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PREDICTING COMMUNITY RESPONSE TO BLAST NOISE

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

This report presents a preliminary method for predicting levels of annoyance from artillery or blast noise in the environs of a military base. The means are given to relate various artillery pieces to a TNT equivalent and to normalize the overpressure from detonating various quantities of TNT to the overpressure from the detonation of one pound of TNT. Buried charges and aboveground

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detonations are also considered. Various ways to predict probable blast overpressure and frequency spectrum as a function of distance are discussed.

The annoyance of man by blast noise is predicted using the composite noise rating (CNR) and, for this calculation, the impulsive noise startle correction factor suggested by Kryter is added to the perceived noise level. Because CNR is utilized, the prediction method is suitable for computer computation of equal annoyance contours. Blast noise case histories are considered and serve to verify the prediction method. Additional data and tests are needed to more accurately predict blast pressure spectrum levels and the precise reaction of man to these blasts.

FOREWORD

This report was prepared in 1971 for the Directorate of Military Construction under Project 6.21.12.A 4A062112, "Permanent Construction Materials and Techniques," Task 05, "Environment Compatible Military Facilities," Work Unit 002, "Sound and Vibration Tolerance Limits — Residential Areas." Mr. Frank Beck was the Technical Monitor.

Dr. L.R. Shaffer is Director of CERL.

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PREDICTING COMMUNITY RESPONSE TO BLAST NOISE

1 INTRODUCTION

Background. This work dealing with blast noise will be considered an important step forward by the Department of the Army in the area of noise impact prediction and noise control. It is natural to assume — and public law requires — that the Army be able to predict the noise impact of any large, new, or altered program. Thus, it is expected that the Department of the Army will need and require a means to predict the noise impact arising from not only blast noise but also noise from rotary wing aircraft, vehicular sources, and fixed sources. Moreover, it should be anticipated that there will be areas of conflict between noise impact and land use. Thus consideration should be given to determining methods to alleviate incompatible land use situations. These methods may include not only attenuation of the noise, but also such factors as changes in location and operation, changes in land use, and monitoring and warning systems.

The original goal of this work was to "establish distance criteria as related to sound and vibration arising from blast operations." Because of the relative magnitude of the problem to the Army, only noise has been considered. Ground vibrations due to surface blasts or artillery fire die out very quickly. Reported structural vibrations result from the acoustic blast wave impacting on the structural surface and not from ground vibrations. Distance is not a viable impact prediction criteria since the sources at a military installation are apt to be spread out over a large area, and since the human response is related to frequency of operation, frequency content of the blast, time of day of operation, as well as blast amplitude.

This report is intended primarily for laymen in the area of acoustics. The use of the decibel, however, has been retained for a number of reasons. The decibel is a means to compare different magnitudes of power and, with appropriate modification it can also be applied to other units such as pressure, voltage, or velocity. Being a logarithmic comparison, it is most useful for relating vastly different magnitudes; hence, it is normally used in the area of acoustics.

Given two powers, P_1 and P_2 and a gain, G, equal to P_1/P_2, the decibel difference (dB) or gain between P_1 and P_2 is defined by:

$$G_{dB} = 10 \log_{10} P_1/P_2$$
$$= 10 \log_{10} G \qquad \text{[Eq 1]}$$

Clearly, from a computational standpoint, writing $G_{dB} = 130$ is preferable to writing $P_1/P_2 =$ 10,000,000,000,000. In fact "from the rustle of leaves to the thunder of cannon" corresponds to a thousand-trillion (1,000,000,000,000,000) change in intensity level (150 dB). A one trillion change is the range of the ear for short periods of time (130 dB); a one billion change in level (100 dB) is the ordinary range of the ear.

The decibel, being a logarithmic measure, approximates the response of the human ear, and the ear perceives logarithmically for probably the same reasons that logarithmic measure is desired computationally: the fantastic range of sound intensity. Very often the layman is misled by advertising that reports a product to be 50 percent "quieter," etc. What is really being said here is that the *acoustic signal intensity* has been reduced by 50 percent. (It may also be that the acoustic output of the standard is 50 percent more intense than the output of the new product.) In either case, the resulting change is *just barely perceptible* to the human ear (3 dB). A factor of two in loudness or annoyance corresponds approximately to a 1000 percent change in intensity (x10) or 10 dB; a factor of four, much louder, to a 10,000 percent change in intensity (x100) or 20 dB, as shown in Table 1.

Table 2 lists common sources of sound, with their corresponding sound pressure levels (SPL). SPL's are a logarithmic function of the sound pressure. Although intensity is proportional to pressure squared, the SPL is so arranged that 3 dB (x2 pressure) corresponds to x2 intensity. Appendix H contains a reference chart summarizing these relations.

To further aid the reader, Appendix A defines technical terms used in this report.

Problem. Noise, as it impacts on man, is increasingly recognized as a major problem. Work is underway internationally to assess the effects of noise on man and to discover the means to eliminate and attenuate noise. For many years, acceptable levels of noise in offices and commercial establishments have been known; recently, levels have been set to protect workers in industrial areas. Recent interest has focused on noise as it affects man where he lives. Blast noise is a community noise problem but is almost exclusively an Army problem. Letters of complaint to installations and to congressmen concerning Army blast noise are a matter of record. It is also a matter of record that the ability of military installations to function and fulfill their mission has been compromised because of blast noise problems.

Table 1

Subjective Effect of Changes in Sound Characteristics

Change in Sound Level	Change in Apparent Loudness
3 dB	Just perceptible
5 dB	Clearly noticeable
10 dB	Twice as loud (or 1/2)
20 dB	Much louder (or quieter)

Table 2

Comparison of Intensity, Sound Pressure Level, and Common Sounds

Relative Energy Intensity (units)	Decibels	Loudness
1,000,000,000,000,000	150	Artillery at 500 feet
100,000,000,000,000	140	Jet aircraft at 50 feet
10,000,000,000,000	130	Threshold of pain
1,000,000,000,000	120	
100,000,000,000	110	Near elevated train
10,000,000,000	100	Inside propellor plane
1,000,000,000	90	Full symphony or band
100,000,000	80	Inside auto at high speed
10,000,000	70	
1,000,000	60	Conversation, face-to-face
100,000	50	Inside general office
10,000	40	Inside private office
1,000	30	Inside bedroom
100	20	Inside empty theater
10	10	
1	0	Threshold of hearing

The first step toward solving a major community noise problem is to identify, quantify, and qualify the important noise sources. A community noise problem may arise from the operation of a metropolitan airport, a busy road or highway, a large manufacturing plant, or a military installation. While the total noise from these sources is the sum of their constituent parts, one plane, one truck, one motor, or one artillery round does not normally create a significant noise-annoyance problem. Rather, the noise problem is created by the summation of flights per hour, artillery rounds per day, vehicles per week—the total operation. Of course, the individual noise generators are not all equal; for example, certain trucks and certain planes are noisier than others. Efforts at noise reduction must include the identification of these subgroups so that planners, politicians, and administrators may interpret their relative importance and take appropriate action on the basis of all the political, social, and economic factors involved.

Purpose. This report presents a method to predict the noise impact from artillery and blast noise in the environs of a military base. The noise-annoyance units are completely compatible with the units currently used and recognized to predict airport noise-annoyance; hence, the effect of aircraft operations can easily be merged with the artillery and blast noise effects to predict an overall noise impact. The effects of stationary sources (machinery, etc.), vehicular traffic, and small arms may then be added to complete the noise impact picture.

This prediction method is intended to be a tool for planners and administrators. Given the operations, the types of weapons and their charges and locations, the frequency of operation, the time of operation, and the weather conditions, this method predicts the socio-economic reactions of the population in the environs of the base. Specifically predicted are the percentage of people annoyed, the percentage willing to take group or legal action, and the percentage reduction in property values as a function of the affluence of the neighborhood. Changes in operations, weapons, locations, or attenuation methods alter the impact predictions for the base environs. Although the annoyance levels predicted are the summation of a series of simple calculations, millions of calculations result when one considers all possible locations, types of weapons, and charges; hence, planners will probably desire a computerized prediction method to facilitate the generation of the noise predictions.

Report Preview. As previously noted, the first steps toward the solution of any major noise problem include identification, quantification and qualification of the important factors. Chapter 2 identifies the constituent artillery and blast noise sources and relates them quantitatively to an equivalent ground-level detonation of one pound of TNT. Chapter 3 quantitatively describes the pressure impulse resulting from the detonation of one pound of TNT as it propagates through the atmosphere. Allowance is made for the overall lower frequency spectrum which results from larger blasts. Chapter 4 quantitatively and qualitatively describes the effects of blast noise on man.

Because of the scant quantity of reliable data, the predicted annoyance levels will not be as accurate as one might desire, but as scientific experiments refine the elements in the prediction process, the predicted levels will become more accurate (with a higher confidence value and smaller deviation). This refinement will occur within the framework of the overall method; the method itself need not be altered. For example, special measurements, sufficiently distant to eliminate gross, large-amplitude effects but independent of atmospheric effects are needed to more accurately relate artillery firing to pounds of TNT. Community noise monitoring programs are needed to statistically predict probable atmospheric effects in contrast to worst case effects. Psychological tests are needed to determine the effects on man of quasisinusoidal impulses (artillery) in contrast to N-waves (sonic boom). Present theory predicts that an artillery blast is substantially more annoying than a sonic boom of the same level because of spectral differences.

By using the method presented in this report the annoyance level can be predicted at an arbitrary location with respect to the base. When calculated by computer, these levels can be found at many points in the environs of the base, and equal noisiness contours can be constructed. These contours can be drawn to the same distance scale as a map of the base and its surroundings, and the contour map can be used then as an overlay to show graphically the noise impact of base operations.

Chapter 5 includes recommendations on how to interpret annoyance levels for a given set of base operations and assumptions. These interpretation recommendations are given because no standards exist for dealing with blast-related impulse noise. Blast noise has been related to sonic-boom noise, which itself has been related to aircraft noise. Even the airport noise-annoyance contours are intended not as standards but as criteria for planners. California has enacted regulations using airport noise contours as standards and Illinois has proposed the formalized use of these contours for planning. The Department of Housing and Urban Affairs no longer permits the construction of subsidized housing in predicted high noise-annoyance areas.[1] These contours, however, have not generally been recognized by the courts as a basis for damage suits. A California circuit court[2] recently awarded damages on the basis of contours, but this decision is under appeal. In fact, legal authorities have suggested that these contours, when used for regulation rather than planning purposes, violate the principle of due process. Appendix G lists existing state and municipal noise ordinances.

2 SOURCES

Introduction and Scaling. The major military impulse noise sources include artillery fire, shell bursts (at or above ground level), surface blasting, and cratering blasts. In addition, the artillery projectile velocity may be supersonic, creating sonic booms.

1 *Noise Abatement and Control Department Policy, Implementation Responsibilities, and Standards*, Circular 1390.2 (U.S. Department of Housing and Urban Development, 1971).

2 Irving D. Aaron, et al., *Plaintiffs vs City of Los Angeles, a Municipal Corporation, Defendant*, Superior Court of the State of California for the County of Los Angeles, Memorandum Opinion #837799, Bernard S. Jefferson, judge of the Superior Court (5 February 1970).

Each of the above sources will be related to the number of pounds of TNT required to produce an equivalent ground-level blast. All groups and experts agree that the form of the equation relating the overpressure* produced to the quantity of TNT detonated is:

$$P_x \propto \frac{(W_x)^\beta}{(W_0)} P_0 \qquad \text{[Eq 2]}$$

where P_0 and W_0 = reference overpressure and charge weights

P_x and W_x = actual overpressure and equivalent charge weights.

Different groups have used various values for β. Fortunately, these variations are small and do not alter the results greatly. For the purpose of this report, the Atomic Energy Commission (AEC)-Sandia Laboratory[3] value of 0.4 will be used because it is widely accepted and because it is a median value. Using Equation 1 with $\beta = .4$, values of increased pressure for typical explosive weights were calculated. These values are summarized in Table 3.

Artillery Fire. Many studies have been made on the overpressures of artillery fire. Unfortunately, most of these measurements were made close to the weapon, in the near field, or in the pressure range for which the equations of wave motion are quite nonlinear.[4] Hence, this data cannot be used to predict distant pressures or equivalences.

Meenan[5] has made measurements to determine the TNT equivalence for a 175 mm gun, and Bragdon[6] has made measurements to determine 140 dB peak sound pressure level contours for weapons. Because this data was recorded at medium and far distances, it is clouded by atmospheric alterations (explained in Chapter 3).

Table 3

Pressure Increase for Various Blasts Related to One Pound of TNT

Weight, lbs	Multiplication Factor	dB Increase
1	1.00	0
2	1.32	2.4
3	1.55	3.8
4	1.74	4.8
5	1.90	5.6
10	2.51	8.0
15	2.95	9.4
20	3.31	10.4
30	3.89	11.8
40	4.36	12.8
50	4.79	13.6
100	6.31	16.0

Nevertheless, this data and other sources[7,8] indicate that in the direction of fire, there is approximately a one-to-one relationship between propellant charge weight and pounds of TNT. It should be noted that an error of 50 percent in this estimate would result in a barely perceptible change in the acoustic signal. In an actual case history,* reductions in blasting charge weight on the order of 50 percent did very little to alter the incidence of complaints about the noise.

Bragdon's average measurements to the sides or rear of an artillery piece with respect to the front are in substantial agreement with Meenan's

* Throughout this report, different units and terms are used to describe the same quantity because these are the units normally used in a particular area. Hence, overpressure is measured in pounds per square foot (PSF) when considering sonic booms and in pounds per square inch or bars when considering nuclear or conventional blasts. Acousticians consider overpressure in dB re 0.0002 dynes/cm^2, which can also be termed peak level or peak sound-pressure level re 0.0002 dynes/cm^2. (See the conversion chart in Appendix A.)

3 J.W. Reed, *Acoustic Wave Effects Project Airblast Prediction Techniques*, SC-M-69-332 (Sandia Corporation, 1969).

4 H.H. Holland, Jr., *Muzzle Blast Measurements on Howitzer 105mm, XM 103E1*, Human Engineering Laboratory Tech. Memo 23-62 (Aberdeen Proving Ground [APG], 1962).

5 H.J. Meenan, *Sound Pressure Levels of Various Guns vs Bare Charge Detonations (Test Data)*, Report No. DPS-2572, AD 903 457 (USATECOM, 1972).

6 C.R. Bragdon, *Weapon Contours*, Bio-Acoustics Special Study No. 34-004-71/72 (U.S. Army Environmental Hygiene Agency [AEHA]).

7 A.A. Thompson, *The Acoustic Environment Predicted from the Firing of a 175 mm Gun*, Ballistic Research Laboratories Memo. Report No. 1910 AD83275-6 (Aberdeen Proving Ground, 1968).

8 W. Taylor, *Proposed Computational Procedure* (unpublished M.S. written 4 December 1967, transmitted October 1971).

* C.S. Mills, Jr. (Former Chief, Demo. Branch, Fort Belvoir) personal communications.

unpublished data as reported by Thompson.[9] Table 4 summarizes these results. Bragdon's contours further suggest the following empirical relation for directions other than 0°, 90°, 180°, or 270°. For the forward half (−90° to 0° to 90°),

$$\Delta dB = (1 - \cos^2\theta)(2.5) \qquad [Eq\ 3]$$

and for the region 90° to 180° to 270°:

$$\Delta dB = 4.0 + (1 - \cos^2\theta)(1.5) \qquad [Eq\ 4]$$

where ΔdB = the correction to be added to a spherical (non-directional) ground-level blast.

Table 4

Directional Pressure Pattern for Artillery

Direction	dB Change	Pressure Multiplier	Charge Weight % Reduction
Forward 0°	0	1.0	0%
Side 90° or 270°	2.5	0.75	52%
Rear 180°	4.0	0.63	68%

Artillery shell burst noise, on the other hand, is considered to be omnidirectional, and the acoustic output is calculated solely from the effective charge weight of the shell in pounds of TNT.

Ground-Level, Above-Ground, and Below-Ground Blasts. Ground-level blasts are scaled according to Equation 2 with $\beta = 0.4$. If explosives other than TNT are under consideration, then they should be converted to an equivalent weight of TNT. Small differences can be neglected since a 50 percent difference is just perceptible to the human ear.

Vortman[10] shows that for blasts occurring at relatively short distances above ground the peak pressure increase is about 50 percent, or 3.5 dB. Webb and Warren[11] have conducted experiments with a source in the range from 1/2 to 7-1/2 lbs of TNT at an altitude of 450 ft and a distance of 2,000 ft. For this relatively large height, the pressure increase is about 100 percent or 6 dB.

There is little precise knowledge about the effects of below-ground blasts (cratering charges). The general relation is thought by most experts to be of the form:

$$P_c = T(d/W_c^{1/3})\, P_g \qquad [Eq\ 5]$$

where T = transmissivity factor (a function of the depth d and charge weight W_c)

P_c = pressure at a distance X

P_g = pressure W_c lbs of TNT would produce at distance X when exploded at ground level.

To complicate matters further, the acoustic radiation from an underground blast appears to be beamed upward (as light would be beamed from a hole in the ground), and this beamed sound can be focused back onto the ground at points distant from the source. (Chapter 3 deals with this focusing mechanism.) Naturally, the transmissivity is also a function of the soil composition and characteristics. Figure 1 relates the transmissivity factor, T, to the scaled burst depth ($d/W^{1/3}$) based on the curves of Reed[12] and Perkins,[13] but including an allowance for the upward beamed sound.

9 A.A. Thompson, *The Acoustic Environment*.

10 L.J. Vortman and J.D. Shreve, Jr., *The Effect of Height of Explosion on Blast Parameters*, SC 3858 (Sandia Corporation, 1956).

11 D.R.B. Webb and H.E. Warren, "Effect of Bands on Subjective Reaction," *Journal of Sound and Vibration*, Vol 6 (1967), p 375.

12 J.W. Reed, "Airblast from Plowshare Projects," *Education for Peaceful Uses of Nuclear Explosives*, L.E. Weaver, ed. (University of Arizona Press, 1970).

13 B. Perkin, Jr., and W.F. Jackson, *Handbook for Prediction of Air Blast Focusing*, Ballistic Research Laboratory Report No. 1240/AD-602-112 (Aberdeen Proving Ground, 1964).

3 ATTENUATION OF IMPULSES WITH DISTANCE

Sound Propagation in the Atmosphere. Elementary descriptions of the propagation of sound from a source indicate that in the open the amplitude of the sound is inversely proportional to the distance from the source.[14] Hence, the energy density is inversely proportional to the square of the distance. That is, the sound pressure level (SPL) falls 6 dB each time the distance is doubled (20 dB for each factor of ten times the distance). However, this simple description assumes that the velocity of sound is the same in all directions and at all altitudes, and it fails to account for absorption of energy from the sound wave by the air.

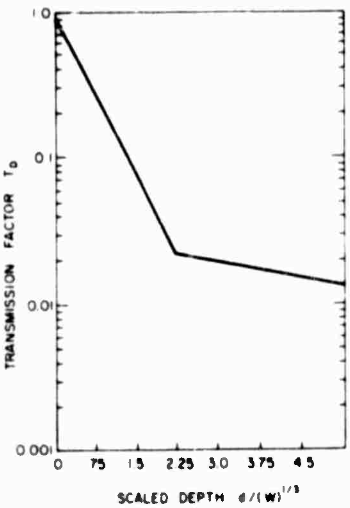

Figure 1. Transmissivity from underground bursts.

In practice, the speed of sound varies with direction and altitude. This variation is primarily a result of wind and temperature changes. The net result is that the atmosphere sometimes acts as a lens and diverts waves traveling away from the ground and focuses them at a distant point on the ground.[15,16] This focus occurs when the variation of the speed of sound with altitude undergoes an inversion; that is, the velocity decreases with altitude near the ground and then increases at greater altitudes. Figure 2 illustrates this velocity profile condition along with the corresponding focusing and ducting of the sound waves. These focuses can appear in the range from 2 to 40 miles from the source.

In addition to the inversion focusing and ducting described above, similar effects occur at greater distances as a result of jet stream ducting, ozonosphere ducting, and ionosphere ducting.[17] Jet-stream ducting occurs in the range from 30 to 300 miles from the source and thus will cause only occasional problems. Ozonosphere- and ionosphere-ducting effects appear only at distances greater than about 80 miles and hence need not be considered, except for large blasts (kilotons or larger).

Clearly, transmission along the ground does not occur during focusing conditions (Figure 2). In fact, areas which are closer to the source than the focal area may be "quiet," with any audible sound resulting from atmospheric perturbations and diffusion. However, for a positive sound velocity gradient (Figure 3), the wave propagates along the ground and overpressure is amplified.

Because the predominant adverse transmission path is via rays transmitted upward and then focused downward (Figure 2), ground terrain variations do not attenuate sound in the manner one might expect. In fact, recent work aimed at shielding areas by using ground cover has met with this problem. Although earth berms (earthen barrier walls) have been used extensively and successfully in Denmark and to some extent in

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14 *Noise Reduction*, L.L. Beranek, ed. (McGraw-Hill, 1966).

15 P. Roshwell, "Calculation of Sound Rays in the Atmosphere," *Journal of Acoustical Society of America*, Vol 19 (1947), pp 205-221.

16 W.W. Bernig, *Investigation of the Propagation of Blast Waves Over Relatively Large Distances and the Damaging Possibilities of Such Propagation*, Ballistic Research Laboratories Report No. 675/PB126757 (Aberdeen Proving Ground, 1948).

17 J.W. Reed, *Acoustic Wave Effects Project: Airblast Prediction Techniques*, SC-M-69-332 (Sandia Corporation, 1969).

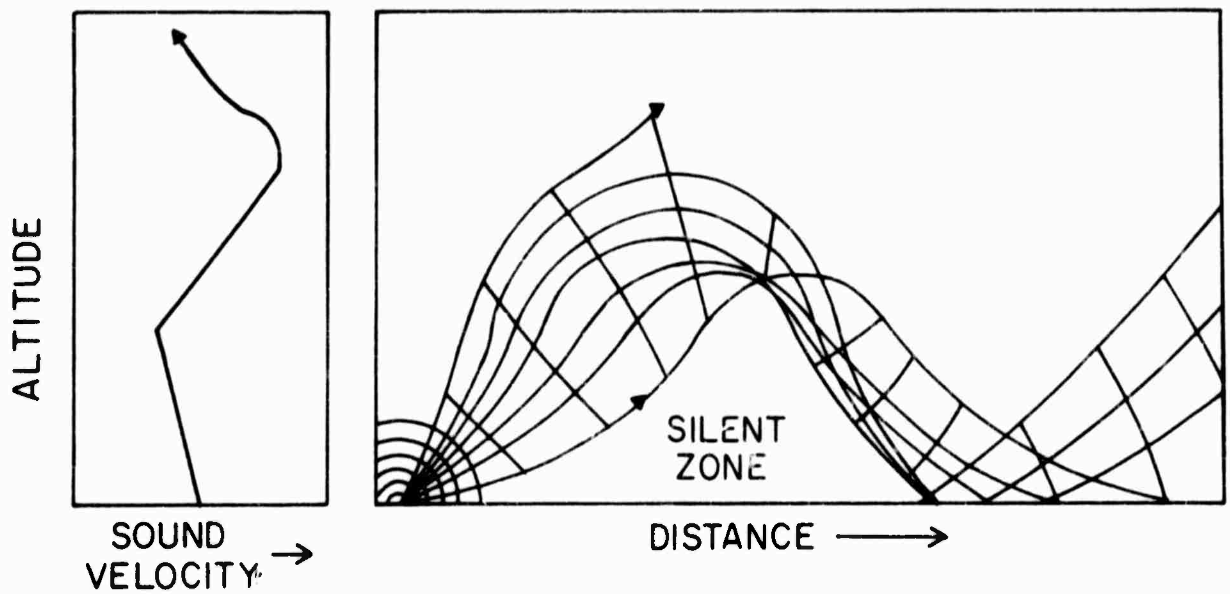

Figure 2. Ray paths in air when the vertical velocity gradient undergoes an inversion.

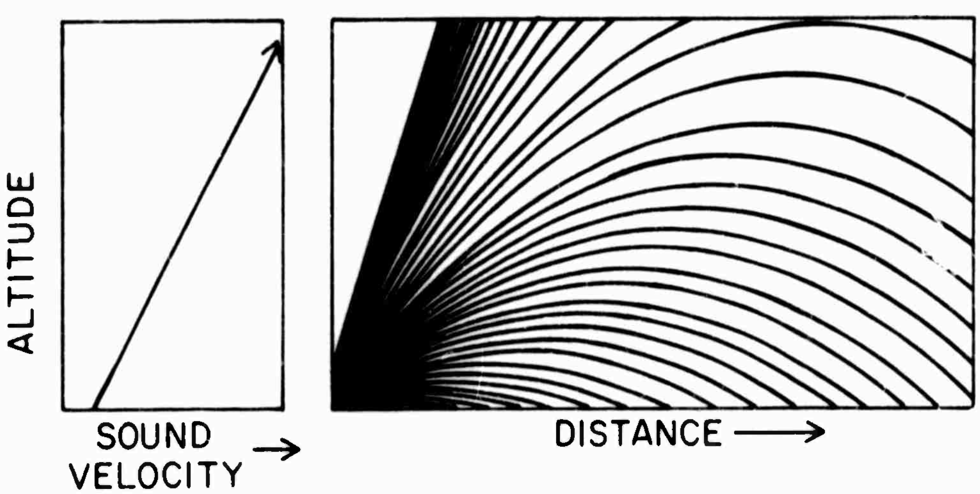

Figure 3. Ray paths in air when the vertical velocity gradient is positive.

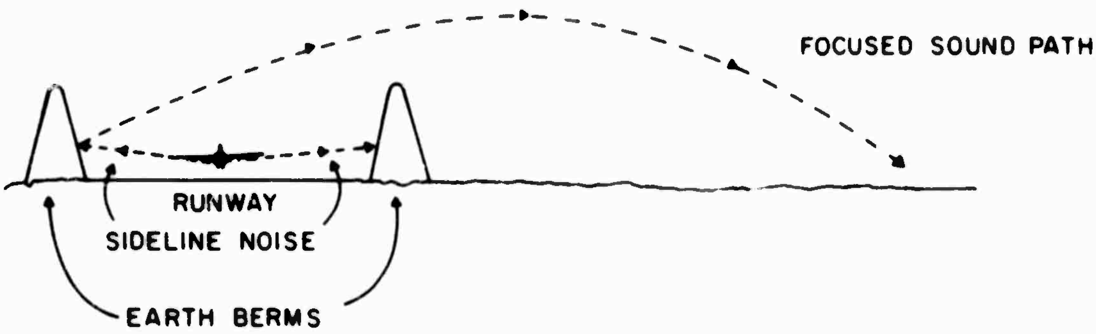

Figure 4. Noise from earth berms.

the United States to shield areas from expressway noise,[18] these berms have been only partially successful when applied to aircraft ground runups and takeoff sideline noise. Sound reflected off of a far side berm is directed upward and then focused downward, as depicted in Figure 4.[19]

Blast Overpressure Prediction Methods. There are two methods to predict the possible overpressure of blasts: the Sandia Laboratory-Atomic Energy Commission (AEC) method,[20] and the Ballistic Research Laboratory (BRL)-Aberdeen Proving Ground (APG) method.[21]

The Sandia method is based on a theoretical curve for standard conditions (still air with no temperature gradients at sea level, 0°C) with the possible focusing effects to this curve as shown in Figure 5. In the jet-stream ducting region, 15 is the predicted maximum focus factor; in the surface inversions region, a maximum factor of 3 is predicted.

The factor of 15 for jet-stream ducting is based on empirical data[22] that consists of 239 recorded data points with 3.15 as the average magnification and a log normal distribution around this average. The maximum recorded factor was 8.31 and the standard deviation was 04.4 dB,* so the factor of 15 was a conservative number chosen for safety. The factor for surface inversions is based on about 75 data points[23] and does not appear to be nearly as conservative as the factor for jet-stream ducting. In fact, based on Reed's data (AEC) which includes a 3x point 6 to 8 appears to be a good and conservative maximum factor (1.8 being the average focus factor).

The Sandia "standard conditions" curve is the IBM problem-M curve[24] extended to lower pressures by an asymptotic approximation. Recently Lehto and Larson[25] of the Naval Ordnance Laboratory (NOL) have presented a new, standard-conditions curve for real air that agrees with the problem-M curve at large amplitudes and has been extended to small amplitudes (.00016 psi) by the same method that Okhotsimskii and Vlasova used to extend the ideal air solution to low pressures. Figure 6 compares the problem-M extension with the NOL prediction; for the remainder of this paper, the NOL curve will be substituted for the problem-M curve ex-

18 G.S. Anderson, "Design of Acoustic Barriers for Highway Noise Reduction," paper presented at the 81st meeting of the Acoustical Society of America, Washington, DC (1971).

19 P. .ensen, "Noise Reduction by Earth Berms," paper presented at the 81st meeting of the Acoustical Society of America, Washington, DC (1971).

20 J.W. Reed, *Acoustic Wave Effects Project: Airblast Prediction Techniques*, SC-M-69-332 (Sandia Corporation, 1969).

21 Perkin and Jackson, *Handbook for Prediction of Air Blast Focusing*.

22 J.W. Reed, *Explosion Wave Amplitude Statistics for a Caustic at Ranges of 30 to 45 Miles*, Report No. SC-RR-67-860 (Sandia Laboratories, 1968).

23 J.W. Reed, *Climatology of Airblast Propagations from Nevada Test Site Nuclear Airbursts*, Report No. SC-RR-69-572 (Sandia Laboratories, 1969).

* A standard deviation of 4.4 dB is a log normal deviation. The actual factor was 3.15 times 1.65 (or times 1/1.65) which can be written (3.15)x(1.65) ± 1.

24 C.D. Broyles, *IBM Problem-M Curves*, Report No. SC-TM-268-56-51 (Sandia Laboratories, 1956).

25 D.L. Lehto and R.A. Larson, *Long Range Propagation of Spherical Shockwaves from Explosions in Air*, No. NOLTR-69-88 (U.S. Naval Ordnance Laboratory, 1969).

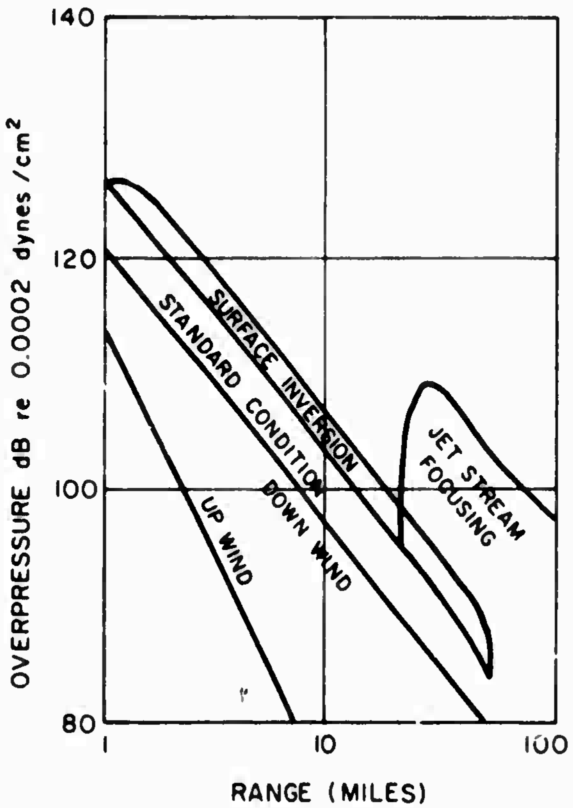

Figure 5. AEC prediction of blast propagation referred to one pound of TNT.

tension since this curve (as will be shown subsequently) seems to fit the empirical data better.

The BRL method uses as its basic curve an empirical curve derived from data measured on days for which the sound profile had a negative velocity profile. Since under conditions of a negative sound-velocity gradient the sound waves are refracted upward, measured pressures will be smaller than standard pressures. The BRL empirical curve therefore lies below the NOL curve. Figure 7 depicts the negative-gradient condition, and Figure 9 compares the BRL and the NOL curves.

Based on this empirical curve, the BRL method predicts a focus factor of 100 for surface inversions, 5 for a positive sound-profile gradient, and 25 for a double positive gradient (Figure 8). These latter two conditions are of interest only close to the source where a focus condition is not possible because of the short distance involved. Figure 10 shows the basic BRL curve with the BRL focus factors "added" to it: 5 at short distances, 25 at medium distances, and 100 at far distances.

