AMERICAN NATIONAL STANDARD

Rationale for Withdrawing ANSI/ASA S12.9-2008/ Part 6 (A Technical Report prepared by ANSI-Accredited Standards Committee S12 and registered with ANSI)

Secretariat:

Acoustical Society of America

ASA Technical Report Registered: July 22, 2018

American National Standards Institute, Inc.

Abstract

This ASA Technical Report provides the rationale for the recommendation by Working Group S12/WG 15 to withdraw the 2008 ANSI/ASA Standard "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." The decision to withdraw the standard is based in part on the relatively small and non-representative corpus of field observations of noise-induced behavioral awakening available for analysis; on the poor generalizability of predicted awakening rates from airport to airport; on practical experience with the limited utility of predictions of "at least one behavioral awakening per night" for purposes of assessing environmental noise impacts, as required by the National Environmental Policy Act; on the statistical assumptions of convenience and post hoc analysis methods used to generate predictions of awakenings; on information published subsequent to development of the original standard; and on the findings of peer-reviewed re-analyses of the findings on which the original standard was based.

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ASA TR S12.9-2018/Part 6

Accredited Standards Committee S12, Noise

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Foreword

[This Foreword is for information only, and is not a part of the Technical Report ASA TR S12.9-2018/Part 6 Rationale for Withdrawing ANSI/ASA S12.9-2008/Part 6*. As such, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the standard.]*

This Technical Report comprises a part of a group of definitions, standards, and specifications for use in noise. It was developed and approved by Accredited Standards Committee S12 Noise, under its approved operating procedures. Those procedures have been accredited by the American National Standards Institute (ANSI). The Scope of Accredited Standards Committee S12 is as follows:

> *Standards, specifications, and terminology in the field of acoustical noise pertaining to methods of measurement, evaluation, and control, including biological safety, tolerance, and comfort, and physical acoustics as related to environmental and occupational noise.*

This Technical Report contains the rationale for a decision to withdraw ANSI/ASA S12.9-2008/Part 6. The decision was based on the findings of peer-reviewed information published subsequent to development of the original Standard; practical experience in the application of the Standard to aircraft noise environmental impact assessments; and re-analyses of the findings on which the original Standard was based.

Publication of this Technical Report that has been registered with ANSI has been approved by Accredited Standards Committee S12, Noise. This document is registered as a Technical Report according to the *Procedures for the Registration of Technical Reports with ANSI*. This document is not an American National Standard and the material contained herein is not normative in nature. Comments on the content of this document should be sent to the Acoustical Society of America Standards Secretariat, 1305 Walt Whitman Road, Suite 300, Melville, NY 11747, or emailed to asastds@acousticalsociety.org.

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Suggestions for improvements of this Technical Report are welcomed. They should be sent to Accredited Standards Committee S12, Noise, in care of the Standards Secretariat of the Acoustical Society of America, 1305 Walt Whitman Road, Suite 300, Melville, New York 11747. Telephone: 631-390-0215; Fax: (631) 923-2875; E-mail: asastds@acousticalsociety.org.

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Introduction

Noise-induced sleep disturbance is a familiar experience for many, but a difficult quantity to define and predict with rigor. Sleep disturbance predictions are nonetheless required by the U.S. National Environmental Policy Act (NEPA) for purposes such as assessing the nighttime environmental impacts of major federally funded projects, including construction of airport and highway infrastructure. The 2008 ANSI/ASA Standard that is the subject of this Technical Report developed a method for predicting transportation-noise-induced sleep disturbance for events heard in homes through secondary analyses of a small corpus of peer-reviewed field observations of behaviorally confirmed awakenings.

Additional information published since the development of ANSI/ASA S12.9-2008/Part 6 ("the Standard") calls into question the generalizability of its predictions, as well as its suitability for NEPA-related purposes. Experience in application of the Standard has also revealed limitations to its ability to distinguish among the environmental impacts of preferred and alternative proposed actions. By itself, however, the newly available information offers no unambiguous basis for revising the 2008 Standard.

This Technical Report provides the background and rationale for the decision by Working Group S12/WG 15 to withdraw ANSI/ASA S12.9-2008/Part 6.

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TECHNICAL REPORT

Rationale for Withdrawing ANSI/ASA S12.9-2008/Part 6

1 Scope

ANSI/ASA S12.9-2008/Part 6 described a method of predicting the probability of awakening at least once per night due to transportation noise intrusions into residential sleeping quarters. This report summarizes the technical and pragmatic bases for the 2016 decision by ASA Working Group S12/WG 15 to withdraw ANSI/ASA S12.9-2008/Part 6.

ANSI/ASA S12.9-2008/Part 6 was developed primarily to assess sleep disturbance created by transportation noise, as required by NEPA and by similar state legislation, for assessing nighttime noise impacts of major, government-funded projects. Limitations of the Standard (described in clause 2 below) that have become evident in the years since its publication outweigh its usefulness for its intended purpose.

The decision of Working Group S12/WG 15 to withdraw ANSI/ASA S12.9-2008/Part 6 implies that the method for calculating “at least one behavioral awakening per night” contained in the former Standard should no longer be relied upon for environmental impact assessment purposes. The Working Group believes that continued reliance on the 2008 Standard would lead to unreliable and difficult-to-interpret predictions of transportation-noise-induced sleep disturbance.

