL

In December 2008, FICAN recommended the use of this new estimation procedure for future analyses of behavioral awakenings from aircraft noise. In that statement, FICAN also recognized that additional sleep disturbance research is underway by various research organizations, and results of that work may result in additional changes to FICAN's position. Until that time, FICAN recommends the use of ANSI S12.9-2008.

DISCUSSION

ANSI/ASA S12.9-2008/Part 6 offers the only accepted method of predicting awakenings from multiple noise events during a night-long period. Previous methods predicted the percent awakenings for annual average daily operations based on the single event per night with the highest SEL, regardless of how many other noise events occur during the annual average night.

This Standard provides a method to predict sleep disturbance from aircraft noise events in home settings where people are familiar with the neighborhood noise environment. The Standard is not applicable to events occurring in a very short time (e.g., 10 gunshots in 10 seconds), or to large-weapon noise (e.g., artillery), explosive demolition, etc.

The Standard provides an equation to quantify the night-long probability of awakening at least once for a population of healthy adult sleepers who are exposed to an outdoor noise event as a function of its indoor SEL. The equation was derived from studies of behavioral awakenings associated with noise events in situations where the noise has been present in both level and in frequency of occurrence for a long time (on the order of a year). The Standard recognizes the number of awakenings in response to “new” noise will be higher prior to habituation during the first year, and recommends the use of the FICAN 1997 curve in Figure 2 when assessing awakenings from “new” noise. A rapid, substantial increase in operations in an area currently exposed or introduction of operations to an area where they do not currently occur are both examples of “new” noise.

The probability ($P_{A\ single}$) that a person of average sensitivity to awakening will be awakened by a single noise event is given by the following formula (Equation 1 in ANSI S12.9-2008):

$$P_{A,\sin gle} = \frac{1}{1+e^{-Z}}$$

where $Z = -6.8884 + 0.04444L_{AE}$, and L_{AE} represents the indoor A-weighted sound exposure level (SEL) of an outdoor single noise event. This equation represents the updated dose-response relationship shown by the ANSI 2008 curve in Figure 2.

Formula notes:

- The indoor single-event SEL may be determined from estimates of the single event or from measurements of SEL caused by representative single events over a minimum of nine hours encompassing the period from 2200 h to 0700 h.

- Any SELs less than 50 dB shall be ignored. That is, the probability of awakening shall be set to zero for any SEL that is less than 50 dB.

- This Standard should be used with caution for indoor SELs in excess of 100 dB, which is the practical extent of the underlying data. The Standard increasingly under-predicts awakenings for SELs in excess of 100 dB. For example, at an SEL of 150 dB, the Standard predicts less than 50% of the population will be awakened. Common experience suggests the percent awakened will be closer to 100% if the indoor SEL were 150 dB. This extension to the curve above 100 dB was made because it was decided that providing data that are too low is preferable to not providing any data at all.

- SEL, if measured, shall be determined with a single microphone located 1.0 m to 1.5 m above the floor and no closer than 1.0 m from any wall within the sleeping quarters.

The Standard provides a procedure for estimating the probability of an exposed population awakening at least once from exposure to multiple nighttime aircraft noise events at different SEL. This is accomplished by multiplying the probabilities of a person of average sensitivity awakening from each single event (using the above equation) over all events at the different SELs. The resulting probability of awakening from the multiple events applies to all persons exposed to those events at the same noise levels. This procedure is described in Appendix 1.

The Standard also provides a procedure for estimating the probability of awakening as a function of the time of the aircraft event(s) since retiring by subdividing the 9-hour nighttime period into multiple (3 hour) sub-time segments, and determining the probability of awakening for each time segment. When the time distribution of these single noise events during the average nighttime period is unknown (as is the case with most military airfield night operations) the Standard instructs the user to use the above equation to calculate the probability of awakening at least once during the 9-hour nighttime period.

To account for the 7-hour normal sleep period as a single segment during the 9-hour nighttime period, the user is instructed to multiply the number of noise events during the 9-hour nighttime period by 7, and then divide by 9. Detailed procedures for applying the above formula are provided in the Appendix.

