Community Annoyance and Sleep Disturbance: Updated Criteria for Assessing the Impacts of General Transportation Noise on People

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The question of prediction of sleep disturbance and annoyance due to transportation noise has been addressed. Two sets of previously published data have been reanalyzed. This project was initiated as part of a long-term U.S. Air Force research program on the effects of aircraft noise on humans. It is concluded that day–night average sound level is still the most adequate noise descriptor for use in environmental impact analyses to assess the annoyance and overall impact of noise from general transportation, including civilian and military aircraft operations. A new logistic curve adopted in 1992 for general use by U.S. federal agencies, is recommended for use in environmental impact statements as the nominal relationship between day–night average sound level and the percent age of a general residential population predicted to be highly annoyed by the noise. A power curve, using A-weighted sound exposure level, is recommended for predicting nighttime sleep disturbance from general transportation noise.

Primary subject classification: 66.1, Secondary subject classification: 68.3

1. Introduction

Technical justifications are presented for two exposure-response relationships for predicting the percentage of a population expected to be highly annoyed (%HA) as a result of transportation noise and for predicting sleep disturbance in response to transportation noise. The two exposure-response curves were adopted in 1992 by the Federal Interagency Committee on Noise[1] (FICON) for use by federal agencies in aircraft noise-related environmental impact analyses and are recommended for prediction of the effects of general transportation noise on people. The curves were described previously in general form[2–4] and have already been used in Environmental Impact Statements.[5] The recommendations in this paper are based on reanalyses of two sets of previously published data. For predicting annoyance, a slightly different approach is taken to the analysis of new data added to the data used to develop the original 1978 Schultz curve[6] in contrast to the approach used for the analysis reported by Fidell *et al.*[7,8] A brief discussion of aircraft noise effects versus the effects of other general transportation noises is also included. Finally, a recommendation is presented for predicting nighttime sleep disturbance for cases where specific situations merit additional environmental impact analysis beyond the prediction of overall community annoyance. The recommended sleep disturbance curve is based on a reanalysis of the percentage of expected awakenings versus A-weighted sound exposure level (SEL) data from the 1989 Pearsons *et al.* review.[9] The curves discussed here are recommended for predicting community annoyance and sleep disturbance in environmental impact assessments of the effects of general transportation noise, particularly aircraft noise, until a sufficient quantity of new data is available to warrant a reexamination of the curves.

2. Background

In the United States, the National Environmental Policy Act (NEPA) requires the use of the best available prediction models in environmental analyses, such as Environmental Impact Statements, to assess health, welfare, and other potential impacts from noise exposure and for land-use management and planning recommendations. Since the U.S. Environmental Protection Agency "Levels Document"[10] and related publications,[11–15] the day–night average sound level (DNL) and an exposure-effect relationship for the percentage of a population reporting in social surveys to be "highly annoyed" by general transportation noise has generally been accepted as the best overall indicator of the impact of environmental noise in residential communities. Early versions of this relationship were superseded by the now-classical analysis in 1978 by Schultz[6] of 12 major social surveys of community annoyance due to transportation noise. Notwithstanding the methodological questions, data interpretation differences, and the problem of community reponse bias, the Schultz synthesis of the social survey results prior to 1978 has been used worldwide as the nominal response curve for characterizing the average community response to environmental (i.e., general transportation) noise. Because the original Schultz curve was published in 1978, a project was initiated to revisit the Schultz curve and determine if that exposure-response relationship should be updated on the basis of additional data from new, techni-

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cally improved community annoyance studies. This project was initiated as part of the long-term U.S. Air Force (USAF) research program on the effects of aircraft noise on humans.[3,16]

Sleep disturbance is not routinely included as a separate environmental effect in noise impact analyses because the 10-dB nighttime penalty levied against sounds during the hours from 22.00 to 07.00 was specifically intended to account for the intrusiveness of noise during those normal sleeping hours and the potential of intrusive noise to disturb sleep. However, sleep disturbance is addressed when warranted by the circumstances of planned environmental actions, as a supplement to the predicted degree of population annoyance. However, there has been no accepted exposure-response relationship for predicting sleep disturbance in response to general transportation noise that adequately reflects the data obtained from laboratory and field studies. In response to this need, published research data on the relationship between environmental noise and sleep disturbance were examined to determine if an appropriate exposure-response relationship could be developed. Although the curves resulting from these analyses were included in the FICON report[1] and quoted in other publications,[2–4] publication of the justification for the algorithms and the shape of the curves is presented here for the first time.