The Working Group further believes that project alternatives that have been endorsed in already-completed environmental assessments on the basis of calculations of “at least one behavioral awakening per night” may be in error and have overestimated numbers of expected awakenings. The Working Group understands that its decision to withdraw the 2008 Standard may be disruptive to acoustical consultants who rely on the Standard for environmental impact assessment purposes. Therefore, two Informative Annexes of the 2008 standard are included in this document for the guidance they can provide until more plausible and technically defensible means are developed for predicting sleep disturbance due to transportation noise.[1]

2 Terms and definitions

ASEL: A-weighted sound exposure level

dB: decibel, A-weighted unless otherwise indicated, re 20 μPa.

CEQA: California Environmental Quality Act

DNL: Day-Night Average Sound Level, a 24-hour time weighted average of A-weighted sound levels

FICAN: U.S. Federal Interagency Committee on Aircraft Noise

NEPA: National Environmental Policy Act

SEL: Sound exposure level

[1] Practitioners and the public may benefit from information that describes the difference between awakening in habituated and unhabituated populations. Higher noise levels have been reported to be required to disturb sleep in an habituated population than for a non-habituated population [Ollerhead, 1992]. This finding may be relevant in assessments conducted for NEPA-related purposes of project-related noise effects on sleep disturbance.

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3 Technical discussion

3.1 Background

International research on noise-induced sleep disturbance has yielded a large and still-growing technical literature (*e.g.,* Passchier-Vermeer *et al.*, 2002; Basner, 2006; Michaud *et al.*, 2007; World Health Organization, 2009; Fidell *et al.*, 2010, 2013). Understanding of noise-induced sleep disturbance remains far from complete, despite extensive analyses of findings reported in this literature. Factors generally recognized as influencing transportation-noise-induced sleep disturbance include age, sex, health status, drug use, time of night, familiarity with and habituation to noise sources, meanings of intruding sounds (Nordic Council of Ministers, 1994) and so forth. Michaud *et al.* (2007) observed that in residential circumstances, "sleep disturbance effects of nighttime aircraft noise intrusions are not dramatic on a per-event basis, and…linkages between outdoor aircraft noise exposure and sleep disturbance are tenuous."

Fidell *et al.* (2010) noted that "epidemiological evidence does not yet support either reliable prediction of noise-induced sleep disturbance, or well-informed policy analysis, much less a plausible technical rationale for regulatory action." They further noted that practical, population-level implications of noise-induced sleep disturbance and its consequences for health and well-being remain poorly understood due to design and other limitations of field studies undertaken to date, and to limitations of the statistical analyses performed to date. Published relationships used to assess the probability or prevalence of noise-induced awakening remain so imprecise that they do not usefully inform policy analyses of noise-induced awakening. In particular, considerable caution is essential in extrapolating to wider populations conclusions about sleep disturbance that have been inferred from the behavior of relatively small and purposive samples of people living near a few airports. Uncertainty about the degree of sleep disturbance that may affect health, and about the primacy of noise-induced sleep disturbance among the many known sources of sleep disturbance, further complicate assessment and interpretation of nighttime transportation noise exposure.

It is difficult in this context to argue on technical grounds that findings in this area are ripe for standardization.[2] Researchers do not agree on matters as basic as the magnitude and nature of effects observed in field studies, nor on the health consequences of sleep disturbance, nor on the most appropriate measures and methods for studying sleep disturbance. Major differences persist among research methods such as laboratory versus field studies, and electrophysiological versus self-reported and behavioral measures of sleep disturbance. Further differences in research design include matters as detailed as electrode placement, criteria for analyzing EEG recordings, definitions of noise events, the dependency of sleep disturbance effects on sequential noise intrusions, appropriate latencies between noise events and awakenings, and so forth. Although basing decisions on records of self-reported sleep quality is intuitively appealing, doing so introduces potential bias, and little agreement exists between self-report and objective measures of sleep status in any event.

Nonetheless, necessities of social policy and transportation noise regulation have created pressures for standardization of methods for predicting objectively measured noise-induced awakenings. Although attempts to predict sleep disturbance on the basis of sound exposure levels (SELs) of noise intrusions alone are understood to be simplifications, this has not prevented publication of several dosage-response relationships between sound levels of noise intrusions into residential sleeping quarters and probabilities that test participants will decide to press a button to indicate that they have been awakened. ANSI/ASA S12.9-2008/Part 6 is one of these simplifications for which the technical evidence and rationale are not obviously superior to other predictive methods (*e.g*., FICAN, 1997, Passchier-Vermeer *et al.*, 2002; Finegold *et al.*, 2002). The following subclauses describe some of the limitations of the former ANSI/ASA S12.9-2008/Part 6 standard.

[2] Standardization in such circumstances is sometimes justified on the basis that it summarizes the state of the art, rather than codifying widely accepted practice. In cases where the state of the art changes over time, or when the state of the art permits only marginally credible or reliable predictions of noise effects, it is sometimes necessary to revise or retract prior standards.

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3.2 Nature of the predicted quantity

Formal environmental impact assessments typically identify a preferred development option and one or more alternatives to it. For example, an airport planning to build a new runway may choose to evaluate noise-related impacts of runway operation for alternatives of varying length, placement on airport property, orientation, and aircraft fleets. The quantity predicted by ANSI/ASA S12.9-2008/Part 6 ("at least one behavioral awakening per night") is not particularly helpful in discriminating among alternative actions, since it does not clearly distinguish among the sleep disturbance created by the preferred action and alternative courses of action. In other words, calculation of the probability of at least one behavioral awakening per night does not permit clear distinctions between construction alternatives which create a high probability of a single awakening per night, and those likely to produce two, ten, or more behavioral awakenings per night.

