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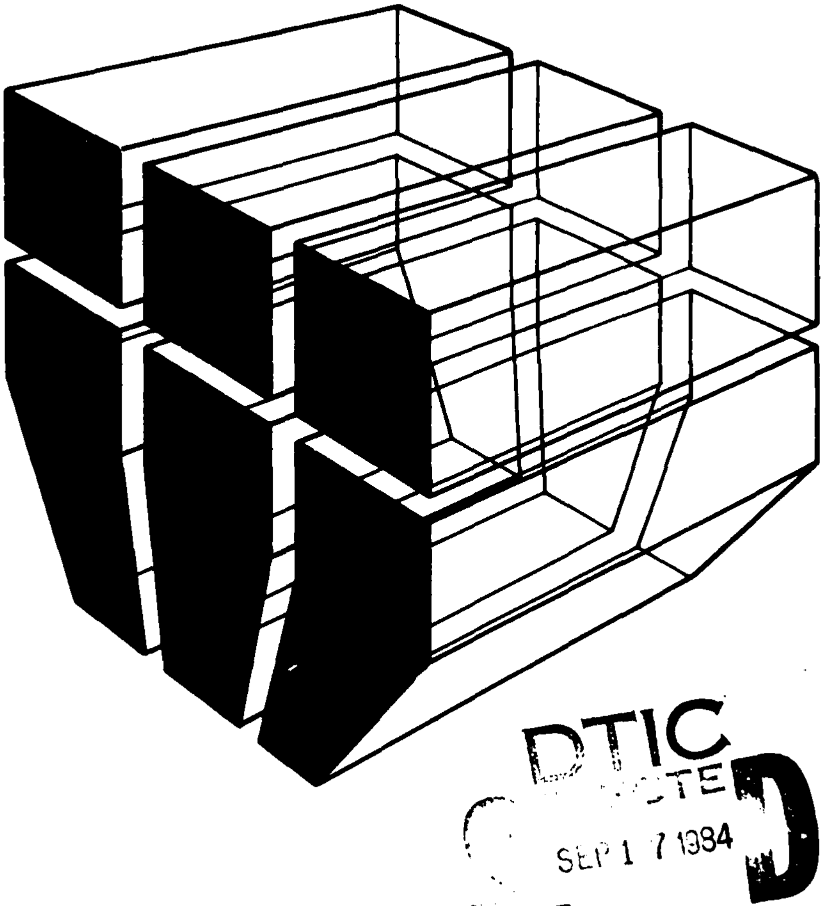
August 1984
Noise Source Emissions: Characterization and
Measurement Standardization

ACOUSTIC DIRECTIVITY PATTERNS FOR ARMY WEAPONS: SUPPLEMENT 2

by
Paul D. Schomer
Richard Raspet



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Acoustic directivity patterns are given for the Abrams tank (M1-E1) 120-mm main gun. Two types of ammunition were tested: the high-explosive anti-tank training practice round (HEAT-TPT). and (2) the kinetic energy or SABOT round. These data supplement the pattern data presented in CERL Technical Report N-60. They have been included in the weapon directivity load module of BNOISE 3.2 and made available to users of the Integrated Noise Contour System (INCS).

(continued on next page)

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Block 20. (Cont'd.)

An investigation of the problem posed by sonic boom (ballistic wave) concluded that it should be considered in evaluating the environmental impact of tank ranges for the HEAT-TPT round. If an impact is predicted, measurements specifically designed to study the ballistic wave at long ranges should be performed.

FOREWORD

This research was conducted for the Directorate of Engineering and Construction, Office of the Chief of Engineers, under Project 4A162720A896, "Environmental Quality Technology"; Task A, "Installation Environmental Management Strategy"; Work Unit 011, "Noise Source Emissions: Characterization and Measurement Standardization." The OCE Technical Monitor was Gordon Velasco, DAEN-ECE-I.

The work was done by the Environmental Division (EN), US Army Construction Engineering Research Laboratory (USA-CERL). Dr. R. K. Jain is Chief of EN. Dr. L. R. Shaffer is Technical Director of USA-CERL, and COL Paul J. Theuer is Commander and Director.

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1 INTRODUCTION

Background

On 20 May 1981, the Army instituted the Installation Compatible Use Zone program (ICUZ). Under ICUZ, an Army installation works with the local civilian community to find ways to prevent or lessen the encroachment of off-installation housing and other noise-sensitive land uses into areas that are, or are likely to be, impacted by Army training noise.[1]

Vital to the success of the ICUZ program is a noise-prediction computer tool developed by the U.S. Army Construction Engineering Research Laboratory (USA-CERL). The Integrated Noise Contour System (INCS) creates distance-scaled noise contours using data on the type, frequency, and time of training operations; weapon types and charge sizes; and target and firing point locations. These contours, when overlayed on a map of an installation and its environs, identify existing or potential conflicts between noise levels produced by training operations and noise-sensitive land uses on or near an installation. Using BNOISE 3.2, the blast noise prediction computer program associated with INCS, contours also can be created that predict how changes in training range operations, siting, use intensity, and weapon types will alter an installation's noise-impact profile.[2] The Army Environmental Hygiene Agency (AEHA) can make noise predictions for any Army installation using USA-CERL's INCS/BNOISE 3.2 program.

One important data type needed for INCS/BNOISE 3.2 is the individual acoustic directivity pattern associated with each impulse-noise producing weapon in the Army inventory. These patterns form a standard module of data for the INCS/BNOISE 3.2 prediction program.

USA-CERL Technical Report N-60 lists directivity pattern data obtained during tests at Fort Sill, OK, for many weapons used routinely in Army training (Table 1).[3] Supplement 1 to that report contains directivity pattern data for the LAW and TOW antitank weapons and three regularly used weapon simulators. This second supplement contains directivity pattern data for the Abrams Tank (M1-E1) 120-mm main gun.

Purpose

The purpose of this study was to determine the acoustic directivity pattern of the Abrams tank (M1-E1) 120-mm main gun, and to investigate the problem posed by the sonic boom (ballistic wave) generated by the shell.

Approach

Noise measurements were made on the M1-E1 120-mm gun at Aberdeen Proving Ground, MD. The measurement method was basically the same as that described in USA-CERL Technical Report N-60. Weapon firings were interspersed with detonations of C-4 plastic explosive. The C-4 was used to "calibrate" the site and provide for correction to the data for wind and terrain effects.

Mode of Technology Transfer

The directivity patterns obtained from this study have been added to the INCS/BNOISE 3.2 input data bank and are available for use by AEHA and all Department of Defense activities. The methods used to perform this study are included in Appendix

Table 1
Weapons Tested (Fort Sill, OK)

Weapon Name	Model
8-in. self-propelled	M110A1
105-mm tank	M60
4.2-in. mortar	M30
81-mm mortar	–
106-mm recoilless rifle	M40A1
90-mm recoilless rifle	M67
105-mm howitzer	M102
155-mm howitzer	M109
8-in. howitzer	M110
152-mm Sheridan (tank gun)	M551
155-mm howitzer	M114
155-mm howitzer	M109A1

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[1] Paul Schomer, "Noise Impact Prediction and Control," *Military Engineer*, Volume 74, Number 479 (April 1982).

[2] Paul D. Schomer, et al., *Blast Noise Prediction Volume I: Data Bases and Computational Procedures*, and Lincoln M. Little, et al., *Volume II: BNOISE 3.2 Computer Program Description and Program Listing*, Technical Report N-98/ADA099440 and ADA099335 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], March 1981).

