



TECHNICAL INFORMATION PAPER

Effects of Noise Exposure

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Studies which examined hearing loss among people living near airports found that, under normal circumstances, people in the community near an airport are at no risk of suffering hearing damage from aircraft noise.



Aircraft noise can affect people both physically and psychologically. It is difficult, however, to make sweeping generalizations about the impacts of noise on people because of the wide variations in individual reactions. While much has been learned in recent years, some physical and psychological responses to noise are not yet fully understood and continue to be debated by researchers.

EFFECTS ON HEARING

Hearing loss is the major health danger posed by noise. A study published by the U.S. Environmental Protection Agency (1974) found that exposure to noise of 70 Leq or higher on a continuous basis, over a very long time, at the human ear's most damage-sensitive frequency, may result in a very small but permanent loss of hearing. (Leq is a pure noise dosage metric, measuring cumulative noise energy over a given time.)

In *Aviation Noise Effects* (Newman and Beattie, 1985, pp. 33-42), three studies are cited which examined hearing



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loss among people living near airports. They found that, under normal circumstances, people in the community near an airport are at no risk of suffering hearing damage from aircraft noise.

The Occupational Safety and Health Administration (OSHA) has established standards for permissible noise exposure in the work place to guard against the risk of hearing loss. Hearing protection is required when noise levels exceed the legal limits. The standards, shown in **Table 1**, establish a sliding scale of permissible noise levels by duration of exposure. The standards permit noise levels of up to 90 dBA for eight hours per day without requiring hearing protection. The regulations also require employers to establish hearing conservation programs where noise levels exceed 85 Leq during the 8-hour workday. This involves the monitoring of work place noise, the testing of employees' hearing, the provision of hearing protectors to employees at risk of hearing loss, and the establishment of a training program to inform employees about the effects of work place noise on hearing and the effectiveness of hearing protection devices.

TABLE 1

PERMISSIBLE NOISE EXPOSURE - OSHA STANDARDS

DURATION PER DAY, HOURS	SOUND LEVEL dBA SLOW RESPONSE	DURATION PER DAY, HOURS	SOUND LEVEL dBA SLOW RESPONSE
8	90	1 1/2	102
6	92	1	105
4	95	1/2	110
3	97	1/4 or less	115
2	100		

Source: 29 CFR Ch. XVII, Section 1910.95(b)

Experience at other airports has shown that even at sites with cumulative noise exposure near 75 DNL, the total time noise levels exceed 80 dBA typically ranges from 10 to 20 minutes, far below the critical hearing damage thresholds (Coffman Associates 1993, pp. 2-11). This supports the conclusion that airport noise in areas off airport property is far too low to be considered potentially damaging to hearing.

With respect to the risk of hearing loss, the authors of an authoritative summary of the research conclude: "Those



There is no strong evidence that noise has a direct causal effect on such health outcomes as cardiovascular disease, reproductive abnormality, or psychiatric disorder.



most at risk [of hearing loss] are personnel in the transportation industry, especially airport ground staff. Beyond this group, it is unlikely that the general public will be exposed to sustained high levels of transportation noise sufficient to result in hearing loss. Transportation noise control in the community can therefore not be justified on the grounds of hearing protection.” (See Taylor and Wilkins 1987.)

NON-AUDITORY HEALTH EFFECTS

It is sometimes claimed that aviation noise can harm the general physical and mental health of airport neighbors. Effects on the cardiovascular system, mortality rates, birth weights, achievement scores, and psychiatric admissions have been examined in the research literature. The question of pathological effects remains unsettled because of conflicting findings based on differing methodologies and uneven study quality. It is quite possible that the contribution of noise to pathological effects is so low that it has not been clearly isolated. While research is continuing, there is insufficient scientific evidence to support these concerns (Newman and Beattie 1985, pp. 59-62). Taylor and Wilkins (1987, p. 4/10) offer the following conclusions in their review of the research.

The evidence of non-auditory effects of transportation noise is more ambiguous, leading to differences of opinion regarding the burden of prudence for noise control. There is no strong evidence that noise has a direct causal effect on such health outcomes as cardiovascular disease, reproductive abnormality, or psychiatric disorder. At the same time, the evidence is not strong enough to reject the hypothesis that noise is in some way involved in the multi-causal process leading to these disorders. . . . But even with necessary improvements in study design, the inherent difficulty of isolating the effect of a low dose agent such as transportation noise within a complex aetiological system will remain. It seems unlikely, therefore, that research in the near future will yield findings which are definitive in either a positive or negative direction. Consequently, arguments for transportation noise control will probably continue to be based primarily on welfare criteria such as annoyance and activity disturbance.



Reviews of laboratory research on sleep disturbance report that the level of noise which can cause awakenings or interfere with falling asleep ranges from 35 dBA to 80 dBA, depending on the sleep stage and variability among individuals.