To check these two prediction curves, empirical data have been gathered from a number of sources.[26-30] Most of this data was acquired on days exhibiting some type of focus condition. Figure 11 shows the NOL curve with the Reed factors added, the BRL curve with its factors, and the empirical data. For comparison purposes, the empirical data items have been reduced by appropriate amounts to make them equivalent to one pound of TNT. Some of the U.S. Army Test and Evaluation Commands (USATECOM) data and the Material Test Directorate-Aberdeen Proving Ground (MTD) data is questionable because the low-frequency cutoff of the instrument used to make the measurements excluded substantial, audible, low-frequency energy. This data has been adjusted by appropriate amounts after "calibration" measurements were made by Army Environmental Hygiene Agency (AEHA) for this purpose. The NASA rocket data has been adjusted downward slightly because of probable in-phase addition of sound arriving along different paths. (In-phase addition does not occur with pulses; rather, a "rumble" is heard as the sounds from the different paths arrive at different times.) Both the Sandia and the BRL curves were derived to predict the possibility of damage under the worst possible conditions; therefore, these "worst case" curves will be high.

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26 H.J. Meenan, *Sound Pressure Levels of Various Guns vs Bare Charge Detonations (Test Data)*, Report No. DPS-2572, AD 903 457 (USATECOM, 1972).

27 R. Alnsley, unpublished measurements made during 1964 by Material Test Directorate, Aberdeen Proving Ground.

28 R.N. Tedrick, et al., *Studies in Far-Field Acoustic Propagation*, NASA Tech. Note D-1277/N 62-14859 (George C. Marshall Space Flight Center, 1962).

29 C. Bragdon, *Artillery Noise Study*, Informal Letter Report of Tests (AEHA).

30 D.L. Lehto and R.A. Larson, *Long Range Propagation of Spherical Shockwaves from Explosions in Air*, No. NOLTR-69-88 (U.S. Naval Ordnance Laboratory, 1969).

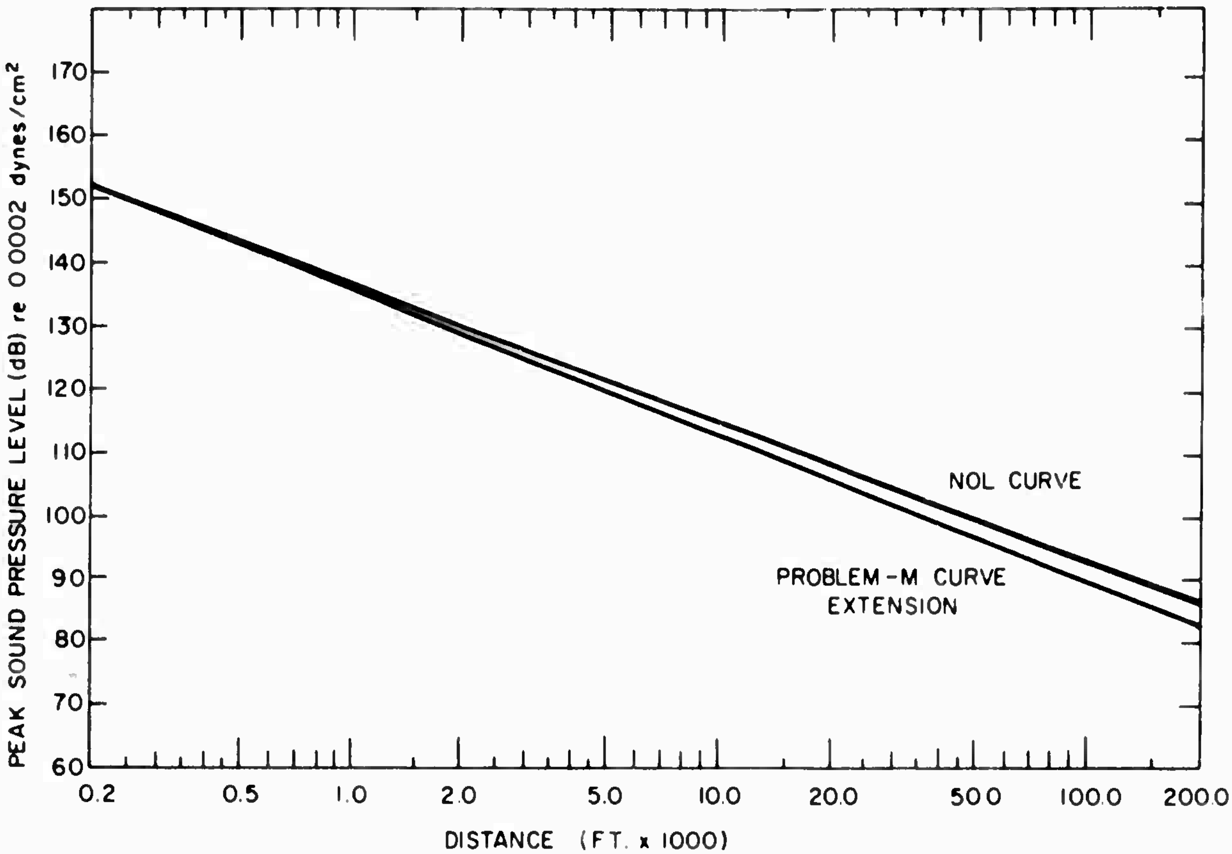

Figure 6. Comparison between IBM problem-M curve extension and the NOL base curve.

Clearly, the BRL limits are more conservative than the Sandia limits for distances up to 150,000 feet, and as previously noted, the Reed estimation of a maximum focus factor of 2 in the inversion ducting region is probably low.

A tentative base curve, tenative gradient condition curve, maximum overpressure curve, and probable overpressure curve (for days exhibiting adverse meteorological conditions) can be established from this background and limited data. The base curve is the NOL curve; the negative gradient curve is the BRL base curve; the maximum overpressure curve is twice the NOL curve in the range from 0 to 2,000 ft, four times in the range from 2,000 to 10,000 ft, eight times in the range from 10,000 to 150,000 ft, and 15 times in the range above 150,000 ft. The probable over-pressure curve is 1.8 times the NOL curve from 0 to 90,000 ft, a gradual change from 1.8 to 3.0 times in the range from 90,000 to 150,000 ft, and 3 times in the range above 150,000 ft. Figure 12 shows the empirical data along with these proposed curves. Figure E-4 in Appendix E shows the curves of Figure 12 on a more detailed grid. The BRL negative gradient base curve and its associated focus factors, on the other hand, do not appear to fit this data as well as the above curves do. Also, with reference to the BRL factors and the standard condition curve of Figure 11, there is no logical reason to assume that as one nears the source, the possible peak focus factor (or average factor) increases with respect to a standard condition curve as is the case with the BRL factors.

Before continuing, it is useful to consider the probability of various meteorological conditions. The limited data seem to indicate that even on days exhibiting adverse conditions, half of the events are likely to follow the probable curve and the other half to follow more nearly the NOL

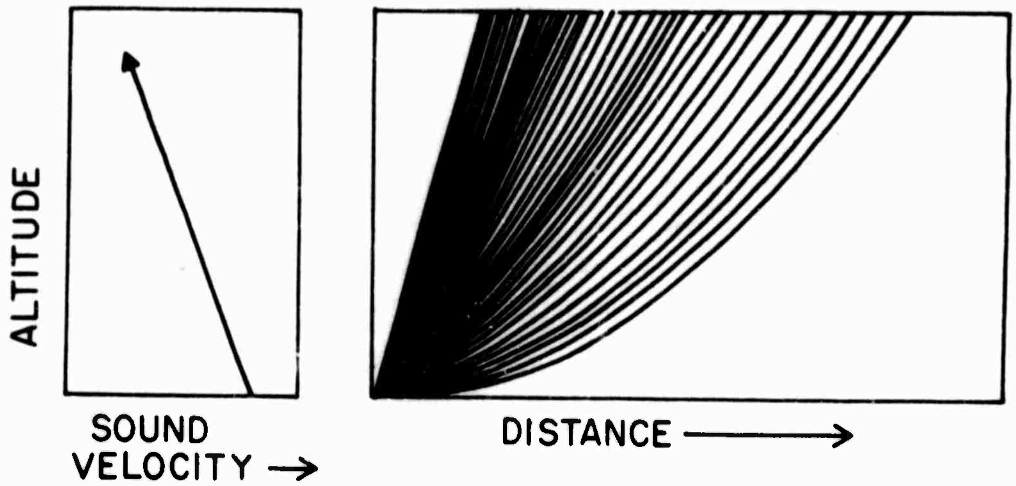

Figure 7. Ray paths in air when vertical velocity gradient is negative.

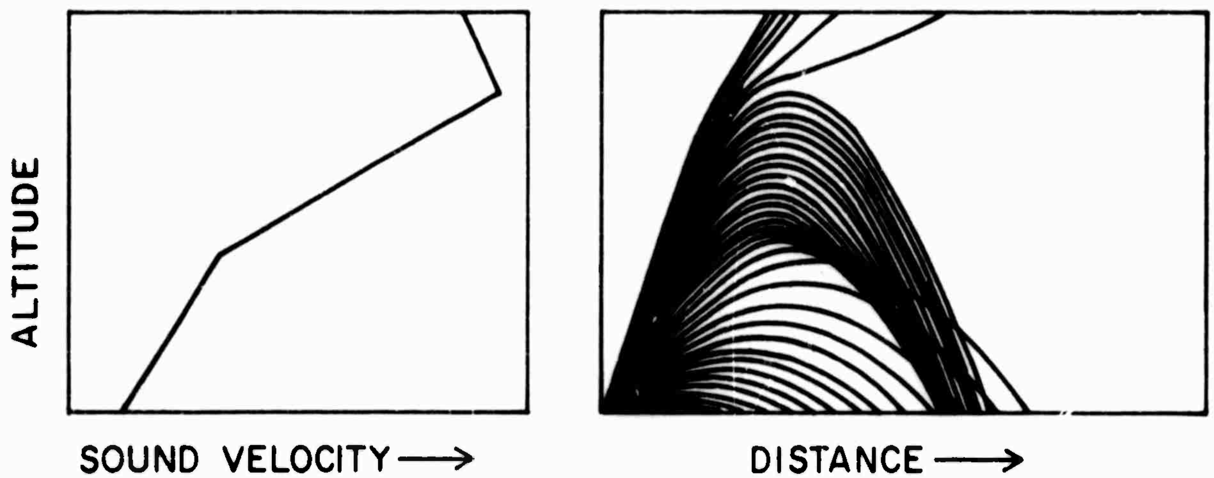

Figure 8. Ray paths in air when vertical velocity gradient has two positive segments.

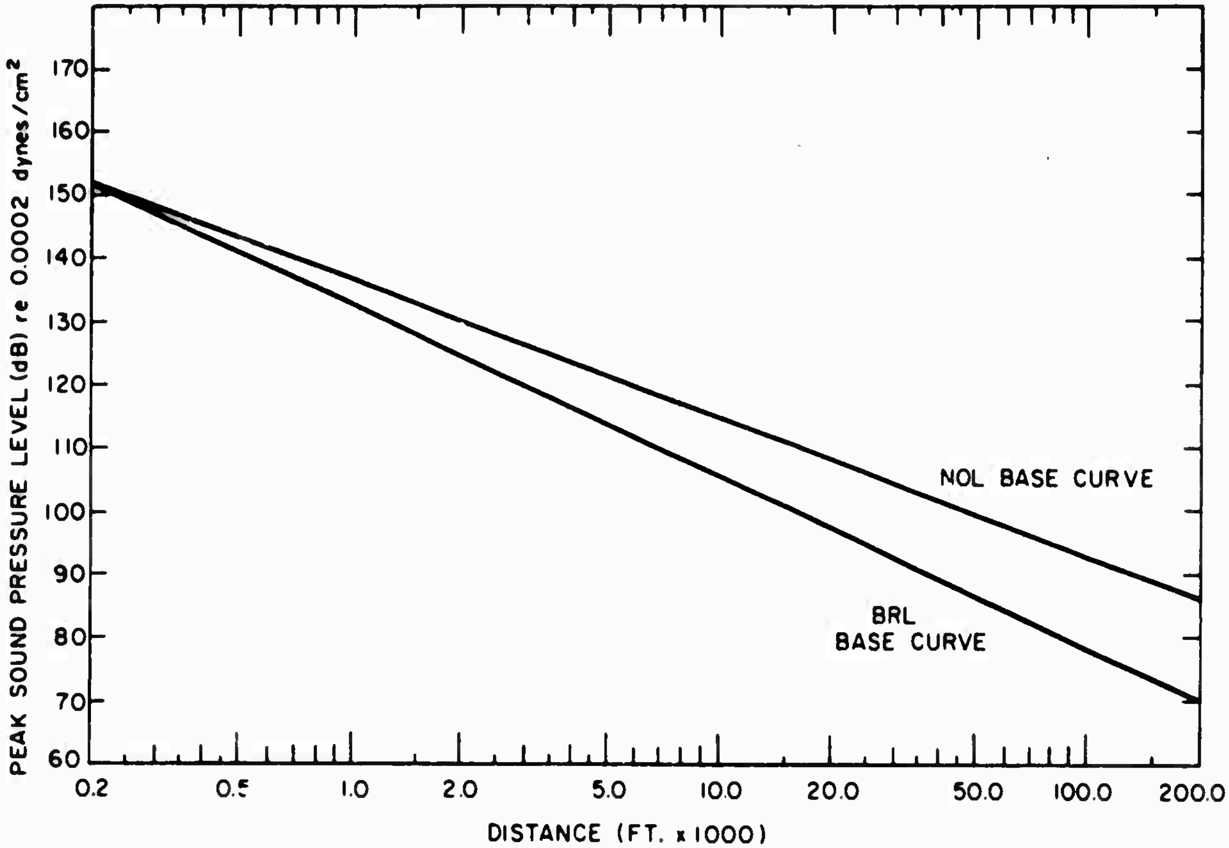

Figure 9. Comparison between BRL and NOL base curves.

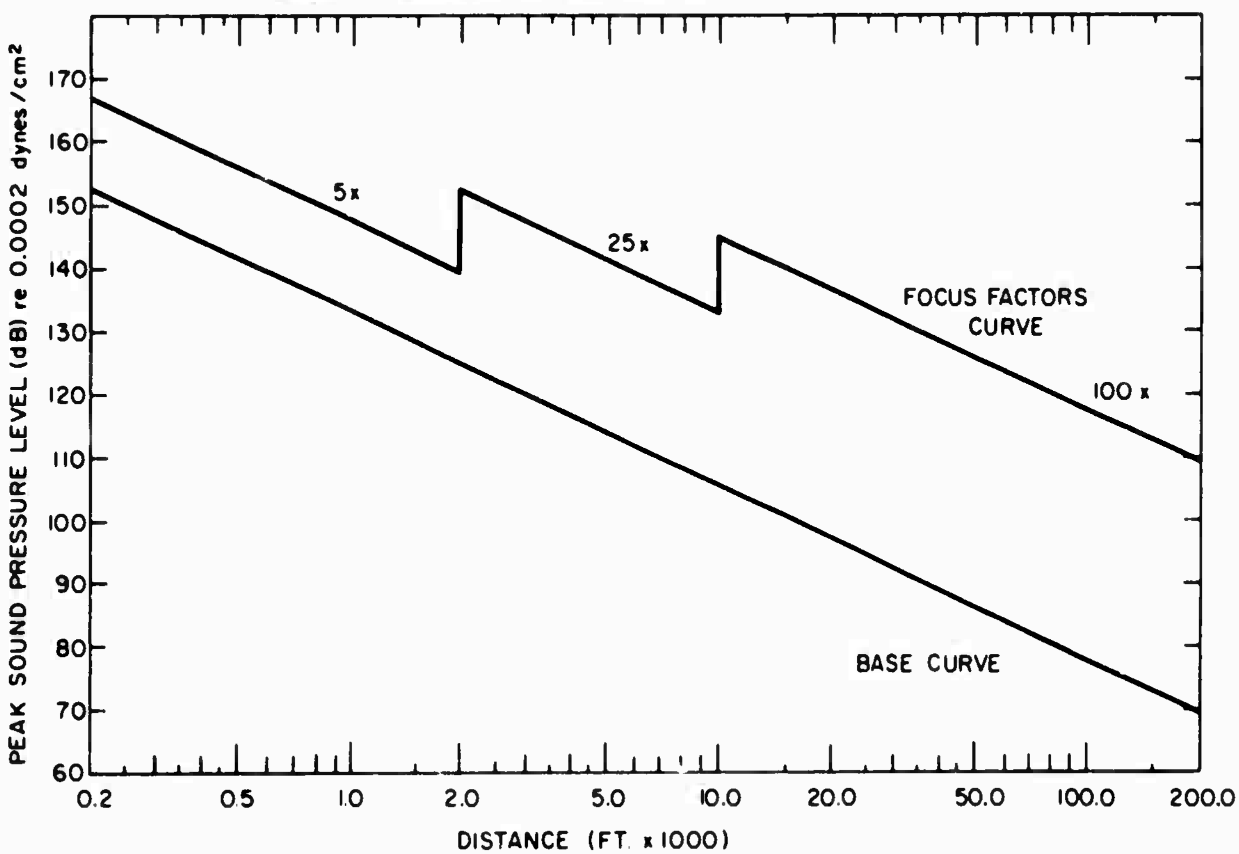

Figure 10. Basic BRL curve with BRL focus factors.

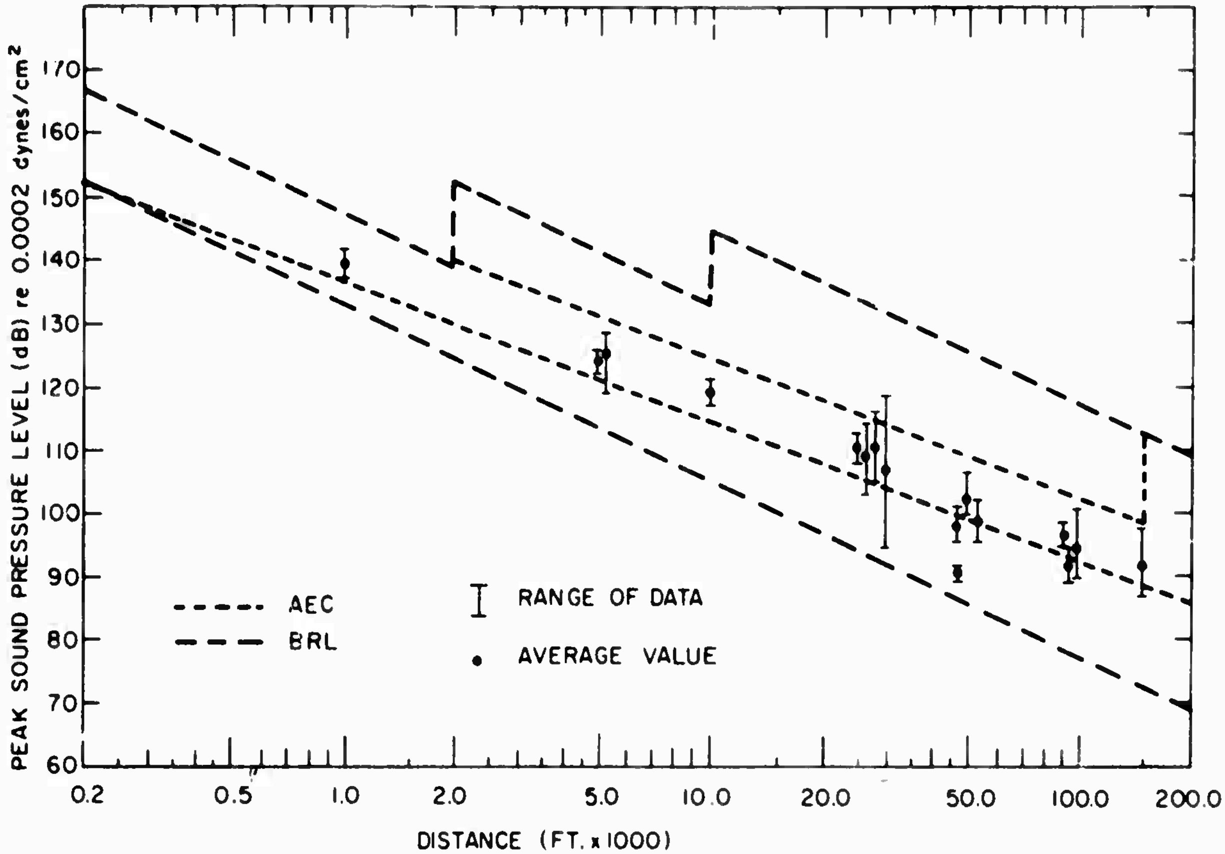

Figure 11. BRL and AEC curves with empirical data included.

base curve because of temperature, wind changes, and atmospheric perturbations and variations. If, based on the limited data, 50 percent is assumed as the percentage of adverse days, then the probable curve is used for 25 percent of all events, the NOL curve is used for 25 percent, and the BRL curve is used for 50 percent. An extensive community noise monitoring program and test measurement program is required to gather the data needed to make better statistical estimates.

Waveform Variation with Distance. Strong shocks from explosions, with peak overpressures greater than 1 psi, usually exhibit the classical pressure-time signature of Figure 13a. This consists of an abrupt, sharp compression followed by a gradual pressure decay into a rounded negative-pressure phase, and finally a gradual recovery to ambient pressure.[31] This shape may be modified to the form of Figure 13b, which includes the effect of a ground reflection.[32]

At medium overpressures (.003-.1 psi) the shape may take on the form of an N-wave followed by a wave that approximates a damped oscillation, as shown in the USATECOM data curve of Figure 14a[33] or the AEHA data curve of Figure 14b.[34] As outlined, the overpressure is a function of source strength, meteorological conditions, and distances; median overpressures tend to imply "median" distances. The important point is that the waveform appears to be more nearly a function of peak overpressure than of distance alone.

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31 J.W. Reed, *Climatology of Airblast Propagations from Nevada Test Site Nuclear Airbursts*, Report No. SC-RR-69-572 (Sandia Laboratories, 1969).

32 H.H. Holland, Jr., *Muzzle Blast Measurements on Howitzer, 155mm M1AE3 with Muzzle Brake No. 8*, Human Engineering Laboratory, Tech. Memo No. 14-61 (Aberdeen Proving Ground, 1961).

33 H.J. Meenan, *Sound Pressure Levels of Various Guns vs Bare Charge Detonations (Test Data)*, Report No. DPS-2572, AD 903-457 (USATECOM, 1972).

34 C.R. Bragdon, *Weapon Contours*, Bio-Acoustics Special Study No. 34-004-71/72 (U.S. Army Environmental Hygiene Agency [AEHA]).

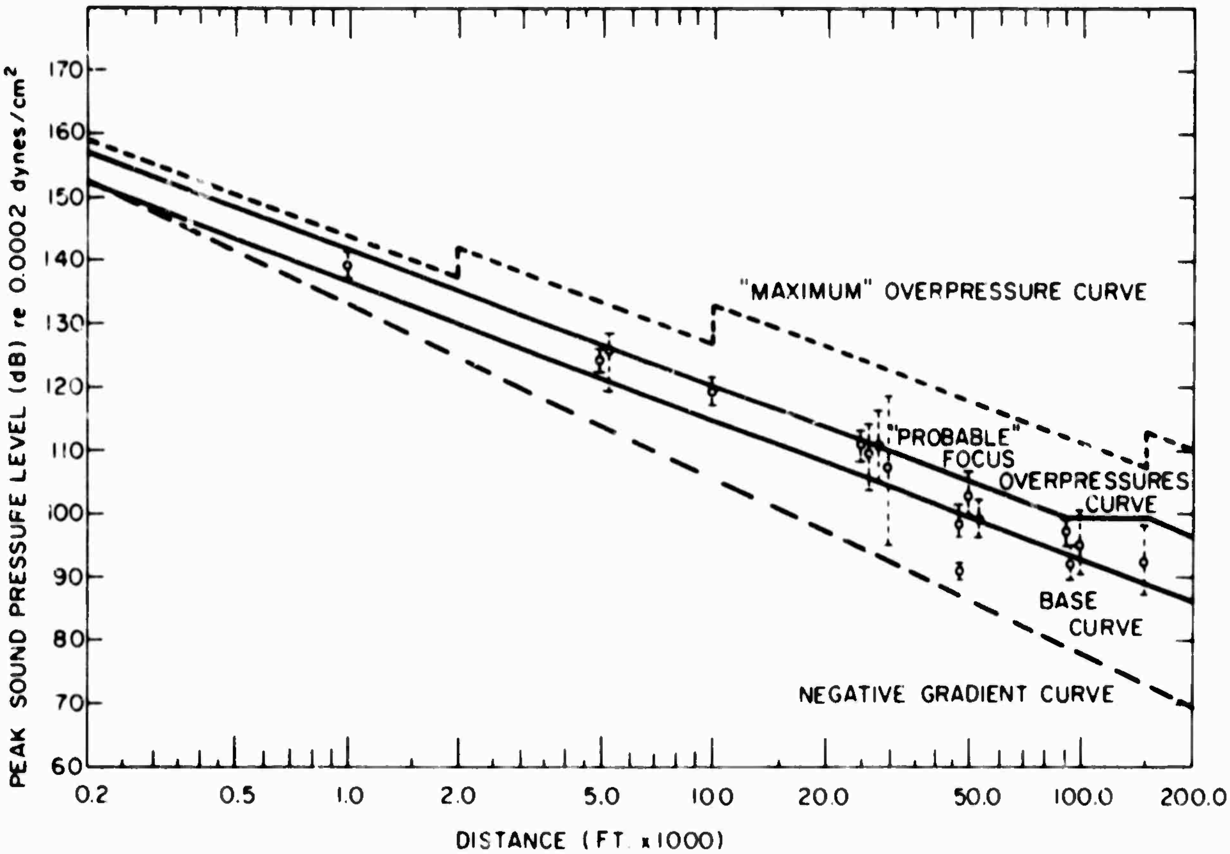
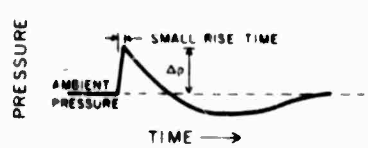
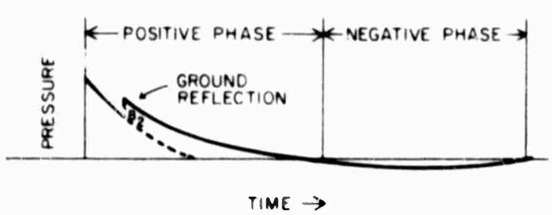


Figure 12. Overpressure predictions for one pound of TNT.

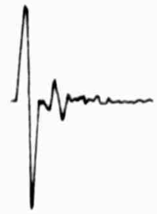


a. "PURE" BLAST

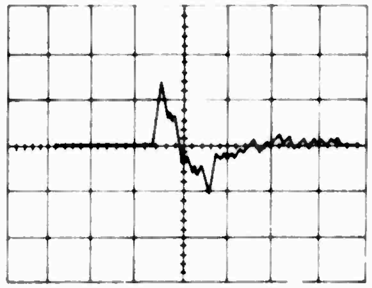


b. BLAST INCLUDING GROUND REFLECTION

Figure 13. Blast impulses, Po > 1 psi.

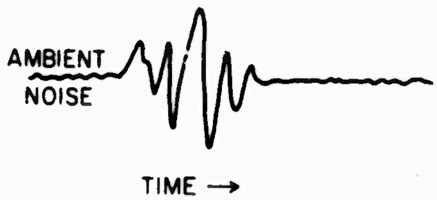


a USTECOM DATA



b AEHA DATA

Figure 14. "Quasi-N" waves, for medium overpressures.



a. SANDIA CURVE

b. USATECOM DATA

Figure 15. "Quasi" sinusoids for lower overpressures.

At lower overpressures (long range), the outcome is usually several cycles of quasi-sinusoidal oscillation in pressure. This effect is evident in the Sandia curve of Figure 15a and the USATECOM data curve of Figure 15b.

Because signals at medium and far distances are usually not repeatable in their detail, Reed suggests that the wave propagation is distorted by atmospheric irregularities and structure with scales of a few hundred to a few thousand feet.[35] Reed also observes that simple approaches to transforming the classical wave form (Figure 13a) into the observed sinusoidal wave (Figure 15) fail to provide the necessary conservation of energy and material during wave passage, and the complex solutions to the wave equation require so many assumptions and simplifications to the atmospheric model that the outcome is usually only qualitatively similar to experimental results. Nevertheless, there are several physical observations with respect to wave propagation that can be made and employed to predict wave shape.

Morse and Ingard[36] indicate two opposing factors affecting large amplitude (nonlinear) wave propagation. First, all waves (even those of very small amplitude) tend to form shock fronts in regions of positive pressure gradient. This "convective" effect is cumulative with distance and directly proportional to the peak overpressure,

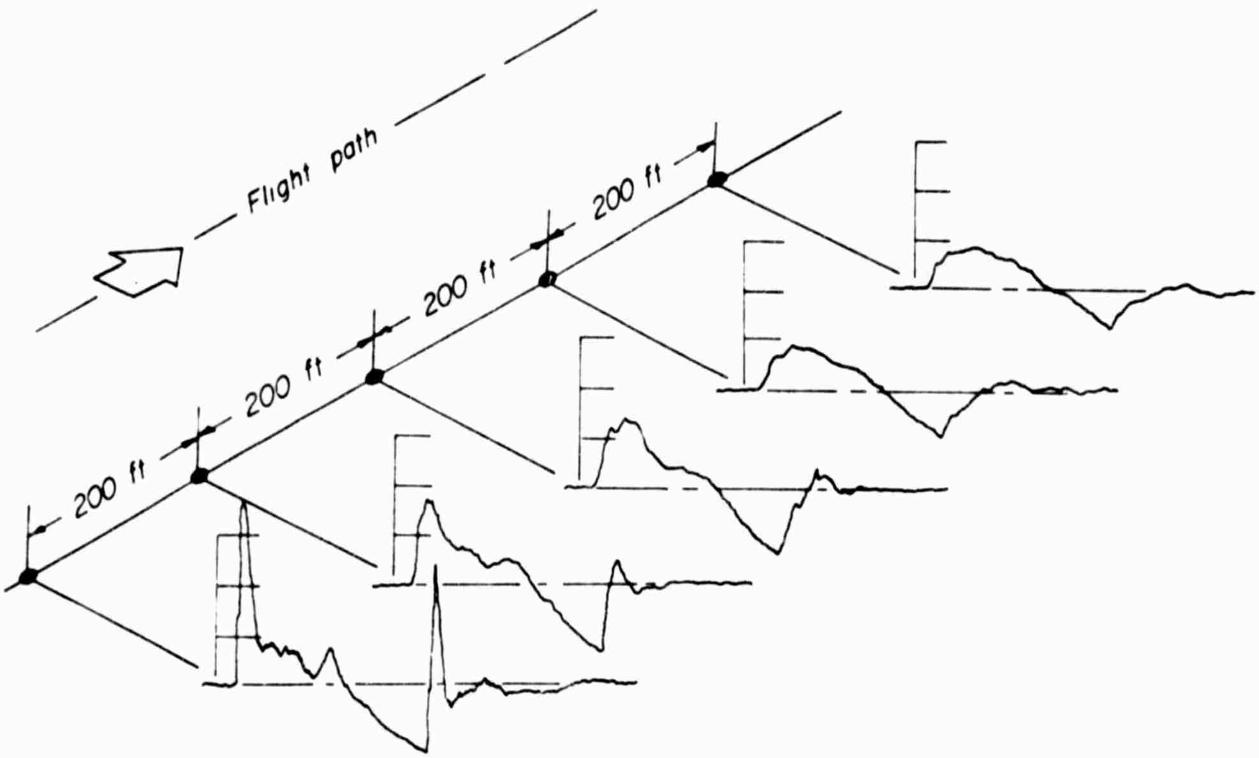


Figure 16. Measured sonic-boom pressure signatures at several points along the ground track of airplane A in steady-level flight at Mach number 1.7 and an altitude of 28,000 feet (from sonic-boom exposure studies during FAA community-response studies over a 6-month period in the Oklahoma City area, NASA TN-D-2539).

35 J.W. Reed, *Climatology of Airblast Propagations from Nevada Test Site Nuclear Airbursts*, Report No. SC-RR-69-572 (Sandia Laboratories, 1969).