[3] P. D. Schomer, L. M. Little, and A. B. Hunt, *Acoustic Directivity Patterns for Army Weapons*, Technical Report N-60/ADA066223 (USA-CERL, January 1979).

C as a draft standard for study and possible inclusion in Military Standard 1474 b. When this standard is completed, similar future measurements may be routinely performed by DARCOM.

2 DATA COLLECTION

Measurements were performed at Aberdeen Proving Ground (APG), MD as part of an ongoing test at that facility. The test site was an open, grassy field. Figure 1 shows the general test area and Figure 2 shows the detailed test site layout. There were two concentric rings of sensors; the inner ring had a radius of 250 yards (228.6 m) and the outer ring had a radius of 500 yards (457.2 m). The inner ring was entirely on the grassy field with no nearby reflecting objects. On the outer ring, site 7 was adjacent to a tree line and sites 10 and 11 were in open grass, but there was a sparse tree line between these two sites and the inner ring (Figure 1). The measurements were made in early December 1982 when the trees were bare of leaves.

The microphones on the inner ring were Endevco piezoresistive transducers close-coupled to USA-CERL-built preamplifiers and line drivers. (Appendix B of Supplement 1 describes the Endevco device and the USA-CERL preamplifiers.) Each microphone was wired to the USA-CERL mobile field acoustics laboratory, where the signal was recorded on an Ampex PR 2230 14-channel FM recorder.

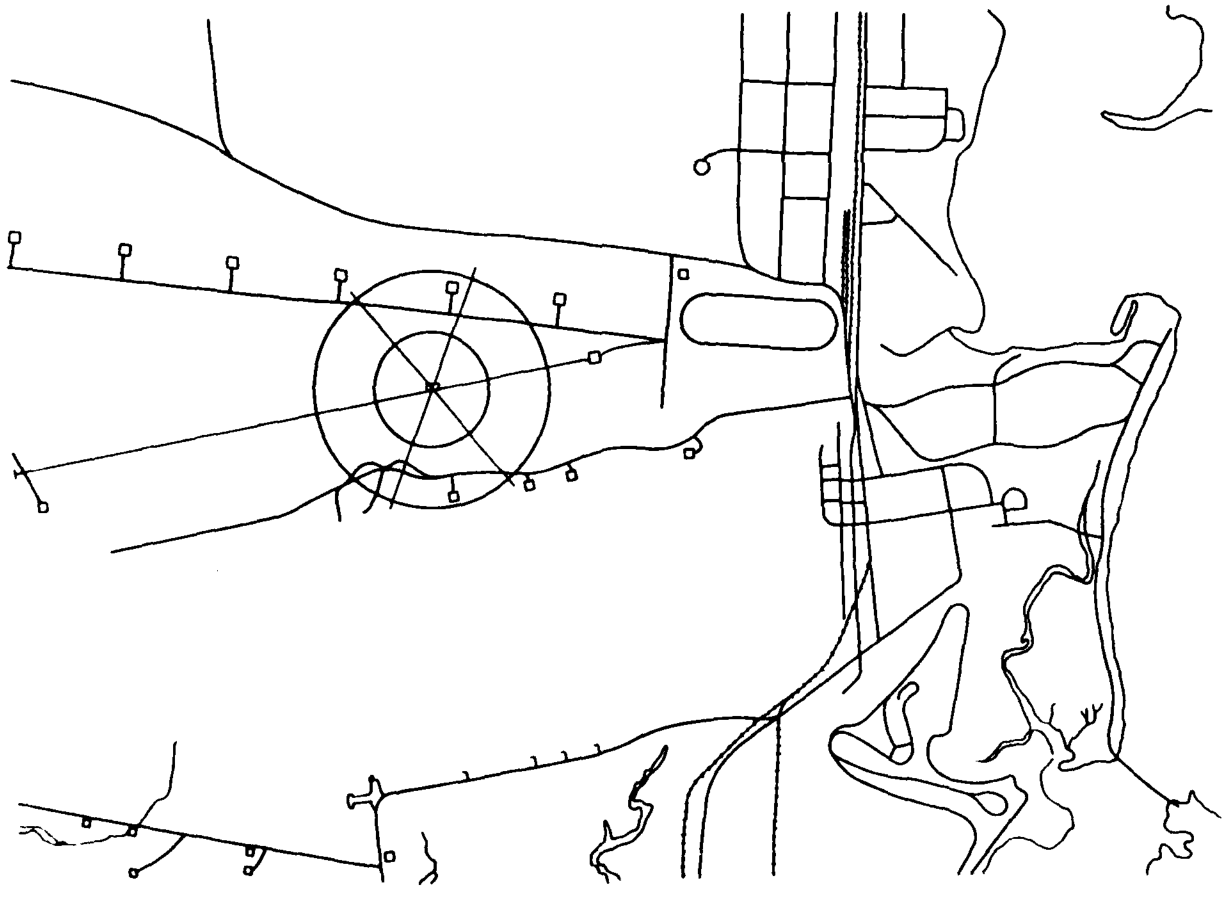
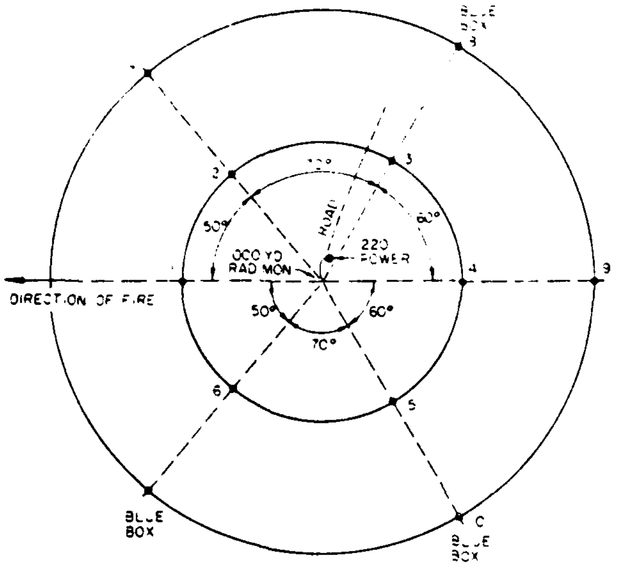


Figure 1. General site layout for noise measurements of the M1-E1 120-mm main gun, APG, MD, Dec 82.



1. DIRECTION OF FIRE IS "T.W. TANK Rq. 24° D.X."
2. CENTER (FIRING POINT) IS "1000 YD RAD MON."
3. RADIUS OF INNER CIRCLE IS 250 YD
   RADIUS OF OUTER CIRCLE IS 500 YD.

Figure 2. Microphone layout, APG, MD, Dec 82.

The outer ring consisted of a variety of equipment. *Site 7 had a B&K 4921 outdoor microphone*, USA-CERL "Blue-Box" noise monitor,[4] and Nagra DJ tape recorder. Sites 10 and 11 had BK 4921 outdoor microphone systems connected over short (500 ft [152.4 m]) cables to a single manned station (Figure 1) consisting of a USA-CERL Blue-Box noise monitor and Nagra SJ-stereo recorder. Sites 7 and 9 had B&K 4921 microphone systems connected over long lines to the van and its PR2230 FM tape recorder. USA-CERL Blue-Box noise monitors were also used in the van for immediate data checking and readout.