Recent case studies on mental illness and hypertension indicate that this conclusion remains valid. Yoshida and Nakamura (1990) found that long-term exposure to sound pressure levels above 65 DNL may contribute to reported ill effects on mental well-being. This case study, however, concluded that more research is needed because the results also contained some contrary effects, indicating that in some circumstances, ill effects were negatively correlated with increasing noise.

Griefahn (1992) studied the impact of noise exposure ranging from 62 dBA to 80 dBA on people with hypertension. She found that there is a tendency for vasoconstriction to increase among untreated hypertensive people as noise levels increase. However, she also found that beta-blocking medication prevented any increase in vasoconstriction attributable to noise. She concluded that while noise may be related to the onset of hypertension, especially in the presence of other risk factors, hypertensive people do not run a higher risk of ill-health effects if they are properly treated.

SLEEP DISTURBANCE

There is a large body of research documenting the effect of noise on sleep disturbance, but the long-range effects of sleep disturbance caused by nighttime airport operations are not well understood. It is clear that sleep is essential for good physical and emotional health, and noise can interfere with sleep, even when the sleeper is not consciously awakened. While the long-term effect of sleep deprivation on mental and physical function is not clear, it is known to be harmful. It is also known that sleepers do not fully adjust to noise disruption over time. Although they may awaken less often and have fewer conscious memories of disturbance, noise-induced shifts in sleep levels continue to occur.

Reviews of laboratory research on sleep disturbance report that the level of noise which can cause awakenings or interfere with falling asleep ranges from 35 dBA to 80 dBA, depending on the sleep stage and variability among individuals (Newman and Beattie 1985, pp. 51-58; Kryter 1984, pp. 422-431). There is evidence that older people tend to be much more sensitive to noise-induced awakenings than younger people.



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Research has shown that, when measured through awakenings, people tend to become somewhat accustomed to noise. On the other hand, electroencephalograms, which reveal information about sleep stages, show little habituation to noise. Kryter describes these responses to noise as “alerting responses.” He suggests that because they occur unconsciously, they may simply be reflexive responses, reflecting normal physiological functions which are probably not a cause of stress to the organism.

Most studies of sleep disturbance have been conducted under controlled laboratory conditions. The laboratory studies do not allow generalizations about the potential for sleep disturbance in an actual airport setting, and, more importantly, the impact of these disturbances on the residents. Furthermore, the range of sound levels required to cause sleep disturbance, ranging from a whisper to a shout (35 dB to 80 dB), and the prevalence of sleep disruption in the absence of any noise, greatly complicates the making of reasonable generalizations about the effect of noise on sleep.

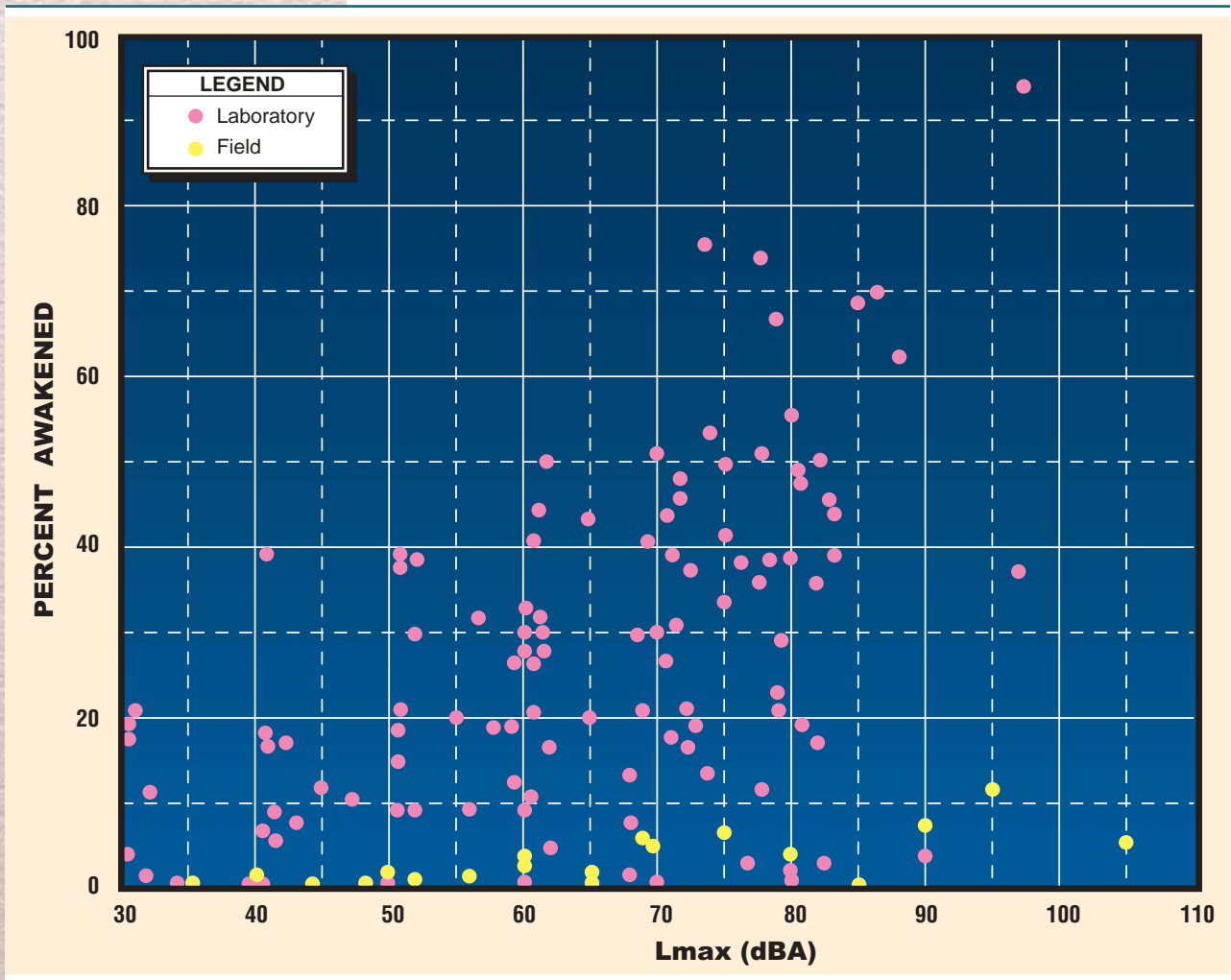
Fortunately, some studies have examined the effect of nighttime noise on sleep disturbance in actual community settings. One report summarizes the results of eight studies conducted in homes (Fields 1986). Four studies examined aircraft noise, the others highway noise. In all of them, sleep disturbance was correlated with cumulative noise exposure metrics such as Leq and L10. All studies showed a distinct tendency for increased sleep disturbance as cumulative noise exposure increased. The reviewer notes, however, that sleep disturbance was very common, regardless of noise levels, and that many factors contributed to it. He points out that, “the prevalence of sleep disturbance in the absence of noise means that considerable caution must be exercised in interpreting any reports of sleep disturbance in noisy areas.”

