Effects of Aviation Noise on Awakenings from Sleep

Federal Interagency Committee on Aviation Noise (FICAN)

June 1997

The effect of aviation noise on sleep is a long-recognized concern of those interested in addressing the impacts of noise on people. In 1992, the Federal Interagency Committee on Noise (FICON) recommended an interim dose-response curve to predict the percent of the exposed population expected to be awakened as a function of the exposure to single event noise levels expressed in terms of SEL.

Since the adoption of FICON's interim curve in 1992, substantial field research in the area of sleep disturbance has been completed. The data from these studies show a consistent pattern, with considerably less percent of the exposed population expected to be behaviorally awakened than had been shown with laboratory studies.

FICAN recommends the adoption of a new dose-response curve for predicting awakening, based on the field data described in this paper and supporting references. The Committee takes the conservative position that, because the adopted curve represents the upper limit of the data presented, it should be interpreted as predicting the "maximum percent of the exposed population expected to be behaviorally awakened", or the "maximum % awakened".

1. SUMMARY

The effect of aviation noise on sleep is a long-recognized concern of those interested in addressing the impacts of noise on people. Historical studies of sleep disturbance were conducted mainly in laboratories, using various indicators of response (electroencephalographic recordings, verbal response, button push, etc). Field studies also were conducted, in which subjects were exposed to noise in their own homes, using real or simulated noise. However, in a 1989 assessment of existing research, Pearsons indicated the need for substantially more work in this area, citing the large discrepancy between laboratory and field studies as a major concern.

In 1992, the Federal Interagency Committee on Noise (FICON) recommended an interim dose-response curve to predict the percent of the exposed population expected to be awakened (% awakening) as a function of the exposure to single event noise levels expressed in terms of sound exposure level (SEL). This interim curve was based on the data presented in the 1989 study. The FICON report also recommended continued research into community reactions to aircraft noise, including sleep disturbance.

Since the adoption of FICON's interim curve in 1992, substantial field research in the area of sleep disturbance has been completed, using a variety of test methods, and in a number of locations. The data from these studies show a consistent pattern, with considerably less percent of the exposed population expected to be behaviorally awakened than had been shown with laboratory studies.

In light of this new information, FICAN recommends the adoption of a new dose-response curve for predicting awakening, based on the field data described in this paper and supporting references. The Committee takes the conservative position that, because the adopted curve represents the upper limit of the data presented, it should be interpreted as predicting the "maximum percent of the exposed population expected to be behaviorally awakened", or the "maximum % awakened". FICAN cautions that the dose-response relationship presented here relies on behavioral awakening as the indicator of sleep disturbance; relationships between aircraft noise and other potential sleep disturbance or related health effects responses have not been established by any of these newer studies. FICAN further notes that this curve should be applied only to long-term residential settings and should not be generalized to include children.

The new finding on the relationship between aircraft noise and sleep disturbance does not call into question the nighttime penalty applied to Day Night Sound Level (DNL). The 10 dB penalty added to noise levels for the period 10 p.m. to 7 a.m. is intended to account for the increased intrusiveness of noise at night. The ambient 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 are much higher during nighttime which could lead to greater annoyance.

Continuing efforts to identify other dose-response relationships are being undertaken by standards-setting organizations, such as the American National Standards Institute. FICAN will evaluate proposed relationships developed by such groups as they are published; until that time, FICAN recommends the use of the curve presented here for assessing potential sleep disturbance caused by aircraft noise.

2. Background

2.1 The Nature of Sleep Disturbance

The effect of aviation noise on sleep is a long-recognized concern of those interested in addressing the impacts of noise on people. Historical studies of sleep disturbance were conducted mainly in laboratories, using various indicators of response (electroencephalographic recordings, verbal response, button push, etc). Field studies also were conducted, in which subjects were exposed to noise in their own homes, using real or simulated transportation noise [Lukas, 1975; Griefahn and Muzet, 1978; and Pearsons et al., 1989].

Based on a 1989 literature review by Pearsons for the U.S. Air Force, no specific adverse health effects have been clearly associated with sleep disturbance, characterized either by awakening or by sleep-state changes [Pearsons, 1989]. Nevertheless, sleep disturbance is deemed undesirable, and may be considered an impact caused by noise exposure.