Calibration

Calibration was done (1) at the beginning of every new tape, (2) at the end of each tape and/or day, (3) when the equipment was first set up, (4) when the equipment or equipment placement was changed, and (5) when any equipment malfunction was suspected. The six Endevco stations were calibrated with a B&K 4220 pistonphone. USA-CERL constructed special housings for the Endevco microphones so calibration could be performed using standard laboratory and field devices. At the beginning of each FM tape, the calibration tone was recorded for about 15 seconds at the measurement tape speed of 60 in./second (1524 mm/second). The B&K 4921 microphone system was calibrated initially using the B&K-type 4220 pistonphone. Subsequent calibrations were performed using its internal 1000-Hz electrostatic actuator.

Test Sequence

Two types of ammunition for the 120-mm gun were measured: (1) the high explosive anti-tank training practice round (HEAT-TPT) and (2) the kinetic energy or SABOT round. Table 2 lists the test sequence for these two rounds and the C-4 calibration shots. The test sequence generally consisted of two or more C-4 shots followed by two or more rounds of the shell under test. This is essentially the same procedure used during the original Fort Sill measurements and the Fort Carson measurements described in Supplement 1.

3 DATA REDUCTION

Primary data reduction was done using the USA-CERL-developed True-Integrating Environmental Noise Monitor and Sound-Exposure Level Meter.

Table 2
Firing Sequence at APG, December 1982

a. Practice Round
b. Practice Round
1. C-4
2. C-4
3. HEAT
4. HEAT
5. HEAT
6. HEAT
7. C-4
8. HEAT
9. HEAT
10. HEAT
11. HEAT
12. C-4
13. C-4
14. C-4
15. SABOT
16. SABOT
17. SABOT
18. SABOT
19. C-4
20. C-4
21. SABOT
22. SABOT
23. SABOT
24. SABOT
25. C-4
26. C-4
27. SABOT
28. SABOT
29. SABOT
30. SABOT
31. C-4
32. C-4

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[4] Aaron Averbuch, et al., *True-Integrating Environmental Noise Monitor and Sound-Exposure Level Meter Volumes I through IV*, Technical Report N-41/ADA050958, ADA072002, ADA083320, and ADA083321 (USA-CERL, May 1978, June 1979, and March 1980).

This data reduction resulted in a measure of the C-weighted sound exposure level (CSEL). The Norland computing oscilloscope was used to remeasure C-weighted data for each gun round at sites 1, 2, 6, 7, and 11. These were the sites which also received a shell-generated ballistic wave (Figure 2). The Norland was used to separate muzzle blast data from the ballistic wave data. Background noise was also measured to ensure that the recorded data were far enough above the noise level to be valid. Appendix A lists analyzed data by event.

Each series of shell data was first corrected by the adjacent (in-time) C-4 calibration events. A set of numbers was found for the C-4 events just before and after the shell events. The C-4 data were corrected to data for an omnidirectional, hemispherical (actually circular in the ground plane) radiating source. The shell data were averaged by microphone and corrected by the set of numbers found to convert the C-4 to a perfect, circular source. These averages are listed in Appendix B. Similar shells (after correction by adjacent C-4 calibrations) were then combined (energy-averaged by microphone) to form the overall weapon/device directivity pattern. Corrections were made to form a symmetrical pattern. Appendix B lists the resultant data by weapon/device.

Table 3, which is based on the data given in Appendix B, lists the data as they are included in the BNOISE 3.2 weapons input table. In the table, the reference distance is 250 m (rather than 250 yards). At this distance, 5 lb (2.2 kg) of C-4 exploded on the ground typically produces a CSEL of 119 dB.

4

POTENTIAL ADVERSE ENVIRONMENTAL IMPACT OF THE 120-MM TANK GUN PROJECTILE'S BALLISTIC WAVE

This chapter considers whether the ballistic wave of the 120-mm tank gun projectiles can cause adverse impact, and, if so, under what conditions. The blast wave and ballistic wave data recorded during blast wave measurements at Aberdeen Proving Ground are used as a basis to estimate the magnitude and location of ballistic wave impact. While a detailed assessment is not possible since the microphone placements were not specifically designed for ballistic wave studies, this estimate will be used to identify potential impacts and areas of study.

Tables 4 and 5 show the data used in this analysis—the ballistics wave data and the muzzle blast data from the HEAT rounds, respectively.

The ballistic wave from the SABOT round could not be isolated at the far microphone due to the ballistic waves from the discarded pieces of the SABOT.

Table 4 shows that the SABOT ballistic wave is much quieter than the HEAT ballistic wave (120.6 dB vs. 131.7 dB at the near microphone), and it has a much shorter predicted duration at further distances.* It should thus present a much smaller problem than the HEAT round. The sonic booms from

Table 3
Input Data for BNOISE 3.2

		Position (degrees)												
		0	30	60[1]	90	120	150	180	210	240	270	300	330	Average
HEAT-TPT	value	120.0	118.9	117.8	117.1	115.6	114.2	112.8	114.2	115.6	117.1	117.8	118.9	117.4
	value re rear of gun	7.2	6.5	5.6	4.3	2.8	1.4	0	1.4	2.8	4.3	5.6	6.5	4.6
SABOT	value	120.4	120.2	120.0	118.7	116.3	115.7	115.0	115.7	116.3	118.7	120.0	120.2	118.6
	value re rear of gun	5.4	5.3	5.2	3.7	1.3	0.7	0	0.7	1.3	3.7	5.2	5.3	3.6

[1] Value altered from the 50° measurement position to the 60° standard position.

---

*The duration of a ballistic wave is largely due to nonlinear effects; the duration at longer ranges is proportional to the peak pressure at shorter ranges.

Table 4
Ballistic Wave Data

	SABOT		HEAT	
	CSEL (dB)	DURATION (ms)	CSEL (dB)	DURATION (ms)
Near Microphone	120.6	1.0	131.7	2.1
Far (175 m) Microphone	——	——	110.9	8.1

Table 5
Muzzle Blast Data from the HEAT Round

Microphones	Angle from Projectile	CSEL* (dB)
1	0°	120.0
2, 6	50°	118.4
3, 5	120°	115.6

*From Table B5.

the discarded SABOT pieces may be significant close to the firing point, but are not expected to cause problems off the installation.

The HEAT ballistic wave (Table 4) has a large CSEL and long enough duration so that it will not undergo rapid decay with distance due to atmospheric attenuation. (For comparison, the blast wave from 1.25 lb of C-4 explosive at 175 m has a CSEL of 118 dB and a duration of about 20 ms.) While the level and detail of data does not justify a detailed analysis, it is sufficient to note that at the 175 m range the ballistic wave had developed into an N-wave with a much longer duration than is given by linear theory:

$$T_o = L/Mv \qquad \text{[Eq 1]}$$

where T_o is the duration, L the projectile length, M is the Mach number, and v is the speed of sound. Under these conditions, the finite wave asymptotic result is that energy decays with the inverse 1.25 power of the sideline distance. This decay rate may be employed to estimate the ballistic wave level. Therefore,

$$\mathrm{SEL}\,(y) = \mathrm{SEL}\,(y_o) - 12.5 \log_{10}\left(\frac{y}{y_o}\right) \qquad \text{[Eq 2]}$$

where y is the perpendicular distance from the projectile path.

The muzzle blast decays as the inverse square of the distance from the firing point:

$$\mathrm{SEL}\,(R) = \mathrm{SEL}(R_o) - 20 \log_{10}\left(\frac{R}{R_o}\right) \qquad \text{[Eq 3]}$$

where R is the distance from the firing point. Note that the ballistic wave decays more slowly with sideline distance than the muzzle blast decays with distance from the muzzle (Figure 2).