A recent review of the literature, Pearsons, et al. (1990), compared the data and findings of laboratory and field studies conducted in the homes of subjects. They found that noise-induced awakenings in the home were much less prevalent than in the laboratory. They also found that much higher noise levels were required to induce awakenings in the home than in the laboratory. **Exhibit A**

compares the percentage of people awakened at different sound levels in laboratory and field studies. The graph clearly shows a marked tendency for people in laboratory settings to be much more sensitive to noise than in their homes. The reason for the large difference is apparently that people in their homes are fully habituated to their environment, including the noise levels.

EXHIBIT A

COMPARISON OF AWAKENING DUE TO NOISE EVENTS FROM LABORATORY VERSUS FIELD STUDIES



Source: Pearson, K.S. et al. 1990.

Finegold et al. (1994) reviewed the data in the Pearsons report of 1990 and developed a regression analysis. As shown in **Exhibit B**, an exponential curve was found to fit the categorized data reasonably well. They recommend that this curve be used as a provisional means of predicting potential sleep disturbance from aircraft





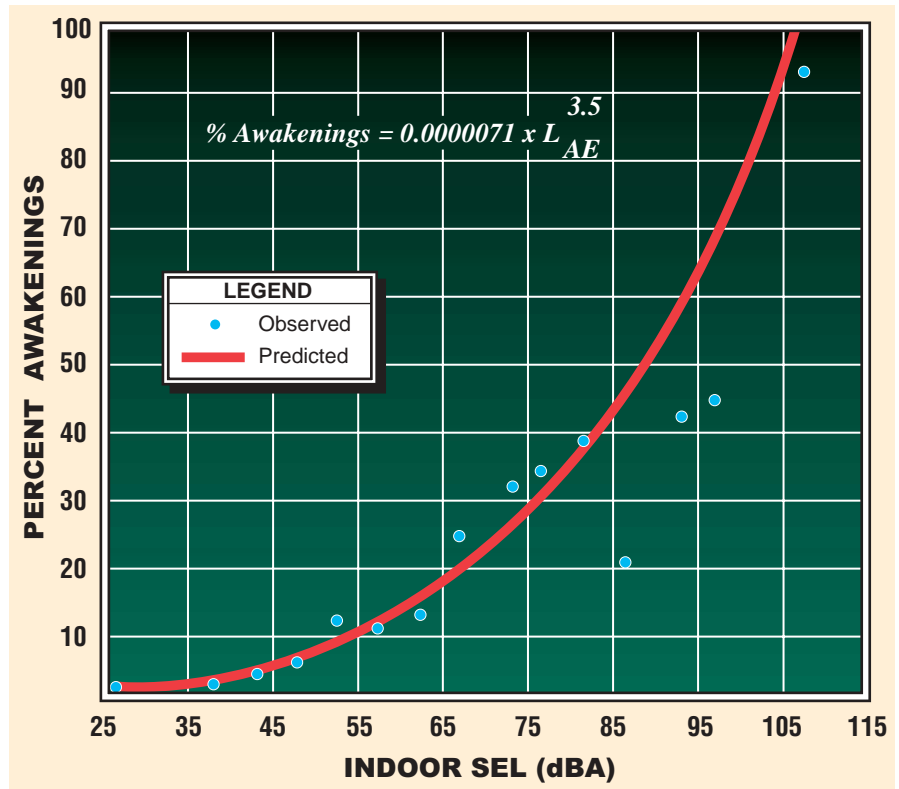
The findings of many of these sleep disturbance studies are of little usefulness to policy-makers and airport residents. For them, the important question is, "When does sleep disturbance caused by environmental noise become severe enough to constitute a problem in the community?"



