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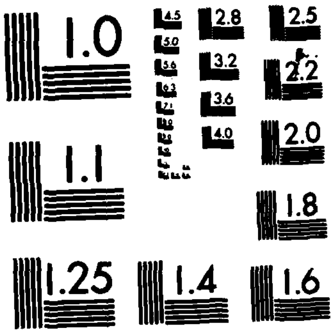

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US Army Corps of Engineers
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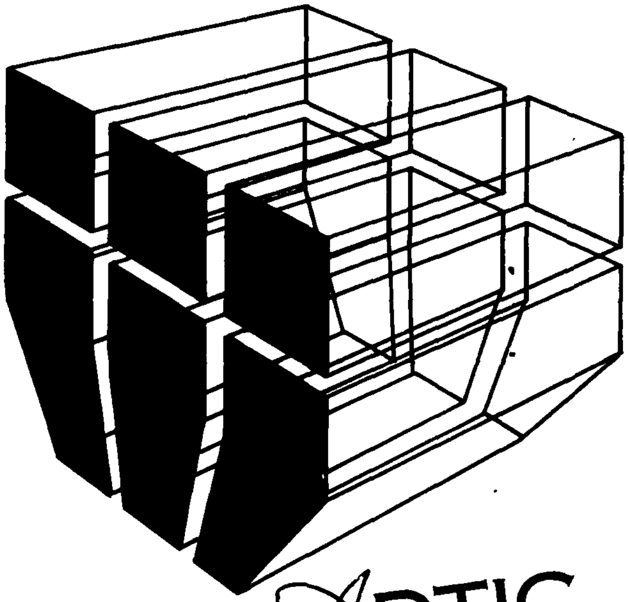
June 1985
Standard Methods to Assess Human and
Community Response to Impulsive Noise

Community Reaction to Impulsive Noise:
A Final 10-Year Research Summary

by
Paul D. Schomer
Robert D. Neathammer

A major concern of Army planners is the trend toward siting off-installation housing and other noise-sensitive land uses in areas exposed to high noise levels produced by Army training or operational activities. To do effective noise-related assessments and planning the Army must be able to assess the community reaction to impulsive noise. Impulsive noise is produced by Army noise sources like armor, artillery, and demolition.

This collection of papers summarizes 10 years of work by the U.S. Army Construction Engineering Research Laboratory (USA-CERL) in the area of community response to impulsive noise. It is based on laboratory tests using a blast noise simulator, a study of Army-wide noise complaints, and attitudinal surveys conducted at Fort Bragg, NC, and Fort Lewis, WA. The attitudinal surveys provide most of the data.



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A major concern of Army planners is the trend toward siting off-installation housing and other noise-sensitive land uses in areas exposed to high noise levels produced by Army training or operational activities. To do effective noise-related assessments and planning the Army must be able to assess the community reaction to impulsive noise. Impulsive noise is produced by Army noise sources like armor, artillery, and demolition.

This collection of papers summarizes 10 years of work by the U.S. Army Construction Engineering Research Laboratory (CERL) in the area of community response to im-

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pulsive noise. It is based on laboratory tests using a blast noise simulator, a study of Army-wide noise complaints, and attitudinal surveys conducted at Fort Bragg, NC, and Fort Lewis, WA. The attitudinal surveys provide most of the data.

The major conclusions show that:

1. An energy type of model such as the C-weighted day/night average sound level (CDNL) is the best available descriptor for community response. Growth in annoyance to all noises increases monotonically with both sound amplitude and frequency of occurrence. This descriptor should incorporate a nighttime adjustment on the order of 10 decibels (dB). → Keywords:

2. Complaints are not a good measure of community response. The percentage of a community which is highly annoyed by noise correlates with CDNL; complaints do not correlate with CDNL. Complaints seem to correlate only with abnormal or unusual events.

3. The exact function for relating the percentage of a community highly annoyed to CDNL remains in question. It appears that the present National Academy of Science Committee on Hearing, Bioacoustics and Biomechanics (CHABA) recommendation may underestimate actual annoyance, and that the functional relation between annoyance and CDNL should be shifted by 3 to 4 dB. However, more research on (a) the percentage of a community highly annoyed vs CDNL and (b) the existence and value of community rise- and decay-time constants is required to clarify the issue.

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FOREWORD

This study was performed for the Directorate of Engineering and Construction, Office of the Chief of Engineers (OCE), under Project 4A162720A896, "Environmental Quality Technology"; Task A, "Installation Management Strategy"; Work Unit 009, "Standard Methods to Assess Human and Community Response to Impulse Noise." The OCE Technical Monitor was Mr. Gordon Velasco, DAEN-ECE-I.

This study was conducted by the Environmental (EN) Division of the U.S. Army Construction Engineering Research Laboratory (CERL). Dr. R. K. Jain is Chief of CERL-EN.

COL Paul J. Theuer is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

COMMUNITY REACTION TO IMPULSIVE NOISE: A FINAL 10-YEAR RESEARCH SUMMARY

1 INTRODUCTION: STUDY ISSUES FOR UNDERSTANDING HUMAN AND COMMUNITY RESPONSE TO IMPULSIVE NOISE

The assessment and control of environmental noise has concerned civilized man for at least 2000 years. Even the Romans and Greeks found it necessary to enact ordinances prohibiting the early morning use of chariots in residential areas. Today, noise produced by transportation sources continues to receive the greatest emphasis in study and research.[1]

During the past 30 years, many attitudinal surveys have been conducted worldwide to better understand and assess human and community response to noise. These studies concentrated mainly on the noise produced by automobile, truck, rail, and fixed-wing aircraft traffic and resulted in a proliferation of noise assessment descriptors. In one fashion or another, these descriptors take into account:

1. The sound level of the noise events.
2. The frequency of occurrence of the noise events.
3. The time of day at which the noise events occur.

Few of these models agree on the best way to measure sound amplitudes; consequently, a confusing array of descriptors has been proposed, including: A-level fast, A-level slow, Perceived Noise Level, Effective Perceived Noise Level, Tone-Corrected Effective Perceived Noise Level, A-weighted Sound Exposure Level (SEL), and Tone-Corrected A-weighted SEL.

The effect that numbers of noise events have on community reaction has also been the focus of considerable debate and discussion. Some researchers have suggested there is no relation at all. At the other extreme, models have used a relation using 145 times the log of the number of events. Most descriptors use a relation about 10 times the log of the number of events.

Time of day differences are also controversial. Some researchers contend that noise at night is no more or little more of a problem than noise during the day. Others would prohibit all noise at night. In general, descriptors use a 10-decibel (dB) nighttime adjustment. Recently, some descriptors such as the Community Equivalent Noise Level have also incorporated a 5-dB evening adjustment. (See the Appendix for an historical perspective of noise descriptors.)

Many of these descriptors have been used in the United States. The Department of Defense (DOD) and the Federal Aviation Administration (FAA) have used the Composite Noise Rating (CNR) and the Noise Exposure Forecast (NEF) to assess aircraft noise. The Federal Highway Administration (FHA) and State highway departments have used the L_{10} (the A-weighted level exceeded 10 percent of the time) to assess highway noise. The Department of Transportation (DOT) has used the L_{eq} (the mean A-weighted level) to assess railroad noise, and the Department of Housing and Urban Development (HUD) has used the L_{33} (the A-weighted level exceeded 33 percent of the time) as a criterion for siting housing with respect to noise. In accordance with the requirements of the Noise Control Act of 1972,[2] the Environmental Protection Agency (EPA) brought a degree of order to this chaotic situation by creating the A-weighted Day/Night Average Sound Level (ADNL) to characterize environmental noise. The ADNL was established by the EPA "requisite to protect health and welfare with an adequate margin of safety."[3] Like most other noise models, the ADNL is based on a 10 times the log of the number of events relation and includes a 10-dB nighttime adjustment. As indicated by its title, it uses the "A" frequency weighting and its definition implies the true integration of the square of the A-weighted sound pressure.

The ADNL descriptor was chosen as an EPA standard based, in part, on a re-analysis study of community response data collected during 18 worldwide

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[1] William J. Galloway and Dwight E. Bishop, *Noise Exposure Forecasts: Evolution, Evaluation, Extensions, and Land Use Interpretations*, Contract No. FA68WA-1900 (Department of Transportation, Federal Aviation Administration [FAA], Office of Noise Abatement, August 1970).

[2] Noise Control Act of 1972, Public Law 92-574, 86 Stat 1234.

[3] *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety*, EPA Report 5-50/9-74-004, PB239429 (EPA, March 1974).

attitudinal surveys.[4] Table 1 lists the data used in the re-analysis and Figure 1 shows some of the re-analysis results. Basically, the study showed that worldwide results tended to collapse into a single curve which relates the percentage of a community found to be "highly annoyed" as a function of the ADNL. This concentration on the percentage of a *community* "highly annoyed," rather than on the *individual* response, marked a great step forward in understanding community response to noise. Many researchers had attempted to predict individual reaction to noise, but these efforts rarely achieved a correlation coefficient with the noise better than 0.4.[5] Many of the theories advanced to explain this poor correlation were based on the idea of "intervening variables," such as a person's attitude towards the noise source or his/her willingness to complain. However, this poor correlation is more readily explained by noting that the worldwide surveys typically categorized respondents into 5 to 10 dB ranges and gathered little, if any, real data on indoor noise exposure or the respondent's lifestyle. Such factors as windows open or shut, radios or televisions on or off, building orientation, and adjacent building shielding or noise reflection can greatly influence the exact noise dose any individual receives. In view of these noise dose variations, community rather than individual response averages provide much more meaningful data.

The Army's problem with the ADNL noise model is that the Army's major noise sources do not readily fit in the context of the sources studied during the past 30 years which led to the development of the ADNL measure.

The Army's major noise problems are impulsive noise sources like armor, artillery, and demolition and such quasi-impulsive sources as helicopters, small ground-to-ground rockets, and small arms fire. Armor, artillery, and demolition are noise sources almost unique to the Army. Their only counterparts in the civilian community are the sonic booms created by supersonic aircraft and the blasting which occurs at quarries and open-pit mines. However, civilian aircraft sonic booms over land have been eliminated by Federal regulation and quarries normally fire no more than one blast per day, always during the day and usually weekdays only.[6] Only the Army creates impulsive noise frequently, day and night, weekday and weekend. Similarly, the Army owns about 80 percent of the nation's helicopters and only the Army has large airfields devoted almost exclusively to rotary-wing traffic.

Because of their unique character, Army noise sources require special procedures for developing data on: (1) source emissions, (2) the propagation of impulsive noise over long distances, and (3) the relation between the noise environment (stimulus) and the community response.

Army impulsive noise is a major concern of Army planners because of the recent trend toward siting off-installation housing and other noise-sensitive land uses in areas exposed to high impulsive noise levels. The Department of Defense *Construction Criteria Manual* and Army Technical Manual 5-803-2 list requirements for locating noise-sensitive land uses on an installation.[7] The Installation Compatible Use Zone (ICUZ) Program, as described in Army Regulation 200-1, is the Army standard for planning off-installation land use to minimize noise impact. The ICUZ program uses blast noise zone maps generated by CERL's blast noise computer prediction program, BNOISE.[8] These maps are correlated with community response data to identify and assess a land use's compatibility with Army impulsive noise.

However, before CERL could develop the ICUZ program, data in three areas had to be collected: (1) source acoustic emissions data; (2) data and equations statistically relating the propagation of sound from source to receiver as functions of such parameters as meteorological conditions, terrain, and surface

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[4] Theodore J. Schultz, "Synthesis of Social Surveys and Noise Annoyance," *Journal of the Acoustical Society of America*, Vol. 64, No. 2 (August 1978), pp 337–406.

[5] Fred L. Hall and S. Martin Taylor, "The Reliability of Social Survey Data on Noise Effect," *Journal of the Acoustical Society of America*, Supplement 1, Vol. 67 (1980), p 553.

[6] *Federal Aviation Administration Regulations on Air Traffic*, CFR, Title 144, Chapter I, Subchapter F, Part 91, Latest Revision 45FR 67066, 67259 (October 9, 1980).

[7] *Construction Criteria Manual*, Department of Defense (DOD) Manual 4270.1-M (DOD); and *Planning in the Noise Environment*, Army Technical Manual (TM) 5-803-2 (Departments of the Air Force, Navy, and Army, 15 June 1978).

[8] *Environmental Quality: Environmental Protection and Enhancement*, Army Regulation (AR) 200-1 (Department of the Army, 15 June 1982); and Paul D. Schomer, et al., *Blast Noise Prediction Volume I: Data Bases and Computational Procedures* and *Volume II: BNOISE 3.2 Computer Program Description and Listing*, Technical Report N-98/ADA099440 and ADA099335 (U.S. Army Construction Engineering Research Laboratory [CERL], March 1981).

Table 1
Worldwide Attitudinal Survey Summary

"Noise -- Final Report," Cmnd. 2056, July 1963, Her Majesty's Stationery Office, London (the so-called "Wilson Report"), Appendix XI.

Robert Josse, "La Gêne Causée parle Bruit des Avions [Annoyance Caused by Aircraft Noise]," Rep. 100, Cahier 869, June 1969, Centre Scientifique et Technique du Bâtiment, Paris; pp 46-51; and Ariel Alexandre, "Prevision de la Gene due au Bruit autour des Aeroports et Perspectives sur les Moyens d'y Remedier" [Prediction of Annoyance Due to Noise Around Airports and Speculations on the Means for Controlling It], Anthropol. Appl., Doc. A.A.28/70 (April 1970).

"Fluglärmwirkungen, Eine interdisziplinäre Untersuchung über die Auswirkungen des Fluglärms suf den Menschen," [Effects of Aircraft Noise: An Interdisciplinary Investigation of the Effects of Aircraft Noise on Man], (in three volumes: Main Report, Appendices, and Social-scientific Supplementary Report), Deutsche Forschungsgemeinschaft, Bonn-Bad Godesberg, 1974. Papers reporting this study were also presented at the International Congress on Noise as a Public Health Question, Dubrovnik (13-18 May 1973), pp 765-776; at InterNoise 73, Copenhagen (22-24 August 1973), pp 289-297); and at the Symposium on Noise in Transportation, University of Southampton (22-23 July 1974), Paper No. 1, Sec. III.

D. Aubree, S. Auzou and J. M. Rapin, "Etude de la Gene due au Trafic Automobile Urbain: Compte Rendu Scientifique [Study of the Annoyance Due to Urban Automotive Traffic: Scientific Report]," no report number (June 1971), Centre Scientifique et Technique du Bâtiment, Paris.

Ragnar Rylander, Stefan Sörensen and Anders Kajland, "Störningsreaktioner vid Flybullerexponering," [Annoyance Reactions from Aircraft Noise Exposure], no report number, April 1972, joint report from the Institute of Hygiene, The Karolinska Institute and the Department of Environmental Hygiene, National Environmental Protection Board, Stockholm, Sweden (in Swedish).

"Sozio-psychologische Fluglärmuntersuchung in Gebiet der drei Schweizer Flughafen: Zürich, Genf, Basel [Sociopsychological Investigation of Aircraft Noise in the Vicinities of Three Swiss Airports: Zurich Geneva and Basel], no report number, Arbeitsgemeinschaft für soziopsychologische Fuglarmuntersuchungen, Bern (June 1973).

F. J. Langdon, "Noise Nuisance Caused by Road Traffic in Residential Areas, Part I and Part II," J. Sound Vib. 47(2), 243-263 and 265-282 (22 July 1976).

D. Aubree, "Enquête Acoustique et Sociologique Permettant de Definir une Echelle de la Gêne Eprouvee par l'Homme dans son Logement du Fait des Bruits de Train" [Acoustical and Sociological Investigation Permitting the Definition of a Scale of Annoyance Felt by People in their Dwellings Due to the Noise of Trains], no report number, Centre Scientifique et Technique du Bâtiment, Paris (June 1973). See also Refs. 52 and 53.

Myles A. Simpson, Karl S. Pearsons, Sanford A. Fidell and Richard H. Muehlenbeck, "Social Survey and Noise Measurement Program to Assess the Effects of Noise on the Urban Environment: Data Acquisition and Presentation," Report No. 2753 (July 1974), Bolt Beranek and Newman, Inc., Submitted to the U.S. Environmental Protection Agency, Office of Noise Control and Abatement, Washington, DC 20460. The data from this survey are not yet published; however, portions of the raw questionnaire response were analyzed for the purposes of this report.

Theodore J. Schultz, "Synthesis of Social Surveys on Noise Annoyance," Journal of the Accoustical Society of America, Vol. 64, No. 2 (August 1978), p 380.

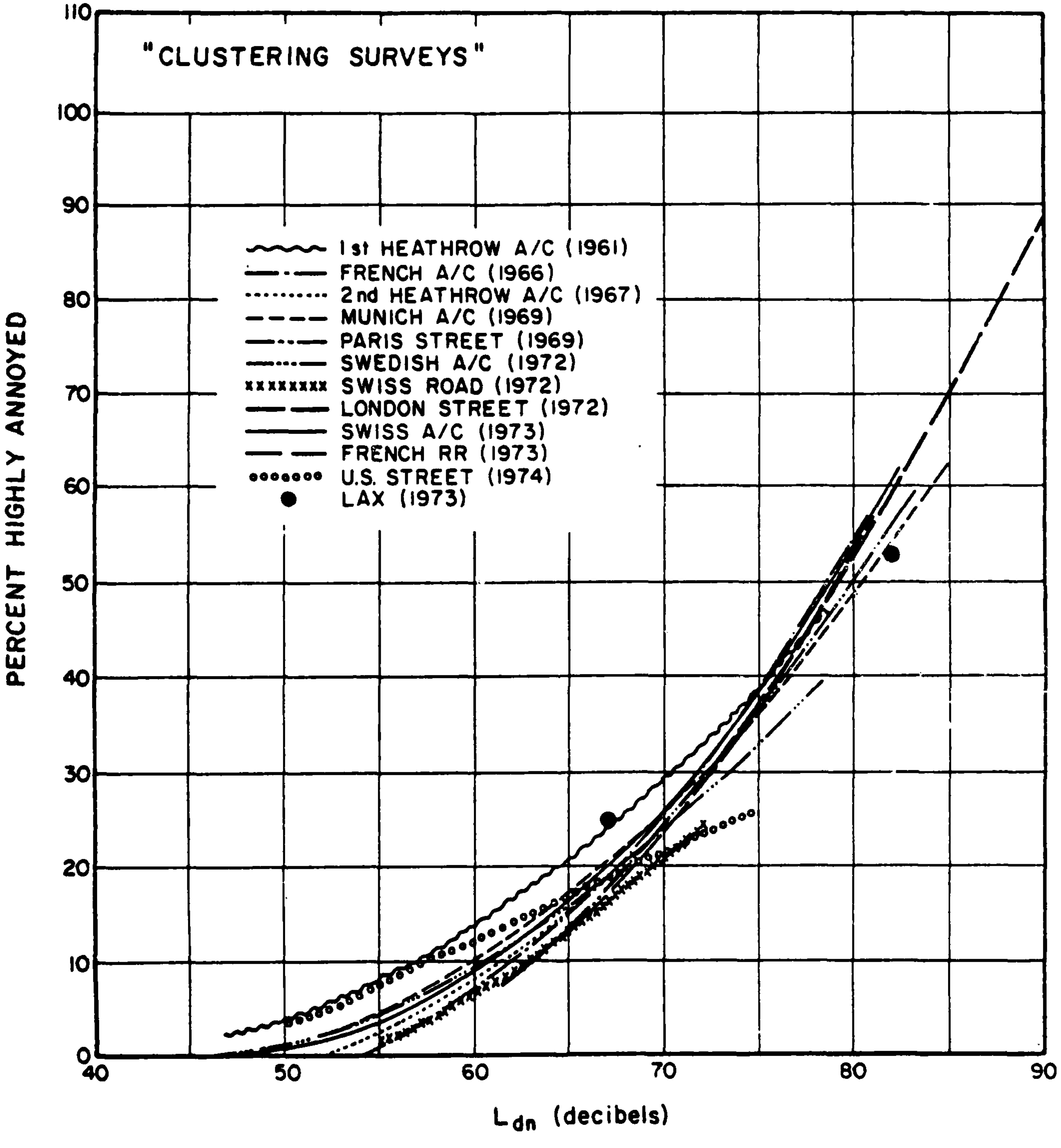

Figure 1. Summary of annoyance data from the surveys listed in Table 1. (Reproduced by permission from Theodore J. Schultz, "Synthesis of Social Surveys and Noise Annoyance," *Journal of the Acoustical Society of America,* Vol. 64, No. 2 [August 1978], pp 377-406.)

characteristics; and (3) a descriptor which correlates the received acoustic stimulus to the community response.

This report collects the results of more than 10 years of CERL research in community response to impulsive noise. This research laid the foundation for the community response criteria in the ICUZ program.

Three types of studies can be used to investigate human and community response to impulsive noise: (1) laboratory studies of human response to impulsive noise, (2) attitudinal surveys of community response to impulsive noise, and (3) field case history studies using specific individuals. Laboratory studies have the advantage of a well-specified acoustic stimulus, but suffer from the fact that the test subjects are not hearing the sounds in their homes. Attitudinal surveys have the advantage of including large numbers of respondents and generating and measuring the response of individuals to the noise stimulus in their home; however, it is not possible to exactly quantify the noise stimulus. Field case studies have the advantage of dealing with individuals in their homes with real stimulus, but are expensive and thus prohibitive with large numbers of subjects.

During the past 10 years, CERL has performed the first two types of studies and is currently embarking on the third type. Working with the Stanford Research Institute, CERL conducted human response tests by using a facility originally designed to generate sonic booms.[9] This facility was modified to create blast sounds. With the University of Illinois, CERL developed and administered attitudinal surveys at Fort Bragg, NC, and Fort Lewis, WA.[10] CERL is now doing individual field case studies using a method developed by the Bureau of Mines.[11]

It has been the practice of the CERL Acoustics Team to publish research results in refereed scientific journals such as the *Journal of the Acoustical Society of America (JASA)*, a publication of the American Institute of Physics. These critically reviewed scientific papers form the basis for the body of this report.

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[9] J. R. Young, *Measurement of the Psychological Annoyance of Simulated Explosion Sequences*, Final Report for Contract DACA 23-74-C-0008 (January 1975).

[10] Paul D. Schomer, *Community Reaction to Impulse Noise: Initial Army Survey*, Technical Report N-100/ADA 101674 (CERL, June 1981).

[11] Sanford Fidell, et al., *Initial Field Studies of Community Response to Blast Noise and Vibration*, Bolt Beranek and Newman Report 4731 for the Twin Cities Research Center, Contract No. J 0205009 (January 1982).

2 PRESENTATION OF PAPERS

Paper 1

Evaluation of *C*-weighted L_{dn} for assessment of impulse noise

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(Received 17 January 1977; revised 22 April 1977)

Community response to impulsive noise, such as sonic boom, artillery fire, and other military ordinance, and quarry and mining operations, is currently a matter of great public interest. Recently, the EPA has proposed the of the *C*-weighted day-night level to estimate community response to large amplitude single-event impulsive noise. This measurement and its associated exposure criteria have been derived largely on the basis of existing community response to sonic boom data. Recent laboratory measurements of human reaction to artillery-type noise, reported on herein, strongly support this *C*-weighted measure.

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INTRODUCTION

The EPA has proposed an interim impulsive noise measure in addition to the day-night average sound level (DNL) which has been specified as the primary descriptor for environmental noise on the basis of the perception by people of audible sound.[1] Basically, this new measure yields a *C*-weighted DNL for single event large amplitude impulsive noises, where large amplitude is defined to mean events having a *C*-weighted sound exposure level [SEL-defined in Eq. (1) below] in the excess of 85 dB during daytime hours (7 a.m.–10 p.m.), and a *C*-weighted SEL in excess of 75 dB during nighttime hours (10 p.m.–7 a.m.). Appendix A describes the *C*-weighted measure.

Large amplitude impulsive sounds, such as those produced by sonic boom, quarry blasts or artillery fire can excite noticeable vibration of buildings and other structures:[2,3] These induced vibrations may generate additional annoyance to people beyond that due to audibility of the impulse because of "house rattling" and "startle," as well as additional contributions to interference with speech or sleep.[4,5] These large amplitude, structure shaking sources are contrasted with small size (small SEL) impulsive sources such as rifle fire, toy "cap" pistols, etc.

In the past, it has been general practice to describe large-amplitude impulsive sounds in terms of the peak sound pressure in a wide-frequency band (e.g., quarry operations, sonic boom). Peak pressure may be satisfactory for description of impulses having a restricted range of peak pressures and durations. It is not sufficient as a general description for use in measurement or prediction of the combined environmental effects of impulses having substantially different pressure versus time characteristics since the energy coupled into a structure is dependent on the spectral content of the impulse. Moreover, use of peak pressure can be unwieldy when a succession of impulses, sometimes overlapping, must be evaluated.

The *C*-weighted average sound level was chosen as a suitable descriptor because it provides the basis of a procedure that relates to the sound-incuded vibrations in buildings. Criteria were established by equating the percent of population highly annoyed to sonic boom at various *C*-weighted levels to the population highly annoyed to more normal noises (primarily aircraft and traffic noise survey data) at various *A*-weighted L_{dn} levels. The Edwards Air Force Base[6] and Oklahoma City[7] studies were primary bases for this procedure for large impulsive sounds.

In the Oklahoma City study, the population was questioned if they were annoyed, and if so, if they were very annoyed, moderately annoyed or little annoyed. The percent very annoyed was chosen as best matching the highly annoyed described in the EPA levels document.[8] Analysis of the data showed that approximately the same percentage of the population was highly annoyed in an environment having an impulsive *C*-weighted L_{dn} level of 60 dB as was a population in an area with an *A*-weighted L_{dn} of 60 dB.

Because of the equivalency of the two measures on a percent highly annoyed basis, DNL for impulse noise is derived from the individual CSEL's and called *C*-weighted day-night average sound level. Further, assessment of the overall noise environment, combining the effects of impulsive sounds described by CDNL, is made in terms of a composite day-night average sound level. The contribution of the impulses, in terms of CDNL (*C*-weighted), is added, logarithmically, to the DNL (*A*-weighted) of other sources to obtain the composite DNL for the combination.[9]

I. PURPOSE

The purpose of this paper is to report on the analysis of new laboratory tests of subjective response to simulated blast sounds. It is important to note that these are laboratory tests in contrast to the survey test data used to initially derive the above C-weighted procedure.

II. THE NEW DATA

The psychological annoyance of simulated explosion sequences have been studied at the Stanford Research Institute.[10] In this study, a special testing room, originally designed for human response to sonic boom research, was modified to create artillery type sounds.[11] In a quasirandom sequence, subjects judged the annoyance of various artillery type sounds (different amplitudes, durations, etc.) in relation to recorded aircraft

TABLE I. Summary of physical and psychological data for stimuli used in the psychoacoustic experiment.

Noises	Physical measures^a				Mean magnitude estimates of annoyance	
	Peak SPL	SEL-A	SEL-C	SEL-D2	$\overline{ME}_g$	$\text{Log}_{10}\overline{ME}_g$
Blasts	95.25	57.25	78.00	65.50	2.4	0.3802
	98.00	62.25	81.50	70.00	3.6	0.5563
	106.75	74.75	93.75	82.50	22.8	1.358
	107.25	74.75	93.50	82.25	26.7	1.427
	102.75	73.50	90.75	80.75	20.0	1.301
	111.75	77.75	96.75	85.75	34.4	1.537
	112.50	81.75	99.75	89.00	41.9	1.622
	119.25	86.50	104.75	94.25	62.6	1.797
Glass breaking	100.25	78.25	80.75	81.75	10.7	1.029
	104.75	85.25	87.25	87.00	13.1	1.117
	105.00	80.00	85.25	85.50	17.5	1.243
	107.75	87.25	90.25	89.75	16.0	1.204
Horn (short)	106.50	92.00	91.75	98.50	53.4	1.728
Horn (long)	106.75	93.50	93.25	100.25	62.9	1.799
747 (take off)	70.00	58.25	64.75	62.75	3.4	0.5314
	80.00	68.25	74.75	72.75	6.2	0.7924
	90.00	78.25	84.75	82.75	10.0^b	1.000
	100.00	88.25	94.75	92.75	26.2	1.418
	110.00	90.25	104.75	102.75	49.1	1.691
DC-8 (landing)	70.00	57.25	64.25	65.75	2.9	0.4625
	80.00	67.25	74.25	75.75	5.9	0.7709
	90.00	77.25	84.25	85.75	11.0	1.041
	100.00	87.25	94.25	95.75	29.9	1.476
	110.00	97.25	104.25	105.75	55.5	1.744

[a] Physical data values are rounded to nearest ¼ dB.
[b] Reference noise with assigned annoyance value of 10.

fly-over sounds, breaking glass sounds and airhorn sounds. The subjects used magnitude estimation procedures to assign annoyance values to the various noise stimuli presented. One of the aircraft fly-over sounds was the reference value and was assigned a magnitude of 10.

The aircraft fly-overs were filtered to have a spectral content and level as normally recorded indoors, the artillery sounds and their associated room vibrations were made to be similar to actual indoor recordings, the glass breaking was an indoor sound and the air horn was "filtered" by the double wall of the test room.

Thirty adult subjects, 18 female and 12 male, hired in the Stanford area, were used for the test. The geometric mean of their magnitude estimates was used as the overall estimate of annoyance for each of the various stimuli. These overall estimates of annoyance were plotted against and compared to four physical measures: peak sound pressure level, *A*-weighted SEL, *C*-weighted SEL and *D*2-weighted SEL. Table I summarizes these data; the terms used in this table are defined as follows:

Peak SPL—The peak value achieved by the time-varying sound pressure during the occurrence of a noise.

ASEL, *CSEL* and *D2SEL*—Sound exposure levels calculated from *A*-, *C*-, or *D*2-weighted sound pressures, respectively.

Sound exposure levels are computed as

$$\text{SEL} = 10\log\left[\frac{1}{p_0^2 t_0}\int_0^T \hat{p}^2(t)\,dt\right] , \qquad (1)$$

where $\hat{p}(t)$ is a time-varying sound pressure weighted by a prescribed frequency-dependent weighting network, such as *A*, *C*, or *D*2.

p_0 is the reference pressure of 20 μPa, and t_0 equals 1 s.

III. ANALYSIS OF THE DATA

In order to compare the validity of equating impulsive *C*-weighted L_{dn} to *A*-weighted L_{dn}, it is first necessary to establish a correction factor for the impulsive noise since buildings will attenuate aircraft noise more than they will attenuate the low-frequency impulsive noise. That is, an aircraft fly-over having an *A*-weighted SEL of 80 dB indoors might have an outdoor *A*-weighted SEL of 95 or 100 dB (the building attenuates 15–20 dB on average). In contrast, a low-frequency, large-amplitude blast noise or sonic boom having a *C*-weighted SEL indoors of 85 dB might have an outdoor *C*-weighted SEL of 90–95 dB because the building attenuation is less to the lower-frequency impulse spectra than it is to the higher frequency aircraft spectra. A few measurements

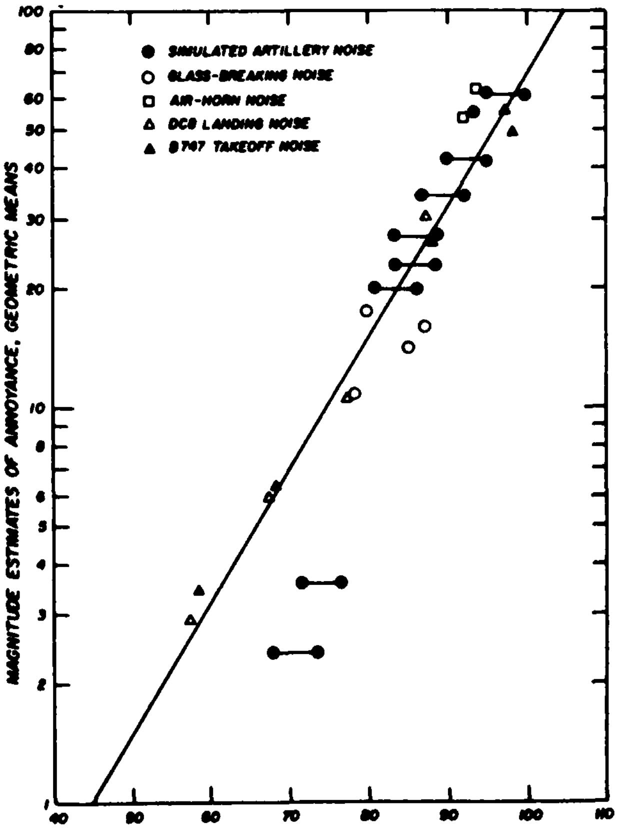

FIG. 1. Relationship between psychological annoyance and physical stimuli values. All stimuli are *A*-weighted SEL's (indoors) except the artillery noise which is *C*-weighted and corrected as explained in the text to account for the reduced building attenuation to low-frequency impulsive noises as compared with the building attenuation to aircraft or airhorn spectra. The solid line is a least-square fit to the nonartillery noises.

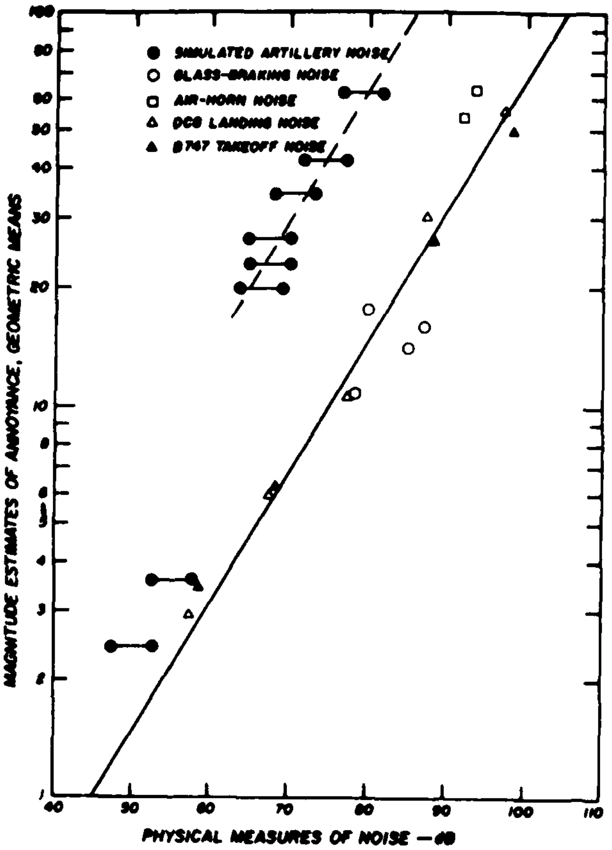

FIG. 2. Relationship between psychological annoyance and physical stimuli values. All stimuli are A-weighted SEL's (indoors) except the artillery noise which is A-weighted and corrected as explained in the text to account for the reduced building attenuation to low frequency impulsive noises as compared with the building attenuation to aircraft or airhorn spectra. The solid line is a least squares fit to the nonartillery noises and the dashed line is approximately fit to the six larger blast noises but constrained to be parallel to the solid line.

by the Construction Engineering Research Laboratory indicate that typical building attenuation for large amplitude impulsive noises is on the order of 5–8 dB[12] and recent measurements by Kamperman give a 4-dB attenuation figure for quarry blasts.[3] Thus, to properly test the equivalence of the outdoor criteria by comparing the indoor A-weighted aircraft, breaking glass and air horn sounds to the indoor C-weighted impulse, it is first necessary to add 5–10 dB to the C-weighted indoor impulsive noise SEL's.

Figure 1 compares "outdoor" A-weighted SEL's for the aircraft, the glass breaking and the air horn to the range of C-weighted SEL's for the blast sounds. As explained above, 5 to 10 dB are added to these blast sound SEL's in order to correctly perform this "outdoor" comparison. The line on the figure is a least squares fit to the A-weighted data.

By way of comparison, Fig. 2 presents the same A-weighted aircraft, glass breaking and air horn sounds along with the A-weighted blast data corrected by 5 to 10 dB. As can be seen, a line fit to six larger blast noise sounds is displaced 15–20 dB from the line fit to the other A-weighted sounds.

IV. CONCLUSIONS

Figure 1 implies a close comparison between the A-weighted L_{dn} measure used out-of-doors for typical sounds and the C-weighted impulse criteria applied out-of-doors. It is also evident from Fig. 1 that when the C-weighted SEL for an impulse is less than about 85 dB, the impulse curve begins to drop below the A-weighted curve and, thus, should not be used. (The EPA procedure cuts off at a C-weighted SEL of 85 dB.) Thus, it is felt that these data offer a very good verification for the EPA's interim C-weighted impulsive noise measure.

