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Assessment of Community Response to High-Energy Impulsive Sounds

Committee on Hearing, Bioacoustics, and Biomechanics

Assembly of Behavioral and Social Sciences

National Research Council

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ASSESSMENT OF COMMUNITY RESPONSE TO HIGH-ENERGY IMPULSIVE SOUNDS

Report of Working Group 84

Committee on Hearing, Bioacoustics, and Biomechanics
Assembly of Behavioral and Social Sciences
National Research Council

National Academy Press
Washington, D.C.
1981

410 723

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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This work relates to Department of the Navy Contract N00014-80-C-0159 issued by the Office of Naval Research under Contract Authority NR 201-124. However, the content does not necessarily reflect the position or the policy of the Department of the Navy or the Government, and no official endorsement should be inferred.

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PREFACE

In 1977 a report entitled "Guidelines for Preparing Environmental Impact Statements on Noise" was issued as the result of the activities of Working Group 69 of the Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) of the National Research Council (NRC). The report provides a comprehensive set of procedures for specifying the physical descriptions of environmental noise and vibration and methods for assessing the degree of impact on people associated with these environments.

CHABA Working Group 84 was established to monitor research on high-energy impulsive sounds and to affirm or to recommend modifications to the 1977 Guideline's procedures when new data became available. The emergence of additional data on human response to high-energy impulsive sounds has been much slower and considerably more sparse than anticipated from governmental program plans available in 1977. Some new data are available, however, and re-analysis of the older sonic-boom data has provided somewhat better insight than was available in 1977.

At various times in its deliberations the Working Group invited and received contributions to the technical discussions from Sanford Fidell, Bolt Beranek and Newman Inc., Canoga Park, California; Jeffrey Goldstein, Office of Noise Abatement and Control, Environmental Protection Agency, Washington, D.C.; Stanley Harris, Aeromedical Research Laboratory, Wright-Patterson Air Force Base, Ohio; David Siskind, Bureau of Mines, Department of Interior, Washington, D.C.; Theodore Schultz, Bolt Beranek and Newman Inc., Cambridge, Massachusetts, Henning Von Gierke, Aeromedical Research Laboratory, Wright-Patterson Air Force Base, Ohio; and Robert Young, Naval Oceans System Center, San Diego, California. The Working Group acknowledges their contributions with thanks, and recognizes that not all of these individuals may be in complete agreement with the conclusions reached as a concensus by the Working Group members.

William J. Galloway, Chair
Working Group 84
Assessment of Community Response
to High-Energy Impulsive Sounds

SUMMARY

A dose-response relationship between day-night average C-weighted sound level and average degree of community annoyance is proposed for high-energy impulsive sounds. This proposal revises the relationship originally recommended in a CHABA report (National Research Council, 1977, hereafter, NRC, 1977) to reflect more recent community response data and additional analyses of previous data. The use of sound level-weighted population as a means for assessing noise impact, as originally proposed (NRC, 1977), is retained in this proposal.

Analyses summarized in this report indicate that growth of annoyance with increasing average sound level is greater for high-energy impulsive sounds than for more conventional sounds, such as those produced by transportation noise sources. This result differs from that in the CHABA report (NRC, 1977) in which growth of annoyance was considered to be the same for both kinds of noise. The equations provided in this report which relate annoyance to average sound level are somewhat simpler than those in the CHABA report (NRC, 1977). A numerical example showing the application of the recommended procedures is provided. Definitions of acoustical measures used in the report are contained in a glossary.

INTRODUCTION

The degree of impact of a noise environment on residential communities is assessed (NRC, 1977) in terms of the expected fraction of a population highly annoyed by the noise. Annoyance, as determined from a variety of social surveys, was the measure of adverse reaction that was most highly correlated with exposure to community noise environments. The dose-response relationship was found to be largely independent of the sources of noise, at least for the transportation noise sources which dominate most residential environments.

Among the environments considered (NRC, 1977) were those produced by high-energy impulsive sounds such as sonic booms, artillery practice ranges, and quarry blasting. It was recognized that such sounds can engender annoyance beyond that associated with the simple audibility of the impulses by inducing house vibrations, startle effects, or other responses, and thus should be treated differently from more common sounds such as those from transportation noise sources. The assessment procedure proposed (NRC, 1977) relied on C-weighted sound exposure level to describe individual high-energy impulsive events (instead of A-weighted sound exposure level used for other environmental sounds) and day-night average C-weighted sound level for the cumulative effect of impulsive sounds in a 24-hour period (instead of day-night average A-weighted sound level, as used for all other sources). The shape of the dose-response relationship between a noise environment and expected community response developed for non-impulsive sounds in terms of day-night average A-weighted sound level was retained for high-energy impulses by substituting day-night average C-weighted sound level on a numerically equal basis.

The general dose-response function specified for transportation noises was developed in 1977 from analyses of data from numerous social surveys. Reasonably high confidence exists that it represents, on average, a good statistical description of expected community response. In contrast, the 1977 impulsive noise response assessment was based on only one sonic boom experiment that was subject to ambiguities in interpretation. The recommendations (NRC, 1977) for impulsive noises were thus considered to be interim only, to be refined when and if further data became available.

Presently available results indicate that the procedures (NRC, 1977) underestimate the degree of response to impulsive sounds, at least at higher exposure levels, and that a revision to the assessment procedures is in order. The present report provides a recommended revision.

The Working Group was also charged with examining the effect of impulsive noise on sleep. However, no research data have been gathered since 1977 that would require the Working Group to reconsider sleep interference. The procedures recommended in this report are thus based exclusively on average community response expressed in terms of annoyance.

