

Using Supplemental Metrics to Communicate Aircraft Noise Effects

May 23, 2007

Mary Ellen Eagan
Harris Miller Miller & Hanson Inc.
77 South Bedford Street
Burlington, MA 01803
T. 781.229.0707
F. 781.229.7939
meagan@hmmh.com

Total words: approx. 2300 plus 9 tables and figures (250 words each) = 4,550

ABSTRACT

Airport noise analyses rely heavily on the use of complex exposure metrics that can be obtuse to the layperson. Individuals often seek out information on aircraft noise levels only to be frustrated by the complexity of the science. In recent years, there has been increasing use of “supplemental” or other non-traditional metrics to describe the impacts of aviation noise on people. Implicit in this usage has been an assumption that supplemental metrics are better understood by the community. This paper proposes that practitioners be much more explicit in relating these supplemental noise metrics to the potential effects of noise, and presents several examples that relate noise effects to lay terms. The FAA’s Integrated Noise Model can be used to predict noise impacts using well established relationships between noise effects and metrics available in the INM. Then, instead of presenting noise level information, it is possible to use these relationships to prepare graphical depictions that represent the extent of the effects, rather than the extent of the noise level metric. With the increased transparency provided by these “effect” maps, policy makers and concerned citizens can engage in a more informed discussion that could ultimately lead to better outcomes for all.

INTRODUCTION

The Federal Aviation Administration's (FAA's) *National Vision for Aviation and the Environment* states "Environmental impacts may be the fundamental constraint on air transportation growth in the 21st century." (1) The report also suggests an "urgent need to address the environmental effects of air transportation" through increased communication and coordination; development of operational, technological and policy options; and development of "more effective metrics to assess and communicate aviation's environmental impacts." (1)

The FAA requires that environmental documents address noise impact around airports using an impact threshold of Day Night Average Sound Level (DNL) 65 dBA (2). Indeed, current regulations prohibit FAA from funding noise mitigation programs outside of DNL 65 (3). FAA estimates that the number of people in the U.S. exposed to DNL 65 dB or greater has decreased by 95% in the last 35 years (1); however, most airport expansion projects experience delay from community concerns over noise and other environmental impacts. Further, the FAA's *National Vision for Aviation and the Environment* predicts significant expansion of commercial air traffic, but with little additional reduction of aircraft noise levels on the horizon. This is likely to result in an increase in DNL contours around many airports.

There is a strongly held view that exclusive reliance on the use of a complex noise metric such as DNL contributes to community concerns and inhibits establishment of trust. Better communication tools could help redress some of the mistrust that is generated by the use of these complicated metrics.

BACKGROUND

The Day Night Average Sound Level (DNL) was first recommended by the EPA in 1974 as a "simple, uniform and appropriate way" of measuring long term environmental noise (4). DNL takes into account both the frequency of occurrence and duration of all noise events during a 24-hour period, and provides a 10-decibel weighting factor for noises from 10 p.m. to 7 a.m. It is expressed by the following equation:

$$L_{dn} = 10 \log \left(\frac{1}{86,400} \sum_{i=1}^N 10^{(SPL_i + W_i)/10} \right)$$

where:	L_{dn}	=Day-Night Average Sound Level, DNL, for one day
	SPL_i	=Instantaneous A-weighted sound level, measured every 0.5s
	86,400	=number of seconds in one day
	W_i	=time of day weighting for ith A-weighted sound level
	N	=86,400/ Δt

DNL and Community Noise Equivalent Level (CNEL, a variant that provides an additional weighting factor for noise from 7 p.m. to 10 p.m. is used only in California (5) are used in virtually all environmental analyses of aviation noise in the U.S., for both civil and military applications. It remains the best overall descriptor of environmental noise and is the best predictor of community annoyance (6).

Nevertheless, DNL is a complex metric that requires a reasonably advanced understanding of both mathematics and physics. It is difficult to explain to lay audiences and has proven to be an obstacle to constructive discussion of aircraft noise issues. In recent years, there

has been increasing use of “supplemental” or other non-traditional metrics to expand discussion beyond DNL. Some states even require the use of these metrics in state environmental reviews⁷. Implicit in this usage has been an assumption that supplemental metrics are better understood by the community. Why? Perhaps because they relate better to people’s experience. This paper proposes that practitioners can be much more explicit in relating supplemental noise metrics to the potential effects of noise. Perhaps with increased transparency, policy makers and concerned citizens can engage in a more informed discussion that could ultimately lead to better outcomes for all.

METHODOLOGY

The table below presents a possible scheme for addressing noise impacts through use of a range of supplemental metrics that are closely related to the kinds of concerns people most often express when talking about aviation noise. These effects represent the range of the most common complaints made to airport noise offices. The table also gives the proposed metrics that closely correlate with the effect, as well as the documented basis for that correlation. Instead of presenting noise level information, it is possible to use these relationships to present graphical depictions of the much more intuitive effects that people experience; i.e., rather than depicting noise contours in decibels, we should depict outcome contours in terms of awakenings, annoyance, etc.

In this way, it is possible for policy makers and the public to review noise impacts in the same terms that they view impacts – rather than making everyone try to understand complicated decibel metrics, this translation allows people to understand noise impacts more intuitively.

The exhibits presented here are based on noise metrics easily available in the FAA’s Integrated Noise Model; all are based on a single day of flight activity (approximately 330 flights) at a major air carrier airport. Each flight was modeled using actual radar data to determine flight path and aircraft type; the data were processed using the Integrated Noise Model, the FAA-required model for computing noise around civil airports (2).