2.2 Methodological Considerations

Sleep disturbance studies have employed a variety of factors in study design, sleep disturbance measurement, and noise exposure assessment. Differences in these techniques can have influences on the results of the studies, and a basic understanding of the differences is important for interpreting the results.

Study Design: Laboratory vs. Field Research

The most important issue with regard to the design of sleep disturbance studies has been the location of test subjects: as demonstrated in the meta-analysis by Pearsons, there has been a consistent, significant difference in the level of disturbance observed between laboratory studies, in which subjects are exposed to noise in a laboratory setting, and field studies, in which subjects are exposed to noise (actual or simulated) in their own home. Generally, laboratory studies have shown considerably more disturbance than field studies [Pearsons, 1995]. Finegold speculates that the significantly greater awakening observed in the laboratory is due to the lack of habituation [Finegold, 1993].

Measures of Sleep Disturbance

Distinctions can be made between a variety of sleep disturbance responses, which can be identified through different data collection methods in sleep studies.

Behavioral awakenings typically are defined as awakening by the subject enough to initiate a physical acknowledgment, such as button-pushing or verbal response. Sleep disturbance also can be defined as arousals or gross bodily movement (motility), identified by periods of actimetric responsei, or by electroencephalographic (EEG) response, which may or may not result in actual awakening. Researchers are careful to point out that the relationship between behaviorally-confirmed awakening and motility is not clear, though both show clearly defined dose-response relationships.

In addition to the variety of measures for identifying disturbances from individual events, most sleep disturbance studies collect data from subjects concerning cumulative sleep effects. For example, measurements can be made of the total sleep time and/or time to fall asleep, and subjects can be questioned on sleep quality (feeling upon arousal, etc.). Two major problems with collecting cumulative data are the potential influences of disturbance caused by non-noise sources, and the difficulty of avoiding bias in test subjects on self-report.

Noise Metrics

Similarly, the noise metrics used to quantify noise exposure in sleep research fall into two categories: (1) measures of individual events, and (2) cumulative measures. Single event measures that have been used in sleep disturbance studies include the Maximum A-weighted Level (Lmax), Perceived Noise Level (PNL), Sound Exposure Level (SEL), Effective Perceived Noise Level (EPNL), and C-Level (CL). Cumulative measures are used to characterize the noise events over an entire night or day, and have included the Equivalent Noise Level (Leq), Composite Noise Level (CNL), Day-Night Average Sound Level (DNL), Community Noise Equivalent Level (CNEL), and Cumulative Distribution Levels or Percentile Levels, (Lx).

A-weighted measures of single events have been most often used in sleep disturbance studies, with either Lmax or SEL being used in most of the recent studies, based on general consensus that single event metrics are more useful for predicting sleep disturbance than cumulative measuresii.

2.3 FICON Sleep Disturbance Recommendations

In 1992, the Federal Interagency Committee on Noise (FICON) recommended an interim dose-response curve to predict the percent of the exposed population expected to be awakened (% awakening) as a function of the exposure to single event noise levels expressed in terms of the sound exposure level, SEL [FICON, 1992]. This interim curve was based on statistical adjustment of Pearsons' 1989 analysis, and included data from both laboratory and field studies [Finegold, 1993]. The recommended dose-response relationship is shown in Figure 1, and can be expressed by the following equation:

Awakenings = 0.000007079 x SEL3.496

The FICON report also recommended continued research into community reactions to aircraft noise, including sleep disturbance.

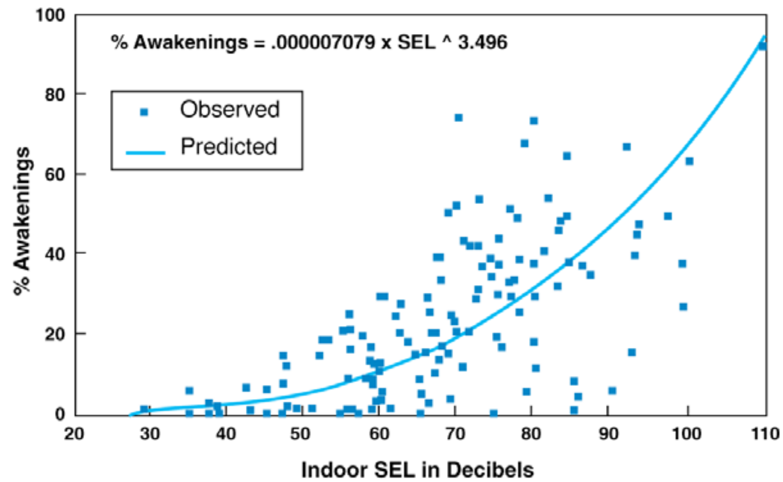

Figure 1. Interim Sleep Disturbance Dose-Response Relationship Recommended by FICON (FICON, 1992)