PHYSICAL SPECIFICATION OF HIGH-ENERGY IMPULSIVE SOUNDS

High-energy impulsive sounds of concern for community response are specified (NRC, 1977) as those for which the C-weighted sound exposure level (see the glossary for the definitions of acoustical measures) in any 2-second time period is greater than 85 decibels (or greater than 75 decibels at night) and is 10 decibels greater than the C-weighted sound exposure level due to other sources in any contiguous 2-second period. These levels correspond to peak overpressures greater than approximately 105 decibels (95 decibels at night), that is, greater than approximately 0.1 pounds per square foot.

Day-night average sound level, which is A-weighted, is the primary descriptor of environmental noise. If the noise environment includes high-energy impulses meeting the above definition, day-night average C-weighted sound level is recommended as an additional descriptor (NRC, 1977).

The use of C-weighted sound exposure levels recommended (NRC, 1977) has two bases:

1) the use of C-weighting provides a reasonable measure of the low-frequency sound pressures associated with high-energy impulses of the type under consideration; and

2) the use of sound exposure level instead of peak sound level meets the need to incorporate a measure of signal duration, since perception of noisiness increases with signal duration (NRC, 1977).

Although essentially all sonic-boom data available in the literature report the magnitude of a boom in terms of peak overpressure in pounds per square foot, as measured on a "linear" frequency response system, the term "linear" is not standardized. The characteristics of a measurement made with a so-called "linear" system depend greatly on the measurement system and pressure-sensing transducer used to make the measurement. The choice of C-weighting was a compromise to obtain low-frequency response with sound measuring instruments that comply with specifications contained in national and international standards. It was recognized that the tolerances permitted in existing standards for C-weighting at frequencies below 20 hertz are quite large. However, most precision sound measuring instruments have frequency responses that are close to that specified in the standards at least down to 5 hertz.

The use of sound exposure level, which is the time integral of sound level over the duration of an event, is consistent with subjective evaluations of sonic booms where it is shown that response is proportional to signal duration (Johnson and Robinson, 1967). It should be noted that in 1977 no subjective response data or social survey data were available in which the magnitudes of the impulses being evaluated were directly measured in C-weighted sound exposure level. Thus the interpretations of response in terms of sound exposure level required a conversion from peak overpressure measurements, based upon analysis of sample recordings of typical sonic-boom sound pressure signatures.

Nothing that has transpired subsequent to 1977 has led the members of Working Group 84 to suggest alternate measures for high-energy impulsive sounds. The considerations leading to the recommendation to use C-weighted sound exposure level and day-night average C-weighted sound level remain the same. The use of these measures has been found practical in both measurement and prediction of community noise environments. Although better measures could likely be developed, there is no pressing need to do so at this time.

It was recommended (NRC, 1977) that C-weighted sound exposure levels above a threshold of 85 decibels (75 at night) should be used in assessing impulse noise. This concept of a threshold was also reviewed by Working Group 84. The original purpose of the threshold was to avoid inclusion of non-impulsive low frequency sounds in measurements intended for impulsive sounds. An argument can be made that the use of a threshold is an unnecessary complication in measurements, but the consensus of the working group was that the threshold concept is useful and should be retained for the time being.

SUBJECTIVE RESPONSE TO HIGH-ENERGY IMPULSIVE SOUNDS

The recommended procedure (NRC, 1977) for relating community response to impulsive noise was first to measure (or predict) the noise environment from high-energy impulsive sounds in terms of day-night average C-weighted sound level. The percentage of a population highly annoyed at this average sound level was then estimated from the dose-response relationship for non-impulsive sounds (Schultz, 1978) by replacing the average A-weighted sound level in that relationship with the average C-weighted sound level at the same numerical value. For many sounds this approximately equivalent to saying that people are 8 decibels more sensitive to impulsive sounds than to non-impulsive sounds. This position was arrived at largely by interpretation of a social survey of a population exposed to sonic booms in a six-months test at Oklahoma City (Borsky, 1965).

At the time Working Group 84 was established, it was expected that one or more new social surveys of people exposed to impulsive noise artillery firing ranges would provide a more current basis for examining the assessment of community response to impulsive noise. The results of one such survey are now available (Schomer, 1980). In addition, the Oklahoma City data have been reviewed more thoroughly, as have the results of tests at Edwards Air Force Base comparing the annoyance of subsonic airplane flyovers with that of sonic booms (Kryter, 1968). Interpretations of the combined results of these analyses have led to the revised recommendation for community response assessment described below.

Consider first whether A-weighted sound exposure level by itself is a satisfactory means of assessing human response to sonic booms, either directly, or with an 8-decibel offset as can be inferred from the earlier report (NRC, 1977). Two different experiments can be examined, the paired comparisons between sonic booms and airplane flyover noise (Kryter, 1968) and the Oklahoma City social survey (Borsky, 1965).

The paired comparisons consisted of judgments by groups of listeners to alternating flyovers of a subsonic transport airplane (KC-135) and sonic booms from three different airplanes (B-58, F-104, XB-70). The aircraft flew over at different heights in order to vary the sound level of the subsonic airplane noise and of the boom strength in terms of overpressure. (Although judgements were made both outdoors and indoors, with sound levels measured outdoors, only the indoor judgments will be used here since they are more representative of residential listening conditions.) For each pair of subsonic jet overflights and booms, the listeners were asked which was more annoying. The averages of the listeners' judgments, when analyzed at various sound levels, were used to obtain the maximum perceived noise level of the jet that was judged equally annoying as a sonic boom of specified overpressure, for each airplane type.

In order to examine these data in terms of sound exposure levels, both the sonic-boom overpressures and the jet sound levels must be transformed from their reported measures. Sonic-boom overpressures may be transformed to A-weighted sound exposure levels by the empirical function obtained by Young (1975) who used a series of sonic-boom measurements of military airplanes. Conversion of sonic-boom overpressures to C-weighted sound exposure level may be made from the analyses reported by Schomer (1978) of a representative set of tape recordings of the original test data provided by Kryter. The conversions used here were calculated from linear regressions of measured overpressure, expressed in decibels, on C-weighted sound exposure level in decibels, computed separately for each airplane from the data reported by Schomer. The regression equations are listed in Table 1.