FINDINGS/CONCLUSIONS

An analysis of potential sleep disturbance is recommended when nighttime operations are an issue or a concern expressed by the affected communities. DNWG endorses FICAN's December 2008 recommendation to use the July 2008 American National Standard Institute's and Acoustical Society of America's method discussed in this Technical Bulletin to predict the percent of an exposed population that may be awakened from multiple noise events at least once during a night-long period. However, there are two provisions in the ANSI Standard and FICAN recommendation that may not be appropriate for application to military noise analyses.

First, the Standard provides for the division of the 9-hour nighttime period (2200-0700) into multiple time segments, defining the distribution of noise events for each time segment, and determining the probability of awakening as a function of the time since retiring. This procedure is not recommended for analysis of nighttime military aircraft operations, unless the hourly distribution of flight events by aircraft noise is known and varies little from day to day throughout the year.

Second, the Standard recommends the use of the FICAN 1997 probability of awakening curve as an alternative to the ANSI 2008 relationship for the probability of awakening to a sound that is new to an area, i.e., less than a year since introduction. Since the interest in military noise analyses is to assess the long-term impacts of noise exposure, DNWG does not recommend the use of this more conservative relationship unless there are specific requirements to consider short-term effects.

Currently, there are no established criteria for evaluating sleep disturbance from aircraft noise, although recent studies have suggested a benchmark of an outdoor SEL of 90 dB as an appropriate *tentative* criterion when comparing the effects of different operational alternatives. The corresponding indoor SEL would be approximately 25 dB lower (at 65 dB) with doors and windows closed, and approximately 15 dB lower (at 75 dB) with doors or windows open. According to the ANSI 2008 Standard, the probability of awakening from a single aircraft event at this level is between 1 and 2 percent for people habituated to the noise sleeping in bedrooms with windows closed, and 2 to 3 percent with windows open. The probability of the exposed population awakening at least once from multiple aircraft events at noise levels of 90 dB SEL is shown in Table 1.

An important element in evaluating nighttime noise exposure is presentation of the results in a format that facilitates decision-making and provides the public with understandable information. Whereas the metric for estimating the probability of awakening from a single aircraft noise event is the SEL, there is a requirement for a supplemental metric to present the probability of awakening from multiple aircraft events. The most appropriate metric for this is the Number-of-events Above (NA) metric, which is fully explained in a separate DNWG Technical Bulletin entitled "Using Supplemental Metrics and Analysis Tools," which is available upon request from DNWG or can be downloaded from https://www.denix.osd.mil/portal/page/portal/denix/environment/DNWG.

As its name implies, the NA metric describes the noise exposure at a given location in terms of the number of aircraft events, N, that exceed a specified SEL (to apply the ANSI Standard, you must determine the number of events that occur at or above SEL 90 dBA). This description is written as NASEL (N). Thus, NA90(1), would describe the noise exposure at a location where 1 event exceeds an SEL of 90 dB in a given time period. An assessment of potential sleep disturbance in the vicinity of an airbase would then consist of developing

NA90 SEL contours for a series of number of events; e.g. NA90(1) for one event, NA90(2) for two events, and so on. DNWG recommends NA90 contours be presented in increments of 1, 3, 5, 9, 18, and 27 per 9-hour nighttime period (using increments of 9 events equates to 1, 2, 3, etc. events per hour over the 9-hour nighttime period). Additional increments of nighttime events can be included if the average nighttime activity is 36 or more per night.

It should be recognized that at a location on a NA90(N) contour, not all the aircraft events will be exactly at 90 dB SEL. At a location where the noise exposure is NA90(5); i.e. 5 events above 90 dB SEL, there will most probably be individual events at higher SELs, say 92, 94, and 98, each of which will have a different probability of awakening depending on the level, as calculated using Equation 1. Assuming all the events occur at *exactly* 90 dB SEL will result in a slightly lower overall probability of awakening at least once from the multiple events. DNWG recommends this conservative approach to estimating awakenings, and is the approach used in developing Table 1. If a more detailed analysis is required, the probability of awakening more than once from the multiple events at different levels can be estimated from the procedure described in Appendix 1, which was used to compute the percentages in Table 1. The ANSI Standard considers the percent awakenings in Figure 1 to also be the probability of an individual awakening from a single event. Thus, the Table 1 results are both the probability of an exposed individual being awakened at least once and the predicted percentage of an exposed population that will awakened; and this point must be clearly explained in NEPA documentation.