In contrast, Fig. 2 shows that A-weighting greatly underestimates blast noise annoyance in the absence of a large correction factor.

APPENDIX: EVALUATION OF LARGE AMPLITUDE IMPULSES[13]

A. Large amplitude impulses

A large-amplitude impulse is an event in which the C-weighted sound exposure level, CSEL, is greater than 85 dB in daytime and 75 dB at night. Also, the maximum C-weighted Sound Exposure Level resulting from the event in a single 2-s time period shall be 10 dB greater than the C-weighted Sound Exposure Level resulting from any other 2-s period of the event.

Note: An approximate evaluation of the threshold requirements acceptable for this procedure may be made with a standard sound-level meter, meeting the Type I characteristics of ANSI S1.2-1971, employing C-weighting and "slow" meter characteristic. In order for the impulse to be considered in this procedure it should produce a maximum meter reading in excess of 82 dB in daytime and 72 dB at night.

B. C-weighted sound exposure level—CSEL

The mathematical description of C-weighted sound exposure level in decibels is

$$\mathrm{CSEL} = 10\log\left[\frac{1}{t_0}\int_{-\infty}^{\infty}\frac{p_c^2}{p_0^2}\,dt\right] , \qquad (1)$$

where $t_0 = 1$ s, p_c = C-weighted sound pressure, and $p_0 = 20\ \mu\mathrm{Pa}$.

Note: In practice the integral is often approximated by integration within the time during which the sound level of the event exceeds a threshold value such as 20 dB less than the maximum sound pressure level.

C. C-weighted day–night average sound level · L_{Cdn}

Analogous to the A-weighted DNL, L_{dn}, with a nighttime penalty of 10 dB the C-weighted day–night average sound level is

$$L_{Cdn} = 10\log(1/T_0)\left[15\times 10^{L_{Cd}/10} + 9\times 10^{(L_{Cn}+10)/10}\right] , \qquad (2)$$

where T_0 is 24 hours, L_{Cd} is the average C-weighted sound level over the daytime period of 0700 to 2200 h, L_{Cn} is the C-weighted average level over the nighttime period of 2200 to 0700 h.

Note. The C-weighted average level is most easily calculated from the C-weighted sound exposure levels during the time of interest as follows:

$$L_{Cd} = 10 \log \frac{1}{15 \times 3600} \left[\sum_{i}^{n} 10^{L_{CEi}/10} \right] , \qquad (3)$$

$$L_{Cn} = 10 \log \frac{1}{9 \times 3600} \left[\sum_{i}^{n} 10^{L_{CEi}/10} \right] , \qquad (4)$$

where L_{CEi} is the C-weighted sound exposure level of the ith discrete event.

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[1] Letter from Mr. C. L. Elkins, Environmental Protection Agency, to Mr. P. J. Fliakas, Assistant Secretary of Defense, dated 29 March 1976.

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[7] P. N. Borsky, "Community Reactions to Sonic Booms in the Oklahoma City Area," National Opinion Center, AMRL-TR-65-37 (1965).

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[10] J. R. Young, "Measurement of the Psychological Annoyance of Simulated Explosion Sequences" (Second Year). Stanford Research Institute (February 1976).

[11] J. R. Young, "Measurement of the Psychological Annoyance of Simulated Explosion Sequences" (First Year). Stanford Research Institute (January 1975).

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[13] "Guidelines for Preparing Environmental Impact Statements on Noise," Report of CHABA Working Group No. 69 (February 1977).

Paper 2

Human response to house vibrations caused by sonic booms or air blasts

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Descriptions of the effects of sonic booms or air blasts by observers in buildings have included such statements as "noticeable vibrations" in addition to phrases such as "the house rattles," "the windows rattle," or "bric-à-brac rattles." Analysis of studies of human response to vibrations, vibration complaints in the Toronto area, special tests by Kryter at Edwards Air Force Base, and laboratory studies of human response to sonic booms show that perceived vibration is not normally a factor that contributes significantly to human response to airborne, large-amplitude impulse noise. Rather, human response is solely the result of the impulse noise itself and of audible noise due to induced radiation from vibrating surfaces.

PACS numbers: 43.50.Qp, 43.50.Jh, 43.28.Mw

INTRODUCTION

Large-amplitude impulsive sounds, such as those produced by sonic booms, quarry blasts, or artillery fire, are currently a subject of study.[1,2] These sounds may excite vibration in buildings and other structures and these induced vibrations may generate additional annoyance to people, beyond that due to the audibility of the impulse, because of house rattling, windows rattling and bric-à-brac rattling.[2]

The purpose of this letter is to show that direct perception of vibration is not normally a factor when dealing with human response to airborne, large-amplitude, impulse noise. Rather, people respond only to the impulse noise itself and to the secondary noise radiated by vibrating surfaces.

Four sets of data were examined to assist with the study of the above questions concerning the role of vibration in human response to impulse noise. The sets of data include studies on human sensitivity to vibration such as the work by Reiher and Meister,[3] Wright and Green,[4] or by Wiss and Parmelee,[5] studies of complaints dealing with vibration in the Toronto Area,[6] the studies by Kryter at Edwards Air Force Base,[7] and the general studies on human response to sonic boom by Broadbent and Robinson,[8] Johnson and Robinson,[9] Pearsons and Kryter,[10] and Kryter and Lukas.[11]

DISCUSSION

In Wiss and Parmelee's study of human response to transient vibration, participants were subjected to vertical floor vibrations having a time history as pictured in Fig. 1. They used frequencies ranging from 2.5 Hz to 16% of critical. Depending on damping the stimulus duration ranged from about 0.3 to 5 s. Figure 2 summarizes their results for "barely," "distinctly," and "strongly perceptible" as a function of damping. (The logarithmic standard deviation of their data approximately equalled the spacing between groupings.) From these data, one can infer that peak velocities below about 1.5 mm/s are "barely perceptible" and that peak velocities between 1.5 and 9 mm/s are "distinctly perceptible."

The data of Reiher and Meister[3] and others for barely

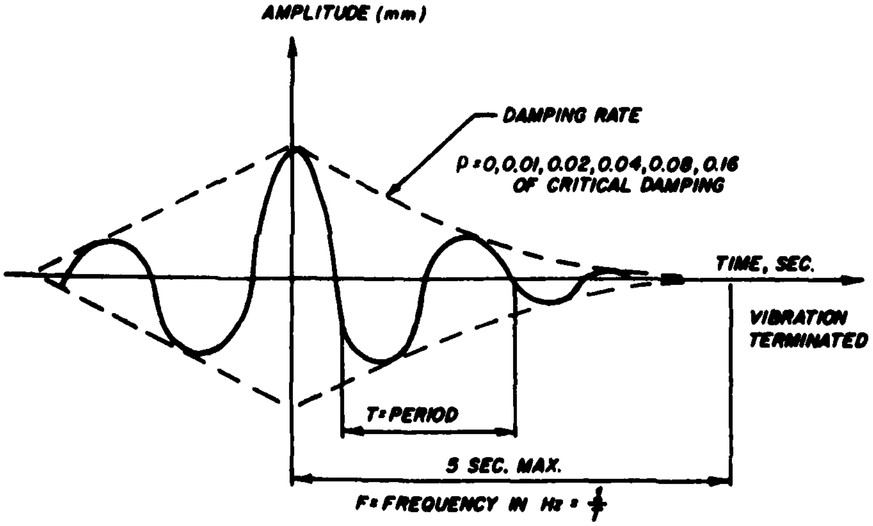

FIG. 1. Typical wave form of the vertical floor vibrations used as a test stimulus.

perceptible vibration are in general agreement with the above results by Wiss and Parmelee even though these earlier tests considered continuous vibration. For continuous vibrations, the literature data show that slightly weaker vibrations result in the same respective response description, as compared to the Wiss and Parmelee findings.

By way of further comparison, CHABA Working Group 69 recommends,[13] based in part upon the work of ISO/TC 108/SC 4,[14] that peak impulsive shock acceleration be below 0.1 m/s^2 (one event per day) in order that there be less than 1% complaints. Because of the frequency weighting used to measure the acceleration, the CHABA recommendation translates approximately into a constant maximum velocity limit of 3 mm/s for frequencies above 5.6 Hz.

Taylor[6] reports on "vibration" complaints and annoyance in the Toronto area. In one set of investigations the complaints and annoyance dealt with "vibration" from subways. The measured velocities were about 0.5 mm/s, certainly no more than just barely perceptible if at all. At the same time the increase in the *C*-weighted sound level in the adjacent homes was about 12 dB. This noise level increase resulted from vibrations of the home.

In a second set of investigations, Taylor investigated several noise-vibration problems resulting from impact machinery where the energy was transmitted via the ground. The result, however, was low-frequency, airborne sound within the residence. Invariably the complaint referred to vibration, although Taylor found the measured vibrations to be in the region of or well below the threshold of perception. The airborne sound produced by small movements in the floors and walls of the structure caused relatively high sound levels as well as excited secondary noise from windows and bric-à-brac.

In one recorded case, the impulse sound levels in the house were 79, 67, 52, and 44 dB, respectively, in the 31, 63, 125, and 250 Hz octave bands. The impact machinery was inaudible outside the house. In a second case the noise levels were a few decibels lower than in the case above and the floor vibration velocity was 0.25 mm/s. In both cases the inhabitants were disturbed and referred to the "vibrations."

At Edwards Air Force Base, Kryter[7] subjected test participants to sonic booms and sub-sonic aircraft overflights. The test subjects were located both indoors and out-of-doors. As a part of these tests, for one series of 16 missions, about half the subjects in the houses and about half the subjects outdoors sat on chairs placed on a piece of plywood that was isolated from the ground or the floor by an air-inflated pad. Each subject sat on a vibration isolated chair during half the tests, and on a normal nonvibration isolated chair during the other half.

No statistically significant difference was found in the responses for subjects with or without vibration isolation, either indoors or outdoors. Kryter states, "This finding is perhaps somewhat unexpected because in many locations within the house the subjects and the experimenters could 'feel' the floor shake when the house was subjected to sonic boom; at the same time, however, they could hear the sounds made in the house as the results of its being vibrated by the boom. It would appear that the auditory component was nearly as or perhaps slightly more effective than the actual vibrations as felt by the subjects in determining their response to sonic booms and the noise from the subsonic aircraft."

During the tests at Edwards AFB, measurements were made of wall displacement and acceleration. These measurements indicated peak wall velocities on the order of 2.5–25 mm/s. No measurements were made of floor vibrations. Clearly the wall vibrations were of sufficient magnitude to radiate substantial acoustical energy.

The fourth set of data to be considered concerns laboratory studies of human response to real or simulated sonic booms. These studies include the early chamber tests by Broadbent and Robinson[8] and by Pearsons and Kryter,[10] the indoor/outdoor field tests by Johnson and Robinson[9] and by Kryter,[7] and the later chamber tests by Kryter and Lukas.[11]

In the early chamber tests, Broadbent and Robinson constructed a test room and used lousdpeakers to provide simulated "indoor" sonic booms and "indoor" normal aircraft flyovers to a group of test subjects for comparison purposes. Broadbent and Robinson state that their chamber was lacking in low-frequency response. In a similar test, Pearsons and Kryter built a chamber, again using loudspeakers but with somewhat better low-frequency response. Later, Kryter built a new chamber driven through a plenum by a mechanical piston which was capable of achieving excellent low-frequency response and inducing substantial vibrations in the walls of the test room. In the field tests by Johnson and Robinson and by Kryter, test participants were located both indoors and outdoors and subjected to sonic booms and

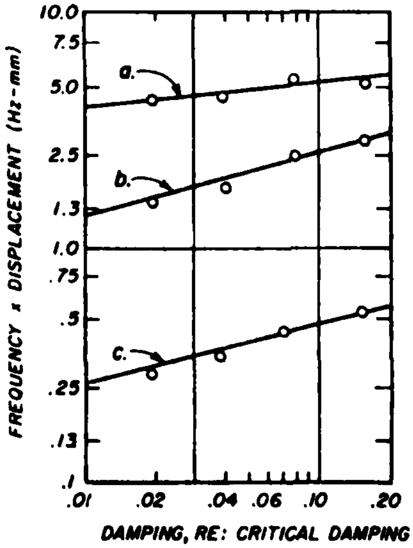

FIG. 2. Levels of transient vibration (Hz mm) found to be (a) "strongly," (b) "distinctly," or (c) "barely" perceptible as a function of the damping.

TABLE I. Equivalence between subsonic aircraft flyover noise and sonic booms: A history of findings.

Experimenter(s)	Boom over-pressure (dB *rc* 20 μPA)	Subsonic aircraft maximum PNL (dB *rc* 20 μPa)	Difference (dB)
Broadbent and Robinson[8]	133	110	23
Pearsons and Kryter[10]	135	113	22
Johnson and Robinson[9]	130	108[a]	22
Kryter–Edwards AFB[7]	132	109	23
Kryter–Chamber[12]	131[b]	109[c]	22

[a] Johnson and Robinson reported 103 dB outdoors, a 5 Phon difference between indoor and outdoor responses to booms, so 5 dB has been added to their outdoor value.

[b] Test stimulus with 3.5 ms rise time.

[c] Kryter measured 89 dB indoors; 20 dB has been added to allow for the outdoor-to-indoor reduction of a house.

subsonic aircraft flyovers. Johnson and Robinson also used explosives to simulate sonic booms. Because of the setup of these last two experiments, normal vibrations resulting from sonic booms were guaranteed to be present.

Table I summarizes the results from these five experiments. In each case the equivalency is given between peak sonic boom over pressure levels (dB), and the judged equivalent subsonic aircraft flyover sound expressed in terms of the maximum Perceived Noise Level (dB). It is important to note that although the early chamber tests by Broadbent and Robinson, and to some extent those by Pearson and Kryter, lacked low-frequency response, the recordings used to produce the simulated indoor sonic booms were made inside houses being overflown by sonic booms and thus presumably included the secondary noise radiations within the houses wherein the recordings were made.

From the close results between the tests which did and did not incorporate substantial low frequencies, it appears that only the acoustical stimulus dictates the human response. The correlation coefficient r between the peak boom over pressure levels and the subsonic aircraft maximum Perceived Noise Levels is 0.96.

CONCLUSIONS

The above independent tests and studies indicate that indoor human response to large-amplitude impulse noise, such as blasts or sonic boom, and to continuous low-frequency and low-amplitude vibration results from audible noise of the source and the noise radiated by vibrating surfaces (walls, windows, bric-a-brac) and not from direct human perception of vibrations.

[1] P. D. Schomer, Evaluation of C-weighted L_{dn} for Assessment of Impulse Noise," J. Acoust. Soc. Am. 62, 396–400 (1977).

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[3] H. Reicher and F. J. Meister, "The Effect of Vibration on People," Translation from German, Rep. No. F-TS-616-RE, HQ Air Material Command, Wright Field, OH (1946).

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[13] "Guide for the Evaluation of Human Exposure to Whole-body Vibration," ISO 2631-1974 (E), International Organization for Standardization, and Addendum 2, "Vibration and Shock Limits for Occupants in Buildings."

Paper 3

Growth function for human response to large-amplitude impulse noise

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The U. S. Environmental Protection Agency has proposed the use of *C*-weighted day/night level for the assessment of impulse noise such as the noise resulting from sonic boom, blast noise (artillery, armor, demolition, etc.) and other large-amplitude impulse sources. One remaining question pertaining to the use of *C*-weighting has been the growth function for human response to impulse noise. This question arises because work by Kryter and by Young using peak values and/or small amplitudes exhibited growth functions of 6–7dB for a doubling of annoyance, while the growth function for human response to common sources (planes, vehicles, etc.) increases by about 10 dB for a doubling of annoyance. Kyter's and Young's data are reanalyzed herein by using *C*-weighting and by including only large-amplitude data. This reanalysis results in a growth function for human response to impulse noise which increases by about 10 dB for a doubling of annoyance. This equality of growth function between common *A*-weighted noise and *C*-weighted impulse noise further supports the use of *C*-weighted day/night level for assessment of sonic boom, blast noise, or other large-amplitude impulse noises having similar spectral content.

PACS numbers: 43.50.Ba, 43.50.Qp, 43.28.Mw

INTRODUCTION

The U. S. Environmental Protection Agency has proposed an iterim impulse noise measure to be used in addition to the day/night average *A*-weighted sound level (DNL) which has previously been specified as the primary descriptor for environmental noise on the basis of the perception by people and audible sound.[1] Basically, this new measure yields a *C*-weighted DNL for the totality of single-event, large-amplitude impulsive noises throughout the day. Large amplitude is defined to mean events having a *C*-weighted sound exposure level [SEL, defined in Eq. (1)] in excess of 85 dB (*re* 400 ρPa^2-s) during daytime hours (7a.m.–10 p.m.), and a *C*-weighted SEL in excess of 75 dB during nighttime hours (10 p.m.–7 a.m.).

Large amplitude impulsive sounds, such as those produced by sonic booms, quary blasts, or artillery fire can excite noticeable vibration of buildings and other structures.[2,3] These large-amplitude, structure-shaking sources are contrasted with small size (small SEL) impulsive sources such as rifle fire, toy "cap" pistols, etc. The induced vibration in buildings generate additional annoyance beyond that due to audibility of the impulse because of "house rattling" and "startle."[4,5]

In the past, it has been general practice to describe large-amplitude impulsive sounds in terms of the peak sound pressure in a wide-frequency band. Peak pressure may be satisfactory for description of impulses having a restricted range of peak pressures and durations. It is not sufficient as a general description for use in measurement or prediction of the combined environmental effects of impulses having substantially different pressure-versus-time characteristics, since the energy coupled into a structure is dependent on the spectral content of the impulse. Moreover, use of peak pressure can be unwieldy when a succession of impulses, sometimes overlapping, must be evaluated.

The *C*-weighted SEL was chosen as a suitable descriptor because it provides the basis of a procedure that relates to the sound-induced vibrations in buildings. Criteria were established by equating the percent of population highly annoyed to more commonly experienced noises (primarily aircraft and traffic noise survey data) at various *A*-weighted DNLs.[6] For example, the *C*-weighted DNL for a population consisting of 30% "highly annoyed" to booms was equated to the *A*-weighted DNL for another population consisting of 30% "highly annoyed" to commonly experienced noises. The Edwards Air Force Base[5] and Oklahoma City[7] studies, which both dealt with sonic booms, were the primary bases for this procedure for large impulsive sounds.

In the Oklahoma City study, the population was questioned if they were annoyed, and if so, if they were "very annoyed," "moderately annoyed," or "little annoyed." The percent very annoyed was chosen as best matching the "highly annoyed" described in the EPA levels document.[8] Analysis of the data showed that approximately the same percentage of the population was highly annoyed when the *C*-weighted DNL in an impulse noise environment equalled the *A*-weighted DNL in another more common environment.

One unanswered question is the growth function for human response to impulse noise. Many studies have shown that for everyday noises such as aircraft or road traffic, subjective judgments of loudness or annoyance double for each 10-dB increase in the noise level. Young[9] found a steeper slope when analyzing simulated artillery sounds, about 7 dB corresponded to a doubling of annoyance. Young's data were presented in terms of *C*-weighted sound exposure levels. Earlier Kryter had analyzed the data taken on sonic booms at Edwards Air Force Base in terms of peak amplitudes. He found that about a 7-dB change in peak amplitude was equivalent to a 10-dB change in effective perceived noise level (EPNL) for the flyover of a control aircraft.

I. PURPOSE

The purpose of this paper is to reexamine the growth function data in Young's paper and in Kryter's report by translating the data into *C*-weighted SELs and by excluding data below an 85-dB SEL cutoff. During the process of reexamination it is shown that use of *C*-weighted SEL is otherwise consistent with the analysis and results obtained originally by Kryter and at times complements and augments his analysis.

II. THE YOUNG DATA

The psychological annoyance of simulated artillery firing sequences were studied at the Stanford Research Institute. In this study, a special testing room, originally designed for human response to sonic boom research, was modified to create artillery type sounds. In a quasirandom sequence, subjects judged the annoyance of various artillery-type sounds (different amplitudes, durations, etc.) in relation to recorded aircraft flyover sounds and other sounds. Subjects used magnitude estimation procedures to assign annoyance values to the various noise stimuli presented. One of the aircraft flyover sounds was the reference value and was assigned a magnitude of 10. Table I summarizes the *A*-weighted data for the aircraft and the *C*-weighted data for the simulated artillery. The terms used in this table are defined as follows: *A*SEL and *C*SEL are the sound exposure levels calculated from *A*- or *C*-weighted sound pressures, respectively.

Sound exposure levels are computed as

$$\mathrm{SEL} = 10 \log(1/p_0^2 t_0) \int_0^T p^2(t)\, dt \, , \qquad (1)$$

where $p(t)$ is a time-varying sound pressure weighted by a prescribed weighting, such as *A* or *C*. p_0 is the reference pressure of 20 μPa, and $t_0 = 1$ s.

TABLE I. Summary of physical and psychological data for stimuli used in the psychoacoustic experiment.

	Physical measures[a]		Mean magnitude estimates of annoyance	
Noises	*A*SEL	*C*SEL	$\overline{MEg}$	$\log_{10}\overline{MEg}$
Blasts		78.00	2.4	0.38
		81.50	3.6	0.56
		93.75	22.8	1.36
		93.50	26.7	1.43
		90.75	20.0	1.30
		96.75	34.4	1.54
		99.75	41.9	1.62
		104.75	62.6	1.80
747 (take off)	58.25		3.4	0.53
	68.25		6.2	0.79
	78.25		10.0[b]	1.00
	88.25		26.2	1.42
	98.25		49.1	1.69
DC-8 (landing)	57.25		2.9	0.46
	67.25		5.9	0.77
	77.25		11.0	1.04
	87.25		29.9	1.48
	97.25		55.5	1.74

[a] Physical data values are rounded to nearest ¼ dB.

[b] Reference noise with assigned annoyance value of 10.

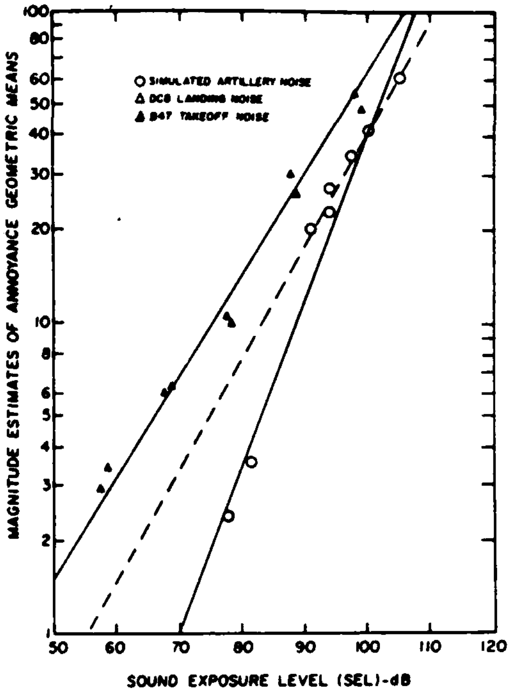

FIG. 1. Plotted on this figure are the indoor *A*-weighted SELs for aircraft sounds and the *C*-weighted SELs for simulated artillery sounds. Regression lines are fitted to the aircraft sounds (solid line), to the artillery sounds (solid line), and to the artillery sounds with SEL data below 85 dB excluded (dashed line). Elimination of the SEL blast data that is less than 85 dB results in a growth function rate which is very close to the growth function rate found for the aircraft sounds. The lateral shift between the *A*- and *C*-weighted data is explained in Ref. 10.

Figure 1 is a plot of the data in Table I. The solid lines are linear curves fitted to the *A*-weighted aircraft data and *C*-weighted blast data, respectively. The dashed line is a linear regression curve fitted to the *C*-weighted data with SELs in excess of 85 dB. The *C*-weighted (dashed line) and *A*-weighted slopes are 8.4 and 9.7 dB, respectively, for doubling of annoyance and the correlation coefficients r are 0.988 and 0.993, respectively. Thus for this experiment, the growth rate for impulse noise evaluated using *C*-weighting compares favorably with the growth rate found for the aircraft noise using *A*-weighting. Moreover, Fig. 1 illustrates that it is the lower level *C*-weighted data (below 85-dB CSEL) that causes the regression line slope (solid line) to be as shallow as it is.

III. THE KRYTER DATA

In these sonic boom tests a total of approximately 300 subjects were located outdoors at Edwards Air Force Base and in houses which were specially constructed to be representative of typical midwestern U. S. houses for the 1970's. The subjects were exposed to the noise of pairs of sonic booms, pairs consisting of one sonic

TABLE II. Estimated C-weighted SEL vs nominal peak overpressure in decibels and other data.

		Measurements		
Aircraft	Nominal ΔP (dB)	ΔP (dB)	20–1000-Hz (SEL)	Estimated CSEL
XB-70	135.6	136.0	111.7	110.0
XB-70	133.9	134.2	108.7	106.9
XB-70	130.3	130.2	104.6	103.5
F-104	136.5	137.8	116.4	113.9
F-104	132.1	134.8	111.0	108.9
F-104	130.5	130.5	107.2	105.3
F-104	125.1	126.8	101.8	99.7
B-58	135.6	135.6	110.9	108.8
B-58	134.9	136.0	110.7	108.6
B-58	133.9	134.3	109.6	107.6
B-58	132.1	132.4	106.5	104.7

boom and one subsonic aircraft flyover, and pairs of subsonic aircraft flyovers. The subjects judged the relative acceptability of the sounds in each pair and also rated each sound on a numerical scale from very acceptable to unacceptable.

In Kryter's analysis both nominal boom overpressures and median measured boom overpressures were used. The nominal overpressure is the pressure predicted from the aircraft type, speed, and altitude while the median measured pressure results, as the name implies, from a set of measured data. While these are generally close to one another, the analysis that follows considers both but concentrates on the nominal data which were found by Kryter to be more consistent and regular.

Kryter presented curves relating peak boom overpressure to equivalent maximum Perceived Noise Level PNL for a subsonic flyover. These curves (Fig. 10 of Ref. 5) clearly show that a doubling of overpressure (6 dB) was judged equivalent to an increase of 10 dB or so in the maximum PNL of a subsonic aircraft flyover. Because of this type of apparent disparity in growth functions, an impulse correction function was hypothesized by Kryter.[11] In the reanalysis of the data which follows, the peak boom overpressure data are converted, approximately, to C-weighted SELs. Also, the EPNL of the aircraft flyovers is used in place of the peak PNL because the integrated measures have subsequently been found to be usually a better predictor of response[12] and because they are more similar to the EPA's current use of A-weighted SEL.[13]

To convert the boom data from peak SPLs to C-weighted SELs requires spectral information on the booms. The only spectral data published are in Ref. 5. Table 13 of Ref. 5 contains the mean and standard deviation for the measured peak and the SEL in various bands as shown. Missions with the same nominal peak overpressure are grouped together.

One can estimate the C-weighted SEL by considering the likely SEL in various bands, weighted appropriately. The bands used are 0-10, 10–20, 20–30, and 30–1000 Hz. The detailed estimation of C-weighted SEL data is presented in Appendix A.

Table II gives the estimated C-weighted sound exposure level for the sonic boom spectral data given in Ref. 5. For convenience Table II also includes the nominal peak overpressure in decibels, the average peak overpressure in decibels, and the 20–1000-Hz SEL. Figure 2 presents the nominal and average peak overpressure levels as functions of C-weighted SEL. The solid curves on the figures are regression lines fit to the B58/XB70 data and the F-104 data, and the dashed lines are regression lines fit to all the aircraft data together.

In Fig. 2 the shift between aircraft types, especially at higher peak overpressures, results from the small fighter aircraft creating a shorter boom and thus having relatively higher spectral components. Moreover the smaller aircraft (the F-104) must fly at a lower altitude (or at a much higher speed) to produce the same overpressure as the larger aircraft. For this reason the rise time will be faster for the small aircraft than it will for the larger aircraft when both produce the same nominal peak overpressure.

Table III gives the slope and standard error of estimate of the slope for the correlation coefficient regression lines shown in Fig. 2 and for similar lines calculated for the 20–1000-Hz SEL data. From the regression line slopes it is clear that the estimated C-weighted SEL and the 20–1000-Hz SEL grow at rates of about 12–13 dB for each 10-dB increase in peak overpressure, which is about the rate hypothesized by Kryter as the impulse correction factor when he compared maximum PNLs for subsonic flyovers to peak boom levels. Thus, the growth rate of C-weighted SEL for booms equals the growth rate of maximum PNL for subsonic aircraft flyovers.

As an additional test of the growth function, data are abstracted from Table III of Kryter's report. Again, these data are for subjective responses indoors. This table lists the integrated perceived noise level, E_{15}PNL, and the tone-corrected E_{15}PNL$_t$ for the subsonic aircraft noise which were found equal in annoyance to the sonic booms for the three F-104 groupings. (E_{15}PNL designates the integration of the PNL by ½-s steps over a 15-s period.)

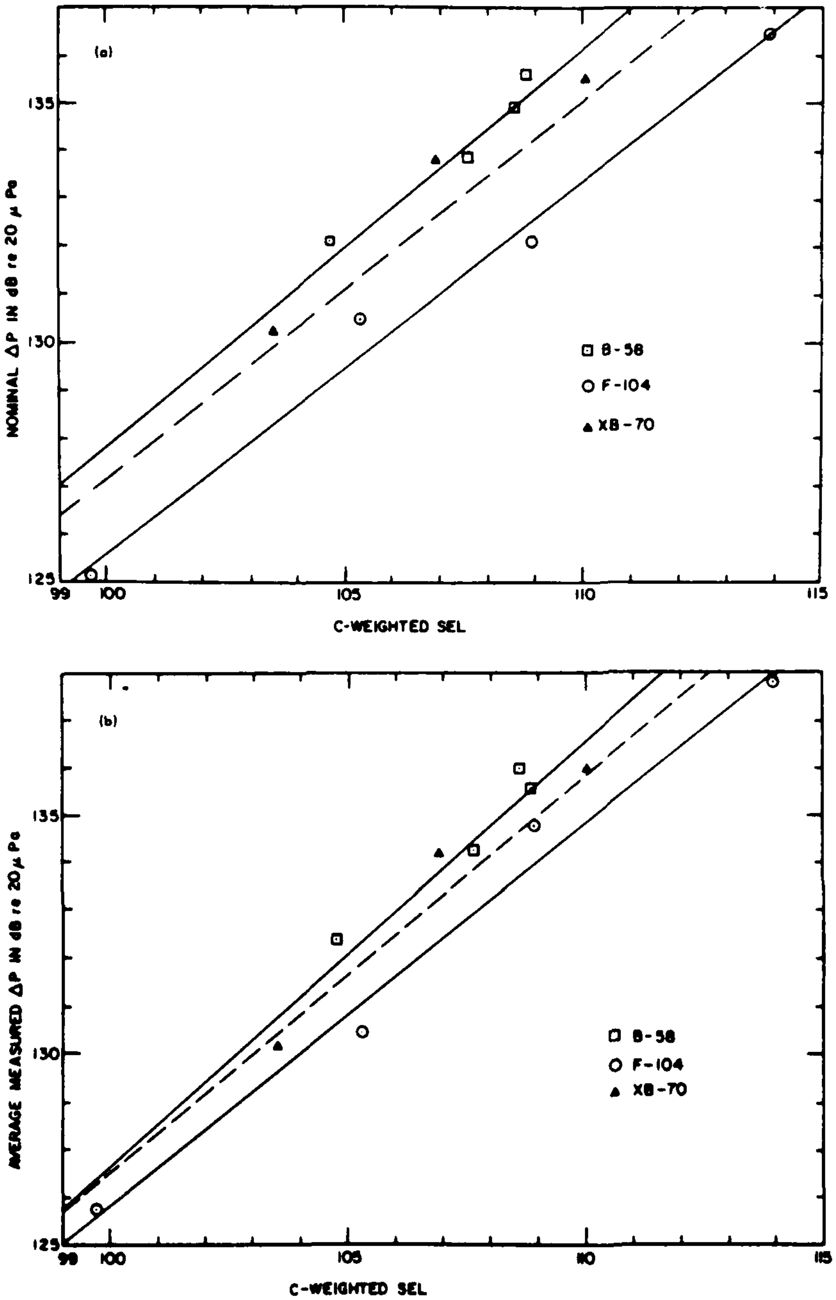

FIG. 2. This figure shows the nominal and measured peak levels for sonic booms as functions of the *C*-weighted SEL for these same booms. The solid curves are regression lines fitted to the large aircraft (B-58/XB-70) and to the small aircraft (F-104), and the dashed curve is a regression line fit to the combined data. The slope of about 0.8 completely accounts for the impulse correction hypothesized by Kryter. Thus, such a correction is not required when using *C*-weighted SEL to measure these types of impulses.

Figure 3 presents a plot of these data. Here regression lines have been fitted to the estimated *C*-weighted CSEL as a function of the aircraft E_{15}PNL and E_{15}PNL$_t$ data. The slope of the solid regression lines are 0.99 and 1.02, respectively, with standard errors of 0.10 and 0.07. The dashed line is fitted to the two sets of data. From this figure and the overall regression slope of 1.00 it is further demonstrated that the subjective response to the sonic booms when measured using *C*-weighted SEL is growing at virtually the same rate as the human response to the subsonic aircraft flyover noise when using EPNL or tone-corrected EPNL. (The 20–1000-Hz (or 20–200-Hz) SEL data grow at virtually the same rate as the CSEL data and are not included here for the sake of brevity).

Table 14 of Ref. 5 gives the rank correlations between the median subject ratings and the various outdoor measures for these indoor subject judgments. (It is the indoor judgments which are of most interest since people spend most of their at home time indoors and since it is the vibration of buildings which are a problem when dealing with high-amplitude impulse noise.) The best correlations are with the 20–1000-Hz SEL or with the

TABLE III. Data on the regression lines in Fig. 2 and for similar 20–1000-Hz SEL data.

Curve	Slope	Standard error of the slope	Correlation coefficient (r^2)
C-weighted SEL, measured ΔP, all aircraft	0.83	0.08	0.92
C-weighted SEL, measured ΔP, F-104	0.80	0.07	0.98
C-weighted SEL, measured ΔP, B-58/XB-70	0.89	0.10	0.94
C-weighted SEL, nominal ΔP, all aircraft	0.80	0.07	0.83
C-weighted SEL, nominal ΔP, F-104	0.78	0.10	0.99
C-weighted SEL, nominal ΔP, B-58/XB-70	0.82	0.17	0.96
20–1000-Hz SEL, measured ΔP, all aircraft	0.78	0.07	0.91
20–1000-Hz SEL, measured ΔP, F-104	0.78	0.09	0.98
20–1000-Hz SEL, measured ΔP, B-58/XB-70	0.82	0.15	0.96
20–1000-Hz SEL, nominal ΔP, all aircraft	0.75	0.13	0.80
20–1000-Hz SEL, nominal ΔP, F-104	0.76	0.07	0.98
20–1000-Hz SEL, nominal ΔP, B-58/XB-70	0.76	0.05	0.98

20–200-Hz SEL. (These data closely approximate *C*-weighted data because *C*-weighting cuts off at 20 Hz and because the boom has little energy above 200 Hz.)

One other observation can be made about the data. Figure 2 seems to indicate that at relatively high peak overpressures, the F-104 boom will be a few decibels more annoying than the larger aircraft booms and that annoyance tends to become equal at lower peak overpressures. Examination of Fig. 10 of Ref. 5 indicates exactly this relationship. At large peak overpressures, the F-104 lies three or four decibels above the other aircraft whereas at lower overpressure levels the results for all three aircraft tend to merge together.

IV. CONCLUSIONS

In these experiments the growth function for human response to impulsive noise (simulated artillery or sonic boom) was virtually equal to the growth function for human response to aircraft noise when *C*-weighted SEL (or its close approximation, 20–1000-Hz SEL) is used to describe the impulse, when impulses with CSELs below 85 dB are excluded and when a suitable integrating measure, such as *E*PNL$_t$ or *A*-weighted SEL, is used to describe the control aircraft noise.

Moreover, since the best correlations, and normally very high correlations, between physical measures of the sonic boom and subjective response were obtained using 20–200-Hz SEL and 20–1000-Hz SEL data, it is reasonable to use something like *C*-weighted SEL or 20–1000-Hz SEL as a predictor of human response to this type of noise.

It must be emphasized that most of the energy in sonic booms or blasts is below 50 Hz, and that house vibrations occur primarily in the 10–30-Hz range; thus the above result should not be applied to sources having spectral characteristics which are vastly different from sonic booms or blasts.