Maximum perceived noise levels for the subsonic airplane were converted to A-weighted sound exposure levels for the KC-135 airplane from measurements reported by Speakman (1977). The procedure used was to enter Speakman's table of sound level measures, listed as functions of distance, with the reported maximum perceived noise level to determine the height at which that level would occur. At this same height, the A-weighted sound exposure level was determined from the tabulated data. The resulting conversions are listed in Table 1.

A-weighted sound exposure levels for aircraft noise and sonic booms when judged equally annoying during indoor listeing are plotted on Figure 1. Within the data for a specific airplane type the sound exposure levels are highly correlated ($r^2 > 0.98$ when adjusted for small data sets), yet a small but definite offset exists between the B-58 and F-104 data (the minor difference in slopes for the regression lines is insignificant). The shape of a sonic-boom signature, and thus its spectral content, is directly related to airplane shape and length. The approximately 4 decibel difference between the two functions relating sonic boom to airplane noise is not surprising. These data indicate that the A-weighted sound exposure level of sonic booms must be from 11 to 15 decibels lower than the sound exposure level of subsonic airplane noise when judged equally annoying, and that the size of this offset is source dependent.

Notwithstanding this outcome, one can examine the Oklahoma City experiment to see how well day-night average A-weighted sound level relates to community response to sonic booms. Eight supersonic overflights were performed on a daily basis for six months. Altitudes and airspeeds were selected to obtain three different nominal overpressures for the three successive time intervals of the tests. Personal interviews of respondents were made during three time periods that corresponded to the three different nominal overpressures. Interviews were conducted at three different distances from the ground projection of the flight path to obtain different exposures for each of the three boom levels.

The questionnaire structure and response scaling used in the social survey were such that direct comparison with other surveys is difficult. The responses to a question on degree of annoyance due to "house rattles" caused by the booms were used as the primary measure to quantify community response (NRC, 1977). The category termed "serious" annoyance by Borsky (1965) was considered to be most comparable to the "highly" annoyed categories used in analyzing transportation noise surveys (Schultz, 1978). Further, the percentage of respondents reporting

Table 1

Various Outdoor Measures of Jet Noise and Sonic Booms When Judged Equally Annoying During Indoor Listening (converted from Kryter, 1968)

	Sonic Booms				KC-135 Jet Noise	
	Δp	L_{pk}	L_{CE}	L_{AE}	L_{PN}	L_{AE}
B-58	1.94	133.6	106.3	99.2	109	109.9
	2.56	135.7	108.7	101.7	114	112.5
	2.91	136.9	110.1	103.2	117	114.4
F-104	0.86	126.3	99.3	89.2	99	103.4
	1.40	130.5	104.5	95.3	107	109.1
	2.77	136.4	111.8	101.5	121	116.9
XB-70	1.35	130.2	103.2	94.5	107	109.1

Δp peak overpressure in pounds per square foot
L_{pk} peak "linear" sound level in decibels
L_{CE} C-weighted sound exposure level in decibels
L_{AE} A-weighted sound exposure level in decibels
L_{PN} Maximum perceived noise level in decibels

