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## DERIVING A DOSAGE-RESPONSE RELATIONSHIP FOR COMMUNITY RESPONSE TO HIGH-ENERGY IMPULSIVE NOISE

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### INTRODUCTION

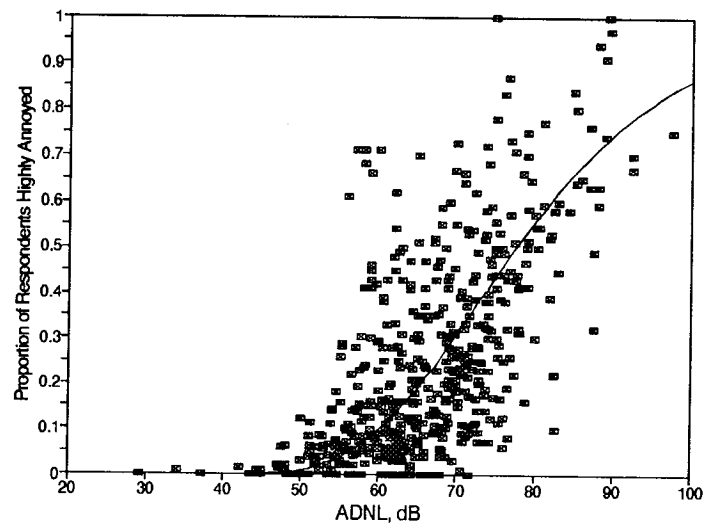
The inability to systematically predict community response to exposure to sonic booms (and other high energy impulsive sounds) is a major impediment to credible analyses of the environmental effects of supersonic flight operations. Efforts to assess community response to high energy impulsive sounds are limited in at least two important ways. First, a paucity of appropriate empirical data makes it difficult to infer a dosage-response relationship by means similar to those used in the case of general transportation noise. Second, it is unclear how well the "equal energy hypothesis" (the notion that duration, number, and level of individual events are directly interchangeable determinants of annoyance) applies to some forms of impulsive noise exposure.

Some of the issues currently under consideration by a CHABA working group addressing these problems are discussed. These include means for applying information gained in controlled exposure studies about different rates of growth of annoyance with impulsive and non-impulsive sound exposure levels, and strategies for developing a dosage-response relationship in a data-poor area.

The state of the art in prediction of community response to high energy impulsive noise exposure - essentially, sonic booms, artillery fire, and blasting - is much less advanced than prediction of community response to general transportation noise. The most obvious difference between the two cases is between an embarrassment of social survey information about the annoyance of general transportation noise and a scarcity of similar findings about the annoyance of impulsive noise.

Fields (1991) notes that more than 300 social surveys of community response to the general din of the urban environment have been conducted in the last few decades. Schultz (1978) found enough quantitative information about 161 of these data points to permit his well-known synthesis of a descriptive dosage-response relationship between Day-Night Average Sound Level and the prevalence of a consequential degree of self-reported annoyance in urban settings. Limiting themselves to the same selection criteria as Schultz (1978), Fidell, Barber and Schultz analyzed another 232 data points in 1991. Others (notably FICON, 1992) have suggested alternate fitting functions for various subsets of the same data, as summarized in Table 1 of Fidell and Pearsons (1993).

As seen in Figure 1, information about community response to general transportation noise is now so abundant - and so variable - that it is doubtful that information collected in any further social surveys can substantially affect commonly accepted fitting functions and interpretations. As a complement to purely descriptive accounts of this mass of data, efforts such as that of Green and Fidell (1991) have recently begun to develop theory-based explanations for the variability in annoyance rates in different communities with similar noise exposure.