3. Community Annoyance in Response to General Transportation Noise

Detailed results of the major community annoyance database update sponsored by the USAF Armstrong Laboratory are summarized here in a slightly different manner than in Refs. 7 and 8. A somewhat different relationship is proposed for practical use in environmental noise impact analyses. As reported by Fidell *et al.*,[7,8] an additional 292 data points from 11 social surveys (13 data sets) published since 1978 and the four "addenda" studies from Schultz were added to the original Schultz 161 exposure-reponse data points, for a new total of 453 data points. The additional data resulted in nearly tripling the size of the database for predicting annoyance due to general transportation noise exposure.

Fidell *et al.* used five screening criteria for deciding which data to include in their analysis. An additional criterion, not used by those authors, is proposed here: namely, whether or not a significant correlation exists between the day–night average sound levels and the related population

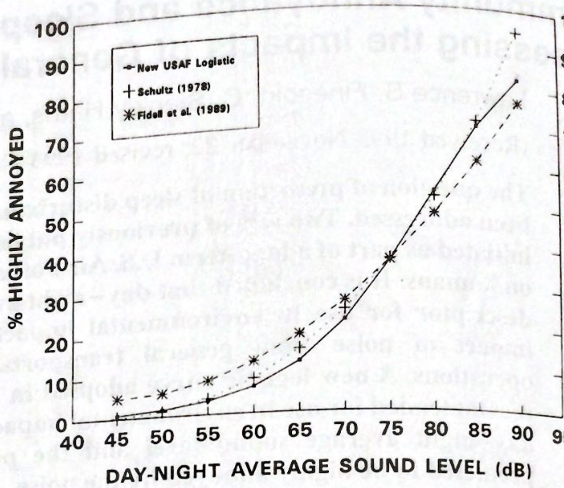

Fig. 1 – New USAF logistic curve (400 data points), Schultz (Ref. 6) third-order polynomial (161 data points) and Fidell et al. *(Refs. 7 and 8) quadratic curve (453 data points).*

annoyance ratings. Using this additional criterion, we re-analyzed the Fidell *et al.* data. The result was that six data sets (from five separate studies) were excluded because they did not show a significant correlation between day–night average sound level and the percentage of the population reporting to be highly annoyed (%HA). This exclusion resulted in a loss of 53 data points (12% of the original data points), leaving 400 data points as the new total. Data sets excluded from the Fidell *et al.* data are listed in Table 1.

The second issue concerns the choice of an algorithm to describe the relationship between day–night average sound level and population annoyance. The 1978 Schultz curve used a third-order polynomial for the original 161 data points. Fidell *et al.* identified the following quadratic fit as being the most parsimonious equation, based on the full 453 data points:

$$\%HA = 78.9181 - 3.2645\, L_{dn} + 0.0360\, L_{dn}^2. \quad (1)$$

This article recommends the following logistic fit as the prediction curve of choice, based on the final 400 data points:

$$\%HA = 100/[1+\exp(11.13 - 0.14\, L_{dn})]. \quad (2)$$

The original Schultz curve (third-order polynomial—161 data points), the Fidell *et al.* curve (quadratic—453

TABLE 1 – Data sets with nonsignificant correlations between day–night average sound level and annoyance [from Fidell *et al.* (Refs. 7 and 8)].

Study	Correlation coefficient (Pearson r)	r^2	Number of data points	Probability level
Hall, aircraft only (1977)	0.586	0.343	9	>0.05
Rylander, traffic only (1977)	0.556	0.309	6	>0.05
Rylander, tramway only (1977)	0.454	0.206	6	>0.05
Decatur Airport (1983)	0.894	0.799	4	>0.05
Burbank Airport (1985)	−0.142	0.020	20	>0.05
Westchester Airport (1985)	0.246	0.061	8	>0.05

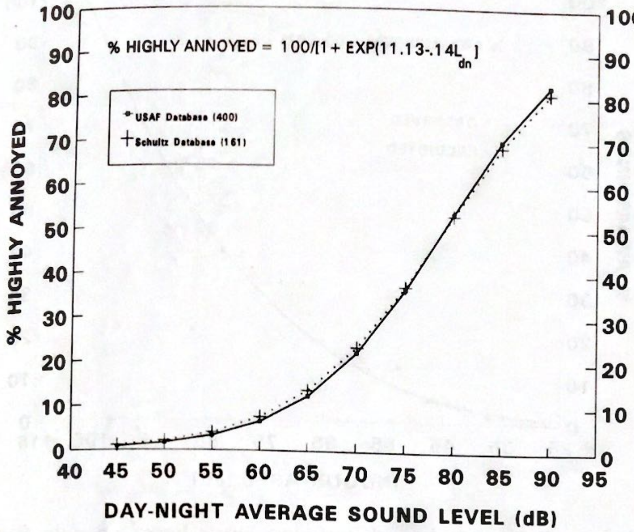

Fig. 2 – Logistic fit to 400 community annoyance social survey data points and 1978 Schultz (Ref. 6) curve.