NOISE EFFECTS FOR CONSIDERATION

The most common effects regarding aircraft noise are related to annoyance, activity interference (speech disruption, sleep disturbance), learning (especially effects on children), and noise induced vibration (rattle). Each of these effects has been studied extensively, and relationships between various noise metrics and effects have been established. The following sections summarize these effects, and present exhibits that clearly depict the extents of the effects, based on current understanding of the relationships between noise and the various effects.

Annoyance

The 1978 Schultz curve⁸ has long formed the basis for noise compatibility planning in the U.S., and was re-validated by FICON (9) and others (10,11) in the 1990’s. The curve relates the percentage of people “Highly Annoyed” by various noise sources to the Day Night Average Sound Level (DNL). Miedema’s more recent work comparing annoyance caused by various types of transportation sources concludes that people are more annoyed by aircraft noise than by other forms of transportation (12); he proposes the relationship between DNL and annoyance from aircraft as follows:

$$\% HA = 1.460 \times 10^{-5} (DNL - 37)^3 + 1.511 \times 10^{-2} (DNL - 37)^2 + 1.346 (DNL - 37)$$

A comparison of the Schultz and Miedema annoyance curves is shown in Figure 1, below.

Using this relationship, it is possible to depict annoyance as a function of DNL or Lden, simply by re-labeling the respective contours at the corresponding annoyance values. Figure 2 depicts annoyance contours, using the Miedema curve.

Speech Disruption

Aircraft noise events can mask or drown out speech and other communication (telephone conversations, television viewing). The relationship between background noise levels and speech communication was determined in the 1970's, and suggests the following: in order for two people to communicate reasonably using normal voice levels indoors, the background noise level should not exceed 60 dBA (4). In other words, a noise event that exceeds 60 dBA has the potential to cause speech and communication disruption. Assuming an average 15 decibels of outdoor-to-indoor noise level reduction (this is typical of residential construction throughout most of the U.S.), the number of speech disruptions indoors during a day can be predicted with the outdoor N75 value (number of events with maximum level above 75 dBA). This speech disruption is depicted in Figure 3.

Sleep Disturbance

The current federal guidance with respect to sleep disturbance is from the Federal Interagency Committee on Aviation Noise (FICAN) (13). The relationship predicts the maximum percent of people likely to be awakened by a single event for a given indoor Sound Exposure Level, or SEL.

$$\% \text{Awakening} = 0.0087 \times (SEL - 30)^{1.79}$$

One significant weakness of this guidance is that the relationship predicts awakening for only a single event for only an average person; it does not predict what happens over the course of an entire night for a typical population, when a community may be exposed to multiple noise events. Miller and Anderson have proposed a metric they have called "Percent Awakening" that is based on the FICAN sleep disturbance curve, and the use of probability calculations to predict percent of a typical population awakening from repeated aircraft noise events (14). Using data underlying the FICAN curve, and calculations of awakenings from multiple independent events, the probability of awakening from multiple events can be computed as follows:

$$\begin{aligned} P_{\text{awake,multiple}} &= 1 - P_{\text{sleep,multiple}} \\ &= 1 - \prod_{a=1}^N (P_{\text{sleep,single}})_a \\ &= 1 - \prod_{a=1}^N (1 - P_{\text{awake,single}})_a \end{aligned}$$

where: $P_{\text{awake,multiple}}$ = Probability of awakening from multiple events

$P_{\text{sleep, multiple}}$	= Probability of sleeping through multiple events
$P_{\text{sleep, single}}$	= Probability of sleeping through one event
$P_{\text{awake, single}}$	=Probability of awakening from a single event
N	=Number of events

These joint probabilities of awakening are repeated for a population distributed across the full range of sensitivity to noise induced awakening. Note that these joint probabilities assume that the events are independent; this may or may not be a reasonable assumption, but in any case, is likely to be conservative. Figure 4 depicts these joint probabilities for a range of events. Figure 5 presents the predicted Percent Awakening for a population exposed to a full night of aircraft noise events.

Learning

Research on the effects of aircraft noise on children's learning suggests that aircraft noise can interfere with learning in the following areas: reading, motivation, language and speech acquisition, and memory (15). The strongest findings to date are in the area of reading, where the majority of studies have shown that children in high noise impact zones are negatively affected by aircraft (16). Researchers have proposed that noise creates speech interference, which in turn leads to delayed language acquisition (17).

The American National Standards Institute (ANSI) has developed a standard for classrooms that states that the sound levels during the noisiest hour should not exceed a one-hour average A-weighted steady background noise level (L_{eq}) of 40 dBA for schools exposed to intermittent sources, such as airport and other transportation noise. The criteria further states that the one-hour L_{eq} should not be exceeded more than 10% of the noisiest hour (18). Figure 6 depicts an outdoor L_{eq} contour of 55 dBA for the loudest hour of an 8-hour school day, based on operations occurring during the school-day of the activity presented above; assuming a typical 15-dB outdoor-to-indoor noise level reduction, this would translate to an interior L_{eq} of 40 dBA. Based on observations of aircraft noise levels, the L_{10} for this noisiest hour is likely to be approximately the same as the L_{eq} .

Rattle

Finally, residents who live in areas located to the rear and side of aircraft departure runways frequently complain about the apparent low-frequency effects of takeoffs: rumbling noises, rattle of windows, houses "shaking". Since A-weighted decibels, which are normally used in environmental analyses, discount low frequency noise, we recommend the use of a C-weighted L_{max} . This approach is the best available for addressing low frequency for a number of reasons: (1) first, C-weighting is the only weighting scale currently available in the INM that addresses low frequency noise, (2) work done by Miller *et al* in the late 1990s showed that C-weighted metrics appeared to correlated with subjective evaluations of low frequency noise from aircraft departures (19), and (3) the Hubbard criteria show that perceptible wall vibrations are likely to occur for C-weighted L_{max} exceeding 75 - 80 dB (20). Figure 7 presents contours showing numbers of low frequency events likely to produce vibration / rattle for one day's activity.