3. Recent Sleep Disturbance Research

Three recent studies have added considerably to the stock of data on sleep disturbance caused by aviation noise. The first of these was conducted in the United Kingdom in 1992; the second in the U.S. near Castle Air Force Base and near Los Angeles International Airport in California in 1992; and the most recent study was conducted in communities near Stapleton International Airport (DEN) and near Denver International Airport (DIA) in Colorado, both before and after the opening of DIA in 1995. These studies are summarized below.

3.1 U.K. Study

The United Kingdom's (U.K.'s) Civil Aviation Authority initiated a study of aircraft noise and sleep disturbance in 1990 to assist the U.K. Department of Transport in developing proposals for future restrictions on nighttime aircraft operations at the London airports [Ollerhead et al., 1992]. In this field study, nearly 50,000 subject-hours of sleep disturbance were collected at four airports, using both activity meters (actimeters) and EEG to measure sleep disturbance in test subjects. In total, 5,742 subject-nights of actimetry data and 178 subject-nights of sleep-EEG data were collected.

The major conclusions of the study are as follows:

- All subjective reactions to noise vary greatly from person to person and from time to time and sleep disturbance is no exception; deviations from the average can be very large. Even so, this study indicates that, once asleep, very few people living near airports are at risk of any substantial sleep disturbance due to aircraft noise, even at the high event levels.
- At outdoor event levels below 90 dBA SEL (80 dBA Lmax), average sleep disturbance rates are unlikely to be affected by aircraft noise. At higher levels, and most of the events upon which these

> conclusions are based were in the range 90 to 100 dBA SEL (80 to 95 dBA Lmax), the chance of the average person being wakened is about 1 in 75. Compared with the overall average of about 18 nightly awakenings, this probability indicates that even large numbers of noisy nighttime aircraft movements will cause very little increase in the average person's nightly awakenings. Therefore, based on expert opinion on the consequences of sleep disturbance, the results of this study provide no evidence to suggest that aircraft noise is likely to cause harmful after effects [Ollerhead et al., 1992].

Finally, the study emphasized that these are estimates of average awakenings, and it acknowledges that some individuals in any exposed population are likely to be more sensitive to nighttime noise, while others will be less sensitive.

3.2 Los Angeles Study

The 1992 study conducted for the USAF [Fidell et al., 1994] observed the effects of nighttime noise exposure on the in-home sleep of residents near Castle Air Force Base and near Los Angeles International Airport and in several suburban control households with negligible aircraft noise exposure. Test participants pressed a button upon awakening for any reason, after retiring for the evening. A total of 1,887 subject-nights of data were collected from 38 men and 47 women living in 45 different homes. Length of residence for the test subjects ranged from two to more than 40 years. Major findings of the study are as follows:

- A statistically reliable relationship was observed between sound exposure levels of noise intrusions in sleeping quarters and behaviorally confirmed awakenings within five minutes of occurrence of noise intrusions.
- Although outdoor noise exposure level at the test sites varied over the range of levels of principal interest for environmental analysis purposesiii, the prevalence for awakening among test participants did not increase greatly with sound exposure levels of noise intrusions in sleeping quarters.
- Of a total of 4,452 awakening responses, only 326 could be associated with noise events.
- The average spontaneous rate of behaviorally confirmed awakenings among test participants at all sites was approximately two per night. This figure did not differ significantly across sites with varying levels of nighttime noise exposure [Fidell et al., 1994].
- The authors cautioned that the test subjects may not be representative of all residential situations, and that generalizations of the data obtained in the study should be limited to long term residents of areas with stable nighttime noise exposure.