noise. They caution that because the curve was derived using Pearsons' laboratory, as well as in-home data, the predictions of sleep disruption in an actual community setting derived from this curve are likely to be high.

EXHIBIT B

FINEGOLD'S SLEEP DISTURBANCE CURVE



Source: Finegold et al. 1994.

Note: Based on laboratory and field data reported in Pearsons et al. 1989.

The findings of many of these sleep disturbance studies, while helping to answer basic research questions, are of little usefulness to policy-makers and airport residents. For them, the important question is, "When does sleep disturbance caused by environmental noise become severe enough to constitute a problem in the community?" Kryter (1984, pp. 434-443) reviews in detail one important study that sheds light on this question. The Directorate of Operational Research and Analysis (DORA) of the British Civil Aviation Authority conducted an in-depth survey of 4,400 residents near London's Heathrow and Gatwick Airports over a four-month period in 1979 (DORA 1980). The study was intended to answer two policy-related questions: "What is the level of aircraft noise which will disturb a sleeping person?" and "What level of aircraft noise prevents people from getting to sleep?"



The 65 DNL contour defines a noise impact envelope which encompasses all of the area within which significant sleep disturbance may be expected.

Analysis of the survey results indicated that the best correlations were found using cumulative energy dosage metrics, namely Leq. Kryter notes that support for the use of the Leq metric is provided by the finding that some respondents could not accurately recall the time association of a specific flight with an arousal from sleep. This suggests that the noise from successive overflights increased the general state of arousability from sleep.

With regard to difficulty in getting to sleep, the study found 25 percent of the respondents reporting this problem at noise levels of 60 Leq, 33 percent at 65 Leq, and 42 percent at 70 Leq. The percentage of people who reported being awakened at least once per week by aircraft noise was 19 percent at 50 Leq, 24 percent at 55 Leq, and 28 percent at 60 Leq. The percentage of people bothered "very much" or "quite a lot" by aircraft noise at night when in bed was 22 percent at 55 Leq and 30 percent at 60 Leq. Extrapolation of the trend line would put the percentage reporting annoyance at 65 Leq well above 40 percent.

DORA concluded with the following answers to the policy-related questions: (1) A significant increase in reports of sleep arousal will occur at noise levels at or above 65 Leq; (2) A significant increase in the number of people reporting difficulty in getting to sleep will occur at noise levels at or above 70 Leq. Kryter disagrees with these findings. He believes that a more careful reflection upon the data leads to the conclusion that noise levels approximately 10 decibels lower would represent the appropriate thresholds — 55 and 60 Leq.

At any airport, the 65 DNL contour developed from total daily aircraft activity will be larger than the 55 Leq developed from nighttime activity only. (At an airport with only nighttime use, the 65 DNL contour will be identical with the 55 Leq contour because of the effect of the 10 dB penalty in the DNL metric.) Thus, the 65 DNL contour defines a noise impact envelope which encompasses all of the area within which significant sleep disturbance may be expected based on Kryter's interpretation of the DORA findings discussed above.

A recent study was conducted by the British Civil Aviation Authority to examine the relationship of nighttime aircraft noise and sleep disturbance near four major airports —





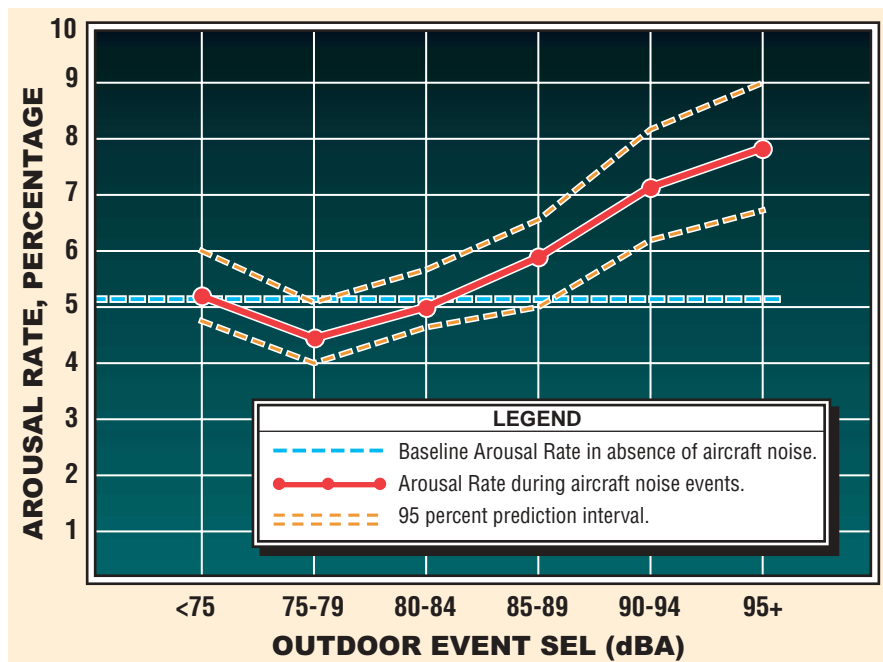
Researchers found that for aircraft noise events below 90 SEL, as measured outdoors, there was likely to be no measurable increase in rates of sleep disturbance.