CONCLUSIONS

Figure 8 presents a compilation of all of the measures described above, along with the DNL metric required by FAA.

Several conclusions can be drawn from the figure: first, DNL is a reasonable predictor of other noise effects, and because the effects evaluated here were generally quantified using A-weighted metrics, there is high correlation among them. Second, the FAA bases environmental decisions on land use compatibility criteria of DNL 65 dB; however, depictions of other noise effects illustrate that their extents can go well beyond the land use compatibility guidelines.

Depiction of supplemental noise metrics using the noise effects of most interest to airport neighbors can provide an opportunity to engage in more informed policy making. Use of intuitively understandable metrics can also enable informed discussions that could ultimately lead to better outcomes for airports, communities and for the air transport system in general.

ACKNOWLEDGEMENTS

The author wishes to acknowledge Nick Miller, Grant Anderson and others at Harris Miller Miller & Hanson Inc. (HMMH) for their work on sleep disturbance. This paper is an extension of that thinking to include other noise effects. The author also wishes to thank Michael Hamilton for preparation of the exhibits in this paper.

REFERENCES

- 1 Waitz I., J., Townsend, J. Cutcher-Gershengfeld, E. Greitzer, and J. Kerrebrock. *Report to the United States Congress. Aviation and the Environment: A National Vision Statement, Framework for Goals and Recommended Actions*, Massachusetts Institute of Technology, December, 2004.
- 2 *Environmental Impacts: Policies and Procedures*. FAA Order 1050.1E, CHG1. FAA, U.S. Department of Transportation, March 20, 2006.
- 3 Public Law 108-176 – Dec. 12, 2003, Vision 100 – Century of Aviation Reauthorization Act
- 4 *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety*. EPA Report 550/9-74-004. U.S. Environmental Protection Agency. March 1974.
- 5 California Division of Aeronautics Title 21, Subchapter 6, Noise Standards
- 6 *Public Health and Welfare Criteria for Noise*. EPA Report 550/9-73-002. U.S. Environmental Protection Agency. July, 1973.
- 7 As found by the State of California Court of Appeal, First District, Division 2, California. in *Berkeley Keep Jets Over the Bay Committee v. Board of Port Commissioners of the City of Oakland*, Aug. 30, 2001.
- 8 Schultz, T.J. Synthesis of Social Surveys on Noise Annoyance. *Journal of Acoustical Society of America*, Vol. 64, No. 2, 1978, pp. 377-405.
- 9 *Federal Agency Review of Selected Airport Noise Analysis Issues*. Federal Interagency Committee on Noise, August 1992.
- 10 Fidell, S. D. Barber, and T. Schultz, 1989. *Updating a Dosage-Response Relationship for the Prevalence of Annoyance Due to General Transportation Noise*. HSD-TR-89-009. Wright-Patterson AFB, Ohio; U.S. Air Force, Noise and Sonic Boom Impact Technology.
- 11 Finegold, L.S., C.S. Harris, H.E. VonGierke, “Community Annoyance and Sleep Disturbance: Updated Criteria for Assessing the Impacts of General Transportation Noise On People”, *Noise Control Engineering Journal*, Vol. 42, No. 1, 1994, pp. 25-30.
- 12 Miedema, H.M.E, and C.G.M. Oudshoorn. Annoyance from Transportation Noise: Relationships with Exposure Metrics DNL and DENL and Their Confidence Intervals. *Environmental Health Perspectives*, Vol. 109, No. 4, 2001, pp. 409-416.
- 13 *Effects of Aviation on Awakenings from Sleep*. Federal Interagency Committee on Aviation Noise, June 1997.
- 14 Anderson, G., and N. Miller, Alternative Analysis of Sleep Disturbance Data. *Noise Control Engineering Journal* (submitted, 2006).
- 15 Evans, G.W. and S.J. Lepore. Nonauditory Effects of Noise on Children: A Critical Review. *Children’s Environments*, Vol 10, 1993, pp.31-51.
- 16 Stansfeld, Stephen A., B. Berglund, C. Clark, I. Lopez-Barrio, P. Fischer, E. Öhrström, M. Haines, J. Head, S. Hygge, I. van Kamp, B. Berry. “Aircraft and road traffic noise and children’s cognition and health: a cross-national study”, *Lancet* 2005; 365: 1942-49.
- 17 Evans, Gary W. and L. Maxwell. Chronic Noise Exposure and Reading Deficits: The Mediating Effects of Language Acquisition. *Environment and Behavior*. Vol 29, No 5, September 1997, pp. 638-656.
- 18 ANSI S12.60-2002 *American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools*.
- 19 Miller N. P. E.M. Reindel, D.A. Senzig, and R.D. Horonjeff. *Low-frequency Noise From Aircraft Start Of Takeoff*, Proceedings Internoise 98
- 20 Hubbard, H.H. Noise Induced House Vibrations and Human Perception. *Noise Control Engineering Journal*. Vol. 19., No. 2., 1982, pp. 49-55,.

TABLE 1 Supplemental Metrics to Address the Effects of Noise

FIGURE 1 Comparison of Relationships between Noise Level and Percent of People ‘Highly Annoyed’

FIGURE 2 Percent of People ‘Highly Annoyed’ over a Typical Day.

FIGURE 3 Number of Speech and Communication Disruptions in a Typical Day.

FIGURE 4 Predicted awakenings for multiple aircraft, average person.

FIGURE 5 Percent of Population Likely to be Awakened over a Typical Night.

FIGURE 6 Limits of ANSI Standard for Classroom Noise Levels, based on a Typical 8-hour School-day.

FIGURE 7 Number of Noise-induced Vibration (Rattle) Events in a Typical Day.