36 P.M. Morse and K.U. Ingard, *Theoretical Acoustics* (McGraw-Hill, 1968).

and this effect may explain the formation of N-waves as shown in Figure 14. Opposing this is a diffusion effect that results from absorption of wave energy by the atmosphere. Diffusion tends to "round" sharp pulses; a sharp pulse takes on the shape of a Gaussian distribution with the standard deviation (spreading) proportional to the square root of distance. This time domain spreading is, of course, a result of the fact that the absorption of energy is proportional to the frequency squared; hence, high frequencies are attenuated relative to the low.

Since the convective effect is proportional to pressure at small peak overpressures (large distances) the diffusion effect should overpower the convective effect and the pulse should round. Blackstock and Morfey consider these effects and predict a transition distance in an ideal homogenous atmosphere.[37] These results, coupled with atmospheric variations, could produce the observed quasi-sinusoidal signatures. Experimental data from USATECOM and AEHA tend to confirm that he transformation from the blast signature to the quasi-sinusoidal signature is a function of the peak overpressure, which in turn is related to distance, although not directly because of focusing effects.

Figure 16 further demonstrates the variability of sound transmission in air. In this figure, sonic boom measurements made 200 feet apart along the flight path of an airplane and taken sequentially as the plane flew overhead exhibit distinct changes in form and a four-to-one (12 dB) variation in amplitude.

Spectral Variation. There is a time duration, T_D, associated with each of the waveforms described above: the combined duration of the positive and negative phase of the classical blast impulse, the duration of the N-wave, and the duration of the largest amplitude cycle of the sinusoidal signature. Corresponding to each duration is a frequency, f_D, equal to T_D^{-1}. In Figure 17, peak level vs f_D is plotted for a number of USATECOM, AEHA, Willow Run Laboratory (WRL),[38] and National Physical Laboratory (NPL)[39] data sets. From this data, empirical curves are drawn relating f_D to peak sound-pressure level for small and large blasts (over or under 10 equivalent pounds).

In addition to the prominent wave shapes and time durations discussed above, in the 130 to 155 dB range, both the classical pulse and the N-wave contain "saw-tooth" oscillations of substantial amplitude (20 dB below the peak level)

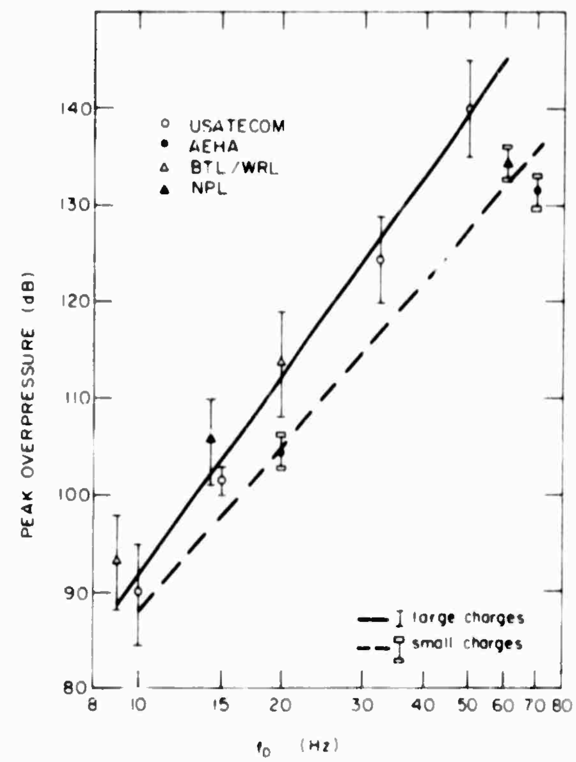


Figure 17. Peak amplitude vs f_D.

37 P.M. Morse and K.U. Ingard, *Theoretical Acoustics* (McGraw-Hill, 1968).

38 *An Investigation of Factors Affecting Sound Ranging Literature Search and Analysis*, Technical Report AD698565 (Willow Run Laboratories, University of Michigan, 1969).

39 R. Johnson and D.W. Robinson, "The Subjective Evaluation of Sonic Bangs," *Acoustics*, Vol 18 (1967), pp 241-258.

in the 500 to 1000 Hz range. Pierce[40] explains the generation of these oscillations in terms of a "wave-front folding mechanism."

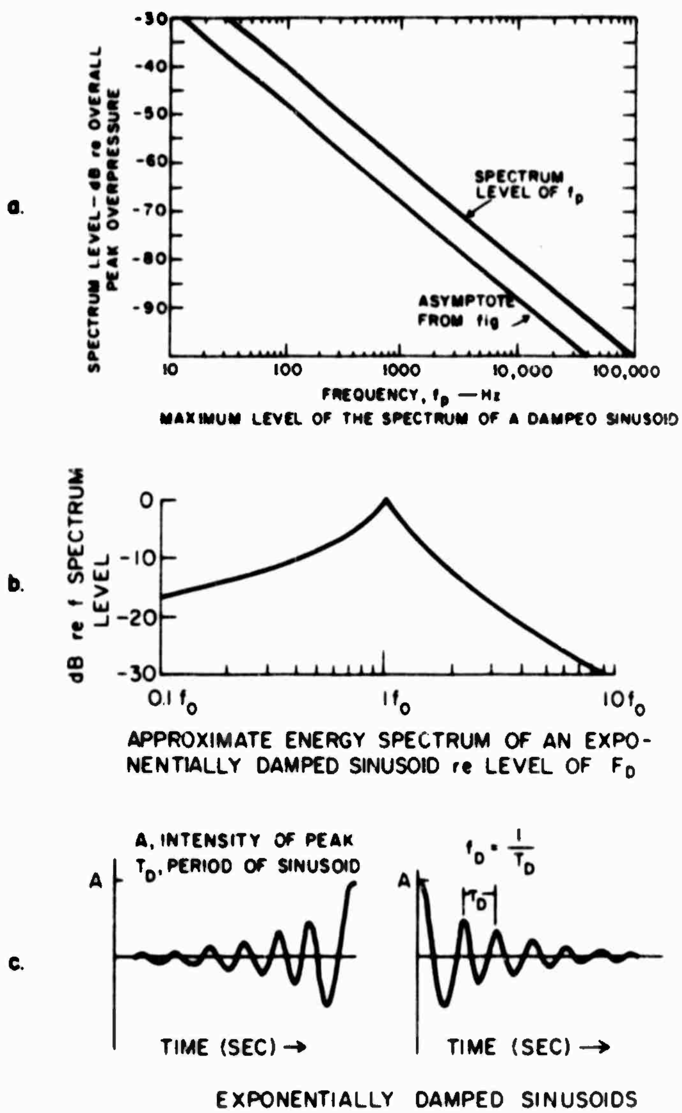


Figure 18. Spectrums of damped sinusoids.

40 A.D. Pierce and C.L. Thomas, "Atmospheric Correction Factor for Sonic Boom Pressure Amplitudes," *Journal of Acoustical Society of America*, Vol 46 (1969), pp 1366-1382.

Most important, however, is the estimation of the overall spectra of these various waveforms and the effective length of time that these spectra are present. Kryter[41] presents a method based on earlier Air Force work by Young to obtain these spectrum estimates. Figure 18 illustrates the estimation of the spectrum of a damped sinusoid. The spectrum illustrated, Figure 18b, is the well-known spectrum for an underdamped system.[42] The minimum value of the pressure spectrum level in dB (RMS) re the peak level (overpressure in dB) is really a function of the damping ratio and is given by

$$\text{dB} = 20 \log_{10} \frac{1}{\sqrt{2}\, \phi\, \omega_0} \qquad \text{[Eq 6]}$$

where ω_0 = frequency at which the pressure spectrum level attains a maximum

ϕ = the damping ratio.

The typical case presented by Kryter (Figure 18c) corresponds to a damping ratio of 0.1. This value of ϕ corresponds to a "system Q" of 5 and a 3 dB bandwidth of one-third of an octave. Unfortunately, actual waveforms depart markedly from one another and from this shape.*

The impulse spectrum envelope estimation method (Figure 19), on the other hand, is quite exact, since all factors are explicitly included. The general shape dictates the slope of the low-frequency asymptote. The "peak" frequency, f_p, is given by

$$f_p = \frac{1}{2 T_D} \qquad \text{[Eq 7]}$$

and high frequency break f_b (from a 6 dB to a 12 dB per octave slope) is given by

$$f_b = \frac{1}{3 T_R} \qquad \text{[Eq 8]}$$

where T_R = impulse rise time.

41 K.D. Kryter, *The Effects of Noise on Man* (Academic Press, 1970), pp 18-22.

42 E Brenner and Mansour Javid, *Analysis of Electric Circuits* (McGraw-Hill, 1967), pp 113-126.

* Accurate field data would provide the means to predict the probable octave and 3rd octave spectral variations.

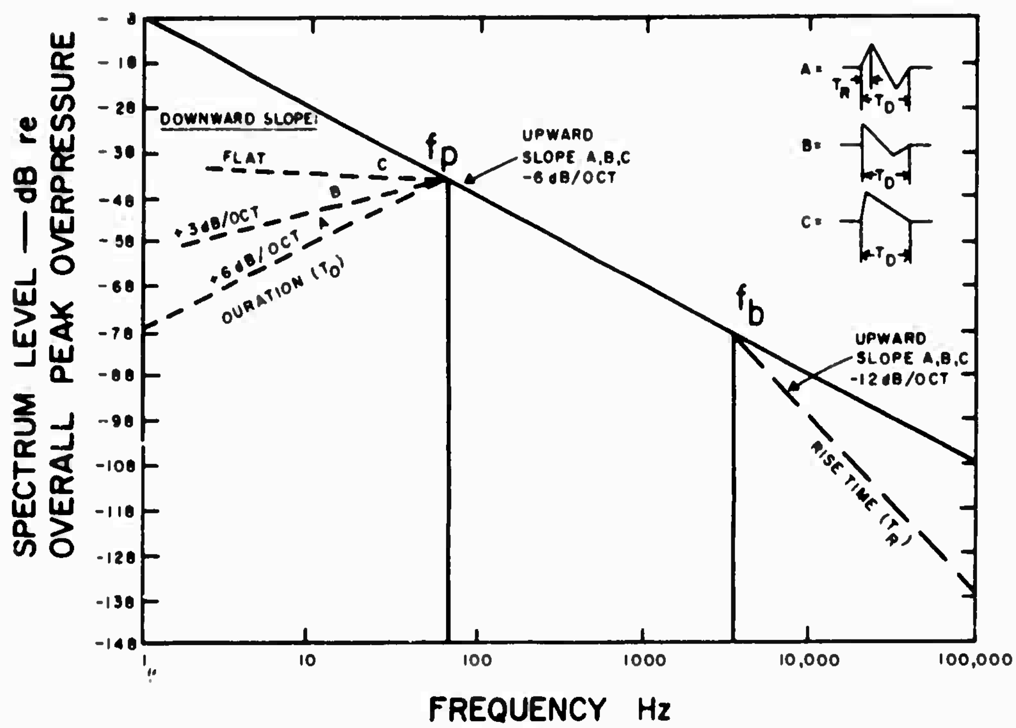


Figure 19. General spectrum level envelope of impulses having various waveforms.

Similar work by Pease[43] with like results also indicates that the approximate spectra of a sonic boom are a function of duration and rise time. Further, one can note that increasing the duration of a sonic boom past about 50 ms does nothing to the audible spectrum. In fact, 3rd octave measurements made on sonic booms by Johnson and Robinson[44] show that it is primarily the transition at the beginning and the end of the signature that contributes to the audible signal, and that these signal components are present for no longer than the duration of the significant part of the response of the 3rd octave filters. Thus, for sonic booms, etc., audible energy is present for only about 50 to 100 ms (the lower frequency bands—smaller bandwidths—are present for longer durations and the response to these lower frequency bands occurs at later points in time, as expected).

Filters respond to exponentially damped sinusoids in much the same way as they do to pulses. However, for the same T_p and peak level, the sinusoid spectrum attains its maximum value at F_D, which is twice the frequency for the pulse or N-wave, and the spectrum level at F_D (for the damping ratio shown) is 4 dB higher than the corresponding pulse spectrum level at $F_D/2$. Moreover, because the sonic boom spectral peak is normally infrasonic, and the artillery noise spectral peak is just into the sonic range, the lowest octave band SPL for artillery noise is about 7 or 8 dB higher than the corresponding band for a sonic boom. Also because the quasi-sinusoidal signals are usually present with oscillations of significant levels for about 0.5 seconds, they can be thought of as the sum of three or even four damped sinusoids (Figure 20). Note specifically that the two sinusoids "back to back" closely approximate the curves of Figure 14. Three or more terms come about by atmospheric perturbations, reflections, imperfect focus conditions, etc., and are perceived as "rumble."

43 C.B. Pease, "A Note of the Spectrum Analysis of Transients and the Loudness of Sonic Bangs," *Journal of Sound and Vibration*, Vol 6 (1967), pp 310-314.

44 R. Johnson and D.W. Robinson, "The Subjective Evaluation of Sonic Bangs," *Acoustics*, Vol 18 (1967) pp 241-258.

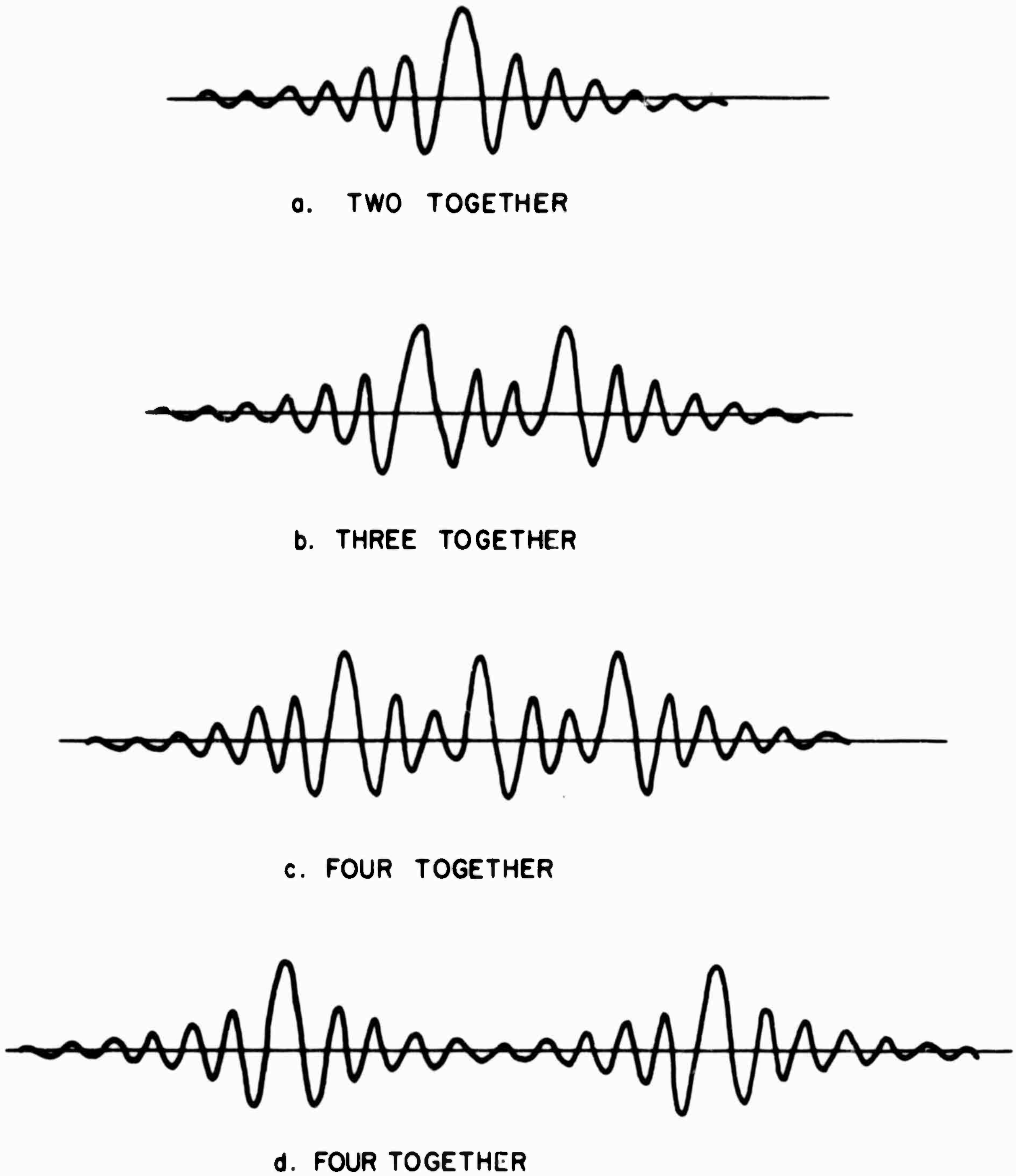


Figure 20. Combinations of waveforms.

The USATECON data and the AEHA data indicate an approximate breakpoint of 130 dB, below which the signature is quasi-sinusoidal and above which the signal is an N-wave or the classical pulse. The difference in shape between these two does not lead to substantial spectral differences at frequencies of interest (above 20 Hz).

Before one can fully estimate the spectrum as a function of peak level and distance, it is necessary to consider the effects of air absorption. These effects become significant when the wave motion becomes essentially linear at about the 130 dB level as noted above. The high frequencies are attenuated with respect to the lows, resulting in the gradual lowering of f_D shown in Figure 17. It is expected, however, that the spectrum at lower levels and large distances will fall off much faster than the 6 dB per octave predicted in Figure 18.

Various individuals and groups have recently restudied the effects of air absorption to gain a better theoretical understanding of the physical mechanisms involved and to gather more accurate data. Recent work includes studies by Bishop, Simpson, and Chang[45] and by Sutherland[46] on experimental atmospheric absorption values from aircraft flyover noise signals, theoretical considerations by Evans, Boss, and Sutherland,[47] considerations of the effects of dust by Henley, and Hoidale,[48] and laboratory measurements by Harris.[49-51]. It is useful to compare the Bishop attenuation data measured from aircraft flying 1500 feet overhead (a medium-level source implying somewhat nonlinear wave motion) to the Harris data for low-level linear conditions, and to consider both as they relate to the Henley observations. Since the Bishop data is from warm, somewhat humid weather, it is compared to Harris' data for 25°C and 70 percent relative humidity. Table 5 lists the results.

From these data a number of general statements and observations can be made. The lower absorption at higher frequencies in the Bishop data may be the result of nonlinear generation of high frequency energy. Nevertheless, the data does indicate large absorption above 1000 Hz for SPL's below about 130 dB. The absorption coefficient is never significantly lower than the values indicated in Table 5; at lower temperatures and humidities, the absorption coefficients are even larger. The indication that the attenuation values measured in the field for lower frequencies (less than 2000 Hz) are higher than the Harris values is predicted by Henley's thesis that dust and turbulence are the principal sources of attenuation at these frequencies. In fact, Henley's report indicates that below 2000 Hz an attenuation of 2 dB per 1000 feet is typical.[52]

Based on the means given to determine approximate spectra, the values of T_D, the 130 dB breakpoint, and the excess air absorption, Appendix B lists the estimated octave levels for small and large weapons (under and over 10 equivalent pounds) in the range from 105 to 135 dB.

4 ANNOYANCE OF MAN BY BURST NOISES

Introduction. The evaluation method to be used to rate the effects of artillery noise and shell bursts on man is the composite noise rating

45 D.E. Bishop, et al., *Experimental Atmospheric Absorption Waves from Aircraft Flyover Noise Signals*, NASA Contractor Report No. CR-1751 (Bolt Beranek & Newman, Inc., Van Nuys, CA, 1971).

46 L.C. Sutherland, "Air to Ground Propagation—Some Practical Considerations," paper presented at the 82nd Meeting of the Acoustical Society of America, Denver (1971).

47 L.B. Evan, et al., "Atmospheric Absorption of Sound: Theoretical Predictions," preprint submitted to *Journal of Acoustical Society of America* (1971).

48 D.C. Henley, *Attenuation and Dispersion of Acoustic Energy by Atmospheric Dust*, ECOM-3370/AD 728-103 (Atmospheric Sciences Laboratory, 1971).

49 C.M. Harris, "Absorption of Sound in Air in the Audio-Frequency Range," *Journal of Acoustical Society of America*, Vol 35 (1963), pp 16-17.

50 C.M. Harris, et al., *Absorption of Sound in Air Below 1000 CPS*, NASA Contractor Report CR-237/N65-24773 (Columbia University, 1965).

51 C.M. Harris, *Absorption of Sound in Air vs Humidity and Temperature*, NASA Contractor Report CR-647/N67-16662 (Columbia University, 1967).

52 D.C. Henley, *Attenuation and Dispersion of Acoustic Energy by Atmospheric Dust*, EMCOM-3370/AD 728-103 (Atmospheric Sciences Laboratory, 1971).

Table 5

Air Absorption Attenuation (in dB per 1000 ft)

Frequency	Harris – Low Level Laboratory Data	Bishop – Medium Level Field Data
125	.1	–
250	.22	–
500	.48	–
1000	1.3	1.8
2000	3.2	2.7
4000	7.2	6.4
8000	18.0	12.0

(CNR) described in TM-5-365,[53] modified by NASA-CR-1636,[54] and as further modified herein.

The CNR was first derived to assess the noise impact of landing and take-off operations on the environs of an airport. In the above TM, the units used to judge "noisiness" of an aircraft operation were its perceived noisiness (PN) in noy or perceived noise level (PNL or PNdB) in dB.[55,56]

Let us first review the history of the PNdB unit. In 1943 at the Harvard Psychoacoustics Laboratory under the direction of Professor S.S. Stevens, equal noisiness contours were experimentally determined. A sound of 2 noy was said to be subjectively twice as noisy as a sound of 1 noy; 4 noy, twice as noisy as 2 noy, etc. Later work by Kryter and Pearsons,[57,58] and work by Wells[59] using bands of noise, served to refine these contours. In all cases, these contours were derived from laboratory tests using standard laboratory acoustic stimuli; they were not generated for a specific purpose (such as aircraft annoyance) or with specific stimuli (such as aircraft flyover noise). For this reason and because the energy spectrum reveals how the signal will be perceived by the auditory system in dimensions that are common to all sounds (impulsive or nonimpulsive), investigators were led to use CNR to describe sonic boom annoyance. For the same reasons artillery and bursting sound may be rated by the CNR system.

Since CNR has traditionally been used to describe the noise impact of airport operations and because CNR, with the modifications herein described, is quite compatible with noise exposure forecasts (NEF), which are also used to rate airport noise impacts, it will be extremely easy to evaluate the operations of a base with respect to aircraft as well as artillery and bursting noises. Moreover, there is every indication that it will be possible to include all other noises, such as tank and other vehicular noises, sonic booms, and stationary noise sources, within the CNR framework.

Rather extensive data has been compiled to relate the annoyance resulting from sonic booms to known sources, e.g., sub-sonic aircraft operations. Limited data which relates the annoyance resulting from burst noise to that from sonic booms is also available. The best available method for quantitatively assessing blast noise annoyance is to relate this annoyance to sonic boom annoyance, which has already been related to the standard aircraft noise annoyance.*

Relating Impulsive Noises to PNL. For quite some time, there has been a great deal of interest in the annoyance or noisiness of sonic booms and other impulses. Three major research studies have been conducted by the government:

53 B. Beranek, *Land Use Planning with Respect to Aircraft Noise* Newman Technical Report (FAA, 1964) and Appendix A (1965); also AFM 86-5, TM 5-365, NAVDOCKS P-98.

54 K.D. Kryter, *Possible Modifications to the Calculation of Perceived Noisiness*, NASA Contractor Report CR-1636 (Stanford Research Institute, 1970).

55 L.L. Beranek, et al., "Reaction of People to Exterior Aircraft Noise," *Noise Control* (1959), pp 23-31.

56 K.D. Kryter, "Scaling Human Reactions to the Sound from Aircraft," *Journal of Acoustical Society of America*, Vol 31 (1959), pp 1415-1429.

57 K.D. Kryter and K.S. Pearsons, "Some Effects of Spectral Content and Duration on Perceived Noise Level," *Journal of Acoustical Society of America* Vol 35 (1963), pp 866-883.

58 K.D. Kryter and K.S. Pearsons, "Modification of Noy Tables," *Journal of Acoustical Society of America*, Vol 36 (1964), pp 394-397.

59 R.J. Wells, "Recent Research Relative to Perceived Noise Level," *Journal of Acoustical Society of America*, Vol 42 (1967), p 1151.

* This relating scheme was unanimously decided upon in a meeting which included the Director of the Federal EPA Office of Noise Abatement Control and his Director for Government Agencies, a designated representative of the Army Environmental Hygiene Agency, and the author of this report from the Construction Engineering Research Laboratory of the Corps of Engineers.

the Oklahoma City test in 1964; the Edwards Air Force Base test in the summer and winter of 1966; and attitude surveys made in Atlanta, Chicago, Dallas, Denver, and Los Angeles. Recently, Fidell and Pearsons[60-61] have reported on the loudness and annoyance of impulsive sounds; Thompson and Sales[62] have reported on their part in the International Round Robin tests to determine the subjective loudness level of impulsive noises, and Johnson and Robinson[63] have reported on sonic boom and explosive tests in the United Kingdom.

In the Oklahoma City test,[64] Borsky reports on interference with ordinary living activities, annoyance with sonic boom, desires to complain and actual complaints about sonic booms, and long-range acceptability of sonic booms. The test covered three time periods. During the first period (3 February to 19 April) the median boom level was 1.13 pounds per square foot (PSF); during the second period (20 April to 14 June), 1.23 PSF; and during the third period (15 June to 25 July), 1.60 PSF.

Table 6 lists by type of interference the percentage of the population affected, and Table 7 lists the overall percentage of residents reporting serious or "more than a little" annoyance. The rise in annoyance with time, as evident in Table 7, is probably primarily a result of the increase in the intensity of the sonic booms, but part of this increase may have been caused by continued exposure.

60 S. Fidell and K.S. Pearsons, *Study of the Audibility of Impulsive Sounds*, NASA Contractor Report CR-1598 (Bolt Beranek & Newman, Inc., Van Nuys, CA, 1970).

61 S. Fidell, et al., "The Noisiness of Impulsive Sounds," *Journal of Acoustical Society of America*, Vol 48 (1970), pp 1304-1310.

62 P.O. Thompson and R.S. Gales, "Subjective Judgment of Loudness Level of Impulsive Noises for the International Round Robin Tests," paper presented at the 82nd meeting of the Acoustical Society of America, Denver (1971).

63 R. Johnson and D.W. Robinson, "The Subjective Evaluation of Sonic Bangs," *Acoustics*, Vol 18 (1967), pp 241-258.

64 P.N. Borsky, *Community Reactions to Sonic Booms in the Oklahoma City Area*, Report No. AMRL-TR-65-37 AD613630 (Aerospace Medical Research Laboratories, 1965).

Table 8 lists the overall percentage of residents who felt like complaining (the complaint potential) and the percentage that actually did complain. The relatively low complaint level, according to Borsky, was primarily the result of three factors: ignorance about where to complain, the feeling that complaining would be futile, and the fact that only 25 percent of all people felt like complaining about a serious local problem when they had one.

Table 9 lists the long-range acceptability of sonic booms. It shows that at the end of six months about 25 percent of all people felt they could *not* learn to accept the booms. Moreover, over 40 percent felt that the booms damaged their houses. Fifty percent of the annoyed and 86 percent of the complainers agreed. It is also interesting to note that a Tracor report[65] on subsonic aircraft shows that fear of aircraft crashing in the neighborhood is the best indicator of the relation between annoyance and aircraft noise.

Table 6

Reported Types of Interference by Sonic Booms Oklahoma City Area (February-July 1964)

Type of Interference	3 Feb-19 Apr	Total 20 Apr-14 June	15 June-25 July
House rattles	89%	89%	94%
Startles	39%	35%	38%
Interrupts sleep	14%	15%	18%
Interrupts rest	11%	12%	17%
Interrupts conversation	9%	12%	14%
Interrupts radio, TV	7%	8%	9%
Number of respondents*	2019	2026	1915

* Includes only persons who feel people should complain if annoyed.

In the Edwards Air Force Base[66] test, Kryter used military supersonic and subsonic jet aircraft to perform paired comparison tests with subjects

65 *Community Reaction to Airport Noise*, NASA Contractor Report CR-1761/N71-29032 (Tracor, Inc., 1971).

66 K.D. Kryter, *Sonic Boom Experiments at Edwards Air Force Base*, Report No. NSBEO-1-67 AD655310 for the National Sonic Boom Evaluation Office (Stanford Research Institute, 1967).

placed both inside and outside typical residences. These tests yielded the following equivalences:

1. B-58 (Δp = 169 PSF) 109 PNdB observing *indoors*

2. B-58 (Δp = 1.69 PSF) 105 PNdB observing *outdoors*

(Both of the above figures have 90 percent confidence limits of $+4$ and -2 dB.) Independently, Broadbent and Robinson[67] measured:

(Δp = 1.69 PSF) 107 to 113 PNdB observing indoors.

Table 7

Reported More than a Little Annoyance by Type of Interference

Type of Interference	3 Feb-19 Apr	Total 20 Apr-14 June	15 June-25 July
House Rattles	33%	44%	54%
Startles	20%	22%	28%
Interrupts sleep	9%	11%	14%
Interrupts rest	8%	11%	14%
Interrupts conversation	5%	7%	10%
Interrupts radio, TV	4%	5%	6%
Number of respondents*	2019	2026	1915

* Includes only persons who feel people should complain if annoyed.

Table 8

Potential Complaint vs Actual Complaint Percentages

	3 Feb-19 Apr	20 Apr-14 June	15 June-25 July
Complaints	3%	1.2%	0.7%
Potential complaints	16%	23.0%	22.0%

Table 9

Ability to Accept Eight Booms per Day

Period	Percent
3 Feb – 19 Apr	90
20 Apr – 14 June	81
15 June – 25 July	73

This higher annoyance level indoors results primarily from the secondary noise produced when objects such as windows and bric-a-brac are set into vibration. Other parts of the Edwards test used subjects from Redlands and Fontana who were not accustomed to loud aircraft noises or sonic booms. These subjects indcated a 3 to 5 PNdB higher level for the same overpressure. Tests were continued with these three sets of subjects, both indoors and outdoors, with different overpressures. Figure 21 illustrates these results.

One can note that a factor of three (10 dB) increase in overpressure results in a 20 to 25 dB increase in PNdB. Calculations of the PNdB level of these booms produces values that are much lower than the empirical values and which, moreover, do not exhibit the great increase with a relatively small peak pressure increase.

Because of the above discrepancy, an impulse correction factor has been postulated by Kryter[68] and proposed in a somewhat different form by Robinson[69] and by Goldstein.[70] Basically, the correction factor is a linear function of the difference between the background PNL and the peak PNL of the impulse. On the basis of limited data, the Kryter impulse correction factor (given explicitly below) attempts to account for the otherwise unexplained large increase in annoyance for a modest increase of overpressure. This correction factor can also be thought of as accounting for the "startle" one experiences when he hears a blast or boom.