$$L_{pk} = 20 \log_{10} (\Delta p) + 127.6$$
$$L_{CE} = a\, L_{pk} + b$$

	B-58	F-104	XB-70
a	1.1363	1.2300	1.0756
b	-45.5	-56.0	-36.8

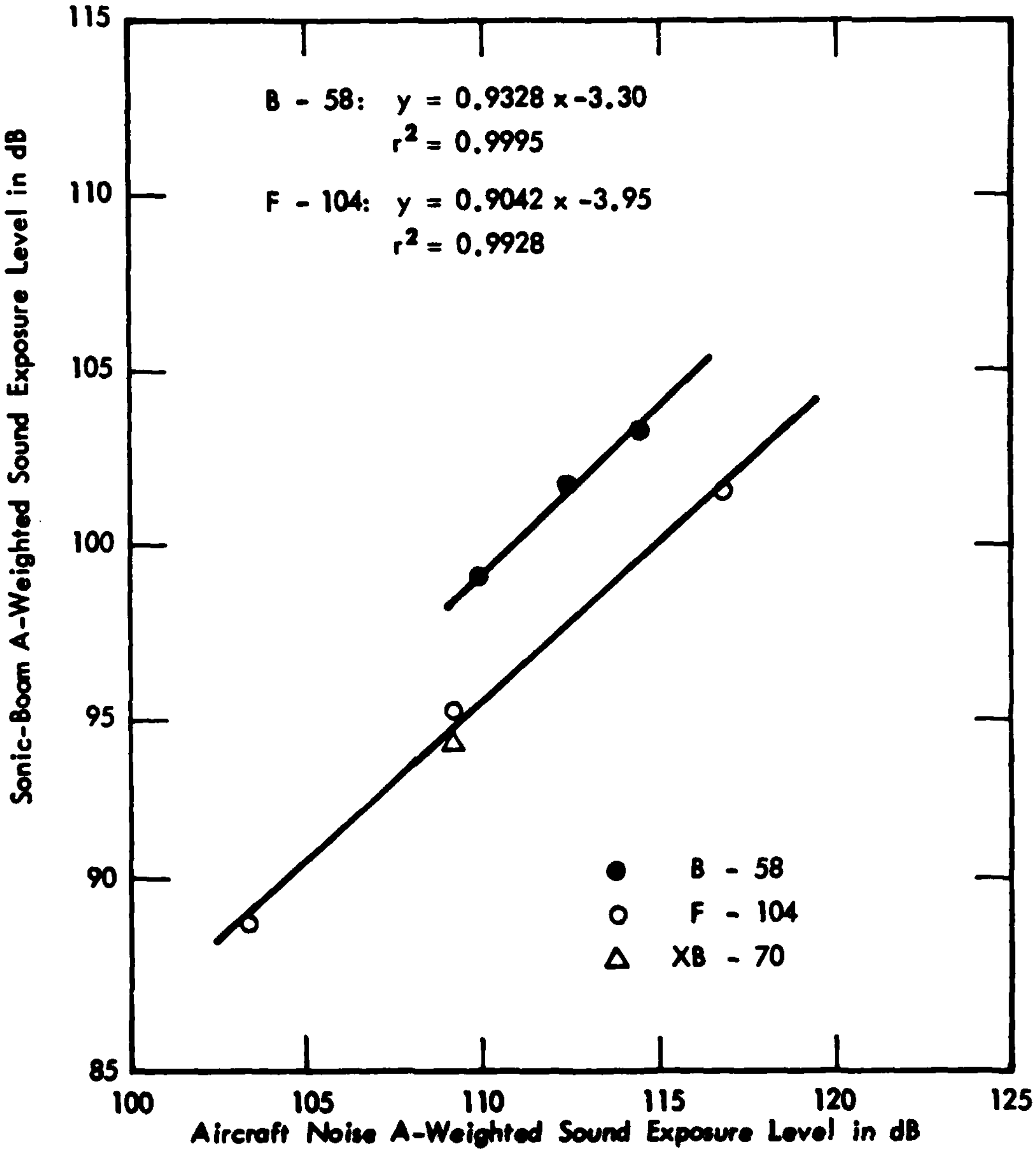

FIGURE 1. Sound Exposure Levels for Aircraft Noise and Sonic Booms When Judged Equally Annoying - Indoor Listening (Converted from Kryter, 1968)

serious annoyance at different boom levels (NRC, 1977) was not of the total population sample, but only of that fraction of the sample that believed it appropriate to complain about governmental actions. To compare these responses to the total populations used in other surveys an adjustment for the total population was made in the current analysis by reducing the reported fractional data by 60 percent.

Conversion of nominal overpressures to A-weighted and C-weighted sound exposure levels was performed as above, except an average difference of 26 decibels between peak overpressure, in decibels, and C-weighted sound exposure level was used. Day-night average sound levels were computed for 8 booms per day (there were no nighttime booms) from the sound exposure levels. These latter data and the percentage of respondents "seriously" annoyed, adjusted for total population, are listed in Table 2.

The data for percentage "serious" annoyance as a function of day-night average A-weighted sound level are plotted in Figure 2. A least-squares fit to an exponential function accounts for virtually all of the variance in the data ($r^2 = 0.94$). Also shown in the figure is the response curve relating percentage highly annoyed to day-night average A-weighted sound level as derived by Schultz (1978) from a synthesis of a number of social surveys of community response to transportation noise. This function was used in the earlier report (NRC, 1977). As would be expected from the above analysis of the Edwards Air Force Base data, the response to sonic booms is much greater, for the same average sound level, than the response to transportation noise.

While the Oklahoma City data show that a response function can be constructed on the basis of A-weighted sound exposure levels, two important factors provide an argument against this approach. The first, as discussed above, is the fact that different sources have different A-weighted sound exposure levels when judged equally annoying as subsonic airplane noise (see Table 1). Thus, a function equally applicable to various impulses does not appear feasible. These differences are even more apparent where other high-energy impulses such as those from artillery firing are considered (Schomer, 1976). The second point is that it is highly desirable to be able to measure the day-night average sound level for impulsive sounds as well as other noises in the community. Traffic noise itself will generally produce a day-night average A-weighted sound level greater than 50 decibels in most suburban and urban environments. In the Oklahoma City study, the contribution of sonic booms to the overall day-night average A-weighted sound level would have been completely masked by the other noise sources for all but the highest sonic-boom exposure cases.

At least for sonic booms, the first problem (differences in sound exposure levels for different sources when equally annoying as a particular subsonic airplane) can be avoided by measurement of sonic booms in C-weighted sound exposure level. The Edwards Air Force Base data

Table 2

Day-n ght Average Sound Levels and Percent of Total Population Expressing "Serious" Annoyance From Sonic-Booms at Oklahoma City (Converted from Borsky, 1965)

	Nominal Δp	L_{dn}	L_{Cdn}	Percent Annoyed
Location 1				
1st period	1.13	52.6	62.3	10.5
2nd period	1.23	53.6	63.0	16.1
3rd period	1.60	56.1	65.3	21.7
Location 2				
1st period	0.8	47.6	59.3	7.9
2nd period	1.1	52.1	62.0	12.2
3rd period	1.3	54.1	63.5	15.2
Location 3				
1st period	0.65	44.1	57.7	3.0
2nd period	0.85	48.6	59.8	6.5
3rd period	1.0	50.6	61.2	10.1