Heathrow, Gatwick, Stansted, and Manchester (Ollerhead, et al. 1992). A total of 400 subjects were monitored for a total of 5,742 subject-nights. Nightly awakenings were found to be very common as part of natural sleep patterns. Researchers found that for aircraft noise events below 90 SEL, as measured outdoors, there was likely to be no measurable increase in rates of sleep disturbance. (The indoor level can be roughly estimated as approximately 20 to 25 decibels less than the outdoor level.) Where noise events ranged from 90 to 100 SEL, a very small rate of increase in disturbance was possible. Overall, rates of sleep disturbance were found to be more closely correlated with sleep stage than with periods of peak aircraft activity. That is, sleep was more likely to be disrupted, from any cause, during light stages than during heavy stages.

Exhibit C shows the relationship between arousal from sleep and outdoor sound exposure levels (SELs) found in the 1992 British study. The results have been statistically adjusted to control for the effects of individual variability in sleep disturbance. The study found that the arousal rate for the average person, with no aircraft noise, was 5.1 percent. Aircraft noise of less than SEL 90 dBA was

EXHIBIT C

RELATIONSHIP BETWEEN AVERAGE SLEEP DISTURBANCE AND AIRCRAFT NOISE LEVEL



Source: Ollerhead, J.B. et al. 1992, p. 25.

Note: Estimates controlled for the effects of individual arousability.





While vibration contributes to annoyance reported by residents near airports, especially when it is accompanied by high audible sound levels, it rarely carries enough energy to damage safely constructed structures.



found not to be statistically significant as a cause of sleep disturbance. (According to the study, this would correspond to an L_{max} of approximately 81 dBA. L_{max} is the loudest sound the human ear would actually hear during the 90 SEL noise event. The interior L_{max} would be approximately 20 to 25 decibels less — roughly 56 to 61 dBA.) The 95 percent prediction interval is shown on the graph not to rise above the 5.1 percent base arousal rate until it is above 90 dBA. Again, it should be emphasized that these conclusions relate to the average person. More easily aroused people will be disturbed at lower noise levels, but they are also more likely to be aroused from other sources (Ollerhead, et al. 1992).

STRUCTURAL DAMAGE

Structural vibration from aircraft noise in the low frequency ranges is sometimes a concern of airport neighbors. While vibration contributes to annoyance reported by residents near airports, especially when it is accompanied by high audible sound levels, it rarely carries enough energy to damage safely constructed structures. High-impulse sounds such as blasting, sonic booms, and artillery fire are more likely to cause damage than continuous sounds such as aircraft noise. A document published by the National Academy of Sciences suggested that one may conservatively consider noise levels above 130 dB lasting more than one second as potentially damaging to structures (CHABA 1977). Aircraft noise of this magnitude occurs on the ramp and runway and seldom, if ever, occurs beyond the boundaries of a commercial or general aviation airport.

The risk of structural damage from aircraft noise was studied as part of the environmental assessment of the Concorde supersonic jet transport. The probability of damage from Concorde overflights was found to be extremely slight. Actual overflight noise from the Concorde at Sully Plantation near Dulles International Airport in Fairfax County, Virginia was recorded at 115 dBA. No damage to the historic structures was found, despite their age. Since the Concorde causes significantly more vibration than conventional commercial jet aircraft, the risk of structural damage caused by aircraft noise near airports is considered to be negligible (Hershey et al. 1975; Wiggins 1975).



The psychological impact of aircraft noise is a more serious concern than direct physical impact.