FIGURE 8 Summary of Noise Effects for a Typical Day.

TABLE 1 Supplemental Metrics to Address the Effects of Noise

Effect	Proposed Metric	Documented Basis
Annoyance	DNL	Schultz ⁸ , Miedema ¹²
Sleep disruption	% Awakening	FICAN ⁹
Speech Interference	N75	EPA ⁴
Learning	Leq(8)	ANSI Standard ¹⁵
Rattle	Lmax(c)	Hubbard ²⁰

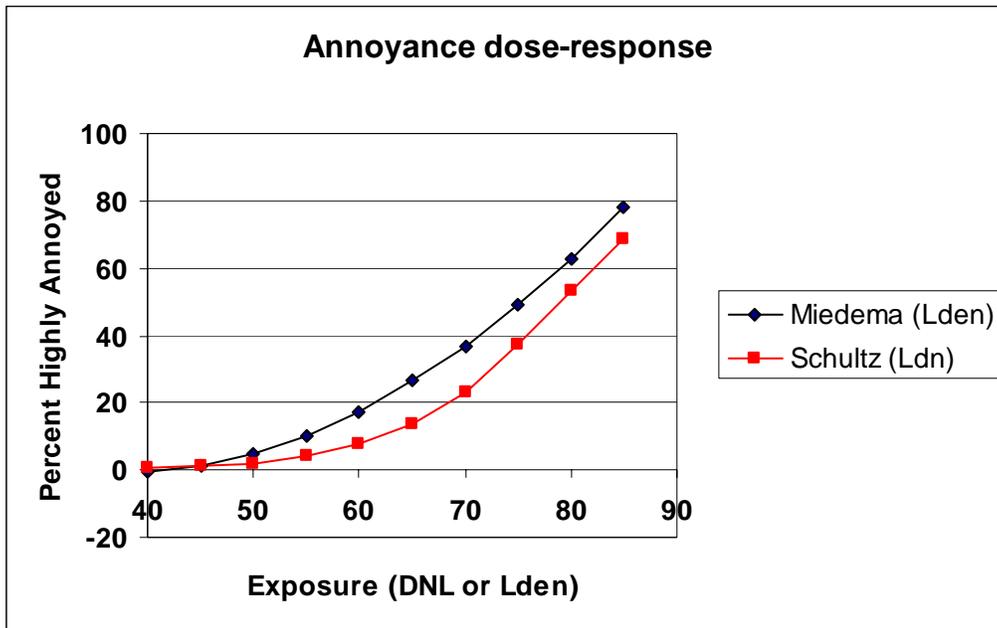


FIGURE 1 Comparison of Relationships between Noise Level and Percent of People 'Highly Annoyed'