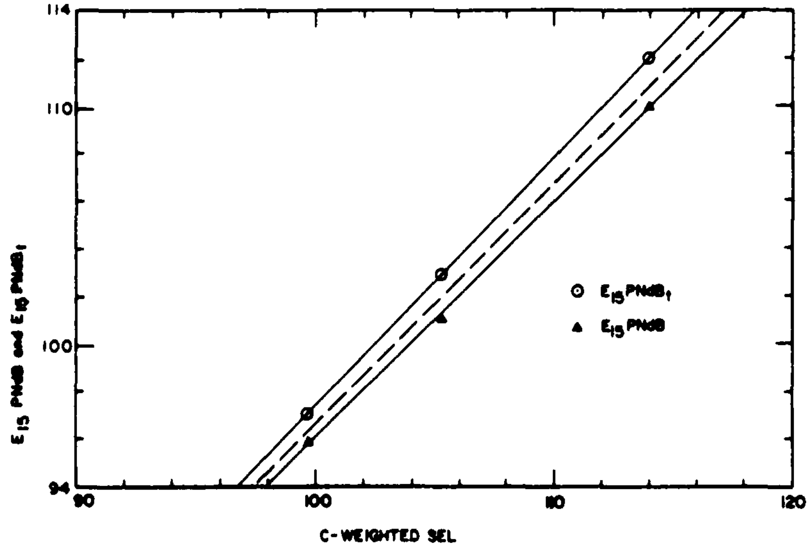

FIG. 3. This figure shows aircraft flyover EPNL data versus judged equivalent *C*-weighted SEL sonic boom data. The solid curves are regression lines fit to the regular and the tone-corrected EPNL data, and the dashed curve is a regression line fitted to the combined data. The slope of 1.0 for the combined data indicated identical growth functions for aircraft assessed using EPNL and for sonic booms assessed using *C*-weighted SEL.

APPENDIX A: CALCULATION OF ESTIMATED C-WEIGHTED SOUND EXPOSURE LEVELS

C-weighted SEL can be estimated from the data in Table II. To do so two sets of estimates are required, one for the *C*-weighted corrections in large frequency bands, and the other for the energy content in these bands. For the estimations that follow the energy is divided into the 0–10-Hz band, the 10–20-Hz band, the 20–30-Hz band and the 30–1000-Hz band. The *C*-weighting is estimated to be −22, −11.3, −5.3, and −1 dB, respectively, for these bands.

The energy in the four bands is estimated using two extreme opposite sets of assumptions yielding two estimates for *C*-weighted SEL. The actual value used in the text is the average of these two extreme values. Generally these two extreme values are 3–4 dB apart. For both extremes the energy in the 0–10-Hz band is estimated to be the energy in the 0–50-Hz band minus the energy in the 10–30-Hz band. The energy above 30 Hz is considered inconsequential compared to the energy below 30 Hz.

For case 1 the energy in the 10–20-Hz band is estimated as the energy in the 10–30-Hz band minus the energy in the 20–200-Hz band. In contrast, for case 2, the energy in the 10–20-Hz band is estimated as the energy in the 10–30-Hz band without any subtraction.

The energy in the 20–30-Hz band for case 1 is estimated as the energy in the 10–30-Hz band minus the energy estimated under case 1 for the 10–20-Hz band. For case 2 the energy in the 20–30-Hz band is 0 since all the energy has been assumed to be in the 10–20-Hz band.

The energy in 30–1000-Hz band under case 1 is estimated as the energy in the 20–1000-Hz band minus the estimated value under case 1 for the energy in the 20-30-Hz band. Under case 2 the energy in the 30–1000-Hz band is given by the energy in the 20-1000-Hz band since 0 has been estimated for the energy in the 20–30-Hz band. The case 1 and case 2 data were averaged and this average estimated *C*-weighted SEL is used in Table II and Fig. 2.

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[12] W. J. Galloway and D. E. Bishop, "Noise Exposure Forecasts: Evolution, Evaluation, Extensions, and Land Use Interpretations," Federal Aviation Adminstration, FAA-NO-70-9 (August 1970).

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Paper 4

The Growth of Community Annoyance With Loudness and Frequency of Occurrence of Events*

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Representations of community response models have been constructed on the hypothesis that in a generalized sense, frequency of noise event occurrence multiplied by loudness of individual events is proportional to annoyance. Based on a community attitudinal survey conducted in the vicinity of a large army base, **Paul D. Schomer**† examines this hypothesis. Respondents "sort" themselves into categories based on their perception of loudness and frequency of occurrence. Since this survey portrays reactions to blast and helicopter noise in a like manner to all other noises such as airplanes, traffic and children, it is possible to compare and contrast the growth in annoyance for all of these sources. This analysis shows the growth in annoyance with frequency of occurrence to be equivalent across all sources; but the integration period for blast noises extends down to once every few months, *while for the other sources, it extends down to several events per month.* However, the growth of annoyance with loudness is not the same across sources. Blast noise, airplanes and helicopters fall into one category having a steeper annoyance growth rate; traffic and children fall into a second category having a shallower annoyance growth rate.

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Models to describe community reaction to noise have been the focus of study for at least the past quarter century.[1,2] Common to most of these models are three hypotheses:

- community response increases monitonically with sound amplitude
- community response increases monitonically with frequency of occurrence
- the community response to sound at night increases versus the same sound during daytime

The day-night average sound level, DNL, is a typical representation of these models.[3] It hypothesizes that the community reaction grows in direct proportion to the growth in sound exposure level (SEL), that the community reaction grows in proportion to 10 log of the number of events, and that a nighttime (2200 to 0700) penalty of 10 dB is appropriate. Indeed, recently Schultz has shown excellent agreement for survey data taken worldwide when the percentage of highly annoyed respondents in a given noise zone is analyzed.[4]

In most of the survey analyses, respondents are stratified by noise zone, and percentages of respondents within a noise zone are analyzed. Schultz, in his reanalysis of these analyses, defined respondents "highly annoyed." Typically, by his definition, respondents choosing the top 1-1/2 to 2 categories in a five-point scale were thus classified, with the 1/2-step range resulting from the specifics of the scale and wording employed. Based upon this type of analysis, Schultz has demonstrated a very clear function relating highly annoyed and the DNL noise zone.

This article takes an entirely new approach. Rather than categorize respondents on the basis of exterior noise zone strata, it categorizes respondents on the basis of their own perception of loudness and frequency of occurrence.

This analysis is based upon survey data gathered by the U.S. Army Construction Engineering Research Laboratory in the vicinity of a large Army base. The purpose of the overall survey was to examine community response to the impulse noise generated by such sources as artillery or tanks and helicopters as compared to more normal noise sources such as fixed wing aircraft, street traffic and children.

The analysis in this article forms one part of the analysis of this survey. Other portions of the analysis (to be published as separate papers) consider such topics as the community response by source as a function of noise zone (the traditional form of analysis), the nighttime penalty, and the type of activity disruption caused by the various sources. Taken as a group these articles will show by source type whether community response to a type of noise, such as impulse noise, can be described by a DNL type of model and, if so, what form the model should take. The purpose of this article is to deal with the first two hypotheses listed above; the growth of community response with amplitude and frequency of events.

Data Development

The survey instrument was typical of others previously used in the United States and other western countries. It was administered face to face, approved by OMB, and took typically 30 minutes to administer. The University of Illinois Survey Research Laboratory handled the details of survey administration and sampling. Using the C-weighted DNL measure of the National Academy of Science and EPA, noise contours were predicted by computer for the blast noise resulting from such activities as armor and artillery fire, and A-weighted DNL contours were predicted for some of the helicopter operations. These physical predictions of exterior noise zones are based upon approximately one year's operational data. A goal was set for the number of questionnaires to be completed in each of seven distinct noise zone strata; four blast noise strata, two helicopter noise strata and one control area. Random sampling of households within each strata was employed. The respondent was selected randomly from among those in the household over 18 years of age. Because of a small number of households within the highest of the blast noise zones, almost 100% of these households were sampled.

The study area was in the vicinity of a large Army base. Only small towns and one moderate-size city (200,000) are in the immediate area. The general noise climate has not changed for many years.

As stated in the introduction, this analysis classifies respondents by their own perception of loudness of the source and its frequency of occurrence, rather than classifying respondents by exterior noise zone. Hopefully, this approach eliminates the variability in results one gets within a noise zone caused by the differing exposures to individual respondents resulting from their different situations. Although the exterior noise zone in an area may be a constant, differing types of building construction, differing life styles (TVs and radios on or off), and differing window and room exposures with respect to rather localized noise sources (children, street traffic, and so on) all combine and result in a rather large uncertainty as to the actual exposure received by any individual respondent. Thus, one problem, which this approach eliminates, is the variability in results which occurs because of uncertainty as to the actual exposure received by respondents indoors.

A second reason for this rather unconventional approach to the analysis is that independent analysis of the first two hypotheses listed in the introduction is impossible in any given area using the more conventional analysis of respondents within given noise zone strata. In the conventional analysis, the exterior noise zones are predicted or measured based upon amplitudes of events and frequencies of occurrence, both of which are highly correlated together within any noise zone owing to the physical realities of the situation. It is the differing building constructions and building orientations which cause the variations in actual received loudness and frequencies of occurrence by

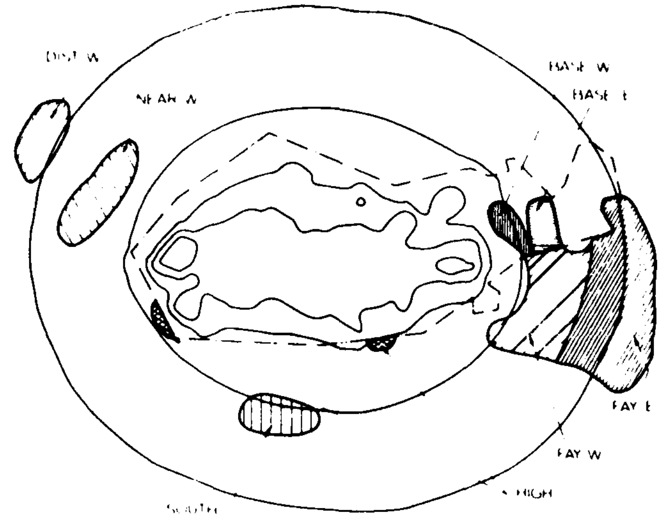

Figure 1—Predicted C-weighted DNL contours and predominant respondent groups in the study area—the respondent areas are indicated by cross-hatching

respondents indoors, and it is the differing styles which further vary respondents perceptions of these quantities. Since measurement of the received dose of each respondent to each source was well beyond the resources of this study, the next best means to study the hypothesis is to utilize the respondent's own perception of loudness and frequency of occurrence of events.

Naturally the reader will wonder how closely a respondent's answers correspond with the actual interior loudness and frequency of occurrence. Although proof that the respondents are "accurate noise monitors" is impossible without the very indoor measurements described above (which were beyond the scope of the resources of this study) the analysis below indicates that in general the respondents are differentiating between varying amplitudes and frequencies of occurrence.

As a part of the survey indicated above, respondents were asked the following question: "What are some of the different kinds of noises you hear around here?" Spontaneous answers were recorded. The respondents were also prompted with the following sources if they did not spontaneously indicate these: artillery, street traffic, airplanes, helicopters, children and dogs.

Next, the respondents were asked: "How loud is the noise from **(source)** compared to normal conversation?" They could respond: much more, more, about the same, less, much less, or **(don't know)**. The **(don't know)** was not a written choice and very few respondents chose it — less than 1%.

Next, respondents were asked, "How often do you hear **(source of noise)**?" They could respond: every day, several times a week, several times a month, once every few months, or less often than that. As above, they could also respond by **(don't know)** and again less than 1% responded in

TABLE 1
LOUDNESS JUDGMENTS
NOISE LEVELS COMPARED TO NORMAL CONVERSATION

Area	Much More	More	Same	Less	Much Less	Never Hear
HIGH	37.5	16.7	18.1	8.3	0	19.4
FAY W	14.9	15.5	12.6	13.8	1.7	40.2
FAY E	10.9	15.8	15.7	11.5	3.2	42.3
BASE W	17.1	25.4	12.2	11.2	3.4	30.7
BASE E	13.2	12.7	13.2	5.9	2.9	51.2
BASE TOTAL	15.1	19.0	12.7	8.5	3.2	41.0
SOUTH W	17.6	27.0	4.1	6.8	1.4	43.2
NEAR W	12.0	14.7	18.3	19.5	6.0	29.1
FAR W	0	7.1	4.8	26.2	4.8	57.1

this manner. If a respondent answered every day, he was asked how many times during the day.

In the next question, respondents were asked by source a series of questions which included: "Do you hear **(source of noise)** more often during a certain time of year?," "What season is that?," "Some days more than others?," and so on. Finally, in the last part of this question they were asked: "In general, taking everything into consideration, does the noise from **(source)** ever bother or annoy you?" The possible response was either yes or no. If yes, they were asked: "Overall, how annoyed are you by noise from **(source)**?" The possible responses were: extremely, very much, moderately and slightly. The "not at all" response, which is the fifth point in the five-point scale, was given by the "no" response to the yes/no filter question described above.

The analysis in this article makes use of these three questions which, in effect, ask the respondent: how loud the sound appears to them, how often they perceive it, and how annoyed they are overall. One immediately notes that these, plus the nighttime penalty, are the generalized ingredients in most noise models and indeed the DNL representation.

Before going into the general analysis, it is useful to examine the responses to the above questions by noise zone area. While the specifics of a noise model to describe impulse noise is the subject of another report which will follow this article, some of those data are useful in indicating that the responses to the questions dealing with frequency of occurrence and loudness of noise events generally correspond with prediction. Figure 1 indicates predicted noise zones resulting from impulse noise in the vicinity of the study base. Indicated on this figure are several discrete respondent geographic areas. These contours are in 5 dB increments; the absolute values are unimportant for purposes of this discussion. Tables 1 and 2 give the responses to these two questions by geographic area.

These tables show that respondent judgments of loudness and frequency of occurrence both decrease as one moves lower in noise zone and away from the base and that responses within a given zone are generally equivalent. Specifically, it is suggested that the reader compare the responses of Fay E to Fay W, Near W to Dist W, and

TABLE 2
FREQUENCY OF OCCURRENCE

Area	Every-day	Several Per Week	Several Per Month	Once Every Few Months	Less Often	Never Hear
HIGH	18.1	29.2	25.0	8.3	0	19.4
FAY W	5.2	14.9	21.8	14.4	2.3	40.2
FAY E	2.4	13.8	21.5	17.2	1.7	42.3
BASE W	9.8	25.9	23.9	8.8	1.0	30.7
BASE E	2.9	13.2	22.4	7.3	1.5	51.2
BASE TOTAL	6.3	19.5	23.2	8.0	1.2	41.0
SOUTH	8.1	21.6	17.6	8.1	0	43.2
NEAR W	2.0	13.1	27.9	24.7	1.6	29.1
FAR W	0	0	19.0	19.0	2.4	57.1

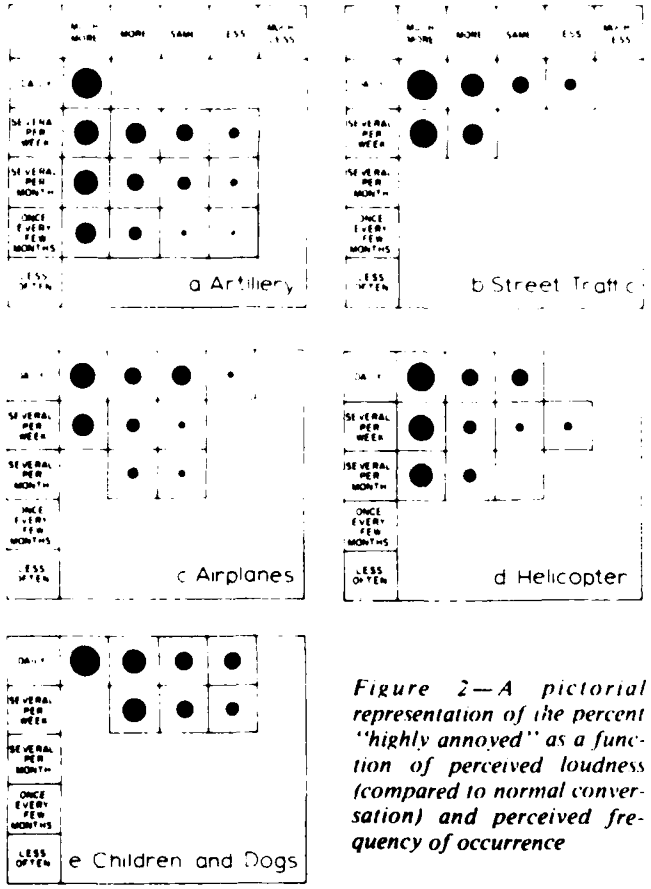

Figure 2—A pictorial representation of the percent "highly annoyed" as a function of perceived loudness (compared to normal conversation) and perceived frequency of occurrence

Base E to Base W. Finally, it is noted that responses in the Fay W area show no significant differences from the responses in the Base Total area when one takes into account that the Base Total area is in perhaps a 1 dB higher noise zone on average. This last comparison shows that different groups objectively report frequency of occurrence and loudness. A later report will show that these same groups (on and off-post) significantly differ on their levels of annoyance.

Appendix A presents the basic data used in this analysis. It contains one table, with five sections for each of the sources specifically considered — blast sources (artillery), helicopters, airplanes, street traffic, children and pets. Each section consists of 25 cells. The columns indicate the respondents' assessment of the loudness compared to normal conversation and range from much more to much less. The rows indicate the respondents' assessment of frequency of occurrence and range from everyday to less often than once every few months. Each cell contains four numbers which, in order, are: the number of respondents in that cell indicating the highest category of annoyance, the number of respondents in that cell indicating the second highest category of annoyance, the total number of respondents in that cell, and the percentage of respondents within the cell "highly annoyed" (the sum of the first two numbers divided by the third).

Figure 2 graphically illustrates the data in the appendix. This figure, divided into five parts based upon the types of noise sources enumerated above, is broken into the same cells based upon perception of loudness and frequency of occurrence, as are the data in the appendix. A solid circle with area proportional to the percent highly annoyed is placed in each cell. This figure graphically shows that the annoyance increases both with perceived amplitude and frequency of occurrence. This figure also shows that the community response to blast noise continues when events occur once every few months; whereas for the other sources, there is no meaningful community response at this low rate of occurrence. (In this figure, cells with less than 40 total respondents have been shown as blank since the actual percentages with these few numbers of respondents are considered highly unreliable. For example, the second column in the fifth row of section five shows one respondent out of a total of three as highly annoyed for a percentage of 33%. In Fig. 2, this cell is not shown because this percentage of 33 is not considered reliable.)

Discussion

In order to better examine the growth of percentage highly annoyed as a function of increases in frequency of occurrence, data were aggregated across all levels of loudness and across several of the sources. That is, within a source or across several sources, sums were calculated over all five loudness ranges yielding the number of respondents indicating extremely annoyed, very much annoyed, and the total number of respondents. These calculations were performed for artillery alone; for helicopters alone; for traffic, children, aircraft and helicopters together; and finally for helicopters, traffic and aircraft together. These groupings are chosen to contrast blast noise and helicopter noise with each other and "all other" noise sources; these data are contained in Table 3. Based on these data, Table 4 indicates the ratio of highly annoyed from one frequency of occurrence to the next (one row to the next) within each grouping (column in Table 3).

TABLE 3
AGGREGATED DATA OVER ALL LOUDNESS BY FREQUENCY OF OCCURRENCE (PERCENT HIGHLY ANNOYED-NUMBER IN PARENTHESES)

	Blast	Helicopter	Traffic Children and Aircraft	Helicopter Traffic Children and Aircraft	Helicopter Traffic and Aircraft
Daily	35 (89)	29 (453)	29 (1478)	29 (1931)	27 (1433)
Several Per Week	23 (338)	17* (425)	18* (724)	17* (1149)	16* (945)
Several Per Month	15 (474)	9* (200)	11 (275)	10* (475)	9* (427)
Once Every Few Months	7 (320)	2 (65)	8 (75)	5 (140)	2 (125)
Less Often	3 (33)	4 (23)	9 (66)	8 (155)	9 (129)

*The only significant differences (Fishers test at the 0.05 level) are the percent highly annoyed for blast noise as compared to other groupings

TABLE 4
RATIO INCREASE IN PERCENT HIGHLY ANNOYED WITH AN INCREASE IN PERCEIVED FREQUENCY OF OCCURRENCE

	Blast	Helicopter	Traffic Children and Aircraft	Helicopter Traffic Children and Aircraft	Helicopter Traffic and Aircraft
Several per week to daily	1.5	1.7	1.6	1.7	1.7
Several per month to several per week	1.5	1.9	1.6	1.7	1.8
Once every few months to several per month	2.1	4.5	1.4	2.0	4.5
Less often to once every few months	2.3	0.5	0.9	0.6	0.2

TABLE 5
PERCENT OF RESPONDENTS HIGHLY ANNOYED BY FREQUENCY OF OCCURRENCE (NUMBER IN PARENTHESES)

	Helicopter	Aircraft	Traffic	Helicopter Traffic and Aircraft
8 or more	36 (152)	32 (165)	31 (264)	33 (581)
3-7 per day	30 (185)	23 (193)	32 (135)	28 (513)
1-2 per day	12 (98)	16 (101)	23 (71)	16 (270)

These data reveal five general trends:

- Table 3 shows that for a given frequency of occurrence, the percentages annoyed by blast noise are somewhat larger than for the other noise sources. The other noise sources are otherwise all quite similar.
- Table 4 shows that the first two ratio changes for all other noises, as compared to blast noise and indeed across all noise sources, are quite similar.
- The third* ratio change for blast noise (Table 4) is much larger than for the other noise sources. As noted for Fig. 2, this result indicates that the community response integration period for blast noise apparently extends down to and beyond once every few months.
- For the other sources, the integration period appears to be shorter extending down to occurrences more on the order of several per month.
- All of the sources in terms of community annoyance response drop away when occurrences drop to less often than once every few months.

Within the daily grouping for frequency of occurrence, data for helicopters, aircraft and traffic were examined as a function of number of events per day. These data were divided into: 1 to 2 occurrences per day, 3 to 7 occurrences per day, and 8 or more occurrences per day. Table 5 contains the results of this analysis. Examination of the percentage shift in highly annoyed for helicopters, aircraft and traffic together as a function of number of occurrences shows good consistency between the daily and yearly data. That is, the percentage change in highly annoyed (28/16 = 1.75) between 1-2 per day and 3-7 per day (a factor of about 4 in frequency of occurrence) is the same as the percentage change (about 1.70) between several per week and several per month (a factor of 4 in frequency of occurrence)

One discrepancy, however, does exist. The absolute value of the percentage highly annoyed as a function of the number per day is shifted downward as compared to the data in Table 3. For example, the percentages in the 1 to 2 per day cell of Table 5 are approximately the same as the percentages for several per week cell in Table 3. This seems to indicate that the growth in annoyance with frequency of occurrence undergoes some type of shift when attention changes from long-term considerations to within-a-day considerations.

Based on several studies, which over a short time (minutes to hours) indicate a 3 dB growth rate for frequency of occurrence, these ratio of percentages can be correlated with the number of occurrences by calculating 10

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*Errata: "The fourth ratio..."

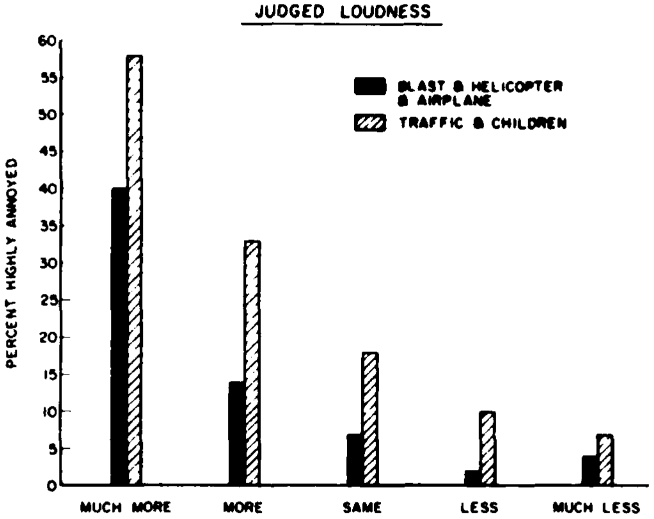

Figure 3—The percent "highly annoyed" at various judged loudness levels for the two combined groups: aircraft, blast and helicopter; and, street traffic, children and pets

TABLE 6
AGGREGATED DATA OVER ALL FREQUENCIES OF OCCURRENCE BY LOUDNESS (PERCENT HIGHLY ANNOYED-NUMBER IN PARENTHESES)

Loudness/ Source	Much More	More	Same	Less	Much Less
Blast[1]	38 (280)	18 (340)	8 (313)	3 (251)	4 (70)
Airplane[1]	39 (267)	12 (349)	6 (260)	1 (137)	3 (36)
Helicopter[1]	43 (372)	12 (372)	6 (254)	2 (133)	3 (35)
Traffic[2]	54 (155)	31 (254)	16 (187)	10 (132)	2 (45)
Children[2]	63 (139)	36 (213)	20 (212)	10 (156)	11 (76)
Blast, Airplane & Helicopter[3]	40 (919)	14 (1061)	7 (827)	2 (521)	4 (141)
Traffic & Children[3]	58 (294)	33 (467)	18 (399)	10 (288)	7 (121)

[1] These three groups (by loudness level) are not significantly different from each other. Each is significantly different from the traffic and children groups (Fishers test at 0.01 level).
[2] These two groups (by loudness level) are not significantly different
[3] These two groups (by loudness level) are significantly different (Fishers test at 0.01 level)

TABLE 7
RATIO OF INCREASE IN PERCENT HIGHLY ANNOYED WITH INCREASE IN PERCEIVED LOUDNESS

	More to Much More	Same to More	Less to Same	Much Less to Less
Blast	2.1	2.2	2.7	0.8
Airplane	3.2	2.0	6.0	0.3
Helicopter	3.6	2.0	3.0	0.7
Traffic	1.7	1.9	1.6	5.0
Children	1.7	1.8	2.0	0.9
Blast, Airplane & Helicopter	2.9	2.0	3.5	0.5
Traffic & Children	1.8	1.8	1.8	1.4

log (ratio of the number of occurrences.)[5,6,7] On this basis, the ratio of several per week (perhaps three) to daily (perhaps two) indicates a shift of 6 dB. The ratio of several per month to several per week indicates exactly 6 dB, and the ratio of once every few months (3 or 4 per year) to several per month (30 to 40 per year) indicates about 10 dB. These data indicate that a function on the order of 30 log (ratio of percentages) corresponds to the assumed decibel shift with frequency of occurrence in formulations such as DNL.

Table 6 is similar in concept to Table 3, but averages by sources and combination of sources over frequencies of occurrence in order to examine the growth function with respect to loudness. This table is constructed for each source alone, for children and traffic together, and for blast sources, helicopters and airplanes together. These two groupings are formed because their members are significantly different from one another as indicated in the table.

Table 7 indicates the ratio change in highly annoyed from one loudness to the next within each grouping. Unlike Table 4, which reveals that the ratio changes are about the same from one source to another (except for very infrequent occurrences), the ratio changes with loudness are different from one type of source to another. The trends indicate that the five sources can be divided into the two groups: blast sources, helicopters and airplanes; and, street traffic, children and pets (see Fig. 3). There are two distinct differences between these groups: for a given loudness, there is a substantially higher percentage highly annoyed to street traffic, children and pets than to the other group of sources; and, the growth slope of annoyance with loudness is steeper for the blast/aircraft category than for the other category. That is, the percentage annoyed apparently increases more quickly for the former category than for the latter. This result, that the growth rate for blast noise is equal to the growth rate for aircraft, is consistent with the results in two previous articles by this author.[6,9]

It should be noted that this survey was primarily designed to understand blast noise in context with other more traditional noises (for example, aircraft and traffic). The aircraft in the survey area are primarily prop and propjet, with very little pure jet activity. Also, with the exception of limited localized areas, the helicopters remain distant from populated areas. Thus, the above result should not be construed to indicate that traffic or children would be more annoying near a major metropolitan airport. Rather, the

Appendix A—LOUDNESS*

Sec. 1

ARTILLERY

Frequency	much more	more	same	less	much less
Daily	19 6 43 (58)	1 5 21 (29)	0 0 13 (0)	0 0 10 (0)	0 0 2 (0)
Several Per Week	21 14 98 (36)	9 16 98 (26)	5 9 79 (18)	2 1 54 (6)	1 0 9 (11)
Several Per Month	15 21 96 (37)	7 15 142 (15)	2 7 116 (8)	2 1 92 (3)	1 0 28 (4)
Once Every Few Months	6 5 42 (26)	1 5 71 (8)	0 2 100 (2)	0 1 84 (1)	0 1 23 (4)
Less Often	0 0 1 (0)	0 1 8 (13)	0 0 5 (0)	0 0 11 (0)	0 0 8 (0)

Sec. 2

AIRPLANES

Frequency	much more	more	same	less	much less
Daily	30 47 176 (44)	5 23 162 (17)	5 6 89 (12)	1 0 45 (2)	0 0 8 (0)
Several Per Week	10 10 66 (30)	2 8 127 (8)	1 2 86 (3)	0 1 47 (2)	0 0 15 (0)
Several Per Month	3 5 18 (44)	2 1 45 (7)	1 1 66 (3)	0 0 29 (0)	0 0 7 (0)
Once Every Few Months	0 0 4 (0)	0 1 14 (7)	0 0 13 (0)	0 0 10 (0)	0 0 4 (0)
Less Often	0 0 3 (0)	0 0 1 (0)	0 0 6 (0)	0 0 6 (0)	0 1 2 (50)

Sec. 3

HELICOPTERS

Frequency	much more	more	same	less	much less
Daily	51 44 201 (47)	11 15 157 (17)	2 8 65 (15)	0 1 23 (4)	0 0 7 (0)
Several Per Week	24 29 126 (42)	1 12 140 (9)	1 3 101 (4)	0 2 49 (4)	0 0 9 (0)
Several Per Month	4 7 34 (32)	2 4 65 (9)	0 0 61 (0)	0 0 35 (0)	0 0 5 (0)
Once Every Few Months	1 0 9 (11)	0 0 9 (0)	0 0 18 (0)	0 0 20 (0)	0 0 9 (0)
Less Often	0 0 2 (0)	0 0 1 (0)	0 0 9 (0)	0 0 6 (0)	0 1 5 (20)

Sec. 4

STREET TRAFFIC

Frequency	much more	more	same	less	much less
Daily	33 26 106 (56)	13 44 164 (35)	9 14 130 (18)	3 2 81 (6)	0 1 19 (5)
Several Per Week	10 8 37 (49)	7 9 61 (26)	1 5 39 (15)	2 4 33 (18)	0 0 9 (0)
Several Per Month	2 2 8 (50)	3 2 23 (22)	0 0 10 (0)	1 0 11 (9)	0 0 5 (0)
Once Every Few Months	0 1 3 (33)	0 0 4 (0)	0 0 4 (0)	0 0 2 (0)	0 0 2 (0)
Less Often	1 0 1 (100)	1 0 2 (50)	0 0 4 (0)	0 1 5 (20)	0 0 10 (0)

Sec. 5

CHILDREN AND PETS

Frequency	much more	more	same	less	much less
Daily	45 26 109 (65)	23 27 141 (35)	8 22 132 (23)	5 6 88 (13)	2 4 28 (21)
Several Per Week	3 10 23 (56)	9 12 58 (36)	2 9 62 (18)	1 2 40 (8)	0 1 21 (5)
Several Per Month	2 0 5 (40)	1 1 9 (22)	1 1 16 (13)	0 0 16 (0)	0 0 7 (0)
Once Every Few Months	0 1 2 (50)	1 1 2 (100)	0 0 1 (0)	0 0 4 (0)	1 0 6 (17)
Less Often	0 0 0 (-)	0 1 3 (33)	0 0 1 (0)	0 1 8 (13)	0 0 14 (0)

*The first three numbers in each cell are the numbers expressing (1) "extreme" annoyance (2) "very much" annoyance and (3) the total number of respondents in the cell. The fourth number, in parentheses, is the percent "highly annoyed."

growth rates developed above indicate that noisier jet aircraft or helicopters near to homes would be judged more annoying than corresponding louder road traffic. That is, the absolute percentages highly annoyed and the growth rates are such that the curves for the two categories of sources would cross one another.

One possible explanation for this apparent difference in growth in annoyance with loudness for these two categories of sources may lie in people's expectations. That is, people may expect aircraft, helicopters and blast noise to be loud and thus exhibit less annoyance when these sources are relatively quiet, whereas, they expect neighborhood sources to be quiet and thus exhibit annoyance at relatively low loudness levels. A second possible explanation is that "fear" increases as these particular sources grow louder. Third, as pointed out by one of the reviewers, the blast/aircraft group represent distinct events, while the traffic/children grouping may represent a more or less constant background.

Conclusions

The growth in annoyance (community response) to all noises increases monitonically both with sound amplitude and with frequency of occurrence.

The growth of annoyance with increasing frequency of occurrence from several per month up to daily is the same across all noises. For blast noise, the integration period extends down to once every few months.

The growth in annoyance with increases in amplitude differs between sources and can be divded into two categories: blast noise, helicopters and airplanes; and, street traffic, children and pets. The growth rate is steeper for the former than for the latter.

A residual annoyance in some segment of the population appears even when the assessed amplitude is much less than normal speech, and the frequency of occurrence is less often than once every few months. Occasionally, this residual annoyance is even at the high annoyance level.

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Paper 5

A Model to Describe Community Response to Impulse Noise*

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This article summarizes some of the results of a study primarily designed to assess community response to impulse noise (for example artillery, demolition) in comparison with more normal community noise sources, such as fixed wing aircraft, street traffic and neighborhood children. **Paul D. Schomer**† analyzes what type of energy model best describes community response to impulse noise. It is concluded that C-weighting offers the best standard measure available to assess impulse noise and that C-weighting DNL is a reasonable community assessment measure. No compelling justification can be found for retaining the present 85 dB sound exposure level (SEL) threshold incorporated in the current National Academy of Science procedures, nor can any compelling justification be found for developing or utilizing some form of "impulse correction factor" based on the individual SEL level of events. It is recommended that an equivalency be established between C-weighted DNL levels for impulse noise and A-weighted DNL levels for other noise by means of the percent of a population "highly annoyed" by a given noise climate. In order to establish this equivalency, it is found that about 6 dB should be added to C-weighted DNL levels so that the resultant equivalent level describes a noise climate where the percent of the population highly annoyed is numerically the same as another area having an A-weighted DNL level of that value.

Models to describe community reaction to noise have been the focus of study for at least the past quarter of a century.[1,2] Common to most of these models are three hypotheses:

(1) The community response increases monotonically with sound amplitude.

(2) The community response increases monotonically with frequency of occurrence.

(3) The community response to the sound environment at night increases compared to the same environment during the daytime.

The day/night average sound level (DNL) is a typical representative of these models.[3] It is based on the hypotheses that the community reaction grows in direct proportion to growth in sound exposure level (SEL), that the community reaction grows in proportion to 10 log of the number of events, and that a nighttime (2200 to 0700) "penalty" of 10 dB is appropriate. This model is typical of a number which are termed "equal energy" models in that a growth of 3 dB in sound exposure level is considered equivalent to a doubling of the number of events.