The Tracor attitude surveys[71] in a number of cities included the following conclusions:

1. Respondents had a negative attitude, and this attitude increased rapidly in

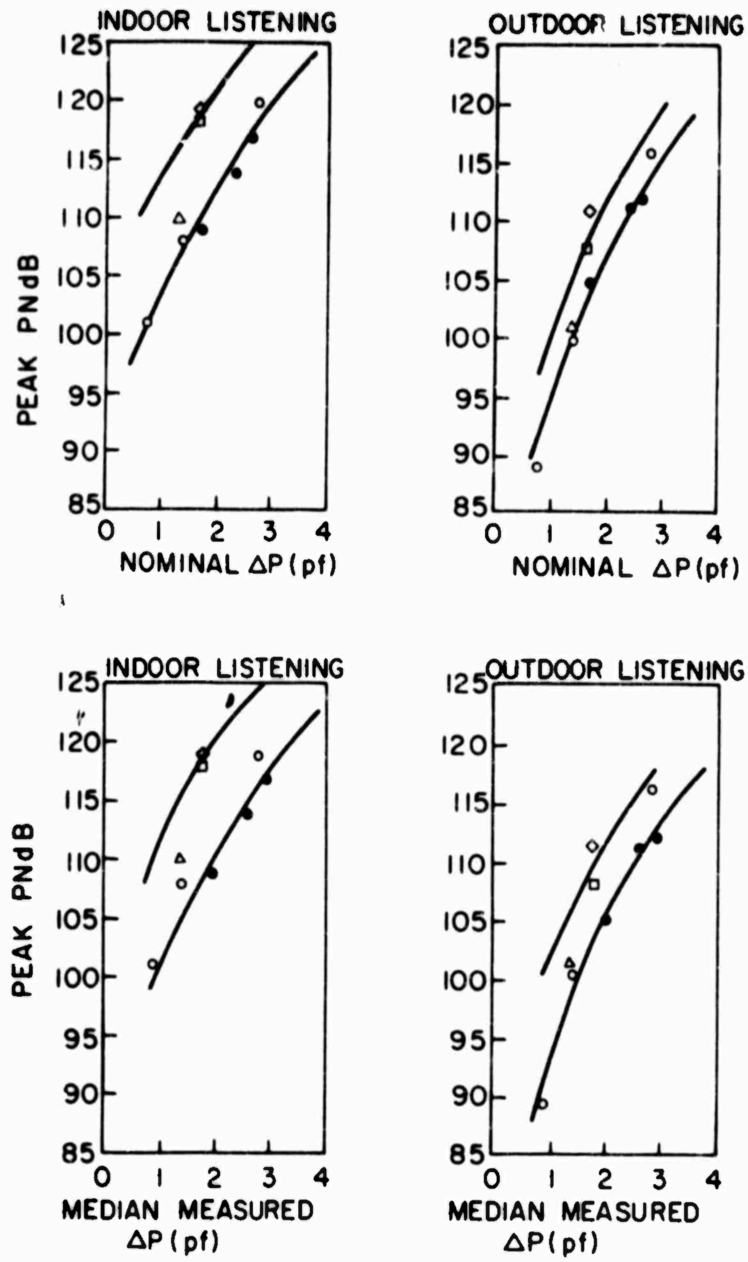
67 K.D. Kryter, *Sonic Boom Experiments at Edwards Air Force Base*

68 K.D. Kryter, *Possible Modifications to the Calculation of Perceived Noisiness*, NASA Contractor Report CR-1636 (Stanford Research Institute, 1970).

69 D.W. Robinson, *The Concept of Noise Pollution*, Report No. AL38/N69-34272 (National Physical Laboratory, 1969).

70 S.N. Goldstein, "A Prototype Standard and Index for Environmental Noise Quality," paper presented at the 82nd meeting of the Acoustical Society of America (1971).

71 *Public Reaction to Sonic Booms*, NASA Contractor Report CR-1665/N71-10026 (Tracor, Inc., 1970).



BOUNDARY	CODE	SONIC BOOM A/C	SUBJECTS
UPPER	◇	B-58	FONTANA
	□	B-58	REDLANDS
LOWER	△	XB-70	EDWARDS
	○	F-104	
	●	B-58	

Figure 21. Results of paired-comparison judgments for subjects from different communities (from National Sonic Boom Evaluation Office Report 1-67).

strength as the number of booms per day increased.

2. Respondents ranked the boom as unnecessary. "Since the majority of respondents described the boom as *startling*, it seems reasonable to expect that this impulse type sound would not cause disturbance of activities but certainly it would rank high as an unwanted sound."

3. There were no real differences in the socioeconomic level of complainants. The only real difference between complainants and noncomplainants was that 90 percent of the complainants owned their homes and *felt* that the boom damaged their homes.

In general, the disturbance and annoyance levels reported in the Tracor study are very close to (and usually a little larger than) the Oklahoma City findings. Recall that Borsky reported that 27 percent "could not accept" eight booms per day; the Tracor study shows that 75 percent "would object" to more than five booms per day.

More recently, Fidell and Pearson[72,73] have studied the audibility and annoyance of impulsive sounds. Their results show that for noise-band bursts (time-varying or oscillatory rather than N-shaped), the loudness increases 3 dB per doubling of duration. This finding is in contrast to Kryter's[74] observation that the judged annoyance does not increase as an N-wave (sonic boom) duration is increased. This effect is to be expected, since lengthening an N-wave increases the very lowest frequency energy, which conributes least to annoyance, whereas lengthening a noise burst should double the annoyance. This fact is also borne out by some of Pearson's data,* which indicates that balloon bursts containing predominantly low frequencies and having a lower overall SPL than an N-wave do exhibit higher annoyance levels.

Johnson and Robinson[75] have tested 61 subjects both indoors and outdoors in order to relate annoyance to aircraft operation and sonic booms. Fortunately, they included white noise bursts and explosion for comparison purposes. Their conclusions relating sonic-booms to subsonic operation are in substantial agreement with the other works reported here.

Most interesting, however, is the comparison between sonic booms and explosive noises having the same duration and peak overpressure. Johnson and Robinson find empirically that the annoyance level resulting from explosive noises is about 8 PNdB units higher than the level resulting from the sonic booms. It should be recalled from Chapter 3 that Kryter's spectrum estimation method predicts this difference in spectral level. The results of the Johnson and Robinson study and, to some extent, the data of Pearson, confirm the importance of these spectral differences.

Thompson and Gales[76] have just reported their findings on the subjective judgment of impulsive-noise loudness level for the International Round Robin tests. Their results further indicate the great disagreement (20 dB) between observers in judging the loudness of impulsive sounds. In summation:

1. Fear for person or property (founded or unfounded) correlates well with complaints and annoyances.

2. The increased annoyance from impulsive sounds is greater than would

72 S. Fidell and K.S. Pearsons, *Study of the Audibility of Impulsive Sounds*, NASA Contractor Report CR-1598 (Bolt Beranek & Newman, Inc., Van Nuys, CA, 1970).

73 S. Fidell, et al., "The Noisiness of Impulsive Sounds," *Journal of Acoustical Society of America*, Vol 48 (1970), pp 1304-1310.

74 K.D. Kryter, *Possible Modifications to the Calculation of Perceived Noisiness*, NASA Contractor Report CR-1636 (Stanford Research Institute, 1970).

* K.S. Pearsons, personal communication of unpublished data.

75 R. Johnson and D.W. Robinson, "The Subjective Evaluation of Sonic Bangs," *Acoustics*, Vol 18 (1967), pp 241-258.

76 P.O. Thompson and R.S. Gales, "Subjective Judgment of Loudness Level of Impulsive Noises for the International Round Robin Tests," paper presented at the 82nd meeting of the Acoustical Society of America, Denver (1971).

be expected from the increase in overpressure alone.

3. Variations in duration, when they do not change the spectral content, alter a signal's annoyance value.

4. Spectral differences materially alter a signal's annoyance value.

5. The standard deviation between individual responses is likely to be quite large.

The CNR Measurement Unit. As previously stated the CNR unit is primarily as described in the Federal Aviation Administration report on Land Use Planning Relating to Aircraft Noise.[77] CNR is a time integration of the annoyance resulting from single events during the course of a day, and it is based on the premise that the human response is related to an integration of the activities occurring during a 24-hour period. Because of the statistical nature of daily operations (wind and other meteorological factors, inception location for landings and destination for take-offs, type of aircraft, payload, etc.) the probable daily average figures are used in the computations. Because of increased annoyance during nighttime hours (2200-0700), a 10 dB "penalty" is assessed to operations during these hours.

The basic elements of the CNR system were first described by Rosenblith and Stevens in 1953.[78] Corrections for impulsive sounds (of the pile-driver type), the socioeconomic level of the community, the number of events, and the time of day were included. Since aircraft flyovers were the real object of interest, it was assumed that each event had about the same time duration. The 1957 version of the CNR system, presented by Stevens and Pietrasanta,[79] dropped the adjustment for discrete frequencies and the impulse correction factor, but included a specific measure of the duration of an event, assuming that human response (annoyance) doubled (3 dB) for a doubling of duration.

The present (1964) version, TM-5-365,[80] dropped the socio-economic correction factors (included below for reference purposes) and, most important, adopted the PN (and PNdB) measurement unit of Kryter, the unit which best accounted for the annoyance resulting from the high-pitched whine of modern jet engines.

In the period from 1967 to 1969, the Noise Exposure Forecast (NEF) evolved from the CNR.[81,82] NEF analyzed each operation in detail rather than grouping various operations into broad classes. The effective perceived noise level (EPNdB), an outgrowth of the PNdB unit, was used as the measurement unit. It included a specific measure of the duration of the event, corrections for discrete tones, and provided for the spectral analysis of the signal in one-third-octave rather than octave increments.[83,84]

Recently, Kryter[85] further updated the PNdB unit to provide options for using either one-third

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77 B. Beranek, *Land Use Planning with Respect to Aircraft Noise*, Newman Technical Report (FAA, 1964) and Appendix A (1965); also AFM 86-5, TM 5-365, NAVDOCKS P-68.

78 W.A. Rosenblith and K.N. Stevens, *Handbook of Acoustic Noise Control*, Vol II, "Noise and Man," WADC Technical Report 52-204 AD01826 (Wright Air Development Center, Wright-Patterson Air Force Base, 1953).

79 K.N. Stevens and A.C. Pietrasanta, *Procedures for Estimating Noise Exposure and Resulting Community Reaction from Air Base Operations*, WADC Technical Report TN 57-10/AD100705 (Wright Air Development Center, Wright-Patterson Air Force Base, 1957).

80 B. Beranek, *Land Use Planning with Respect to Aircraft Noise*, Newman Technical Report (FAA, 1964) and Appendix A (1965); also AFM 86-5, TM 5-365, NAVDOCKS P-98.

81 D.E. Bishop and R.D. Horonjeff, *Procedures for Developing Noise Exposure Forecast Areas for Aircraft Flight Operations*, Report DS-67-10 (Federal Aviation Administration, 1967).

82 *Technique for Developing Noise Exposure Forecasts*, Report No. DS-67-14 (Federal Aviation Administration, 1967).

83 K.D. Kryter, *The Effects of Noise on Man* (Academic Press, 1970), pp 18-22.

84 W.J. Galloway and D.E. Bishop, *Noise Exposure Forecasts: Evolution, Evaluation, Extensions, and Land Use Interpretations*, Report No. 70-9 (Federal Aviation Administration, 1970).

85 K.D. Kryter, *Possible Modifications to the Calculation of Perceived Noisiness*, NASA Contractor Report CR-1636 (Stanford University Institute, 1970).

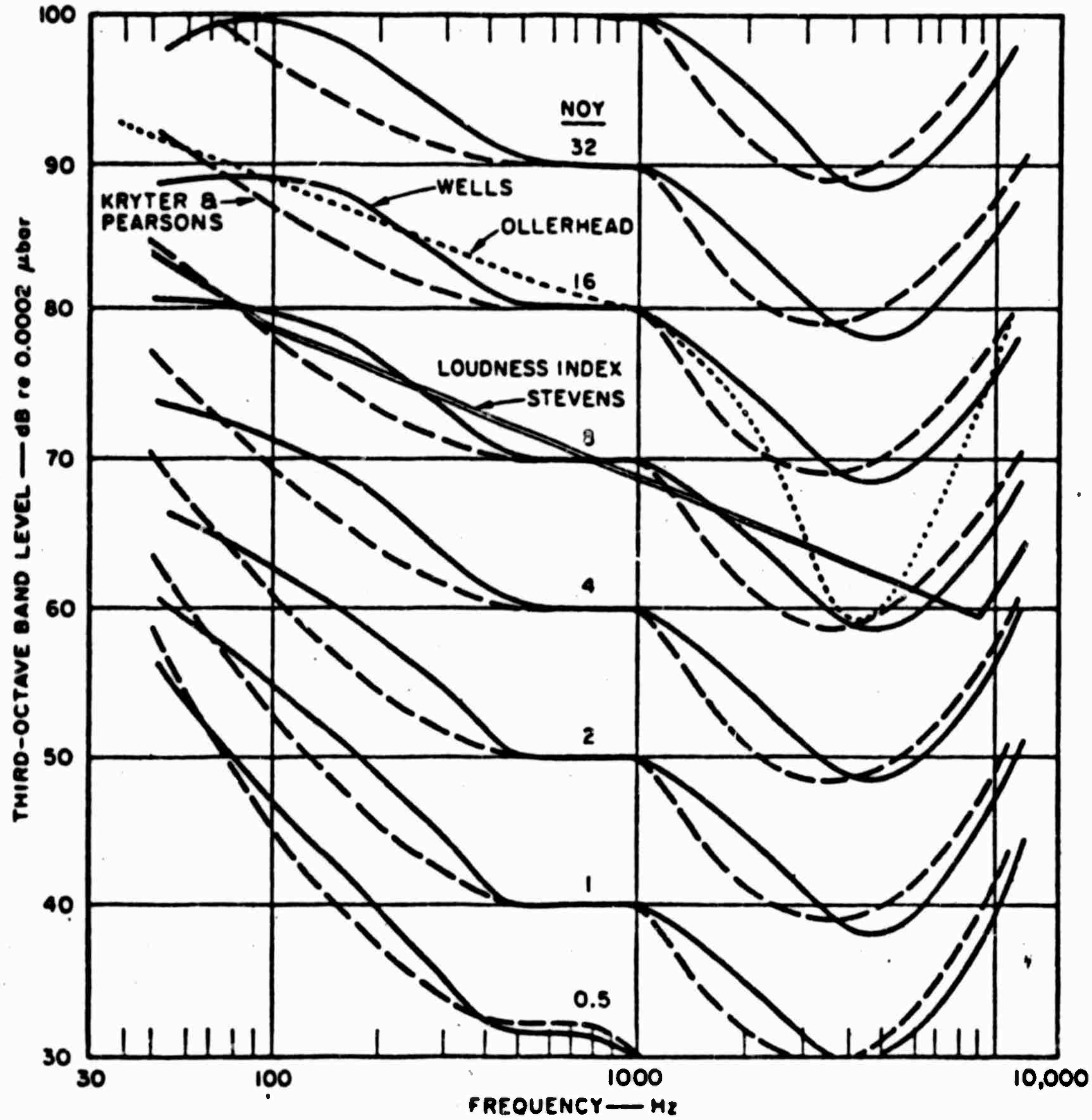

Figure 22. Equal noisiness contours as found by Kryter and Pearsons, Ollerhead and Wells, and equal loudness index contour (from NASA CR-1636).

octave or octave analysis, discrete frequency corrections, and duration effects by integrating by 0.5 second discrete steps. With these changes, CNR and NEF are virtually the same. Additionally, Kryter suggests the inclusion of three other corrections: an "onset" correction (oc) to allow for the annoyance people experience in "waiting" for the arrival of a passing plane or car, an "impulse" correction (ic) to account for the "startle" impulses cause, and an allowance at low frequencies for the effects of the critical bandwidth of the ear.

The allowance for the critical bandwidth recognizes that at low frequencies (below about 400 Hz), the ear acts as four 100 Hz filters.[86] Thus, Kryter suggests summing the energy from the lowest octave or third octave bands together before calculation. The problem that surfaced with the old "straight-band summation" method was that the PNdB value computed for piston aircraft (having substantial energy in the 80 to 400 Hz range) was a few dB high when compared to empirical values.

Before specifically explaining the Kryter modification, it is useful to consider some other data which indicate that, in the case of artillery and blast noise, a further change in Kryter's method is appropriate. Figure 22 compares equal noisiness contours found by Kryter and Pearsons,[87] Ollerhead,[88] and Wells.[89] In contrast to Kryter's study, which used narrow bands of noise, Wells' contours were based on judgments of very broadband, random-noise spectra. These curves show the lower frequency region (80-400 Hz) to be generally of less importance; accounting for the discrepancies of a few dB found for piston aircraft, whose spectra contain proportionally greater energy at lower frequencies. At the lowest frequencies (20-80 Hz) and at high levels, however, the curves indicate increasing annoyance, and this effect occurs in exactly the range encompassed by artillery and small blast spectra.

Kryter takes the summed, octave-band levels (added on a 10 $\log_{10}$ basis) to find the noy value at low frequencies, assigns this sum to the octave band having the highest original level, and then finds the noy value for this band and level. If two bands are equal, he takes the higher band. To allow for Wells' curve at low frequencies, the calculations described here (in Appendix C) sum the same, three octave bands and use for reference the 63 Hz band when either the 31.5 Hz or 63 Hz band has the largest SPL. (A corresponding modification is included in Appendix C for one-third-octave calculations.)

To allow for "startle" effects, Kryter proposes an impulse correction as shown in Figure 23. Basically, it is a measure of the difference between the ambient level and the impulse level. One may recall from Chapter 2 that for sonic booms the annoyance level increase was greater

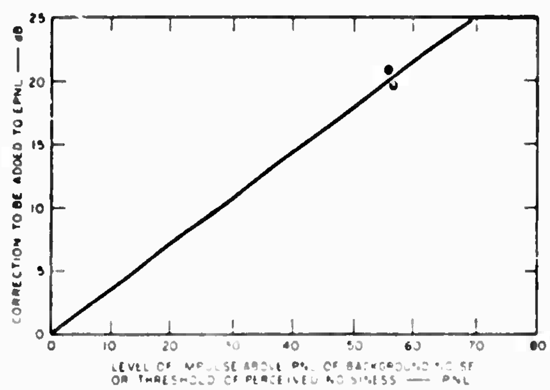

Figure 23. Correction to EPNL for contribution to perceived noisiness of startle to expected impulsive sounds. The level of the impulse is taken as amount, in PNL, the impulse exceeds the PNL of the background noise or the threshold of perceived noisiness, whichever is higher. (From NASA CR-1636).

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86 E. Zwicker, "Subdivision of the Audio Frequency Range into Critical Bands," *Journal of Acoustical Society of America*, Vol 33 (1961), p 248.

87 K.D. Kryter and K.S. Pearsons, "Modification of Noy Tables," *Journal of Acoustical Society of America*, Vol 36 (1964), pp 394-397.

88 J.B. Ollerhead, *Subjective Evaluation of General Aircraft Noise*, FAA Report No. 68-35, AD 673 987 (Wyle Laboratories, 1968).

89 R.J. Wells, "Possible Modifications in the Computation of Perceived Noise Level," paper F-1-6, presented at the 6th International Congress on Acoustics, Tokyo (1968).

than the corresponding peak level increase. The impulse correction factor attempts to account for that effect. The downward turn in the Wells' curves at low frequencies and high levels may also partially account for this effect, but not enough is known at this time to form any conclusions.

Lastly, the procedure of calculating the EPNdB by integrating the PNdB values by 0.5 second discrete intervals must be examined. For sonic booms, as noted in Chapter 3, changing the duration from 0.1 to 0.35 or 0.5 second does not change the audible spectrum or the length of time that the audible signal is present. However, three damped sinusoids or even four factors, as shown in Figure 20, can be expected to be more annoying than two.

Fidell's report[90] clearly demonstrates a 3 dB increase in annoyance per doubling of duration for bands of noise. This result indicates that a quasi-sinusoidal signature lasting less than 0.5 second should be less annoying than one lasting 0.5 second. However, it must be recalled that Kryter's estimate is based on sonic boom data which, as noted, only presents audible signals for 100 ms or less, and that these audible signals result primarily from the two transitions. Therefore, artillery blasts lasting 0.5 second and resulting from three or four damped sinusoids, as shown in Figure 20, may be expected to be more annoying than presently predicted, but the data does not exist to make a conclusive judgment.

In the case of artillery and blast noise, 0.5 second approximates the duration for most cases of interest. The signal persists for this long or longer, as previously noted, because of atmospheric perturbations, incomplete focusing, and reflections (all perceived as rumble). Only close to the source (under 10,000 feet) is the duration shorter, but again the data does not exist to accurately predict the exact duration for shape.

Annoyance Level Predicted by CNR; Mitigating Factors. During the 15 years that the CNR system has been in use, CNR predictions have been verified empirically by a large number of experiments. Figure 24 indicates from case histories the expected community response to various CNR values. It is based on Figure A-3 of NASA CR-1636 with the addition of data reported in Figure 238 of Kryter's book. Of the two figures shown for percentage loss in value of housing, the one reported by Kryter is based on a long-range analysis of this problem in England; the other corresponds to a recent Los Angeles court award to individuals owning property in an area with a CNR of 115.

As a further illustration, Kryter has related community response to CNR for specific case histories taken from Rosenblith and Stevens. Table 10 contains the Rosenblith table with Kryter's results. Galloway and von Gierke have presented a review of case histories and have related the community response to the CNR. These results are presented in Figure 25. Moreover, courts appear to be moving in the direction of accepting nuisance damage claims for "excessive" noise. A New York court awarded damages to individuals residing in an area with a CNR of 115, and the Department of Housing and Urban Affairs (HUD) terms a 115 CNR area as "unacceptable" for housing.[95] The 100-115 CNR range is termed "normally unacceptable" for housing by HUD, and various states have enacted or are considering laws (with respect to

90 S. Fidell, et al., "The Noisiness of Impulsive Sounds," *Journal of Acoustical Society of America*, Vol 48 (1970), pp 1304-1310.

91 K.D. Kryter, *The Effects of Noise on Man* (Academic Press, 1970), pp 18-22.

92 Irving D. Aaron, et al., *Plaintiffs vs City of Los Angeles, A Municipal Corporation, Defendant*, Superior Court of the State of California for the County of Los Angeles, Memorandum Opinion #837799, Bernard S. Jefferson, Judge of the Superior Court (5 February 1970).

93 W.A. Rosenblith and K.N. Stevens, *Handbook of Acoustic Noise Control*, Vol II, "Noise and Man," WADC Technical Report 52-204 AD01826 (Wright Air Development Center, Wright-Patterson Air Force Base, 1953).

94 W. Galloway and H.E. von Gierke, "Individual and Community Reaction to Aircraft Noise: Present Status and Standardization Efforts," paper prepared for International Conference on the Reduction of Noise and Disturbance Caused by Civil Aircraft, London (1966).

95 *Noise Abatement and Control: Departmental Policy, Implementation Responsibilities, and Standards*, Circular 1390.2 (U.S. Dept. of Housing and Urban Development, 1971).

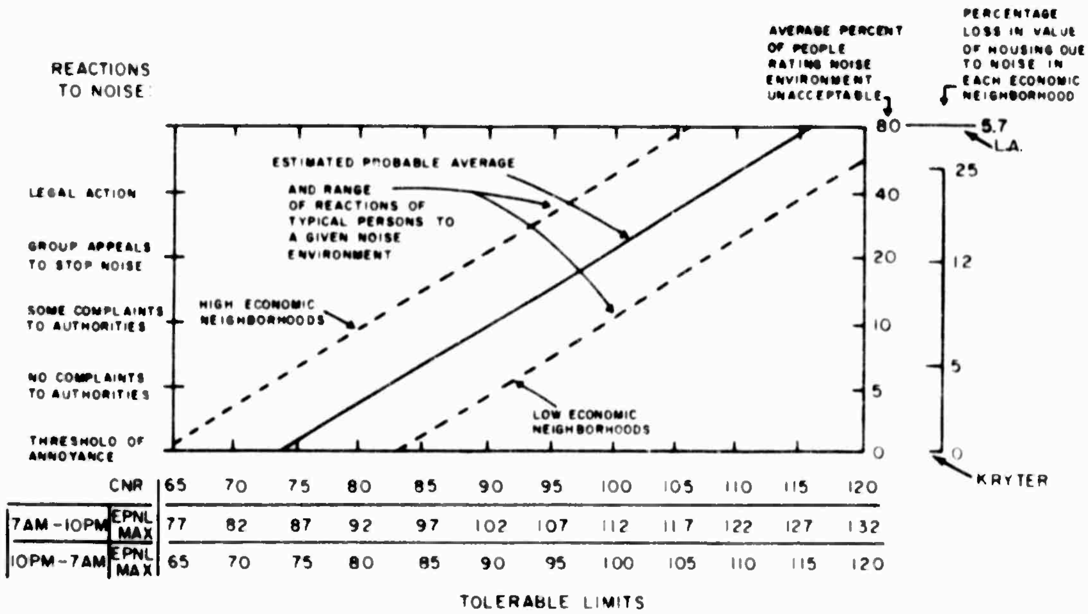

Figure 24. General reactions of people and communities to environmental noise and estimated tolerance limits (after Kryter, NASA CR-1636).

airport operations) to eliminate conflict between land use and noise impact. Recently, a California court awarded damages specifically on the basis of property being located within the 115 CNR range; the damages awarded were 5.7 percent of the market value of the property.[96]

There are a number of positive and negative factors that tend to shift community reaction. These include:

1. The financial dependence of the individual on the noise source.

2. The individual's belief in the necessity (or lack thereof) for the noise source.

3. The time of year.

4. The knowledge of how to register complaints effectively.

5. The fear of harm to person.

6. The fear of harm to property.

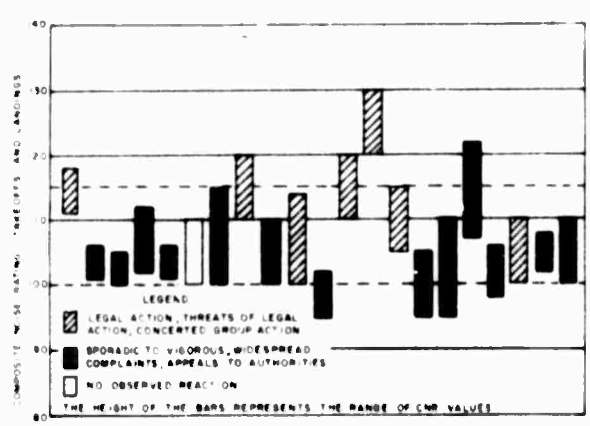

Figure 25. Reactions of people to different CNR values (after Galloway & von Gierke).

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96 Irving D. Aaron, et al., *Plaintiffs vs City of Los Angeles, A Municipal Corporation, Defendant* Superior Court of the State of California for the County of Los Angeles. Memorandum Opinion #837799. Bernard S. Jefferson, Judge of the Superior Court (5 February 1970).

Table 10
Summary of Case Histories of Responses to Noise in Residential Areas (from Rosenblith and Stevens)

No.	Description of Facility and Noise	CNR*	Predicted Average Response	Actual Response
1	Large wind tunnel in Midwest	110	Vigorous legal action	Municipal authorities forced facility to shut down
2	Large wind tunnel in Midwest	100	Threats of legal action	Vigorous telephone complaints and injunction threats. Management took immediate steps to lessen noise
3	Exhaust for air pumps, factory in industrial area	95	Strong complaints	Lodging house owner entered complaints with client and with local Dept of Health
4	Engine run-ups, aircraft mfg. plant	80	Less than mile annoyance	No complaints reported by management. Operations restricted to daytime only
5	Airport ground run ups	95	Strong complaints	Complaints by civic organizations, individual telephone calls and letters of complaint
6	Aircraft in flight near airport	95	Strong complaints	Vigorous complaints by letter and telephone. One town attempted to prevent passage of aircraft
7	Aircraft engine mfg. plant test cells	85	Mild annoyance	No complaints reported for daytime operation; a few for operation after 11 p.m.
8	Loading platform with trucks, men shouting, etc.	100	Threats of legal action	Vigorous complaints to management. Acoustical consultant called in by firm
9	Transformer noise in very quite res. area	105	Between threats of legal action and vigorous legal action	Injunction threats
10	Large fan at power company; single freq. components	90	Strong complaints	Residents complained consistently, consultants called in to advise on noise control
11	Weapons range, intermittent firing, 3-sec bursts several times per day	100	Threats of legal action	Vigorous complaints from nearby residents for winter operation

* Estimated by Kryter on basis of "level rank" band spectral measures as given by Rosenblith and Stevens.

7. The individual's belief about how annoying a given source should be.

8. The economic background of the individual.

Factor 1, financial dependence, is probably present at most rural military installations.

Factor 2, belief in necessity, is indicated by the Tracor study.[97] People who believed the SST to be unnecessary were more annoyed by sonic booms than those who believed it necessary. Sixty-three percent of complainants listed the boom as unnecessary vs 19 percent of the noncomplainants.

Factor 3, time of year, relates primarily to whether windows are open or closed. In summer, annoyance increases because the indoor levels are higher.

Factor 4, knowledge of how to complain, is also indicated by the Tracor study. People complain more if they know who to complain to and if they feel that their complaints will receive proper attention. In the case of military installations, people will probably complain to congressmen and civil authorities if they feel the base commanding officer does not heed their complaints.

Factor 5, fear of harm to person, while listed most important in some studies with conventional aircraft, was listed as the reason to eliminate boom noise by only 10 percent in the Tracor study.

Factor 6, fear of damage to property, was first in importance in the Tracor study, with 52 percent of complainants and 26 percent of noncomplainants citing it as the reason to eliminate boom noises.

Factor 7, how annoying a source should be, is illustrated in a study by Wilson in which aircraft and motor vehicles with the same dB(A) level were compared on the basis of annoyance. At low levels, the aircraft were found to be more annoying, but above about 70 dB(A), the motor vehicles were more annoying. This result tends to indicate that people expect different results from different sources; in this case, "vehicles should be less noisy than aircraft."

Factor 8, economic background, is illustrated in Figure 24. In essence, the residents of more affluent neighborhoods expect a quieter neighborhood. This should not be construed to mean that people in apartments or lower economic neighborhoods are less annoyed by the same stimuli than those people living in affluent neighborhoods. Rather, at this time, individuals in more affluent neighborhoods will overtly react to lower level stimuli than will the others.

For further reference, Appendix F contains the summary from the Tracor study.

Other Noise Ratings. Robinson[98] recently proposed a rating of the noise pollution level (L_{np}), which he defines as follows:

$$L_{NP} = L_{eq} + K\sigma \qquad \text{[Eq 9]}$$

where L_{eq} = equivalent, frequency-weighted, continuous noise level measured in dB(A), dB(D), PNL, or any other unit

Compute Factor for Short Distance Figure E-5

σ = standard deviation of the "instantaneous" noise levels, and

K = constant (provisionally K = 2.56).

97 W. Galloway and H.E. von Gierke, "Individual and Community Reaction to Aircraft Noise: Present Status and Standardization Efforts," paper prepared for International Conference on the Reduction of Noise and Disturbance Caused by Civil Aircraft, London (1966).

98 D.W. Robinson, *The Concept of Noise Pollution*, Report No. AL38/N69-34272 (National Physical Laboratory, 1969).

In the special case of short duration impulses, Robinson reduces Equation 9 to:

$$L_{NP} = L_{MAX} + (10)(\log(x)) + (2.56)(x)(\Delta L) \quad \text{[Eq 10]}$$

where x = the fraction of time that the intense stimuli is present

ΔL = the difference between L_{MAX} and the background level.

If one considers a series of indentical sounds (such as repetitive firing from the same gun) having 0.5 second duration, measures L in EPNdB, and considers that $(x)(\Delta L) \gg 1$, then:

$$L_{NP} = \text{EPNdB} + 10 \operatorname{Log}_{10} N + \text{const} \quad \text{[Eq 11]}$$

where N = number of occurrences.

For this example:

$$\text{CNR} = \text{EPNdB} + 10 \operatorname{Log}_{10} N - 12 \quad \text{[Eq 12]}$$

so, except for a constant, CNR and L_{NP} are equivalent for impulsive noise.

More recently, Goldstein has presented what he terms "a prototype standard and index for environmental noise quality."* He also indicates that any unit can be used as a measurement and he includes to some extent the effect of the standard deviation. However, his suggestion that 100 dB(A) is permissible for five minutes total during the day is much too liberal. In the absence of *any other* annoying sound, this would still result in a CNR of about 117.

As previously noted, Noise Exposure Forecasts (NEF) are equivalent to the CNR measured with EPNdB. (In fact, NEF + 76 = CNR.) Also equivalent to CNR are isopsophic index (N, France), noisiness index (NI, South Africa), and weighted, noise-exposure level (WECPNL, International CIVIL Aviation Organization [ICAO]). Very similar, but not equivalent, are total noise load (B, Netherlands), mean annoyance level (Q, Germany), and noise and number index (NNI, United Kingdom).

Recently, California has adopted Noise Regulations for California airports using the Community Noise Equivalent Level (CNEL). This is basically a CNR or NEF measure utilizing dB(A) (overall sound level reading with a scale-weighting curve) rather than EPNdB. Their rationale is that it is better to use units that are easily measured for regulation purposes at the expense of accuracy of prediction. Except for a constant, this system is the same as NI and very similar to B and Q which also use A-weighted measures.

Case Histories and Experiments. Recent data from annoyance complaints arising from artillery firing and blasting serve to both illustrate and confirm the CNR predictions. Included here are data from Aberdeen Proving Ground, Aberdeen Maryland,* Wildflecken Training Area, Germany [99] and Fort Belvoir, Virginia.* The CNR value for each of these cases is calculated on the basis of the data available. Appendix E, which reproduces these calculations in detail, also serves as an example of the application of this method.