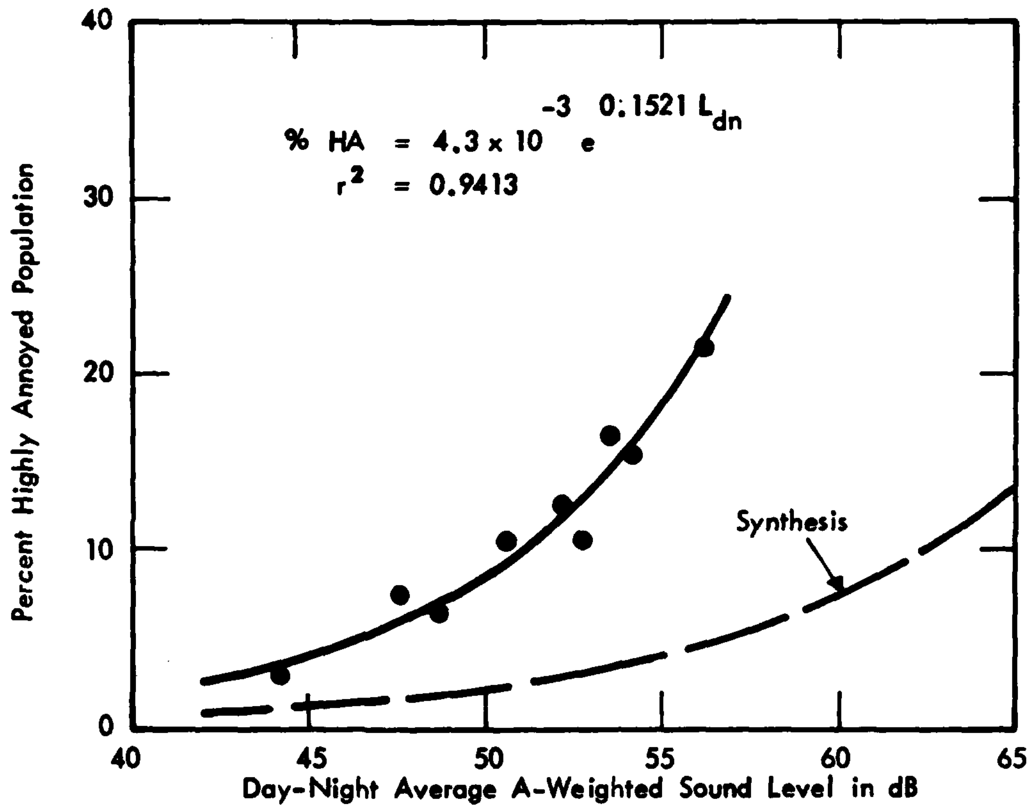

FIGURE 2. Oklahoma City Sonic-Boom Response for Total Population

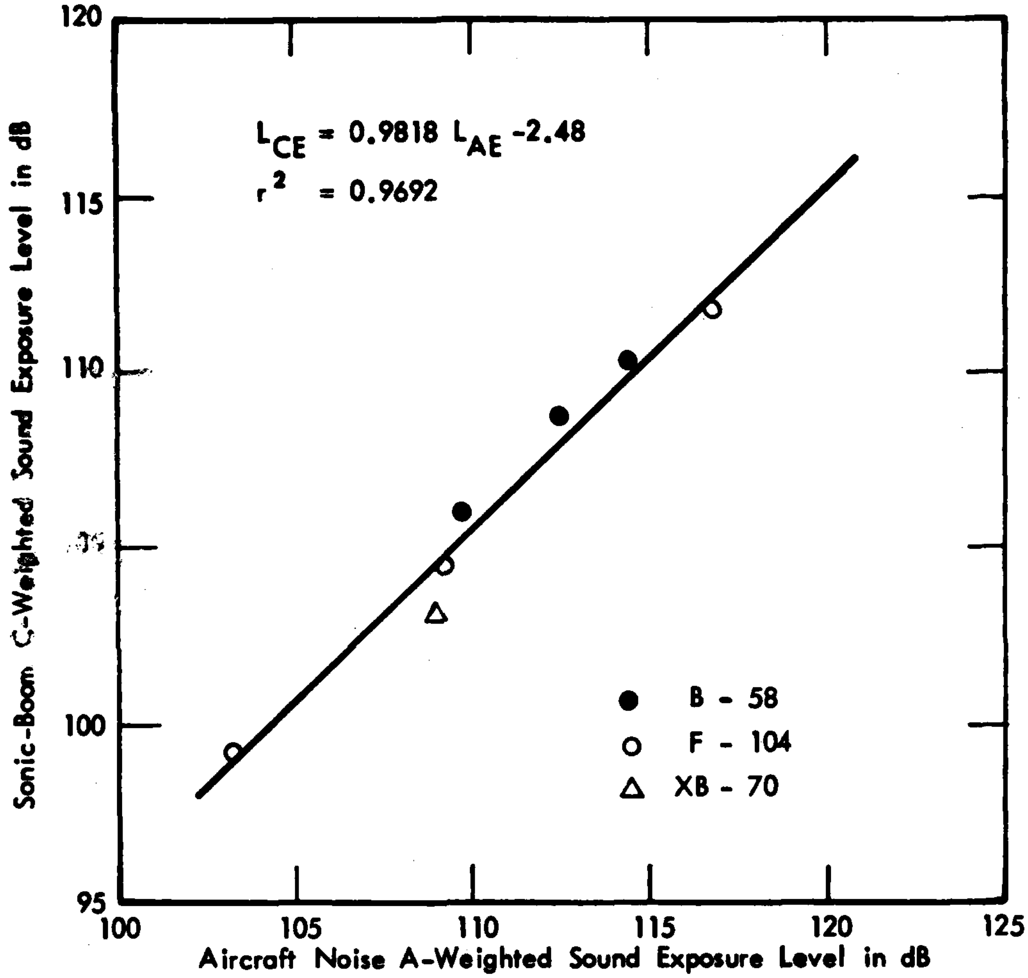

FIGURE 3. A-weighted Sound Exposure Level of Subsonic Jet When Judged Equally Annoying as a Sonic Boom of Specified C-weighted Sound Exposure Level - Indoor Listening (Converted from Kryter, 1968)

from Table 1 are shown in Figure 3, to display the relationship between C-weighted sound exposure levels for sonic booms and A-weighted sound exposure levels for subsonic airplane noise when the two sources are judged equally annoying. In contrast to the data in Figure 1, here the booms from different airplanes collapse into a single function. However, an assumption in the earlier report (NRC, 1977) is not substantiated by these data: C-weighted sound exposure levels for impulse noise, when numerically equal to A-weighted sound exposure levels for non-impulsive noise, do not cause equal annoyance. Rather, the C-weighted sound exposure level is approximately 5 decibels lower than the A-weighted sound exposure level for airplane noise when judged equally annoying. That is, people seem to be more sensitive to impulsive sounds than was indicated in the earlier report (NRC, 1977).