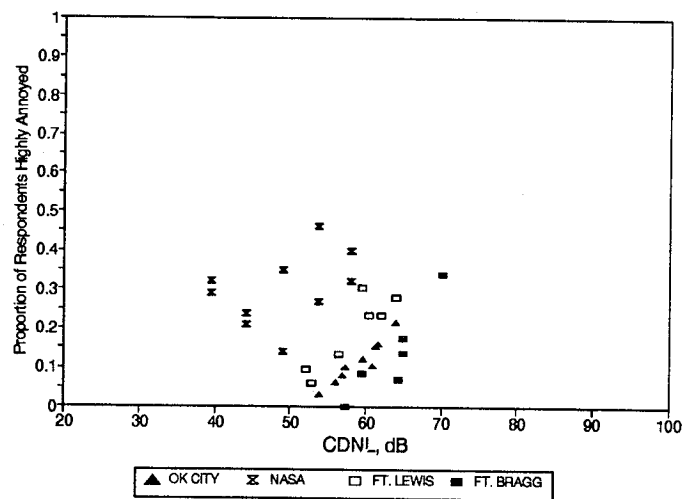


**Figure 1** Social survey findings on the prevalence of annoyance associated with residential exposure to general transportation noise. (Fitting function from one parameter model of Green and Fidell, 1991.)

In contrast, only a few social surveys have been conducted on the effects of high energy impulsive noise exposure on communities, and only one well-accepted synthesis of a descriptive dosage-response relationship for these data has been completed. Figure 2 summarizes the information presently available from which a dosage-response relationship between impulsive noise exposure and the prevalence of annoyance can be directly synthesized. The data displayed in Figure 2 are derived from the well-known Oklahoma City study (Borsky, 1966); from two surveys of reactions to artillery noise (Schomer, 1985); and from a recent NASA study of reactions to sonic booms reported elsewhere in these proceedings by Fields, Moulton, Baumgartner and Imm-Thomas. All of the original noise measurements at Ft. Lewis and Ft. Bragg were modified to account for pressure doubling. The plotted values also reflect new information about the Oklahoma City noise measurements (Schomer, 1994).

The best known dosage-response relationship (that of CHABA Working Group 84) was not based on even this much information, however. Galloway (1981) was forced to develop a dosage-response relationship from only 14 data points. Another CHABA Working Group on Assessment of Community Response to High Energy Impulsive Sounds now revisiting the problem 13 years later is attempting to interpret what has been learned empirically and theoretically about community response to impulsive noise exposure in the interim.

The most obvious remedy for the paucity of information about community response to impulsive noise exposure is the conduct of several new large scale social surveys. This is not a realistic possibility for several reasons. First, opportunities to conduct surveys of adventitious exposure to high energy impulsive noise are limited. Because no civil aircraft fly supersonically over land, and because the military confines its overland supersonic operations to areas of relatively low population density, only small populations have yet experienced high levels of exposure to sonic booms on a regular, long



**Figure 2** Social survey findings on prevalence of annoyance associated with exposure to high energy impulsive noise.

term basis. Blasting, artillery training and other sources of non-aircraft, high energy impulsive noise are also generally experienced only by localized populations.

Second, opportunities for conducting field studies involving intentional exposure of entire communities to sonic booms have been all but foreclosed in the United States since passage of the National Environmental Policy Act of 1969.

Third, it is doubtful that information about effects of sonic booms in the exposure ranges of greatest interest for purposes of developing a dosage-response relationship can ever be collected. C-weighted DNL values in systematic studies of community response to high energy impulsive noise exposure that have been conducted to date are all in the region below 70 dB. No community has yet experienced the numbers of daily supersonic flights necessary to produce greater long term impulsive noise exposure, nor is it possible for a variety of reasons to create or credibly simulate such exposure on a large scale.

Controlled studies of subjective judgments of the annoyance of individual impulsive sounds can contribute information that might be used to complement social survey findings. Kryter, Johnson and Young's (1968) field study comparing the annoyance of sonic booms to that of subsonic aircraft overflights is one source of such information that was considered by CHABA Working Group 1984. Schomer (1994) has since collected newer information about the relative annoyance of other impulsive sounds. This information was derived from direct paired comparison judgments of the annoyance of impulsive and non-impulsive noises heard in laboratory and field settings. Schomer's outdoor noise measurements of sounds presented for judgment in field testing were made at the time of signal presentations, and pressure doubled for the sake of consistency with those typically made of sonic booms.

In Schomer's data set, the annoyance created by an impulsive noise event of a given CSEL grows at twice the rate as the annoyance of a non-impulsive noise event of a numerically equivalent ASEL. This means that CDNL values cannot be directly calculated for purposes of predicting annoyance as a logarithmic sum of CSEL values of constituent noise events. Just as OSHA employs a 5 dB/doubling rule rather than a 3 dB/doubling rule for calculating noise exposure for purposes of predicting hearing damage risk, Schomer's data suggest that a 6 dB/doubling rule is required when CDNL values are used for purposes of predicting the prevalence of annoyance due to a summation of high energy impulses.