At Aberdeen, complaints have been received from numerous areas. One area in particular that has produced many complaints and some community action is Gibson Island, a very exclusive, private, island community in Chesapeake Bay, some 25 miles south of Aberdeen Proving Ground. The data from Aberdeen indicates that at the time of the complaints, 250 impulses could be expected on a typical firing day (for 175 mm guns). As shown by the calculations in Appendix E, this condition corresponds to a CNR value of 96. Examination of Figure 24 indicates that in a high socioeconomic area complaints and possibly some group appeals are to be expected with this CNR value.

* R. Ainsley, Material Test Directorate, Aberdeen Proving Ground, (unpublished data and personal communications).

* Unpublished data and personal communications.

99 C. Bragdon, Bio-Acoustics Consultation Report No. 34-009-71 (AEHA, 1971).

* C.S. Mills, Jr., Former Chief, Demo. Branch, Fort Belvoir, personal communications.

In October of 1970, the U.S. Army Environmental Hygiene Agency made a study of noise conditions in the Wildflecken area in response to complaints and operations in conflict with German Law. The Wildflecken report indicates what is probably a more typical situation; unfortunately, the report does not indicate the economic status of the complainants. Note also that, in general, European noise ordinances are both more stringent and better enforced than their American counterparts. During this study, measurements were made in many surrounding residential areas. Specifically, measurements were made at the three lightly populated areas listed as Stations 1, 2, and 3 in Table 11 with the results shown. These measurements were made on days exhibiting negative velocity gradients near the earth's surface. Table 11 also lists the expected peak overpressures and corresponding CNR value for "bad days" (positive velocity gradient). Complaints are to be expected with these CNR values.

Examination of the Fort Belvoir papers indicates the following conditions for the town of Accokeek, which is situated about 7½ miles (12,070 meters or 39,600 feet) from the site of blasting operations. On a typical day, the schedule might include:

40 surface detonations of 1 lb of TNT
12 surface detonations of 10 lbs of TNT
2 detonations of 500 lb cratering charges buried 5 ft underground

This schedule indicates a CNR value of 91, which can be expected to generate some complaints.

It is also interesting to examine the contents o a letter written by one of the Accokeek residents to his Senator:

> Dear Senator _______:
>
> As a constituent in the Accokeek area of Prince Georges County, I have a brief but explicit complaint to make, for which I ask your assistance.
>
> Citizens in the area in the vicinity of the Potomac are periodically plagued with the noise and impact from munitions detonations, apparently emanating from both the Fort Belvoir and Indian Head activities.
>
> Aside from being annoying and nerve-wracking, these explosions are beginning to damage my house, which I deem inexcusable. I have a new home, barely two years old, which now has loose windows due to a succession of these explosion impacts.
>
> Repeatedly we get shocked by a series of detonations strong enough to rattle crockery in kitchen cabinets, not to mention the terrifying of wives and small children.
>
> If we were under some form of hostile bombardment I could understand the need to bear this situation—but as we are not, I think this constitutes an intolerable form of harrassment, and I earnestly reques your help in bringing it to a halt. What would you do, Mr. _________, if your home were continuously subjected to this kind of outrage?

This letter contains most of the previously mentioned factors. The act of writing this letter indicates that this individual knows how to complain. The third paragraph indicates his fear of damage to his home and to his wife's and children's nerves. It is also important to note the reference to the rattling of windows and crockery (bric-a-brac). The last paragraph shows that this individual feels that the noise source is unnecessary. These factors, the CNR value, and the high socioeconomic character of the area, combined to produce this typical complaint.

A brief experiment was conducted at CERL as a rough check on the CNR predictions. Using signals which approximate blast noises, seven subjects indicated that, on the average, they would become quite annoyed at CNR levels of about 107. It must be emphasized that this experiment was not conducted to gather new data, but to partially confirm the CNR predictions, which it did.

Table 11
Actual and Predicted CNR Values at Wildflecken

Station	Distance in Feet	Average Peak Overpressure Measured	CNR	"Bad Day" Peak Overpressure Prediction	"Bad Day" CNR
1	3281	117-121	111	132-136	121
2	5840	114-118	107	126-130	115
3	5250	114-118	107	126-130	117

The use of a modified CNR (TN-5-365) has been presented. The measurement units contained therein have been related to sonic booms, which in turn have been related to blast noise. Several important results from sonic boom studies apparently directly carry over to blast noise, and these include: the "startle" effect, fear of damage to people, and the fear of damage to property. Annoyance seems to result from the following factors: time of operation, frequency of operation, amplitude of the stimuli, frequency content of the stimuli, duration of the stimuli, and whether the stimuli is "startling." Finally, case histories and confirmatory testing tend to indicate the feasibility and applicability of the method.

5 CONCLUSIONS AND RECOMMENDATIONS

The methods suggested in this report* will be of use to planners for predicting and defining noise impact. Because of incomplete knowledge of the statistics of sound propagation and its effects on man, the CNR values attached to equal noisiness contours cannot be expected to fall within the limits normally associated with aircraft operations (5 dB), but the contours, assuming equal probability for meteorological and terrain effects should indicate probable incompatible land use areas. Areas with predicted CNR values above 120 should be regarded with alarm, and those above 110 with concern. Complaints, as shown by the examples, can be expected from areas having predicted CNR values as low as 90.

With refinement of the prediction elements — psychological testing, statistical prediction of sound propagation, including probable wind and terrain effects, and community noise monitoring — the method should achieve the accuracy presently associated with airport predictions. When this accuracy is achieved, these contours will no longer be only an aid to planners, but also a guide by which to test the validity of nuisance and damage claims. Damage and nuisance claims from areas having a CNR value in the low 90's, although expected, might be more easily rejected (a CNR area of 90 receives the same impact as an area removed about 25 miles from a major airport). Again, it must be emphasized that the method in its present form is of use to planners, but refinement of the prediction components is necessary to increase the accuracy of the predictions and create a tool that can be used to test the validity of claims.

It is probable that this method overestimates the CNR values because it uses fairly conservative estimates of meteorological effects (unless the human response is underestimated). Consequently, it may be concluded that complaints in some of the example areas were truly unwarranted.

It is, therefore, recommended that contours be established for all the U.S. military installations around the world. Computerization of the method is recommended to facilitate the establishment and use of these contours. Field evaluation of the method and use of better input data is recommended to increase the confidence level of the quantitative results.

* Contained in summary computational form in Appendix E.

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APPENDIX A:
DEFINITIONS AND ABBREVIATIONS

Definitions. Definitions are in alphabetical order. Citation numbers in parentheses correspond to listings in ANSI-S1.1-1960, *Acoustical Terminology*, issued by the American Nationa Standard Institute.

ACOUSTIC, ACOUSTICAL (1.3): The qualifying adjectives "acoustic" and "acoustical" mean containing, producing, arising from, actuated by, related to, or associated with sound. Acoustic is used when the term being qualified designates something that has the properties, dimensions, or physical characteristics associated with sound waves; acoustical is used when the term being qualified does not designate explicitly something that has such properties, dimensions or physical characteristics.

Note 1: The following examples qualify as having the "properties or physical characteristics associated with sound waves" and hence would take acoustic: impedance, inertance, load (radiation field), output (sound power), energy, wave, medium, signal, conduit, absorptivity, transducer.

Note 2: The following examples do not have the requisite physical characteristics and therefore take acoustical: society, method, engineer, school, glossary, symbol, problem, measurement, point of view, end-use, device.

Note 3: As illustrated in the preceding notes, the generic term is usually modified by acoustical, whereas the specific technical implication calls for acoustic.

ACOUSTICS (1.2): (1) Acoustics is the science of sound, including its production, transmission, and effects. (2) The acoustics of a room are those qualities that together determine its character with respect to distinct hearing.

AMBIENT NOISE (1.25): Ambient noise is the all-encompassing noise associated with a given environment, usually being a composite of sounds from many sources near and far.

AUDIO FREQUENCY (1.12): An audio frequency is any frequency corresponding to a normally audible sound wave.

Note 1: Audio frequencies range roughly from 15 to 20,000 cycles per second.

Note 2: The word "audio" may be used as a modifier to indicate a device or system intended to operate at audio frequencies, e.g., "audio amplifier."

BACKGROUND NOISE (1.26): Background noise is the total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal.

Note 1: Ambient noise detected, measured, or recorded with the signal becomes part of the background noise.

Note 2: Included in this definition is the interference resulting from primary power supplies; separately, it is commonly described as hum.

BAND PRESSURE LEVEL (2.7): The band pressure level of a sound for a specified frequency band is the sound pressure level for the sound contained within the restricted band. The reference pressure must be specified.

Note: The band may be specified by its lower and upper cut-off frequencies, or by its geometric center frequency and bandwidth. The width of the band may be indicated by a prefatory modifier; e.g., octave band (sound pressure) level, half-octave band level, third-octave band level, 50 cps band level.

BEL (2.2): The bel is a unit of level when the base of the logarithm is 10. Use of the bel is restricted to levels of quantities proportional to power.

CYCLE (1.8): A cycle is the complete sequence of values of a periodic quantity that occur during a period.

DECIBEL (2.3): The decibel is one-tenth of a bel. Thus, the decibel is a unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power.

Note 1: Examples of quantities that qualify are power (any form), sound pressure squared, particle velocity squared, sound intensity, sound-energy density, voltage squared. Thus the decibel is a unit of sound-pressure-squared level; it is common practice, however, to shorten this to sound pressure level because no ambiguity ordinarily results from so doing.

Note 2: The logarithm to the base the tenth root of 10 is the same as ten times the logarithm to the base 10; e.g. for a number x^2 $\log_{10^{1/10}} x^2 = 10 \log_{10} x^2 = 20 \log_{10} x$. This last relationship is the one ordinarily used to simplify the language in definitions of sound pressure level, etc.

DISTORTION (1.33): Distortion is an undesired change in waveform. Noise and certain desired changes in waveform, such as those resulting from modulation or detection, are not usually classed as distortion.

DURATION OF THE OCCURRENCE OF A SOUND: The time in seconds between the moment a sound starts to rise above the threshold or practical threshold of perceived noisiness and the next succeeding moment in time it recedes to the threshold or threshold of noisiness.

ECHO (1.30): An echo is a wave that has been reflected or otherwise returned with sufficient magnitude and delay to be detected as a wave distinct from that directly transmitted.

EFFECTIVE PERCEIVED NOISE LEVEL (EPNL) IN EPNdB and EdB(A): The sum (as calculated by formulae given) of PNdBs in successive 0.5-sec intervals during the occurrence of a sound, minus 12 plus a correction for onset duration or impulse level, as appropriate. The value −12 comes from the choice of 16 one-half second intervals (a duration of 8 seconds) as a standard duration to which all effective levels are referred.

EFFECTIVE SOUND PRESSURE (ROOT-MEAN-SQUARE SOUND PRESSURE) (1.50): The effective sound pressure at a point is the root-mean-square value of the instantaneous sound pressures, over a time interval at the point under consideration. In the case of periodic sound pressures, the interval must be an integral number of periods or an interval that is long compared to a period. In the case of nonperiodic sound pressures, the interval should be long enough to make the value obtained essentially independent of small changes in the length of the interval.

Note: The term "effective sound pressure" is frequently shortened to "sound pressure."

FREQUENCY (1.9): The frequency of a function periodic in time is the reciprocal of the primitive period. The unit is the Hertz (Hz).

IMPULSE INTERVALS OF SOUND: The difference in PNL (measured PNdB) of an impulse from the PNL of the background noise is called the impulse level.

IMPULSE LEVEL CORRECTION: The impulse level in PNdB is used to determine a correction value (called ic).

INFRASONIC FREQUENCY (1.14): An infrasonic frequency is a frequency lying below the audio frequency range.

Note 1: The word "infrasonic" may be used as a modifier to indicate a device or system intended to operate at an infrasonic frequency.

Note 2: The term "subsonic" was once used in acoustics synonymously with infrasonic; such usage is now deprecated.

INTENSITY LEVEL (SOUND-ENERGY FLUX DENSITY LEVEL) (2.14): The intensity level, in decibels, of a sound is 10 times the logarithm to the base 10 of the ratio of the intensity of this sound to the reference intensity. The reference intensity shall be stated explicitly.

Note 1: A common reference sound intensity is 10^{-15} watt per square centimeter in a specified direction.

Note 2: In a free progressive plane or spherical wave, there is a known relation between sound intensity and sound pressure, so that sound intensity level can be deduced from a measurement of sound pressure level. In general, however, there is no simple relation between the two, and a measurement of sound pressure level should not be reported as one of intensity level.

LEVEL (2.1): In acoustics, the level of a quantity is the logarithm of the ratio of that quantity to a reference quantity of the same kind. The base of the logarithm, the reference quantity, and the kind of level must be specified.

Note 1: Examples of kinds of levels in common use are electric power level, sound-pressure-squared level, voltage-squared level.

Note 2: The level as here defined is measured in units of the logarithm of a reference ratio that is equal to the base of logarithms.

Note 3: In symbols,

$$L = \log_r (q/q_0) \qquad \text{[Eq A-1]}$$

where L = level of kind determined by the kind of quantity under consideration, measured in units of $\log_r$

r = base of logarithms and the reference ratio

q = the quantity under consideration

q_0 = the reference quantity of the same kind

Note 4: Differences in the levels of two like quantities q_1 and q_2 are described by the same formula because, by the rules of logarithms, the reference quantity is automatically divided out:

$$\log_r (q_1/q_0) \quad \log_r (q_2/q_0) = \log_r (q_1/q_2) \qquad \text{[Eq A-2]}$$

MICROBAR, DYNE PER SQUARE CENTIMETER (1.46): A microbar is a unit of pressure commonly used in acoustics. One microbar is equal to 1 dyne per square centimeter.

Note: The term "bar" properly denotes a pressure of 10^6 dynes per square centimeter. Unfortunately, the bar was once used in acoustics to mean 1 dyne per square centimeter, but this usage is no longer correct.

N-WAVE: An N-wave is a transient pressure signature in the form of an N. It is characterized by a fast compression, a slow decay into a rarified state, and a sharp return to ambient pressure.

NONIMPULSIVE INTERVALS OF SOUND: All 0.5-second intervals of sound that are not impulsive.

NOISE (1.24): (1) Noise is any undesired sound. By extension, noise is any unwanted disturbance within a useful frequency band, such as undesired electric waves in a transmission channel or device. (2) Noise is an erratic, intermittent, or statistically random oscillation.

Note 1: If ambiguity exists as to the nature of the noise, a phrase such as "acoustic noise" or "electric noise" should be used.

Note 2: Since the above definitions are not mutually exclusive, it is usually necessary to depend upon context for the distinction.

NOY: The unit of perceived noisiness is called the "noy." Noy values, as the result of judgment tests conducted in the laboratory, have been assigned to the SPL of bands of frequencies present during an interval of 0.5 seconds.

OCTAVE (13.11): (1) An octave is the interval between two sounds having a basic frequency ratio of two. (2) An octave is the pitch interval between two tones such that one tone may be regarded as duplicating the basic musical import of the tone at the nearest possible higher pitch.

Note 1: The interval, in octaves, between any two frequencies, is the logarithm to the base 2 (or 3.322 times the logarithm to the base 10) of the frequency ratio.

Note 2: The frequency ratio corresponding to an octave pitch interval is approximately, but not always exactly, 2:1.

OCTAVE AND 1/3-OCTAVE BAND LEVEL: The SPL re 0.0002 μbar as measured on a Sound Level Meter set on "slow" and flat-frequency weighting in conjunction with 1/3-octave or octave band filters having cutoff frequencies as specified in ANSI document S1.6, 1967.

ONSET CORRECTION: The onset duration in seconds is used to determine an onset correction value (called oc).

ONSET DURATION: The onset duration of a nonimpulsive sound is the time between the first 0.5-sec interval during which a nonimpulsive sound is at Max PNL and the last preceding 0.5-sec interval during which the sound was at the PNL of the background noise, or the threshold of noisiness, or the practical threshold of noisiness, whichever is higher.

OSCILLATION (1.4): Oscillation is the variation, usually with time, of the magnitude of a quantity with respect to a specified reference when the magnitude is alternately greater and smaller than the reference.

OVERPRESSURE: The overpressure is the maximum instantaneous pressure that occurs during the interval of an impulse. In this report, the decibel equivalent of the overpressure re 0.0002 dynes/cm^2 is identical to the "peak level" or "peak sound pressure level."

PEAK LEVEL (2.12): The peak level is the maximum instantaneous level that occurs during a specified time interval. In acoustics, peak sound pressure level is to be understood, unless some other kind of level is specified.

PEAK SOUND PRESSURE (1.49): The peak sound pressure for any specified time interval is the maximum absolute value of the instantaneous sound pressure in that interval.

Note: In the case of a periodic wave, if the time interval considered is a complete period, the peak sound pressure becomes identical with the maximum sound pressure.

PERCEIVED NOISE LEVEL (PNL) IN PNdB AND MAXIMUM PNL IN MAX PNdB: The sum, as calculated according to prescribed procedures, of the noy value of a frequency band (or bands) of sound is designated as perceived noise level in PNdB. The highest values of the PNdBs calculated for each 0.5-sec interval during the occurrence of a sound is called the Max PNdB of the sound.

PERIODIC QUANTITY (1.6): A periodic quantity is an oscillating quantity whose values recur for certain increments of the independent variable.

Note 1: If a period quantity v is a function of t, then

$$v = f(t) = f(t + T) \qquad \text{[Eq A-3]}$$

where T = a constant; a period of v.

Note 2: In general, a periodic function can be expanded into a series of the form

$$y = f(t) = A_0 + A_1 \sin(\omega t + a_1) + A_2 \sin(2\omega t + a_2) + \ldots \qquad \text{[Eq A-4]}$$

where

ω = a positive constant, equal to 2π divided by the period T

A's and a's = constants, which may be positive, negative, or zero.

PHASE OF A PERIODIC QUANTITY (1.18): The phase of a periodic quantity, for a particular value of the independent variable, is the fractional part of a period through which the independent variable has advanced, measured from an arbitrary reference.

Note: The arbitrary reference is generally so chosen that the fraction is less than unity. In case of a simple harmonic quantity, the reference is often taken as the past previous passage through zero from the negative to positive direction.

POWER (LEVEL) GAIN (2.15): Power level gain in decibels is the amount by which the output power level in decibels exceeds the input power level in decibels. By reason of the properties of

Other Sounds, Z24.3-1944. The weighting employed must always be stated. The reference pressure is 0.0002 microbar.

Note: A suitable method of stating the weighting is, for example, "The A-sound level was 43 dB."

SOUND PRESSURE (1.47): The sound pressure at a point is the total instantaneous pressure at that point in the presence of a sound wave minus the static pressure at that point.

SOUND PRESSURE LEVEL (2.6): The sound pressure level, in decibels, of a sound is 20 times the logarithm to the base 10 of the ratio of the pressure of this sound to the reference pressure. The reference pressure shall be explicitly stated.

Note 1: The following reference pressures are in common use:

1. 2×10^{-4} microbar
2. 1 microbar.

Referenced pressure (1) is in general use for measurements concerned with hearing and with sound in air and liquids, while (2) it has gained widespread acceptance for calibration of transducers and various kinds of sound measurements in liquids.

Note 2: Unless otherwise explicitly stated, it is to be understood that the sound pressure is the effective (rms) sound pressure.

Note 3: It is to be noted that in many sound fields the sound pressure ratios are not the square roots of the corresponding power ratios.

SPECTRUM (1.34): (1) The spectrum of a function of time is a description of its resolution into components, each of different frequency and (usually) different amplitude and phase. (2) "Spectrum" is also used to signify a continuous range of components, usually wide in extent, within which waves have some specified common characteristic; e.g., "audio-frequency spectrum."

Note: The term "spectrum" is also applied to functions of variables other than time, such as distance.

SPECTRUM LEVEL (SPECTRUM DENSITY LEVEL) (2.8): The spectrum level of a specified signal at a particular frequency is the level of that part of the signal contained within a band 1 Hz wide, centered at the particular frequency. Ordinarily this has significance only for a signal having a continuous distribution of components within the frequency range under consideration. The words "spectrum level" cannot be used alone but must appear in combination with a prefatory modifier; e.g., pressure, velocity, voltage.

Note: For illustration, if L_{p2} be desired pressure spectrum level, p the effective pressure measured through the filter system, p_0 the reference sound pressure, Δf the effective bandwidth of the filter system (see 7.27), and $\Delta_0 f$ the reference bandwidth (1 Hz), then

$$L_{p2} = 10 \log_{10} \left[\frac{p^2/\Delta f}{p_0^2/\Delta_0 f} \right] \qquad \text{[Eq A-5]}$$

For computational purposes, if L_p is the band pressure level observed through the filter, the above relation reduces to

$$L_{p2} = L_p - 10 \log_{10} \left[\frac{\Delta f}{\Delta_0 f} \right] \qquad \text{[Eq A-6]}$$

STATIC PRESSURE (1.45): The static pressure at a point is the pressure that would exist at that point in the absence of sound waves.

THRESHOLD OF PERCEIVED NOISINESS: The threshold of perceived noisiness is the level measured during the day (between 7 a.m. and 10 p.m.); indoors it is 40 PNdB, outdoors it is 60 PNdB. This threshold during the night (10 p.m. to 7 a.m.) is 10 PNdB lower than during the day.

WAVE (1.19): A wave is a disturbance propagated in a medium in such a manner that at any point in the medium the quantity serving as measure of disturbance is a function of the time, while at any instant the displacement at a point is a function of the position of the point. Any physical quantity that has the same relationship to some independent variable (usually time) that a propagated disturbance has, at a particular instant, with respect to space, may be called a wave.

WAVELENGTH (1.20): The wavelength of a periodic wave in an isotropic medium is the perpendicular distance between two wave fronts in which the displacements have a difference in phase of one complete period.

WHITE NOISE (1.28): White noise is a noise whose spectrum density (or spectrum level) is substantially independent of frequency over a specified range.

Note: White noise need not be random.

ULTRASONIC FREQUENCY (1.13): An ultrasonic frequency is a frequency lying above the audio frequency range. The term is commonly applied to elastic waves propagated in gases, liquids, or solids.

Note 1: The term "ultrasonic" may be used as a modifier to indicate a device or system intended to operate at an ultrasonic frequency.

Note 2: "Supersonic" was a term once used in acoustics synonymously with ultrasonic; such usage is now deprecated.

Abbreviations

1.	AEC	Atomic Energy Commission
2.	AEHA	Army Environmental Hygiene Agency
3.	BRL	Ballistic Research Laboratories
4.	CERL	Construction Engineering Research Laboratory
5.	CNR	Composite Noise Rating
6.	dB	decibel
7.	ECOM	U.S. Army Electronics Command
8.	EPA	Environmental Protection Agency
9.	FAA	Federal Aviation Administration
10.	HEL	Human Engineering Laboratory
11.	HUD	U.S. Department of Housing and Urban Development
12.	MTD	Material Test Directorate
13.	NASA	National Aeronautics and Space Administration
14.	NEF	noise exposure forecasts
15.	NOL	Naval Ordnance Laboratory
16.	NPL	National Physical Laboratory (British)
17.	WRL	Willow Run Laboratory
18.	SAE	Society of Automotive Engineers
19.	SLM	Sound Level Meter
20.	TECOM	U.S. Army Test and Evaluation Command

APPENDIX B:
BLAST NOISE SPECTRAL LEVELS

Figures B-1 and B-2 contain the *estimated* spectra for blast noises arising from sources in the one-to-ten and ten-to-one-hundred-pound ranges, respectively. They are based on the methods and considerations presented in Chapter 3. It must be emphasized that *these are only estimates*. New field data is needed to predict the probable spectra as a function of overpressure, source, and distance, and to accurately assess the effects of air absorption and nonlinear wave motion.

Tables B-1 and B-2 list the average pressure spectra levels in each octave band. Appropriate allowance is made for peaks occurring in lowest, middle, or highest third octave of an octave band. Peaks occurring below the 31.5 Hz octave band but above 15 Hz are included in the energy of the 31.5 Hz band (with appropriate adjustment for their narrower bandwidth) because this energy is perceived by the ear in a manner similar to that energy within the 31.5 Hz band. (Actually, as described in Chapter 4 and Apendix C, all of the energy in 31.5 Hz band and below is ultimately treated as if it were in the 50 Hz band.)

Tables B-4 and B-5 list the octave band levels corresponding to the levels in Tables B-1 and B-2. Table B-3 lists the conversion factors used to convert average levels to octave band levels. In each case, the conversion has been rounded upward by 0.5 dB. The levels were rounded downward by 0.5 dB when calculating the average levels to compensate for this adjustment (Tables B-1 and B-2). (It is felt the estimates are so inexact that they do not warrant even an indication 0.5 dB accuracy.) Also listed in Tables B-4 and B-5 are the sums on a 10 $\log_{10}$ basis of the energy in the three lowest octave bands (31.5, 63, and 125 Hz).

Note that the spectral peak amplitude is inversely proportional to frequency and increases 6 dB for each decrease of one octave in frequency, whereas the energy bandwidth decreases by 3 dB for each octave decrease. The net result is a 3 dB increase in amplitude for each octave reduction in frequency.

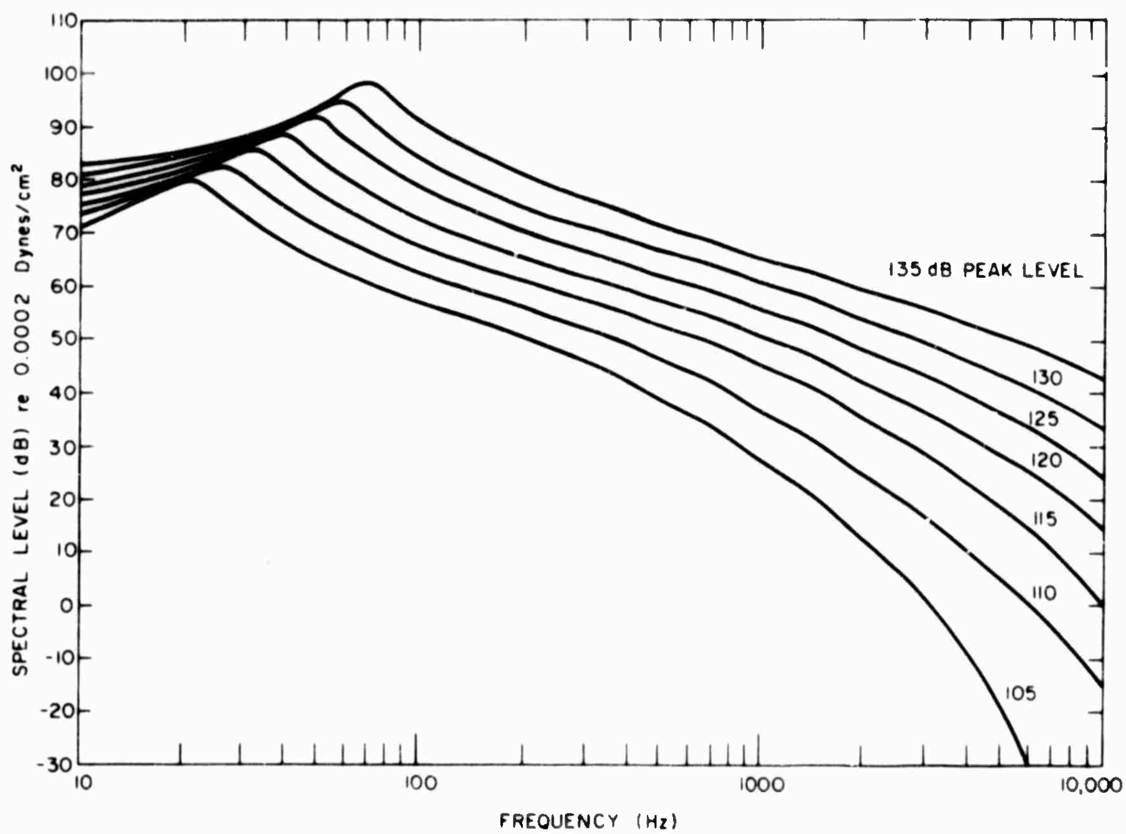

Figure B-1. Spectra for impulses originating from 1 to 10 pound charges.

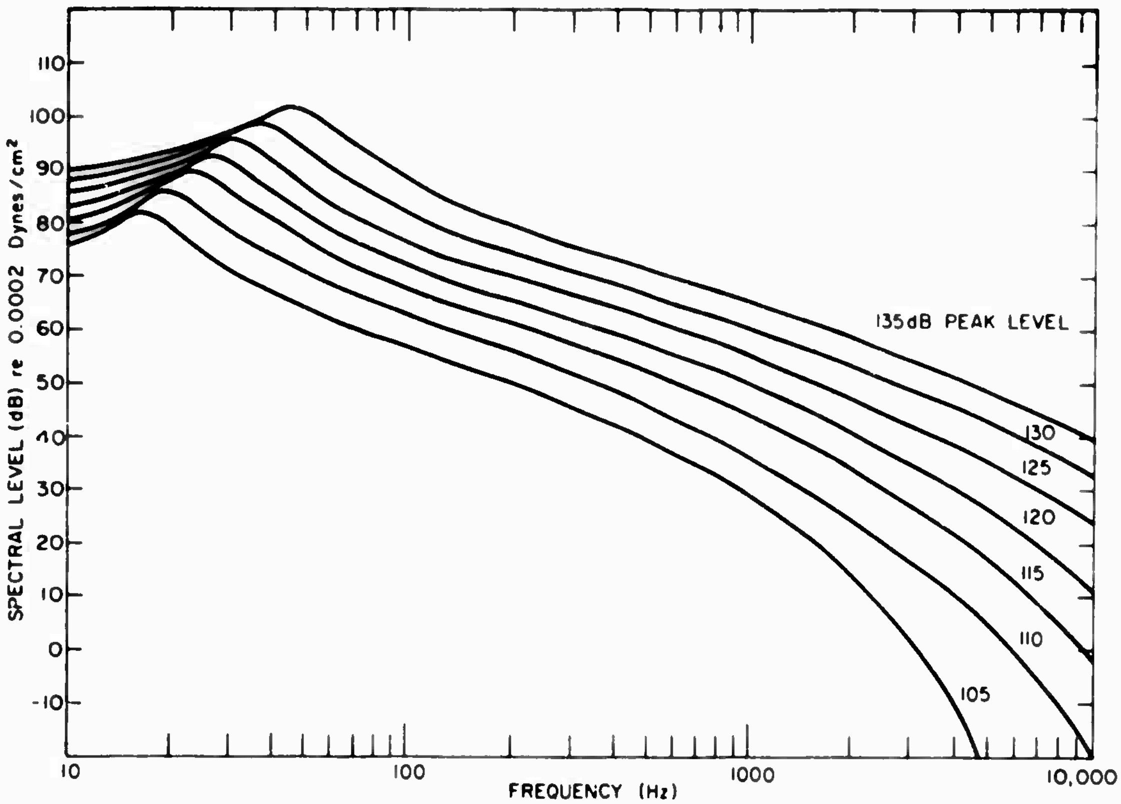

Figure B-2. Spectra for impulses originating from 10-100 pound charges.