From Table B6, one can develop a correction for the muzzle blast directivity pattern. A reasonable fit to the data for $\phi < 90°$ is

$$\mathrm{SEL}(\phi) = 116.9 + 2.8\cos^2\phi\ (\mathrm{dB}) \qquad \text{[Eq 4]}$$

where ϕ is the angle formed with respect to the line of fire.

The ballistic wave exists only at an angle to either side of the projectile which is the complement of the Mach angle. The Mach angle is given by

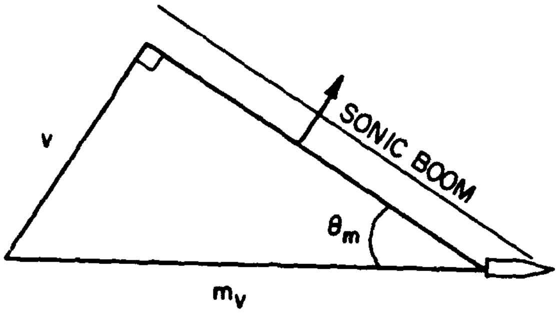
$$\theta_m = \sin^{-1} 1/M \qquad \text{[Eq 5]}$$

When the projectile impinges on the target, the ballistic wave is no longer generated, although sound is diffracted in the forward direction. This noise should not present an environmental problem since structures are not permitted behind the target for safety reasons.

The geometry of this analysis is shown in Figure 3. Region I is where no ballistic wave exists, and Region II is where the ballistic wave is diffracted and decays spherically or faster (the CSEL decays as 20 $\log_{10}$ (R)). In the shaded region, labeled III and IV, the ballistic wave is significant. Since the ballistic wave decays slowly as 12.5 $\log_{10}$ (y/y_o), it can have a large CSEL at large sideline distances.

Eq 1, 2, and 3 can be solved to give the boundary between regions where the muzzle blast is greater than the ballistic wave (Region III) and where the ballistic wave is louder than the muzzle blast (Region IV). Three factors are expected to limit the area of impact:

1. The ballistic waves are of short duration and therefore will be affected quickly by atmospheric attenuation and incoherence.



m_v = SHELL SPEED
v = SPEED OF SOUND

Figure 3. Sonic boom Mach angle.

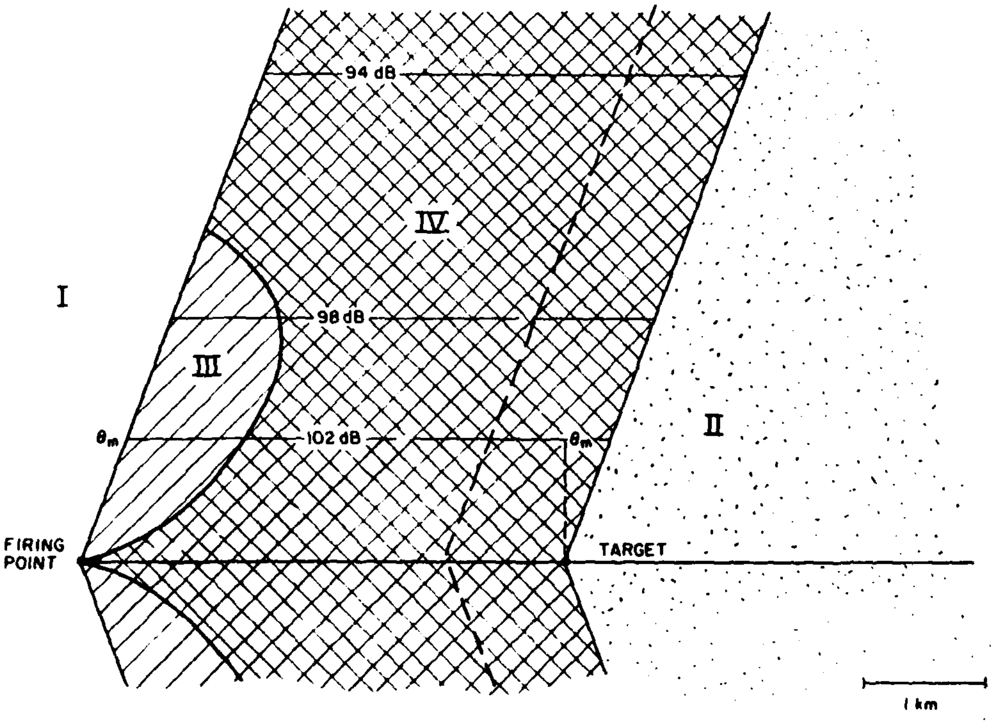


Figure 4. Noise pattern from muzzle blast and ballistic wave of HEAT round. (The dashed line shows the zone IV cut off if the target range is 3 km rather than 4 km.)

2. The ballistic wave decay will become spherical as the sideline distance approaches the path length of the projectile.

3. Safety fans should encompass large areas of the impacted region.

In light of 1 and 2 above, it is not expected that the ballistic wave will be significant beyond a 4 km sideline distance; this is indicated by the shading in Figure 4.

In conclusion, the ballistic wave should be considered in evaluating the environmental impact of tank ranges for the HEAT-TPT round. If an impact is predicted, measurements specifically designed to study the ballistic wave at long ranges should be performed.

5 CONCLUSIONS

The report gives the acoustic directivity patterns for the M1-E1 120-mm main gun. These data supplement the pattern data presented in USA-CERL Technical Report N-60. These supplemental pattern data have been included in the weapon directivity pattern load module of BNOISE 3.2 and made available to users of the Integrated Noise Contour System.

The ballistic wave should be considered in evaluating the environmental impact of tank ranges for the HEAT-TPT round. If an impact is predicted, measurements specifically designed to study the ballistic wave at long ranges should be performed.