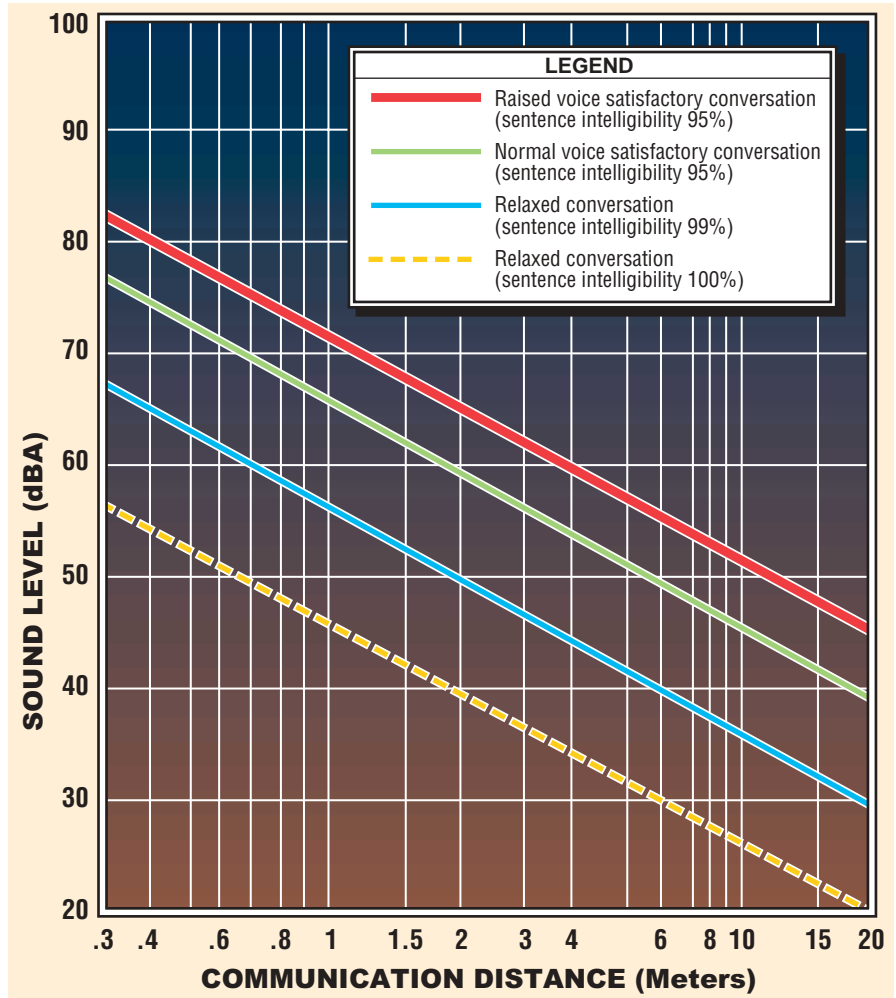
OTHER ANNOYANCES

The psychological impact of aircraft noise is a more serious concern than direct physical impact. Studies conducted in the late 1960s and early 1970s found that the interruption of communication, rest, relaxation, and sleep are important causes for complaints about aircraft noise. Disturbance of television viewing, radio listening, and telephone conversations are also sources of serious annoyance.

Exhibit D shows the relationship between sound levels and communicating distance for different voice levels. Assuming a communicating distance of 2 meters, communication becomes unsatisfactory with a steady

EXHIBIT D

MAXIMUM DISTANCES OUTDOORS OVER WHICH CONVERSATION IS SATISFACTORILY INTELLIGIBLE IN STEADY NOISE



Source: U.S. Environmental Protection Agency, 1974. Cited in Caltrans, 1993.