Alternatively, a greater rate of growth of annoyance for impulsive than non-impulsive noise events could be interpreted as requiring that the slope of dosage-response relationship for community response to the impulse noises be considerably steeper than the slope of the dosage-response relationship for non-impulsive noise.

One might think that a difference in the fit to the data of two dosage-response relationships with slopes differing by a factor of two would be immediately apparent from simple visual inspection. This is not the case, however, because the small number of data points and their considerable variability do not greatly constrain the shape of a fitting function. It is therefore important to explore other means for checking the reasonableness of drawing inferences for the shape of a dosage-response relationship for community response to impulsive noise exposure from the findings of controlled exposure studies.

One reasonableness check can be made by analogy with the case of predicting community response to non-impulsive noise. Green and Fidell (1991) attempted to infer the shape of a dosage-response relationship from first principles, rather than through statistical curve fitting exercises. They likened the prevalence of annoyance in a community to a response to a dose of noise exposure: like any other treatment administered to a human population, the response to the same dose can be expected to vary from individual to individual, and hence from community to community.

Green and Fidell suggested that the relationship between dose and response has two components: one associated with the effective loudness of the noise exposure, and one associated with the sum of all nonacoustic influences on self-reports of annoyance. The nonacoustic influences may be considered in the aggregate as a form of response bias. The former term establishes the slope of the dosage-response relationship, whereas the latter establishes its position along the abscissa.

Green and Fidell showed that a one-parameter model provides a good account of the relationship between exposure to general transportation noise and the prevalence of annoyance in communities. It is thus reasonable to ask whether the same model can also be applied to the case of impulsive noise exposure. The one parameter model assumes that reactions of community members to noise exposure are exponentially distributed with a mean population value,  $m$ . The value of  $m$  is assumed to be related to the Day-Night Average Sound Level by:

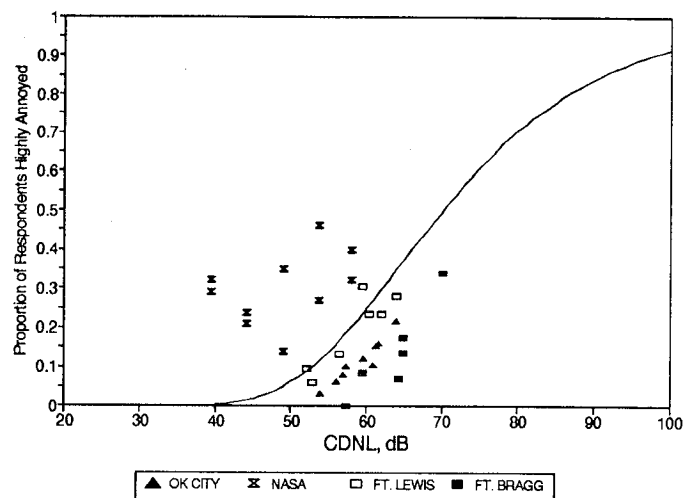
$$10 \log m = 0.3 L_{dn}$$

Thus, noise exposure creates a distribution of reactions within a community with a mean value that increases with the level of noise exposure. Individuals describe themselves as highly annoyed when their reactions to noise exposure exceed a criterion value for reporting annoyance. The proportion of the population describing itself as highly annoyed is predicted as

$$P = e^{-(A/m)}$$

where  $P$  is the probability of reporting high annoyance,  $m$  is defined as above, and  $A$  is the criterion value for reporting annoyance.

Figure 3 shows the fit of the Green and Fidell model to the data displayed in Figure 2. The curve is generated by the relationship shown in Equation 1. The value of the parameter that controls the slope of the curve - that is, the power to which DNL is raised to calculate the effective loudness of noise exposure - is 0.3. The horizontal position of the curve on the abscissa is determined by the average value of CDNL at which respondents describe themselves as highly annoyed in this data set.