Accepting C-weighted sound exposure level as the preferred measure for individual high-intensity impulsive sounds, the day-night average C-weighted sound level for the Oklahoma City data and Schomer's (1980) Army base artillery noise survey can be used to derive a function relating community annoyance to average sound level. The data from Oklahoma City are listed in Table 2. A brief description of Schomer's survey is in order.

Schomer's study consisted of interviews of groups of residents at sites in the vicinity of an Army base where extensive artillery firing training takes place. The six sites that were off base were considered here. Noise monitoring using integrating sound level meters was conducted on a continuous 24-hour basis for an average of approximately 25 days per site. These measured average sound levels, in conjunction with computer-based predictive models, were used to estimate annual average of day-night average C-weighted sound levels for blast noise associated with the environments in which the survey respondents lived. The social survey used scales similar to other recent surveys (for example, see Schultz, 1978). The group average responses for annoyance from blast noise are of interest here. The percentage of respondents reporting high annoyance, adjusted for the total population sample, are listed in Table 3 with their associated average sound levels.

The annoyance data from Table 2 for Oklahoma City sonic booms and from Table 3 for artillery blast noise are plotted in Figure 4 against day-night average C-weighted sound levels. The consensus of the Working Group is that the data at low average sound levels (those below about 60 decibels) should not be regarded with the same validity as those at higher average sound levels, because of possible confounding with the day-night average A-weighted sound levels from other noise sources. Further, average sound levels below 55 to 60 decibels are considered to have a negligible effect on public health and welfare.

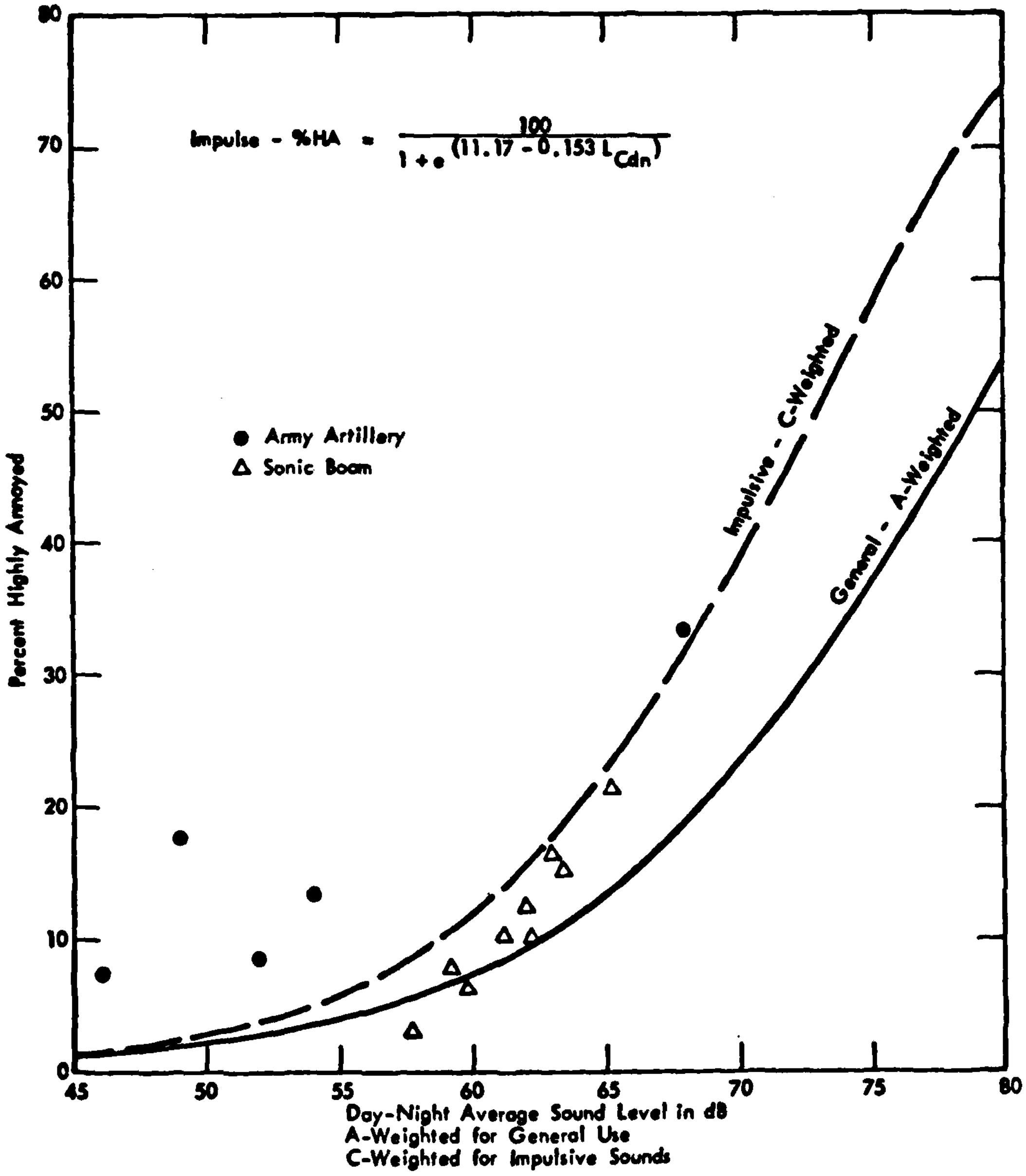

FIGURE 4. Recommended Relationships for Predicting Community Response to High-Energy Impulsive Sounds and to Other Sounds

The data at average sound levels above 60 decibels indicate, as did the Edwards Air Force Base tests discussed above, that annoyance produced by artillery noise rises more rapidly with increasing sound levels than indicated by the transportation noise response function when day-night average C-weighted and A-weighted sound levels are equated on a numerical basis. The synthesized transportation noise function is plotted in Figure 4. A separate function for high-energy impulsive noise, arrived at by a concensus of the Working Group, is also plotted in Figure 4.