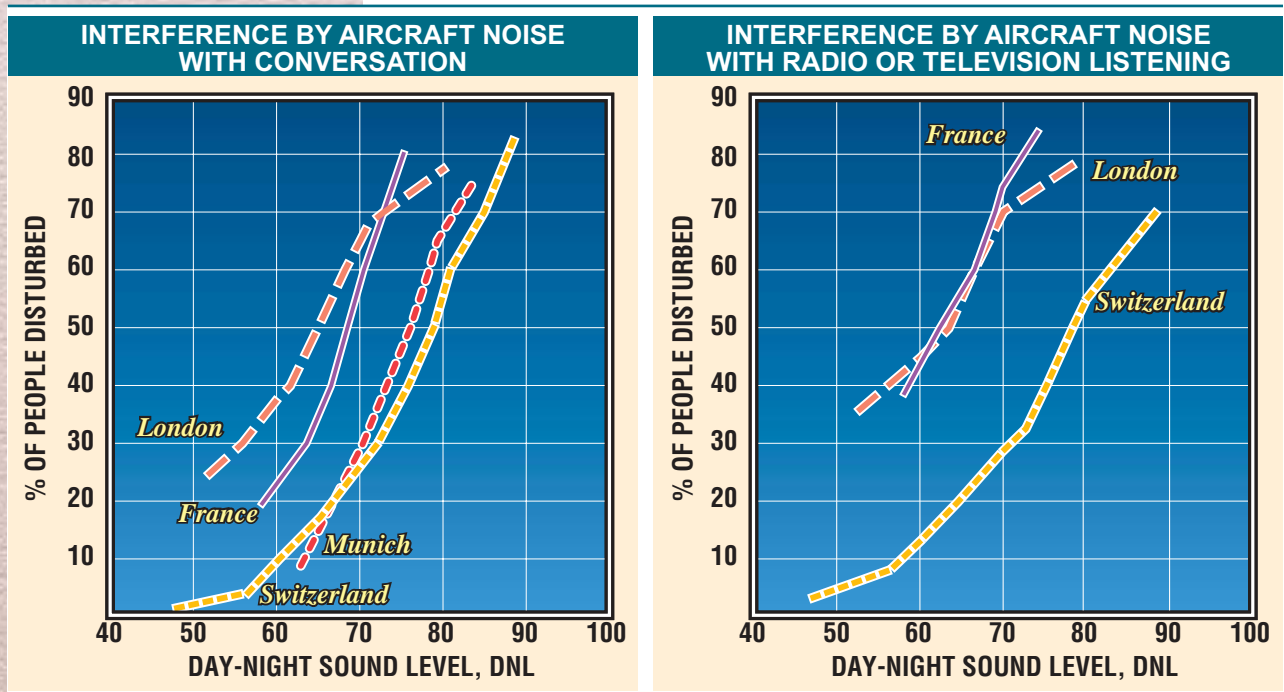


noise level above approximately 65 decibels. At 65 decibels, a raised voice is required to maintain satisfactory conversation. Another way to interpret this is that a raised voice would be interrupted by a sound event above 65 decibels. A normal voice would be interrupted, at 2 meters, by a sound event of 60 decibels.

Exhibit E shows the impact of aircraft noise on conversation and radio or television listening. These results, summarized by Schultz (1978), were derived from surveys conducted in London, France, Munich, and Switzerland. Differences in the amount of disturbance reported in each study are based on how each survey defined disturbance. The British study counted mild disturbance, the French moderate disturbance, and the German and Swiss great disturbance.

EXHIBIT E

INTERFERENCE BY AIRCRAFT NOISE WITH VARIOUS ACTIVITIES



Note: Differences in amount of interference reported are related to how individual surveys defined interference. London counted mild disturbance, France moderate disturbance, and Munich and Switzerland great disturbance.

Source: Shultz, T.J. 1978.



In the case of conversation disruption, nine percent were greatly annoyed by noise of 60 DNL in the Swiss study. About 12 to 16 percent of those in the Swiss and German studies considered themselves to be greatly disturbed by aircraft noise of 65 DNL. At 75 DNL, 40 to 50 percent



Individual human response to noise is highly variable and is influenced by many emotional and physical factors.



considered themselves greatly disturbed. In the French study, 23 percent considered themselves moderately disturbed by aircraft noise at 60 DNL, 35 percent at 65 DNL, and 75 percent at 75 DNL. In the British study, 37 percent were mildly disturbed by aircraft noise at 60 DNL, 50 percent at 65 DNL, and about 72 percent at 75 DNL.

Regarding interference with television and radio listening, about 13 percent in the Swiss study were greatly disturbed by aircraft noise above 60 DNL, 21 percent at 65 DNL, and 40 percent at 75 DNL. In the British and French studies, 42 to 45 percent were mildly to moderately disturbed by noise at 60 DNL, 55 percent at 65 DNL, and 75 to 82 percent at 75 DNL.

In some cases, noise is only an indirect indicator of the real concern of airport neighbors — safety. The sound of approaching aircraft may cause fear in some people about the possibility of a crash. This fear is a factor motivating some complaints of annoyance in neighborhoods near airports around the country. (See Richards and Ollerhead 1973; FAA 1977; Kryter 1984, p. 533.) This effect tends to be most pronounced in areas directly beneath frequently used flight tracks (Gjestland 1989).

The EPA has also found that continuous exposure to high noise levels can affect work performance, especially in high-stress occupations. Based on the FAA's land use compatibility guidelines, discussed in the Technical Information Paper on Noise and Land Use Compatibility, these adverse affects are most likely to occur within the 75 DNL contour.

Individual human response to noise is highly variable and is influenced by many factors. These include emotional variables, feelings about the necessity or preventability of the noise, judgments about the value of the activity creating the noise, an individual's activity at the time the noise is heard, general sensitivity to noise, beliefs about the impact of noise on health, and feelings of fear associated with the noise. Physical factors influencing an individual's reaction to noise include the background noise in the community, the time of day, the season of the year, the predictability of the noise, and the individual's control over the noise source.