This article is specifically concerned with community response to large amplitude impulse noise, such as is created by sonic booms, artillery fire, demolition, etc. The National

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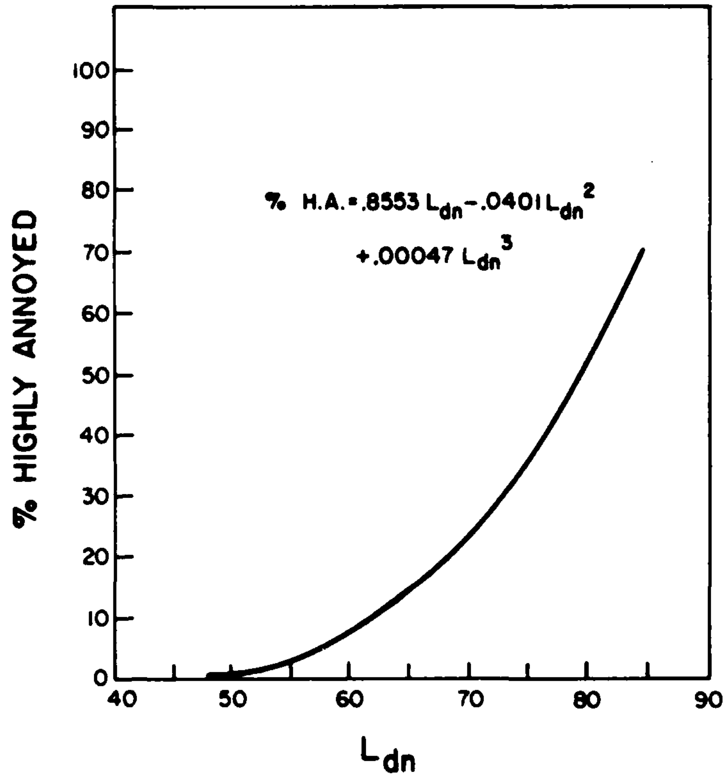

Figure 1—The Schultz relation for percent highly annoyed versus A-weighted DNL level

Academy of Science (NAS) in 1977 recommended the use of C-weighted DNL for assessment of this type of large amplitude impulse noise.[4] Large amplitude is defined to be impulses having C-weighted sound exposure levels in excess of 85 dB (75 dB at night). This C-weighted DNL is calculated in a similar fashion to A-weighted DNL. In this procedure, it is estimated that the percent of a community highly annoyed to a given C-weighted DNL level, such as 70 dB, is numerically the same as the percent of a community highly annoyed to normally encountered, everyday noises when the A-weighted DNL value is 70 dB. That is, there is no offset (0 dB) in establishing the equivalency between various A-weighted or C-weighted environments in terms of the percent of a community highly annoyed. Schultz has shown excellent agreement for survey data taken world-wide when the percentage of highly annoyed respondents in a given DNL zone is analyzed, and it is this relation (Fig. 1) which is used to define the percent of a community highly annoyed to an A-weighted DNL level.[5] Recently, working group 84 of the Committee on Bioacoustics and Biodynamics of NAS met and altered the 1977 procedure based in part on the data and materials herein.[6] The change is inclusion of a decibel offset (0 to 7 dB) to establish the equivalency between various A-weighted or C-weighted DNL environments.

The analysis contained in this article is based upon survey data gathered by the U.S. Army Construction Engineering Research Laboratory (CERL) in the vicinity of a large Army base. The purpose of the overall survey was to examine community response to the impulse noise generated by such sources as artillery or tanks and helicopters, as compared to more normal noise sources such as fixed-wing aircraft, street traffic, and children. This is the second article in a series and the analysis forms one part of the analysis of the survey. The first article considered such topics as the growth of community annoyance with growth in amplitude of events and with increases in the frequency of occurrence of events.[7] A third article will consider the existence of and quantitative values for nighttime and evening penalties. The following article concentrates on examining various models to describe community response to impulse noise as a function of the levels predicted by that model. This article also describes and analyzes the type of activity disruption caused by impulse noise as compared to other forms of noise, since frequently overall annoyance to noise has been generated as an index based upon the various forms of activity disruption.

Results from the first article (see Ref. 7) show that the community response to impulse noise, when judged by the respondent's perception of loudness, grows in an equivalent fashion to the growth in community response to increases in the loudness of fixed-wing or rotary-wing aircraft noise. This same analysis shows that the community response, as a function of frequency of occurrence of events, grows in an equivalent fashion to the growth in community response with increases in the frequency of occurrence of fixed-wing aircraft, rotary-wing aircraft, traffic noise, or neighborhood noises. That analysis indicates that there is no threshold below which impulse noises should be discarded as unimportant; however, the present NAS recommendations incorporate such a lower limit.

These results would seem to indicate that if the equal energy hypothesis (which is incorporated within the A-weighted DNL model for aircraft noise) is appropriate, then the same model structure is also appropriate for impulse noise. However, it may be that people's judgments of loudness do not correlate directly with the physical stimulus for blast noise in the same fashion as they do for aircraft noise. Therefore, the following analysis explores different threshold levels and explores the possibility of the existence of an impulse correction factor.

Basic Data Development

The Construction Engineering Research Laboratory has developed a computerized model for predicting

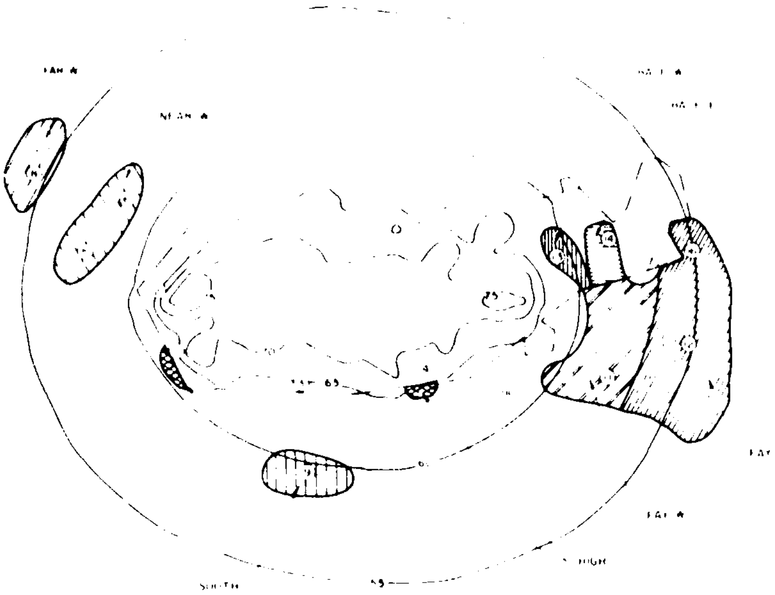

Figure 2—Predicted C-weighted DNL contours, monitor sites and predominant respondent groups in the study area.

C-weighted DNL contours based upon the operations at an Army base. This program operates in analogous fashion to other noise contouring programs, but is designed to implement the National Academy of Science's recommended procedures for assessing impulse noise. Basically, the original 1977 National Academy of Science procedure utilizes C-weighting and predicts a C-weighted DNL, including a 10 dB nighttime penalty. Equation 1 serves to define SEL:

$$\mathrm{SEL} = 10 \log [(1/p_0)^2 \int_I p^2(t) dt], \quad (1)$$

where p_0 is the reference pressure and I encompasses the effective duration of the event. The integration is performed over the entire effective duration of the event. By definition in the National Academy of Science procedures, the effective event duration must be less than approximately two seconds for the event to be defined as a single impulse. This formulation discards single-event sound exposure levels that are less than 85 dB during the daytime and less than 75 dB at night. Figure 2 contains these contours in the study area for the year preceding the survey.

Extensive 24-hour monitoring was performed in the vicinity of the Army base studied. Specially designed monitoring equipment was employed for this purpose at 17 sites.[8] The number of complete 24-hour days of monitoring at these sites ranged from 4 to 67 with 25 being a typical value. Extensive testing and checking was performed to eliminate all but blast noise from the C-weighted data. Wind meters were incorporated to minimize the effects of noise generated by wind at the microphone by turning off the monitors when the winds increased above approximately 18 kilometres per hour. Whenever the monitors went above the preset threshold of 105 dB peak level (95 dB at night), an analog tape recorder was turned on along with a special digital timer. If the wind threshold signal came on at all during the time period, then the data in that six minute block were discarded. If the threshold was exceeded for more than two seconds, then a technician listened to the analog tape to determine if the signal was caused by impulses or some other source, such as an aircraft or helicopters. If any other type of source could be detected on the analog tape, then this six minute block of data was discarded. Thus, the only data included were those for which the wind threshold was not triggered, no other source could be heard, and/or the event was less than two seconds in duration.

As stated, Fig. 2 illustrates the study area. This figure contains a generalized outline of the Army base. Overlaid on this outline are predicted C-weighted DNL contours for the year prior to administration of the survey. Also shown are the locations of 15 of the 17 monitoring sites (the other two sites were near airfields and measured only aircraft noise). This figure also indicates generalized land areas which have been grouped by their geographic area and noise zone. On-post and off-post respondents in the same general area and noise zone are grouped separately. Table 1 gives the predicted and measured noise levels by monitoring site.

Based upon the data in Table 1, Table 2 gives the estimated C-weighted DNL noise level by area (indicated in Fig. 2) for the year preceding the survey. The yearly predictions are altered based on the results of monitoring. In the high noise zones, 4 dB is added to the contour values, reflecting the results of nearby on-post monitoring. It should be noted that especially high noise levels were measured at sites 1 and 2, since units assigned firing points within a kilometre of these monitors actually fired much closer to the monitors, causing the extreme departure from prediction. In the areas to the east, the monitored results ranged from 11 dB below, to 3 dB above prediction. As generalized "correction" values, 5 dB has been subtracted from predicted values nearer to firing points (2-5 miles to nearest point), and 3 dB has been subtracted from the predictions for the more distant points.

For the eastern sites, where measured values were generally close to those predicted, all the predominant noise came in one to several days, and was characterized by a period of high noise caused by focus conditions for the sound.[9] In contrast, the monitor sites (Numbers 5, 6, 8 and 9) to the south and west exhibited no such focus days. As a consequence, Table 2 indicates a much larger difference for these locations between the computer-predicted values and the resultant estimated values. It should be noted that had monitoring been performed in other seasons when wind shears and inversions are somewhat different, then loud noise might also have been measured to the south and west on some days. However, no data exist to confirm or deny this assertion.

Respondents were asked to judge the loudness of the noise, the overall frequency of occurrence and their overall annoyance to that noise (for those respondents ever hearing the noise). These questions were asked for the five separate categories: impulse noise, rotary-wing aircraft, fixed-wing aircraft, vehicles, children and pets. This parallel presentation provides a context in which to examine impulse noise. Tables 1 and 2 of Ref. 7 summarize the responses for loudness and for frequency of occurrence by area (see Fig. 2) for impulse noise. Table 3 of this article summarizes the responses for overall annoyance by area (see Fig. 2) for impulse noise.

Examination of the data in Tables 1 and 2 of Ref. 7 shows that judged loudness and judged frequency of occurrence both decreased as one got further from the base. One can compare, for example, Fay E with Fay W, Base E with Base W, or Near W with Far W. Also, the loudness judgments from the Base Total area compare favorably with the responses from the Fay W area. These loudness judgments in the Base Total area are slightly higher than in the Fay W area. According to Fig. 2, these should be higher, since the Base Total area lies in a slightly higher noise zone. The high level of the loudness judgments from the South and Near W areas (as compared with the other areas) seems to indicate that the monitored data (Tables 1 and 2 of this paper) are low in these areas. That is, the responses fit the computer predicted C-weighted DNL values better than they fit the monitored levels.

TABLE 1
PREDICTED AND MEASURED NOISE LEVELS BY MONITORING SITE

Station Number	Number of Days Monitored	Monitored L_{ADN}	Monitored L_{CDN}	Predicted During Monitoring Period L_{CDN}	Predicted for Year Prior to Survey L_{CDN}
1	11	63	103	63	66
2	84	57	88	67	64
3	34	56	70	68	64
4	81	59	73	69	66
5	81	56	46	61	58
6	12	64	49	60	58
7	78	64	49	60	58
8	44	60	42	59	55
9	42	58	49	61	59
10	34	56	53	64	62
11	26	58	58	59	57
12	12	62	51	57	55
13	28	58	54	64	61
14	33	59	55	60	58
15		72		only aircraft noise received	
16	80	58	61	58	55
17		61		only aircraft noise received	

TABLE 2
ESTIMATED L_{CDN} NOISE LEVEL BY AREA FOR YEAR PRECEDING SURVEY

Area	L_{CDN}	Difference from Predicted Contour (dB)
HIGH	68	+4
FAY W	54	−5
FAY E	52	−3
BASE W	56	−5
BASE E	53	−5
BASE TOTAL	55	−5
SOUTH	49	−10
NEAR W	46	−12
FAR W	40	−15

Table 3 of this paper, which deals with overall annoyance, contains the same trends as do Tables 1 and 2 of Ref. 7, except for on-base responses. On base, the annoyance levels are smaller than off-base. In particular, in the Base Total area, the top three categories in Tables 1 and 2 of Ref. 7 are greater than in the Fay W area. However, the top three categories in Table 3 show that the overall annoyance levels for the Base Total area are lower than in the Fay W area. The top two categories, "extreme" and "very much," are used to form the high annoyance indicator. This change in high annoyance, 8 percent versus 13 percent, is found to be statistically significant at the 0.05 level.

This difference is perhaps related to expectations of respondents. On base they expect to hear blast noise, but off base they expect to leave their work behind. This is especially true since 43 percent of off-base respondent households have at least one member working for the government, and this does not include retired personnel. Because of the significant shift in on-base judgment responses for annoyance as compared with off-base, only off-base responses were used for most of the final analysis. Again, it is emphasized that off-base responses include approximately 43 percent of households having one or more members working for the government (not including retired military personnel).

In addition to the questions dealing with loudness, frequency of occurrence, and overall annoyance, question 34 asks: "Do you think people around here ought to complain about the noise from government facilities or operations if they find it annoying?" The possible answers were "yes" or "no." Table 4 shows, by area, the group size, the percentage of that group answering question 34 in the affirmative, and the percent indicating overall high annoyance (responding either "extremely" or "very much" to

TABLE 3
OVERALL DEGREE OF ANNOYANCE (PERCENT OF RESPONDENTS) BY AREA FOR BLAST NOISE

Area	Extreme	Very Much	Moderate	Slight	Not at All	Never Hear
HIGH	18.1	12.5	23.6	11.1	15.3	19.4
FAY W	5.2	8.0	9.8	4.6	31.6	40.8
FAY E	3.5	4.9	9.7	4.6	34.1	42.5
BASE W	5.9	5.9	10.7	7.3	39.5	30.7
BASE E	2.4	2.4	8.8	7.3	25.9	51.7
BASE TOTAL	4.1	4.1	9.8	7.3	32.7	41.2
SOUTH	8.1	10.8	14.9	8.1	14.9	43.2
NEAR W	3.2	3.6	6.4	10.4	46.6	29.1
FAR W	0	0	4.8	11.9	26.2	57.1

TABLE 4
PERCENT HIGHLY ANNOYED TO BLAST NOISE BY AREA: THOSE WHO FEEL ONE SHOULD VERSUS SHOULD NOT COMPLAIN ABOUT GOVERNMENT FACILITIES

Area	Group Size	% Should Complain	% HA (Should Complain)	% HA Should Not Complain)	% Overall HA	% Overall Adjusted HA*
HIGH	72	51	45.9	14.3	30.6	33.9
FAY W	174	60	20.0	2.8	13.2	13.5
FAY E	919	62	11.8	2.8	8.4	8.4
BASE W	204	64	15.3	5.5	11.8	11.6
BASE E	204	68	7.2	0	4.8	4.5
BASE TOTAL	408	66	11.1	2.9	8.2	8.0
SOUTH	74	68	28.0	0	18.9	17.4
NEAR W	251	53	8.3	5.1	6.8	7.1
FAR W	42	53	0	0	0	0

*Percent overall highly annoyed is adjusted as explained in the text. The purpose is to normalize the data to a group in which 62 percent feel they "should complain if bothered."

the overall annoyance question dealing with artillery noise) as a function of whether they answered question 34 affirmatively or negatively. These results show that one's disposition to complain is strongly correlated with his/her judgment on overall annoyance. The two groups shown in this table are approximately related by a factor of four.

The next column in Table 4 gives the overall percent "highly annoyed" within each area for the "yes" and "no" responses combined. Finally, the last column in Table 4 gives the overall percent "highly annoyed," which likely would have resulted for each group if each contained 62 percent of the respondents answering question 34 affirmative. The choice of 62 percent is somewhat arbitrary. It represents approximately a population weighted average of the data. Using this normalization process allows for better comparison between the different areas, since the responses in the High area are otherwise probably 10 percent or so low. Also, this 62 percent figure is more or less consistent with the sonic boom studies in Oklahoma City, which had about 65 percent respondents overall who thought one should complain about government facilities and 35 percent who answered in the negative.[9] The Oklahoma City study merely deletes all data for those respondents indicating they should not complain and considers only those saying they should complain, in the overall calculations performed and results presented. It is felt that the 62 percent common denominator arrangement in Table 4 is a more reasonable representation of the overall community than is the approach of deleting all those who indicate in the negative with respect to complaints.

Activity Interference Data

A portion of the questionnaire contained ten questions relating to activity interference. These questions were:

- Does noise ever wake you up or prevent you from falling asleep?
- Does noise ever interfere with your listening to radio or TV?
- Does noise ever interfere with conversation? Either face-to-face or over the phone?
- Does noise ever interfere with activities out-of-doors around your home/apartment?
- Does noise or vibration ever make your house rattle or shake?
- Does noise ever startle you?
- Does noise ever frighten you?
- Does noise ever interfere with activities that require your care or concentration?
- Does noise ever disturb your rest and relaxation in your home?
- *(If applicable)* Does noise ever bother or disturb anyone else in the household?

For each of these ten activities, respondents, after being asked if noise ever interfered or affected these activities (and indicating an answer in the affirmative), were then asked what noises caused this interference and how often each occurred. The possible responses to the frequency of occurrence were every day, several times a week, several times a month, once every few months, and less often than that. Finally, each respondent was asked, by source, how annoyed they were by that level of interference occurring that many times. For example, they would be asked, "How annoyed are you by *(airplanes)* interfering with conversation *(several times a week)*?" The possible responses were on a 5-point scale, with the two end points being noted as "extremely" on the one hand and "not at all" on the other.

In the past, it has been the practice to form an overall annoyance index based upon a linear combination of the responses to a set of questions such as those indicated above. For this analysis, the responses to these ten questions were placed on a binary scale (rather than using the annoyance numbers as cardinal numbers ranging from 1 through 5) by defining respondents to be highly annoyed to a given activity interference if they chose either of the top two numerics on the 5-point scale.

Examination of these data, as compared with respondents indicating overall high annoyance to that noise source, indicated a high degree of redundancy and overlap between certain subsets of activity interferences. For example, a respondent highly annoyed by aircraft noise might also indicate problems with listening to radio/TV, conversation face-to-face or over the phone, or both, and still have the same overall annoyance reaction. Similarly, a respondent highly annoyed by blast noise might indicate that the noise startled or frightened him or both and still have the same overall response. Again, the same can be said for the question relating to the rest and relaxation as compared with the question relating to sleep. A respondent might choose one or the other or both and still have the same overall annoyance reaction. Thus, it was decided to merely tabulate the respondents indicating high annoyance to a given activity interference by noise source category, and also to indicate the number of those respondents also indicating overall high annoyance. These data are contained in Table 5. This table shows that the primary problems with impulse noise are house rattles, startle, and fright; whereas with other sources such as airplanes and helicopters, speech interference becomes the major problem; and with still others such as street traffic and neighborhood sources, interference with sleep becomes the major problem. (It should be noted that all of the noise sources in this study area had more or less equal percentages of nighttime occurrance.)

The data were examined to see if any of the activity interference factors were an indicator of high annoyance, or if any combination of these was a useful predictor of high annoyance. No such relation could be found. Rather, it appears that the number of activity interferences found to be highly annoying is the best predictor of whether a respondent will be overall highly annoyed by that noise source category. Table 6 illustrates these data by source category and number of activities generating high annoyance. For each source category, the percent of respondents rises as a function of the number of activities generating high annoyance until the point where 50 to 60 percent of respondents express high, overall annoyance, usually at around three activities. By the time six or seven activities generate high annoyance, these few respondents almost universally indicate that they are highly annoyed.

TABLE 5

NUMBER OF RESPONDENTS EXPRESSING HIGH ANNOYANCE TO INDICATED ACTIVITY BY NOISE TYPE*

	Artillery	**Street Traffic**	**Airplanes**	**Helicopters**	**Children/ Pets**
Sleep	105 (74)	118 (14)	103 (34)	80 (35)	181 (28)
Radio TV	56 (37)	82 (15)	139 (40)	168 (59)	39 (14)
Conversation	41 (36)	61 (11)	95 (29)	125 (44)	40 (8)
Outdoors	9 (8)	34 (3)	17 (5)	43 (20)	34 (5)
Rattles	350 (161)	11 (1)	89 (19)	106 (37)	2 (0)
Startle	200 (97)	55 (8)	42 (14)	44 (13)	22 (5)
Freight	112 (63)	40 (9)	39 (13)	37 (16)	16 (2)
Care/Concentration	87 (55)	57 (10)	75 (24)	82 (36)	47 (13)
Rest/Relaxation	131 (77)	109 (18)	100 (39)	122 (47)	119 (23)
Disturb other household members	171 (85)	90 (11)	101 (29)	116 (39)	124 (25)

*The figure in parenthesis is the *number* of those respondents in that cell also expressing overall high annoyance to that noise type. For example, 105 respondents expressed high annoyance to sleep interference by blast noise. Of these 105 respondents, (about 70 percent) 74 respondents expressed overall high annoyance at blast noise.

TABLE 6

NUMBER AND PERCENT OF RESPONDENTS EXPRESSING OVERALL HIGH ANNOYANCE AS A FUNCTION OF NUMBER OF ACTIVITY INTERFERENCES FOUND HIGHLY ANNOYING BY THESE RESPONDENTS*

		1	2	3	4	5	6	7	8	9
Artillery	Total No.	183	97	61	49	44	20	8	7	6
	Total also HA	34	28	32	31	31	11	8	6	6
	% HA	19	29	52	63	70	55			
Street Traffic	Total No.	115	50	35	20	21	10	8	2	2
	Total also HA	44	28	21	12	19	8	7	2	2
	%HA	22	45	43	67	82	80			
Airplanes	Total No.	109	56	40	24	28	16	5	8	3
	Total also HA	24	25	21	16	23	12	4	5	2
	%HA	22	45	53	67	82	75			
Helicopters	Total No.	123	52	45	30	27	29	8	5	4
	Total also HA	39	21	33	18	21	24	7	5	4
	% HA	32	40	73	60	78	83			
Children/Pets	Total No.	137	82	36	27	14	5	1	0	0
	Total also HA	56	49	28	21	12	5	0	0	0
	% HA	41	60	78	78	86				

*For example, 183 respondents found exactly one activity interference item to be highly annoying. Of these 183 respondents, 34 respondents or 19 percent of the 183 found blast noise overall to be highly annoying.

Alternative Data and Other Considerations

For blast noise, the data were examined to compare the responses of respondents who owned their home versus those who rented. This comparison was performed only off the military post (on-post, people do not own homes) and was performed for each of the areas in Table 2. No statistically significant differences were found for the level of high annoyance overall for those who owned their homes as compared to those who rented. Areas were combined and

TABLE 7

DIFFERENCE BETWEEN L_{CDN} AND THE EQUIVALENT L_{ADN} CALCULATED FROM THE PERCENT HIGHLY ANNOYED USING THE SCHULTZ RELATION

Area	% HA	Estimated L_{CDN}	Equivalent L_{ADN}	Difference* (dB)
HIGH	33.9	68	74	6
FAY W	13.5	54	64	10
FAY E	8.4	52	60	8
SOUTH	17.4	49	66	17
NEAR W	7.1	46	58	12
FAR W	0	40		

*Difference is the A-weighted DNL representing the percent HA in an area (as taken from Fig. 1) minus the estimated C-weighted DNL for that area

again there were no statistically significant differences.

The data were also examined to compare responses for households with one or more members employed by the government to those with none. Again, no statistically significant differences could be found in any area.

As stated above, the 1977 and the current National Academy of Science procedures to assess community response to impulse noise utilize C-weighting and predict a C-weighted DNL. This C-weighted DNL includes a 10 dB nighttime penalty. This formulation discards single-event sound exposure levels which are less than 85 dB during the daytime and less than 75 dB at night. Different variations and alternatives can be considered in addition to this basic procedure. For example, the threshold can be effectively eliminated by dropping it to 40 dB; the threshold can be kept constant both for day and night rather than allowing the threshold to drop 10 dB at night; the threshold level can be changed to higher levels; and, some form of impulse correction factor can be added based upon the sound exposure level of the event itself. Table 7 summarizes the basic data developed and Table 8 lists these results, along with three variant means to formulate a C-weighted DNL. Table 7 includes, by area, the adjusted percent highly annoyed (from Table 4), the estimated yearly C-weighted DNL (from Table 2), the equivalent A-weighted DNL for the percent highly annoyed as taken from the Schultz relation (Fig. 1), and the difference in dB between these latter two values. The equivalent A-weighted DNL is calculated from the Schultz relation by determining the A-weighted DNL value which would yield the given percent highly annoyed. For example, an A-weighted DNL of 74 corresponds to approximately 34 percent of a population being described as highly annoyed.

Table 8 summarizes the data for the base case (the National Academy of Science procedure) and three variant cases. Case 2 raises the 85 dB threshold to 95 dB. Case 3 considers the imposition of an impulse correction factor in the formulation of the C-weighted DNL, and Case 4 eliminates any threshold or correction factor.

The impulse correction factor was formulated based upon the results of the sonic boom studies by Borsky in the Oklahoma City area.[10] Appendix A contains the basic formulation of this correction. Table A2 lists the C-weighted DNL and percent highly annoyed calculated for the three distances and three survey periods (having different boom over-pressures) in the Oklahoma City study. Based upon the percent highly annoyed, the Schultz function is used to define an equivalent A-weighted DNL level (Fig. 1). The difference between the C-weighted DNL calculated and the equivalent A-weighted DNL is shown in this table. Since there were eight booms per day at Oklahoma City, all during daytime, the C-weighted DNL is reconverted back to a C-weighted sound exposure level per event by adding approximately 40 dB to the C-weighted DNL values, since:

$$\text{SEL per event} = \text{LCDN} + 10 \log (86{,}400) - 10 \log (8), \quad (2)$$

where 86,400 is the number of seconds in a day and 8 is the number of events. These values are also shown in Table A2. Based upon this table, an approximate piece-wise continuous correction function was developed by the following:

$$\text{If CSEL} \leq 92.5 \text{ dB}, \quad (3a)$$

$$\text{then CSEL} = \text{CSEL}.$$

$$\text{If } 92.5 \text{ dB} < \text{CSEL} \leq 102.5 \text{ dB}, \quad (3b)$$

$$\text{then CSEL} = \text{CSEL} + (\text{CSEL} - 92.5).$$

$$\text{If CSEL} > 102.5 \text{ dB}, \quad (3c)$$

$$\text{then CSEL} = \text{CSEL} + 10.$$

Since house rattles are found to be the primary adverse factor (Table 5), it is interesting to compare the annoyance and frequency of occurrence judgments to the house rattle question with the judgments given earlier in this article and in Ref. 7 to overall noise. The results of this comparison show that the judged frequency of occurrence of house rattles goes down as compared to the judged frequency of occurrence of hearing impulse noise. In contrast, the annoyance to house rattles goes up as compared with overall judgments of annoyance to impulse noise.

Comparison With Previous Results

In the Oklahoma City test, respondents were subjected to eight sonic booms per day (none during the night). The average energy peak levels of these booms, in different noise zones and at different time periods, ranged from 123 dB to 131 dB, with the overall extremes being perhaps 116 to 136 dB. In contrast, this present study encompasses data from below the threshold of audibility up to approximately 145 dB.

TABLE 8

ALTERNATIVE C-WEIGHTED DAY/NIGHT LEVEL FORMULATIONS

		Case 1 (Base Case)		Case 2 (95 dB Threshold)		Case 3 (Impulse Correction)[1]		Case 4 (40 dB Threshold)	
	Equivalent L_{ADN}	Value[2]	Difference[3] (dB)	Value[2]	Difference[3] (dB)	Value[2]	Difference[3] (dB)	Value[2]	Difference[3] (dB)
HIGH	74	68	6	66	8	73	1	68	6
FAY W	64	54	10	52	12	57	7	56	8
FAY E	60	52	8	49	11	55	5	55	5
SOUTH	66	49	17	47	19	52	14	50	16
NEAR W	58	46	12	44	14	49	9	48	10
FAR W		40		36		43		44	

[1] As explained in the text, the impulse correction is applied to each event based on its SEL

[2] "Value" is the C-weighted DNL calculated for the various formulations

[3] "Difference" is the A-weighted DNL representing the percent HA in the area minus the "value" of C-weighted DNL for that case and area

The frequently reported Borsky data are the responses from only respondents who felt one should complain about a government activity or agency if it bothered them and these data specifically are addressed to the respondent's annoyance to "house rattles and shakes." Thus, the Oklahoma City data probably represent the highest possible percentages, since the data in the present study indicate that responses to "house rattles" generate greater overall annoyance levels than do responses to the general overall annoyance question, and since people who feel they should complain express higher annoyance (at a rate of about 4 to 1) over those who feel that one should not complain about government activities.

Appendix A summarizes the Borsky data and converts his peak levels into approximate C-weighted DNL levels. Table 9 summarizes the present study's results in terms of percent of respondents highly annoyed by building rattles (only respondents indicating that one should complain about government activities if annoyed) as compared to the yearly C-weighted DNL, and as compared with the Borsky-developed data under these same conditions. These data show that for a given C-weighted DNL level, the percentage highly annoyed is some 10 to 20 percent larger in the present study than with the Borsky-developed data. Unfortunately, Borsky never asked the question dealing with overall annoyance to sonic boom. Rather, he created an index based upon the various activity interference questions. Furthermore, he never reported the data for those indicating a disbelief in complaints about government activities.

Discussion of Data and Results

Borsky Data. The differences between the Borsky results in Oklahoma City and the results obtained in this study may be due to any or all of at least three factors. First, the differences may reflect real differences in the response of people to the noise source. That is, for a given C-weighted DNL, the community is much more annoyed by artillery noise than by sonic boom noise. Alternatively, this possible result, which can be stated as the C-weighted DNL measure, is not the measure to be used for impulse noise, and a measure is required which further emphasizes artillery noise as compared with sonic boom noise. This type of conclusion certainly supports the use of some type of measure which cuts out low frequencies, since the difference between sonic boom and artillery noise lies in the fact that the sonic boom contains greater quantities of sub-audible energy.

A second possible explanation is that no difference in responses exists. That is, if Borsky had asked a question dealing with the overall annoyance to sonic boom noise and included the universe of respondents, then the responses might have been equivalent to those presented in Table 4.

A third possibility is that the apparently lowered annoyance levels result from the fact that, in the Oklahoma City study, the respondents either knew a test was occurring which had a fixed duration and/or had only been subjected to the sonic booms for a relatively short period of time (approximately 6 to 8 weeks for each interview period). This third possibility would further support the one-year equal energy concept by indicating that responses to 6 to 8 weeks of noise are much lower than responses to one year of noise. Also, the very presence of the "test" may have influenced judgments, although only 60 percent even knew that a test was in progress during the first interview period.

Monitoring. The monitored data to the east of the base were typically 3 to 5 dB below predicted levels. These monitored data were characterized by one or several loud days, along with many quiet days. This monitoring result generally correlates with the community response indicating that loud events and house rattles generally occur less often than every day or several times per week, especially in the more distant areas. The monitored levels to the west and south were much lower than predicted, the data showing only generally low noise days and none of the interspersed high-level days. However, the respondent data would seem to indicate that these high levels do occur and that the monitoring must not have gone on for a long enough time or during the right season to obtain these results.

Near the base boundary in areas to the south and southwest of predominant noise sources, measured levels were 2 to 4 dB above prediction. In this study area, winds are generally from the north or northeast. Thus, the resulting monitored data possibly support published data indicating that at relatively short distances, sound propagation is enhanced in the downwind direction (the present computer predictions take into account temperature inversion frequencies but do not take wind directions into account).

Alternative Weightings. The data in Table 1 include measured values for the A-weighted DNL at the monitor locations. This table shows no correlation between the measured A-weighted and C-weighted levels at any site. Moreover, it is clear from Tables 1 and 3 combined that there is no correlation between the measured A-weighted levels and the percents of respondents highly annoyed. Along these same lines, both the Oklahoma City study and this present study show that house rattles are the predominant adverse factor in the community. Since it is predominantly the energy in the 10 to 30 Hz range which contributes to house rattles, A-weighting of impulse noise would delete nearly all the information relevant to the cause of house rattles.

Alternative C-weighted DNL Formulations. No definite conclusions on the alternative formulations for a C-weighted DNL measure can be drawn from the data in Table 8. With the reader's attention directed primarily at the first three areas, High, Fay W, and Fay E (since the latter three areas are based upon more questionable monitoring results), Case 2 is no different than Case 1, and Case 4 is only marginally better than Case 1 in that the deviations among the values are slightly smaller. In case 3, inclusion of an impulse correction factor, seems to move the results in the wrong direction by increasing the relative differences between areas.

Formation of Equivalent Levels. In order to assess the total noise produced by Army/DOD installations, it is necessary to be able to combine and portray the effects of all noise on the surrounding community so that meaningful land-use patterns can be developed both on and off post. Thus, it is necessary to establish some equivalency between the measures used to assess impulse noise and the A-weighted DNL levels used to assess all other noises. The percentage of the community characterized as highly annoyed to a given noise environment appears to offer the best means to develop this equivalency, given the emphasis which the National Academy of Science and EPA have placed upon the use of this concept in assessing the impact of noise environments.[11]

The data in Table 8, Case 4, show that the C-weighted DNL value underpredicts the percentage of respondents highly annoyed when used in conjunction with the Schultz relation. For example, the data show 34 percent highly annoyed in the 68 dB zone. The Schultz relation shows that it takes an A-weighted DNL of 74 dB to make 33 percent of respondents highly annoyed. The difference between these values is the indicated 6 dB in Table 8. These data indicate that the present C-weighted DNL always underpredicts the percent highly annoyed when utilizing the Schultz curve. Adding a constant 6 dB to the C-weighted DNL values seems to be the simplest means of establishing an equivalent impulse noise level which can be directly compared with A-weighted levels. Adding 6 dB yields equivalent DNL levels which, when utilizing the Schultz relation, closely predict the actual percent of respondents indicating high annoyance. In developing this recommendation to add a constant 6 dB, the results for areas to the south and west of the base are somewhat discounted since the responses for loudness, frequency of occurrence, annoyance and house rattles all indicate that noise levels frequently, at least during some portion of the year, are higher than those actually measured during the specific days of monitoring.

TABLE 9

PERCENT HIGHLY ANNOYED TO BUILDING RATTLES*

Present Study			Oklahoma City Data**	
Area	LCDN	% HA	% HA	LCDN
HIGH	68	59.4	35.3	64
FAY W	54	22.8	25.9	61
FAY E	52	17.9	25.4	62
SOUTH	49	32.0	19.4	60
NEAR W	46	14.4	16.9	59
FAR W	40	4.5	16.6	60
			12.5	56
			11.0	57
			5.1	54

*Only those who feel one should complain about Government facilities or operations

**From Table A1

Conclusions

A previously published article (see Ref. 7) showed that for impulse noise, the growth in annoyance for increases in loudness or frequency of occurrence is equivalent to the corresponding annoyance growth to such common noises as fixed-wing aircraft and vehicle noise. Thus, to the extent that fixed-wing aircraft and vehicle noise can be described by an energy type of model such as DNL, then impulse noise can be equally described by such a type of model.

The analysis herein shows that a measure which takes note of house rattles is definitely required, since house rattles is the most often cited adverse factor. A-weighting cannot and does not perform this function. On the other hand, there is an indication that a measure which incorporates more low-frequency energy than does C-weighting will further emphasize sonic booms as compared to artillery noise and increase the disparity in results between these two sources. Since energy in the 10 to 30 Hz range must be included in order to assess impulse noise's contribution to building rattles, C-weighting still appears to be the best available standardized weighting network with which one can assess impulse noise.

APPENDIX A

The author has previously shown that for sonic booms from transport size aircraft (B58/XB70) at high altitudes:[12]

$$\text{CSEL} = (10/8.5)\,(\text{Peak Level}) - 50.35. \qquad (\text{A1})$$

This equation is used to convert the Oklahoma City data from peak levels to CSEL. Essentially, the lower the peak level, the more rounded (lower frequency) the boom, and the more energy the C-weighting eliminates.

In Oklahoma City, there were 8 booms per day. So total daily CSEL equals the CSEL per boom plus 9 dB, and:

$$\text{LCDN} = \text{CSEL} + 9 - 49.4. \qquad (\text{A2})$$

Using Eqs. A1 and A2, the Oklahoma City data for (energy) average PSF and percent highly annoyed by time period yield the results summarized in Table A1.