**Figure 3** Fit of one parameter model (Green and Fidell, 1991) to data displayed in Figure 2, exponent = 0.3.

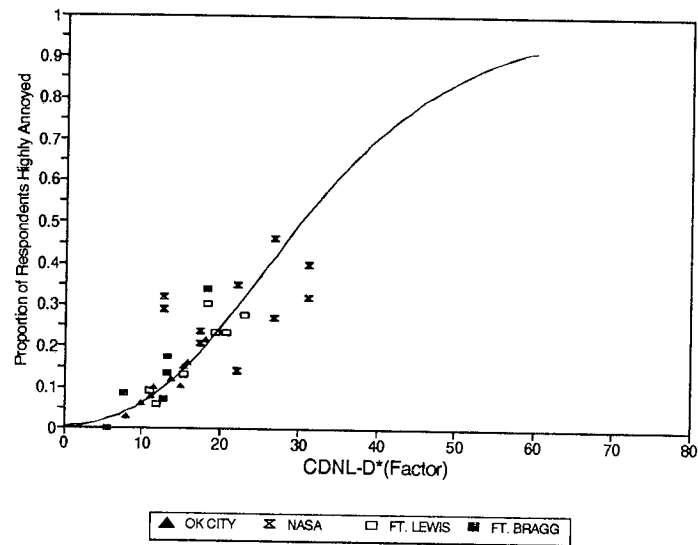
A predictive relationship that provides a useful account for a data set should reduce the amount of variance unaccounted for in the data set. Figure 4 shows that this is in fact the case by replotting the data of Figure 3 in a manner that removes the effects of response bias. The abscissa of Figure 4 subtracts the average response bias observed in each study (expressed in units of CDNL) from the measured CDNL values for each data point. This normalization of each data set to the average value of CDNL at which survey respondents in a study described themselves as highly annoyed effectively removes response bias, and leaves apparent the correspondence between the observed and predicted rates of growth of annoyance with exposure level. The reduction in variability in Figure 4 with respect to that of Figure 3 is readily apparent.

If annoyance with impulsive noise exposure grows with level at a rate faster than it grows for non-impulsive noise, one might expect a larger exponent for CDNL than for ADNL. Schomer (1989), for example, has suggested that a value of 0.4 might be more appropriate than 0.3. Figure 5 shows the fit of the Green and Fidell model with a value of 0.4 for its one free parameter to the same data set.

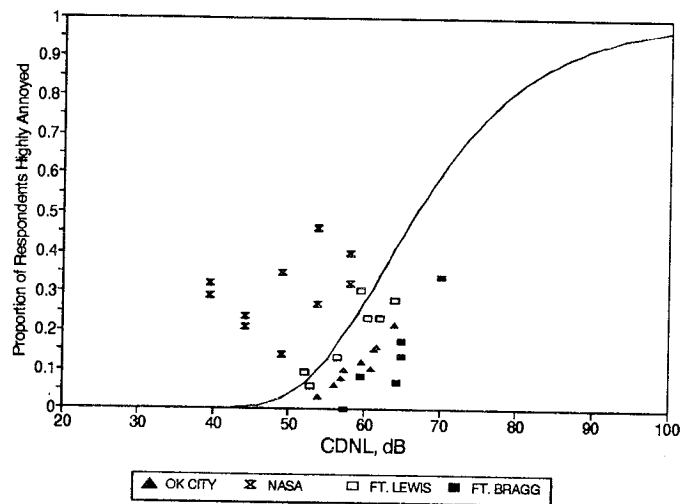
The standard deviation of the differences between the observed and predicted proportions highly annoyed for the fit shown in Figure 3 is 3.2%, while the corresponding standard deviation for the fit shown in Figure 5 is 3.8%. The differences in standard deviations are so slight that there is no compelling argument for adopting one that suggests a higher rate of growth of annoyance with exposure level in the impulsive case.

Thus, it is not yet apparent how the observations of controlled exposure studies in which the annoyance of impulsive and non-impulsive sounds are directly compared can be applied to derivation of a dosage-response relationship for the prevalence of annoyance due to high energy impulsive

sounds in communities. Further analyses of these data are expected before the current CHABA working group makes any new recommendations.



**Figure 4** Reduction in variability in social survey findings displayed in Figure 3 attainable by normalization to remove effects of response bias.



**Figure 5** Fit of one parameter model (Green and Fidell, 1991) to data displayed in Figure 2, exponent = 0.4.

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