Table B-1

Average Pressure Spectrum Level (dB) in Each Octave Band For 1-10 Pound Charges

Peak Level (dB)	Octave Band (Hz) 31.5	63	125	250	500	1000	2000	4000	8000
135	89	95	87	78	71	65	60	53	46
130	88	92	81	72	67	61	54	46	37
125	87	88	76	68	62	56	48	40	29
120	87	81	70	63	57	51	42	32	20
115	83	73	65	59	53	45	35	23	7
110	79	67	60	54	46	37	25	10	-8
105	76	61	55	48	39	27	13	-9	-40

Table B-2

Average Pressure Spectrum Level (dB) in Each Octave Band
For 10-100 Pound Charges

Peak	Octave Band (Hz)								
Level (dB)	31.5	63	125	250	500	1000	2000	4000	8000
135	98	96	85	78	72	66	59	52	43
130	96	89	78	72	66	60	53	45	36
125	93	83	74	68	62	55	47	38	28
120	89	78	70	63	58	50	41	30	17
115	85	73	65	59	52	44	34	22	5
110	81	68	61	54	46	36	24	10	9
105	76	61	55	48	39	29	14	10	44

Table B-3

Conversion Factors for Octave Band Levels

Octave Band Center Frequency (Hz)	Conversion (dB) to Octave Band Levels
31.5	14
63	17
125	20
250	23
500	26
1000	29
2000	32
4000	35
8000	38

Table B-4

Octave Band Levels (dB) for 1-10 Pound Charges

Peak	3-Band	Octave Band (Hz)								
Level (dB)	Sum	31.5	63	125	250	500	1000	2000	4000	8000
135	113.5	103	112	107	101	97	94	92	88	84
130	110.5	102	109	101	95	93	90	86	81	75
125	117.0	101	105	96	91	88	85	80	75	67
120	113.0	101	98	90	86	83	80	74	67	58
115	98.0	97	90	85	82	79	74	67	58	45
110	93.5	93	84	80	77	72	66	57	45	30
105	90.5	90	78	75	71	65	56	45	26	2

Table B-5

Octave Band Levels (dB) for 10-100 Pound Charges

Peak Level (dB)	3-Band Sum	Octave Band (Hz) 31.5	63	125	250	500	1000	2000	4000	8000
135	116.0	112	113	105	101	98	95	91	87	81
130	112.0	110	106	98	95	92	89	85	80	74
125	108.0	107	100	94	91	88	84	79	73	66
120	104.0	103	95	90	86	84	79	73	65	55
115	99.5	99	90	85	82	78	73	66	57	43
110	95.5	95	85	81	77	72	65	56	45	29
105	90.5	90	78	75	71	65	58	46	25	-6

APPENDIX C: PROCEDURES FOR THE MEASUREMENT OF NOISE AND NOISE ENVIRONMENT WITH RESPECT TO PERCEIVED NOISINESS (ANNOYANCE)*

This appendix describes procedures for evaluating the perceived noisiness (annoyance) of nonimpulsive and impulsive noises and noise environments.*

The unit named PNdB, which is based on band spectral measures of the noise, is explained in this appendix. At the time of this writing, there are some data to suggest that the procedures of Stevens for calculating perceived noisiness, that of summing noy values for different frequency bands, should be discarded in favor of a somewhat simpler procedure of summing on a power basis the SPLs of the bands adjusted according to equal noy contours. It is suggested that PNdB units calculated by the alternative procedure to be described below be designated PNdB′. If the suspected virtue of this power summation procedure is verified from a re-examination of previous judgment data and by new data, this procedure could be standardized as the preferred or only means of calculating PNdB, and the prime designation could then be removed.

It is a matter of opinion whether the state of the art has been reached at which the method of obtaining the units PNdB and EPNdB for perceived noisiness may be standardized. If such standardization was deemed appropriate, the authors of the NASA report recommend that the following material be involved, with the realization that some changes and simplifications will undoubtedly take place with further research.

Procedure for Calculating Perceived Noise Level (PNL) in PNdB.

Step 1. Determine the sound pressure level that occurs in each 1/3 or full-octave band in each successive 0.5-sec interval of time.

Step 2—1/3-Octave Bands. Add on a 10 $\log_{10}$ antilog basis the band levels of the 1/3 octave bands having the center frequencies of:

a. 31.5, 40, 50, 63, 80, and 100 Hz; assign the result to the band center frequency above 50 Hz having the greatest intensity or to the 50 Hz band if that or a lower band has the highest intensity.

b. 125, 160, and 200 Hz; assign the result to the band center frequency having the greatest intensity.

c. 250 and 315 Hz; assign the result to the band center frequency having the greatest intensity.

Note: If the greatest intensity in Step 2a, b, and c is present in more than one band within a step, assign the sum to the band with the highest frequency.

*Step 2—Full-Octave Bands.** Add on a 10 $\log_{10}$ antilog basis the band levels of the octave bands having the center frequencies of 31.5, 63, and 125 Hz. Assign the result to the band center frequency above 31.5 Hz having the greatest intensity or to 50 Hz if the 31.5 Hz band has the highest intensity.

Note: If the intensity is the same in the two bands, assign the sum to the band with the highest frequency.

Step 3. If any band (or summed bands below 355 Hz) for nonimpulsive sounds is abutted above and below by hands (or summed bands below 355 Hz) that are both less intense than the band in question, determine a correction

* Most of the material presented here is taken from K.D. Kryter, *Possible Modifications to the Calculation of Perceived Noisiness*, with the modifications discussed in Chapter 4 of this report.

* Steps 2 and 5 are given for both 1/3- and full-octave bands; use one or the other method, depending on which bands are used for the band spectrum analysis of a given sound.

from the appropriate abscissa on Figure C-2 and add it to the SPL of the respective bands or summed bands.

Note 1: In Figure C-1, the abscissa is

$$L_B \qquad \frac{L_{B-1} + L_{B+1}}{2} \qquad \text{[Eq C-1]}$$

where L_B = the SPL in dB of band (or sum of bands below 355 Hz) B
B-1 = the abutted lower frequency band
B+1 = the abutted higher frequency band
The addition of L_{B-1} to L_{B+1} is arithmetic.

Note 2: When the highest frequency band of a sound is 3 dB more intense than the band immediately below it, L_{B+1} is taken as 3. When the lowest frequency band of a sound is 3 dB more intense than the band immediately above it, L_{B-1} is taken as 3.

Note 3: Ensure that the presence of a pure tone or very narrow band (less than 1/3-octave wide) of concentrated energy is not overlooked because its center frequency is at or near the crossover frequencies between two adjacent filter bands. When there are pure-tone or very narrow-band, spectral components at or near filter crossover points between two adjacent filter bands, add the appropriate amount found in Figure C-1 to the band of higher intensity (or to the band of higher frequency when the two adjacent bands are of equal intensity).

Step 4. Find the noy values from Table C-1 for: (1) the summed band levels at the assigned center frequencies which fall at and below 355 Hz as obtained in Step 2 and as corrected in Step 3; and (2) the band levels present in each band having center frequencies at and above 355 Hz, as corrected in Step 3.

Step 5—1/3-Octave Bands. Add to the largest noy value obtained for any single band in Step 4 the sum of the noy values for all the other bands as found in Step 4 multiplied by .15. The result is called PN for that 0.5-sec interval of a given sound.

Step 5—Octave-Bands. Add to the largest noy value obtained for any single band in Step 4 the sum of the noy values for all the other bands as found in Step 4, multiplied by .3. The result is called PN for the 0.5-sec interval of a given sound.

Alternative Step 5. Find from Table C-1 the 10 antilog_{10} values for the SPL of the band centered at 1000 Hz that has the *same or closest* noy value as each of the bands (or summed bands below 355 Hz), as corrected in Step 3. Sum these 10 $\log_{10}$ values.

Step 6. Convert the PN for each 0.5-sec interval of sound into PNdB by reference to Table C-2. The result is called PNdB for each 0.5-sec interval of sound.

Alternative Step 6. Convert the sum found in Alternative Step 5 into "dB" by reference to the left-hand columns of Table C-1. Add to this value the constant number 12. The result is called PNL in PNdB' for each 0.5-sec interval of time.

Procedures for Calculating EPNL for Impulsive and Nonimpulsive Sound.

$$EPNL = 10 \log_{10} \Sigma_i \log_{10}^{-1} (PNL_i/10) \quad 12 + oc + ic \qquad \text{[Eq C-2]}$$

where i = successive .5-sec intervals of time
oc = an onset-duration correction
ic = an impulsive level correction.

Step 1. Sum on a 10 $\log_{10}$ antilog basis the PNLs found occurring in 0.5-second intervals between points in time during which the level is above the threshold or the practical threshold of perceived noisiness.

Note 1: The practical threshold of perceived noisiness should be used as a starting point only when it exceeds the threshold of perceived noisiness.

Note 2: The practical threshold of perceived noisiness should be used only when considerations related to sound measurement procedures

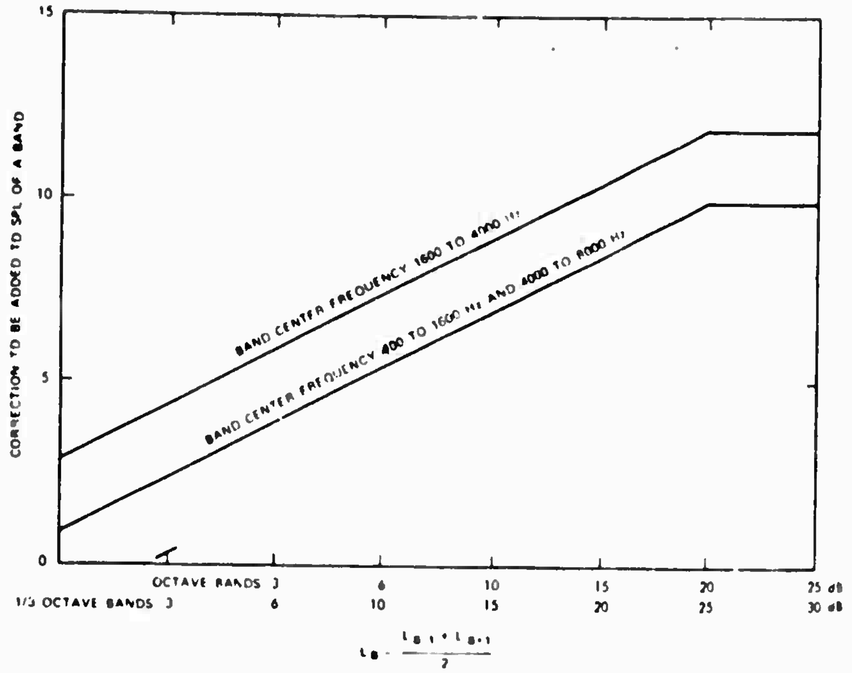

Figure C-1. Showing decibel correction to be added to SPL of band that exceeds adjacent bands by amount shown on abscissa (from NASA CR-1636).

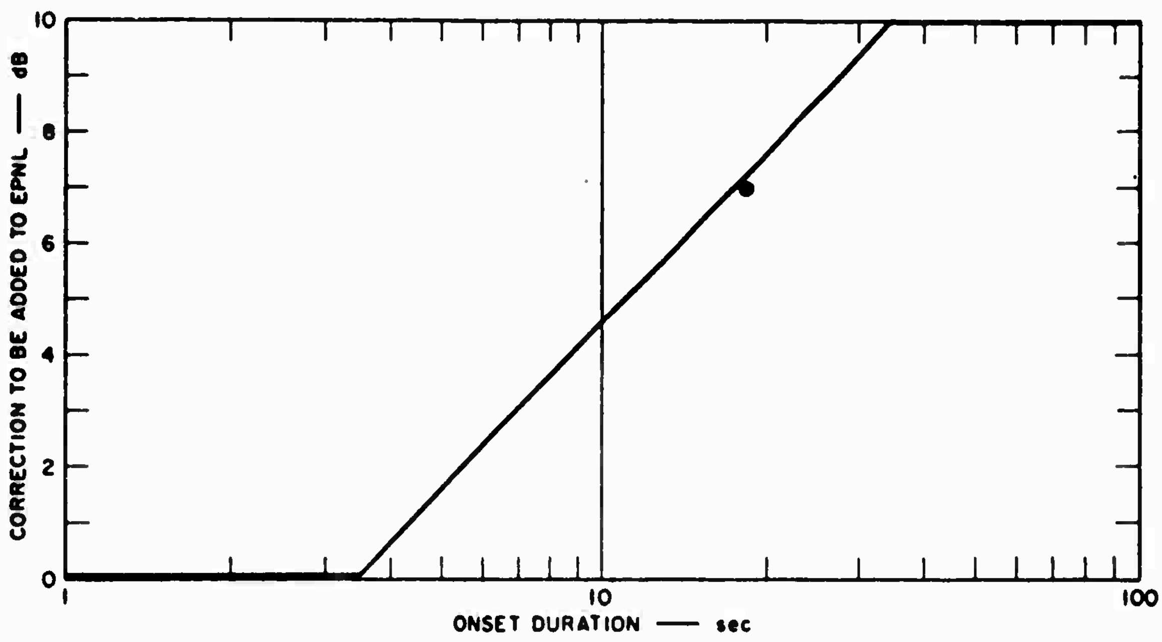

Figure C-2. Correction to EPNL for contribution to perceived noisiness of onset duration of nonimpulsive sounds (from NASA CR-1636).

Table C-1. Antilog (base 10) of SPL/10 and Noys as a Function of SPL

SPL-dB	$\log_{10}^{-1}$ (SPL/10) (EXPON. NUMERIC FORM. EXAMPLE 7.94E 02 = 7.94×10^2)	BAND CENTER FREQUENCY 50HZ	63HZ	80HZ	100HZ	125HZ	160HZ	200HZ	250HZ	315HZ	400HZ	500HZ	630HZ	800HZ	1KHZ	1.2KHZ	1.6KHZ	2KHZ	2.5KHZ	3.1KHZ	4KHZ	5KHZ	6.3KHZ	8KHZ	10KHZ
29	7.94E 02																			1.0	1.0				
30	1.00E 03																		1.0	1.1	1.1				
31	1.26E 03																		1.1	1.1	1.1	1.0			
32	1.58E 03																	1.0	1.1	1.2	1.2	1.1			
33	2.00E 03																	1.1	1.2	1.3	1.3	1.2	1.0		
34	2.51E 03																1.0	1.2	1.3	1.4	1.4	1.3	1.1		
35	3.16E 03																1.1	1.3	1.4	1.5	1.5	1.4	1.2		
36	3.98E 03																1.2	1.3	1.5	1.6	1.6	1.5	1.4		
37	5.01E 03																1.3	1.4	1.6	1.8	1.8	1.6	1.5	1.0	
38	6.31E 03															1.0	1.3	1.5	1.8	1.9	1.9	1.7	1.6	1.1	
39	7.94E 03															1.1	1.4	1.6	1.9	2.0	2.0	1.9	1.8	1.2	
40	1.00E 04										1.0	1.0	1.0	1.0	1.0	1.2	1.5	1.7	2.0	2.2	2.2	2.0	1.9	1.4	
41	1.26E 04										1.1	1.1	1.1	1.1	1.1	1.3	1.6	1.8	2.2	2.4	2.4	2.2	2.0	1.5	1.0
42	1.58E 04									1.0	1.1	1.1	1.1	1.1	1.1	1.3	1.7	2.0	2.4	2.6	2.6	2.4	2.2	1.7	1.1
43	2.00E 04									1.1	1.2	1.2	1.2	1.2	1.2	1.4	1.8	2.2	2.6	2.8	2.8	2.6	2.4	1.8	1.2
44	2.51E 04								1.0	1.1	1.3	1.3	1.3	1.3	1.3	1.5	2.0	2.4	2.8	3.0	3.0	2.8	2.6	2.0	1.4
45	3.16E 04								1.1	1.2	1.4	1.4	1.4	1.4	1.4	1.6	2.1	2.6	3.0	3.2	3.2	3.0	2.8	2.2	1.5
46	3.98E 04							1.0	1.2	1.3	1.5	1.5	1.5	1.5	1.5	1.7	2.3	2.8	3.2	3.4	3.4	3.2	3.0	2.4	1.7
47	5.01E 04							1.1	1.3	1.4	1.6	1.6	1.6	1.6	1.6	1.8	2.4	3.0	3.4	3.6	3.6	3.4	3.2	2.6	1.8
48	6.31E 04						1.0	1.2	1.4	1.5	1.7	1.7	1.7	1.7	1.7	2.0	2.6	3.2	3.6	3.9	3.9	3.6	3.4	2.8	2.0
49	7.94E 04						1.1	1.3	1.5	1.6	1.9	1.9	1.9	1.9	1.9	2.1	2.8	3.4	3.9	4.1	4.1	3.9	3.6	3.0	2.2
50	1.00E 05						1.2	1.4	1.6	1.7	2.0	2.0	2.0	2.0	2.0	2.3	3.0	3.6	4.1	4.4	4.4	4.1	3.9	3.2	2.4
51	1.26E 05					1.0	1.3	1.5	1.7	1.9	2.1	2.1	2.1	2.1	2.1	2.4	3.2	3.9	4.4	4.7	4.7	4.4	4.1	3.4	2.6
52	1.58E 05					1.1	1.4	1.6	1.9	2.0	2.3	2.3	2.3	2.3	2.3	2.6	3.5	4.1	4.7	5.0	5.0	4.7	4.4	3.6	2.8
53	2.00E 05				1.0	1.2	1.5	1.7	2.0	2.1	2.5	2.5	2.5	2.5	2.5	2.8	[illegible]	4.4	5.0	5.3	5.3	5.0	4.7	3.9	3.0
54	2.51E 05				1.1	1.3	1.6	1.9	2.1	2.3	2.6	2.6	2.6	2.6	2.6	3.0	4.0	4.7	5.3	5.7	5.7	5.3	5.0	4.1	3.2
55	3.16E 05				1.2	1.4	1.7	2.0	2.3	2.4	2.8	2.8	2.8	2.8	2.8	3.2	4.3	5.0	5.7	6.1	6.1	5.7	5.3	4.4	3.5
56	3.98E 05			1.0	1.3	1.5	1.9	2.2	2.4	2.6	3.0	3.0	3.0	3.0	3.0	3.5	4.6	5.3	6.1	6.5	6.5	6.1	5.2	4.7	3.7
57	5.01E 05			1.1	1.4	1.7	2.0	2.4	2.6	2.8	3.2	3.2	3.2	3.2	3.2	3.7	5.0	5.7	6.5	7.0	7.0	6.5	6.1	5.0	4.0
58	6.31E 05			1.2	1.5	1.8	2.2	2.6	2.8	3.0	3.5	3.5	3.5	3.5	3.5	4.0	5.3	6.1	7.0	2.5	7.5	7.0	6.5	5.3	4.3
59	7.94E 05			1.3	1.7	2.0	2.4	2.8	3.0	3.2	3.7	3.7	3.7	3.7	3.7	4.3	5.7	6.5	7.5	8.0	8.0	7.5	7.0	5.7	4.6
60	1.00E 06		1.0	1.4	1.8	2.2	2.6	3.0	3.2	3.5	4.0	4.0	4.0	4.0	4.0	4.6	6.1	7.0	8.0	8.7	8.7	8.0	7.5	6.1	5.0
61	1.26E 06		1.1	1.5	2.0	2.4	2.8	3.2	3.5	3.7	4.3	4.3	4.3	4.3	4.3	5.0	6.5	7.5	8.7	9.3	9.3	8.7	8.0	6.5	5.3
62	1.58E 06		1.2	1.7	2.2	2.6	3.0	3.5	3.7	4.0	4.6	4.6	4.6	4.6	4.6	5.3	7.0	8.0	9.3	10.0	10.0	9.3	8.7	7.0	5.7
63	2.00E 06		1.3	1.8	2.4	2.8	3.2	3.7	4.0	4.3	4.9	4.9	4.9	4.9	4.9	5.2	2.5	8.2	10.0	11.0	11.0	10.0	9.3	7.5	6.1
64	2.51E 06	1.0	1.5	2.0	2.6	3.0	3.5	4.0	4.3	4.6	5.3	5.3	5.3	5.3	5.3	6.1	8.0	9.3	11.0	13.0	11.0	11.0	10.0	8.0	6.5
65	3.16E 06	1.1	1.6	2.2	2.8	3.2	3.7	4.3	4.6	5.0	5.7	5.7	5.7	5.7	5.7	6.5	8.7	10.0	11.0	12.0	12.0	11.0	11.0	8.7	7.0
66	3.98E 06	1.2	1.8	2.4	3.0	3.5	4.0	4.6	5.0	5.4	6.1	6.1	6.1	6.1	6.1	7.0	9.3	11.0	12.0	13.0	13.0	12.0	11.0	9.3	7.5
67	5.01E 06	1.4	2.0	2.6	3.3	3.7	4.3	5.0	5.4	5.9	6.5	6.5	6.5	6.5	6.5	7.5	10.0	11.0	13.0	14.0	14.0	13.0	12.0	10.0	8.0
68	6.31E 06	1.6	2.2	2.8	3.6	4.0	4.6	5.4	5.9	6.4	7.0	7.0	7.0	7.0	7.0	8.0	11.0	12.0	14.0	15.0	15.0	14.0	13.0	11.0	8.7
69	7.94E 06	1.8	2.3	3.0	3.9	4.3	5.0	5.9	6.4	6.9	7.5	7.5	7.5	7.5	7.5	8.7	11.0	13.0	15.0	16.0	16.0	15.0	14.0	11.0	9.3
70	1.00E 07	2.0	2.5	3.3	4.2	4.6	5.4	6.4	6.9	7.5	8.0	8.0	8.0	8.0	8.0	9.3	12.0	14.0	16.0	17.0	17.0	16.0	15.0	12.0	10.0
71	1.26E 07	2.2	2.8	3.6	4.6	5.0	5.9	6.9	7.5	8.0	8.6	8.6	8.6	8.6	8.6	10.0	13.0	15.0	17.0	19.0	19.0	17.0	16.0	13.0	11.0
72	1.58E 07	2.3	3.0	3.9	5.0	5.4	6.4	7.5	8.0	8.7	9.2	9.2	9.2	9.2	9.2	11.0	14.0	16.0	19.0	20.0	20.0	19.0	17.0	14.0	11.0
73	2.00E 07	2.5	3.3	4.2	5.4	5.9	6.9	8.0	8.7	9.3	9.8	9.8	9.8	9.8	[illegible]	11.0	15.0	17.0	[illegible]	21.0	21.0	20.0	19.0	15.0	12.0
74	2.51E 07	2.8	3.7	4.6	5.9	6.4	7.5	8.7	9.3	10.0	10.6	10.6	10.6	10.6	[illegible]	[illegible]	16.0	19.0	[illegible]	23.0	23.0	21.0	20.0	16.0	13.0
75	3.16E 07	3.0	4.1	5.0	6.4	6.9	8.0	9.3	10.0	11.0	11.3	11.3	11.3	11.3	[illegible]	[illegible]	[illegible]	20.0	[illegible]	24.0	24.0	23.0	21.0	17.0	14.0
76	3.98E 07	3.3	4.5	5.4	6.9	7.5	8.7	10.0	11.0	11.0	12.0	12.0	12.0	12.0	[illegible]	[illegible]	19.0	21.0	[illegible]	26.0	26.0	24.0	23.0	19.0	15.0
77	5.01E 07	3.7	5.0	5.9	7.5	8.3	9.3	11.0	11.0	[illegible]	13.0	13.0	13.0	13.0	[illegible]	[illegible]	20.0	23.0	[illegible]	28.0	28.0	26.0	24.0	20.0	16.0
78	6.31E 07	4.1	5.4	6.4	8.3	9.1	10.0	11.0	12.0	13.0	14.0	14.0	14.0	14.0	[illegible]	[illegible]	21.0	24.0	[illegible]	30.0	30.0	28.0	26.0	21.0	17.0
79	7.94E 07	4.5	5.9	6.9	9.1	10.0	11.0	12.0	13.0	14.0	15.0	15.0	15.0	15.0	[illegible]	[illegible]	23.0	26.0	[illegible]	32.0	32.0	30.0	28.0	23.0	19.0
80	1.00E 08	5.0	6.4	7.5	10.0	11.0	11.0	13.0	14.0	15.0	16.0	16.0	16.0	16.0	[illegible]	[illegible]	24.0	28.0	[illegible]	35.0	35.0	32.0	30.0	24.0	20.0
81	1.26E 08	5.5	6.9	8.3	11.0	11.0	12.0	14.0	15.0	16.0	18.0	18.0	18.0	18.0	[illegible]	[illegible]	26.0	30.0	[illegible]	37.0	37.0	[illegible]	32.0	26.0	21.0
82	1.58E 08	6.1	7.5	9.1	11.0	12.0	13.0	15.0	16.0	17.0	19.0	19.0	19.0	19.0	[illegible]	[illegible]	[illegible]	32.0	[illegible]	40.0	40.0	[illegible]	35.0	28.0	23.0
83	2.00E 08	6.8	8.3	10.0	12.0	13.0	14.0	16.0	17.0	[illegible]	20.0	20.0	20.0	20.0	[illegible]	[illegible]	30.0	35.0	[illegible]	42.0	42.0	[illegible]	37.0	30.0	24.0
84	2.51E 08	7.5	9.1	12.0	13.0	14.0	15.0	17.0	19.0	20.0	21.0	21.0	21.0	21.0	[illegible]	[illegible]	[illegible]	37.0	[illegible]	45.0	45.0	[illegible]	40.0	32.0	26.0
85	3.16E 08	8.3	10.0	13.0	14.0	15.0	16.0	19.0	20.0	21.0	23.0	23.0	23.0	23.0	[illegible]	[illegible]	[illegible]	40.0	[illegible]	47.0	47.0	45.0	42.0	35.0	[illegible]
86	3.98E 08	9.1	12.0	13.0	15.0	16.0	17.0	20.0	21.0	23.0	24.0	24.0	24.0	24.0	[illegible]	[illegible]	37.0	42.0	[illegible]	50.0	50.0	[illegible]	45.0	37.0	30.0
87	5.01E 08	10.0	13.0	14.0	16.0	17.0	19.0	21.0	23.0	24.0	26.0	26.0	26.0	26.0	[illegible]	[illegible]	40.0	45.0	[illegible]	55.0	55.0	[illegible]	47.0	40.0	[illegible]
88	6.31E 08	11.0	11.0	15.0	17.0	19.0	20.0	23.0	24.0	26.0	28.0	28.0	28.0	28.0	[illegible]	[illegible]	[illegible]	47.0	[illegible]	60.0	60.0	[illegible]	50.0	42.0	[illegible]

This formulation for noys represents an approximation to the contours of Fig. A-1 and is used as a practical convenience for computer calculation of perceived noisiness (R.A. Pinker, *Computation of Perceived Noise Level: Mathematical Formulation of the Noy Tables.* Note NT. 684 (Ministry of Aviation, Farnborough, Great Britain, 1968).

Table C-1 (Cont'd)

SPL-dB	LOG_{10}^{-1} (SPL/10) (EXPON. NUMERIC FORM. EXAMPLE: 7.94E 02 = 7.94 x 10^2.)	50HZ	63HZ	80HZ	100HZ	125HZ	160HZ	200HZ	250HZ	315HZ	400HZ	500HZ	630HZ	800HZ	1KHZ	1.2KHZ	1.6KHZ	2KHZ	2.5KHZ	3.1KHZ	4KHZ	5KHZ	6.3KHZ	8KHZ	10KHZ
		BAND CENTER FREQUENCY																							
89	7.94E 08	12	14	16	19	20	21	24	26	28	30	30	30	30	30	35	45	50	60	63	63	60	55	45	32
90	1.00E 09	14	15	17	20	21	23	26	28	30	32	32	32	32	32	37	47	55	63	67	67	63	60	47	40
91	1.26E 09	15	16	19	21	23	24	28	30	32	34	34	34	34	34	40	50	60	67	21	21	67	63	50	42
92	1.58E 09	16	17	20	23	24	26	30	32	35	37	37	37	37	37	42	55	63	71	75	75	71	67	55	45
93	2.00E 09	17	19	21	24	26	28	32	35	37	39	39	39	39	39	45	60	67	75	80	80	75	71	60	47
94	2.51E 09	19	20	23	26	28	30	35	37	40	42	42	42	42	42	47	63	71	80	86	86	80	75	63	50
95	3.16E 09	20	21	24	28	30	32	37	40	42	45	45	45	45	45	50	67	75	86	93	93	86	80	67	55
96	3.98E 09	21	23	26	30	32	35	40	42	45	49	49	49	49	49	55	71	80	93	100	100	93	86	71	60
97	5.01E 09	23	24	28	32	35	37	42	45	47	52	52	52	52	52	60	75	86	100	108	108	100	93	75	63
98	6.31E 09	24	26	30	35	37	40	45	47	50	56	56	56	56	56	64	80	93	108	116	116	108	100	80	67
99	7.94E 09	26	28	32	37	40	42	47	50	55	60	60	60	60	60	69	86	100	116	125	125	116	108	86	71
100	1.00E 10	28	30	35	40	42	45	50	55	60	64	64	64	64	64	74	93	108	125	133	133	125	116	93	75
101	1.26E 10	30	32	37	42	45	47	55	60	64	69	69	69	69	69	79	100	116	133	142	142	133	125	100	80
102	1.58E 10	32	35	40	45	47	50	60	64	69	74	74	74	74	74	84	108	125	142	150	150	142	133	108	86
103	2.00E 10	35	37	42	47	50	55	64	69	74	79	79	79	79	79	91	116	133	150	162	162	150	142	116	93
104	2.51E 10	37	40	45	50	55	60	69	74	79	84	84	84	84	84	97	125	142	162	123	173	162	150	125	100
105	3.16E 10	40	42	47	55	60	64	74	79	84	91	91	91	91	91	104	133	150	173	186	186	173	162	133	108
106	3.98E 10	42	45	50	60	64	69	79	84	91	97	97	97	97	97	111	142	162	186	200	200	186	173	142	116
107	5.01E 10	45	47	55	64	69	74	84	91	97	104	104	104	104	104	119	150	173	200	215	215	200	186	150	125
108	6.31E 10	47	50	60	69	74	79	91	97	104	111	111	111	111	111	128	162	186	215	232	232	215	200	162	133
109	7.94E 10	50	55	64	74	79	84	97	104	111	119	119	119	119	119	137	173	200	232	250	250	232	215	173	142
110	1.00E 11	55	60	69	79	84	91	104	111	119	128	128	128	128	128	147	186	215	250	266	266	250	232	186	150
111	1.26E 11	60	64	74	84	91	97	111	119	128	137	137	137	137	137	158	200	232	266	284	284	266	250	200	162
112	1.58E 11	64	69	79	91	97	104	119	128	137	147	147	147	147	147	169	215	250	284	300	300	284	266	215	123
113	2.00E 11	69	74	84	97	104	111	128	137	147	158	158	158	158	158	181	232	266	300	324	324	300	284	232	186
114	2.51E 11	74	79	91	104	111	119	137	147	158	169	169	169	169	169	194	250	284	324	346	346	324	300	250	200
115	3.16E 11	79	84	97	111	119	128	147	158	169	181	181	181	181	181	208	266	300	346	372	372	346	324	266	215
116	3.98E 11	84	[illegible]	104	119	128	137	158	169	181	194	194	194	194	194	223	284	324	372	400	400	372	346	284	232
117	5.01E 11	91	97	111	128	137	147	169	181	194	208	208	208	208	208	239	300	346	400	430	430	400	372	300	250
118	6.31E 11	97	104	119	137	147	158	181	194	208	223	223	223	223	223	256	324	372	430	464	464	430	400	324	266
119	7.94E 11	104	111	128	147	158	169	194	208	223	239	239	239	239	239	274	346	400	464	500	500	464	430	346	284
120	1.00E 12	111	119	137	158	169	181	208	223	239	256	256	256	256	256	294	372	430	500	532	532	500	464	322	300
121	1.26E 12	119	128	147	169	181	194	223	239	256	274	274	274	274	274	315	400	464	532	568	568	532	500	400	324
122	1.58E 12	128	137	158	181	194	208	239	256	274	294	294	294	294	294	338	430	500	568	600	600	568	532	430	346
123	2.00E 12	137	147	169	194	208	223	256	274	294	315	315	315	315	315	362	464	532	600	648	648	600	568	464	372
124	2.51E 12	147	158	181	208	223	239	274	294	315	338	338	338	338	338	388	500	568	648	692	692	648	600	500	400
125	3.16E 12	158	169	194	223	239	256	294	315	338	362	362	362	362	362	416	532	600	692	744	744	692	648	532	430
126	3.98E 12	169	181	208	239	256	274	315	338	362	388	388	388	388	388	446	568	648	744	800	800	744	692	568	464
127	5.01E 12	181	194	223	256	274	294	338	362	388	416	416	416	416	416	478	600	692	800	860	860	800	744	600	500
128	6.31E 12	194	208	239	274	294	315	362	388	416	446	446	446	446	446	512	648	744	860	928	928	860	800	648	532
129	7.94E 12	208	223	256	294	315	338	388	416	446	478	478	478	478	478	549	692	800	928	1000	1000	928	860	692	568
130	1.00E 13	223	239	274	315	338	362	416	446	478	512	512	512	512	512	588	744	860	1000	1064	1064	1000	928	744	600
131	1.26E 13	239	256	294	338	362	388	446	478	512	549	549	549	549	549	630	800	928	1064	1136	1136	1064	1000	800	648
132	1.58E 13	256	274	315	362	388	416	478	512	549	588	588	588	588	588	676	860	1000	1136	1200	1200	1136	1064	860	692
133	2.00E 13	274	294	338	388	416	446	512	549	588	630	630	630	630	630	724	928	1064	1200	1296	1296	1200	1136	928	744
134	2.51E 13	294	315	362	416	446	478	549	588	630	676	676	676	676	676	776	1000	1136	1296	1384	1384	1296	1200	1000	800
135	3.16E 13	315	338	388	446	478	512	588	630	676	724	724	724	724	724	832	1064	1200	1384	1488	1488	1348	1296	1064	860
136	3.98E 13	338	362	416	478	512	549	630	676	724	776	776	776	776	776	891	1136	1296	1488	1600	1600	1488	1384	1136	928
137	5.01E 13	362	388	446	512	549	588	676	724	776	832	832	832	832	832	955	1200	1384	1600	1720	1720	1600	1488	1200	1000
138	6.31E 13	388	416	478	549	588	630	724	776	832	891	891	891	891	891	1024	1296	1488	1720	1856	1856	1720	1630	1296	1064
139	7.94E 13	416	446	512	588	630	676	776	832	891	955	955	955	955	955	1098	1384	1600	1856	2000	2000	1856	1720	1384	1136
140	1.00E 14	446	478	549	630	676	724	832	891	955	1024	1024	1024	1024	1024	1176	1488	1720	2000			2000	1856	1488	1200
141	1.26E 14	478	512	588	676	724	776	891	955	1024	1098	1098	1098	1098	1098	1261	1600	1856					2000	1600	1296
142	1.58E 14	512	549	630	724	776	832	955	1024	1098	1176	1176	1176	1176	1176	1351	1720	2000						1720	1384
143	2.00E 14	549	588	676	776	832	891	1024	1098	1176	1261	1261	1261	1261	1261	1448	1856							1856	1488
144	2.51E 14	588	630	724	832	891	955	1098	1176	1261	1351	1351	1351	1351	1351	1552	2000							2000	1600
145	3.16E 14	630	676	776	891	955	1024	1176	1261	1351	1448	1448	1448	1448	1448	1663									1720
146	3.98E 14	676	724	832	955	1024	1098	1261	1351	1448	1552	1552	1552	1552	1552	1783									1956
147	5.01E 14	724	776	891	1024	1098	1176	1351	1448	1552	1663	1663	1663	1663	1663	1911									2000
148	6.31E 14	776	832	955	1098	1176	1261	1448	1552	1663	1783	1783	1783	1783	1783	2019									