Table 1. Minimum Probability of Awakening at Least Once from Aircraft Noise Events at 90 dB SEL

No. of Aircraft Events at 90 dB SEL for Average 9-Hour Night	Minimum Probability of Awakening at Least Once	
	Windows Closed*	Windows Open**
1	1%	2%
3	4%	6%
5	7%	10%
9 (1 per hour)	12%	18%
18 (2 per hour)	22%	33%
27 (3 per hour)	32%	45%

*'Windows Closed' assumes there is a 25 dB noise level reduction (NLR) between the outdoors and indoors, e.g., 90 dB SEL outdoors is 65 dB SEL indoors.

**'Windows Open' assumes there is a 15 dB NLR between the outdoors and indoors, e.g. 90 dB SEL outdoors is 75 dB SEL indoors).

Sleep disturbance research still lacks sufficient specificity to accurately estimate the population awakened for a specific exposure environment, or the difference in population awakened for a given change in that environment. The procedure described in the ANSI 2008 Standard and endorsed by FICAN is based on probability calculations that have not yet been scientifically validated. While this procedure certainly provides a much better method for evaluating sleep awakenings from multiple aircraft noise events, the estimated probability of awakenings can only be considered approximate. It is for this reason that DNWG recommends against the presentation of contours in terms of percent awakenings. NA90 SEL contours for multiple events can be plotted on a local area map, but the associated percent awakenings should only be presented in narrative or tabular format.

Figure 3 shows contours plotted in the recommended increments. As the number of events increases, the size of the exposure area decreases and the probability of at least one awakening for each exposed individual increases. For example, in the geographic area between the NA90(5) contour and the smaller NA90(9) contour, the average probability for each exposed person to awakening at least once is between 7 percent and 12 percent for the windows-closed condition.