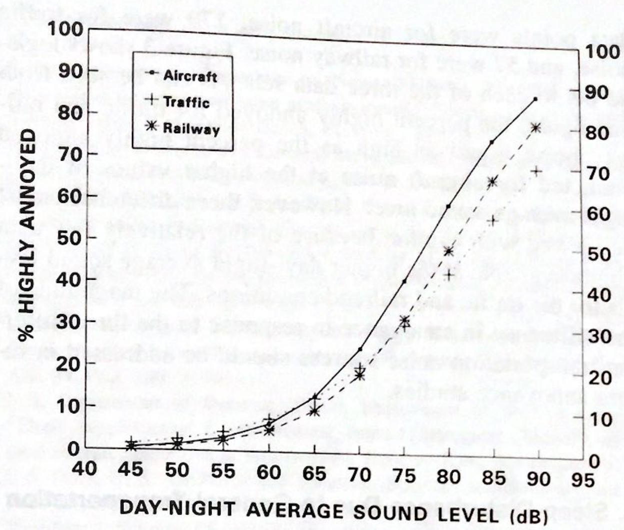

Fig. 3 – % highly annoyed vs DNL from aircraft, road traffic, and railway noise, based on data from Fidell et al. *(Refs. 7 and 8).*

data points) and the USAF updated community annoyance curve (logistic—400 data points), according to Eq. (2), are presented in Fig. 1. Figure 2 shows the logistic curve for the USAF 400 data-point set along with a logistic fit to the original Schultz database. None of these curves differ significantly from each other. However, the new USAF logistic fit, Eq. (2), is preferred because (1) it gives the same predictive utility as both the original Schultz curve and the Fidell *et al.* curve; (2) it allows the prediction of annoyance to approach but not reach 0% or 100%; (3) it approaches a 0% community annoyance prediction at a day–night average sound level of approximately 40 dB, rather than having the anomaly of showing an increase in annoyance at day–night average sound levels less than 45 dB like the Fidell *et al.* curve; (4) the use of a logistic function has a history of success in federal environmental impact analyses for over a decade; and (5) it is based on the most defensible social survey database.

Additionally, use of a logistic function was endorsed by the Committee on Hearing, Bioacoustics and Biomechanics (CHABA) of the National Academy of Sciences.[17] In the opinion of the authors, these advantages make the logistic function the algorithm of choice. The effort to develop a revised community annoyance prediction curve based on a considerably expanded database has validated the general approach which has been used since 1978. With the new curve presented here [Eq. (2) and Fig. 2], there will be even more support for the ability to predict annoyance due to general transportation noise, including noise from aircraft overflights.

4. Aircraft Noise Versus Other Transportation Noise Sources

Virtually all community noise impact analyses based on self-reports of annoyance since the late 1970s have been based on a combination of aircraft and other general transportation noise sources.[15] However, since Schultz published his exposure-response relationship in 1978, controversy has continued over whether all types of transportation noise should be combined under the rubric of "general transportation noise." Many researchers see evidence that aircraft noise is rated as being more annoying than other types of transportation noise, such as railroad and highway noise.

As has been pointed out elsewhere,[18–22] some of the differences observed in published social surveys of population annoyance in response to aircraft noise versus other types of transportation noise sources could be due to methodological differences in the studies, variability in the criterion for reporting high annoyance, community response biases, and because the acoustical measurements were seldom reported with the desired accuracy. One reason why it is difficult to compare published data on human responses to noise exposure levels from various sound sources is that there are, typically, large differences in sound exposure for living and sleeping areas in a home from aircraft overflight noise compared with the sound exposure from road traffic noise. Noise from an aircraft overflight virtually surrounds a home, entering the living and sleeping areas through the roof and two or more sides of the dwelling, while street traffic noise enters predominantly through only one or two sides of the dwelling. This difference in sound exposure within a home is, typically, not accounted for, or discussed, in social surveys when researchers estimate the noise exposure of subjects.