Table C-2
Perceived Noise Level in Steps of 1 PNdB as Function of Total Perceived Noisiness of a Sound

PN			PNL in PNdB	PN			PNL in PNdB
Lower	Mid	Upper		Lower	Mid	Upper	
1.0	1.0	1.0	40	43.8	45.2	46.8	95
1.1	1.1	1.1	41	46.9	48.5	50.2	96
1.1	1.1	1.2	42	50.3	52.0	53.8	97
1.2	1.2	1.3	43	53.9	55.7	57.7	98
1.3	1.3	1.4	44	57.8	59.7	61.8	99
1.4	1.4	1.5	45	61.9	64.0	66.3	100
1.5	1.5	1.6	46	66.4	68.6	71.0	101
1.6	1.6	1.7	47	71.1	73.5	76.1	102
1.7	1.7	1.8	48	76.2	78.8	81.6	103
1.9	1.9	1.9	49	81.7	84.4	87.4	104
2.0	2.0	2.1	50	87.5	90.5	93.7	105
2.1	2.1	2.2	51	93.8	97.0	100.4	106
2.3	2.3	2.4	52	100.5	104.0	107.6	107
2.5	2.5	2.5	53	107.7	111.4	115.3	108
2.6	2.6	2.7	54	115.4	119.4	123.6	109
2.8	2.8	2.9	55	123.7	128.0	132.5	110
3.0	3.0	3.1	56	132.6	137.2	142.0	111
3.2	3.2	3.4	57	142.1	147.0	152.2	112
3.5	3.5	3.6	58	152.3	157.6	163.1	113
3.7	3.7	3.9	59	163.2	168.9	174.8	114
4.0	4.0	4.1	60	174.9	181.0	187.4	115
4.2	4.3	4.4	61	187.5	194.0	200.8	116
4.5	4.6	4.7	62	200.9	207.9	215.3	117
4.8	4.9	5.1	63	215.4	222.8	230.7	118
5.2	5.3	5.5	64	230.8	238.8	247.3	119
5.6	5.6	5.8	65	247.4	256.0	265.0	120
5.9	6.1	6.3	66	265.4	274.4	284.0	121
6.4	6.5	6.7	67	284.1	294.0	304.4	122
6.8	7.0	7.2	68	304.5	315.2	326.3	123
7.3	7.5	7.7	69	326.4	337.8	349.7	124
7.8	8.0	8.3	70	349.8	362.0	374.8	125
8.4	8.6	8.9	71	374.9	388.0	401.7	126
9.0	9.2	9.5	72	401.8	415.8	430.5	127
9.6	9.8	10.2	73	430.6	445.7	461.4	128
10.3	10.6	10.9	74	461.5	477.7	494.5	129
11.0	11.3	11.7	75	494.6	512.0	530.0	130
11.8	12.1	12.5	76	530.1	548.7	568.1	131
12.6	13.0	13.5	77	568.2	588.1	608.9	132
13.6	13.9	14.4	78	609.0	630.3	652.6	133
14.5	14.9	15.4	79	652.7	675.5	699.4	134
15.5	16.0	16.6	80	699.5	724.1	749.6	135
16.7	17.1	17.7	81	749.7	776.0	803.3	136
17.8	18.4	19.0	82	803.4	831.7	861.1	137
19.1	19.7	20.4	83	861.2	891.4	922.9	138
20.5	21.1	21.8	84	923.0	955.4	989.1	139
21.9	22.6	23.4	85	989.2	1024.0	1060.1	140
23.5	24.2	25.1	86	1060.2	1097.5	1136.1	141
25.2	26.0	26.9	87	1136.2	1176.2	1217.7	142
27.0	27.8	28.8	88	1217.8	1260.6	1305.1	143
28.9	29.8	30.9	89	1305.2	1351.1	1398.8	144
31.0	32.0	33.1	90	1393.9	1448.2	1499.1	145
33.2	34.3	35.5	91	1499.2	1552.1	1606.7	146
35.6	36.8	38.1	92	1606.8	1663.4	1722.1	147
38.2	39.4	40.8	93	1722.2	1782.8	1845.7	148
40.9	42.2	43.7	94	1845.8	1910.7	1978.2	149

and indeterminate knowledge about background noise conditions makes use of the threshold of perceived noisiness impractical.

Step 2. Subtract 12 from the number found in Step 1.

Note: The sum −12 comes from the use of 8 seconds as a reference duration, the nominal duration of the reference standard as defined; specifically,

$$12 = 10 \log_{10} 8/.5 \qquad \text{[Eq C-3]}$$

where 8 seconds = reference duration

0.5 = the 0.5-sec interval at which sound pressure levels are measured

$10 \log_{10}$ = converts the value to equivalent decibels

Step 3. Find the onset duration of the sound in seconds above the PNL of the background noise.

Note 1: The practical threshold of noisiness shall be used in place of the PNL of the background noise when the latter is not known or has not been measured.

Step 4. From Figure C-2, read the correction, oc, corresponding to this duration. Add the correction to the number found in Step 2.

Step 5. Find the difference in PNL between the level reached during impulsive interval of sound and the level of the background noise.

Step 6. Find from Figure 23 of text the impulse level correction, ic, for the difference found in Step 5. Add ic to the result of Step 4 above. The result is called EPNL in EPNdB or EPNdB′.

Procedure for Calculating Composite Noise Rating (CNR) from EPNL Values.

[Eq C-4]

$$\begin{aligned} CNR = {} & \overbrace{[EPNL_1 + 10 \log_{10} O_1] + [EPNL_2 + 10 \log_{10} O_2] + \ldots + [EPNL_n + 10 \log_{10} O_n]}^{7\text{ a.m.} - 10\text{ p.m.}} - 12 \\ & + \overbrace{[EPNL_{1p} + 10 \log_{10} O_{1p}] + [EPNL_{2p} + 10 \log_{10} O_{2p}] + \ldots + [EPNL_{np} + 10 \log_{10} O_{np}]}^{10\text{ p.m.} - 7\text{ a.m.}} - 2 \end{aligned}$$

where $O_1 \ldots O_n$ = numbers of occurrences of sounds of EPNL's 1 through n during the hours of 7 a.m. to 10 p.m.

$O_{1p} \ldots O_{np}$ = occurrences of sounds of EPNL's 1 through np during the hours of 10 p.m. to 7 a.m.

Step 1. Add arithmetically to the EPNL of each given value 10 $\log_{10}$ of the number of occurrences of sounds for each given EPNL value.

Step 2. Sum on a 10 $\log_{10}$ antilog basis the results of Step 1 for the time period from 7 a.m. to 10 p.m. and subtract 12 from the sum.

Step 3. Sum on a $\log_{10}$ antilog basis the results of Step 1 for the time period from 10 p.m. to 7 a.m. and subtract 2 from the sum.

Step 4. Sum on a 10 $\log_{10}$ antilog basis the results of Steps 2 and 3. The results is called the Composite Noise Rating in EPNdB or EPNdB′.

APPENDIX D: EPNdB AS A FUNCTION OF PEAL LEVEL (INCLUDING SAMPLE CALCULATIONS)

The following is a sample calculation of the PNdB and EPNdB values for a 115 dB peak level blast in the 10 to 100 pound range.

Calculations of the PNL. First, Step 1 of Appendix C requires the octave band levels which have been calculated in this work and which are listed in Table B-5. For Step 2, the 31.5, 63, and 125 Hz octave-band levels (from Table B-5, 99, 90, and 85 dB respectively) are added on a 10 $\log_{10}$ antilog basis:

$$SUM_{dB} = 10 \log_{10} \sum_i 10^{\frac{\text{level } i}{10}}$$

$$= 10 \log_{10}(10^{99/10} + 10^{90/10} + 10^{85/10})$$

$$= 99.5 \text{ dB} \qquad \text{[Eq D-1]}$$

Step 3 is omitted since for impulse there are no "pure tones."

For Step 4, the noy values are found from Table C-1. Since the largest SPL occurs in the 31.5 Hz band, the 50 Hz band value is used to find the noy value for the sum of the 31.5, 63, and 125 Hz octave bands. Table D-1 lists the remainder of the noy values. Linear interpolation between the 99 and 100 dB rows under the "50 Hz" column yields a noy value of 27.

In Step 5 the total noy value is found. The largest noy value is 27, so:

$$\text{Total noy value} = 27 + 0.3\,(16 + 14 + 9.8 + 11 + 7 + 1.8)$$

$$= 44.8 \qquad \text{[Eq D-2]}$$

Finally, in Step 6, a PN value of 44.8 is converted to 95 PNdB by using Table C-2.

Calculation of the EPNL. Since for artillery and blast noises at medium distances (over about 6,000 to 10,000 feet) the duration of the signature is about 0.5 seconds, it follows that the calculation (with respect to blast noise) for EPNL, Equation C-2 becomes:

$$EPNL = PNL - 12 + ic \qquad \text{[Eq D-3]}$$

(The onset correction [oc] is zero for impulses.) In this example, with the background level at 60 PNdB for daytime the ic is approximately 12 EPNdB units, and the total EPNL is 95 EPNdB. For nightime, the background level is 50 PNdB. The ic is approximately 16 EPNdB units, and the total EPNL is 99 EPNdB. Table D-2 summarizes these results.

Table D-3 lists the PN and corresponding PNdB values for the different peak levels. Since a calculated difference in PNL level between small and large blasts occurs only for 115 dB peak level signals, and since the actual difference is small, the PNdB values for the 10 to 100 pound range will be used for the entire 1 to 100 pound range. Table D-4 lists peak level, PNL, daytime impulse corrections, and daytime EPNL values. The 103 dB peak level EPNL value has been rounded up to 115 dB because the 109 PNL value for 10 to 100 pound charges was close to 100 PNdB, while the EPNL value corresponding to the 115 dB peak level signal has been rounded downward since the PNL value for the 1 to 10 pound charges was 94 PNdB as noted above.

Thus, Equation D-1 summarizes the daytime EPNL values corresponding to various peak levels.

$$
\begin{aligned}
EPNL &= 121 + 10\,(\Delta pdB - 135) \text{ for } 145dB > pdB > 135dB \\
&= 109 + 12\,(\Delta pdB - 125) \text{ for } 135dB > \Delta pdB > 125\,dB \\
&= 95 + 14\,(\Delta pdB - 115) \text{ for } 125dB > \Delta pdB > 115\,dB \\
&= 79 + 16\,(\Delta pdB - 105) \text{ for } 115dB > \Delta pdB > 105\,dB
\end{aligned}
\qquad \text{[Eq D-4]}
$$

EPNL units corresponding to the 100 to 105 dB peak level range can be estimated by:

$$EPNL = 79 - 8(105 - \Delta pdB) \text{ for } 105 \geqslant \Delta pdB \geqslant 100 \quad \text{[Eq D-5]}$$

Table E-3 lists peak levels and corresponding EPNL values.

Nighttime EPNL values are given by the daytime value plus 3.6 dB since the background level is 10 PNdB units lower, making the impulse corrections larger. With the addition of the 3.6 dB constant, Equations D-4 and D-5 yield nighttime EPNL values.

It must again be noted that the above EPNL values are for 0.5 sec durations and for signals having the Q (damping ratio) indicated in Figure 17. Signals exhibiting smaller Q's (more damping) and shorter durations will result in smaller EPNL values.

Table D-1

Noy Values for 115 dB Peak Level Blast

Band	SPL	NOY Value
3-band sum	99.5	27
250 Hz	82	12
500 Hz	78	14
1000 Hz	73	9.8
2000 Hz	66	11
4000 Hz	53	7
8000 Hz	43	1.8

Table D-2

EPNL for 115 dB Peak Level Blast

	Daytime	Nighttime
PNL	95	95
Background PNL	60	50
ic	≃12	≃16
−12	−12	−12
EPNL	95	99

Table D-3

Noy Values for Various Peak Levels

	1–10 pounds		10-100 pounds	
Peak Overpressure	PN	PNdB	PN	PNdB
135	169.7	114	173.6	114
130	120.1	109	122.4	109
125	87.9	105	87.6	105
120	63.6	100	63.6	100
115	43.0	94	44.9	95
110	29.1	89	30.8	89
105	20.1	83	20.2	83

Table D-4

EPNL Values and Impulse Corrections for Different Peak Levels

Peak Level (dB)	PNdB	ic	Day EPNdB
135	114	19.3	121
130	109	17.5	115
125	105	16.0	109
120	100	14.3	102
115	95	12.5	95
110	89	10.35	87
105	83	8.2	79

APPENDIX E:
CNR CALCULATIONS—SAMPLES

This appendix contains sample calculations of the CNR values for the case histories in Chapter 4. The calculation of the CNR value at a given location requires the use of three forms included here as Figures E-1, E-2, E-3, and denoted as Form A, Form B, and Form C, respectively. Also included, for reference purposes, are useful graphs and charts from throughout the report. Figures E-17 and E-18 are flow charts reviewing these calculations.

Basically, Form A is a listing or inventory of the sources causing blast noise at the location for which the CNR value is to be calculated. In general, the sources may be any type, at any distance, and any direction. (Naturally, the component effect of any source singly can be "calculated" in this manner, but this is rather meaningless since it is the sum of the sources which evokes the human response.) Each source is listed by number and description on Form A. For an artillery piece, the firing and the shell burst (and the supersonic flight of 155 and 175 mm gun projectiles) are considered separate sources. The equivalent weight in pounds of TNT, and the corresponding "dB" change are listed in Column 5. Table E-1 lists some common weapons and their corresponding charge and blast weights. (Composition B is slightly more powerful than TNT for the same weight, but this difference can be ignored for noise purposes.)

Equation E-1 yields the weight correction factor

$$dB = 20 \log_{10} (W)^{0.4} \qquad \text{[Eq E-1]}$$

where W = the equivalent weight in pounds.

Table E-2 lists some of these corrections.

The direction of the receiving location with respect to the line of fire is listed in column 6 of Form A along with the "dB" correction factor calculated from Equations 2 and 3 herein repeated as Equations E-2 and E-3. (There is no correction [0 db] for blasts or shell bursts, since these radiate omnidirectionally.) For $0^\circ \leq \theta \leq$ and $0^\circ \leq \theta \leq 90^\circ$

$$\Delta dB = (1 \quad \cos^2 \theta)(2.5)$$

and for $90^0 \leq \theta \leq 180^0$ and $-90^0 \leq \theta \leq 180^0$

$$\Delta dB = 4.0 + (1 - \cos^2 \theta)(1.5) \qquad \text{[Eq E-2]}$$

The height above or below ground at which a blast occurs (other than an artillery firing) is listed in column 7. As discussed in Chapter 2, a +3dB factor is added for blasts occurring a relatively short distance above the ground.

For buried charges, Figure 1 of text (repeated here as Figure E-4) yields the transmissivity factor, Td, as a function of scaled burst depth. The ΔdB factor is given by:

$$\Delta dB = 20 \log_{10} T_d \qquad \text{[Eq E-4]}$$

The number of occurrences per day (N_D) and per night (N_N) of each source are listed in columns 8 and 9 respectively. The ΔdB correction factors are calculated by:

$$\Delta dB = 10 \log_{10} N \qquad \text{[Eq E-5]}$$

(Daytime is defined as 0700-2200 and nighttime is defined as 2200-0700). When the number of occurrences per night (or day) is zero, no ΔdB correction factor is entered.

Column 4 is the algebraic sum of the ΔdB correction factors in columns 5, 6, and 7.

Partial annoyance factors for each source are calculated and listed on Form B, with daytime and nighttime occurrences listed and summed separately. For each source, the three overpressure values corresponding to the "average focus" curve, the base curve, and the negative gradient curve are entered as read from Figure

1	2	3	4		5	6	7	8	9
SOURCE NUMBER	SOURCE DESCRIPTION	DISTANCE (feet)	OVERPRESSURE CORRECTION dB (sum 5, 6, 7)		EQUIVALENT WEIGHT TNT (pounds)	DIRECTION (degrees)	HEIGHT ABOVE OR BELOW GROUND (feet)	NUMBER PER DAY 0700-2200	NUMBER PER NIGHT 2200-0700
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					

PAGE ____

NOTES:

LOCATION: ____________________

____

Figure E-1. Form A.

1		2	3	4	5	6		7	8	9
SOURCE NUMBER		OVERPRESSURE dB GRAPH E	dB CORRECTION FORM A-4	SUM 2 + 3	EPNL TABLE E3	REPETITION FACTOR N_{dB} - K	K	OTHER FACTORS dB	SUM 5+6+7	$10 \frac{SUM_8}{10}$
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
								SUM		

PAGE ____ DAY/NIGHT LOCATION ____________________

NOTES: ____________________

Figure E-2. Form B.

1	2	3	4	5	6	7	8
LOCATION	TOTAL DAYTIME SUMS FROM FORM B's	DAYTIME SUM dB S_D	DAYTIME CNR SUBTOTAL $S_D - 12$	TOTAL NIGHTTIME SUMS FROM FORM B's	NIGHTTIME SUM dB S_N	NIGHTTIME CNR SUBTOTAL $S_N - 2$	TOTAL CNR 4 + 7 added on a 10 $\log_{10}$ basis

PAGE ____

NOTES:

Figure E-3. Form C.

Table E-1

Propelling and Explosive Charges

Weapon	Designation	Zone	Charge Weight	Designation	Explosive	Weight
105MM How	M67	1	8.55 oz	M1	TNT	4.25 lb
		2	9.98 oz		Comp B	4.60 lb
		3	12.51 oz			
		4	16.31 oz			
		5	22.08 oz			
		6	30.85 oz			
		7	45.24 oz			
155MM How	M3A1	1	28.3 oz	M107	Comp B	15.4 lb
		2	36.6 oz		TNT	14.6 lb
		3	49.4 oz			
		4	64.4 oz			
		5	87.5 oz			
	M4A2	3	62.3 oz			
		4	81.9 oz			
		5	109.7 oz			
		6	154.6 oz			
		7	210.4 oz			
	M119	8	326.4 oz			
175MM Gun	M124	1	16.94 lb	M437	Comp B	31.3 lb
	M86A2	1	23.56 lb			
		2	39.70 lb			
		3	57.24 lb			
8 In. How	M1	1	85.3 oz	M106	TNT	36.3 lb
		2	100.5 oz			
		3	120.3 oz			
		4	152.6 oz			
		5	210.5 oz			
	M2	5	10 lb-13.9 oz			
		6	22 lb - 0.2 oz			
		7	28 lb - 2.2 oz			

NOTES:
1. Propellant charge weights by zone are cumulative.
2. All HE weights for 105, 155, and 8 inch are for deep cavity intrusion. The 175MM HE weight is for shallow cavity.
3. Where two explosives are shown, both have been or are being used.

E-5 or calculated from Equations E-6, E-7, or E-8. The base curve is given by:

$$P_0 dB = 153 - 22.3 \log_{10}(D/200) \qquad [Eq\ E\text{-}6]$$

where D = the distance in feet as recorded in column 3 of Form A.

The "average" focus curve is given by:*

$$P_f dB = P_0 dB + 5 \quad \text{for } 200' \leq D \leq 90{,}000'$$
$$= 99 \quad \text{for } 90{,}000' \leq D \leq 150{,}000'$$
$$= P_0 dB + 10 \quad \text{for } D \leq 150{,}000' \qquad [Eq\ E\text{-}7]$$

The negative gradient curve is given by:

$$P_n dB = 153 - 28 \log_{10}(D/200) \qquad [Eq\ E\text{-}8]$$

Table E-2
dB Correction for Equivalent Weights of TNT

Weight Pounds	dB Correction	Weight Pounds	dB Correction
1	0	32	12.0
2	2.4	34	12.2
3	3.8	36	12.4
4	4.8	38	12.6
5	5.6	40	12.8
6	6.2	42	13.0
7	6.8	44	13.1
8	7.2	46	13.3
9	7.6	48	13.4
10	8.0	50	13.6
12	8.6	52	13.7
14	9.2	54	13.9
16	9.6	56	14.0
18	10.0	58	14.1
20	10.4	60	14.2
22	10.7	65	14.5
24	11.0	70	14.8
26	11.3	75	15.0
28	11.6	80	15.2
30	11.8	90	15.6

For each source, the ΔdB correction factor in column 4 of Form A is entered in column 3 of Form B and the algebraic sum of columns 2 and 3 in column 4 of Form B.

* For computer computation, replace 99 with 98.8333609 and 10 with 9.9472271.

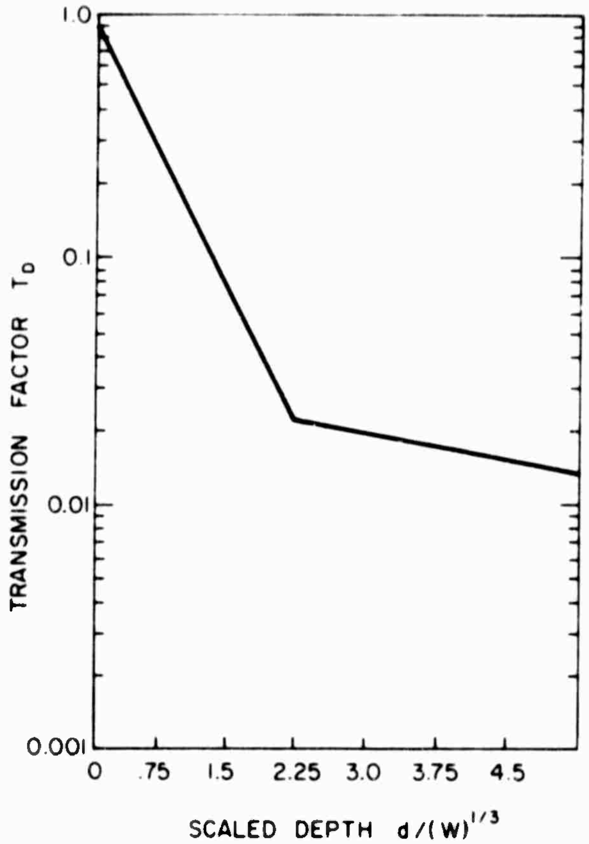

Figure E-4. Transmissivity from underground bursts.

The EPNL value corresponding to the corrected peak level in column 4 is entered in column 5. This EPNL value is calculated from Equations E-9 and E-10 or extrapolated from Table E-3. From Equation D-4, one has

$$EPNdB = 109 + 1.2(\Delta pdB - 125) + F_N \text{ for } 135 \leq \Delta pdB \leq 125$$
$$= 95 + 1.4(\Delta pdB - 115) + F_N \text{ for } 125 \leq \Delta pdB \leq 115$$
$$= 79 + 1.6(\Delta pdB - 105) + F_N \text{ for } 115 \leq \Delta pdB \leq 105$$
$$[Eq\ E\text{-}9]$$

where $F_N = 0$ for daytime
$F_N = +3.6$ for nighttime.

In the peak overpressure range of $105 \leq \Delta pdB \leq 100$, EPNL can be estimated by:

$$EPNdB = 79 - 0.8(105 - \Delta pdB) + F_N \qquad [Eq\ E\text{-}10]$$

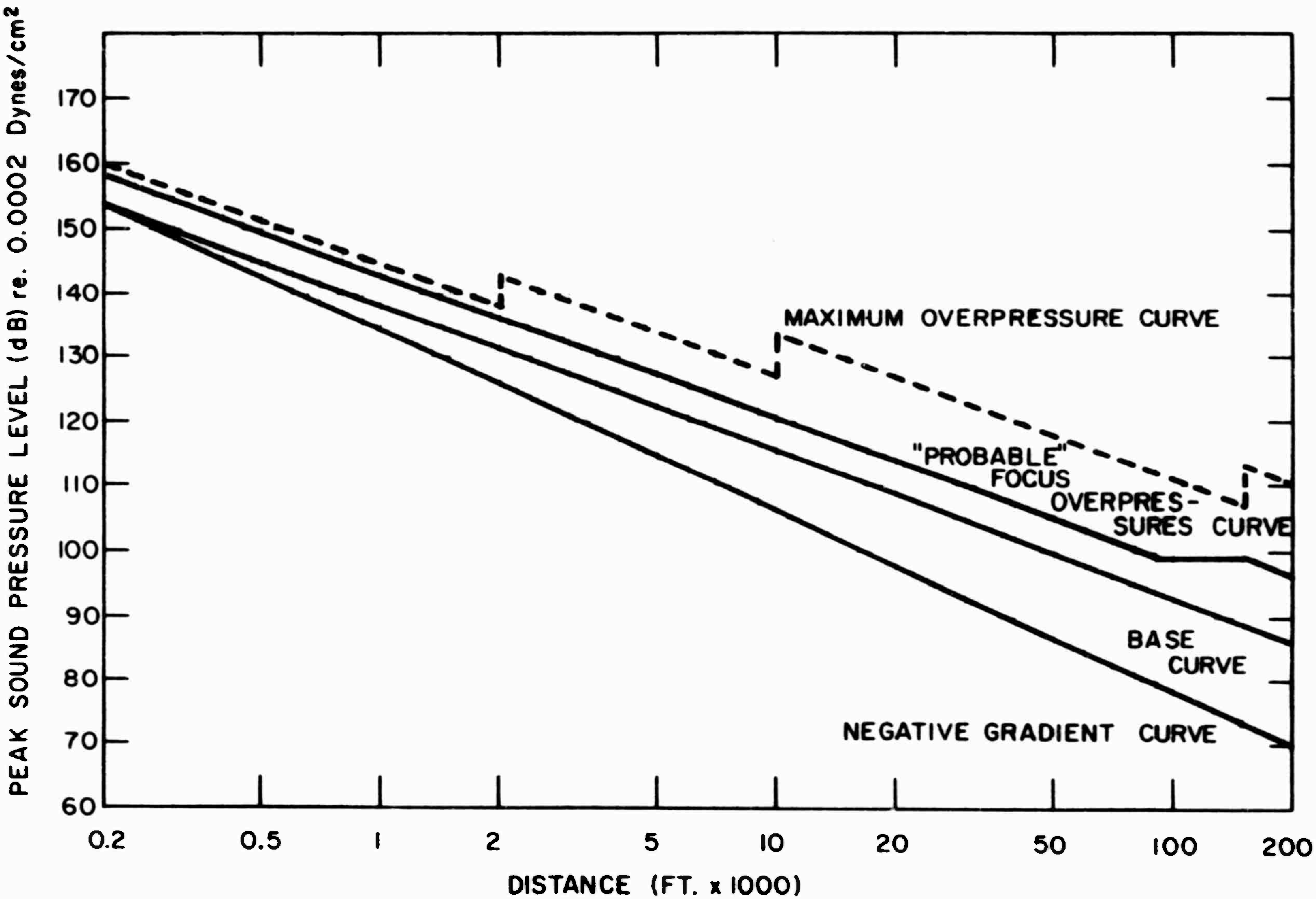

Figure E-5. Overpressure predictions for one pound of TNT.

Table E-3

EPNL Values for Different Peak Levels

Peak Level dB	Daytime EPNL	Nightime EPNL	Peak Level	Daytime EPNL	Nighttime EPNL
135	121.0	124.6	117	97.8	101.4
134	119.8	123.4	116	96.4	100.0
133	118.6	122.2	115	95.0	98.6
132	117.4	121.0	114	93.4	97.0
131	116.2	119.8	113	91.8	95.4
130	115.0	118.6	112	90.2	93.8
129	113.8	117.4	111	88.6	92.2
128	112.6	116.2	110	87.0	90.6
127	111.4	115.0	109	85.4	89.0
126	110.2	113.8	108	83.8	87.4
125	109.0	112.6	107	82.2	85.8
124	107.6	111.2	106	80.6	84.2
123	106.2	109.8	105	79.0	82.6
122	104.8	108.4	104	77.4*	81.0*
121	103.4	106.0	103	75.8*	79.4*
120	102.0	105.6	102	74.2*	77.8*
119	100.6	104.2	101	72.6*	76.2*
118	99.2	102.8	100	71.0*	74.6*

* Estimated

The repetition factor, column 6 of Form B, is calculated by subtracging 6 dB or 3 dB as indicated from the day or nighttime occurrence numbers, expressed in dB($10 \log_{10} n$). The daytime and nighttime occurrence numbers are taken from columns 8 and 9, respectively, from Form A. Subtraction of 6 dB causes the repetition factor to correspond to 25 percent of the occurrences; subtraction of 3 dB causes it to correspond to 50 percent of the occurrences.

Other corrections to the EPNL value are entered in column 7. These might include a correction for a duration known to be much shorter than 500 ms. Figure E-5 shows a correction which can be added for blasts at short distances (short durations).

Column 8 of Form B contains the algebraic sum of the factors in columns 5, 6, and 7, and column 9 contains a linear factor corresponding to the "dB" sum in column 8. This linear factor, S_p, is given by:

$$S_p = 10^{(\text{sum } 8)/10} \qquad \text{[Eq E-11]}$$

where sum 8 = "dB" sum.

The daytime and nighttime linear factors are added separately and the total respective sums entered into columns 2 and 5 of Form C (Figure E-3). In general, these sums will be the result of a number of Form B pages.

The SdB equivalents of the day and nighttime totals (S) are calculated from:

$$SdB = 10 \log_{10} S \qquad \text{[Eq E-12]}$$

and entered into columns 3 and 6 respectively. The daytime CNR subtotal is given by the daytime decibel sum (S_DdB) minus 12 (column 4) and the nighttime CNR subtotal is given by the nighttime decibel sum (S dB) minus 2 (column 7). The resulting two CNR subtotals, added on a $10 \log_{10}$ basis yield the total CNR:

$$CNR = 10 \log_{10} \left(10^{\frac{S_D dB - 12}{10}} + 10^{\frac{S_N dB - 2}{10}} \right) \qquad \text{[Eq E-13]}$$

The following two examples relate to the Gibson Island area near Aberdeen Proving Ground and the Accokeek area near Fort Belvoir. In all of the following examples, every effort is made to be as factual as possible, but in some cases, because of insufficient data, minor points were assumed.