APPENDIX A: ANALYZED DATA LISTED BY EVENT

M1-E1 120-mm Main Gun, Aberdeen Proving Ground

	1	2	3	4	5	6	7	8	9	10	11
a. Practice Round	125.1	122.0		114.7	115.4	121.4	117.1	102.2	108.0	111.45	117.1
b. Practice Round	125.0	122.9	118.1	113.8	115.4	122.1	117.6	100.0	111.4	108.9	118.2
1. C-4	124.2	123.1	121.5	119.7	120.4	122.1	116.6	106.6	113.6	113.4	118.4
2. C-4	123.7	122.4	121.2	120.2	120.6	122.5	116.3	106.4	115.0	113.6	118.3
3. Shell	124.7	121.1	117.6	114.1	117.3	121.5	116.4	104.3	110.1	110.6	117.3
4. Shell	124.8	122.1	117.9	114.8	115.7	121.8	116.0	103.5	109.2	110.1	117.2
5. Shell	124.7	121.7	118.2			121.6	115.5	104.6		110.0	116.4
6. Shell	124.8	121.7	118.0			121.5	116.3	104.3		108.6	116.7
7. C-4	123.3	121.6	121.1	120.2	119.0	122.5	116.7	107.5	114.6	113.3	117.4
8. Shell	124.1	121.9	118.0	114.5	115.8	121.0	116.1	105.0	108.5	110.2	116.5
9. Shell	123.9	121.7	117.9	113.9	116.0	120.9	116.1	104.5	108.3	109.8	116.1
10. Shell	124.2	121.4	118.7	113.1	116.3	120.6	116.2	103.8	108.6	109.7	115.5
11. Shell	124.0	121.4	117.6	113.8	116.3	121.7	116.0	104.6	108.3		116.5
12. C-4	122.7	122.7	122.1	120.1	119.8	122.2	116.2	109.1	108.5	113.8	117.4
13. C-4	123.1	122.3	122.2	121.1	120.1	120.8	117.1	109.8	116.3	114.2	114.6
14. C-4	123.3	122.0	122.7	121.2	120.1	121.1	117.3	110.5	116.8	114.2	115.3
15. Shell	123.6	123.1	120.4	117.9	118.2	122.0	118.7	107.7	113.0	112.0	116.6
16. Shell	123.7	123.2	120.3	117.7	118.7	122.1	118.4	107.7	112.6	110.7	115.4
17. Shell	124.6	123.1	119.8	108.9	118.0	123.3	117.9	107.2	112.7	111.9	116.9
18. Shell	124.9	122.3	119.6	107.8	117.9	123.6	117.2	106.3	113.3	112.0	117.4
19. C-4	122.8	122.2	122.1		121.8	121.8	116.4	108.8	116.9	116.5	115.6
20. C-4	124.0	121.4	121.8	121.2	120.9	122.0	116.7	108.5	116.5		116.5
21. Shell	124.3	123.2	119.8		118.4	122.8	117.8	106.6	112.1	111.9	118.2
22. Shell	124.7	123.5	119.8		118.2	123.5	118.2	106.2	113.8	113.8	117.8
23. Shell	125.1	123.8	118.9	118.1	118.1	124.4	118.8	104.8	111.5	113.1	118.4
24. Shell	125.4	123.7	119.4	117.6	117.7	123.6	119.2	105.3	111.3	112.5	118.3
25. C-4	123.6	123.3	122.5	121.1	120.7	122.2	117.9	108.0	115.9	116.2	117.2
26. C-4	123.1	122.5	122.6	121.4	121.8	122.5	117.3	108.5	115.9	116.2	117.5
27. Shell	125.4	123.8	120.2	118.3	120.0	123.6	118.8	106.2	114.0	114.1	117.8
28. Shell	125.0	123.6	120.0	117.2	118.7	123.8	119.1	106.7	112.9	114.3	118.3
29. Shell	124.6	123.7	120.3	119.0	118.3	123.6	118.2	106.1	113.5	113.3	117.1
30. Shell	124.6	122.8	120.6	118.9	118.1	123.3	118.2	107.2	113.9	114.0	117.1
31. C-4	123.2	122.1	122.8	121.9	121.0	122.2	117.2	108.5	116.7	115.9	116.8
32. C-4	123.7	123.0	123.4	122.5	121.5	122.1	117.6	109.7	117.8	117.9	116.9

APPENDIX B: DATA CALCULATIONS

Table B1 contains energy averages by microphone of like sources. For example, C1 is for the first set of C-4 charges, events 1 and 2. The raw data are taken from Appendix A. Station eight did not function properly so these data are omitted from Appendix B.

Table B2 contains the energy average of consecutive C-4 groups. For example, C12 is the average of groups C1 and C2 from Table B1. These data are used to form Table B3 and correct the data, S_i, for site factors such as wind which cause the sound propagation for a blast to depart from omnidirectional spherical spreading. The last column contains the energy average of the six microphone positions.

Table B3 contains the corrections to be added to corresponding shell data. In each case, CR i,i+1 is used to correct S_i. For example CR 4,5 is used to correct S_4. Each term in this table is formed in two steps. First, the difference between the corresponding term in Table B2 and the energy average for that set of blasts is found. Second, the difference between the energy average for that set and 119.0 dB is found. The entry in Table B3 is the sum of these two factors. For example, the first row, first column entry is +4.7 which is the sum of (123.7-121.8) + (121.8-119.0). Thus, in each case, the real entry is the difference between the data entry in Table B2 and 119 dB, where 119 dB is the standard value for 5 lb of C-4 set off on a 3-ft (0.9 m) post at a distance of 250 m.

Table B4 contains the S values from Table B1 corrected by the corresponding CR values in Table B3. This table also contains the energy average for all the HEAT-TPT and SABOT rounds.

Table B5 contains the HEAT-TPT and SABOT data, averaged to be symmetrical. That is, position 2 is averaged with position 8 and position 3 is averaged with position 5. (Positions 1 and 4 have no counterparts.)

Table B6 contains the data for the BNOISE 3.2 input. First, the data from Table B5 are extrapolated to fill every 30 degree position (rows 1 and 3 in Table B6). Second, the value for the rear of the gun (180 degrees) is subtracted from every other value (rows 2 and 4 in Table B6). In Table B6, the A values come from the averages in rows 1 and 3, and the "Average" values come from the averages in rows 2 and 4.

Tables B7 and B8 show calculated noise differences between inner and outer rings of microphones and averages based on these values, respectively.

Table B1
Average of Events by Grouping and Position

		Measurement Position									
Event(s)		1	2	3	4	5	6	7*	9*	10*	11*
1,2	C1	124.0	122.8	121.4	120.0	120.5	122.3	116.5	114.4	113.5	118.4
3,4	S1	124.8	121.6	117.8	114.5	116.6	121.7	116.2	109.7	110.4	117.3
7	C2	123.3	121.6	121.1	120.2	119.0	122.5	116.7	114.6	113.3	117.4
8,9,10,11	S2	124.1	121.6	118.1	113.9	116.1	121.1	116.1	108.4	109.9	116.2
12,13,14	C3	123.0	122.3	122.3	120.8	120.0	121.4	116.9	115.1	114.1	115.9
15,16,17,18	S3	124.2	122.9	120.0	115.2	118.1	122.8	118.1	112.9	111.7	116.6
19,20	C4	123.4	121.8	122.0	121.2	121.4	121.9	116.6	116.7	116.5	116.1
23,24	S4	125.3	123.8	114.2	117.9	117.9	124.0	119.0	111.4	112.8	118.4
25,26	C5	123.4	122.9	122.6	121.3	121.3	122.4	117.6	115.9	116.2	117.4
27,28,29,30	S5	124.9	123.5	120.3	118.4	118.8	123.6	118.6	113.6	113.9	117.6
31,32	C6	123.5	122.6	123.1	122.2	121.3	122.2	117.4	117.3	117.0	116.9

*Outer ring.

Table B2
Average of Consecutive Sets of C-4

	1	2	3	4	5	6	Average
C12	123.7	122.2	121.3	120.1	119.8	122.4	121.8
C23	123.2	122.0	121.7	120.5	119.5	122.0	121.6
C34	123.2	122.1	122.2	121.0	120.8	121.7	121.9
C45	123.4	122.4	122.3	121.3	121.4	122.2	122.2
C56	123.5	122.8	122.9	121.8	121.3	122.3	122.5

Table B3
Correction Table to Convert Measured Shell Data to Omnidirectional Site Independent Data re 5 lb of C-4 (119 dB at 250 m)

	Position					
	1	2	3	4	5	6
CR 1,2	4.7	3.2	2.3	1.1	0.8	3.4
CR 2,3	4.2	3.0	2.7	1.5	0.5	3.0
CR 3,4	4.2	3.1	3.2	1.8	2.0	2.7
CR 4,5	4.4	3.4	3.3	2.3	2.4	3.2
CR 5,6	4.5	3.8	3.9	2.8	2.3	3.3

Table B4
Corrected Shell Data by Group and Overall Average for the HEAT-TPT and SABOT re 5 lb of C-4 (119 dB at 250 m)