3.3 Practical experience with application of current standard

NEPA-related assessments of transportation noise impacts are among the most common uses for a sleep disturbance standard such as ANSI/ASA S12.9-2008/Part 6. For example, in CEQA (California Environmental Quality Act) litigation over the long-term Master Plan for Oakland International Airport (City of Alameda *et al.* v. Port of Oakland *et al*., Alameda County Superior Court Nos. 815052-9, 815330-6 & 815053-8, First District Court of Appeal Nos. A086708, A087959 & A089660), California courts ruled that DNL-based measures of aircraft noise impacts do not adequately address sleep disturbance. The courts required that environmental impact assessments conducted under CEQA predict sleep disturbance explicitly. Since the ANSI Standard in question relies on SELs of individual noise intrusions (rather than a 24-hour time-weighted measure such as DNL), it has become the customary basis for assessing sleep disturbance for aircraft noise-related proposed projects.

The role played by Standards in such exercises can be disproportionate to the reliability of their predictions of (in this case) sleep disturbance. Courts do not construe their own roles as extending to independent analyses of technical information, and they rarely, if ever, have the ability or means to evaluate the rationale and technical adequacy of Standards. Thus, courts do not typically concern themselves with the accuracy, precision, representativeness, or reasonableness of Standards-based assumptions, analyses and conclusions. Instead, courts typically defer to arguments advanced by project proponents or by opposing parties who assert that their analyses are consistent with standardized analytic procedures.

Consequently, consultants working for project proponents or for parties opposed to proposed projects often argue that a project will or will not "significantly" increase the probability of at least one behavioral awakening per night. Their arguments are based on reassurances that a standardized method of assessing sleep disturbance was relied upon to support their conclusions. This is so even when a consultant has only a meager understanding (in the present case) of the plausibility of assumptions underlying a statistical analysis, nor any idea whether predictions based on statistical constructs tailored to the "sleep sensitivity" of a population at one airport have any relevance at another airport.

Unfortunately, ANSI/ASA S12.9-2008/Part 6 yields results which are not only non-intuitive, but also inconsistent with the underlying findings upon which the standard was based (Fidell *et al.*, 2010). Informative Annexes A and B of the current Technical Report provide awakening curves for habituated (Annex A) and newly exposed populations (Annex B). Annex B shows that awakenings in habitually exposed populations are notably lower than in newly exposed populations.

The 2008 Standard's limitation is realized when applied to very large population (say, more than a few thousand residences), for which the Standard predicts that even a noise level increase of a fraction of a decibel is likely to produce a substantial number of awakenings. This prediction is an artifact of multiplying a small probability of awakening per noise event by a large residential population, and of

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assuming that each noise intrusion is an independent event. The inadequacy of such a prediction is clear when viewed in the context of how often sound levels change by a fraction of a decibel over the course of a sleep night. Since the 2008 Standard lacks any advice concerning situational limits of its applicability, the Standard may be misapplied in ever larger study areas, for which it predicts implausibly large total numbers of awakenings, even at imperceptibly low sound levels.

Many well-known non-acoustic sources of sleep disturbance, such as stress, illness, and chronic pain, have no simple remedy. The 2008 Standard makes no mention, however, of the ability of relatively simple actions, such as use of ear plugs, closing windows, and intentional introduction of masking noise in sleeping quarters to substantially affect noise-induced sleep disturbance.

3.4 Accuracy and precision of predictions of 2008 standard

The predictive equations of the Standard include constants and coefficients specified to four decimal places. Some users of the Standard may therefore (incorrectly) assume that the Standard's predictions are highly precise. The Standard, however, lacks any guidance about the reliability of its predictions. In combination with the apparent precision of the predictive equations, this lack of guidance encourages practitioners, who simply apply the predictive equations contained in ANSI/ASA S12.9-2008/Part 6 by rote, to misinterpret and misunderstand the Standard's predictions as engineering calculations of unlimited precision. The general public, for whom environmental impact assessments are prepared, is even more likely to misunderstand the Standard's predictions.

In principle, such misinterpretations and misunderstandings of the predictions specified in the 2008 Standard could be remedied by including appropriate cautions in a revised Standard. Given the very shallow slope of the predictive relationships and the inherent uncertainty of the 2008 Standard's prediction methods, however, they will only rarely be of use for prospectively distinguishing among the awakening potential of project alternatives.

3.5 Representativeness, size, and adequacy of ANSI/ASA S12.9-2008/Part 6 database

Ideally, a Standard intended to predict transportation-noise-induced sleep disturbance would be developed from a large body of carefully designed and conducted empirical field observations that are fully representative of the reactions of diverse populations to noise exposure in many communities. This is not a realistic expectation in the present case, because no such body of research findings exists. The most that a standard can accomplish in these circumstances is to summarize the state of the art at a point in time. Standards based on small and non-representative databases must include explicit cautions against misinterpretation of their provisions, and about the need to reconsider such Standards as additional information about noise-induced sleep disturbance accumulates. Such cautions are particularly important in litigation-related uses of the standard, and in other non-technical contexts.