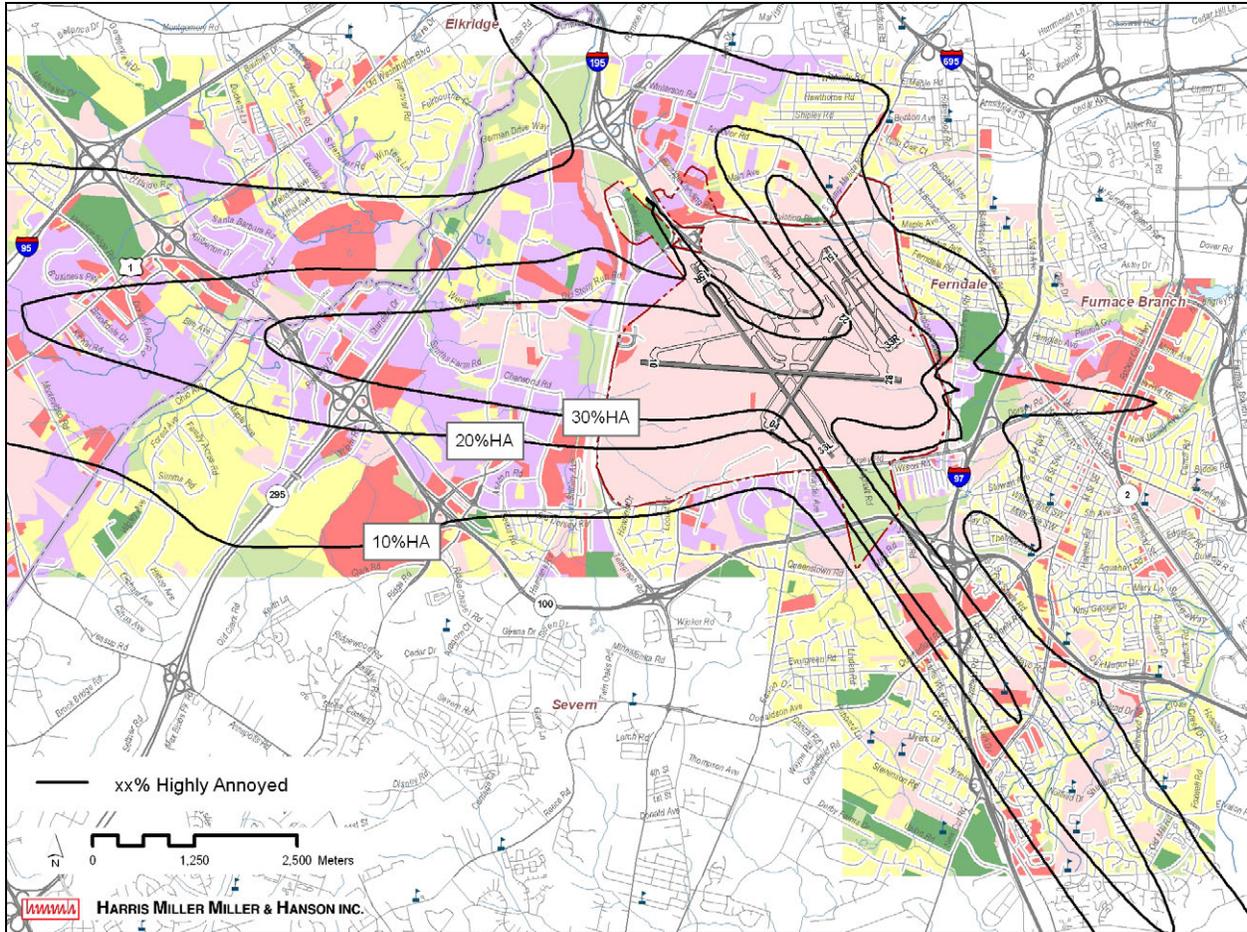


FIGURE 2 Percent of People 'Highly Annoyed' over a Typical Day.

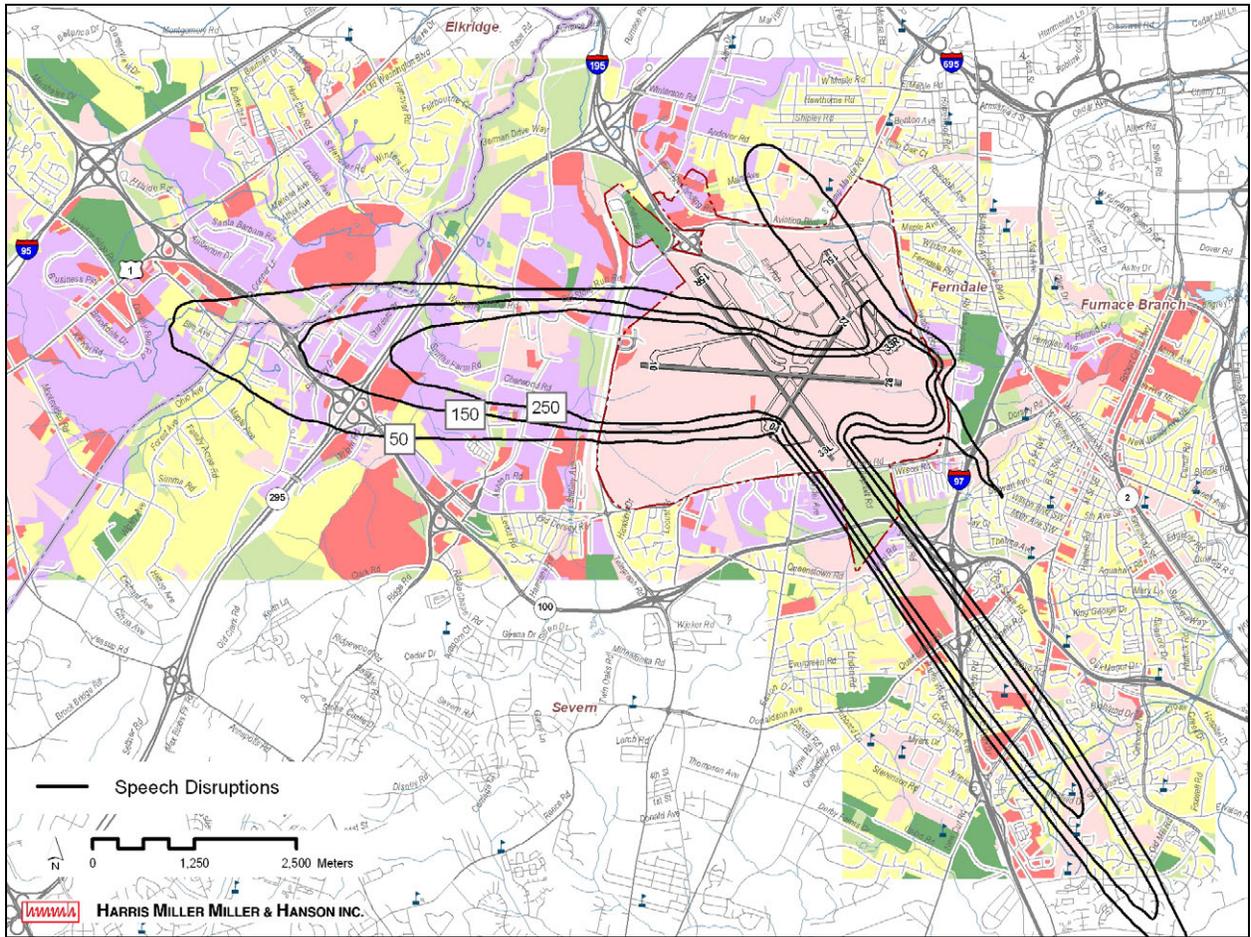


FIGURE 3 Number of Speech and Communication Disruptions in a Typical Day.