	Position					
	1	2	3	4	5	6
Group S_1	120.1	118.4	115.5	113.4	115.8	118.3
Group S_2	119.9	118.6	115.4	112.1	115.6	118.1
HEAT-TPT AVE.	120.0	118.5	115.5	112.8	115.7	118.2
Group S_3	120.0	119.8	116.8	113.4	116.1	120.1
Group S_4	120.9	120.4	115.9	115.6	115.5	120.8
Group S_5	120.4	119.7	116.4	115.6	116.5	120.3
SABOT AVE.	120.4	120.0	116.4	115.0	116.1	120.4

Table B5
HEAT-TPT and SABOT Data Averaged to be Symmetrical re 5 lb of C-4 (119 dB at 250 m)

	Position					
	1	2	3	4	5	6
HEAT-TPT	120.0	118.4	115.6	112.8	115.6	118.4
SABOT	120.4	120.2	116.3	115.0	116.3	120.2

Table B6
Input Data for BNOISE 3.2

		Position (degrees)												
		0	30	60[1]	90	120	150	180	210	240	270	300	330	Average
HEAT-TPT	value	120.0	118.9	117.8	117.1	115.6	114.2	112.8	114.2	115.6	117.1	117.8	118.9	117.4
	value re rear of gun	7.2	6.5	5.6	4.3	2.8	1.4	0	1.4	2.8	4.3	5.6	6.5	4.6
SABOT	value	120.4	120.2	120.0	118.7	116.3	115.7	115.0	115.7	116.3	118.7	120.0	120.2	118.6
	value re rear of gun	5.4	5.3	5.2	3.7	1.3	0.7	0	0.7	1.3	3.7	5.2	5.3	3.6

[1] Value altered from the 50° measurement position to the 60° standard position.

Table B7
Differences in dB Between the Inner and Outer Rings by Radial Position

	No. 2–No. 7	No. 4–No. 9	No. 5–No. 10	No. 6–No. 11
C1	6.3	5.6	7.0	3.9
S1	5.4	4.8	6.2	4.4
C2	4.9	5.6	5.7	5.1
S2	5.5	5.5	6.2	4.9
C3	5.4	5.7	5.9	5.5
S3	4.8	2.3	6.4	6.2
C4	5.2	4.5	4.9	5.8
S4	4.8	6.5	5.1	5.6
C5	5.3	5.4	5.1	5.0
S5	4.9	4.8	4.9	6.0
C6	5.2	4.9	4.3	5.3

Table B8
Selected Average Differences in dB Between the Inner and the Outer Ring by Position*

	No. 2– No. 7	No. 4– No. 9	No. 5– No. 10	No. 6– No. 1	Average
All HEAT-TPT Rounds	5.5	5.1	6.2	4.7	5.4
All SABOT Rounds	4.8	4.6	5.5	5.9	5.2
All Shells	5.1	4.8	5.8	5.4	5.3
All C-4	5.4	5.3	5.5	5.1	5.3

*This table indicates there is no measureable difference in the directivity pattern at 500 yards (457.2 m) vs. 250 yards (228.6 m).

APPENDIX C: PROPOSED STANDARD TEST PLAN FOR LARGE WEAPON NOISE MEASUREMENTS

1.0 BACKGROUND. The Army's Installation Compatible Use Zone Program (ICUZ) as defined in AR 200-1 seeks to achieve compatible land use development in areas adjacent to Army installations which are impacted or likely to be impacted by noise, other physical pollutants, or safety considerations. The technical part of the ICUZ program is the USA-CERL-developed Integrated Noise Contour System (INCS). Among other data, this system requires a specific data base on the noise emissions of the various Army weapons and weapon systems.

2.0 PURPOSE. The purpose of this plan is to define measurement and analysis procedures for developing blast noise emissions data for large Army weapons.

3.0 SCOPE. This test plan applies to all large Army weapon systems which produce blast noise. These weapons include artillery, armor, engineer ordnance and rockets that produce a blast-type sound on ignition. This plan pertains only to the ICUZ program; it does not relate to hearing conservation requirements or any other Army programs. All measurements are made in terms of sound pressure level.

4.0 REFERENCES

4.1 American National Standards Institute (ANSI) S1.11-1971 (R 1966) "Octave, Half-Octave, and Third Octave Band Filter Sets, Specifications for."

4.2 ANSI S1 4-1983, "Sound Level Meters, Specification for."

4.3 ANSI S12.7-198X, "Measurement and Analysis of Impulse Noise" (draft).

4.4 International Electrocommunication Commission (IEC) 225, "Octave, Half-Octave and Third Octave Band Filters Intended for the Analysis of Sounds and Vibration."

4.5 Alan Hunt and Paul D. Schomer, "High-Amplitude/Low-Frequency Impulse Calibration of Microphones: a New Method," *J. Acoust. Soc. Am.*, Vol 65, No. 2, pp 518-523, February 1979.

5.0 INSTRUMENTATION. Microphones, microphone systems, associated amplifiers and recording devices shall meet the requirements of ANSI S1.28.

5.1 **Tape recorders.** AM or FM recorders may be used if they meet the overall bandwidth requirements of 5 Hz to 5 kHz and have a dynamic range of at least 52 dB.

5.2 **One-third octave band analyzer.** The one-third octave band analyzer, if used, shall meet the requirements of ANSI S1.11 Class 3 or IEC 225.

5.3 **Acoustic calibration**

a. The entire instrumentation system, including the microphone or its cable, shall be calibrated at a convenient frequency before and after each test series. An acoustic calibrator with an accuracy of ±0.5 dB or better is required. If a wind screen is used, it shall not degrade the system below the requirements of ANSI S1.4 for type 1 sound level meters.

b. The step-function response of the entire system including microphones, preamplifiers, and any recording and analyzing devices shall be tested acoustically using the methods and apparatus described in Reference 4.5. This test shall be done before the start of measurements on a major weapon system. Alternatively, the step-function response of the electronic amplifiers, recording devices, and analyzing devices may be checked using an electronically generated step-function instead of the acoustically generated step-function coming through the microphone and its associated preamplifier.

c. The frequency response of the system with filters and microphones should be checked at the start of a major weapon system measurement program. If the microphone is not part of the system during this check, it shall be checked separately and certified using the manufacturer's approved test procedure.

5.4 **Anemometer.** An anemometer shall measure wind speed to an accuracy of ±10 percent for winds in excess of 1 meter per second.

6.0 REFERENCE LEVELS, MEASUREMENT LEVELS, FREQUENCY RANGE

6.1 The reference level for sound exposure level is $(20\ \mu Pa)^2$–s.

6.2 Measurement levels shall be in terms of C-weighted sound exposure level (CSEL).

6.3 The frequency range shall at least encompass 5 Hz to 10 kHz.

7.0 DEFINITIONS. The following definitions are in accordance with ANSI S12.7-198X.

7.1 **Impulse noise.** A single short burst or a series of short bursts of sound pressure. The pressure-time history of a single burst includes a rise to a peak pressure, followed by a decay of the pressure envelope.

7.2 **Instantaneous sound pressure.** Total instantaneous pressure at a point in the presence of a sound wave minus the static pressure at that point. Unit: pascal (Pa).

7.3 **Envelope.** Two idealized smooth, continuous lines respectively joining successive positive or negative peaks of the instantaneous sound pressure (Figure C1).

7.4 **Overshoot.** Ratio of the maximum output of the measurement system to the idealized final output in response to a step function input. Unit: percent (%).