TABLE 3

Estimated Percent of Total Population Sampled That Reported High Annoyance to Blast Noise from Artillery Practice Firings (after Schomer, Schomer, 1980)

Area	Day-night average C-weighted sound level	Percent Highly Annoyed
High	68	33.9
Fay W	54	13.5
Fay E	52	8.4
South	49	17.4
Near In	46	7.1
Far W	40	0

The analytic expression recommended by the Working Group for the high-energy impulsive noise function is:

$$\% \text{ HA} = \frac{100}{1 + e^{\left(11.17 - 0.153\ L_{Cdn}\right)}}$$

This function follows the format of a function provided to the Working Group by S. Harris to approximate Schultz's synthesis of annoyance from transportation noise as a function of day-night average A-weighted sound level. This Harris function is:

$$\% \text{ HA} = \frac{100}{1 + e^{\left(10.43 - 0.132\ L_{dn}\right)}}$$

Both functions are considerably simpler than the earlier one (NRC, 1977):

$$\% \text{ HA} = \frac{\left(1.24 \times 10^{-4}\right)\left(10^{0.103\ L_{dn}}\right)}{(0.2)\left(10^{0.03\ L_{dn}}\right) + \left(1.43 \times 10^{-4}\right)\left(10^{0.08\ L_{dn}}\right)}$$

The last two functions for transportation noise provide numerical results that agree within a few tenths of one percent over the range of day-night average sound levels from 40 to 80 decibels.

SOUND LEVEL-WEIGHTED POPULATION

A procedure is given (NRC, 1977) to obtain a single number representative of noise impact for the population affected by a noise environment where different groups of the population experience different average sound levels. To determine the sound level-weighted population, the fraction of total population at each value of average sound level is multiplied by a weighting factor that varies with sound level. The sum of the weighted populations calculated for each sound level is called the level-weighted population. The weighting factor used in the computation was obtained from the relation between percentage highly annoyed and average sound level, as derived from the synthesis of transportation noise surveys, normalized to unity at a day-night average sound level of 75 decibels. The normalizing consisted of dividing the percentage highly annoyed at any average sound level by the percent at 75 decibels, 36.9%. (The Harris function provides 37.1% at this sound level.)

In the report (NRC, 1977), level-weighted population for environments having both high-energy impulsive noise (measured in day-night average C-weighted sound level) and all other sounds (measured in day-night average A-weighted sound level) are calculated by first adding the two average sound levels logarithmically. This addition is performed as follows:

$$L = 10 \log_{10} \left[10^{\frac{L_{Cdn}}{10}} + 10^{\frac{L_{dn}}{10}} \right]$$

Thus the sum of 65 decibels and 70 decibels is 71.2 decibels, not 135. The weighting factor for 71.2 decibels is therefore applied to a population experiencing, simultaneously, a day-night average C-weighted sound level of 70 decibels from high-energy impulsive noise and a day-night average A-weighted sound level of 65 decibels from transportation noise. It is recommended in this present report that the two average sound levels not be directly combined. Instead, the combined effects of high-energy impulsive sound and other audible sounds should be assessed on the basis of equivalent annoyance. This may be accomplished by first finding, for impulsive sounds, the numerical value of day-night average A-weighted sound level (from the "general" response function of Figure 4) that has the same numerical value of percentage highly annoyed predicted by the day-night average C-weighted sound level function. This level is then added logarithmically to the day-night average sound level for the non-impulsive sounds. The percentage highly annoyed, or level-weighted population, is then calculated from this combined average sound level and the general response function. It should be noted that this combination procedure is based on intuition, since no research data are available to support it (or any other procedure).

As an example, consider the same average sound levels as above, 70 decibels for the day-night average C-weighted sound level for impulsive noise and 65 decibels for the day-night average A-weighted sound level for other sounds. From Figure 4 (or the related analytical expressions stated above), at 70 decibels the percentage highly annoyed at the impulsive sounds is 38.7%. This percentage of highly annoyed for non-impulsive sounds is produced at an A-weighted sound level of 75.5 decibels. The general response weighting factor to be used for the combined environment is that associated with the sound level which is the logarithmic sum of 75.5 and 65 decibels, that is 75.9 decibels, corresponding to 39.9% highly annoyed.

LAND-USE PLANNING FOR COMBINED ENVIRONMENTS

Compatibility of various land uses with a given noise environment is related to day-night average sound level. Maps showing contours of equal day-night average sound level are often used to assist in land-use planning, with the contours identified by their numerical values in decibels. The validity of such contours can be assessed by measurements obtained with appropriate acoustical instrumentation.

When land-use maps are prepared for environments in which high-energy impulsive sound (as depicted by day-night average C-weighted sound level) is combined with the general non-impulsive sound environment (depicted by day-night average A-weighted sound level) it is recommended that sound level contours derived from the combination procedure described above <u>not</u> be labeled in decibels. The combination procedure yields a numerical value that is not directly measurable. It is recommended that zones of land use compatibility, at least for residential purposes, be designated by the alphabetical codes described in a report soon to be published by the Federal Interagency Committee on Urban Noise.

GLOSSARY

Acoustical terms used in this report are defined here. The list of terms is arranged approximately in order of their likelihood of use or antecedence over more complex terms.

level. A word added to the names of different parameters in order to indicate that the parameter is expressed in decibels relative to a standardized reference value of the parameter. The use of the word level in any term indicates that the quantity represented by the term is proportional to the logarithm of the ratio of a function of the quantity to the reference quantity for the function.

sound level. The quantity in decibels measured by an instrument satisfying requirements of American National Standard Specification for Sound Level Meters S1.4-1971. Sound level is 10 times the common logarithm of the exponential-time-average of frequency-weighted squared sound pressure, with reference to the square of the standard reference sound pressure of 20 micropascals. A squared pressure time constant of 125 milliseconds is used for "fast" averaging, and one second for "slow" averaging.