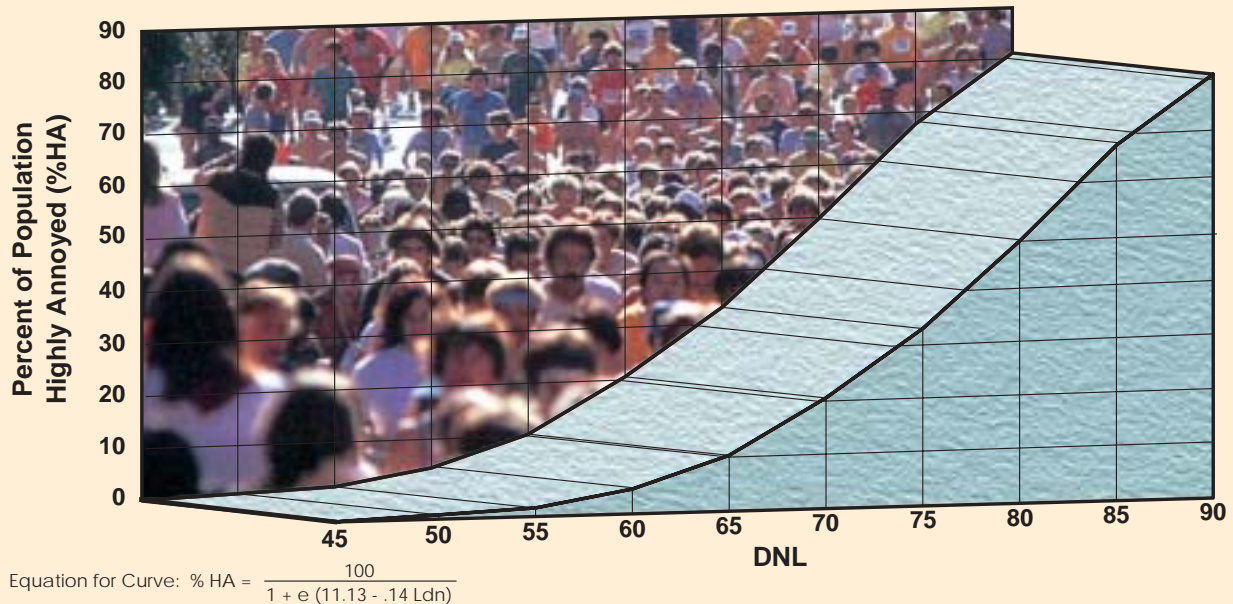
AVERAGE COMMUNITY RESPONSE TO NOISE

Although individual responses to noise can vary greatly, the average response among a group of people is much less variable. This enables us to generalize about the average impacts of aircraft noise on a community despite the wide variations in individual response.

Many studies have examined average residential community response to noise, focusing on the relationship between annoyance and noise exposure. (See DORA 1980; Fidell et al. 1989; Finegold et al. 1992 and 1994; Great Britain Committee on the Problem of Noise 1963; Kryter 1970; Richards and Ollerhead 1973; Schultz 1978; U.S. EPA 1974.) These studies have produced similar results, finding that annoyance is most directly related to cumulative noise exposure, rather than single-event exposure.

EXHIBIT F

PERCENTAGE OF POPULATION HIGHLY ANNOYED BY GENERAL TRANSPORTATION NOISE



PERCENT HIGHLY ANNOYED AT SELECTED NOISE LEVELS

DNL	45	50	55	60	65	70	75	80	85	90
%HA	0.8%	1.6%	3.1%	6.1%	11.6%	20.9%	34.8%	51.7%	68.4%	81.3%

Source: Finegold et al. 1992 and 1994.



Annoyance has been found to increase along an S-shaped or logistic curve as cumulative noise exposure increases, as shown in **Exhibit F**. Developed by Finegold et al. (1992 and 1994), it is based on data derived from a



The updated Schultz Curve shows that annoyance is measurable beginning at 45 DNL, where 0.8 percent of people are highly annoyed. It increases gradually to 6.1 percent at 60 DNL. Starting at 65 DNL, the percentage of people expected to be highly annoyed increases steeply from 11.6 percent up to 68.4 percent at 85 DNL.



number of studies of transportation noise (Fidell 1989). It shows the relationship between DNL levels and the percentage of people who are highly annoyed. Known as the “updated Schultz Curve” because it is based on the work of Schultz (1978), it represents the best available source of data for the noise dosage-response relationship (FICON 1992, Vol. 2, pp. 3-5; Finegold et al. 1994, pp. 26-27).

The updated Schultz Curve shows that annoyance is measurable beginning at 45 DNL, where 0.8 percent of people are highly annoyed. It increases gradually to 6.1 percent at 60 DNL. Starting at 65 DNL, the percentage of people expected to be highly annoyed increases steeply from 11.6 percent up to 68.4 percent at 85 DNL. Note that this relationship includes only those reported to be “highly annoyed.” Based on other research, the percentages would be considerably higher if they also included those who were “moderately or mildly annoyed” (Richards and Ollerhead 1973; Schultz 1978).

SUMMARY

The effects of noise on people include hearing loss, other ill health effects, and annoyance. While harm to physical health is generally not a problem in neighborhoods near airports, annoyance is a common problem. Annoyance is caused by sleep disruption, interruption of conversations, interference with radio and television listening, and disturbance of quiet relaxation.

Individual responses to noise are highly variable, making it very difficult to predict how any person is likely to react to environmental noise. The average response among a large group of people, however, is much less variable and has been found to correlate well with cumulative noise dosage metrics such as Leq, DNL, and CNEL. The development of aircraft noise impact analysis techniques has been based on this relationship between average community response and cumulative noise exposure.



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