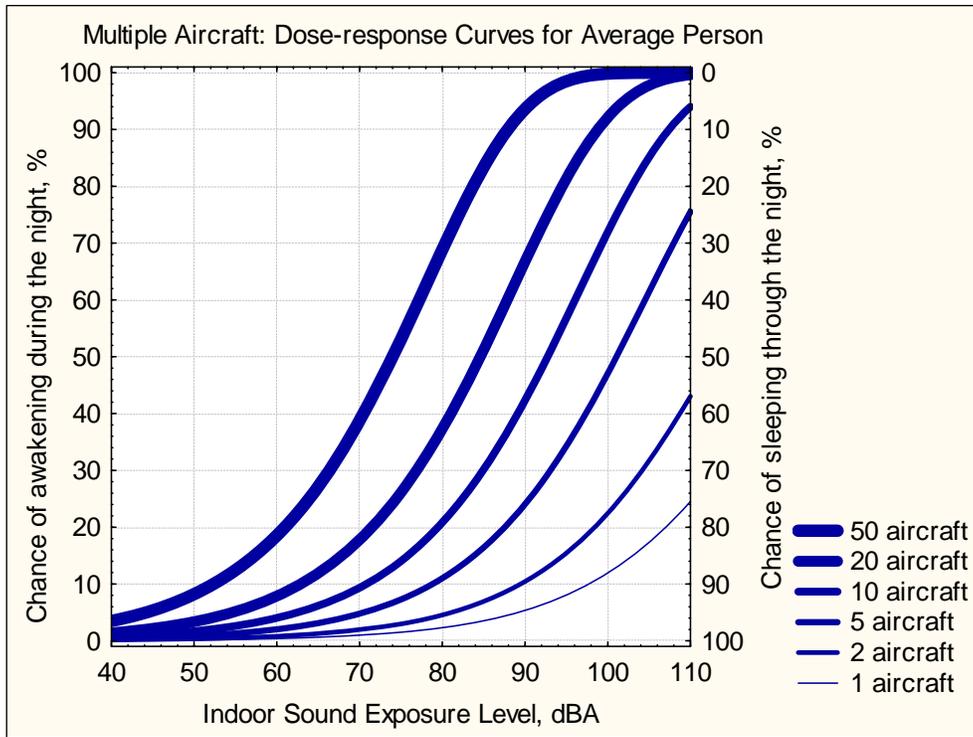


FIGURE 4 Predicted awakenings for multiple aircraft, average person.

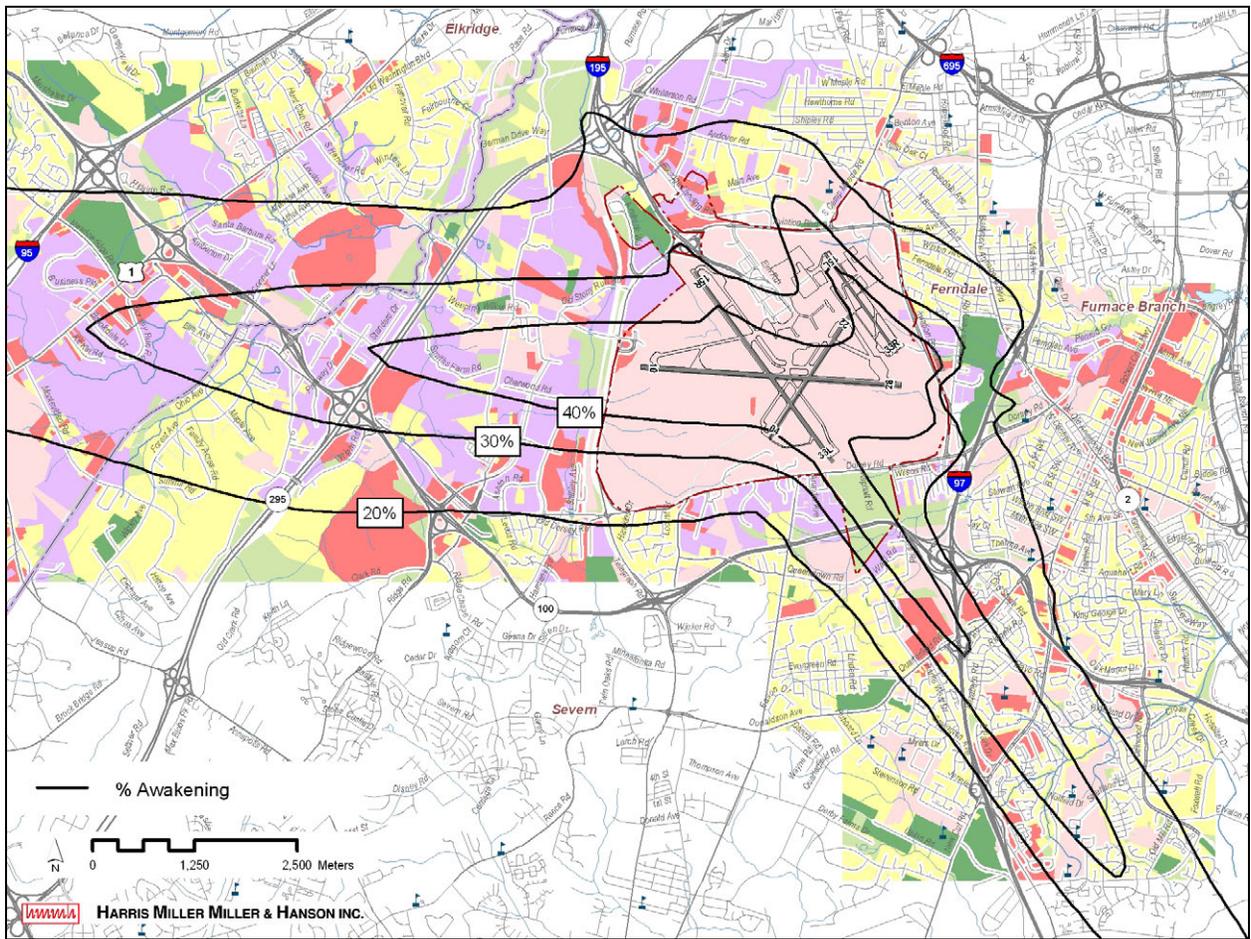


FIGURE 5 Percent of Population Likely to be Awakened over a Typical Night.