The recommendations of ANSI/ASA S12.9-2008/Part 6 are based on analyses of a relatively small number of field observations of behavioral awakenings attributable to transportation noise intrusions. Test participants in such studies are instructed to press a button upon awakening for any reason. Single-event noise exposure measurements are typically made both outside residences and inside sleeping quarters. Transportation-related noise events may be identified by the simultaneous occurrence of noise events of very similar durations, both outdoors and indoors. Attribution of awakenings to transportation noise events is typically justified with respect to a latency criterion for a noise-induced awakening.

The in-home observations of transportation-noise-induced awakenings were made in four studies conducted in the vicinity of several major civil airports and one military airfield (Fidell *et al.*, 1995a; Fidell *et al.*, 1995b; Fidell *et al.*, 2000; and Passchier-Vermeer *et al.*, 2002). The analyses of the standard also extend to a smattering of street-traffic noise cases. They do not include any laboratory findings since these have been shown to differ considerably from the findings of field studies (Pearsons *et al.*, 1995). They also exclude findings of electrophysiological studies of sleep quality. The latter were excluded from

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analysis on the grounds that their findings were not amenable to straightforward interpretation for routine environmental impact assessment purposes.

The corpus of behavioral awakening data is limited largely because such field studies are typically complex and costly. Well-designed behavioral awakening studies require coordinated single-event noise measurements both outdoors and inside sleeping quarters, over extended periods of time. They have also required 1) considerable effort to contact and recruit test participants; 2) repeated visits to test participants' homes to install, maintain, and recover instrumentation; 3) labor-intensive analyses of relationships between noise exposure measurements and behavioral awakening data; and 4) measures to maintain participant privacy.

Further, since the small samples of paid test participants in behavioral awakening studies are typically self-selected, it is unreasonable to interpret their behavior as representative of any larger population. It is likewise important to note that the predictions of the 2008 Standard are of dubious utility in settings with large numbers (> 20) of noise intrusions into sleeping quarters per night, because of the assumption of independence of behavioral awakenings (see below). In short, until methods are developed to permit more cost-effective collection of behavioral awakening data, not to mention a plausible claim of representativeness of observed awakening behavior, a standard predicting behavioral awakening due to transportation noise requires careful qualification.

3.6 Sensitivity of ANSI/ASA S12.9-2008/Part 6 prediction method to analytic assumptions

Predictions based on the method recommended in ANSI/ASA S12.9-2008/Part 6 are critically dependent on two major statistical assumptions.

1. Assumption of independence of awakenings

The more basic of these is of independence of awakenings from one another throughout an entire sleep night. Even the authors of the prediction method characterize this assumption as "not fully persuasive" (Anderson and Miller, 2007).[3] The standard offers no analytic, empirical, or other substantive argument to support the assumption. Instead, the assumption of independence of awakenings is purely an assumption of convenience, adopted because it greatly simplifies calculation of multiple awakenings in successive trials. The standard calculates the likelihood of at least one awakening per night in the same manner that the likelihood of observing at least one head in a series of coin tosses is calculated. This approach differs fundamentally from alternative approaches in the sleep disturbance literature, such as Markov state transition modeling (*e.g.*, Basner, 2006), which do not assume independence of awakenings from one another.

A related assumption—that sleepers are not already awake at the time of occurrence of a noise intrusion into sleeping quarters—is likewise problematic. Both Passchier-Vermeer *et al.* (2002) and Fidell *et al.* (2013) note that a "spontaneous" or "residual" behavioral awakening rate of about 3% may be an artifact of the definition of a latency period between exposure and behavioral response.

2. Assumption of utility of post hoc statistical manipulations

Prediction of awakening from knowledge of noise exposure alone is highly imprecise, because the predictive strength of the model is poor. "Dummy coding" (described in the following paragraphs), a *post hoc* technique employed in the analyses of ANSI/ASA S12.9-2008/Part 6, is used to strengthen the apparent association between predicted and observed awakening rates. Dummy coding constructs

[3] It is widely accepted that sensitivity to noise-induced sleep disturbance fluctuates throughout the night as sleepers cycle through various sleep stages. In general, sensitivity to sleep disruption is greatest in 1-hour shoulder periods before onset and termination of sleep.

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variables assumed to represent characteristics and behaviors of participants in sleep disturbance studies. In essence, dummy coding attributes what would otherwise be considered error variance as variance associated with individual differences.

As explained below, assumed individual differences in sensitivity to awakening, when added to the model, yield a better predictor than noise level alone. However, 1) such individual differences are unknowable prior to the conduct of behavioral awakening studies in populations expected to undergo changes in environmental noise exposure; 2) they represent characteristics of individual study participants, not properties of source noise exposure; 3) they cannot be generalized from one noise source or community to the next; and 4) the distribution of such individual differences in any given community is unknown to those conducting prospective environmental impact assessments.

The ANSI/ASA S12.9/Part 6 (2008) prediction method relies upon *post hoc* inference of "sensitivity coefficients," a purely statistical construct of residents of airport neighborhoods. Miller *et al.* (2011) and Fidell *et al.* (2013) have shown that these coefficients are not generalizable from airport to airport. The following discussion of the analytic approach adopted by Anderson and Miller (2007) to infer individual sensitivity to sleep disturbance closely paraphrases that of Fidell *et al.*, 2010.