7.5 **Peak sound pressure.** For any specified time interval, the maximum absolute value of the instantaneous sound pressure in that interval. Unit: pascal (Pa).

7.6 **Peak sound pressure level.** Maximum instantaneous sound pressure level that occurs during a specified time interval. Unit: decibel (dB).

7.7 **Signal rise time.** The time interval that a signal takes to rise from 10 percent to 90 percent of its highest peak value. Unit: second (s).

7.8 **Slew-rate limit.** Maximum rate of change of the system output in response to a step-function input. Unit: volt per second (V/s).

7.9 **Sound exposure.** Time integral of squared sound pressure. The frequency weighting, if any, shall be specified. Unit: pascal-squared second (Pa^2-s).

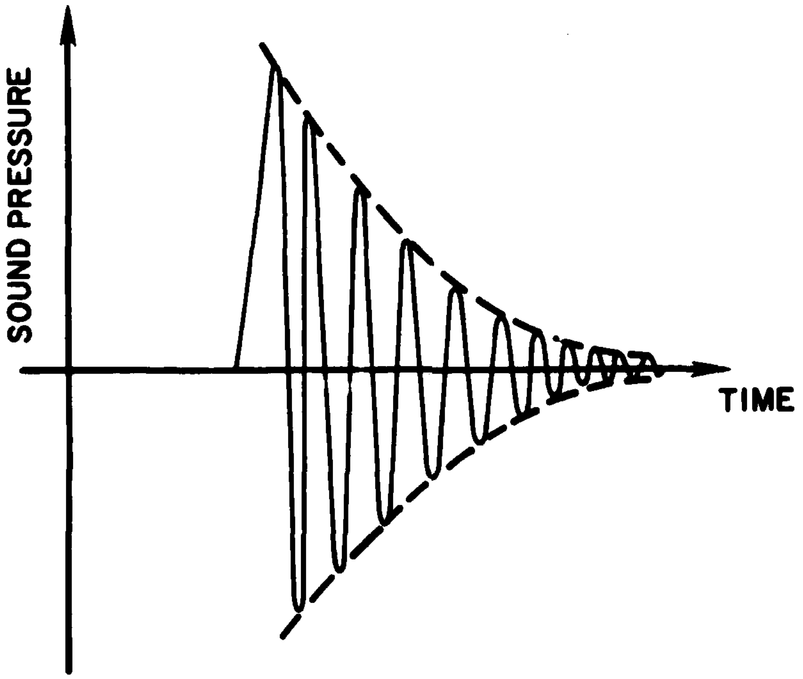


Figure C1. The burst envelope for an impulsive noise is illustrated by the dashed lines.

7.10 **Bandwidth.** Frequency range over which the response of a system is within zero to -3 dB of an idealized flat response. Unit: hertz (Hz).

7.11 **Droop.** The amount by which the system output drops below the idealized final output in response to a step-function input. Unit: percent (%).

7.12 **Dynamic range.** The difference between (1) the maximum signal level or sound pressure level for which the electrical or acoustical system operates within stated specifications and (2) the background noise level. Unit: decibel (dB).

a. The useful dynamic range is limited at low levels by acoustic noise or by electric circuit noise. The nature of the background noise limit should be stated explicitly (e.g., ambient noise, equipment noise, thermal noise).

b. The useful dynamic range is limited at high levels by overloading of the microphone or the electrical instrumentation. The nature of the overload condition should be stated explicitly (e.g., departure from linear response, signal distortion, overheating).

7.13 **Sound exposure level.** Ten times the common logarithm of the ratio of the sound exposure to the product of the squared reference pressure of 20 μPa and the reference duration of 1 s. The frequency weighting, if any, shall be specified. Unit: decibel (dB).

8.0 TEST SITE LAYOUT

8.1 **Normal microphone array.** The test site shall be a large, open, level grassy field. The test microphones are normally arrayed in two concentric circles around the noise source as shown in Figure C2. The inner array consists of six microphones equally spaced in a circle having a radius of 250 m. In the outer array, five equally spaced microphones form a circle having a radius of 500 m. All microphones shall be located on a grassy surface at least 15 m from the nearest hard surface. Small patches of trees or other vegetation are acceptable in the area between the two circles, but no trees or other large reflecting objects should be within 50 m of any microphone, nor within the circle formed by the inner microphone array. Microphones in the other array may not be located within the safety fan of the weapon under test. If the projectile speed of the weapon is such as to cause a sonic boom, the angle that microphones 2,5,7, and 11 make with the line of fire may have to be adjusted in accordance with section 8.2. This adjustment is required so that the sound arriving at the microphone from the weapon fire is separated in time from the sonic boom created by the projectile flight.

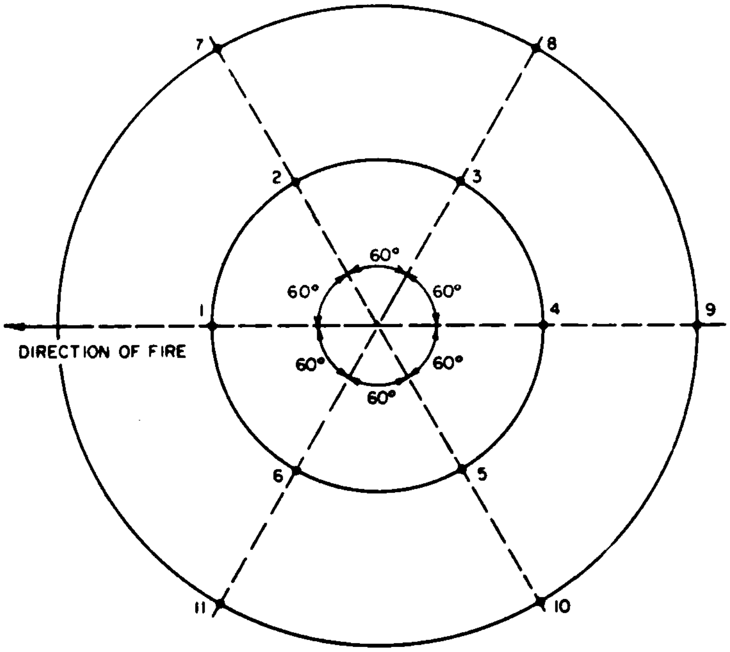


Figure C2. Microphone layout. (Radius of inner ring is 250 m; radius of outer ring is 500 m.)

8.2 **Microphone array adjustments for projectile speed.**

a. Definition of quantities:

M = Mach Number

= speed of projectile/speed of sound

c = speed of sound

= 331 + 0.6T

where T is the temperature in degrees centigrade

ϕ = elevation angle of gun under test

Ψ = angle that microphone makes with the line of fire. The starting and preferred value is 60°.

R = distance in meters from the firing position (gun) to the microphone

b. Calculations:

$$\theta_M = \cos^{-1}(1/M)$$
$$\Gamma = \cos^{-1}[\cos\Psi \cos\phi]$$
$$\xi = \theta_M - \Gamma$$
$$\Delta t = R/C\,(1 - (\sin\xi / M \sin\Theta_M) - (\sin T/\sin\theta_M)]$$

c. Criteria:

Δt must be greater than 30 ms.

If $|\Delta t|$ is greater than 30 ms when $\theta = 60°$, then 60° is the proper value for the measurements.

If $|\Delta t|$ is less than 30 ms and Δt is greater than 0, then increase θ by 5° and recalculate.