TABLE A1
OKLAHOMA CITY DATA

Borsky Measurement Period	Peak PSF	Peak Level (dB)	LCDN	% HA
2 March - 19 April	1.13	128.1	59.9	16.6
	0.8	125.1	56.4	12.5
	0.65	123.3	54.3	5.1
20 April - 14 June	1.23	128.8	60.8	25.9
	1.10	127.8	59.6	19.4
	0.85	125.6	57.0	11.0
15 June - 25 July	1.60	131.1	63.5	35.3
	1.35	129.6	61.7	25.4
	1.00	127.0	58.7	16.9

Using linear regression, the percent highly annoyed (HA), as a function of LCDN is found ($r^2 = 0.93$) as:

$$\%\ \text{HA} = (3.09)(\text{LCDN}) - 164.0.$$

IMPULSE "CORRECTION" FACTORS

LCDN	% HA	LADN	Difference (A-C)
80	83.3	87.6	7.6
75	67.8	84.1	9.1
70	52.4	80.0	10.0
65	36.9	75.0	10.0
60	21.5	68.5	8.5
55	6.0	57.5	2.5

Table A2 data are used to establish the "impulse correction factor" equations given in the text.

The present 85 dB threshold was originally incorporated because data did not exist for lower levels, and because it was felt that only "large amplitude" impulses should be considered. The first study cited above shows that impulse noise fits an energy model in a like manner as aircraft or vehicle noise. Also, Table 8 shows that eliminating the threshold possibly decreases variation from site to site and neither retaining the present threshold, increasing it, nor adding an impulse correction factor, will reduce this variation. Thus, it is concluded that the present 85 dB threshold should be deleted because there is no compelling data to support the retention of this added complexity.

In summary, the conclusions and recommendations up to this point are:

- Impulse noise is described by an energy model as well as any noise is described by an energy model.
- C-weighting is the best available measure to characterize impulse noise.
- There is no threshold below which impulse noise should be deleted, any more than there is a threshold below which aircraft noise or vehicle noise should be deleted from DNL predictions.
- Addition of an impulse noise "correction," which adds a factor to each impulse based on its SEL level, does not increase the ability of C-weighted DNL to predict community response.
- In order to be able to relate impulse noise to other noises, it is recommended that equivalent C-weighted DNL levels be established by adding 6 dB to computed or measured C-weighted DNL values.

Other conclusions of note are:

- For a given noise level, annoyance on-post is, statistically, significantly lower than annoyance off-post.
- There is no statistically significant difference in annoyance levels between respondents who own or rent their homes.
- There is no statistically significant difference in annoyance levels between respondents off-post who do or do not have a family member working for the government. Since 43 percent of off-post respondents contained at least one household member who worked at or for some government facility (this 43 percent figure does not include households of retired military) there is no reason to assume that there would be any smaller levels of annoyance in a community which was less heavily made up of households who had family members working at some government facility. On the other hand, communities around Army bases with far lower percentages of government workers might exhibit higher annoyance levels. However, such communities do not generally exist.

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Paper 6

Time of day noise adjustments or "penalties"

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Community response descriptors, such as Day–Night Average Sound Level (DNL), have included a nighttime adjustment or "penalty" in their formulation. Typically this nighttime penalty has been 10 dB. Some models incorporate an evening penalty in addition to the nighttime penalty. The basis for these penalties is examined in this paper. This analysis is based on results from a community attitudinal survey conducted in the vicinity of a large Army base. The survey sought to compare blast noise (e.g., artillery) and helicopters in the context of all noise such as airplanes, traffic, and children. The analysis shows that there are at least two factors which contribute to a "penalty" during any time period. One factor occurs when individual events are intrinsically more bothersome or annoying during one period of time than during another time period. The second factor occurs because a greater percentage of events are more likely to be noticed and found bothersome during one period of time as compared with another. The results show that single bothersome events are more or less equally annoying during all time periods of the day. There is only a small growth in annoyance during the night and this growth occurs primarily with the more impulsive sources such as artillery and helicopters. The results indicate that the second factor described above is more important in contributing to a total nighttime adjustment or penalty. That is, for a given number of available events, respondents are more likely to notice and be bothered by events during the night than during the day. This factor appears to be a primary contributor to any nighttime adjustment. The nighttime penalty indicated by these two factors is of the order of 5 to 10 dB. These results tend to support retention of a nighttime penalty in descriptors such as DNL. Based on these results, one would not be tempted to depart from the long-established 10-dB value for the penalty.

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INTRODUCTION

Descriptors for community reaction to noise have been the focus of study for at least the past quarter century.[1,2] Common to the assumptions inherent in most of these descriptors are three hypotheses:

(1) The community response increases monotonically with sound amplitude.

(2) The community response increases monotonically with frequency of occurrence.

(3) The community response to sound exposure at night increases compared with the same sound exposure during daytime.

The Day–Night Average Sound Level, DNL, is a typical representation of these descriptors.[3,4] Inherent in this descriptor are the hypotheses that the community reaction grows in direct proportion to the growth in sound exposure level (SEL), that the community reaction grows in proportion to 10 log of the number of events, and that a nighttime (220 to 0700) adjustment or "penalty" of 10 dB is appropriate. Other descriptors such as the Community Noise Equivalent Level (CNEL) inherently incorporate the hypothesis of an evening (1900 to 2200) penalty of 5 dB in addition to the nighttime penalty.[5] These descriptors are typical of a number which are termed "equal energy" models in that a growth of 3 dB in SEL is considered equivalent to a doubling of the number of events.

This paper concentrates on the existence of and value for evening and nighttime adjustments or "penalties" for the assessment of noise. This analysis is based upon community attitudinal survey data gathered by the U. S. Army Construction Engineering Research Laboratory in the vicinity of a large Army base. The purpose of the overall survey was to examine community response to the impulse noise generated by such sources as artillery or tanks and helicopters as compared with more normal noise sources such as fixed-wing aircraft, street traffic, and children. The analysis in this paper forms one part of the analysis of the survey. Other portions of the analysis consider such topics as the growth of community annoyance with growth in amplitude of events and with increases in the frequency of occurrence of events,[6] the community response by source as a function of noise zone, and the type of activity disruption caused by the various sources.[7] These two earlier papers (Refs. 6 and 7) serve to document the survey plan, execution, and analysis. They include dose/response analyses based on both computer simulation and noise monitoring results. The purpose of this paper is to concentrate solely on time-period adjustments.

Previous studies concerning time-period adjustment factors have concentrated mainly on fixed-wing aircraft noise and have usually been performed in the vicinity of major commercial airports (e.g., London, Los Angeles, New York) where there are frequent, loud aircraft flyovers. By way of contrast, this study was not performed near any such major fixed-wing aircraft facility. Rather, this study can be thought of as concentrating on impulse noise, rotary-wing aircraft noise, general aviation aircraft noise (including a few Boeing 727s and Lockheed C-141s) urban traffic noise, and neighborhood noise from children and pets.

These previous studies at large, fixed-wing commercial airports have been performed in a variety of ways and have yielded very mixed results. The first Heathrow survey in London in 1961 indicated a 17-dB Noise and Number Index (NNI) penalty for nighttime operations.[8] This corresponds to approximately an 11-dB penalty in NEF or CNR and about a 10-dB penalty in DNL.[9] Fidell and Jones[10] found no significant change in response when nighttime flights were greatly reduced at the Los Angeles International Airport; but as pointed out by Ollerhead,[11] the nighttime noise, before elimination of nighttime flights, even with the inclusion of the 10 dB penalty, was far outweighed by the daytime noise. So perhaps no significant response should be expected. Borsky,[12] at JFK, finds results somewhere in between the above two extremes. His data indicate a nighttime penalty which can be shown to be on the order of 3–7 dB. In a further study at Heathrow, Ollerhead[13] finds rather mixed results. His data indicate about a 5-dB evening penalty and some nighttime penalty to be imposed during the period when people are trying to fall asleep. More recently, yet another study has been initiated in the vicinity of Heathrow.[14] This study, in its preliminary stages, has concentrated on how the noise keeps people from falling asleep, wakes them up, and the relative annoyance during different time periods. Like Borsky and Ollerhead, this study finds that the annoyance per event remains relatively constant during different time periods of the day. This study also finds a much lower rate of reported awakenings by respondents as compared with the rates of awakening predicted by various laboratory studies such as the work by Lucas *et al.*[15] In a 1979 study Horonjeff and Teffeteller[16] finds no nighttime or evening penalty either on a single event or on an equivalent level (L_{eq}) basis. Thus, the literature presents a rather mixed and inclusive picture. A recent conference at NASA concludes that "time-of-day effects are real" but does little to quantify their nature.[17]

Why might there by a time period adjustment or "penalty?" Several points, both acoustical and nonacoustical, come to mind as potential factors contributing to a time period adjustment. One possible factor is that the sound may be intrinsically more annoying during one or another period. Aircraft at night may be just "more annoying" than during the day. A second possible factor is that annoying sounds may be more readily noticed during one or another period. Internal household masking sounds are lower at night, external background ambient noises are lower at night, and sound frequently propagates better at night (because of diurnal variations in temperature lapse and wind velocity with altitude). A third possible factor is that the activities interfered with by noise during one time period are more critical and, hence, generate greater annoyance as compared with another time period and its activities. For example, sleep interference may be more important than speech interference. A nonacoustical argument asserts that since many more people are at home during the evening and night as compared with daytime, a "penalty" is justified to account for the greater population at risk. Certainly many other factors can be advanced for including or excluding time of day penalties in a noise descriptor.

Some of the studies described above, such as Borsky's, have concentrated on the intrinsic annoyance "value" of an event at night (such as an aircraft flyover) as compared with the annoyance value of the same event during the day. These studies tend to indicate only a small nighttime penalty, if any; 0 to 3 dB being typical. Other of the studies have concentrated on sleep disruption and ability to fall asleep. These results are also inconclusive. Some studies, such as the first Heathrow survey, have not sought to separate the factors. Rather they have compared daytime exposure and its resulting community response with nighttime exposure and its resulting community response to determine the "penalty" necessary to establish equivalence between daytime and nighttime predictions of community response based on exposure. These results are also mixed but tend to indicate the possibility of a substantial nighttime penalty. While some have postulated a nighttime penalty because background noises are lower at night,[18,19] no one has quantitatively examined this factor.

One main purpose of this paper is to quantitatively examine the second factor described above, that noisy or bothersome events are more likely to be noticed during one time period as compared with another. For example, the noise of children playing or dogs barking may be much more noticeable at night than during the day. Because the noise is noticed more, the overall annoyance may increase.

This paper will also examine the first factor, intrinsic annoyance per event. For blast noise, the first Heathrow survey approach will be used to examine the existence of some overall nighttime penalty.

I. APPROACH

The energy type of model will be used to approximately quantify the second factor: the rate of noticing annoying events. The first paper on these community attitudinal survey results (Ref. 6) shows that annoyance increases when respondents subjectively notice annoying events more frequently. The second paper on this survey (Ref. 7) shows that community response to impulse noise exposure fits an energy model. Many other studies show that community response to transportation noise exposure fits an energy model.[20] Since all of the sources in this study appear to fit an energy model, this fact can be used to approximately quantify the penalty implied by changes in the likelihood of noticing bothersome events during one time period or another. If the 10-log (number of events) factor is applied to the number of events noticed by a respondent (in contrast to the number counted from physical records), then some notion can be developed on the importance of the rate of noticing bothersome events.

This factor can be addressed by comparing the known physical frequency of occurrence ratio between one time period and another to the respondent-reported ratio of the frequency of annoying events between one time period and another. For example, respondents may be bothered by twice as many events during the day as during the night. If, however, there are ten times as many actual occurrences during the day as during the night, then respondents (on an equal-number-of-occurrences basis) are being bothered by 1/5 as many of the available events during the day as during the night. On a 10-log basis, this would indicate an adjustment or penalty of 7 dB to be applied to events during the night.

This community response survey asked respondents how often they were bothered by various events during the day (0700 to 1900 h), evening (1900 to 2200 h), and during the night (2200 to 0700 h). Records were available on relative event frequencies by day and night for blast noise, fixed-wing aircraft, and rotary-wing aircraft, and official estimates were available for traffic noise. Thus the above indicated quantitative analysis on the rate of noticing bothersome events is quite viable.

Quantifying the first factor, the intrinsic annoyance value of an event as a function of the time period is less straightforward. Respondent data are used to assess annoyance per bothersome event as a function of time period. However, no generally acceptable means exist to quantify shifts in annoyance per bothersome event on a decibel basis. Fortunately, these shifts appear to be small and so quantifying this factor largely becomes a moot point.

Finally, an additional notion of nighttime penalty is developed by using the first Heathrow survey methodology to examine blast noise. Daytime and nighttime exposure and their respective resulting community response (annoyance) are compared. The number of decibels required to make daytime and nighttime predictions of annoyance equivalent is established by this comparison.

II. DEVELOPED DATA

As a part of the survey indicated above, respondents were asked whether or not they were generally home during the day, evening, or night, both for weekdays and weekends. The general times of 7 a.m., 7 p.m., and 10 p.m. were given to respondents as guidelines for the boundaries of these time zones. Respondents home during a given time period were asked if they were bothered by any of the noise sources and, if so, how often they were bothered. They could respond: every day, several times a week, several times a month, once every few months, or less often than that. They could also respond by (*don't know*). However, less than 1% of respondents responded in this fashion. Finally, respondents who had indicated that they were bothered were asked how annoyed they were *for that time period* (i.e., day, evening, or night; weekday or weekend). Specifically, they were asked: "And in general, taking everything into consideration, how annoyed are you by noise from (*source*) during the (*time period*)?" Annoyance was judged on a 5-point scale which included: extremely, very much, moderately, slightly, or not at all.

The analysis in the next section uses only data derived from respondents normally home during all three time periods so that the same respondents are comparing day with night. The analysis is more credible by having day, evening, and night responses from the same set of respondents; so long as one can show that the responses of these respondents home at all times compare favorably with the responses for those respondents home only part of the time. The following discussion considers this comparison along with further introducing and explaining the data.

The data were examined to see if respondents home at all times could act as a surrogate for the larger completed data set. Only weekday data were utilitized to compare the responses of respondents home at all times with those home only part of the time. Respondents were grouped according to their time periods generally at home. The set of respondents generally home days, evenings, and nights formed one group. A second group contained respondents home days and nights but not evenings, and a third group contained respondents home evenings and nights but not days. No other groups contained sufficient numbers of respondents to be statistically reliable. The set of respondents home during all times formed the basic set for analysis. The other two groups were used to test for differences which might exist between the responses of the people home all three time periods and people home only two of the three times.

Tables I–V list the basic data developed for the group of respondents home during all three time periods. These tables analyze the frequency with which respondents were annoyed during each time period (i.e., day, evening, or night). Each cell of the table lists the number of respondents reporting a given frequency of annoyance (e.g., every day, several per

TABLE I. Artillery: Respondents usually home day, evening, and night during weekdays.

Frequency of being bothered or annoyed	Daytime			Evening			Night		
	No. bothered	No. HA[a]	% HA	No. bothered	No. HA	% HA	No. bothered	No. HA	% HA
Everyday	17	12	71	11	7	64	10	9	90
Several per week	54	27	50	28	17	61	26	17	65
Several per month	46	15	33	36	11	31	23	11	48
Once every few months	22	2	9	19	5	26	23	10	43
Total by time period	139	56	40	94	40	43	82	47	57
"Day to night" total	Daytime plus evening 233—96—41						82	Nighttime 47	57

[a] HA is an abbreviation for the term "highly annoyed" which is explained in the text.

TABLE II. Airplanes[a]: Respondents usually home day, evening, and night during weekdays.

Frequency of being bothered or annoyed	Daytime			Evening			Night		
	No. bothered	No. HA[b]	% HA	No. bothered	No. HA	% HA	No. bothered	No. HA	% HA
Everyday	64	36	56	27	12	44	16	13	81
Several per week	44	16	36	31	16	52	19	10	53
Several per month	16	2	12	15	3	20	14	3	21
Total by time period	124	54	44	73	31	42	49	26	53
"Day to night" total	Daytime plus evening 197—85—43						Nighttime 49	26	53

[a] Airplanes in this study consisted mainly of single-engine, propeller-driven, general-aviation aircraft, with a small number of jet and prop-jet propelled military and commercial aircraft.

[b] HA is an abbreviation for the term "highly annoyed" which is explained in the text.

TABLE III Helicopters: Respondents usually home day, evening, and night during weekdays.

Frequency of being bothered or annoyed	Daytime			Evening			Night		
	No. bothered	No. HA[a]	% HA	No. bothered	No. HA	% HA	No. bothered	No. HA	% HA
Everyday	79	48	61	32	21	66	20	17	85
Several per week	68	24	35	38	14	37	19	8	42
Several per month	21	2	10	15	4	27	13	3	31
Total by time period	168	74	44	85	39	46	52	29	56
"Day to night" total	Daytime plus evening 253—113—45						Nighttime 52	29	56

[a] HA is an abbreviation for the term "highly annoyed" which is explained in the text.

TABLE IV. Street traffic: Respondents usually home day, evening, and night during weekdays.

Frequency of being bothered or annoyed	Daytime			Evening			Night		
	No. bothered	No. HA[a]	% HA	No. bothered	No. HA	% HA	No. bothered	No. HA	% HA
Everyday	59	35	59	52	34	65	23	19	83
Several per week	23	8	35	31	16	52	25	15	60
Several per month	3	2	67	7	3	43	11	3	27
Total by time period	85	45	53	90	53	59	59	37	63
"Day to night" total	Daytime plus evenings 175—98—56						Nighttime 59	37	63

[a] HA is an abbreviation for the term "highly annoyed" which is explained in the text.

TABLE V. Children or pets: Respondents usually home day, evening, and night during weekdays.

Frequency of being bothered or annoyed	Daytime			Evening			Night		
	No. bothered	No. HA[a]	% HA	No. bothered	No. HA	% HA	No. bothered	No. HA	% HA
Everyday	56	36	64	40	32	80	43	37	86
Several per week	24	10	42	27	15	56	44	26	59
Several per month	5	1	20	9	3	33	14	7	57
Total by time period	85	47	55	76	50	66	101	71	70
"Day to night" total				Daytime plus evening 161—97—60			101	Nighttime 71	70

[a] HA is an abbreviation for the term "highly annoyed" which is explained in the text.

week, etc.). Second, each cell of the table contains the number of respondents within that cell reporting "high annoyance" to that frequency of annoyance *during that time period*. (In accordance with the previous practice of Schultz[21] and others, "high annoyance" was defined to be those respondents choosing the top two annoyance responses out of the 5-point scale described above.) Finally, each cell contains the percentage of respondents that were highly annoyed out of the total number of respondents in the cell. For example, in Table I, 17 respondents reported being annoyed every day during daytime by artillery and 12 expressed high annoyance for a total of 71% of the 17. At the bottom of each column in each table, the number of respondents are totaled and a new percentage calculated. In addition, the total number of respondents for day and evening are added together and this percentage calculated. The reader should note that the total daytime percentage is merely a weighted average of the daytime and evening data.

For comparison purposes, the same procedure outlined above was performed for respondents home only during the day and night and for respondents home only during the evening and night. Again, the numbers of respondents were totaled across the various possible frequencies of occurrence. Table VI compares by noise source the daytime and nighttime percentages calculated for people home at all times and people home only during the day and night but not the evening. Table VII does the same for the evening and nighttime periods for people home day, evening, and night compared with people home only during the evening and night but not the day. These tables serve to compare groups of respondents home only two of the time periods with the group of respondents home all three time periods. Specifically, these tables compare the increase in annoyance (if any) for the same number of occurrences by comparing the percentage of respondents highly annoyed. These tables also compare the respondent's perception of the number of occurrences which are

TABLE VI. Comparison of responses for respondents home all times (DEN) with responses for respondents home only daytime and nighttime but not evenings (DN); weekday data.

Source	Group	Numbered bothered			Number HA[a]		Percent HA[a]		
		Day	Night	Ratio day/night	Day	Night	Day	Night	Ratio night/day
Artillery	DEN	145	94	1.54	59	48	41	51	1.24
	DN	14	7	2.00	4	3	29	43	1.48
Airplanes[b]	DEN	127	56	2.27	55	28	43	50	1.16
	DN	7	6	1.17	3	1	43	17	2.53
Helicopters	DEN	174	59	2.95	75	31	43	53	1.23
	DN	10	2	5.00	4	1	40	50	1.25
Traffic	DEN	86	63	1.37	45	38	52	60	1.15
	DN	8	6	1.33	3	4	38	67	1.76
Children and pets	DEN	89	111	0.80	47	74	53	67	1.26
	DN	11	9	1.22	5	3	45	33	0.73

[a] HA is an abbreviation for the term "highly annoyed" which is explained in the text.

[b] Airplanes in this study consisted mainly of single-engine, propeller-driven, general-aviation aircraft, with a small number of jet and prop-jet propelled military and commercial aircraft.

TABLE VII. Comparison of responses for respondents home all times (DEN) with responses for respondents home only evenings and nighttime but not daytime (EN); weekday data.

		Numbered bothered			Number HA[a]		Percent HA[a]		
Source	Group	Day	Night	Ratio day/night	Day	Night	Day	Night	Ratio night/day
Artillery	DEN	98	94	1.04	43	48	44	51	1.16
	EN	134	105	1.28	57	52	43	50	1.16
Airplanes[b]	DEN	76	56	1.36	31	28	41	50	1.22
	EN	144	98	1.47	60	58	42	59	1.40
Helicopters	DEN	89	59	1.51	39	31	44	53	1.20
	EN	135	83	1.63	69	43	51	52	1.02
Traffic	DEN	91	63	1.44	54	38	59	60	1.02
	EN	139	94	1.48	72	52	52	55	1.06
Children and pets	DEN	84	111	0.76	52	74	62	67	1.08
	EN	137	141	1.11	71	85	51	60	1.18

[a] HA is an abbreviation for the term "highly annoyed" which is explained in the text.

[b] Airplanes in this study consisted mainly of single-engine, propeller-driven, general-aviation aircraft, with a small number of jet and prop-jet propelled military and commerical aircraft.

bothersome (1) at night as compared with during the day or (2) at night as compared with during the evening.

One can especially note the close comparison between the group home at all times and those home only during the evening and night but not the day. The comparison is not quite as good between the group home at all times and those home only during the day and night but not the evening. However, the group home only during the day and night is rather small (7 to 14 per cell) and so a close comparison should not necessarily be expected. In comparison, the group home during the evening and night has 100 to 150 respondents per cell. Tests of significance by source and time period show no significant difference between the group home all times and those home only day and night but not evening (Table VI), or between the group home at all times and those home only evening and night but not day (Table VII). Overall, Tables VI and VII indicate that the respondents home all times respond similarly to those home only part of the time.

As an additional test of the use of respondents home at all times as a surrogate for the entire group of respondents, overall respondent group annoyance ratings were examined. In an earlier question in the survey, respondents were asked in general how often they heard (in contrast to being bothered) a given source, how loud they perceived it to be and overall how annoyed they were. The possible responses for frequencies of occurrence and degrees of annoyance were as outlined above.

Table VIII shows the basic percentage of respondents in each group highly annoyed to a given noise source category, the group size, and the response to the same questions by the universe of respondents. The data in this table show that of the three weekday response groups, the group home day, evening, and night had most nearly the same response as

TABLE VIII. Comparison of respondent group size and overall percent HA[a].

		Weekdays		Weekend	
Group/source	DEN	DN	EN	DEN	All respondents
Group size	728	63	891	1292	2147
Artillery	10.1	11.1	11.4	11.2	9.6
Street traffic	9.0	7.9	12.5	10.8	9.6
Airplanes[b]	7.4	9.5	10.4	9.0	7.8
Helicopters	11.4	12.7	12.7	11.9	10.5
Children and dogs	12.3	11.1	13.0	12.0	10.7

[a] HA is an abbreviation for the term "highly annoyed" which is explained in the text.

[b] Airplanes in this study consisted mainly of single-engine, propeller-driven, general-aviation aircraft, with a small number of jet and prop-jet propelled military and commerical aircraft.

TABLE IX. Comparison of responses for respondents home at all times on weekends.

	Number bothered				Percent HA[a]			
Source	Day	Evening	Day plus evening	Night	Day	Evening	Day plus evening	Night
Artillery	175	142	317	133	46	49	47	48
Airplanes[b]	159	125	284	97	44	48	46	54
Helicopters	185	134	319	97	51	54	52	61
Traffic	185	192	377	151	55	58	57	58
Children and pets	170	163	333	178	55	60	57	61

[a] HA is an abbreviation for the term "highly annoyed" which is explained in the text.

[b] Airplanes in this study consisted mainly of single-engine, propeller-driven, general-aviation aircraft, with a small number of jet and prop-jet propelled military and commercial aircraft.

given by the overall universe of respondents, and that the two other groups (day–night and evening–night) both exhibit slightly higher response rates than do the day/evening/night group and the universe of responses. Langdon[22] has reported on similar results in research by Aubru; that is, greater overall annoyance for respondent groups home part of the day rather than the whole day. Respondents usually home all times on weekends, as a group, also compare favorably with the universe of respondents, but the responses are somewhat higher than for the weekday group. Thus, by this test, the groups usually home at all times (either during the week or on weekends) appear to be appropriate groups for use in analyzing and quantifying a nighttime or evening penalty. As noted earlier, this result, that only respondents home all times be used to represent all the respondents, simplifies the following analysis, since the same respondents provided their reactions to sounds in the day, the evening, and the night.

The data used in the analysis in this paper are the sums appearing at the bottoms of Tables I–V. Before performing this addition, tables similar to Tables I–V were constructed for the group home only daytime and nighttime but not evenings and for the group home evening and nighttime but not daytime. These 15 tables were examined (1) by group, (2) by frequency of occurrence, and (3) by noise source category to discover unusual variations, if any, in the percent highly annoyed. No inconsistencies of any kind could be determined. Thus it was concluded that the data in Tables I–V could be reduced by adding the number of respondents in each column as shown in these tables.

As a source of additional data, weekend responses were analyzed by methods similar to those outlined above. Unlike

TABLE X. Comparison of responses for respondents homes all times, during weekdays and during weekends.

		Numbered bothered			Number HA[a]		Percent HA		
Source	Group	Day plus evening	Night	Ratio (day plus evening)/night	Day plus evening	Night	Day plus evening	Night	Ratio (night/day plus evening)
Artillery	Weekday	243	94	2.59	102	48	42	50	1.21
	Weekend	317	133	2.38	150	64	47	48	1.02
Airplanes[b]	Weekday	203	56	3.62	86	28	42	50	1.19
	Weekend	284	97	2.93	130	52	46	54	1.17
Helicopters	Weekday	263	59	4.46	114	31	43	53	1.23
	Weekend	319	97	3.29	167	59	52	61	1.17
Traffic	Weekday	177	63	2.81	91	38	56	60	1.07
	Weekend	377	151	2.50	214	87	57	58	1.02
Children and pets	Weekday	173	111	1.50	99	74	57	67	1.18
	Weekend	333	178	1.87	191	109	57	61	1.07

[a] HA is an abbreviation for the term "highly annoyed" which is explained in the text.

[b] Airplanes in this study consisted mainly of single-engine, propeller-driven, general-aviation aircraft, with a small number of jet and prop-jet propelled military and commercial aircraft.

TABLE XI. Rate of noticing bothersome events.

Source	Group	Number bothered; (day plus evening/night)[a]	Actual occurrence; (day plus evening/night)	Ratio R; (column 2/column 1)	10 log(R)
Artillery	Weekday	2.6	6.5[b]	2.5	4.0
	Weekend	2.4	15.0	6.2	7.9
Airplanes[c]	Weekday	3.6	10[d]	2.8	4.5
	Weekend	2.9	13	4.5	6.5
Helicopters	Weekday	4.5	24[d]	5.3	7.2
	Weekend	3.3	24	7.3	8.6
Traffic	Weekday	2.8	12 – 20[e]	4 – 7	6 – 8
	Weekend	2.5	12 – 20	5 – 8	7 – 9
Children and pets	Weekday	1.6	10 – 20[f]	6 – 12	8 – 11
	Weekend	1.9	10 – 20	6 – 11	8 – 11

[a] From Table X.

[b] Base records.

[c] Airplanes in this study consisted mainly of single-engine, propeller-driven, general-aviation aircraft, with a small number of jet and prop-jet propelled military and commercial aircraft.

[d] Records—airfields.

[e] State Highway Department estimate.

[f] Author's estimate.

during the week, only the group composed of respondents normally home days, evenings, and nights on weekends was sufficiently large to analyze and obtain reliable results. These data are similar to the weekday results and are included in Table IX and in the results following (Tables X–XII).

III. QUANTIFICATION OF THE PENALTY WHICH RESULTS BECAUSE EVENTS ARE MORE LIKELY TO BE NOTICED AT NIGHT

As described in the approach, this analysis depends on two primary data sets: respondents' estimates of the frequency of occurrence of bothersome events and physical records as to the actual frequencies of occurrence. Since these latter data were only available by day (0700 to 2200 h) and by night (2200 to 0700 h) it was decided to concentrate only on a nighttime adjustment or penalty.

In order to do this, the frequency of occurrence responses for daytime and evening combined ("overall" daytime) are compared with nighttime for respondents home during the day, evening, and night (Table X). This table uses the summed responses from during the day and evening and compares them to the nighttime responses. Respondents were asked their assessment of frequency of occurrence separately by day (7 a.m. to 7 p.m.), evening (7 p.m. to 10 p.m.), and night (10 p.m. to 7 a.m.). Thus adding the day with evening figures gives the overall respondent assessment of number of bothersome events occurring between 7 a.m. and 10 p.m. This day total is compared with the nighttime number of bothersome events.

Table X contains both weekday and weekend data by source and time period. There is only one significant difference. For helicopters during the day plus evening, the 43% figure for weekdays is significantly different from the 52% figure for weekends at the 0.01 level. So, in general, the weekday and weekend data tend to support one another.

TABLE XII. Percent highly annoyed by impulse noise during daytime and nighttime hours for two ranges of C-weighted day-night average sound level.

LDN range		Day plus evening[a] No. Home	Day plus evening[a] No. HA	Day plus evening[a] % HA[b]	Night No. Home	Night No. HA	Night % HA[b]
	Weekday	83	16	19	59	16	27
> 60	Weekend	112	21	19	57	13	23
	Total[c]	639	112	19	409	106	26
	Weekday	2 422	155	6	1 744	93	5
<60	Weekend	2 896	140	5	1 648	71	4
	Total[c]	17 902	1055	6	12 016	602	5

[a] Day plus evening is a summation of the responses for those people home during daytime with those home during evenings. As such, the percent highly annoyed represents a total daytime average weighted by the relative number of respondents home daytime and/or evening.

[b] Percent HA is the number of "HA" responses divided by the total number of responses during the indicated time period.

[c] The total number is five times the weekday number plus two times weekend number in order to account for the five weekdays and two weekend days in a week.

The first of the center data columns in Table XI summarizes the ratio of the number of noise events noticed and bothersome during daytime hours to the number noticed and bothersome during nighttime hours. In all cases, the ratio is greater than one. More events are noticed and found bothersome during the day than during the night. However, there are many more daytime events to be noticed than there are nighttime events.

The factor of interest (R) is given by:

$$R = \frac{\text{(number noticed and bothersome per night)}}{\text{(physical number of events per night)}} \div \frac{\text{(number noticed and bothersome per day)}}{\text{(physical number of events per day)}} .$$

This factor can be rewritten as

$$R = \frac{\text{(physical number of events per day)}}{\text{(physical number of events per night)}} \div \frac{\text{(number noticed and bothersome per day)}}{\text{(number noticed and bothersome per night)}} .$$

The ratios of physical occurrences were obtained from site records and are also listed in Table XI. Finally, Table XI contains the values (R) and 10 log (R). As discussed in the approach, 10 log (R) yields an indication of the nighttime adjustment or penalty which results because events are more likely to be noticed at night than during the day.

IV. QUALIFICATION OF THE INTRINSIC ANNOYANCE PER BOTHERSOME EVENT

Tables I–V summarize annoyance per bothersome event as the "percent highly" annoyed. This is defined by the ratio of the number of highly annoyed respondents (in a time period) to the number of bothersome events. It can be thought of as "annoyance per bothersome event." Table IX summarizes these data for the three time periods and for day and evening combined (daytime total). These data reveal no significant differences between day and evening. Annoyance per bothersome event does not significantly vary between these two time periods.

Examination of these same data reveals that in most cases annoyance per bothersome event does increase somewhat at night. To better illustrate this increase, the daytime and evening data were combined (as indicated in Tables I–V) to form an all day (7 a.m. to 10 p.m.) percent highly annoyed. Since this is a percentage, it represents a time period weighted average of the daytime and evening data (data which do not differ significantly from one another anyway). Table X lists these data. The ratios of the nighttime to the "all day" percent highly annoyed are shown in the last column of Table X. These ratios can be thought of as the intrinsic increase in annoyance per bothersome event during the night as compared with during the day.

V. AN ALTERNATIVE ANALYSIS TO DETERMINE A NIGHTTIME PENALTY FOR BLAST NOISE

The Construction Engineering Research Laboratory has developed a computerized model for predicting C-weighted DNL contours based upon the operations at Army bases.[23] This program operates in an analogous fashion to other noise contouring programs, but is designed to implement the procedures for assessing high-amplitude transient sounds recommended by the National Research Councils Committee or Hearing, Bioacoustics and Biomechanics (CHABA).[24] Basically, this procedure utilizes a C-weighted DNL to predict community response. It includes a 10-dB nighttime penalty. This formulation discards single event sound exposure levels that are below 85 dB during the daytime and below 75 dB at night. As program options, one can produce contours for night only or for day only and one can select the value of the lowest sound exposure level to be included in the computation.

For this alternate analysis, the above program was utilized separately for day and for night. The value of the lowest sound exposure level included was adjusted downward to 40 dB so that all audible events were included. The thresholds were eliminated so that one could compare the size of the daytime sound exposure level contours with the size of the nighttime sound exposure level contours without presupposing that a 10-dB nighttime penalty was appropriate. The results of this analysis showed that the night only contours (with a 10-dB penalty) are typically 0 to 2 dB greater than the day only contours in areas off-post where the DNL value is in the range from 50 to 70 dB.

The off-post impulse noise survey data were analyzed by C-weighted DNL zone and time period. Table XII contains these results for the 60 to 70 dB and the 50-to 60-dB zones. The data are shown separately for weekdays and weekends and separately for daytime (day plus evening) and for nighttime. The daytime data were developed by adding together the total responses of those respondents indicating that they were normally home during the day to the total for respondents indicating that they were normally home during the evening. For these same two time groups, the numbers of respondents in each group indicating high annoyance were summed. The percent highly annoyed was calculated from these two sums. As indicated above, this additional process represents a weighted average of the two time periods: day and evening. The contour results, however, are based upon the average day, which is a reflection both of weekdays and weekends. In order to combine the weekday and weekend data without too heavily weighting the weekend, the weekday totals were multiplied by 5 and added to the weekend totals multiplied by 2. This weighting should account for the five weekday days and two weekend days in a week. These overall sums were then used to again calculate a revised percentage of respondents highly annoyed. The overall results showed a slight increase in the percent of respondents highly annoyed at night as compared to the day for the higher noise zones and no increase for the lower noise zones.

Since the highly annoyed percentage was the same during daytime and nighttime, one can ask what nighttime adjustment must be incorporated into the DNL formulation such that the daytime and nighttime contours are both approximately the same in size and shape. From the contour analysis contained above, it appeared that a nighttime adjustment on the order of 9 dB was required to establish this equivalence between daytime and nighttime responses.

VI. CONCLUSIONS

The results in Table XI show that bothersome events are more likely to be noticed at night than during the day. This factor alone can justify some nighttime penalty. The value of this penalty appears to be on the order of 5–10 dB.

The intrinsic annoyance per bothersome event (Table X) does not appear to change greatly between day and night although it does increase slightly at night. This result is consistent with previous research which has addressed this specific question.

The results for blast noise differ slightly from the results for the other sources. Blast noise exhibits the smallest increase in likelihood of being noticed at night as compared to daytime. This result is not surprising since the nature of blast noise is a sharp impulse which rises above the ambient and is thus quite noticeable at all times. Put another way, normal indoor or outdoor background noises will not mask blast noise during any time of the day.

Although the increase in likelihood of being noticed is smallest, blast noise exhibits the largest increase in intrinsic annoyance per bothersome event. If one takes into account the results of the alternative analysis which indicated a nighttime penalty on the order of 9 dB, then one can suggest that the two factors (i.e., increase in likelihood of being noticed and increase in intrinsic annoyance per bothersome event) are combining to yield a nighttime penalty for blast noise which is also on the order of 5 to 10 dB.

Overall, these results tend to support retention of a nighttime penalty in descriptors such as DNL. Further, based on these results, one would not be tempted to depart from the long-established 10-dB value for the penalty. Most importantly, this study indicates that the increase in the likelihood of an event being noticed at night as compared with day is a main factor in favor of the existence of a nighttime penalty. The increases in the intrinsic annoyance per bothersome event is not as important a factor.