Anderson and Miller's 2007 approach to predicting at least one behaviorally confirmed aircraft-induced awakening per night begins with a logistic regression based on three predictors of per-event awakenings: (1) the indoor SEL of an overflight, (2) the time of occurrence of the noise event with respect to the time since the test participant retired, and (3) a *post hoc* index of subject "sensitivity."

By itself, the indoor SEL of a noise event is the *least* effective of the three predictors of behavioral awakening. Fidell *et al.* (2010) note that "… *(absolute)* levels of intruding noise events and awakenings simply are not strongly related to one another. The point biserial correlation between indoor SEL values and awakening responses in the Fidell *et al.* three-airport data set is only $r = 0.048$. This correlation is not merely small, but also smaller than the correlation between awakening responses and ambient noise levels immediately prior to aircraft noise events that elicited awakenings ($r = 0.08$)." The correlation between awakening and absolute SEL is "even smaller than the correlation between a completely nonacoustic variable (time since retiring) and awakening responses ($r = 0.11$)."

"The average indoor SEL that *failed* to awaken test participants [in the Fidell *et al.* three-airport data set] was 70.5 dB, whereas the average indoor SEL associated with awakenings was only 2.7 dB greater (73.2 dB)." (The difference in corresponding values of maximum indoor sound levels was smaller yet—only 1.8 dB.) The mean difference in SEL values of noise events associated with awakening responses and those which are not associated with awakenings is far smaller than the standard deviation around either mean level."

"Further, the 50-dB range of indoor SELs that *failed* to awaken sleepers at the three airports completely encompassed the less than 40 dB range of SELs that *did* awaken sleepers."

In other words, although awakening is significantly related to SEL (Wald $z = 16.75$, $P < 0.001$), the SEL of a noise event is almost completely ineffective as a predictor of awakening. The statistical significance of the prediction is due almost entirely to the large number of individual noise events in the data set. Randomizing the SELs associated with noise events that elicited and failed to elicit awakening responses in the data set—or for that matter, omitting the SEL of noise events entirely from the prediction equation—has no meaningful effect on the predictive strength of the model. In short, predictions of awakenings based on noise level alone must be viewed as highly unreliable.

The time at which an aircraft overflight occurs with respect to the time that test participants retired for the night is a more effective predictor of behavioral awakening than the SEL of an intruding noise event.

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Logistic regression shows that waking is significantly, albeit very weakly, related to time since retiring (Wald z = 46.59, P < 0.001, Nagelkerke R^2 = 0.033).[4]

Times of occurrence of nighttime noise events vary from airport to airport however. Nighttime operations at large hub (primarily passenger) airports rarely exceed 10% of all operations. At express cargo and military airports, both the percentages and times of occurrence of nighttime operations can differ greatly. Applying predictions made on the basis of awakening responses observed at a small number of airports to airports with different nighttime operating conditions could lead to appreciable errors of estimate.

The sensitivity of predictions of aircraft-noise-induced sleep disturbance to airport operating schedules implies that simple and universal prediction of sleep disturbance is unlikely. The alternative for environmental impact disclosure purposes (custom-tailored analyses, often based on assumptions about hypothetical operating schedules years in the future) is costly both in economic terms and in terms of the ratio of assumptions to predictions.

Anderson and Miller refer to the most effective predictor of awakening in the data set as "subject sensitivity," scaled in logit units derived from logistic regression in which each subject was coded to reflect individual differences. Logistic regression shows that awakening is significantly related to these subject-specific individual differences, categorized as 32 dummy variables[5] (Wald z = 169.77, P < 0.001, Nagelkerke R^2 = 0.126.) Table 4 of Fidell *et al.* (2010) shows differences in "subject sensitivity" between those awakened by a given aircraft overflight vs. those not awakened. Not surprisingly, subjects who were classified as more "sensitive" were more likely to be awakened by *any* aircraft overflight, regardless of its SEL. In signal detection terms, this is akin to achieving a high hit rate as a byproduct of adopting a high false alarm rate.

The very high correlation between the logit-scaled measure of sensitivity and the logarithm of button-pushing rate (r_{31} = 0.911, P < 0.001) calls into question the primacy of the role that sound levels play in awakening, and on attribution of awakenings to sound levels of noise intrusions in sleeping quarters. As Anderson and Miller (2007) define the term, "subject sensitivity" differs little from individual differences in button pushing rates.

Unless "sensitivity" can be measured, predicted, or otherwise quantified prior to observation of the responses of test subjects, *post hoc* definitions of individual differences among test subjects amounts to little more than using the data to predict the data, or to devising another name for error variance. In analysis of variance terms, the strategy of dummy coding for "subject sensitivity" removes between-subject variance from a generalized error term simply by reclassifying it from error variance to an effect of interest.

The logic of predicting sleep disturbance from unspecified individual differences, scaled in logit or any other units, differs little from predicting sleep disturbance on any other nonexplanatory form of individual difference: height, weight, hair color, political preference, etc. The utility of such predictions is further reduced when the characteristic used to predict awakening, and its distribution over exposed populations, is biologically implausible and/or unknowable in advance. The statistical machinery "works," in the sense of capitalizing on chance, but must inevitably be readjusted to reflect unexplainable differences in the next

---

[4] A small Nagelkerke pseudo-R^2 value implies that a predictive model based on SPL as a sole predictor of awakening has a rather limited predictive strength, even though such a model may be "significantly" better than a model with no predictor.