3.3 Denver Study

A large scale field study of noise-induced sleep disturbance was conducted in the vicinities of Stapleton International Airport (DEN) and Denver International Airport (DIA) in anticipation of the closure of DEN and the opening of DIA. Both indoor and outdoor measurements of aircraft and other nighttime noises were made during four data collection periods. Measurements were made in 57 homes, over a total of 2,717 subject-nights of observations. Sleep disturbance was measured by several methods, including button pushes upon awakening and body movements, recorded by actimeters.

Although average noise event levels measured outdoors decreased significantly at sites near DEN after its closure and increased slightly at sites near DIA after its opening, indoor noise levels varied much less in homes near both airports. No large differences were observed in noise-induced sleep disturbance at either airport, as measured before and after the DIA opening. Indoor Sound Exposure Levels of noise events were, however, closely related to and good predictors of actimetrically defined motility and arousal.

The major findings of the Denver study are the following:

- The current findings closely resemble those of prior field studies of noise-induced sleep disturbance.
- Outdoor nighttime Leq decreased about 12 dB on average at DEN upon closure of the airport, but increased only about 3 dB at DIA after opening of the airport. Indoor nighttime Leq varied little at either location with the transfer of flight operations from DEN to DIA.

- The average number of behavioral awakenings per night was 1.8 at DEN and 1.5 at DIA. The number of spontaneous awakening responses (unassociated with noise events) was 1.5 per night at DEN and 1.3 at DIA.
- Statistically reliable relationships were observed between sound exposure levels of individual noise intrusions as measured inside sleeping quarters and several measures of sleep disturbance. [Fidell et al., 1995]

4. Recommended Revised Sleep Disturbance Relationship

FICAN has evaluated the data and conclusions of the three field studies described in this paper. The combined data are presented in Figure 2, along with data from six previous field studies [Pearsons, 1989]. The "FICAN 1997" curve shown in Figure 2 predicts a conservative dose-response relationship for the combined field data. The FICON curve is also depicted, for comparison purposes; based on the current field data, the dose-response relationship given by this older curve significantly overestimates the extent of aircraft noise-related awakenings for a given SEL exposure.

The FICAN 1997 curve represents the upper limit of the observed field data, and should be interpreted as predicting the "maximum percent of the exposed population expected to be behaviorally awakened", or the "maximum % awakened" for a given residential population. The central tendency of the recent data was not chosen as the recommended curve because it could underestimate awakenings for some situations or communities. FICAN cautions that the dose-response relationship presented here relies on behavioral awakening as the indicator of sleep disturbance; relationships between aircraft noise and other potential sleep disturbance or related health effects responses have not been established by any of these newer studies.

FICAN further cautions that these data should be applied only to long term residents, although the inclusion of data from the opening of Denver International Airport suggests that people adapt to "new" noise rapidly. This curve should not be applied to estimate sleep disturbance in campgrounds, trailer parks, or other temporary residences. Nor should it be assumed that the curve can be generalized to include children, as only adults were included in the field studies.

The FICAN 1997 curve also is represented by the following equation:

$$\text{Awakenings} = 0.0087 \times (\text{SEL}-30)1.79$$

Continuing efforts to identify other dose-response relationships are being undertaken by standards-setting organizations, such as the American National Standards Institute. FICAN will evaluate proposed relationships developed by such groups as they are published; until that time, FICAN recommends the use of the curve presented here for assessing potential sleep disturbance caused by aircraft noise.