ACKNOWLEDGMENT

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Paper 7

Assessment of community response to impulsive noise

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The U.S. Army Construction Engineering Research Laboratory has completed community attitudinal surveys at two major Army installations. The main purpose of these surveys was to better understand community response to the impulsive noise generated by large Army weapons such as tanks, artillery, or demolition. The results show that an energy type of model such as the C-weighted day/night average sound level (CDNL) is the best available descriptor for community response for these types of impulsive sound. Growth in annoyance to all noises increases monotonically with both sound amplitude and frequency of occurrence. This descriptor should incorporate a nighttime adjustment on the order of 10 decibels (dB). The exact function for relating the percentage of a community highly annoyed to CDNL remains in question. It appears that the present National Academy of Science Committee on Hearing, Bioacoustics and Biomechanics (CHABA) recommendation may underestimate actual annoyance, and that the functional relation between annoyance and CDNL should be shifted by 3–4 dB. However, more research on (a) the percentage of a community highly annoyed versus CDNL and (b) the existence and value of community rise- and decay-time constants is required to clarify this issue.

PACS numbers: 43.50.Ba, 43.50.Qp, 43.50.Sr, 43.50.Pn

INTRODUCTION

Descriptors for community reaction to noise have been the focus of study for at least the past quarter century. Common to the assumptions inherent in most of these descriptors are three hypotheses[1]:

(1) The community response increases monotonically with sound amplitude;

(2) the community response increases monotonically with frequency of occurrence; and

(3) the community response to sound exposure at night increases compared with the same sound exposure during daytime.

The Day–Night Average Sound Level, DNL, is a typical representation of these descriptors. Inherent in this descriptor are the hypotheses that the community reaction grows in direct proportion to the growth in sound exposure level (SEL), that the community reaction grows in proportion to 10 log of the number of events, and that a nighttime (2200–0700) adjustment or "penalty" of 10 dB is appropriate. Other descriptors, such as the Community Noise Equivalent Level (CNEL), inherently incorporate the hypothesis of an evening (1900–2200) penalty of 5 dB in addition to the nighttime penalty. These descriptors are typical of a number of descriptors which are termed "equal energy" models in that a growth of 3 dB in SEL is considered equivalent to a doubling of the number of events.

This paper concentrates on these issues. This analysis is based upon community attitudinal survey data gathered by the U.S. Army Construction Engineering Research Laboratory in the vicinity of two large Army bases. The purpose of the overall survey was to examine community response to the impulsive noise generated by such sources as artillery or tanks and helicopters as compared with more normal noise sources such as fixed-wing aircraft, street traffic, and children.

Two types of data are required for a total attitudinal survey analysis; attitudinal information, computer-predicted noise zone maps, and physically monitored site-specific information. This paper describes the measures and procedures used to develop and obtain these data in the vicinity of Fort Lewis, Washington, and compares the results of that study to one performed earlier in the vicinity of Fort Bragg, North Carolina. The Combined Army Survey results[2–4] are compared with sonic boom results[5] and with the recommendations of Working Group 84 of the National Academy of Science Committee on Hearing, Bioacoustics and Biomechanics (CHABA).[6]

The survey instrument was a questionnaire developed by the U.S. Army Construction Engineering Research Laboratory (CERL) and outside consultants. To enhance the cross-comparability of CERL's data, CERL adopted the five-level adjectival description scale for annoyance used in many earlier American surveys. Using this scale, survey respondents could rate themselves to be (1) not at all annoyed, (2) slightly annoyed, (3) moderately annoyed, (4) very much annoyed, or (5) extremely annoyed. Respondents who chose the latter two ratings, "extremely annoyed" and "very much annoyed," were combined into a single "highly annoyed" category. This questionnaire was the same instrument used for a similar, earlier study performed at Fort Bragg, except that a few open-ended questions were deleted.

The survey instrument was typical of those previously used in the United States and other Western countries. It was administered by interviewers and took about 30 min. The University of Illinois Survey Research Laboratory (SRL) handled the details of survey administration and sampling.

Using the procedures recommended by Working

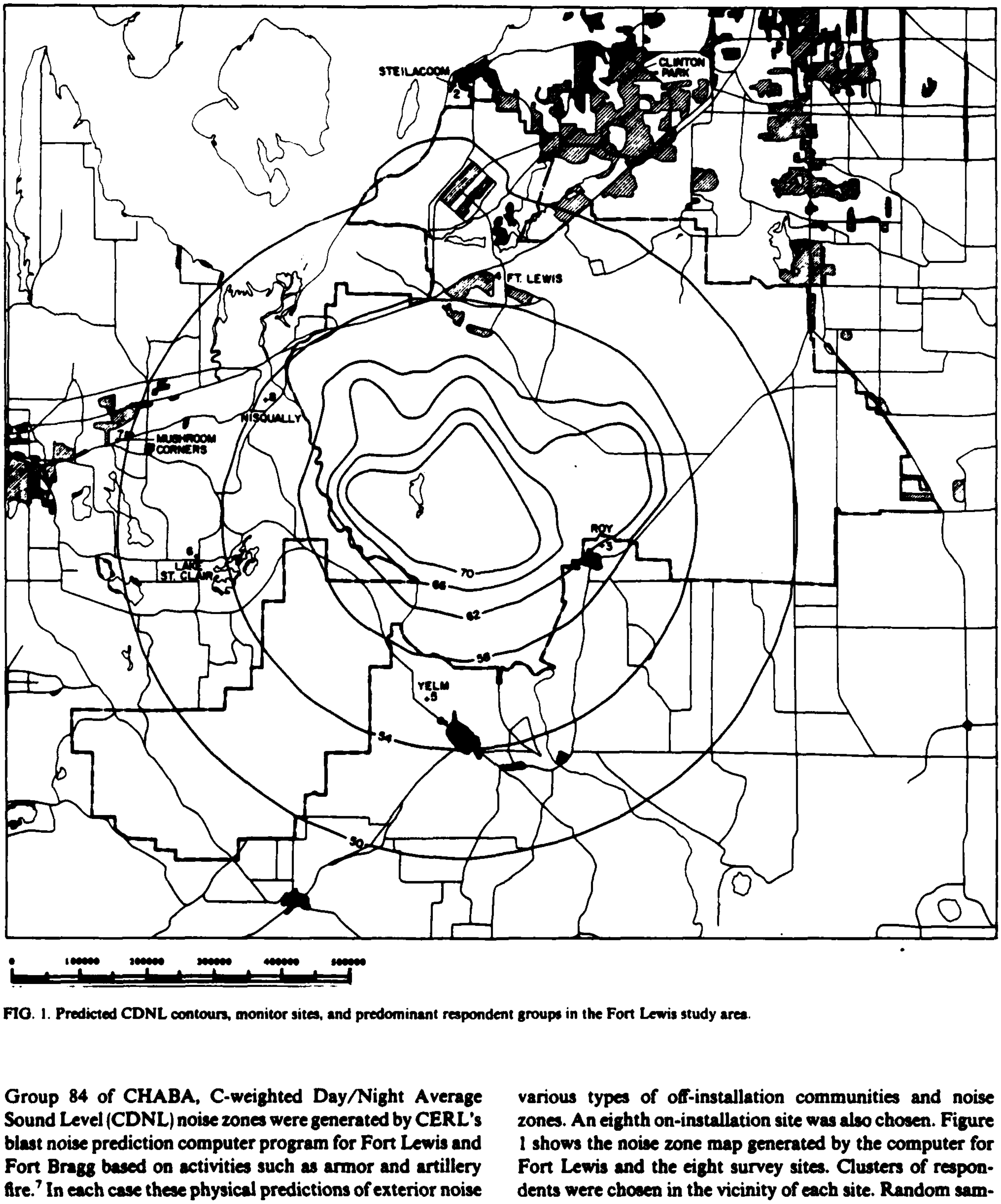


FIG. 1. Predicted CDNL contours, monitor sites, and predominant respondent groups in the Fort Lewis study area.

Group 84 of CHABA, C-weighted Day/Night Average Sound Level (CDNL) noise zones were generated by CERL's blast noise prediction computer program for Fort Lewis and Fort Bragg based on activities such as armor and artillery fire.[7] In each case these physical predictions of exterior noise zones were based on a whole year's operational data.

Fort Bragg is adjacent to Fayetteville, NC, on the east and southeast with smaller towns nearby to the south and west. The Fort Bragg test plan called for random survey sampling in the various noise strata and a quasirandom distribution of 15 monitoring locations throughout the study area. The Fort Bragg study is described in detail in Refs. 2–4.

At Fort Lewis, seven sites are chosen to represent the various types of off-installation communities and noise zones. An eighth on-installation site was also chosen. Figure 1 shows the noise zone map generated by the computer for Fort Lewis and the eight survey sites. Clusters of respondents were chosen in the vicinity of each site. Random sampling was used within a cluster area if the area's population was large enough; other areas were exhaustively sampled. Table I lists the goals set for the number of completed interviews in each cluster area and the actual number of completed interviews at each cluster site. Impulsive noise monitoring using the CERL noise monitor was performed at each of these eight locations for the 6 months before the attitudinal survey was administered.[8]

TABLE I. Cluster/monitor sites in the vicinity of Fort Lewis.

Site number	Site name	Metric grid coordinates	Number of surveys (goal)	Number of surveys completed
1	Clinton Park (Tacoma)	35 800, 223 700	150	109
2	Steilacoom	29 700, 223 300	150	153
3	Roy	35 100, 206 050	150	146
4	On-Installation (Davis)	30 700, 216 000	200	197
5	Yelm	28 500, 200 200	200	198
6	Lake St. Clair	19 800, 205 550	150	160
7	Mushroom Corners (Olympia)	16 800, 209 950	150	143
8	Nisqually	22 350, 211 500	150	147
			1300	1253

Fort Lewis is adjacent to Puget Sound, just south of Tacoma and somewhat north of Olympia. There are extensive housing areas on perhaps one-third or one-fourth of the installation's perimeter; the remainder of the perimeter is of a rural or sparse surburban character. The survey cluster areas were chosen to represent all the different types of communities on the installation perimeter. The survey's sample design and monitoring strategy departed markedly from that used at Fort Bragg and was designed to streamline data collection and enhance the results. Rather than use the Fort Bragg method, which called for random survey sampling and quasirandom noise monitoring within the total noise strata, the Fort Lewis study closely coupled the noise monitoring with the sample design. Thus eight cluster sites were chosen for intensive study based on geological area and computer-predicted CDNL noise zones.

CERL's monitoring procedures were used successfully at Fort Bragg to obtain a fair comparison between predicted and measured values. However, these same monitoring procedures failed at Fort Lewis. The monitoring procedures are designed to minimize inclusion of nonblast noises into the measured CDNL. Only blast noises having a peak level in excess of 105 dB are included. Any noises having a duration greater than 2 s are recorded on analog tape and later listened to by a technician to insure that it is not a nonblast noise such as helicopter noise. If the wind speed goes above a preset threshold of 18 km/h, the data are discarded. Clearly, these procedures, which are designed to insure that only blast noise is used in the measured total, will eliminate some valid blast noises from the measured total. Also, since weather patterns and resulting sound propagation conditions are seasonal, the 5-month period of measurement at Fort Lewis possibly was insufficient. Reference 9 offers more details on these monitoring issues.

The results of the monitoring are inconsistent with the survey results. As will be shown, the community attitudinal results compare favorably with the predicted noise zone map for Fort Lewis. However, the attitudinal survey results imply far too much annoyance when arrayed against the measured noise data. Because of this monitoring problem, this paper uses only the CDNL noise zones predicted by the computer for correlation with the attitudinal survey data. If only the monitored data had been used, the analysis results would have implied that (1) communities have large levels of annoyance to very low levels of impulsive noise, (2) the current National Academy of Science recommendation and Army procedures greatly underestimate the community annoyance, and (3) CERL's noise contour computer program greatly overestimates the physical noise. However, the large body of scientific data already accumulated indicates that the community annoyance was not greatly underestimated, and, hence, the computer program is not greatly overestimating the physical sound. Rather, it appears that state-of-the-art blast noise monitoring procedures may not accurately quantify physical sound levels in all cases because of source identification and temporal sampling limitations.

A. Questionnaire design

Two survey instruments were used: the Interviewer Report Form (IRF) and the Community Attitudes Survey (CAS) questionnaire. The questionnaire was designed to determine what noises people hear, their frequency and level of annoyance, and to compare various noises.

The IRF was completed by the interviewer, based on his/her observations. Demographic data about the respondent and his household, house, and neighborhood were recorded in addition to the respondent's attitude toward noise.

The CAS begins by asking information on the respondent's neighborhood rating, his likes and dislikes about the neighborhood, and if the respondent every considered moving away. After this general beginning, questions 9–35 are devoted to noise. Question 9 was intended to find out what noises the respondent hears; the interviewer was allowed to prompt the respondent by naming specific noise sources. Question 10 evaluated the frequency and magnitude of the noises. Question 11 evaluated the seasonality and general annoyance level.

Questions 12–18 addressed the frequency of occurrence and the annoyance level of noises heard for various times of the day; it also established whether the noises occurred on weekdays or weekends. Questions 20–22 and 27 evaluated the extent to which noise interfered with the respondent's activities. Questions 23 and 24 dealt with vibration and damages caused by noises. Questions 25 and 26 were concerned with frightening or startling noises. Question 27 asked whether noise interfered with activities which require care and concentration. Questions 19 and 28 asked about what noises disturbed the respondent's sleep, rest, or relaxation. Question 29 asked about noises which disturbed others in the household. Question 30 evaluated the respondent's opinion of how much could be, should be, and is being done about noises. Questions 31 and 32 asked about the respondent's sensitivity to noises. Questions 33 and 34 dealt with the respondent's attitude toward Government installations and asked him whether he thought he should complain to them about noises. Question 35 asked if the respondent owned his home. Questions 36–39 were demographic questions.

Survey data were analyzed by CERL using the Statistical Package for the Social Sciences on a CDC 6700 computer located at Boeing Computer Services, Renton, WA.

B. Fort Lewis survey results

The remainder of this paper will discuss the results of the Fort Lewis survey and compare them with the survey results reported in Refs. 2–4. The referenced papers described the community attitudinal survey, computer prediction, and direct monitoring results for Fort Bragg, a large Army installation. Specifically, Ref. 2 describes the growth of annoyance with increases in loudness of events or increases in frequency of occurrence of events. Reference 3 suggests the overall descriptor to relate community response to blast noise. Reference 4 describes nighttime adjustments or penalties for noise descriptors. Each of these papers builds its case and develops its conclusions based on a set of tables listing data reduced in various fashions. In each paper, a subset of the total tables are used to support the final conclusions of that paper. In this paper, the most important tables are presented for the combined Fort Lewis–Fort Bragg data set, and general conclusions are developed based on this enlarged data set.

One of the most remarkable results of the Fort Lewis study is that there generally are not statistically significant differences (at 95% confidence level) between the Fort Lewis and the Fort Bragg study. Those differences which do exist are concerned mainly with airplanes, street traffic, and neighborhood noise sources (children and/or pets), and not with blast noise sources or helicopters. Thus the analysis and results in this paper are greatly strengthened since they are based on the combined results of two surveys administered at different times and in different parts of the country.

In light of the second (Fort Lewis) survey results, this paper again analyzes (1) the growth of community response with increases in loudness or frequency of occurrence, (2) the overall descriptor with which to assess impulsive noise, and (3) the overall existence and numerical value of nighttime adjustments or penalties. The combined results reinforce the materials in Refs. 2–4. The main result—the percentage of a community which is "highly annoyed" as a function of the CDNL—is indistinguishable between Fort Lewis and Fort Bragg.

I. GROWTH OF COMMUNITY RESPONSE WITH INCREASES IN LOUDNESS OR FREQUENCY OF OCCURRENCE OF EVENTS

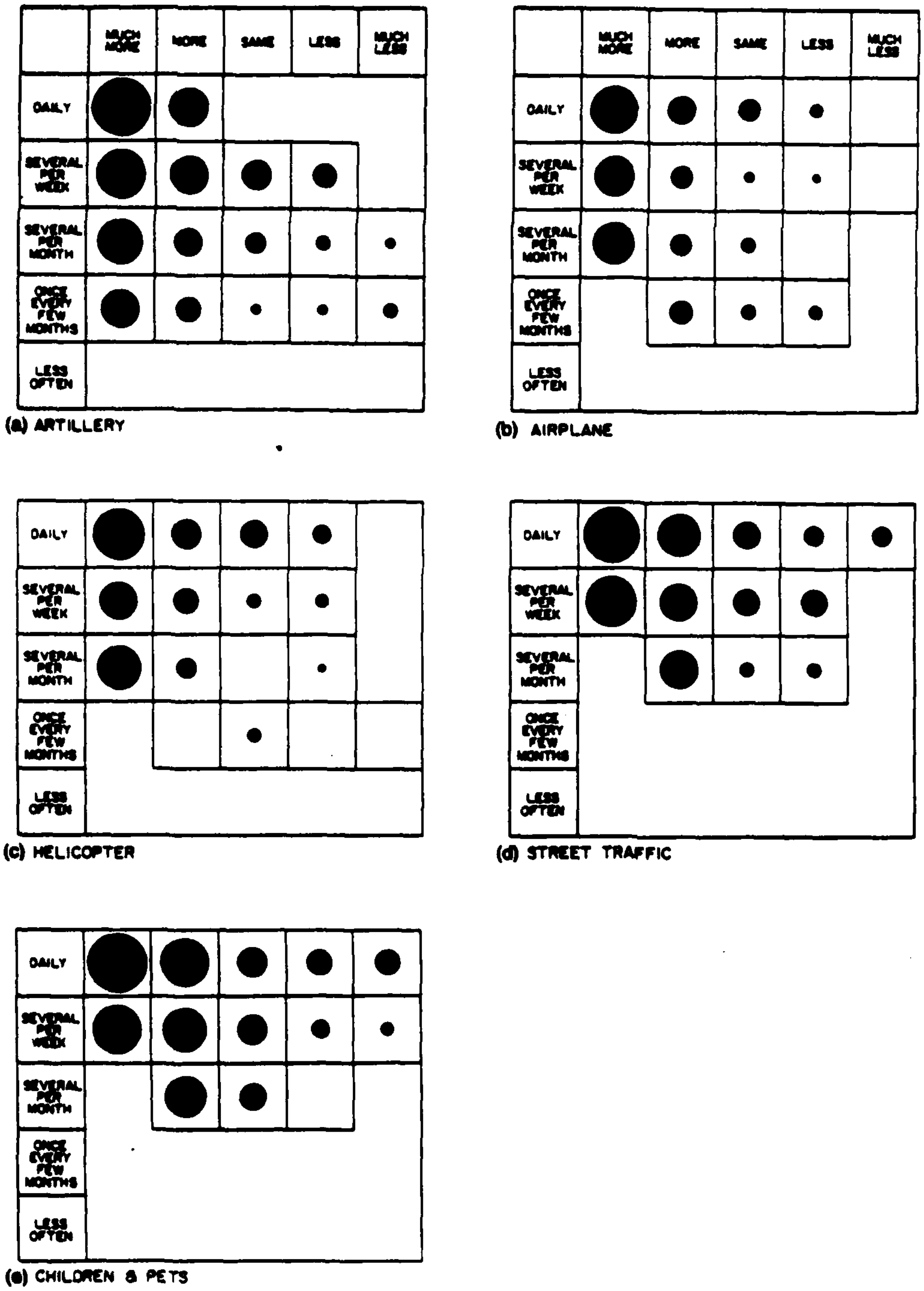
References 2 and 10 describe the increase in community response with increases in loudness of events or with increases in frequency of occurrence of events. For the Ref. 2 analysis, respondents were classified by their own perception of how loud the source was and its frequency of occurrence, rather than by exterior noise zone. This was done because, even if the exterior noise in an area is a constant, differing types of building construction, lifestyles (e.g., televisions or radios on or off), and window and room exposures with respect to rather localized noise sources (children, street traffic, etc.) may combine to produce a rather large uncertainty as to the actual exposure received by any individual respondent. This approach of classifying respondents by their judgment of loudness should help eliminate the variability in results one gets within a noise zone because of variations in the interior noise level with a constant exterior noise level. For example, respondents normally having windows open may judge the sounds as louder than do respondents with windows normally shut. The former respondents may also be more annoyed because of the increased loudness they experience.

There was a second reason for this rather unconventional analysis approach. In a conventional analysis, exterior noise zones are predicted and measured based on amplitude of events and frequencies of occurrence, both of which are highly correlated within any noise zone because of the physical realities of the situation. That is, amplitude and frequency of occurrence are highly correlated and it is impossible to independently analyze the growth of annoyance with frequency of occurrence and with loudness of events for a given area by analyzing the responses of individuals within a given noise zone. It is differing building construction and building orientation which cause the variations in actual received loudness and frequencies of occurrence by respondents indoors, and it is differing lifestyles which further vary respondents' perceptions of these quantities. Since this study did not have the resources to measure the received dose of each respondent to each source, the next best way to perform the study was to use the respondents' own perception of loudness and frequency of occurrence of events.

Naturally, the reader will wonder how closely a respondent's answers correspond with the actual interior loudness and frequency of occurrence. Although proof that respondents are "accurate noise monitors" is impossible without indoor measurements, the analysis given at the beginning of Ref. 2 indicates that respondents generally differentiate between varying amplitudes and frequencies of occurrence. The results of both the Fort Bragg and Fort Lewis studies show that responding groups nearer to the installation report blast noise sources as louder and more frequent than do those groups further from the installation. These results correspond with the physical situation.

Both the Fort Bragg and Fort Lewis surveys consider five noise source categories: (1) artillery, (2) airplanes, (3) helicopters, (4) street traffic, and (5) children and/or pets. For each category, the data were arrayed by loudness, frequency of occurrence, and percentage of respondents "highly annoyed." Figure 2 presents these data. Within a cell, the size of the circle is proportional to the percentage of respondents "highly annoyed." The aggregated data in this figure clearly show that, for all sources, annoyance increases as frequency of occurrence increases or as perceived loudness increases, or as both increase.

To better examine the growth in the percentage of respondents "highly annoyed" as a function of increase in frequency of occurrence, data were aggregated across all levels of loudness and across several source categories. For each frequency of occurrence, sums were calculated over all five loudness ranges. In some cases, these totals were further aggregated over two or more types of sources such as fixed and rotary using aircraft. This yielded the number of respondents who indicated they were "extremely annoyed" or "very much annoyed," plus the total number of respondents. These calculations were done for the following noise source



(a) ARTILLERY

(b) AIRPLANE

(c) HELICOPTER

(d) STREET TRAFFIC

(e) CHILDREN & PETS

FIG. 2. A pictorial representation of the percentage of respondents "highly annoyed" as a function of perceived loudness (compared with normal conversation) and perceived frequency of occurrence.

categories: (1) artillery alone, (2) helicopters alone, (3) traffic + children and/or pets + airplanes, (4) traffic + children and/or pets + airplanes + helicopters, and (5) helicopters + traffic + airplanes. These groups were chosen to contrast (1) blast with helicopter noise and (2) blast or helicopter noise with all other noise categories. Table II lists and Fig. 3 illustrates some of these data. While the percentage in Table II for blast noise is higher than for other noise sources, the *ratios from one frequency to the next are similar from source to source.* Table III indicates the ratio of "highly annoyed" from one frequency of occurrence to the next (one row to the next) within each group. For example, the 1.4 in column 1 is the ratio of 40 (the percentage for daily) to 28 (the percentage for several per week).

These data reveal five general trends:

(1) Table II shows that for a given frequency of occurrence, the percentage of respondents annoyed by blast noise is somewhat larger than for the other noise sources. The other noise sources are otherwise quite similar.

(2) Table III shows that the first three ratio changes for all other noises as compared with blast noise (and indeed across all noise sources) are quite similar. (Helicopters de-

TABLE II. Aggregated data overall loudness by frequency of occurrence; percentage of respondents "highly annoyed" (number in cell in parentheses).

Frequency	Blast[a]	Helicopter	Traffic + children + aircraft	Helicopter + traffic + children + aircraft	Helicopter + traffic + aircraft
Daily	40 (176)	29 (664)	26 (2474)	27 (3138)	25 (2228)
Several per week	28 (700)	15 (668)	16 (1271)	16 (1939)	15 (1565)
Several per month	17 (900)	8 (440)	10 (579)	9 (1019)	8 (909)
Once every few months	8 (492)	2 (156)	8 (188)	5 (344)	4 (308)
Less often	2 (63)	2 (48)	8 (133)	6 (247)	6 (204)

[a] The percentage of respondents "highly annoyed" to blast noise was compared to the other four noise groups using Fishers' exact test. The blast percentage is significantly (0.01 level) higher than the other for each of daily, several per week, and several per month frequencies. For once every few months, it is significantly higher than the helicopter percentage and the helicopter + traffic + aircraft percentages. There are no significant differences for the less often frequency.

part somewhat on the third ratio, i.e., several per month to once every few months.)

(3) In Table III, the last ratio change in the blast noise column (once every few months to less often) is much larger than for the other noise sources. As shown in Fig. 3, this result indicates that the community response integration period for blast noise apparently extends down to and beyond once every few months.

(4) For the other sources, the integration period appears to be shorter, extending down to occurrences more on the order of several per month or once every few months.

(5) All of the sources (in terms of community annoyance) become unimportant when occurrences drop to less often than once every few months.

Table IV examines the growth function with respect to loudness by averaging, by source and combination of sources, over frequencies of occurrence. It lists results for (1) each source alone, (2) children and/or pets + traffic, and (3) blast sources + helicopters + airplanes. (The latter two groups were formed because their members are significantly different from one another.) Table V indicates the ratio change in the percentage of respondents "highly annoyed" from one loudness to the next within each group. Unlike Table III, which revealed that the ratio changes are about the same from one source to another (except for very infrequent occurrences), the ratio changes with loudness are different from one type of source to another. The trends indicate that the five sources can be divided into the two groups: (1) blast sources + helicopters + airplanes, and (2) street traffic + children and/or pets (see Fig. 4). These groups have two distinct differences between them. For a given loudness, there is a substantially higher percentage of respondents "highly annoyed" by street traffic + children + pets than by the other source group. The first ratio ("much more annoyed" to "more annoyed") for blast + aircraft is twice the value of the other group.

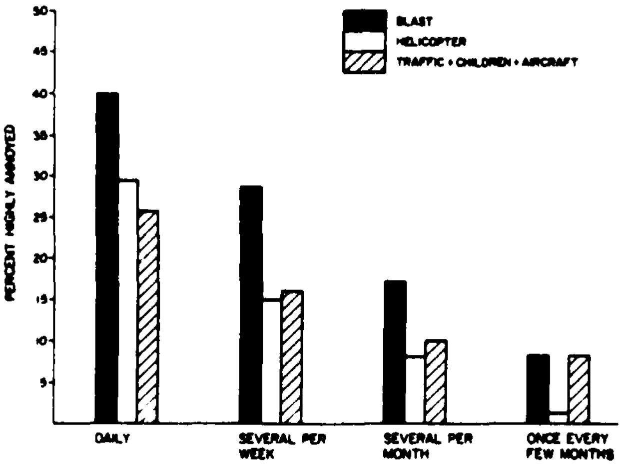


FIG. 3. Judged frequency of occurrence.

II. AN OVERALL DESCRIPTOR TO CORRELATE COMMUNITY RESPONSE WITH IMPULSIVE NOISE

The purpose of this section is to array and discuss dose-response data for impulsive noise. The dose is taken as the CDNL descriptor recommended by CHABA. This CDNL descriptor incorporates a threshold which, in effect, discards single events with daytime exposure levels of less than 85 dB and nighttime exposure levels of less than 75 dB. Response is defined in terms of the percentage of respondents "highly annoyed"; i.e., "highly annoyed" respondents are those that answer in the top two categories of the five-point adjectival scale to the overall question about their annoyance towards blast noise in their community. Table VI lists study areas at Fort Bragg and Fort Lewis and their corresponding CDNL.

TABLE III. Ratio increase in percentage of respondents "highly annoyed" with an increase in perceived frequency of occurrence.

Frequency	Blast[a]	Helicopter	Traffic + children + aircraft	Helicopter + traffic + children + aircraft	Helicopter + traffic + aircraft
Daily to several per week	1.4	1.9	1.6	1.7	1.7
Several per week to several per month	1.6	1.9	1.6	1.8	1.9
Several per month to *once every few months*	2.1	4.0	1.3	1.8	2.0
Once every few months to less often	4.0	1.0	1.0	0.8	0.7

At Fort Bragg, the estimated CDNL attached to each study area was based on a combination of the monitoring results and a computer-predicted noise zone (for details, see Ref. 3). However, the estimated CDNL zones at Fort Lewis are based solely on the computer prediction because the monitored results were so much less than the computer prediction. Table VI also summarizes the overall community response for the various cluster areas for both the Fort Bragg and Fort Lewis studies. The table lists, by cluster, the number and percentage of respondents answering in the five annoyance categories. The percentage of respondents "highly annoyed" is the sum of those answering "extremely annoyed" or "very much annoyed" divided by the total number of respondents (including those who said they never hear blast noise).

Question 33 of the CAS asked: "Do you think people around here ought to complain about the noise from Government facilities or operations if they find it annoying?" The possible answers were "yes" or "no." Table VI shows, by area, (1) the group size; (2) the percentage of that group answering "yes" to question 33, and (3) the percentage of the group that indicated overall high annoyance (i.e., those who responded either "extremely annoyed" or "very much annoyed" to the overall annoyance question dealing with artillery noise) as a function of whether question 33 was answered "yes" or "no." These results show that whether the respondent thinks he ought to complain strongly correlates with his judgment on overall annoyance. The difference between the ratios for the "yes" and "no" group is about a factor of 4.

The last column in Table VI gives the overall percentage of respondents "highly annoyed" adjusted to represent the likely results for each group if 62% of the respondents in each group answered question 33 "yes." The 62% value is somewhat arbitrary. It represents approximately a population-weighted average of the data. This normalization process allows a better comparison between the different areas.

TABLE IV. Aggregated data for overall frequency of occurrence by loudness and percentage of respondents "highly annoyed" (number in cell in parentheses).

	Loudness				
Loudness/source	Much more	More	Same	Less	Much less
Blast	41 (689)	18 (626)	8 (457)	4 (405)	3 (154)
Airplane	35 (438)	11 (564)	5 (407)	1 (277)	2 (101)
Helicopter	42 (563)	11 (629)	5 (432)	2 (260)	1 (92)
Traffic	52 (242)	30 (403)	12 (346)	8 (289)	4 (100)
Children	58 (215)	39 (375)	16 (444)	8 (305)	7 (139)
Blast + Airplane + Helicopter[a]	40 (1690)	14 (1819)	6 (1296)	3 (942)	2 (347)
Traffic + Children	54 (457)	35 (778)	15 (790)	8 (594)	5 (239)

[a] The percentage of respondents "highly annoyed" by the "blast + airplane + helicopter" group are significantly (at least the 0.05 level) and substantially smaller than for the "traffic + children" group. There are small (although sometimes significant) differences between the "blast," "airplanes," and "helicopters" groups, but no significant differences between the "traffic" and "children" groups.

TABLE V. Ratio of the increase in percentage of respondents "highly annoyed" with an increase in perceived loudness.

Noise source	Loudness Much more to more	 More to same	 Same to less	 Less to much less
Blast	2.3	2.2	2.0	1.3
Airplane	3.2	2.2	5.0	0.5
Helicopter	3.8	2.2	2.5	2.0
Traffic	1.7	2.5	1.5	2.0
Children	1.5	2.4	2.0	1.1
Blast + airplane + helicopter	2.9	2.3	2.0	1.5
Traffic + children	1.5	2.3	1.9	1.6

Also, the 62% value is consistent with the results of sonic boom studies in Oklahoma City, where about 65% of the respondents thought they should complain about Government facilities and 35% thought they should not complain. In that study, all data for those respondents who felt they should not complain were deleted. Only data for those respondents who felt they should complain were considered in the Oklahoma City study's overall calculations and results. The 62% factor was used to generate the data in Table VI; it was felt this value more reasonably represents the overall community than a value obtained by deleting data for respondents who thought they should not complain.

A. Activity interference data, home ownership, and employment

The CAS had ten questions about activity interference. These are listed in Ref. 3 and not included here for the sake of brevity. The general analysis and results for Fort Lewis and for the combined data are the same as for the Fort Bragg data. The main impulsive noise problems are house rattles, startle, and fright. By way of comparison, the main problem for other sources, such as airplanes and helicopters, is speech interference. Sleep interference also is a problem with street traffic and neighborhood noise sources.

The activity interference data also seem to indicate that blast noise is potentially as bad or worse than other noises in terms of adverse health effects. Sleep interference is cited as often for blast noise as for any other source—even at Fort Lewis, where less than 2% of the blast noise events occur at night, and startle and fright, the factors known to cause physiological reactions, occur most often for blast noise. Only the incidences of interference with communications or out-of-doors activities are lower for blast noise than for other noises, and those are factors which will not directly contribute to adverse health effects.

For blast noise, the data were examined to compare the responses of those who owned their home versus those who rented. This comparison only used data from respondents who lived off the military installation (on-installation housing is not privately owned). The comparison was done for each of the areas listed in Table VI. No statistically significant differences were found for the overall level of high annoyance for those who owned their homes as compared with those who rented.

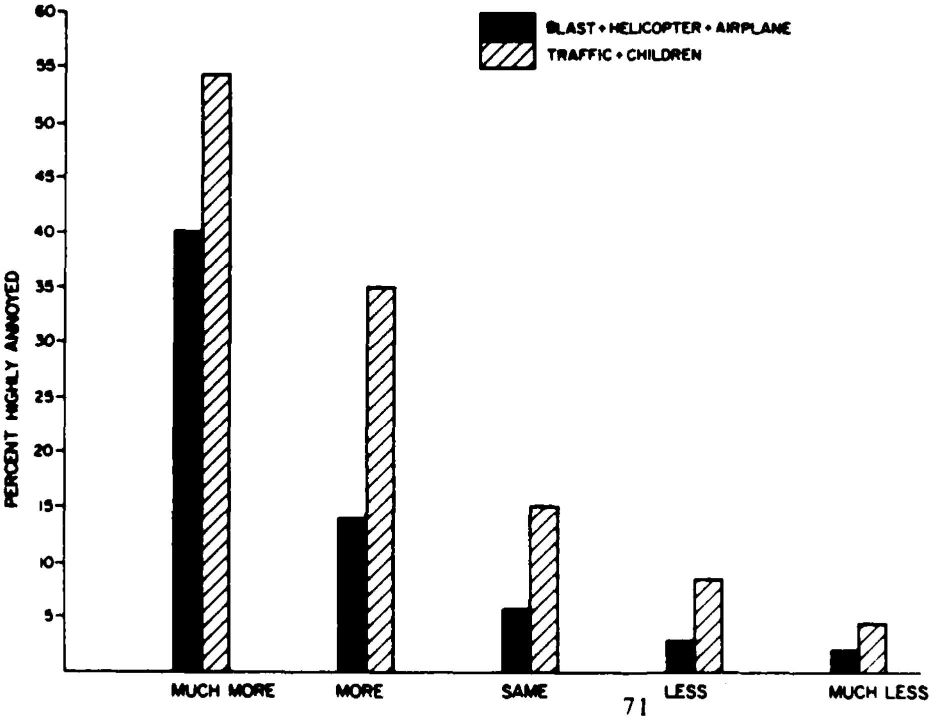


FIG. 4. Judged loudness (traffic + children compared with blast + helicopter + airplanes).

TABLE VI. Survey study areas, CDNL[a] and percentage of respondents "highly annoyed": those who feel they should complain versus those who feel they should not complain about noise from government facilities.

Fort Bragg[b]	CDNL	Group size	% should complain	"Highly annoyed" (should complain)	"Highly annoyed" (should not complain)	Overall percentage "highly annoyed"	Adjusted percentage "highly annoyed"
High	68	72	51	45.9	14.3	30.6	33.9
Fay W	54	174	60	20.0	2.8	13.2	13.5
Fay E	52	919	62	11.8	2.8	8.4	8.4
Base W	56	204	64	15.3	5.5	11.8	11.6
Base E	53	204	68	7.2	0	4.8	4.5
Base total	55	408	66	11.1	2.9	8.2	8.0
South	49	74	68	28.0	0	18.9	17.4
Near W	46	251	53	8.3	5.1	6.8	7.1
Far W	40	42	53	0	0	0	0
Fort Lewis[c]							
Clinton Park	48	126	52.4	15.2	0	8.8	9.4
On-installation	50	206	64.1	25.0	6.9	19.4	18.1
Lake St. Clair	62	163	58.3	44.2	7.6	28.8	30.3
Mushroom Corner	55	150	66.0	19.2	3.9	14.0	13.4
Nisqually	57	149	57.7	34.9	4.8	22.8	23.5
Roy	54	154	66.2	41.2	6.2	29.2	27.9
Steilacoom	52	155	62.6	7.2	3.6	5.8	5.8
Yelm	55	204	61.8	31.8	10.3	23.5	23.6

[a] For the year before the survey.