[5] A "dummy variable" is a statistical construct which re-classifies error variance—that is, variance that is not accounted for by a pre-specified main effect or interaction among effects—as an effect of interest. In effect, dummy coding permits analysts, after examining the results of an experiment, to create new variables. In the current case, this is done by creating groups of test participants with supposedly differing "sensitivities to awakening." The name given to the dummy variable is an arbitrary one chosen by the analyst, not one that necessarily corresponds to any aspect of the study design.

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data set to which it is applied. Including individual differences as the strongest predictor variable in a regression equation is tantamount to asserting that the probability of awakening has (much) more to do with the particular set of self-selected subjects who happen to participate in a data collection exercise, than with any unique or measurable property of a set of noise events.

3.7 Other limitations of the former standard

The former standard's regression model which includes "time since retiring" as a predictor variable was developed without consideration of the 20% of study participants who were never awakened by aircraft events. This was done of mathematical necessity (because the logarithm of zero is undefined, and hence impossible to include in a regression based on the natural logarithm of an odds ratio), and in order to render the recommended regression model comparable to another one that includes a "subject sensitivity" variable. The resulting prediction equation therefore overestimates awakenings.

The predictive equations take into account only the SELs of "typical" outdoor noise events, not the relationship between such noise events and ambient noise levels in neighborhoods, nor the novelty of exposure to nighttime noise intrusions into sleeping quarters. The Standard's recommended prediction methods could well be improved by incorporating such information.

3.8 Alternative interpretation of published behavioral awakening findings

Prediction of "at least one behavioral awakening per night" *per* S12.9-2008/Part 6 was based on the Anderson and Miller (2007) analysis of absolute SELs of noise intrusions. A re-analysis by Fidell *et al.* (2013) of the database of behavioral awakening findings published in S12.9-2008/Part 6 reached very different conclusions, however. The latter analysis categorized noise intrusions into sleeping quarters by their *relative* (standard deviate) SEL values. Fidell *et al.* (2013) found that probabilities of awakening were much more closely related to SELs scaled in units of standard deviates of local distributions of aircraft SELs, than to absolute sound levels.

Further, as shown in Figure 1, the relationships between relative levels of noise intrusions into sleeping quarters and probabilities of awakening were quite similar for the three airports at which such data were available. Anderson and Miller required substantial differences in dummy-coded "sensitivity to awakening" values at different airports.

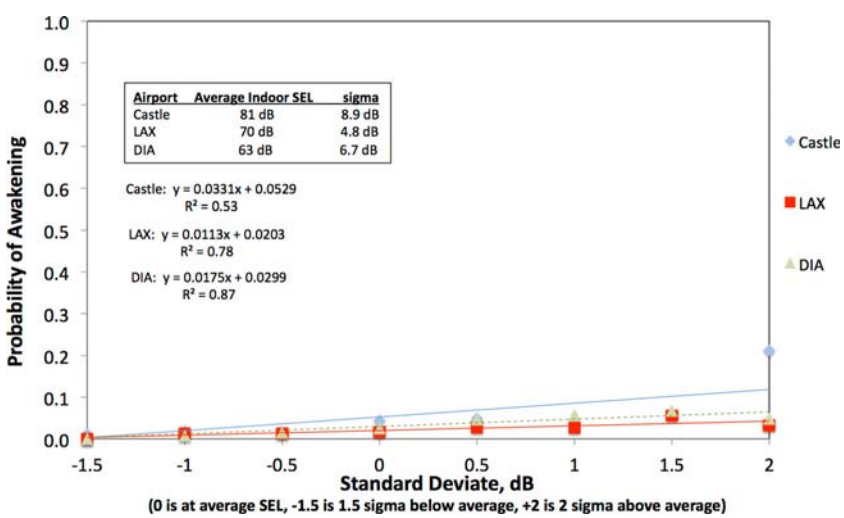

Figure 1 – Relationship between standard deviates of noise intrusion SELs and probabilities of awakening at three airports.

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Fidell *et al.* (2013) concluded (*inter alia*) that:

> "Intruding noises with which sleepers are familiar only rarely awaken them, and are tolerated at levels far higher than those with which they are unfamiliar";
>
> "Residential populations appear to self-select for tolerance to nighttime aircraft noise, so that community-wide behavioral awakening rates vary directly with median noise levels of nighttime aircraft operations"; and that
>
> "Improved efforts to predict noise-induced awakenings must explicitly address their strong dependence on habituation."

These conclusions are inconsistent with the method of predicting sleep disturbance in ANSI/ASA S12.9-2008/Part 6. The first conclusion establishes that a factor not addressed in ANSI/ASA S12.9-2008/Part 6 (familiarity) plays a major role in sleep disturbance. The second conclusion indicates that the same absolute SELs of noise intrusions are associated with different probabilities of awakening in different communities (not to mention in the same sleeper in different communities). The third conclusion implies that a sleep disturbance standard must address habituation to noise exposure if it is to yield useful predictions in different communities.