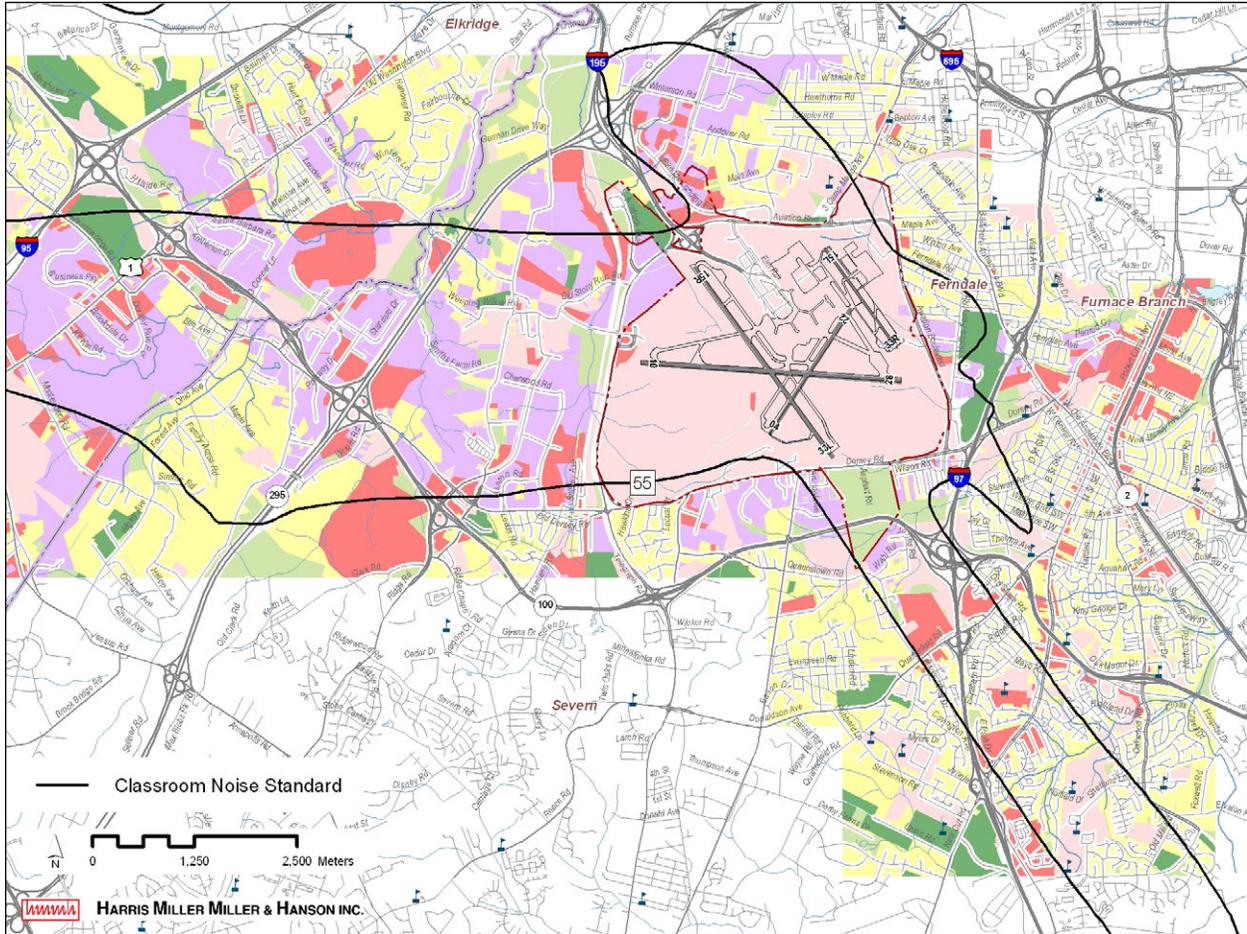


FIGURE 6 Limits of ANSI Standard for Classroom Noise Levels, based on a Typical 8-hour School-day.