If $|\Delta t|$ is less than 30 ms and Δt is less than 0, then decrease θ by 5° and recalculate.

9.0 **Measurement Procedures.** The C-weighted sound exposure level shall be either directly measured for each firing of the weapon and for each C-4 calibration round, or recorded for later laboratory analysis. If a large central recording facility is used, it shall be at least 50 m from the nearest microphone. If individual portable recorders are used (with or without a human operator), they shall be no closer than 7-½ m to any microphone.

10.0 TEST OPERATION

10.1 **Site calibration.** The site is calibrated by using known 5 lb test charges. For this purpose, 5 lb of C-4 explosives shall be shaped into a circular ball and placed on a .9-m high post within 6 m of the center of the array. Detonation of the C-4 can be by either electric or nonelectric fusing. The C-4 calibration charge is used to correct the measured weapon data for any ground cover, terrain, or weather effects.

10.2 **Weapon fire.** The weapon under test shall be fired from the center of the array in the direction of the line of fire indicated in Figure C2. Approximately four rounds shall be fired in a row with two to three groups of four rounds used for each type of ammunition or charge size under test.

10.3 **Order of fire.** The order of fire shall consist of two to four leading C-4 calibration charges followed by a set of approximately four weapon rounds, followed by two C-4 rounds, followed by approximately four weapon rounds, etc. As explained below, the C-4 rounds are used to "correct" the raw weapon data for terrain, weather, and other site effects.

11.0 DATA ANALYSIS. Data analysis consists of nine steps as described in the following paragraphs. Examples are given in Appendix B.

11.1 **"Average" the various alternating groups of C-4 and weapons data by microphone position using Equation 11.1.**

$$L_{ave} = 10 \log \left(\sum_{i=1}^{N} 10^{(L_i/10)} \right) \Sigma\, 10^{(L_i/10)} \quad \text{(Eq 11.1)}$$

As an example, Table B1 represents such an averaging of the raw data in Appendix A. The line labeled C1 in the table represents the energy average of the first two events which were C-4 rounds, and the second line, S1, represents an energy average of events 3 and 4, the first two weapon events. Note that the weapon and C-4 groups alternate.

11.2 **Compute a table of the energy averages of adjacent sets of C-4 rounds by microphone.** That is, the averages of the first and second group of C-4 rounds are averaged together using Equation 11.1, and the averages of the second and third groups of C-4 rounds are averaged together by microphone using Equation 11.1, etc. Table B2 illustrates such an averaging process for the group averages in Table B1.

11.3 **Form a correction table from the consecutive sets of C-4 averages.** This table indicates the number of decibels that must be subtracted from each measured adjacent set average of C-4 data (Table B2) such that it then becomes the standard value of 119 dB at 250 m. These correction factors represent the values calculated in step 2 minus 119. Table B3 illustrates this correction table. In this example, 119 has been subtracted from each entry in Table B2 to yield the corresponding entries in Table B3.

11.4 **Correct and tabulate the weapons data by group using the correction values calculated in Step 3.** For example, correction values (1,2) are used to correct weapon group 1 by microphone, and correction values (2,3) are used to correct weapon group 2 by microphone, etc. In addition, each weapon type is averaged over all groups by microphone using Equation 11.1. Table B4 illustrates this tabulation. The values for correction factor (1,2) (Table B3) have been subtracted from the S1 group values in Table B1 and have yielded the first line in Table B4, the group S1 line. The other group lines were calculated similarly, and the two weapons were averaged by microphone using Equation 11.1.

11.5 **Make the weapon summary data calculated in step 11.4 symmetrical by microphone position.** The pairs of microphones (Nos. 2 and 6 and Nos. 3 and 5) shall be averaged separately using Equation 11.1, since the directivity pattern of the weapon should be symmetrical with respect to the line of fire. (Table B5 illustrates this operation performed by microphone on the weapon summary averages in Table B4.)

11.6 **Input data for BNOISE 3.2.**

a. **Correction for other than 60-degree angles.** If microphones 2 and 6 were located at other than 60 degrees with respect to the line of fire, their value must be adjusted by approximate linear interpolation to the 60-degree position. (For example, Table B6 shows the value at 60 degrees and 300 degrees to be 117.8 dB. These values were adjusted from the 50-degree and 310-degree position and a value of 118.4.)

b. **Addition of 30-degree angles not included in the original six microphones.** Approximate linear interpolation is used to include the six 30-degree positions not included in the original six microphones. These are the positions of 30, 90, 150, 210, 270, and 330 degrees. Again, symmetrical microphone positions must maintain the same value. For example, Table B6 shows these values included in addition to the six primary microphone positions (0, 60, 120, 180, 240, and 300 degrees).

c. **Energy average.** Calculate the energy average for the 12 microphone positions using Equation 11.1. For example, Table B6 shows the average for the HEAT-TPT round as 117.4.

d. **Directivity pattern.** Subtract the value at the rear of the gun, the 180-degree position, from all of the values calculated in paragraphs 11.6b and 11.6c. In this fashion, the value to the rear of the gun becomes 0 dB and all the other values show the directivity pattern relative to the rear of the gun. (This step is also illustrated in Table B6.)

11.7 **Calculate differences between the inner and outer rings of microphones.**

a. Using the values from the table calculated in step 11.1 above, calculate the differences in decibels between the outer and inner rings for microphone pairs lying on a radial. Table B7 illustrates this calculation. Normally, there would be five such entries for the five pairs of microphones since, in front of the gun, the outer ring omits the last microphone because of the safety fan. In the example, however, one of the outer ring microphones failed so there are only four comparison columns.

b. Calculate averages based on the values calculated in 11.7. Calculate decibel averages by microphone pair and for the overall average by each type of shell, by the total for the test, and by the total for the C-4. Table B8 illustrates such a table. In this example, the inner and outer rings are very regular with respect to the C-4, and the overall averages yield a value on the order of 5.3 dB.

11.8 **Test for a change in directivity pattern with distance.** The values in the table calculated in 11.7b must lie within ±1 dB of the average for that round, and the round averages must lie between ±0.5 dB of the overall average. In Table B8, for example, the HEAT-TPT rounds had an average of 5.4 dB. The largest difference—the difference between microphones 10 and 5—was 6.2 dB, which is within 0.8 dB of the average. All of the other examples in this table are within a closer tolerance of the average. Also, the averages for the four groups are 5.4, 5.2, 5.3, and 5.3 dB. The overall average is 5.3 dB, and in this case, the four group averages are within 0.1 dB of the overall averages.

11.9 **Correct for a change in directivity with distance.**

(1) If the data do not meet the criteria in step 11.8, calculate a new set of microphone data based on the outer ring, to be used in steps 11.1 through 11.6. This new set of starting data is similar to that in step 11.1 above but is based only on the outer ring and microphone 1. Add the average difference by group, calculated in step 11.7a, to each of the outer ring microphone values found in step 11.1 to form a new "approximate inner ring value." Combine these five new values with the microphone 1 data.

(2) Using the new set of raw group data described above, repeat steps 11.2 through 11.6 to form a new set of input data for BNOISE 3.2.

(3) Using the directivity values referenced to the rear of gun calculated for the inner ring and the outer ring separately, perform a decibel average by

direction for these corresponding sets, perform a decibel average of the average energy value calculated for the inner and outer rings, and calculate a new average value for the rear of the gun, using the Equation 11.1 from the averages calculated in this step. This forms the final input data for BNOISE 3.2 when the significant differences are found between the inner and outer ring.

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