4 Summary of technical adequacy of former standard

ANSI/ASA S12.9-2008/Part 6 does not usefully predict transportation-noise-induced sleep disturbance for the following reasons:

- It is based on analysis of a relatively small amount of non-representative information about noise-induced sleep disturbance;
- Its predictions of probabilities of "at least one awakening per night" are based on implausible and untenable statistical assumptions and analytic methods, and cannot be generalized from one airport to another;
- The predicted quantity ("at least one awakening per night") does not usefully distinguish degrees of sleep disturbance among preferred and alternate project actions;
- For lack of cautions in the language of the Standard, its methods are readily misapplied, and its predictions of "at least one awakening per night" are easily over-interpreted;
- The standard attempts to characterize an intuitively appealing form of objectively measured sleep disturbance, but in so doing, it fails to acknowledge the many complexities that impact sleep and other forms of sleep disturbance that are known to be sensitive to nighttime noise exposure;
- The standard does not quantitatively address the roles of familiarity with noise sources and habituation to noise exposure as determinants of sleep disturbance.

5 Recommendation for further standardization efforts

No further analytic effort intended to propose alternate awakening prediction methods is recommended until a substantial body of new peer-reviewed field observations has been published. Such data should be tabulated in a form similar to that suggested in Table 1. Column 6 should contain information about behaviorally confirmed awakening. The yellow-highlighted column may be extended to include actigraphic or other definitions of awakening or sleep disturbance.

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Table 1 – Form of table suggested for inclusion in next iteration of sleep disturbance standard, incorporating information to be collected in future sleep disturbance field studies. Sample entries are entirely speculative, as the results of future sleep studies will require careful consideration of the many variables known to impact sleep.

Test participant	Noise event	Time of night	Time since retiring (minutes)	SEL of noise intrusion into sleeping quarters (db)	Awakening within (n) minutes of noise event?	Deviation from background levels	Other measure(s) of sleep disturbance
1	*1*	*10:00 PM*	*60*	*65*	*No*	1.5 dB	
1	*2*	*10:05 PM*	*65*	*72.5*	*Yes*	5.0 dB	
1	*3*	*10:23 PM*	*83*	*74.1*	*No*	3.1 dB	
…	…	…	…	…	…	…	

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Annex A

(Informative)

Behavioral awakening data

Table A.1 – Tabulation of behavioral awakening observations from prior studies

STUDY Pearsons *et al*.1995 [7]	ASEL (dB)	% Awakened
Vallet *et al.*, 1980 Aircraft	46.3	1
	56.3	2
	66.3	3
	76.3	4
	86.3	5
	96.3	6.5
Pearsons *et al.*, 1973 Aircraft	52.4	0
	62.4	6
	72.4	0
	82.4	12
	92.4	6
Vernet 1979 Trains	47.8	0
	55.8	0
	59.8	0
	63.8	1.5
	67.8	1.5
	71.8	2.5
	76.8	1.5
	80.8	4.5
Rylander 1973 Truck	74.3	0

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STUDY Fidell et al. 1995a [3]	ASEL (dB)	% Awakened
Control	58	0
	61	0.9
	64	2.4
	67	2.1
	70	4.5
	73	6.5
	76	8.3
	79	11.8
USAF	64	2.5
Castle AFB	67	1.1
	70	1.8
	73	3
	76	1.9
	79	4.6
	82	3.6
	85	3.2
	88	4.7
	91	2.7
	94	9
	97	16.6
	100	24.1
USAF LAX	61	1.5
	64	1.2
	67	1.4
	70	2.2

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STUDY Fidell et al. 1995a [3]	ASEL (dB)	% Awakened
	73	2.8
	76	3.7
	79	1.9
	82	4.7
	85	20.7

STUDY	ASEL (dB)	% Awakened
Study 1 (Fidell et al. 1995b) [4]	52	0.5
Denver Noisy	55	0.9
	58	0.7
	61	1.1
	64	0.8
	67	1.2
	70	1.9
	73	1.8
	76	0.6
	79	1.7
	82	0.9
	85	2
0	88	1.3
	91	1.5
	94	1.3
	97	0
	100	1.5
	103	8.3

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Denver Quiet	52	0.9
	55	0.9
	58	1
	61	1.8
	64	2.1
	67	1.5
	70	1.9
	73	1.7
	76	0.8
	79	0.7
	82	0.9
	85	1
	88	2.8
	91	0
	94	0
Study 2 (Fidell et al. 1997) [5]	61	1.5
Atlanta	64	1.2
	67	6.3
	70	2.5
	73	1
	76	1.2
	79	1.9
	82	4.9
	85	3.7

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Annex B

(Informative)

Probability of behavioral awakening as a function of the single-event indoor ASEL, habituated population

Equation (B.1) quantifies the night-long probability of awakening for a population of sleepers who are exposed to an outdoor noise event as a function of the indoor ASEL associated with the noise event in the sleeper's quarters. This equation was derived from behavioral awakenings associated with noise events in "steady-state" 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 probability that a person of average (dummy coded) sensitivity to awakening will be awakened by a single noise event is given by the following formula.

Probability of awakening:

$$P_{\mathrm{A,single}} = \frac{1}{1+e^{-Z}} \tag{B.1}$$

where Z = −6.8884 + 0.04444L_{AE}, and L_{AE} represents the indoor A-weighted sound exposure level (ASEL) of an outdoor single noise event.

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

Any ASELs that are less than 50 dB shall be ignored. That is, the probability of awakening shall be set to zero for any ASEL that is less than 50 dB.