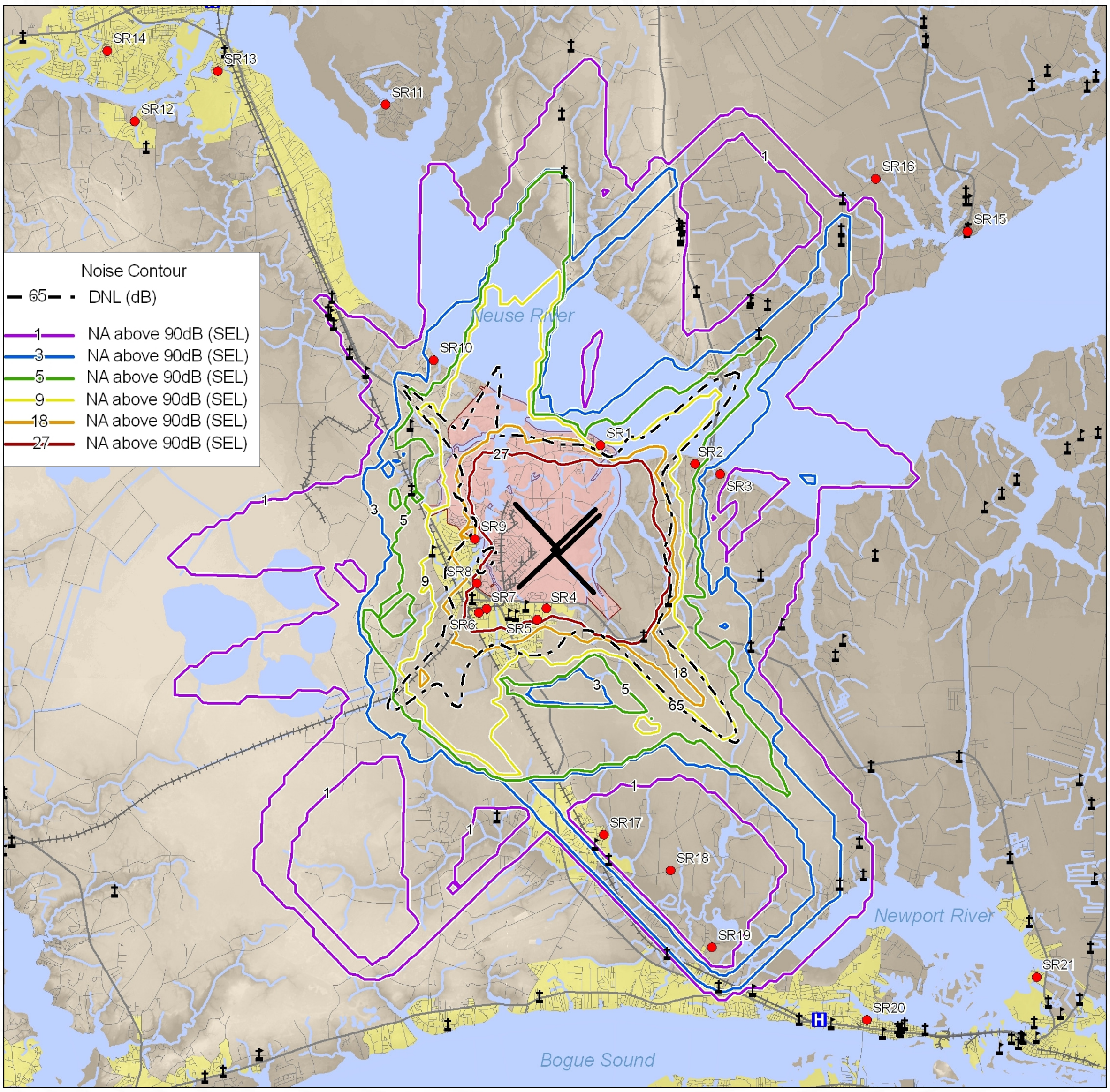


Figure 3. MCAS Cherry Point NA90 (SEL) and DNL 65 dB contours

Study reports and public presentations should include graphics showing the selected SEL contours plotted on an appropriate background map along with the DNL 65 dB contour and a table similar to the one above showing the estimated probability of awakenings for the selected contour increments. Using the contours graphic and Table 1 values, the range of estimated awakenings for each contour increment can be clearly communicated to the public.

Figure 3 also serves as an example of presenting more information than can be absorbed by the affected public or decision-maker. This is a case where it would be appropriate to present fewer contours to help convey the message on sleep disturbance. For example, always retain the NA90(1) contour because it shows how far the potential for awakenings extends from the facility. But, it may be advisable to remove the NA90(5) contour, in this case, because its location coincides with the NA90(3) in many sections. Similarly, one might remove the NA90(18) contour because of its close proximity to NA90(9) and NA90(27) in many sections in this case. An alternative to showing fewer contours in a single graphic is to include additional graphics that zoom in on areas of interest, showing all of the contour lines in that area.

Performing a more detailed analysis with smaller increments between contours or with higher SEL levels would merely result in a smaller percentage range of predicted awakenings for areas between each contour. In the event the NA90(27) contour includes large residential areas, additional contours for a higher number of events can be plotted to show areas with an even higher probability of awakenings. Alternatively, if most or all of the nighttime events expose sizable residential areas to SELs above 100 dB or higher, then some NA100(SEL) contours could also be plotted and presented with a table showing the probability of awakenings for these contour areas.

When study results show a considerable shift of, or increase in, the size of the SEL contours will result from a proposed action, a sizable change in estimated awakenings at specific noise sensitive locations within the contours may occur. In such cases, supplementing the noise contour analysis with a geographic Point of Interest (POI) analysis may be advisable. This entails calculating the change in the number of events above 90 dB SEL at the selected POI for the existing and future scenarios and presenting the results in tabular form. For each selected POI, the table would show in separate columns the existing number of events above 90 dB SEL, the number of events above 90 dB SEL for each alternative considered, the estimated probability of awakenings for the existing condition, and the estimated probability of awakenings for each alternative. Additional columns may be used to show the computed increases or decreases in the number of events above 90 dB SEL and the estimated awakenings for each alternative at each POI.