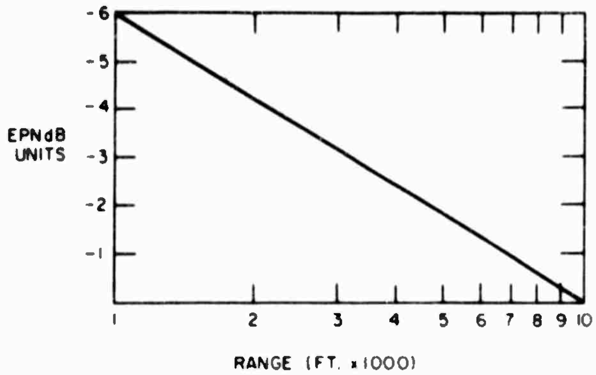

Figure E-6. EPNdB units to be subtracted for short-range (short-duration) EPNL calculations.

Figure E-7 lists the sources affecting Gibson Island. These include firing at a distance of 160,000 feet and shell bursts at a distance of 80,000 feet. For this example, the sonic boom noise resulting from supersonic descent of the shell is treated as equivalent to the projectile blast, and so in effect, about 100 rounds were fired per day; 50 of these were live and 50 were inert. From Table E-1 the propelling charge (Charge 3) weighs 57 pounds (14 dB correction) and the shell contains 31 pounds of explosives (11.9 dB correction). The peak levels are found from Figure E-5 and the corrections from Form A are added to these peak levels. These sums are entered in column 3 of Form B (Figure E-8) and the EPNL values are determined from extrapolation of Table E-3. Each of the column 8 "dB" sums are converted to linear factors by Equation E-11. For example:

$$\begin{aligned} 26.3 \times 10^9 &= 10^{\frac{104.2}{10}} \\ &= 10^{10.42} \\ &= 10^{1.42} \times 10^9 \end{aligned} \qquad \text{[Eq E-14]}$$

The total daytime linear sum, 71.0×10^9, is covered to its "dB" equivalent by Equation E-12, where:

$$108.5 = 10 \log_{10}(71.0 \times 10^9) \qquad \text{[Eq E-15]}$$

Since there were no nighttime firings, the total CNR is given by the daytime value.

Figure E-9 also contains the final Accokeek CNR calculation. Figures E-10 and E-11 are the Accokeek area Forms A and B respectively. Here, source 3 is a 500 lb cratering charge buried five feet underground.

From Figure E-4, the transmissivity factor, Td, for a 500-pound charge buried five-feet deep is about 0.4, and the corresponding correction is −8 dB [(depth/$500^{1/3}$) = 0.6]. Again, in this example, there were no known night blasts.

The third example comes from Wildflecken, Germany. In this case, only the firings were reported, and so it is assumed that the shell bursts were either inert or much "quieter" than the firings.

The calculations for receiving position one are the only calculations included here in detail (see Figures E-12, E-13, and E-14), but for each case the receiving positions were at angles of 125° with respect to the line of fire; two of the positions were to the left and one was to the right of the line of fire. The correction calculated from Equation E-3 is −3 dB. Also, because of the relatively short distance (short duration), −3 dB is included in "other factors" (column 7 Form B; see Figures E-13 and E-14).

It is interesting to note that although there are a total of 100 rounds per day and only 10 per night, the nighttime rounds contribute considerably more to the overall annoyance than do the daytime rounds.

Finally, "CNR" is calculated from the actual Wildflecken measurements. The 100 rounds per day and 10 per night result in an average peak level of 119 dB at position one and 116 dB at positions two and three. Table E-4 illustrates the calculation of CNR from a known set of measurements.

In this case (position 1), with the average peak level of 119 dB, the corresponding EPNL is 100.6 and 104.2, respectively, for daytime and nighttime (Figure E-14). The repetition factors

1	2	3	4		5	6	7	8	9
SOURCE NUMBER	SOURCE DESCRIPTION	DISTANCE (feet)	OVERPRESSURE CORRECTION dB (sum 5, 6, 7)		EQUIVALENT WEIGHT TNT (pounds)	DIRECTION (degrees)	HEIGHT ABOVE OR BELOW GROUND (feet)	NUMBER PER DAY 0700-2200	NUMBER PER NIGHT 2200-0700
1	175 mm firings	160,000	14	UNITS	57	0°	0	100	0
				dB CORRECTION	14.0	0	0	20.	—
2	175 mm Projectile bursts	80,000	11.9	UNITS	31	0°	0	150	0
				dB CORRECTION	11.9	0	0	21.8	—
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					

PAGE 1

NOTES: SONIC BOOMS GENERATED BY THE PROJECTILE DECENT ARE INCLUDED AS EQUIVALENT TO THE 31 POUND PROJECTILE BURST

LOCATION: GIBSON ISLAND

ABERDEEN PROVING GROUND

Figure E-7. Form A for Gibson Island.

1		2	3	4	5	6		7	8	9
SOURCE NUMBER		OVERPRESSURE dB Figure E-5)	dB CORRECTION FORM A-4	SUM 2 + 3	EPNL TABLE E3	REPETITION FACTOR N_{dB} - K	K	OTHER FACTORS dB	SUM 5+6+7	$10^{\frac{SUM_8}{10}}$
1	FOCUS	98	14	112	90.2	14	6	0	104.2	26.3×10^9
	BASE	88		102	74.2			0	88.3	0.7×10^9
	NEG. GRAD.	72		86	too low	17	3	—	—	
2	FOCUS	100	11.9	111.9	90.0	15.8	6	0	105.8	38.0×10^9
	BASE	95		106.9	82.0			0	97.8	6.0×10^9
	NEG. GRAD.	80		91.9	too low	18.8	3	—	—	
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
								SUM	71.0×10^9	

PAGE ____ DAY/NIGHT LOCATION GIBSON ISLAND

NOTES: ABERDEEN PROVING GROUND

Figure E-8. Form B for Gibson Island.

1	2	3	4	5	6	7	8
LOCATION	TOTAL DAYTIME SUMS FROM FORM B's	DAYTIME SUM dB S_D	DAYTIME CNR SUBTOTAL $S_D - 12$	TOTAL NIGHTTIME SUMS FROM FORM B's	NIGHTTIME SUM dB S_N	NIGHTTIME CNR SUBTOTAL $S_N - 2$	TOTAL CNR 4 + 7 added on a 10 $\log_{10}$ basis
GIBSON ISLAND	7.0×10^{9}	108.5	96.5	0	--	-	97
ABERDEEN PROVING GROUND							
ACCOKEEK MD	2.07×10^{8}	103.2	91.2	0	-	-	91
FORT BELVOIR							

PAGE ____ NOTES:

Figure E-9. Form C for Gibson Island and Accokeek.

1	2	3	4		5	6	7	8	9
SOURCE NUMBER	SOURCE DESCRIPTION	DISTANCE (feet)	OVERPRESSURE CORRECTION dB (sum 5, 6, 7)		EQUIVALENT WEIGHT TNT (pounds)	DIRECTION (degrees)	HEIGHT ABOVE OR BELOW GROUND (feet)	NUMBER PER DAY 0700-2200	NUMBER PER NIGHT 2200-0700
1	1 lb TNT	39,600	0.0	UNITS	1	0	0	40	0
				dB CORRECTION	0	0	0	16	—
2	10 lb TNT	39,600	8.0	UNITS	10	0	0	12	0
				dB CORRECTION	8.0	0	0	10.8	—
3	500 lb TNT	39,600	13.6	UNITS	500	0	5	2	0
				dB CORRECTION	21.6	0	-8	3	—
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					

PAGE ____ NOTES:

LOCATION: ACCOKEEK MD

FORT BELVOIR

Figure E-10. Form A for Accokeek.

1		2	3	4	5	6		7	8	9
SOURCE NUMBER		OVERPRESSURE dB Figure E-5	dB CORRECTION FORM A-4	SUM 2 + 3	EPNL TABLE E3	REPETITION FACTOR N_{dB} - K	K	OTHER FACTORS dB	SUM 5+6+7	$10^{\frac{SUM_8}{10}}$
1	FOCUS	106.5	0.0	106.5	81.2	10	6	0	91.2	13.2 x 10^8
	BASE	101.5		101.5	~73			0	83	2.0 x 10^8
	NEG. GRAD.	92.0		92.0	[illegible]	13	3	0	-	-
2	FOCUS	106.5	8.0	114.5	94.2	45	6	0	99.0	79.4 x 10^8
	BASE	101.5		104.5	82.2			0	91.0	12.6 x 10^8
	NEG. GRAD.	92.0		100.0	~71	78	3	0	78.8	0.7 x 10^8
3	FOCUS	106.5	13.6	120.1	102.2	-3	6	0	99.2	83.2 x 10^8
	BASE	101.5		115.1	95.2			0	92.2	16.6 x 10^8
	NEG. GRAD.	92.0		105.6	79.8	0	3	0	79.8	1.0 x 10^8
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
								SUM	208.7 x 10^8	

PAGE ___ DAY/NIGHT LOCATION ACCOKEEK, MD

NOTES: FORT BELVOIR

Figure E-11. Form B for Accokeek.

1	2	3	4		5	6	7	8	9
SOURCE NUMBER	SOURCE DESCRIPTION	DISTANCE (feet)	OVERPRESSURE CORRECTION dB (sum 5, 6, 7)		EQUIVALENT WEIGHT TNT (pounds)	DIRECTION (degrees)	HEIGHT ABOVE OR BELOW GROUND (feet)	NUMBER PER DAY 0700-2200	NUMBER PER NIGHT 2200-0700
1	120mm Tank firing	3280	+0.8	UNITS	3*	125°	0	75	5
				dB CORRECTION	3.8	-3.0	-	11	7
2	106mm jeep recoilless firing	3280	+0.8	UNITS	3*	125°	0	25	5
				dB CORRECTION	3.8	-3.0	-	14	7
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					
				UNITS					
				dB CORRECTION					

PAGE ____

NOTES: * estimate

LOCATION: Wildflecken - Position 1

GERMANY

Figure E-12. Form A for Wildflecken.

1		2	3	4	5	6		7	8	9
SOURCE NUMBER		OVERPRESSURE dB Figure E-5	dB CORRECTION FORM A-4	SUM 2 + 3	EPNL TABLE E3	REPETITION FACTOR N_{dB} - K	K	OTHER FACTORS dB	SUM 5+6+7	$10^{\frac{SUM_8}{10}}$
1	FOCUS	130	0.8	130.8	119.6	1	6	-3*	117.6	57.5 × 10^10
	BASE	125		125.8	113.6			-3	111.6	14.5 × 10^10
	NEG. GRAD.	118		118.8	104.0	4	3	-3	105.0	3.2 × 10^10
2	FOCUS	130	0.8	130.8	119.6	1	6	3	117.6	57.5 × 10^10
	BASE	125		125.8	113.6			-3	111.6	14.5 × 10^10
	NEG. GRAD.	118		118.8	104.0	4	3	-3	105.0	3.2 × 10^10
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
								SUM	150.4 × 10^10	

PAGE ____ DAY/NIGHT LOCATION Wildflecken Position 1

Germany

NOTES: * Short duration

Figure E-13. Form B for Wildflecken.

1		2	3	4	5	6		7	8	9
SOURCE NUMBER		OVERPRESSURE dB Figure E-5	dB CORRECTION FORM A-4	SUM 2 + 3	EPNL TABLE E3	REPETITION FACTOR N_{dB} - K	K	OTHER FACTORS dB	SUM 5+6+7	$10 \frac{SUM_8}{10}$
1	FOCUS	130	0.8	130.8	116.0	13	6	-3*	126.0	398.1 x 10^{10}
	BASE	125		125.8	110.0			-3	120.0	100.0 x 10^{10}
	NEG. GRAD.	118		118.8	100.4	16	3	-3	113.4	21.9 x 10^{10}
2	FOCUS	130	0.8	130.8	116.0	8	6	-3	121.0	125.9 x 10^{10}
	BASE	125		125.8	110.0			-3	115.0	31.6 x 10^{10}
	NEG. GRAD.	118		118.8	100.4	11	3	-3	108.4	6.9 x 10^{10}
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
								SUM	684.4 x 10^{10}	

PAGE ____ DAY/NIGHT LOCATION WILDFLECKEN POSITION 1

NOTES: * SHORT DURATION GERMANY

Figure E-14. Form B for Wildflecken.

are 20 dB (100 rounds) for daytime and 10 dB (10 rounds) for nighttime. Again, −3 dB is included to account for the short duration. The EPNL sums are the "totals" for day and night and are entered into columns 3 and 6 respectively, from Form C (Figure E-16). From this point, the calculations proceed in standard fashion.

As expected, the measured CNR is lower than the predicted value because the measurements were made under conditions of a negative sound velocity gradient, while the prediction is for a positive gradient which is "sometimes" positive.

Table E-4

CNR From Blast Measurements

	Average Peak Overpressure dB	Corresponding EPNL	Repitition dB	Other Factors	EPNL Sum
Daytime	119	100.6	20	−3	117.6
Nighttime	119	104.2	10	−3	111.2

1		2	3	4	5	6		7	8	9
SOURCE NUMBER		OVERPRESSURE dB Figure E-5	dB CORRECTION FORM A-4	SUM 2 + 3	EPNL TABLE E3	REPETITION FACTOR N_{dB} - K	K	OTHER FACTORS dB	SUM 5+6+7	$10 \frac{SUM_8}{10}$
MEASURED DAY	FOCUS			119	100.6	20	6	-3*	117 6	
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
MEASURED NIGHT	FOCUS			119	104 2	10	6	-3	111 2	
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
	FOCUS						6			
	BASE									
	NEG. GRAD.						3			
								SUM		

PAGE ____ DAY/NIGHT LOCATION WILDFLECKEN POSITION 1
GERMANY

NOTES: MEASURED VALUES
* SHORT DISTANCE

Figure E-15. Form B for Wildflecken (measured values).

1	2	3	4	5	6	7	8
LOCATION	TOTAL DAYTIME SUMS FROM FORM B's	DAYTIME SUM dB S_D	DAYTIME CNR SUBTOTAL $S_D - 12$	TOTAL NIGHTTIME SUMS FROM FORM B's	NIGHTTIME SUM dB S_N	NIGHTTIME CNR SUBTOTAL $S_N - 2$	TOTAL CNR 4 + 7 added on a 10 $\log_{10}$ basis
PREDICTED POSITION 1	684.9×10^{10}	128.3	116.3	156.4×10^{10}	121.8	119.8	121
PREDICTED POSITION 2	144.5×10^{10}	121.6	109.6	33.1×10^{10}	115.2	113.2	115
PREDICTED POSITION 3	195.0×10^{10}	122.9	110.9	56.2×10^{10}	117.5	115.5	117
MEASURED POSITION 1		117.6	105.6		111.2	109.2	111
MEASURED POSITION 2		113.4	101.4		107.0	105.0	107
MEASURED POSITION 3		113.4	101.4		107.0	105.0	107

PAGE ____

NOTES: WILDFLECKEN GERMANY
PREDICTIONS AND MEASURED VALUES

Figure E-16. Form C for Wildflecken.

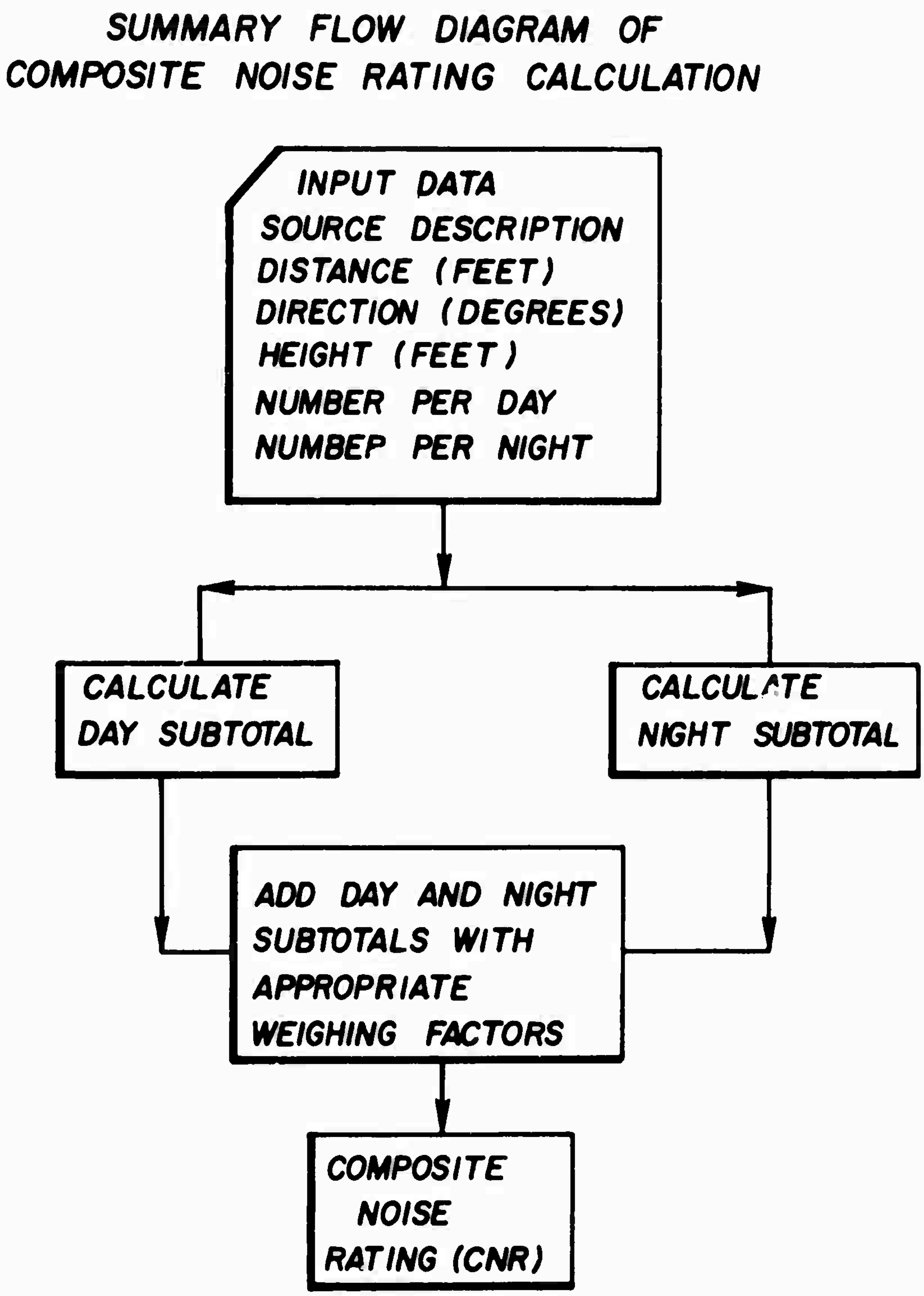

Figure E-17. Summary flow diagram of composite noise rating calculation.

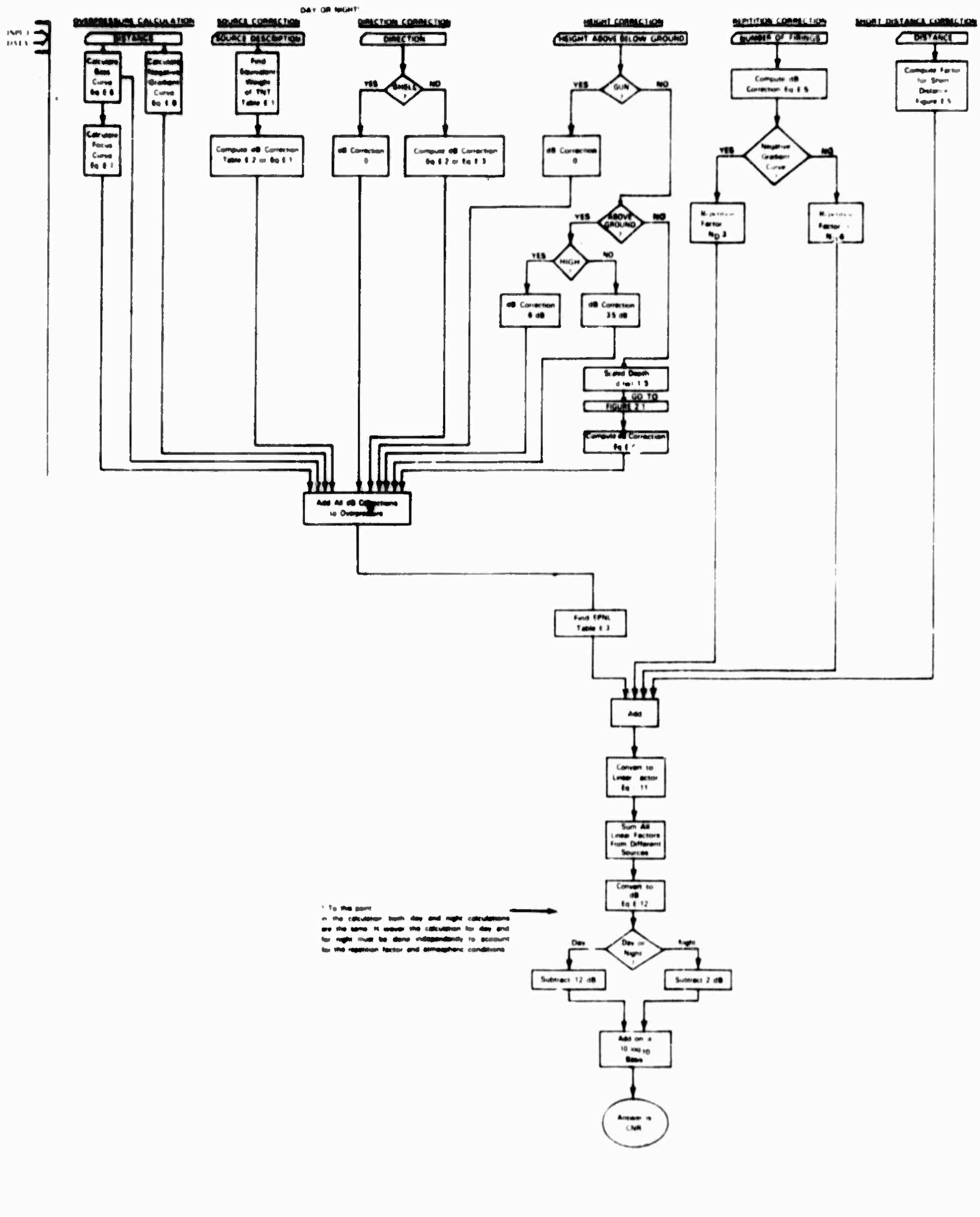

Figure E-18. Flow chart.

APPENDIX F: SUMMARY OF
COMMUNITY REACTION TO AIRPORT NOISE

This report presents the results of a research program for which large amounts of field data on community characteristics, exposure to aircraft noise, and reactions to the noise were acquired. These data were analyzed using a variety of techniques to establish and measure relationships between variables representing exposure, mediating factors, and response.

Social data were obtained by personal interviews based upon questionnaires. In the seven cities, a total of 8207 interviews were secured. Most of the respondents in each city were selected randomly from sample areas under flight paths and extending to 10 or 12 miles from the center of the airport. However, some respondents were selected from lists of noise complainants or from the membership of an anti-noise organization. The noise exposure for each respondent was determined from acoustical measurements and air traffic data. A total of over 10,000 flyover noise signatures were recorded and analyzed.

In the analysis of results, the understanding of annoyance and complaints and their relationship to the noise produced by air traffic has been significantly enhanced. For the first time, the many existing formulations of noise parameters have been compared, using comprehensive physical and social data collected in airport communities. Two ways of evaluating with good accuracy the annoyance in exposed communities have been developed, and the differences in annoyance observed between individuals with the same noise exposure have been explained. The major results of this study, presented in greater detail in Chapter 10 of the Tracor report,* are listed below.

1. Simple weighted sound pressure level values (dBA and dBN) provide adequate approximations to more complex measures for the purpose of determining community noise exposure.

2. As measures of aircraft noise exposure in communities, the Composite Noise Rating (CNR), Noise and Number Index (NNI, as defined in this report), and Noise Exposure Forecast (NEF) are practically interchangeable, although CNR is slightly superior for predicting annoyance.

3. Installations for community monitoring of aircraft noise exposure can use weighted sound pressure level measurement and should be designed to obtain adequate samples of both flyover noise and ambient noise.

4. Estimation of annoyance using noise exposure as the sole predictor is rather poor.

5. The inclusion with noise exposure of certain attitudinal or psychological variables affords good prediction of individual annoyance. Prediction is improved by use of a nonlinear model.

6. An equation can be written for predicting individual annoyance with good accuracy.

7. For a significant reduction in annoyance, a CNR value of 93 or less is required. Above 107 CNR, annoyance increases steadily and above 115 CNR, noise exposure is associated with increased complaint.

8. Within certain limits, the number of highly annoyed households in a community may be estimated from the number of complainants.

9. Since adjusting for the noise attenuation of the house lowers the correlation between exposure and annoyance, people appear to react to the noise as perceived outdoors rather than indoors.

10. An equation for predicting complaint among a random sample, similar to the predictive equation for annoyance, can be written, but its accuracy is not good.

---

* *Community Reaction to Airport Noise*, NASA Contractor Report CR-1761/N 71-29032 (Tracor, Inc., 1971).

11. There is a substantial difference between predictors of annoyance and predictors of complaint: predictors of annoyance are primarily physical/attitudinal; predictors of complaint are primarily physical/sociological.

12. Complainants are not more sensitive to noise than random respondents. The complainants are less annoyed with typically irritating noises. They are also less annoyed with usual sources of neighborhood noise except for two items — aircraft and sonic booms.

13. On the average, complainants, in comparison to members of the random samples, tend to live nearer the airport, have higher noise exposure, and tend to be older, more highly educated, and more affluent. They also display a higher awareness of and negative attitude toward aircraft operations. On the basis of a very limited sample, members of noise protest organizations tend to be similar to complainants in such characteristics.

14. The seven survey cities (Boston, Chicago, Dallas, Denver, Los Angeles, Miami, and New York) show consistent patterns for mean noise exposure (CNR), negative attitudes concerning aircraft operations, high annoyance, and percentage of complainants. New York, Boston, and Los Angeles generally rate high on these variables; and Dallas, Miami and Denver, low.

15. Alleviation of aircraft noise annoyance by "house attenuation" programs and land zoning controls does not appear to be feasibie except possibly in special cases.

APPENDIX G: LOCAL NOISE ORDINANCES

Noise ordinances exist in many municipalities and states throughout the United States and in most European countries.* In many cases, these ordinances specify maximum dB(A) and octave band levels that may be propagated into a residential area. These ordinances were designed primarily for "steady" noises with occasional allowances given for pure tones, repetitive sounds, impulsive noises of the jack hammer type, and noises having durations as short as 0.5 minutes. They were not designed for blast noise, which is characterized by its very short duration and relatively high intensity.

Figure G-1 shows the range of typical octave band noise ordinances. These should be contrasted with the *lowest* level impulse octave band levels (see Tables B-4 and B-5). With a 10 dB allowance for the short duration and no penalty for the impulsive nature of the sound, only the lowest level impulses meet the more lenient noise ordinances, further demonstrating that these ordinances were not designed with blast noises in mind.

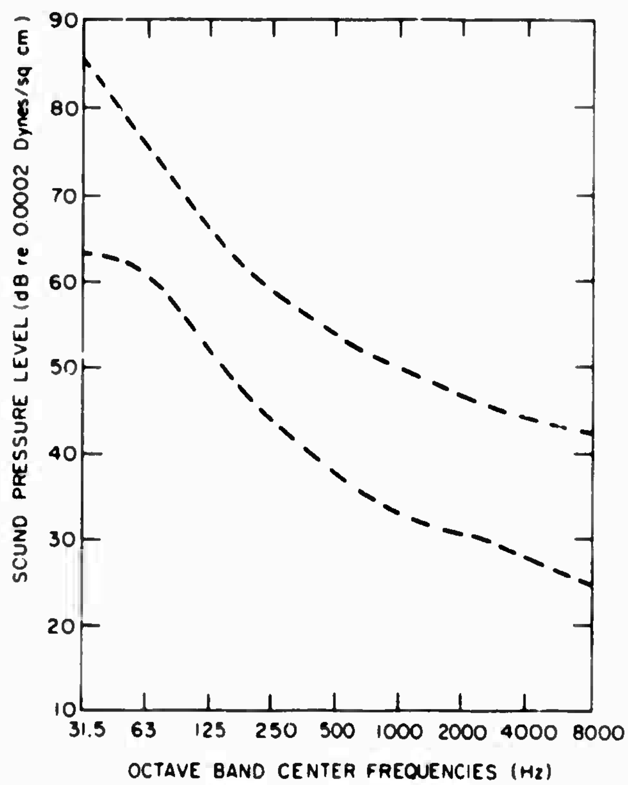

Figure G-1. Range of octave band levels of typical state and municipal noise ordinances.

* Good compilations of local ordinances are found in "Compilation of State and Local Ordinances on Noise Control," *Congressional Record*, 29 October 1969, pp E9031-9110; and in W.E. Blazier, et al., *Chicago Urban Noise Study*, Report to Commissioner (City of Chicago, Department of Environmental Control, 1970).

APPENDIX H:
DECIBEL REFERENCE CHART

Decibel Conversion Chart

(Bar = 1 x 10^6 dyne/cm^2 = 0.98692 atm)

m Bar	Pressure Approx. PSF	Approx PSI	dB re. 0.0002 Dyne/cm^2
707.000		10.0	191
353.500		5.0	185
141.000		2.0	177
70.700		1.0	171
35.300		0.5	165
14.100		0.2	157
7.070		0.1	151
3.530	7.5	0.05	145
1.410	3.0	0.02	137
0.707	1.5	0.01	131
0.353	0.75	0.005	125
0.141	0.3	0.002	117
0.0707		0.001	111
0.0353		0.0005	105
0.0141		0.0002	97
0.00707		0.0001	91
0.00353		0.000 05	85
0.00141		0.000 02	77
0.000707		0.000 01	71

Pressure in dB = 20 $\log_{10} P/P_{ref}$ (Here, P_{ref} = 0.0002 dynes/cm^2.)

NOTE: For power, 10 $\log_{10}$ is used.

For pressure (or voltage or velocity, etc.), 20 $\log_{10}$ is used since power is proportional to pressure squared.

Approximate Decibel Pressure Factors

As stated, pressure gain in decibels, $A_pdB = 20 \log_{10} A_p$, where A_p is the pressure gain. The table below summarizes some approximte results of this relation.

A_p	A_pdB	A_p	A_pdB
1	0	1	0
2	+6	1/2	6
3	+10	1/3	-10
4	+12	1/4	-12
5	+14	1/5	-14
6	+16	1/6	-16
8	+18	1/8	-18
10	+20	1/10	20
100	+40	1/100	-40
1000	+60	1/1000	-60

Examples:

1. $A_p = 40$ implies $A_pdB = 20 \log_{10} 40 = 32$ dB.

or $A_p = 10 \times 4$ implies $A_pdB = +20 + 12 = 32$ dB

since a pressure gain of 10 implies +20 dB and a pressure gain of 4 implies +12 dB.

or $A_p + 8 \times 5$ implies $+18 + 14 = 32$ dB

since a pressure gain of 8 implies +18 dB and a pressure gain of 5 implies +14 dB.

2. $A_p = 75$ implies $A_pdB = 20 \log_{10} 75 = 38$ dB.

or $A_p = 5x5x3$ implies $A_pdB = +14 +14 +10 = 38$ dB

since a pressure gain of 5 implies +14 dB and a pressure gain of 3 implies +10 dB.

Approximate Decibel Power Factors

As stated, power gain in decibels, GdB = 10 $\log_{10}$ G, where G is ten power gain. The table below summarizes some approximate results of this relation.

G	GdB	G	GdB
1	0	1	0
2	+3	1/2	− 3
3	+5	1/3	− 5
4	+6	1/4	− 6
5	+7	1/5	− 7
6	+8	1/6	− 8
8	+9	1/8	− 9
10	+10	1/10	− 10
100	+20	1/100	− 20
1000	+30	1/1000	− 30

Examples:

1. G = 40 implies GdB = 10 $\log_{10}$ 40 = 16 dB,

or G = 10 x 4 implies GdB = 10 dB + 6 dB = +16 dB

since a power gain of 10 implies a +10 dB and a power gain of 4 implies +6 dB,

or G = 8 x 5 implies GdB = +9 +7 = +16 dB

since a power gain of 8 implies +9 dB and a power gain of 5 implies +7 dB.

2. G = 75 implies GdB = 10 $\log_{10}$ 75 = 19 dB,

or G = 5x5x3 implies GdB = +7 +7 +5 = 19 dB

since a power gain of 5 implies +7 dB and a power gain of 3 implies +5 dB.