NOTE Equation B.1 should not be used for indoor ASELs in excess of 100 dB, which is the practical extent of the underlying data. The calculation increasingly under-predicts awakenings for ASELs in excess of 100 dB. For example, at an ASEL of 150 dB, Eq. B.1 predicts less than 50% of the population will be awakened. Common experience suggests that the percent awakened will be closer to 100% if the indoor ASEL were 150 dB.

ASEL, 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.

Annex A contains all of the data from behavioral awakening studies. These data and the predictions from Equation (B.1) are plotted in Figure B.1 along with Equation C.1 which is the curve for exposure to new noise sources.

The prevalence of awakening data shown in Figure B.1 is not in and of itself sufficient to estimate the number of people awakened or the total number of awakenings. In most cases the indoor ASEL will need to be estimated from outdoor ASEL data. That difference will vary based on home construction and whether windows are opened or closed. Both of these will vary by geographic area and prevalence of use of air-conditioning. It is also important to note that Equation B.1 is not based on each flyover as an independent event nor is it likely that flyovers are independent. Further, it is not a matter of this Technical Report to determine whether sleep impact should be measured by the number of people awakened or the number of awakenings. This distinction would significantly affect how Equation B.1 is applied.

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More importantly, Equation B.1 is the agglomeration of data from sleep studies with disparate results. Based on Fidell (2013) there should be a unique Equation B.1 for each airport and the differences may be quite large. In reality, the change in ASEL will be a better predictor of awakening than the absolute level of ASEL.

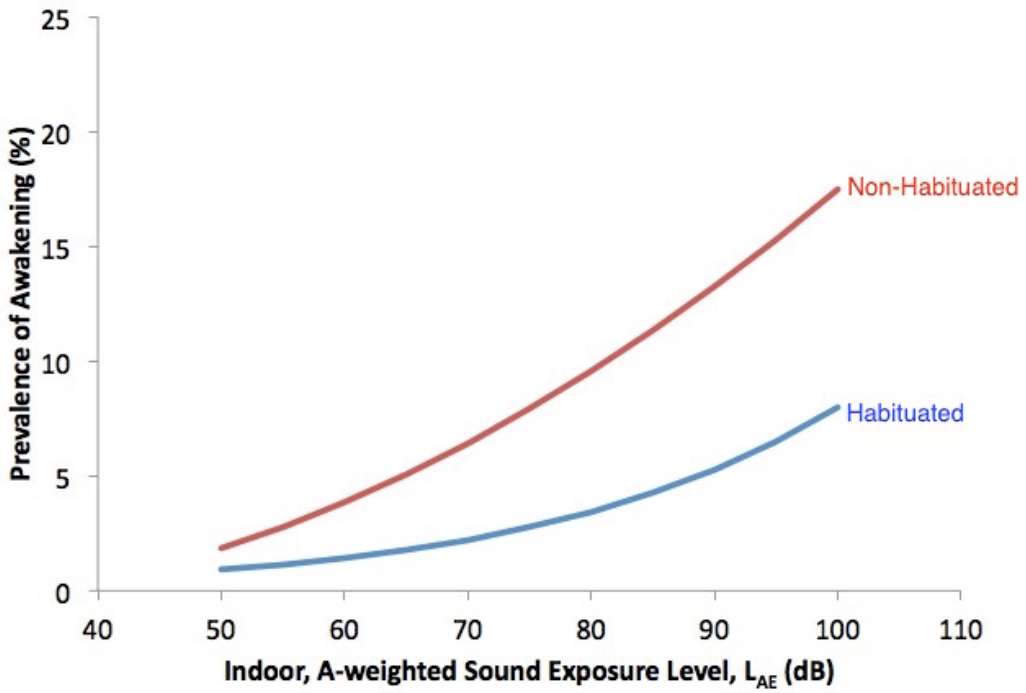

Figure B.1 – A plot of the sleep awakening data: Equation (B.1) and Equation (C.1) versus indoor, A-weighted sound exposure level

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Annex C

(Informative)

Probability of awakening a population with a sound that is new to an area

Nearly all sleep research has concentrated on populations that were exposed to the given noise source for a long period of time (more than one year). But Equation (B.1) is likely to underestimate the probability of awakening for sound that is new to an area. “New” listeners are created when a new highway, a new railway line, a new airport, or a new runway is constructed, or a new operation such as a nighttime air freight operation is instituted. Several effects can be postulated. Over time, a percentage of the population acclimates, at least in part, to nighttime noise. Another percentage of the population develops coping strategies such as keeping windows closed at night. And before a new equilibrium is obtained, some fraction of the population moves away because they cannot cope or acclimate to the nighttime noise. Thus, it is likely that Equation (B.1) underestimates the probability of awakening for sounds that are new to an area.

The Federal Interagency Committee on Aviation Noise (FICAN) has recommended a functional relation that is effectively an upper bound to the behavioral awakening data and, as such, may better represent the effect of new sounds to an area than does Equation (C.1). This FICAN relation is recommended for test and study for possible application to situations involving nighttime sounds that are new to an area. This relation is a function solely of ASEL. If used, the FICAN relation should be used in place of Equation (B.1) and in conjunction with a distribution of ASELs that span the entire 9-hour night (with the number of noise events multiplied by 7/9). The FICAN relation is given as:

$$P_{A,single} = 0.0087 * (L_{AE} - 30)^{1.79} \quad \text{(C.1)}$$

where L_{AE} is the indoor A-weighted SEL of any single outdoor noise event.

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