APPENDIX 1

Interpreting ANSI S12.9-2008

Probability of a person of average sensitivity being awakened by a single event is given in Equation 1 of the Standard:

$$P_{A,single} = \frac{1}{1+e^{-Z}} \qquad \text{(A1)}$$

Where;

$$Z = -6.8884 + 0.04444 L_{AE,indoors},$$

$L_{AE,indoors}$ is the A-weighted indoor sound exposure level (SEL)

$$L_{AE,indoors} = L_{AE,outdoors} - NLR$$

$L_{AE,outdoors}$ is the A-weighted outdoor sound exposure level (SEL)

NLR (Noise Level Reduction) means the amount of noise level reduction in decibels achieved through noise attenuation (between outdoor and indoor levels) in the design and construction of a structure.

Thus;

$$Z = -6.8884 + 0.04444\left(L_{AE,outdoors} - NLR\right)$$

The probability of being awakened at least once by multiple events is given in Equation C.4 of the Standard:

$$P_{A,multiple} = 1 - \prod_{a=1}^{N}\left(1 - P_{A,single}\right)_a \qquad \text{(A2)}$$

Where;

N is the total number of events between 2200 and 0700 hours

$(1-P_{A,single})_a$ is the probability of not being awakened by event *a*

If each event *a* produces a sound level at or above the selected threshold outside the residence, then Equation A2 becomes:

$$P_{A,multiple} \geq 1 - \left(1 - P_{A,single}\right)^N$$

According to the Standard:

"If one elects to retain the 7-h sleep period as a single segment then multiply the number of noise events during the 9-h nighttime period by 7 divided by 9 to account for the 7-h of sleep during the 9-h nighttime period, and use Equation (1) and the method above to calculate the probability of awakening at least once."

Therefore the probability of being awakened at least once by N sound events at or above the selected threshold over the 9-hour nighttime is given by:

$$P_{A,multiple} \geq 1 - \left(1 - P_{A,single}\right)^{N\,7/9}$$

Application to NA90 (SEL)

At NA90;

$L_{AE,outdoors} = 90$ dB

And assuming that NLR = 25 dB for homes with windows closed;

$L_{AE,indoors} = 90 - 25 = 65$ dB

Then;

$$Z = -6.8884 + 0.04444(65) = -3.9998$$

$$P_{A,\sin gle} = \frac{1}{1+e^{-Z}} = \frac{1}{1+e^{-(-3.9998)}} = .018 = 1.8\%$$