The analysis by Miedema[23] of data recompiled from selected social surveys shows a higher level of community annoyance in response to aircraft noise than to noise from ground transportation sources. Miedema chose to use separate curves for aircraft, highway, road traffic, and rail noise. The considerably expanded database developed by Fidell *et al.* also provides evidence that there is a slightly stronger annoyance reaction to aircraft noise than to other transportation noise sources. In the analysis reported here of that database, for the 400 final data points from a total of 22 different international community annoyance surveys, 173 data points were for aircraft noise, 170 were for traffic noise, and 57 were for railway noise. Figure 3 shows logistic fits to each of the three data sets. As can be seen from this figure, the percent highly annoyed for traffic and railway noise is not as high as the percent highly annoyed predicted for aircraft noise at the higher values of day–night average sound level. However, these differences must be viewed with caution because of the relatively few data points available at the higher day–night average sound levels for the traffic and railroad conditions. The magnitude of the difference in annoyance in response to the three different transportation noise sources should be addressed in future annoyance studies.

5. Sleep Disturbance Due to General Transportation Noise

The details of the sleep disturbance review, also sponsored by the USAF Armstrong Laboratory, have been reported by Pearsons *et al.*[9] The Pearsons *et al.* report, which included a discussion of relevant noise exposure descriptors and dependent variables for measuring sleep disturbance, reassessed the data presented in two previous reviews by Lucas[24] and Griefahn,[25] plus seven additional studies. In all, data were examined for 21 original sleep disturbance studies from a total of 53 studies considered.

Pearsons *et al.* concluded that there was too great a difference in the results of published laboratory versus field sleep disturbance studies to warrant determination of a curve to relate aircraft noise to behavioral awakening. They identified several concerns about the use of existing data for predicting sleep disturbance. The present authors agree with the concerns of Pearsons *et al.*; however, a practical (interim) sleep disturbance curve is sometimes needed for compliance with the requirements of NEPA. Therefore, a further analysis of the Pearsons *et al.* data seemed appropriate. In addition to the analysis presented here, and in response to the concerns discussed by Pearsons *et al.*, the USAF is currently sponsoring additional field studies of sleep disturbance as a consequence of nighttime aircraft operations.[16,26]

In the reanalysis presented here of the Pearsons *et al.* data, the following analytical approach was taken: given the highly variable and incomplete databases described in their review, the published values for both laboratory and field study data were averaged within 5-dB intervals to reduce the variability. The data were grouped both because of the variability within the data set and, more importantly, because the number of data points differed greatly as a function of sound exposure level. There were far fewer data points at the higher sound exposure levels than at the lower ones. Any regression based on the actual data points would be biased by the large number of points at the lower sound exposure levels. By averaging the percentage of awakenings in 5-dB intervals across the range of sound exposure levels from approximately 30 to 110 dB, each class interval was given equal weight regardless of the number of data points in the interval. If the data had been evenly distributed across the whole range of sound exposure levels, then this grouping by class interval would produce results very

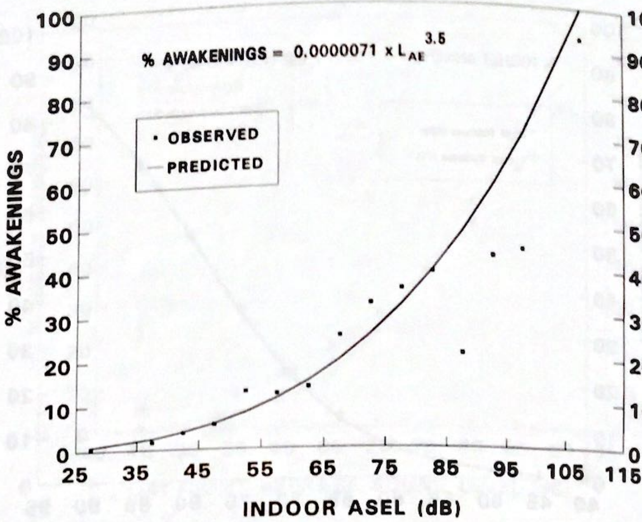

Fig. 4 – Proposed sleep disturbance curve based on data from Pearsons et al. *(Ref. 9); percent awakenings vs indoor A-weighted sound exposure level (ASEL).*

similar to that obtained by using the individual sound exposure levels.