A-weighted. The frequency weighting designated as A in sound level meter standards. A-weighting is progressively less sensitive to sounds of frequency below 1000 hertz (cycles per second), somewhat as is the human ear. At 31.5 hertz, A-weighting is 39.4 decibels less sensitive than at 1000 hertz.

C-weighted. The frequency weighting designated as C in sound level meter standards. C-weighting retains its sensitivity to sounds of frequency below 1000 hertz, but gradually decreases in sensitivity at frequencies below 100 hertz. At 31.5 hertz, C-weighting is 3 decibels less sensitive than at 1000 hertz.

linear-weighting. A non-standard term implying equal sensitivity to sounds of all frequencies. In practice, sensitivity at low and high frequencies is determined by the physical characteristics of transducers, cables, amplifiers and other components of a measurement system.

sound exposure level. The level of sound accumulated over a given time period or event. In decibels, the level of the time integral of frequency-weighted squared sound pressure over a stated time interval or event, with reference to the square of the standard reference pressure of 20 micropascals and reference duration of one second.

average sound level. A sound level typical of the sound levels at a certain place in a stated time interval. Technically, average sound level in decibels is the level of the mean-square frequency-weighted sound pressure during the stated time interval, with reference to the square of the standard reference sound pressure of 20 micropascals. Average sound level differs from sound level in that for average sound level equal emphasis is given to all sounds within the stated averaging interval, whereas for sound level an exponential time weighting puts much more emphasis on sounds that have just occurred than on those which occurred earlier. It is often convenient to calculate average sound level as the mean-square sound exposure level of all events occurring in a stated time interval, plus 10 times the common logarithm of the quotient formed by the number of events in the time interval, divided by the duration of the time interval in seconds.

day-night average sound level. The 24-hour average frequency-weighted sound level, in decibels, from midnight to midnight, obtained after addition of 10 decibels to sound levels in the night from midnight up to 7 a.m. and from 10 p.m. to midnight (0000 up to 0700 and 2200 up to 2400 hours). A-weighting is understood unless otherwise specified.

perceived noise level. The level in decibels obtained by a computational procedure that combines the 24 one-third octave band sound pressure levels in the frequency bands from 50 to 10,000 Hz to obtain a single level. The calculation procedure gives an approximation to the perceived noise level as determined by a subjective experiment on a fundamental psycho-acoustical basis, namely that perceived noise level of a sound is numerically equal to the sound pressure level of a reference sound that is judged by listeners to have the same perceived noisiness as the given sound. Perceived noise level is generally computed for each consecutive 0.5 second time interval during the duration of an aircraft flyover. For typical aircraft flyovers the perceived noise level is numerically 12 to 14 decibels greater than the A-weighted sound level for the same sound.

maximum perceived noise level. The greatest perceived noise level during a designated time interval or event. The value of the maximum sound level for a time-varying event is especially dependent on the averaging time of the instrument and thus must be stated. Perceived noise levels, when standardized for application to aircraft noise, are based onthe "slow" time constant of one second.

overpressure. Pressure at a place and instant considered, minus the static pressure there.

peak overpressure. Greatest absolute instantaneous overpressure during an event or stated time interval. for sonic booms, it has been conventional to state the magnitude of peak overpressure either in pounds per square foot or newtons per square meter.

peak overpressure level. The level in decibels of the squared peak overpressure, with reference to the square of the standard reference sound pressure of 20 micropascals. Also called peak sound level.

sound level-weighted population. The sum, over all people and average sound levels associated with a defined acoustical environment, of the number of people experiencing a stated average sound level, multiplied by a numerical weighting. The weighting is proprotional to average sound level.

SYMBOLS

The following mathematical symbols have been used in this report:

L_{AE} A-weighted sound exposure level in decibels

L_{CE} C-weighted sound exposure level in decibels

L_{dn} day-night average A-weighted sound level in decibels

L_{Cdn} day-night average C-weighted sound level in decibels

L_{pk} peak "linear" sound level in decibels

L_{PN} perceived noise level in decibels

Δp peak overpressure in pounds per square foot

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A110 110
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) ASSESSMENT OF COMMUNITY RESPONSE TO HIGH-ENERGY IMPULSIVE SOUNDS	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) William J. Galloway	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) National Research Council	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Resident Representative George Washington University 2110 G Street, N.W. Washington, D.C.	12. REPORT DATE July 1981
	13. NUMBER OF PAGES 31
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Office of Naval Research Physiology Programs (Code 441) 800 N. Quincy Street Arlington, Virginia 22217	15. SECURITY CLASS. (of this report)
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Annoyance
Community surveys
Impulsive noise
Noise
Environmental Impact Statements

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A dose-response relationship between day-night average C-weighted sound level and average degree of community annoyance is proposed for high-energy impulsive sounds. This proposal revises the relationship originally recommended in a NRC-CHABA report (1977) to reflect more recent community response data and additional analyses of previous data. The use of sound level-weighted population as a means for assessing noise impact, as orginally proposed by CHABA, is retained in this proposal.

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S N 0102-LF-014-6601

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Analyses summarized in this report indicate that growth of annoyance with increasing average sound level is greater for high-energy impulsive sounds than for more conventional sounds, such as those produced by transportation noise sources. This result differs from that in the NRC-CHABA report (1977) in which growth of annoyance was considered to be the same for both kinds of noise. The equations provided in this report which relate annoyance to average sound level are somewhat simpler than those in the NRC-CHABA report (1977). A numerical example showing the application of the recommended procedures is provided. Definitions of acoustical measures used in the report are contained in a glossary.

S N 0102- LF- 014- 6601