[b] Combination of monitored data and computer prediction.

[c] Computer prediction only.

The data were also examined to compare responses for households with one or more members employed by the Government with households which had no Government employees. Again, no statistically significant differences could be found in any area.

III. TIME OF DAY ADJUSTMENTS

Traditionally, descriptors for community reaction to noise have included nighttime adjustments, typically on the order of 10 dB. Some descriptors, such as the community noise equivalent level (CNEL), incorporate an evening adjustment (5 dB for the CNEL descriptor) in addition to the nighttime penalty.

Why must there be a time period adjustment or "penalty?" Several considerations, both acoustical and nonacoustical, which indicate the plausibility of using a time period adjustment are discussed in Ref. 4. One of the purposes of this paper is to quantitatively examine the possibility that noisy or bothersome events are more likely to be noticed during one time period as compared with another. For example, the noise of children playing or dogs barking may be much more noticeable at night than during the day. Because the noise is noticed more, the overall annoyance may increase. This paper will also examine the influence of intrinsic annoyance per event on time-period-related annoyance. In addition, for blast noise, the first Heathrow survey approach is used to help decide whether applying some overall nighttime adjustment is advisable.[11]

An energy-type descriptor is used to approximately quantify the respondent's rate of noticing annoying events. As discussed in this paper and Refs. 2, 8, and 10, annoyance increases when respondents subjectively notice annoying events more frequently. Thus community response to impulsive noise exposure appears to fit an energy model. Many other studies show that community response to transportation noise exposure fits an energy model.[12] Since all of the sources in this study appear to fit an energy model, the model can be used to approximately quantify the adjustment implied by changes in a respondent's likelihood of noticing bothersome events during one time period or another. If the 10-log (number of events) factor is applied to the number of events noticed by a respondent (in contrast to the number counted from physical records), then some notion can be developed about the importance of the rate of noticing bothersome events.

This factor can be addressed by comparing the known physical frequency of occurrence ratio between one time period and another with the respondent reported ratio of the frequency of annoying events between one time period and another. For example, respondents may be bothered by twice as many events during the day as during the night. If, however, there are ten times as many actual occurrences during the day as during the night, then respondents (on an equal-number-of-occurrences basis) are being bothered by one-fifth as many of the available events during the day as during the night. On a 10-log basis, this would indicate that an adjustment of 7 dB should be applied to events during the night.

The community response survey asked respondents how often they were bothered by various events during the day (0700 to 1900 h), evening (1900 to 2200 h), and night (2200 to 0700 h). Records were available on relative-event frequencies by day and night for blast noise and for fixed-

TABLE VII. Comparison of responses for respondents home all times (weekdays versus weekends).

Source	Group	Numbered bothered			Number highly annoyed			Percent highly annoyed		
		Day + evening	Night	Ratio day + evening/night	Day + evening	Night	Ratio day + evening night	Day + evening	Night	Ratio night/ day + evening
Artillery	weekday	514	197	2.61	250	108	2.31	49	55	1.12
	weekend	663	248	2.67	319	132	2.42	48	53	1.10
Airplanes	weekday	298	77	3.87	119	33	3.61	40	43	1.08
	weekend	406	123	3.30	182	63	2.89	45	51	1.13
Helicopters	weekday	399	82	4.87	169	37	4.57	42	45	1.07
	weekend	499	139	3.59	249	82	3.04	50	59	1.18
Traffic	weekday	301	109	2.76	152	62	2.45	50	57	1.14
	weekend	589	225	2.62	296	127	2.33	50	56	1.12
Children	weekday	265	169	1.57	146	109	1.34	55	64	1.16
+ Pets	weekend	513	282	1.82	294	179	1.64	57	63	1.11

wing and rotary-wing aircraft; official estimates were available for traffic noise. Thus data were available to do a quantitative analysis of respondents' rates of noticing bothersome events.

Quantifying the intrinsic annoyance value of an event as a function of the time period is less straightforward. Respondent data are used to assess annoyance per bothersome event as a function of time period. However, no generally acceptable means exist to quantify shifts in annoyance per bothersome event in terms of a change in CDNL. Fortunately, these shifts appear to be small.

During the data analysis for this study, a nighttime adjustment was also developed by using the first Heathrow survey method to examine blast noise. Daytime and nighttime exposure and their respective resulting community response (annoyance) were compared to establish change in C-weighted average sound level required to make daytime and nighttime predictions of annoyance equivalent.

Respondents were asked whether they were generally home during the day, evening, or night; the question was asked separately for weekdays and weekends. Respondents who said they were at home during a given time period were then asked if they were bothered by any particular noise sources and, if so, how often they were bothered. They could respond (1) every day, (2) several times a week, (3) several times a month, (4) once every few months, (5) less often, or (6)

TABLE VIII. Calculation of nighttime adjustments (weekday data).[a]

Source	Group	Reported[b] frequency of being bothered ratio	Actual ratio of occurrence	R^c	10 log(R)	10 log(R avg)
Artillery	Bragg	2.59	6.5[d]	2.5	4.0	12.6
	Lewis	2.63	88.1[d]	33.5	15.3	
Airplanes	Bragg	3.62	10.2[e]	2.8	4.5	4.1
	Lewis	4.52	10.2[f]	2.3	3.5	
Helicopters	Bragg	4.46	24[f]	5.3	7.2	6.7
	Lewis	5.91	24[g]	4.1	6.1	
Traffic	Bragg	2.81	12–20[h]	4.3–7.1	6.3–8.5	7.5
	Lewis	2.70	12–20[h]	4.4–7.4	6.4–8.7	
Children and/or pets	Bragg	1.56	10–20[i]	6.4–12.8	8.1–11.1	9.6
	Lewis	1.59	10–20[i]	6.3–12.5	8.0–11.0	

[a] Weekend data are similar and not included here for clarity.

[b] Calculated from survey responses.

[c] Daytime events are called "day + evening" events in Table VII.

[d] Installation records.

[e] Airfield records.

[f] Typical airfield operations (more than one airfield was near the study areas at Fort Lewis).

[g] Airfield records: The data at Fort Lewis are an estimate since counts are kept for 0700 to 1500, 1500 to 2300, and 2300 to 0700 h.

[h] Highway Department estimates.

[i] CERL estimates.

(*don't know*). (Less than 1% of the respondents chose the "*don't know*" response.) Respondents who had indicated that they were bothered were asked how annoyed they were for that time period (i.e., day, evening, or night; weekday or weekend). Specifically, they were asked "And in general, taking everything into consideration, how annoyed are you by noise from (*source*) during the (*time period*)?" Annoyance was judged on the five-point adjectival scale.

The following analysis uses only data derived from respondents usually home during all three time periods; this was done so the same respondents are comparing day with night. The analysis is more credible by having day, evening, and night responses from the same set of respondents, as long as one can show that the responses of respondents home at all times compare favorably with the responses for respondents home only part of the time. This comparison was done for the Fort Lewis data in a fashion analogous to the comparison made for the Fort Bragg data (Ref. 4). It was concluded that the overall analysis can be made using just those respondents home at all times.

To quantify the frequency of occurrence factor, responses for daytime and evening are combined ("overall" daytime) and compared with nighttime for respondents home during the day, evening, and night. Table VII lists the repsondents' summed day and evening responses and compares them with nighttime responses. Respondents were asked to separately assess frequency of occurrence by day (0700 to 1900 h), evening (1900 to 2200 h), and night (2200 to 0700 h). Thus the day + evening figures give the overall respondent assessment of the number of bothersome events occurring between 0700 and 2200 h. This day total is compared with the nighttime number of bothersome events.

Table VIII summarizes the ratio of the number of noise events the respondents noticed and considered bothersome during daytime hours to the number noticed and bothersome during nighttime hours. In all cases, the ratio is greater than 1. More events are noticed and found bothersome during the day than during the night. However, there are many more daytime events to be noticed than there are nighttime events.

The factor of interest (R) is given by

$$R=\frac{\text{(number of events noticed and bothersome per night)}}{\text{(physical number of events per night)}}\div\frac{\text{(number of events noticed and bothersome per day)}}{\text{(physical number of events per day)}}.$$

This factor can be rewritten as

$$R=\frac{\text{(physical number of events per day)}}{\text{(physical number of events per night)}}\div\frac{\text{(number of events noticed and bothersome per day)}}{\text{(number of events noticed and bothersome per night)}}.$$

Table VIII also lists the ratios of physical occurrences (obtained from site records) and the values (R) and 10 log(R). As discussed, the 10 log(R) value indicates the nighttime adjustment which results because events are more likely to be noticed at night than during the day. Table VIII lists 10 log(R average) value for the five sources considered in the survey.

A. Qualification of the intrinsic annoyance per bothersome event

Annoyance per bothersome event data for the three time periods and for day and evening combined (daytime total) were summarized. These data reveal no significant differences between day and evening for artillery, airplane, or helicopter noise sources. Annoyance per bothersome event does not significantly vary between these two time periods for these three sources, but it does appear to vary for the street traffic and the children and/or pets categories.

In most cases, these same data reveal that annoyance per bothersome event increases somewhat at night for all source categories. To better illustrate this increase, the daytime and evening data were combined to form an "all day" (0700 to 2200 h) value of the percentage of respondents "highly annoyed." Since this is a percentage, it represents a

TABLE IX. Annoyance per bothersome event (respondents home at all times; weekday or weekend).

Source	Day of week	Percentage "highly annoyed" Day	Evening	Day + evening	Night	Ratio, night to day + evening
Artillery	weekday	47	50	49	55	1.12
	weekend	48	48	48	53	1.10
Airplanes	weekday	40	40	40	43	1.08
	weekend	43	47	45	51	1.13
Helicopters	weekday	43	42	42	45	1.07
	weekend	47	53	50	59	1.18
Traffic	weekday	46	55	50	57	1.14
	weekend	46	54	50	56	1.12
Children and/or pets	weekday	50	60	55	64	1.16
	weekend	54	61	57	63	1.11

TABLE X. Comparison of day to night annoyance to blast noise.

	CDNL			Percentage "Highly annoyed"	
Site	Day[a]	Night[a]	Difference[a] in decibels Day–night	Day + evening	Night
Fort Bragg 50 to 60	NA[b]	NA[b]	about +9	6	6
Fort Bragg 60 to 70	NA[b]	NA[b]	about +9	20	22
Clinton Park	48	30	18	2.8	3.0
Steilacoom	49	31	18	2.4	2.8
Roy	60	45	15	21.3	16.9
On installation	54	35	19	8.9	6.6
Yelm	56	38	18	17.0	13.8
Lake St. Claire	54	35	19	24.1	20.7
Mushroom Corners	51	33	18	10.7	7.0
Nisqually	55	35	20	16.3	13.8

[a] The day and night values are equivalent levels; the night levels do *not* include a 10-dB adjustment. The day and night levels both use a sound exposure level (SEL) threshold of 40 dB, as explained in the text.

[b] Not applicable; Fort Bragg data were divided into large zones so single values are not applicable.

time-period-weighted average of the daytime and evening data (data which do not differ significantly from one another anyway). Table IX lists these data. The ratios of the nighttime to the "all day" percentage of respondents "highly annoyed" are shown in the last column of Table IX. These ratios can be thought of as the intrinsic increase in annoyance per bothersome event during the night as compared with during the day.

B. An alternate analysis to determine nighttime adjustment for blast noise

For this alternate analysis, the CERL blast noise computer program (BNOISE) was used to predict separate CDNL contours for day and for night. To ensure that all audible events were included, the value of the lowest SEL included was adjusted downward to 40 dB. Thresholds were eliminated so the size of the daytime CDNL contours could be compared with the size of the nighttime CDNL contours without presupposing that a 10-dB nighttime adjustment was appropriate.

The results of this analysis of Fort Bragg showed that the night-only contours (without a 10-dB adjustment) are typically 8 to 10 dB smaller than the day-only contours in off-installation areas where the CDNL value ranges from 50 to 70 dB. At Fort Lewis the nighttime levels were typically 19 dB below the corresponding daytime levels.

The off-installation impulsive noise survey data were analyzed by CDNL zone and time period. Table X lists these results for the 60- to 70- and the 50- to 60-dB zones at Fort Bragg and the eight individual cluster sites at Fort Lewis. The overall results showed a slight increase in the percentage of respondents "highly annoyed" at night as compared with the day for the higher noise zones and no increase for the lower noise zones at Fort Bragg. At Fort Lewis, the percentage of respondents "highly annoyed" during the day was typically one and one-fourth times the nighttime percentage.

Since at Fort Bragg the percentage of respondents "highly annoyed" was the same during daytime and nighttime, one can ask what nighttime adjustment must be incorporated into the DNL descriptor such that the daytime and nighttime contours are both about the same size and shape. From the contour analysis contained above, it appeared that a nighttime adjustment on the order of 9 dB is required to establish this equivalence between daytime and nighttime responses. At Fort Lewis, the corresponding analysis is not quite as simple since the percentage of respondents "highly annoyed" differs between daytime and nighttime. The actual daytime and nighttime contours typically differ by 19 dB. If the annoyance (percentage of respondents "highly annoyed") were the same for daytime and nighttime, then this result would indicate that an adjustment of 19 dB was required. Since the daytime percentage of respondents "highly annoyed" somewhat exceeds the nighttime percentage, the appropriate adjustment is somewhat less than 19 dB, perhaps 15 dB. Overall, the results at these two installations certainly indicate that a blast noise descriptor should include a nighttime adjustment which is on the order of 10 dB.

IV. DISCUSSION OF THE OVERALL DATA BASE

The primary data base used for relating community response to impulsive noise includes the data for sonic booms at Oklahoma City, the Fort Bragg data, and the Fort Lewis data. (The first two of these three sources, the Oklahoma City data and the Fort Bragg data, were used by CHABA Working Group 84 in formulating Ref. 6. Figure 5 is from that reference.) Figure 5 shows the Oklahoma City (sonic boom) data and the Fort Bragg data used to formulate the recommendations given in the CHABA report. The dashed line in Fig. 5 is the dose-response relation developed by CHABA based on these data. This curve indicates the percentage of a community "highly annoyed" for a given CNDL from impulsive sounds (with deletion of single-event SELs below 85 dB during the daytime or 75 dB at night).

Figure 6 shows the data and curves of Fig. 5, but with the Fort Lewis data added. The Fort Lewis data make clear a disparity between the two data bases. While the Fort Lewis data generally agree and compliment the Fort Bragg data, it is clear that the artillery data as a whole depart from the

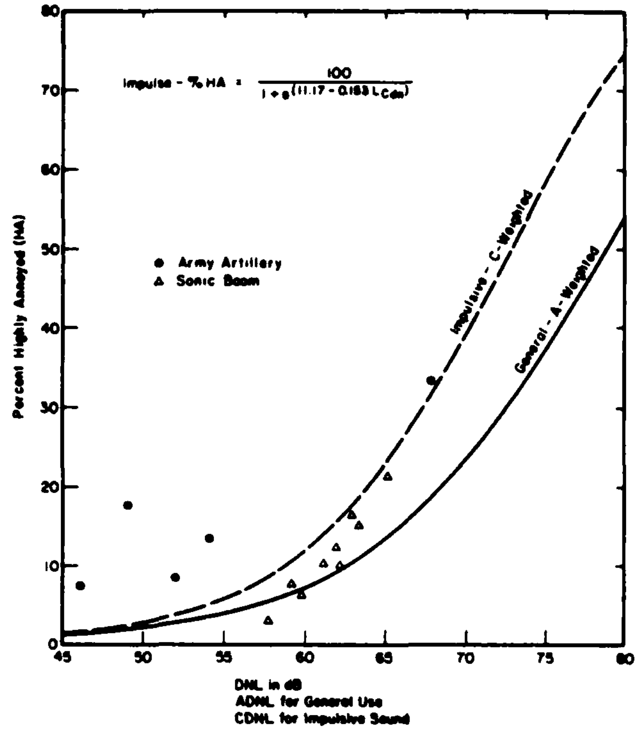


FIG. 5. Recommended relationships for predicting community response to high-energy impulsive sounds and to other sounds.

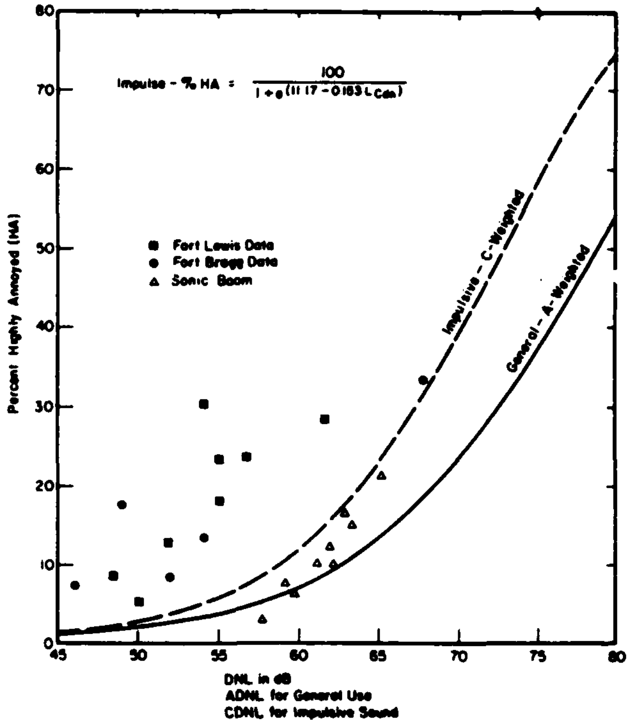


FIG. 6. Figure 5 with Fort Lewis data included.

Oklahoma City sonic boom data and from the general dose-response curve recommended by CHABA. These data seem to indicate that the CHABA dose-response curve may underestimate the community annoyance to blast noise by 5 to 10 dB.

The failure of the sonic boom and artillery data to align themselves into one general curve can be traced to several potential causes. These include (1) incorrect interpretation of the community response data at either Oklahoma City or at Fort Bragg and Fort Lewis, (2) incorrect specification of the noise zones either at Oklahoma City or at Fort Bragg and Fort Lewis, (3) C-weighting is not the best measure to assess impulsive noise, or (4) an energy type of descriptor is not appropriate for assessing impulsive noise.

A. Can there be errors in the interpretation of the community response data?

The artillery data use the exact annoyance question and analysis (top two categories on the five-point adjectival scale) used for most of the general A-weighted data. Thus they must be compatible. The sonic boom data are a translation of three levels of data combined in an index. Thus it is possible they are being misinterpreted. However, the present interpretation represents the best translation the CHABA committee could make of those data.

The Army blast noise data represent community response to a steady, long-term situation. The sonic boom data represent a special study with data taken at the end of 2½, 4½, and 6 months. A simple model has been postulated for community response which suggests a time constant for the response which is similar to the charging of a capacitor by a battery through a resistor (Fig. 7).[13] It has been suggested that this time constant (for aircraft) may be months or years. In other words, if a new noise starts today, it may take months or years until final level of the community annoyance (i.e., percentage of the community "highly annoyed") is realized. What if the time constant for impulsive noise is 6 months? Then the sonic boom data taken at 2½ months (period 1) represents 44% of the final value, the data taken at 4½

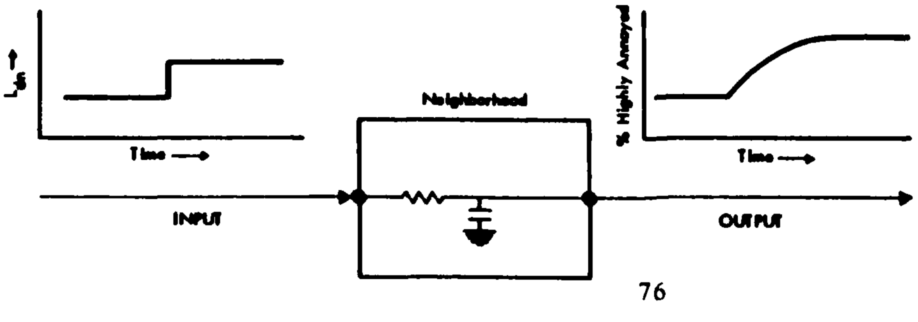


FIG. 7. Simplified model of community adaption to change in noise exposure.

TABLE XI. Oklahoma City sonic boom data converted by a 6-month "community response rise time constant."

Distance	Period	Factor	Percentage "highly annoyed"	Adjusted percentage "highly annoyed"[a]
0–8 miles[b]	1	0.44	10	23
	2	0.53	17	32
	3	0.62	23	37
8–12 miles	1	0.44	8	18
	2	0.53	12	23
	3	0.62	15	24
12–16 miles	1	0.44	4	9
	2	0.53	7	13
	3	0.62	10	16

[a] Adjusted "highly annoyed" equals "highly annoyed" divided by factor (e.g., 23 = 10/0.44).

[b] 1 mile = 1.6 km.

months (period 2) represents 53% of the final value, and the data taken at 5¾ months (period 3) represents 62% of the final value. The converted Oklahoma City sonic boom data are shown in Table XI and plotted in Fig. 8. Clearly, a simple time constant for community response can help explain the discrepancy between the sonic boom and blast noise data.

B. Are there errors in the specification of the noise zones?

The artillery data are based mainly on computer-predicted noise zones and include the results of monitoring in the vicinity of Fort Bragg. Most of the computer-predicted noise zone values at Fort Bragg were reduced when the monitored data were taken into account. Figure 9 shows the data of Fig. 6, but with the artillery data from the Fort Bragg study located only with respect to the computer-generated noise zones and without the added results from the monitoring. In almost all cases, the Fort Bragg monitoring data imply that (1) the computer-predicted noise zones overestimate the true noise, or (2) the monitoring fails to measure the true noise.

The blast noise data in Fig. 9 are based only on computer prediction. If one takes the monitoring into account, then the blast noise data in Fig. 9 generally shift to the left. It is unlikely that the computer predictions underestimate the blast noise, since the monitored values are so much lower than the predicted values. One must conclude that the overall artillery data lie to the left of the sonic boom data. The sonic boom data are based both on prediction and measurement which generally complement one another. Thus com-

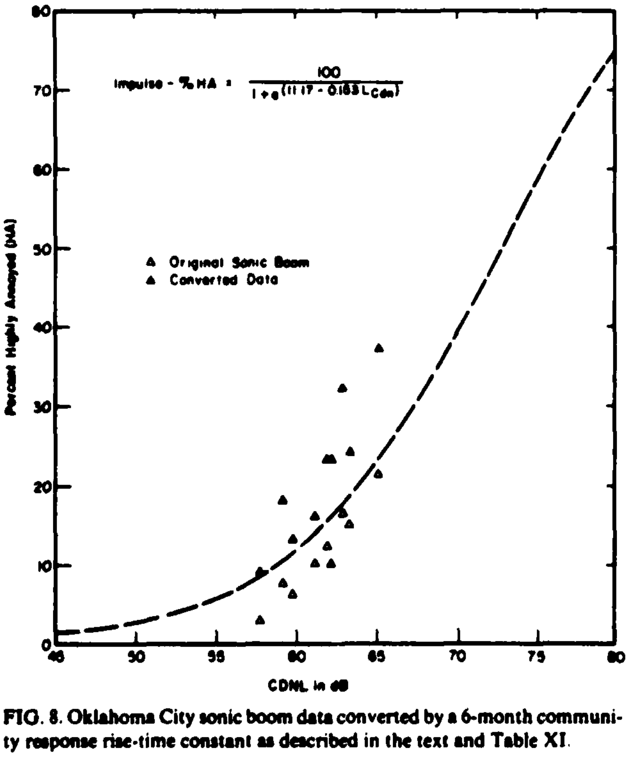


FIG. 8. Oklahoma City sonic boom data converted by a 6-month community response rise-time constant as described in the text and Table XI.

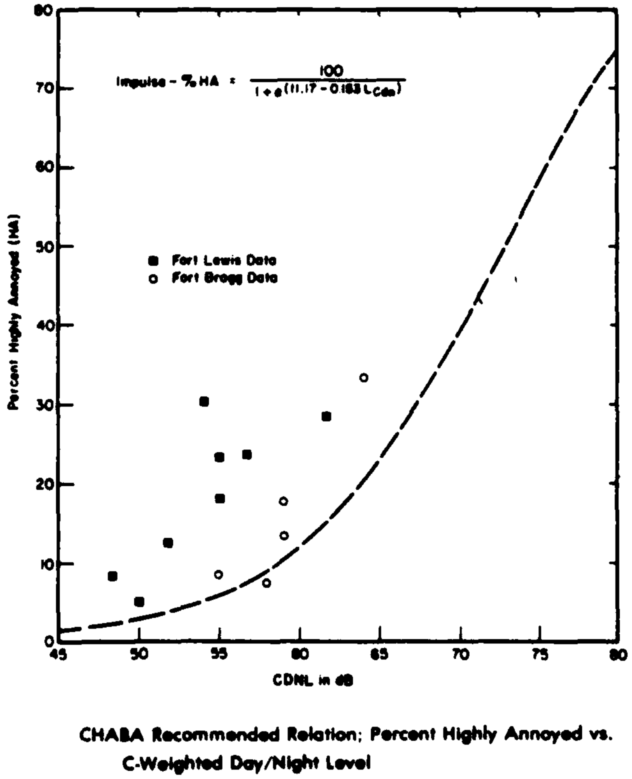


FIG. 9. Fort Bragg and Fort Lewis data (based on computer prediction only).

putational or measurement errors in the specification of the noise zones do not appear to be a likely explanation for the discrepancies.

C. Is C-weighting the optimum measure to use for assessing impulsive noise?

C-weighting was chosen by CHABA as the best of those weighting techniques available. C-weighting incorporates those frequencies contributing to noise-induced building vibrations and rattles. These vibrations and rattles are the main adverse factor reported in both the sonic boom and blast noise studies. Wall modes extend about 1 oct below the C-weighted cutoff of 20 Hz. On the other hand, a higher cutoff is required to align the sonic boom and the blast data since sonic booms generally have lower frequency energy than do Army blast noises. Hence, no conclusions can be drawn without further study as to the exact frequencies to which people respond.

D. Is an energy type of descriptor appropriate for assessing impulsive noises?

Some have suggested that a few "loud" impulses are worse than many "quieter" impulses even though the total daily sound energy in both instances is the same. The sonic boom study represents eight loud impulses per day; the Army studies generally represent many smaller impulses per day. But the results are contrary to expectation: The many quieter impulses are apparently more annoying than the few louder ones. This indicates that perhaps the 85-dB single event threshold in the CHABA procedure should be eliminated. Elimination of the threshold will narrow the differences between the blast and the sonic boom data, but only by 1 to 2 dB. Moreover, the results described throughout this paper support retention of an energy type descriptor. Discarding the energy model will not explain the discrepancy between blast and sonic boom data.

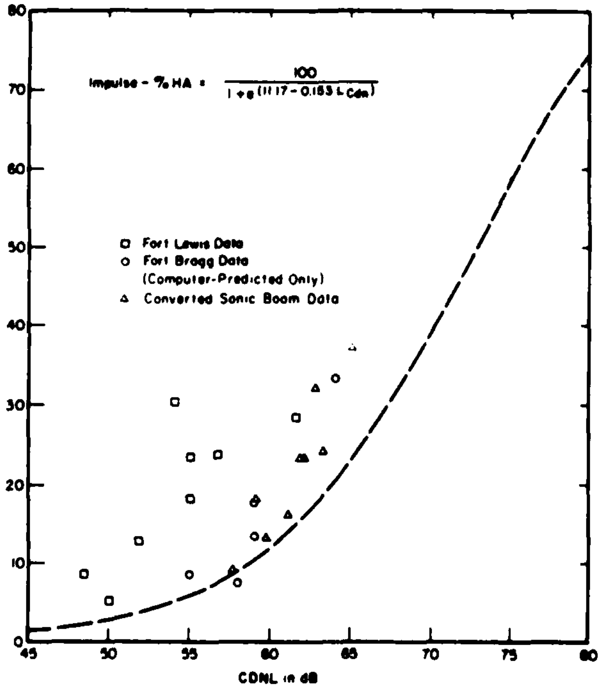


FIG. 10. The total adjusted data, including the blast data from Fig. 7 and the adjusted sonic boom data from Fig. 8.

E. Summary

Figure 10 shows the Fort Lewis data, the Fort Bragg data based only on computer prediction, and the sonic boom data converted by the 6-month rise-time constant theory. Taken together, the data begin to align themselves and indicate that the CHABA impulsive noise dose-response curve may lie 3 to 4 dB to the left of its current position.

V. CONCLUSIONS

The body of data collected through experimentation and administration of established community attitudinal survey methods indicates that computer-generated noise contour predictions based on an energy model noise descriptor can be correlated with attitudinal survey results to reliably portray community response to impulsive noise.

A. Energy model noise descriptor

References 2 and 10 and this paper describe how the growth in annoyance to impulsive sound levels increases monotonically both with sound amplitude and with frequency of occurrence. References 3 and 6 and this paper show that the perception of building rattles is the main adverse impulsive (blast) noise factor, and that CDNL is the best available standard weighting for including those sound energies responsible for building rattle. Since the CDNL descriptor correlates well with the percentage of a community "highly annoyed" by impulsive noise (Refs. 1, 5, and this paper), it is indicated as the best available energy model to use to describe community response to impulsive noise.

B. Nighttime adjustment

These results support the use of the long-established 10-dB nighttime adjustment for noise descriptors such as DNL. Most important, these results indicate that the strongest argument in favor of a nighttime adjustment is the community's greater likelihood of noticing an event at night; in general, intrinsic annoyance per event is not a significant factor.

Reference 4 and this paper described how bothersome noise events are more likely to be noticed by the community during the night than during the day. This indicates that a nighttime adjustment to the noise descriptor is justified. However, deciding on an adjustment for nighttime blast noise events is difficult, since the community response to blast noise events differs from the response to other, nonimpulsive noise sources. Blast noise, because of its high sound levels and impulsive nature, is rapidly noticed at all times of the day and night. Thus the rate of noticing blast noise at night increases less (as a percent) over the daytime rate as compared with the nighttime increase for other noise sources. However, blast noise events produce the largest increase in intrinsic annoyance per bothersome event compared with other noise sources.

The alternate analysis in this paper described the results when day- and night-only blast noise contours were used to correlate with community annoyance. This analysis indicated that the blast noise nighttime adjustment to the noise descriptor should be perhaps 15 dB for the Fort Lewis data and about 10 dB fo the Fort Bragg data.

Generally, the blast noise results are consistent with the 10-dB adjustment recommended for noise sources other than blasts.

C. Health effects

Blast noise is potentially as bad or worse than other noises in terms of adverse health effects. This paper shows that sleep interference was cited as often for blast noise as for any other source—even in an area where less than 2% of the blast noise events occurred at night. Startle and fright, the factors known to cause physiological reactions, occur most often for blast noise.

D. Annoyance and CDNL noise descriptor for impulsive noise

The exact function for relating the percentage of a community "highly annoyed" by blast noise to CDNL remains in question. It appears that the present CHABA recommendation may underestimate actual annoyance, as indicated by the results described earlier. Thus the functional relationship between annoyance and CDNL should perhaps be shifted to the left by 3 to 4 dB. It is apparent that more research into (1) the percentage of a community "highly annoyed" by impulsive noise versus CDNL, and (2) the existence and value of community rise- and decay-time constants are required to clarify the issue.

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Paper 8

An analysis of community complaints to noise

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Noise complaints received Army-wide for a one-year period were analyzed (a) to determine the relationship between the nature of the complaint and the type of noise and (b) to determine the relationship between complaints and the day–night level (DNL). For blast noise, 77% of complaints mentioned vibration or physical damage or both, thus confirming the validity of the C-weighted DNL as a better measure of blast noise than the A-weighted DNL. The relationship between DNL and complaints, however, was a very weak one. Instead, the data confirmed an independent finding of a recent study of Air Force noise complaints—that complaints are generated by unusual rather than typical noise levels. Since a valid measure of community response to noise should be functionally relatable to the noise dose, complaints do not appear to be a good measure of the community response. To deal with the wide variability in the emotional tone of the complaints a psychological model was developed and tested. The implications of this model for how an airport or Army base should deal with complaints are discussed.

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INTRODUCTION

Descriptors of community response to noise have been the focus of study for at least the past quarter century. When acousticians first began their study, their emphasis was on predicting public response. For example, the descriptor recommended in Rosenblith and Stevens (1953) was designed to predict whether or not an exposed populace would complain or take legal action against a specific noise source. With the dawning of a unified national approach to the growing problem of environmental noise in the mid-1970's, the emphasis shifted from a prediction of overt response to a prediction of annoyance.[2] Annoyance, in turn, was a hypothetical variable inferred from responses to social surveys. Implicit in the shift of emphasis was a guarantee that all citizens would be protected from unhealthy levels of noise whether or not they complained. Moreover, annoyance proved to be a much more sensitive measure of subjective reaction than complaints. For example, the sophisticated debate between Schultz and Kryter recently published in this journal[3–5] would have been very difficult if the authors had to use the relatively gross measure of complaints.

Of the various possible descriptors of environmental noise, none has proved to be more robust than the day–night average sound level (DNL). Reviewing much of the worldwide research, Schultz has shown a strong correlation between the noise dose (DNL) and community response (high annoyance).[6] Because of this demonstrated correlation, DNL has emerged in the U. S. as the leading descriptor for Federal agencies[7–10] and many states as well.[11] In addition, Working Group 84 of the National Academy of Sciences' Committee on Hearing, Bioacoustics, and Biomechanics has recommended that DNL be extended to the assessment of sonic booms and heavy weapons noise as well.[12] Although DNL as applied to blast noise differs from the usual descriptor in that the blasts are measured with the C-scale of the sound level meter (CDNL), the methodology is very similar to the A-weighted DNL (ADNL). The C-weighting was chosen to better reflect those frequencies which account for building vibrations since surveys have shown that impulse noise induced building vibration is the most adverse factor related to the noise. Moreover, annoyance has been shown to acceptably correlate with C-weighted DNL.

In shifting to an emphasis on annoyance and DNL, Federal administrators did not abandon the earlier concern with overt public response. In practice, overt response continues to be a driving force in noise mitigation and land use policies. For example, the FAA made a point of compiling and reporting on complaints after introducing the SST into U. S. airports.

Administrators, public officials, and lawyers often cite the presence (or absence) of complaints to "prove" that an adverse noise environment does (or does not) exist. Various sources have suggested a functional relation between DNL and complaints. For example, the U. S. Environmental Protection Agency's guidelines on the application of DNL show complaints to be a function of DNL. As DNL increases, complaints increase. Certainly, as long as complaints and the percentage of a community highly annoyed are highly correlated and functionally related to DNL, either can be used for noise assessment or land use planning. However, the research data base supporting this relationship between complaints and DNL is quite shaky.

The purpose of this paper is to (1) quantitatively study the presumed relations between DNL, high annoyance, and complaints, and (2) to compare complaints about impulse noise with complaints about aircraft (primarily helicopter) noise. The percentage of a community highly annoyed has been shown to be functionally related to the DNL descriptor and this relation contributed substantially to the adoption of the DNL descriptor for noise assessment and land use planning by federal agencies and by ANSI. To the extent that complaints are found not to be functionally related to DNL and correlated with annoyance, they can be used to characterize (quantitatively) community response. If complaints are found to be functionally related to DNL, then caution must be exercised in using complaints as a measure of community response, since a valid measure of community response to noise must be functionally relatable to the noise dose received by the community.

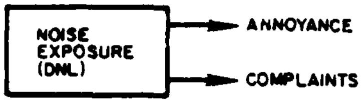
Implicit in the Environmental Protection Agency's equation for predicting complaints are two possible models of human response to annoying noise. These models are shown in Fig. 1. In the first panel, Fig. 1(a), a specific level of DNL results in a specific level of complaint and a specific level of annoyance. In the second panel, Fig. 1(b), a specific level of DNL causes a specific level of annoyance which is then manifested by a specific level of complaint. Both models ignore the cognitive factors underlying the decision to complain. In addition, the failure to define a specific time period for integrating DNL leaves considerable latitude for the user, a latitude ranging from DNL for a particular day to the average busy day[13] or the annual average.

In practice, these simple models are not useful. For example, in a study of noise complaints received by the Air Force, the relationship between average busy day DNL and complaints was very poor.[14] The authors concluded that the data provided "evidence that to a considerable extent, it is the unusual or nonroutine events which provide complaints at AF bases." If, as the Air Force found, the unusual noise events are the true cause of complaints, then a more sophisticated model is needed.