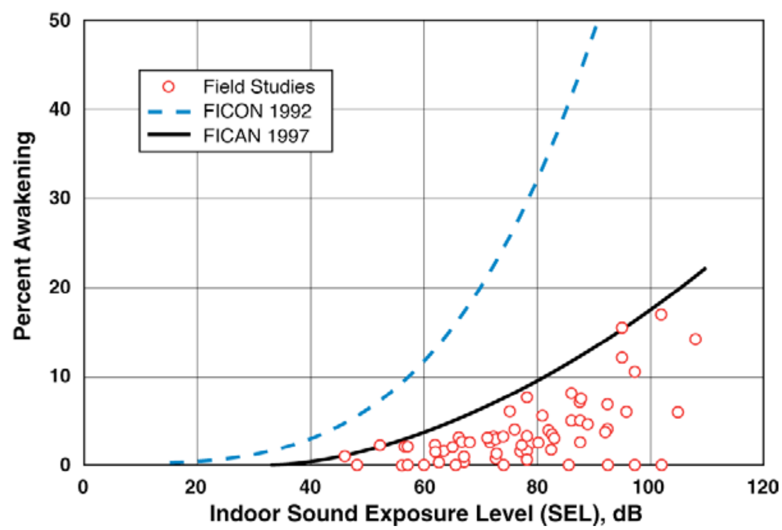

Figure 2. Recommended Sleep Disturbance Dose-Response Relationship

Footnotes

[i] Actimeters are activity monitors, which record significant limb movements over a long period of time. In sleep disturbance studies, they generally are strapped to the wrist. Actimeters are generally considered to be a more practical and cost-effective method of collecting physical sleep disturbance data.
[ii] The use of single event measures in sleep disturbance studies does not suggest that the nighttime penalties used to assess noise in Day-Night Average Sound Level or other cumulative measures are incorrect or need re-evaluation; FICAN continues to support the use of DNL for addressing cumulative impact and its underlying assumptions regarding nighttime noise events.
[iii] Day-Night Average Sound Levels (DNL) at sites near Castle AFB ranged from 50 to 90 dB, while DNL at sites near LAX ranged from 60 to 70 dB. DNL at control sites ranged from about 50 to 70 dB (some control sites were exposed to high levels of road traffic noise).

References

Federal Interagency Committee on Noise (FICON) (1992).
Federal Agency Review of Selected Airport Noise Analysis Issues. Ft. Walton Beach, FL: Spectrum Sciences and Software, Inc.

Fidell, S., K. Pearsons, R. Howe, B. Tabachnick, L. Silvati, and D.S. Barber (1994).
Noise-induced Sleep Disturbance in Residential Settings (AL/OE-TR-1994-0131). Wright Patterson Air Force Base, OH: Armstrong Laboratory, Occupational & Environmental Health Division (AL/OEBN).

Fidell, S., K. Pearsons, R. Howe, B. Tabachnick, L. Silvati, and D.S. Barber (1995).
"Field study of noise-induced sleep disturbance." *Journal of the Acoustical Society of America*, 98(2), 1025-1033.

Fidell, S., R. Howe, B. Tabachnick, K. Pearsons, and M. Sneddon (1995).
Noise-induced Sleep Disturbance in Residences near Two Civil Airports (Contract NAS1-20101) NASA Langley Research Center.

Finegold, L.S., C.S. Harris, and H.E. VonGierke (1993).
"Applied Acoustical Report: Criteria for Assessment of Noise Impacts on People." submitted to *Journal of the Acoustical Society of America*, June, 1992.

Finegold, L.S. (1993).
"Current status of sleep disturbance research and development of a criterion for aircraft noise exposure." *Journal of the Acoustical Society of America*, 94(3) Pt.2, 1807.

Griefahn, B., and A. Muzet (1978).
"Noise-Induced Sleep Disturbances and Their Effect on Health." *Journal of Sound and Vibration*, 59(1): 99-106.

Lukas, J. (1975).
"Noise and Sleep: A Literature Review and a Proposed Criterion for Assessing Effect." *Journal of the Acoustical Society of America*, 58(6).

Ollerhead, J.B., C.J. Jones, R.E. Cadoux, A. Woodley, B.J. Atkinson, J.A. Horne, F. Pankhurst, L. Reyner, K.I. Hume, F. Van, A. Watson, I.D. Diamond, P. Egger, D. Holmes, and J. McKean (1992).
Report of a Field Study of Aircraft Noise and Sleep Disturbance. London: Department of Safety, Environment and Engineering.

Pearsons, K.S., D.S. Barber, and B.G. Tabachnick (1989).
Analyses of the predictability of noise-induced sleep disturbance (HSD-TR-89-029). Brooks Air Force Base, TX: Human Systems Division, U.S. Air Force Systems Command (HSD/YA-NSBIT).

Pearsons, K.S., D.S. Barber, B.G. Tabachnick, and S. Fidell (1995).
"Predicting noise-induced sleep disturbance." *Journal of the Acoustical Society of America*, 97(1), 331-338.