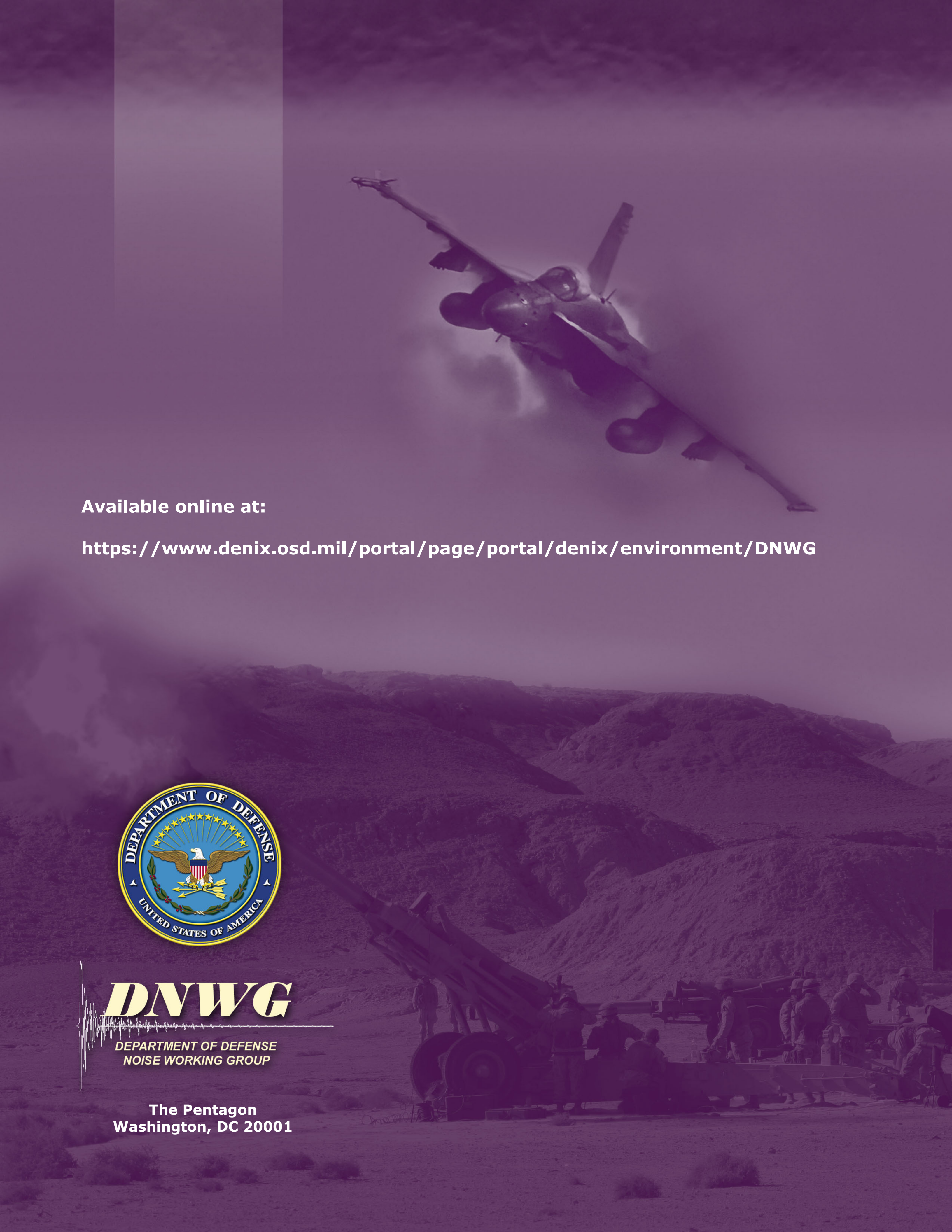
$$P_{A,multiple} \geq 1-\left(1-P_{A,\sin gle}\right)^{N\,7/9} = 1-(1-.018)^{N\,7/9} = 1-(.982)^{N\,7/9}$$

NA90		*Minimum* $P_{A,multiple}$
1	$N = 1$	$\geq 1-(.982)^{N7/9} = 1-(.982)^{7/9} = .014 = 1.4\%$
3	$N = 3$	$\geq 1-(.982)^{N7/9} = 1-(.982)^{21/9} = .041 = 4.1\%$
5	$N = 5$	$\geq 1-(.982)^{N7/9} = 1-(.982)^{35/9} = .068 = 6.8\%$
9	$N = 9$	$\geq 1-(.982)^{N7/9} = 1-(.982)^{63/9} = .119 = 11.9\%$
18	$N = 18$	$\geq 1-(.982)^{N7/9} = 1-(.982)^{126/9} = .224 = 22.4\%$
27	$N = 27$	$\geq 1-(.982)^{N7/9} = 1-(.982)^{189/9} = .317 = 31.7\%$

To calculate the 'Windows Open' condition, repeat the above calculations using NLR = 15 dB instead of 25 dB.

REFERENCES

A complete list of references supporting the information in this Technical Bulletin is available in a document entitled: "Improving Aviation Noise Planning, Analysis and Public Communication with Supplemental Metrics – Guide to Using Supplemental Metrics." Copies of this document are available upon request from DNWG.



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