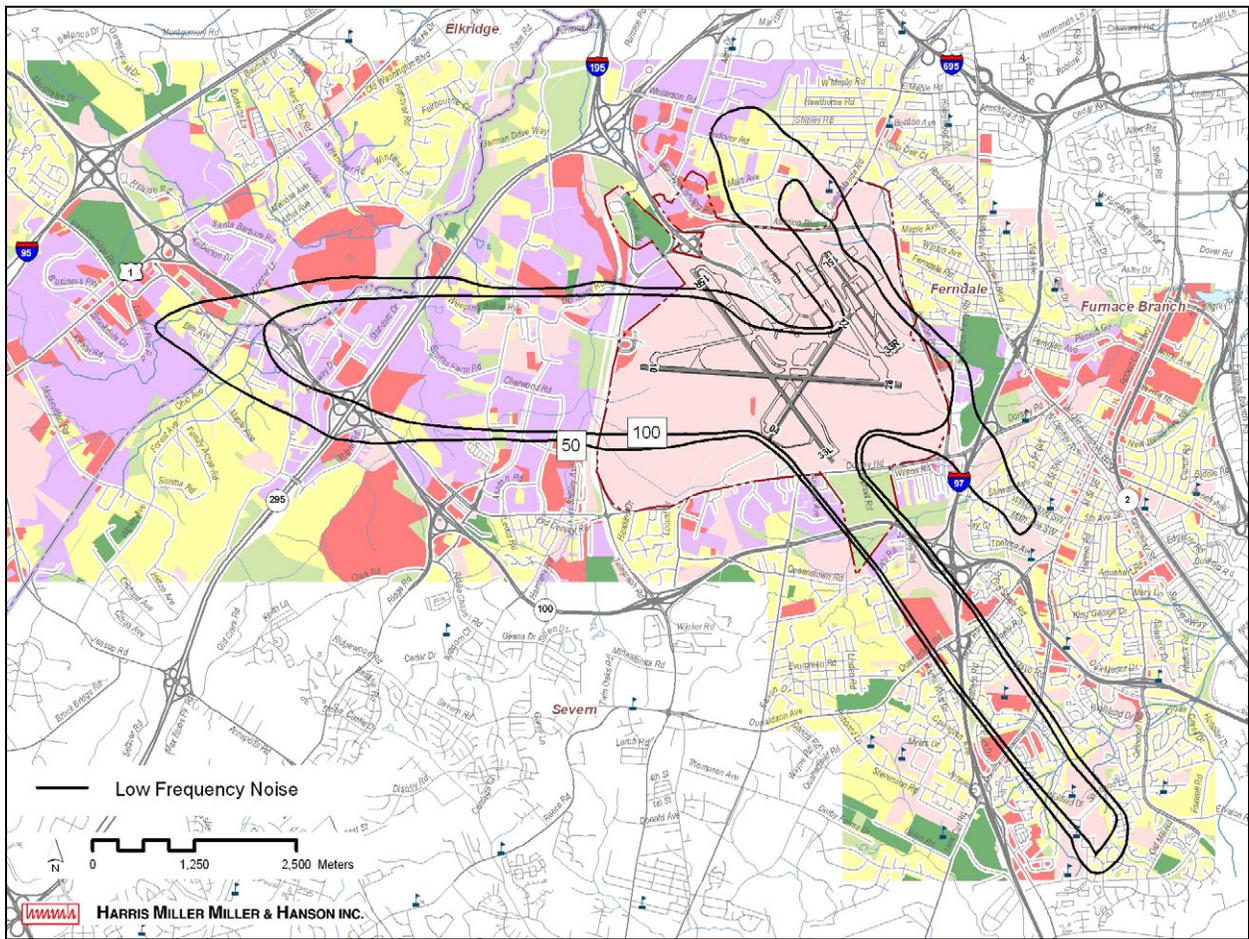


FIGURE 7 Number of Noise-induced Vibration (Rattle) Events in a Typical Day.

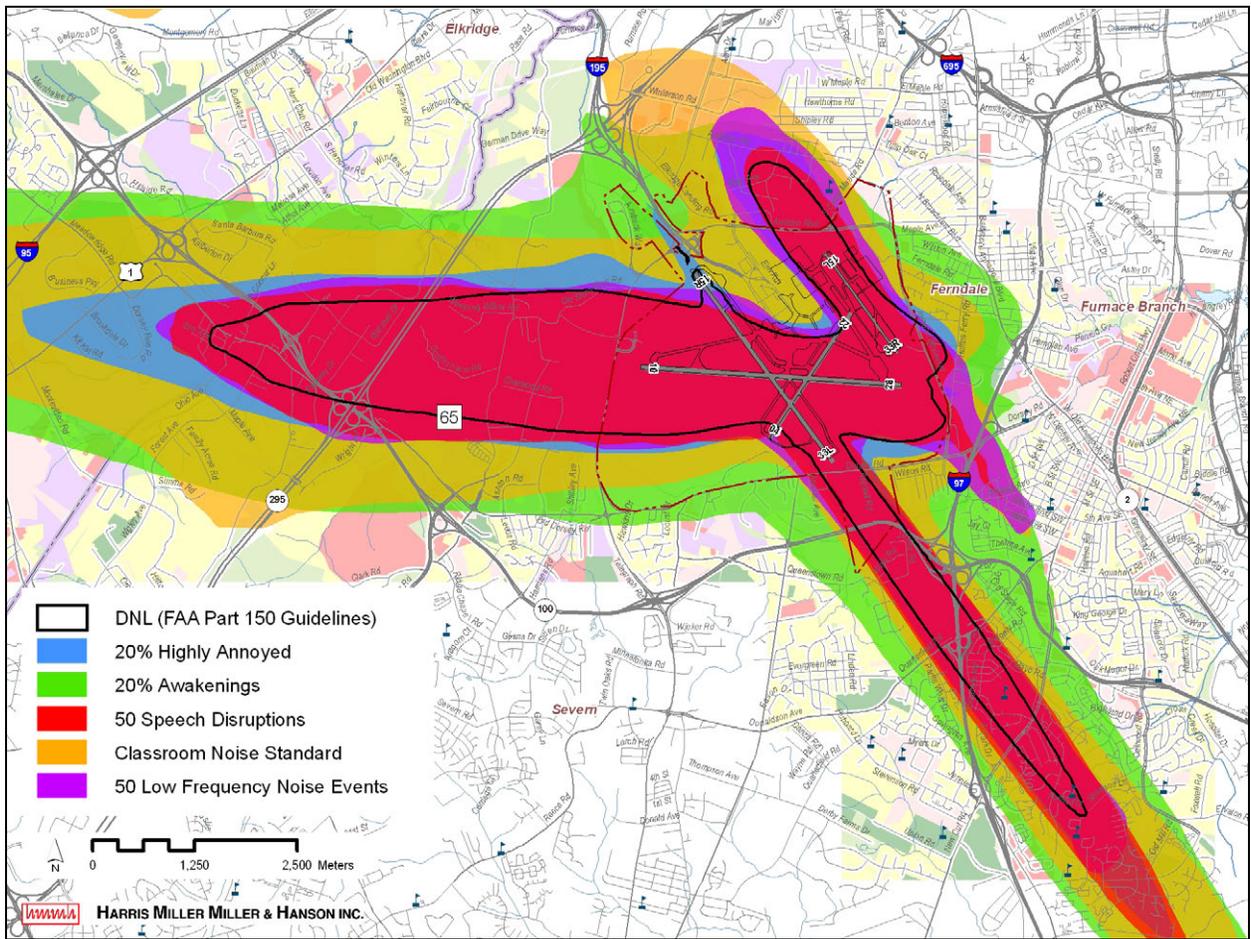


FIGURE 8 Summary of Noise Effects for a Typical Day.