There were 17 intervals in the Pearsons *et al.* database, but two intervals had zero cases. Therefore, the regression fit was conducted on the 15 remaining sound exposure level intervals versus the mean percentage of awakenings in the particular interval. The result of this analysis was the following expression, also shown graphically in Fig. 4:

$$\% \text{ Awakenings} = 7.1 \times 10^{-6} \, L_{AE}^{3.5}, \qquad (3)$$

where L_{AE} is indoor A-weighted sound exposure level.

A recent sleep disturbance field study around the four largest British airports,[27–29] published after the Pearsons *et al.* review,[9] included outdoor noise measurements and collection of in-home sleep disturbance data. The main conclusion reported by Ollerhead *et al.* was that "...below outdoor event levels (i.e., A-weighted sound exposure levels, Ed.) of 90 dB (corresponding approximately to maximum A-weighted sound levels of 80 dB, Ed.), aircraft noise events are most unlikely to cause any measurable increase in the overall rates of sleep disturbance experienced during normal sleep." The results of the UK study indicated that there is probably only a very low level of nighttime sleep disturbance associated with airport operations and agreed closely with the field study data reviewed in the Pearsons *et al.* study. Figure 5 shows the relationship between sleep disturbance and outdoor aircraft A-weighted sound exposure levels from the UK study reports.[27–29] Note that the dependent variable is percent "arousal rate," not actual awakenings, and that only some percentage of arousals result in awakenings. Ollerhead *et al.*[28] used 40% (within a 10% confidence interval) as their awakening-to-arousal ratio. In view of the UK field study results, the curve presented here may overestimate the probability of nighttime sleep disturbance, possibly because of the inclusion of data from both laboratory and field studies in the Pearsons *et al.* review in the present analysis. The Ollerhead *et al.*[28,29] results appear quite similar to the data from the few field studies described in the Pearsons *et al.* report.

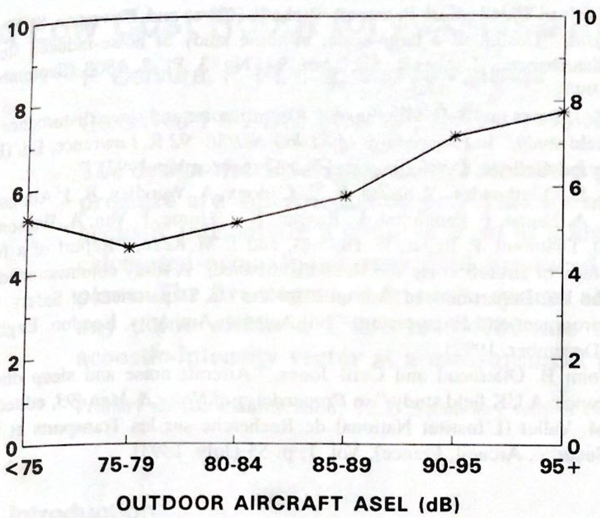

Fig. 5 – Relationship between sleep disturbance (arousal rate) and outdoor aircraft sound exposure levels from UK CAA field study (Ref. 28).

The curve presented in Fig. 4 is proposed for use in environmental impact analyses[1,2] until sufficient data from additional field studies are available. Of course, outdoor sound exposure levels must be translated into indoor sound exposure levels to apply the curve in Fig. 4, either by applying the actual noise reduction of the building structure(s) or by applying the average house noise reduction recommended by the Environmental Protection Agency for typical U.S. construction: 17 dB for windows-opened conditions and 27 dB for windows-closed conditions.[10]

6. Conclusions

According to most published studies and the 1992 report of the Federal Interagency Committee on Noise, day–night average sound level is still considered the most adequate noise descriptor for use in environmental impact analyses to assess the overall impact of noise from general transportation, including civilian and military aircraft operations. Until additional data become available, the new USAF logistic curve presented in Eq. (2) and Fig. 2 is recommended for use in environmental impact analyses as the nominal relationship between the day–night average sound level of environmental (general transportation) noise and the percentage highly annoyed of a residential population.

The 10-dB nighttime penalty levied against sounds during the hours from 22.00 to 07.00 is specifically intended to account for the intrusiveness of nighttime noise and its potential for disturbing sleep. However, flight operations with a large number of nighttime noise events may require that supplemental information, such as an estimate of sleep disturbance, be included in environmental impact analyses. Under those circumstances, the relationship presented in Eq. (3) and Fig. 4 is recommended until appropriate field research requires and supports a change.

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