In the hope of developing a more accurate procedure for predicting complaints, we have attempted to create a more sophisticated model, one that emphasizes the cognitive and psychological factors which lead to the individual's decision to complain. The model is an eclectic one, drawing from such diverse sources as Schultz's explanation for the cubic equation relating DNL to annoyance,[15] the model of physiological habituation put forward by Sokolov,[16] and the concepts of behavioral conditioning as found in any contemporary textbook on introductory psychology. As with any model, its usefulness lies in its ability to predict. This paper tests the functional relations of the model and its predictive validity by applying it to a body of noise complaints.

The noise complaints were gathered in 1979 when the U. S. Army Construction Engineering Research Laboratory (CERL) asked the major commands of the Army to collect noise complaints from their respective installations. The collection period ran from 1 July 1979 to 30 June 1980. During that period, 287 complaints were received. The actual number of complaints generated during that period is thought to have been much higher. For example, at one installation, the authors had access to the records kept by the office in charge of scheduling the use of ranges. These logs showed 23 complaints from May 1977 to May 1978 and another 23 from May 1978 to May 1979. However, CERL only received six complaints from the installation for the third year. Recognizing this caveat, we are still fairly certain that the complaints received are representative and not systematically biased. Complaint forms differed slightly between installations but generally conformed to the sample shown in the Appendix.

(a)COMPLAINTS AS SYMPTOM OF ANNOYANCE



(b)COMPLAINTS AS A RESULT OF ANNOYANCE

(c)COMPLAINTS AS RESULT OF AROUSAL

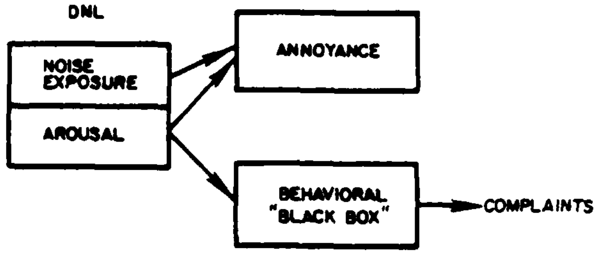


FIG. 1. Models relating complaints to DNL.

The idea for our model came from Schultz's synthesis. Schultz found that the percentage of highly annoyed does not increase as a simple linear function of DNL. Instead, it requires a cubic equation. In a somewhat speculative section, he suggested that the cubic equation can be broken down into two power functions. The first function begins at a relatively low DNL and increases at a low rate. Schultz associated it with average exposure and loudness. The second function begins at a high DNL and increases at a higher rate. Schultz associated it with arousal. Schultz's suggestion, then, is that annoyance is a function of both average exposure and arousal. This relationship is shown in Fig. 1(c). Our innovation is the additional assumption that complaints are only a function of arousal.

Although Schultz did not define arousal, there is good reason for identifying it with the concept of arousal as used in the field of psychophysiology. Following the definition contained in the theory of the Russian psychophysiologist, Sokolov, it is that spurt of neutral activity within the limbic system and stem of the brain observed when a vertebrate is exposed to a new stimulus. Sokolov's thesis was that when an organism is first exposed to a novel stimulus, its brain responds with a series of reflexes designed to gather more information. If the stimulus has no meaning (good or bad) and if it is repeated, the brain builds up a template to inhibit further arousal by that stimulus. Only if the stimulus is changed will the brain become aroused. The process by which an organism stops responding to a repeated stimulus is called "habituation." The process by which change in a stimulus leads to increased arousal is called "dishabituation."

Although the processes of habituation and dishabituation are not normally observable in the data on annoyance, they can appear under special circumstances. Probably the best example was Project Yellowhammer[17] in which residents of a small town were exposed to 24 explosions on Monday, Tuesday, and Wednesday, and then asked about their annoyance on Thursday and Friday. Annoyance showed clear habituation with the number of annoyed persons dropping from 50% in the first week to 20% in the fourteenth week. When the residents were "dishabituated" by either a tripling of number (5-dB increase in DNL) or a doubling of peak pressure (6-dB increase in DNL), annoyance jumped dramatically and by a roughly equal amount. Interestingly, changes in the other direction (reduction to eight blasts per day or halving of pressure) had no effect on annoyance. This asymmetry in response to change is mirrored in a later study of chinchillas taught to respond to a change in a frequently repeated sound.[18] These animals were much more likely to respond defensively to an addition of sound than to a deletion of sound.

To link the process of habituation/dishabituation with the conscious decision to complain about noise, Schultz's germinal model must be elaborated further. This elaboration is shown by the flow chart in Fig. 2. In this flow chart, the loudness power function of Schultz is identified with an unconscious integration of the effects of past noise exposure. It is, in effect, the "neural template" of what one expects to hear. Arousal, on the other hand, is seen as leading to a conscious recognition that an unusual noise has occurred. This intrusion into conscious thought can be an annoyance and, depending on the meaning of the noise (good or bad), the person will take steps to make sure it stops or is not repeated. At this point, the model borrows from the concepts of behavioral conditioning. To eliminate the noise, the individual chooses the behavior that has been most reinforcing in the past. Thus if the best way of getting rid of past annoyance (from noise or anything else) has been to call the police, the person will choose this most reinforced behavior. If this behavior gets rid of the noise, it is "reinforced" and becomes more probable in the future. On the other hand, if noise remains as an annoyance, the chosen action becomes less likely in the future. The process by which the probability of an unreinforced behavior decreases is known as "extinction." Extinction is normally accompanied by a negative emotional affect which English-speaking people often describe as "frustration." Among nonverbal animals in Skinner boxes, extinction is often accompanied by overt aggression against the nonreinforcing instrumentation.

If the model is correct, then an analysis of the Army's noise complaints should demonstrate:

(1) Qualitative differences between complaints about different kinds of noise (high level of conscious involvement).

(2) No direct correlation between the long-term DNL and complaints.

(3) Evidence of unusual conditions in the complaint period.

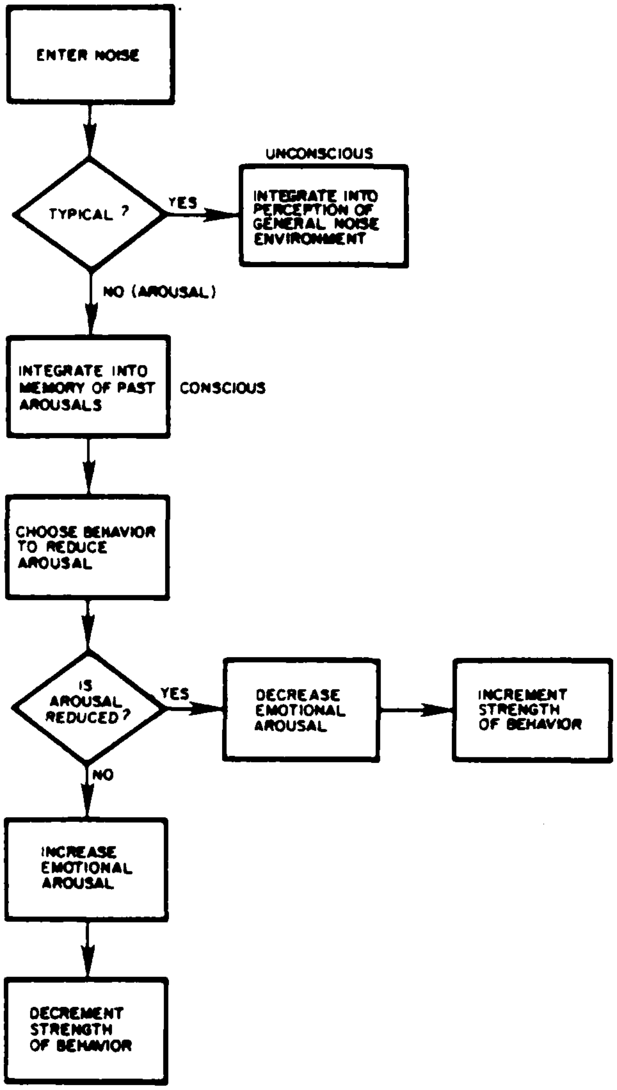


FIG. 2. Flow chart of process governing complaints.

(4) Differences in emotional effect related to the pattern of reinforcement for complaint behavior.

In general, the data conformed to these hypotheses.

I. TESTS OF THE MODELS

A. Qualitative differences

After discarding complaints about obscure noise sources (e.g., bell towers, air conditioners, etc.) and complaints relayed through third parties (e.g., radio stations, newspapers, governmental bodies), the number of remaining complaints were fairly evenly divided between blast complaints (125) and aircraft complaints (139). Nearly all of the aircraft complaints involved helicopters.

From examination of the complaints, it was determined that all could be categorized into one or more of 13 categories. A tally was made of the number of times each category was mentioned. Some limited inferences were made. For example, if a complaint stated that a noise was "too late at night," sleep interference was inferred. For those complaints mentioning several different problems, the tally was incremented in each relevant category. No attempt was made to distinguish between primary and secondary complaints.

There were clear qualitative differences between aircraft and blast. One way to display these differences is to group the 13 complaint categories into complaints about property, complaints associated with fear, and complaints about general nuisance.

Table I shows the complaints about property. Leading the list was vibration with 54% of the blast complaints mentioning it compared with 10% of the aircraft complaints. Complaints of physical damage to buildings (32%) or mention of falling objects (14%) were also significantly higher for blast noise than for aircraft noise (4% and 2%). This result reinforces the use of C-weighting for impulse noise since it is noise induced building vibrations which are generating many of the complaints, and it is the low frequencies in the impulses which induce the vibrations.

In contrast, complaints associated with fear were more common with aircraft (Table II). Leading the field were complaints of aircraft being too close or too low (87%). Although this is not a true measure of fear, it is certainly related. Actual reports of fear or of physiological stress were much lower, but still higher for aircraft (11%) than for blast (4%). Concern for safety was also higher with 7% for aircraft and none for blast. A different measure of fear, disturbance of animals, was also higher for aircraft noise (18%) than for blast noise (5%).

Indicators of general nuisance did not exhibit any strong systematic variations between noises (Table III). Some mention of objectionable sound was found in 30% of blast and 24% of aircraft complaints, and sleep disturbance and disturbance to children were somewhat higher (13% and 10%) with blast noise than aircraft noise (7% and 7%). These differences are not significant.

B. DNL versus complaints

If the percentage of persons highly annoyed is related to the percentage of persons complaining, then the percentage of people complaining should rise with DNL. For the aircraft noise complaints, it was impossible to make a comparison between DNL and complaints because of too little information.

Blast noise was evaluated in accordance with the assessment procedure recommended by working Group 84 of the National Academy of Science Committee or Hearing Bioacoustics and Biomechanics (CHABA). CERL has developed a computer simulation model (BNOISE) which implements these recommendations. A number of contour maps from the CERL BNOISE computer program[19] were already available. Thus it was possible to compare the CDNL contours with complaint locations. However, numbers of complaints in a noise zone do not translate directly into percentages. Higher noise areas are generally smaller than areas of less noise. In addition, the population density may vary in the different noise areas.

With these cautions in mind, it was determined that 115 of the blast noise complaints (including a few of the previously discarded third party complaints) could be related to the blast noise contours available for the various installations. Precise relationships were possible only for a few of these, so the comparison was made in terms of complainants living in high noise zones (Zone III, CDNL above 70), moderately high noise zones (Zone II, CDNL between 62 and 70), and acceptable noise zones (CDNL below 62). When this was done, it was found that most of the complaints were from the acceptable zone (83), the second most from the moderately high zone (27), and only five complaints were from the high zone. These numbers of complaints are inversely related to DNL. However, as noted above, the land area (and perhaps the population) encompassed by a noise zone is smaller for the higher noise zones. Hence it is not possible to compare these complaint ratios with the percentage of complaints predicted by the basic model without detailed population information—data which are lacking.

As a surrogate, examination of specific installations where the approximate populations in the noise zones were known was also undertaken. This analysis revealed no systematic relation between noise zones and the percentage of a population which complain. With the data available, one could neither say that the complaints were directly correlated with the noise exposure nor that they were inversely correlated with the noise exposures. At best, one might suggest that complaints are not correlated with the noise exposure.

TABLE I. Percentage of complaints related to property.

Item	Type of noise Blast	Aircraft
Vibration	54%	10%
Damage to house	32%	4%
Falling objects	14%	2%
Damage to wells	2%	0%
Damage to crops	0%	3%

TABLE II. Percentage of complaints related to fear or defensive responses.

Item	Type of noise Blast	Aircraft
Noise source too close	0%	87%
Disturbed animals	5%	18%
Fear/physiological stress	4%	11%
Safety concerns	0%	7%

TABLE III. Percentage of complaints related to general nuisance.

Item	Type of noise Blast	Aircraft
Objectionable sound	30%	24%
Sleep disturbance	13%	7%
Disturbed children	10%	7%
Speech interference	0%	1%

In any case, it is significant that large numbers of complaints can occur from noise zones where the CDNL is rated as acceptable.

C. Unusual conditions

An important feature of the revised model is that people complain about unusual conditions. For the aircraft noise complaints, the frequent mention of low flying or close aircraft (87%) confirms the hypothesis. Mention of unusual conditions was far less frequent for blast noise, but there was other evidence to suggest that levels were unusually high because of blast noise focusing. Blast noise focusing occurs when weather conditions result in blast energy being propagated to distant locations where it is ordinarily not annoying. Focusing is dynamic and often shifts over the course of several hours.[20] Thus when one observes complaints occurring at the same approximate time in the same general location or occurring very closely in time at distant locations, it is reasonable to expect that focusing was the cause. As a test of focusing in these particular data, complaints were grouped according to whether they were isolated, grouped in pairs, triplets, quadruplets, or larger groups. The results showed high probability of focusing with only 44% of the complaints in isolation, 19% in pairs, 7% in groups of three, 12% in groups of four, and 18% in groups of five or more. Undoubtedly, a large number of the 44% of isolated complaints is also due to focusing, but the plausibility of a focusing explanation increases with the grouped data.

D. Time pattern of complaints (emotional state)

Analyzing the complaints for emotional tone proved to be difficult, for it is very easy to project an emotional state into a particular situation or statement. Only 45 aircraft noise and 45 blast noise complainants were described in adequate detail for determining both emotional tone and past history. (In some cases, multiple complaints were truncated into a single complainant's history. Here the unit of analysis is complainant and not complaint.) Even with some sort of objective criteria, inferring emotional states is somewhat subjective. In this case, it seemed unrealistic to develop more than three categories of emotional tone.

The lowest state of emotion was identified by any of the following words: friendly, good-natured, pleasant, nice, calm, not hostile, good, understanding, courteous, cooperative, helpful, not trying to make waves, cool (the lowest level on one installation's three category checklist).

The highest state of emotion was identified by any of the following words or situations: hostile, mad, upset, irate, belligerent, angry, volatile, indicants of physiological stress, irrational threats (e.g., shooting down aircraft).

The intermediate level of arousal was identified by the following words: concerned, fair, unhappy, medium, sharp, strong protest, aggravated, and combinations of words from levels I and III connected by "but."

It is, of course, unlikely that any two researchers would define the categories exactly as above, but the phenomenon described would still be robust with slightly different categorization.

Using this particular set of criteria, the data fell into the cells as shown in Table IV. In this table, the emotional tone for multiple complaints reflects their last recorded emotional description; complaints were not counted twice.

II. DISCUSSION

An essential feature of all of the models, the distinction between aircraft and blast noise events, was confirmed by the data. Concern about vibrations showed up in 54% of the blast complaints and 77% mentioned either vibration or damage or both. Thus the distinction between C-weighting (which measures both the audible and the low-frequency vibrational energy) and A-weighting (which measures only the audible energy) is an extremely useful one.

The failure to find a strong correlation between noise level and percentage of complaints is a defeat for these models which postulate a functional relation between DNL and complaints. "Annoyance" *per se* does not appear to strongly relate to complaints, since the two variables are not strongly correlated, if at all. The new model succeeds in better explaining the relation between the variables DNL, annoyance, and complaints. As the data show, people appear to be complaining about the "unusual conditions."

The data fit the predictions of the "black box" relating complaints to arousal. First, there are almost twice as many first-time complainants as repeat complainants. Second, more than half the first-time complainants are at the lowest level of emotion, while half the multiple complainants are at the highest level of emotion. These are probably not chance observations; application of the nonparametric test, the chi square, indicated that this relationship would occur by chance less than 0.5% of the time.

III. CONCLUSIONS

The analysis of these data confirms the wisdom of policy which differentiates between annoyance and complaints and assesses the environment based on annoyance rather than complaints. As this paper shows, adverse noise environments may exist without complaints and conversely, acceptable noise environments may exist with complaints. While community response in terms of high annoyance correlates with DNL, complaints correlate only with arousal.

The analysis also highlights the importance of responding to complainants the first time they complain. The data show that first-time complainants are generally courteous and reasonable. Complainants only become unreasonable after having been ignored. In practice, it is far less trouble for an adminstrator to deal with complainants at their first complaint than deal with community action at a later point.

TABLE IV Relationship between frequency of complaint and emotional tone for 90 complainants.

	Number of 1st-time complainants	Number of multiple complainants
Low emotion	39	9
Moderate emotion	14	6
High emotion	6	16

APPENDIX: COMPLAINT FORM

TELEPHONE OR WRITTEN NOISE COMPLAINT
[Environmental Noise (AR 200-1)]

NOTE: The complainant may, of course, refuse to answer any or all of the questions below. Since that is his right, he must be allowed to do so. However, the person receiving the complaint should inform him that proper resolution will require full information and ask him to cooperate.

Date/Time Complaint Received:

Received by Whom:

Method of Complaint: _____ Telephone call _____ Visit _____ Letter _____

Date/Time of Occurrence:

Name of Complainant:

Location of Complainant at time of incident:

Complaint:

Cause of Complaint (As reviewed by complainant):

Damage, if any:

Others Receiving Complaint: (Have you complained to anyone else about this?)

History of Annoyance: (Have you been bothered by this before?)

Complaint History: (Have you called the base to complain before?)

Remarks: (Record comments and request made by the complainant. Comment on the complainant's attitude.)

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3 CONCLUSIONS

The body of data collected by CERL through experimentation and administration of established community attitudinal survey methods indicates that compter-generated noise contour predictions based on an energy model noise descriptor can be correlated with attitudinal survey results to reliably portray community response to impulsive noise. However, a method of accurately and consistently measuring impulsive sound levels at long distances using direct noise monitoring techniques and equipment has yet to be developed.

Energy Model Noise Descriptor

Papers 1, 4, and 8 described how the growth in annoyance to impulsive sound levels increases monotonically both with sound amplitude and with frequency of occurrence. Papers 2, 7, and 8 showed that the perception of building rattles is the main adverse impulsive (blast) noise factor, and that CDNL is the best available standard weighting for including those sound energies responsible for building rattle. Since the CDNL descriptor correlates well with the percentage of a community "highly annoyed" by impulsive noise (Papers 1, 5, and 7), it is indicated as the best available energy model to use to describe community response to impulsive noise.

Nighttime Adjustment

CERL's research supports the use of the long-established 10 dB nighttime adjustment for noise descriptors such as DNL. Most important, CERL's research indicates the strongest argument in favor of a nighttime adjustment is the community's likelihood of noticing an event; in general, intrinsic annoyance per event is not a significant factor.

Papers 6 and 8 described how bothersome noise events are more likely to be noticed by the community during the night than during the day. This indicates that a nighttime adjustment to the noise descriptor is justified. However, deciding on an adjustment for nighttime blast noise events is difficult, since the community response to blast noise events differs from the response to other, nonimpulsive noise sources. Blast noise, because of its high sound levels and impulsive nature, is readily noticed at all times of the day and night. Thus, the rate of noticing blast noise at night increases less (as a percent) over the daytime rate as compared with the nighttime increase for other noise sources. However, *blast noise events produce the* largest increase in intrinsic annoyance per bothersome event compared with other noise sources.

An alternate analysis identified in Paper 7 identified the results when day- and night-only blast noise contours were used to correlate with community annoyance. This analysis indicated that the blast noise nighttime adjustment to the noise descriptor should be perhaps 15 dB for the Fort Lewis data and about 9 dB for the Fort Bragg data.

Generally, the blast noise results are consistent with the 10 dB adjustment recommended for noise sources other than blasts.

Health Effects

Blast noise is potentially as bad or worse than other noises in terms of adverse health effects. Paper 7 described how sleep interference was cited as often for blast noise as for any other source – even in an area where less than 2 percent of the blast noise events occurred at night. Startle and fright, the factors known to cause physiological reactions, occur most often for blast noise.

Annoyance and the CDNL Noise Descriptor for Impulsive Noise

The exact function for relating the percentage of a community "highly annoyed" by blast noise to CDNL remains in question. It appears that the present CHABA recommendation may underestimate actual annoyance, as indicated by the results described in Paper 7. Thus, the functional relationship between annoyance and CDNL should perhaps be shifted to the left by 3 to 4 dB. It is apparent that more research into (1) the percentage of a community "highly annoyed" by impulsive noise vs CDNL and (2) the existence and value of community rise-and decay-time constants is required to clarify the issue.

Complaints and the CDNL Noise Descriptor for Impulsive Noise

As described in Paper 8, complaints are not a good measure of community response. The percentage of a community "highly annoyed" by impulsive noise correlates with CDNL complaints do not correlate with CDNL. Complaints seem to correlate only with "abnormal" or "unusual" events.

APPENDIX:
ASSESSMENT OF COMMUNITY RESPONSE TO HIGH-ENERGY IMPULSIVE SOUNDS

Report of Working Group 84

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

National Academy Press
Washington, D.C.
1981

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

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.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1963, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

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

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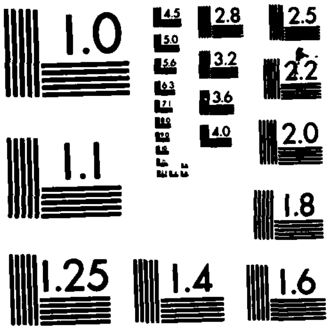

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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

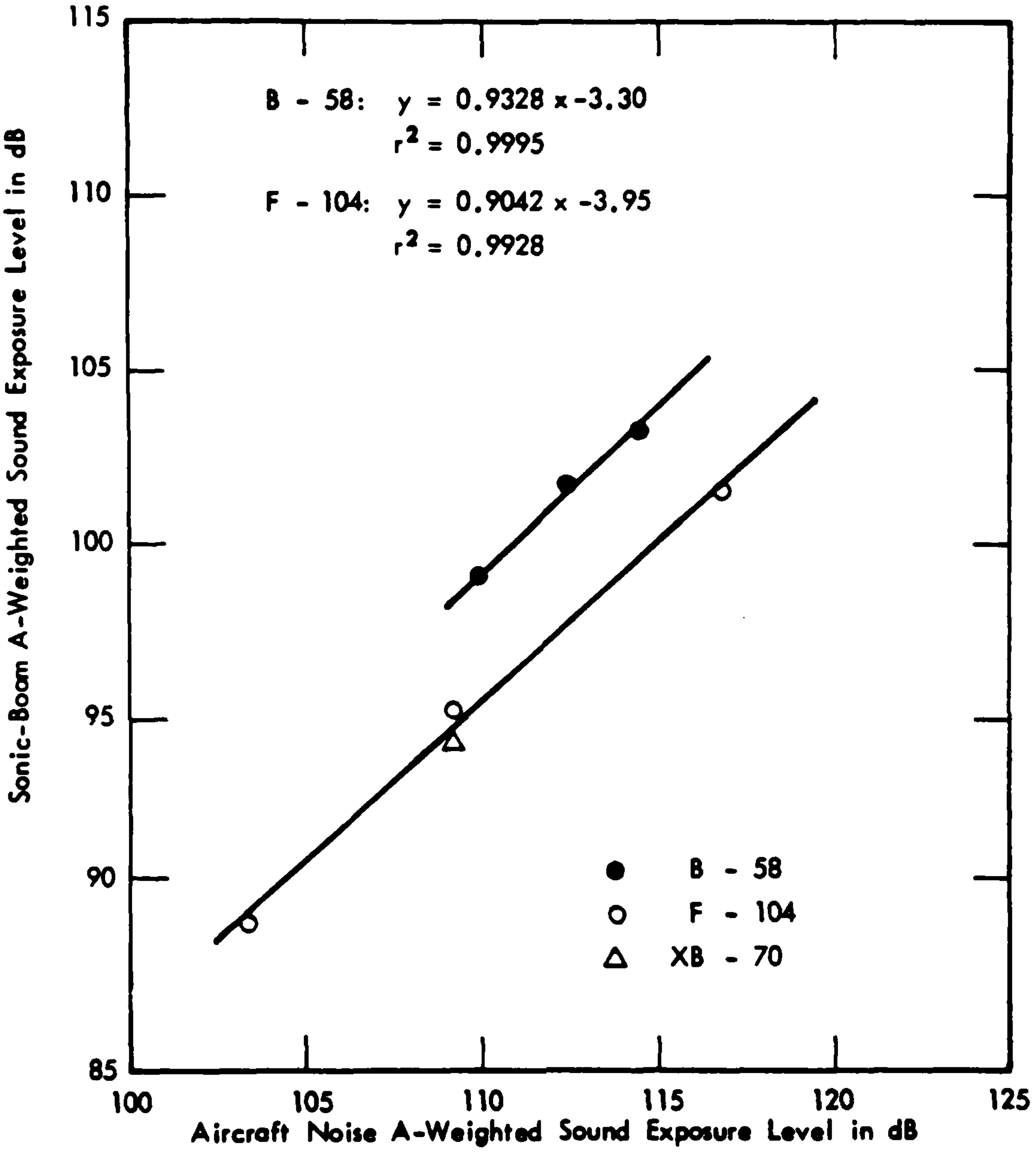

FIGURE 1. Sound Exposure Levels for Aircraft Noise and Sonic Booms When Judged Equally Annoying - Indoor Listening (Converted from Kryter, 1968)

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-night 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

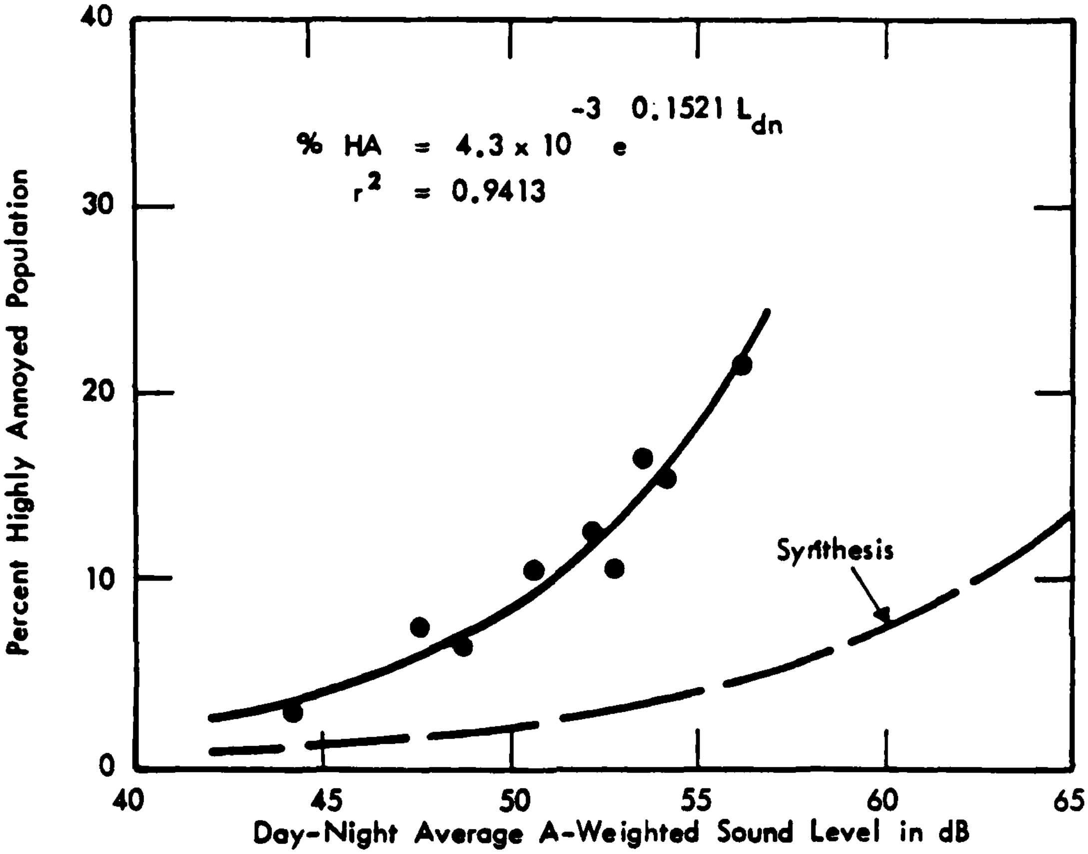

FIGURE 2. Oklahoma City Sonic-Boom Response for Total Population

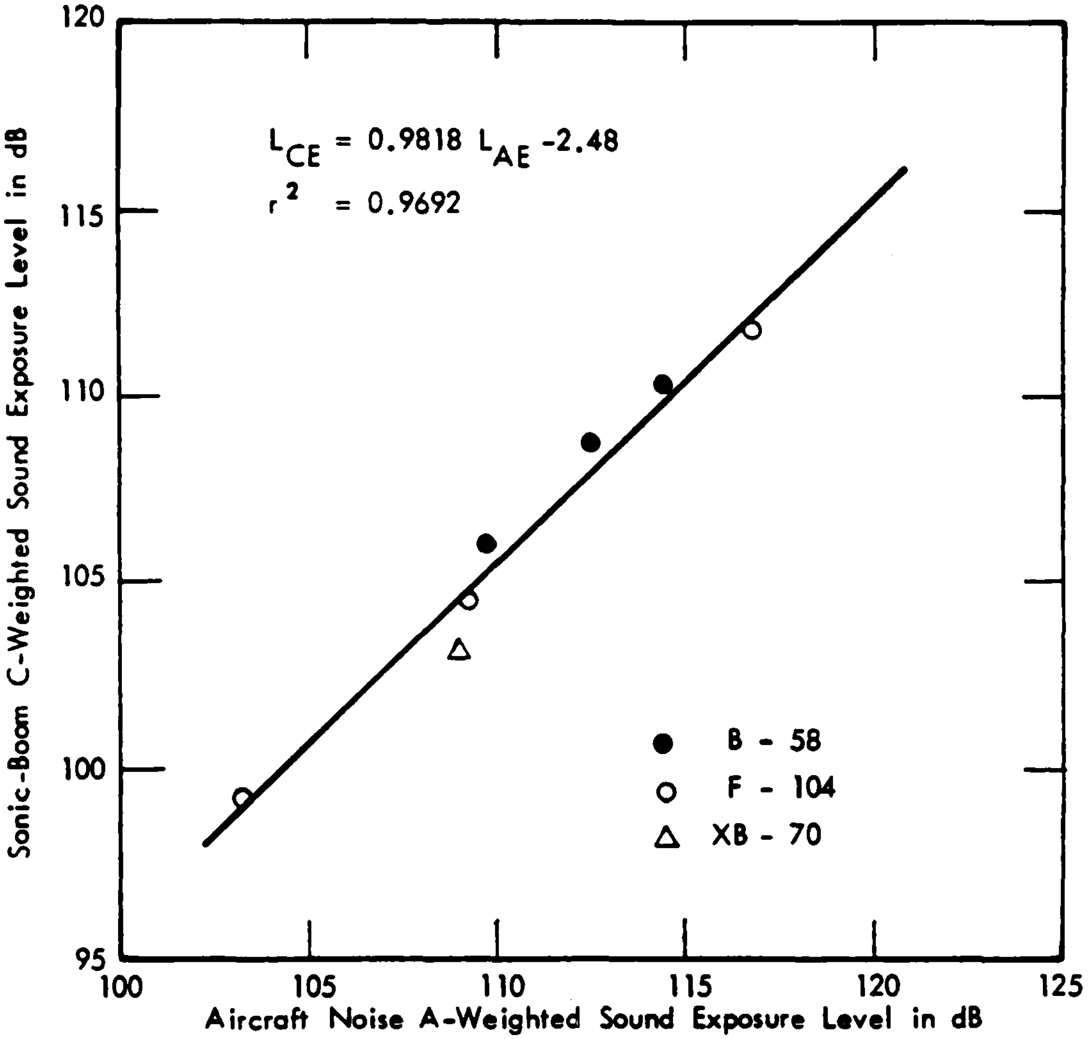

FIGURE 3. A-weighted Sound Exposure Level of Subsonic Jet When Judged Equally Annoying as a Sonic Boom of Specified C-weighted Sound Exposure Level - Indoor Listening (Converted from Kryter, 1968)

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.

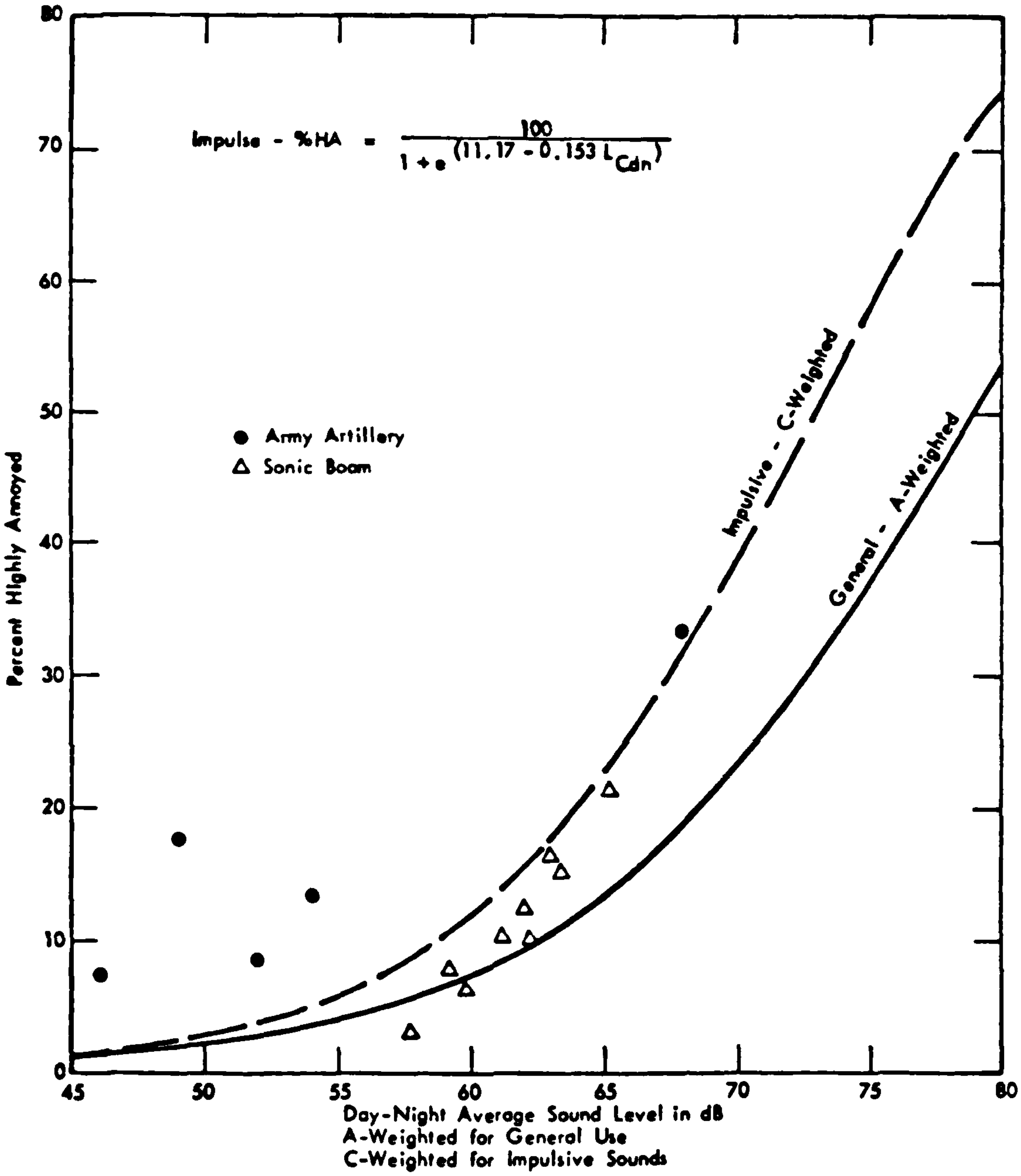

FIGURE 4. Recommended Relationships for Predicting Community Response to High-Energy Impulsive Sounds and to Other Sounds

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 not 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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