ANALYSIS OF RECORDED SOUNDS FROM THE 1970 SHOOTING EPISODE AT KENT STATE UNIVERSITY

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James E. Barger
Creighton M. Gogos
Charles I. Malme
Scott Robinson
Douglas W. Steele
Caleb Warner
Jared Wolf

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U. S. Department of Justice
550 11th Street N.W.
Washington, D. C. 20530

Attention: Mr. J. Stanley Pottinger
Assistant Attorney General
Civil Rights Division

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ACKNOWLEDGEMENTS

Principal Investigators for this analysis effort were Mr. Malme and Dr. Barger. The extensive digital signal processing and computations were performed by Dr. Wolf, who was assisted by Mr. Steele. Analog signal processing, conditioning, and recording were done by Mr. Robinson, Mr. Steele, and Mr. Gogos. Data analysis and interpretation were done by Dr. Barger and Mr. Warner.

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1. INTRODUCTION

This report contains the results of our analysis of tape-recorded sounds from the 1970 shooting episode at Kent State University. This analysis was performed by Bolt Beranek and Newman Inc. over the time period extending from January 16 to February 25, 1974. This work was in support of the Grand Jury Investigation, and was under the direction of Mr. J. Stanley Pottinger, Head of the Civil Rights Division, U. S. Department of Justice. These results were explained to the Grand Jury on February 28, 1974.

2. DESCRIPTION OF RECORDED SOUNDS

2.1 Description of Acoustic Data Recorded By Mr. Strubbe

The primary acoustic evidence is a tape recording obtained by Mr. Terry Strubbe, with his tape recorder on the windowsill of his dormitory room in Johnson Hall. This tape recording was made continuously from about ten minutes before the onset of gunfire, through the gunfire sequence, and beyond. This is the only recording containing sounds of the onset of gunfire. Also available for our analysis is the tape recorder used by Mr. Strubbe. This recorder is of Japanese manufacture, and known as the Campus Pet.

Data analyses are designed to overcome three types of distortion we have found to be present on the Strubbe original recording of sounds originating near the shelter near Taylor Hall:

1. The Campus Pet recorder has deficient low-frequency acoustic sensitivity.
2. The sound recorded at the location of the Strubbe recorder is deficient in high-frequency energy.
3. The sound recorded at the location of the Strubbe recorder is highly reverberant.

The frequency response (fidelity) of the Campus Pet tape recorder and its microphone was measured and the recorded Strubbe data were corrected to restore fidelity. The procedure for this measurement and correction is described in Appendix A. The measurements disclosed that the low-frequency response is deficient. A compensation network was devised, and the original Strubbe tape recording was re-recorded through this compensation network. The resulting re-recording is referred to in this report as the compensated Strubbe recording, and has the same frequency response as would have been obtained with a high-quality (high-fidelity) tape recorder.

The location of the Campus Pet recorder is such that all sounds reaching the microphone from the vicinity of the shelter near Taylor Hall must pass around and over Johnson Hall, or propagate through Johnson Hall itself. Sound propagation over these paths greatly attenuates high frequency energy of the gunfire sounds. Therefore, the acoustic information about the gunfire episode on the Strubbe recording is useful only in the low-frequency range, generally below 500 Hz. In addition to the loss of high-frequency energy, the Strubbe recording contains much reverberation. There are many separate paths by which the low-frequency sound from near Taylor Hall can reach the microphone. The time difference between arrivals of the various echos from a single shot exceeds the average time between shots. The complex echo structure from each shot is referred to as reverberation. The reverberation from each shot is intermingled with reverberation from preceeding shots. Therefore, it is extremely difficult to isolate single gunfire occurrences on the Strubbe tape without resorting to acoustic signal analysis techniques.

2.2 Description of Acoustic Data Recorded By WKYC-TV

A secondary, but important, source of acoustic data is the sound track made by the WKYC-TV camera man. The location of the microphone was in direct line of sight with the majority of the National Guardsmen. The effects of reverberation and high frequency loss on the TV recording is much less serious than on the Strubbe recording. The TV recording was not begun until about 4.34 seconds after the first recorded sound of gunfire on the Strubbe recording.

The tape recording provided to us by ESL Inc., and made from the sound track on the TV recording, was found to be deficient in low-frequency sound energy. We determined from the manufacturer of the microphone and of the camera that the low-frequency response of the equipment was purposefully attenuated at low frequency to minimize wind noise. We constructed an equalization network for the TV tape recording to compensate for this deficiency. The procedure for this is described in Appendix A. A re-recording of the TV sound track was made through the compensation network. This re-recording is called the compensated TV recording. It has the same property as a recording that would have been made through a high quality (fidelity) tape recording system.

2.3 Description of Acoustic Recording by Mr. Lord

A third tape recording was made available to us, that had been recorded by Mr. Lord. Like the TV tape, this recording was turned on about four seconds after the onset of gunfire. The acoustic data recorded on this tape are of no analytical value because the record setting of the Lord recorder was such that gunfire sounds caused electrical overload. This means that the signals had been hopelessly distorted. For this reason, no further analysis of the Lord recording was made, and no results from this recording are reported.

2.4 Description of Acoustic Recording by Mr. Titchenal

A fourth tape recording was made by Mr. Titchenal. Like the Lord recording, the Titchenal recording was turned on about four seconds after the onset of gunfire. Also, this recording was badly overloaded due to an inappropriate record-level setting. No further analysis of this recording has been made, or is reported herein.

2.5 Description of Aberdeen Proving Ground Gunfire Recordings

It was our plan to obtain undistorted tape recordings of the four types of weapons in the possession of the National Guard during the shooting incident. The sound data on these tape recordings could then be compared with the sound data on the Strubbe compensated recording, to determine which type of weapons were fired.

The tape recordings of the weapons fired separately and distinctly were obtained at the Aberdeen Proving Ground. These measurements were arranged by Mr. Charles Ravitsky, of the Advanced Research Projects Agency. The measurements at Aberdeen Proving Ground were made on January 31, 1974, by Mr. H. Forst. The following weapons were tested: 1) Pistol, Caliber 45, Serial #M1911A1NM; 2) Rifle, Caliber 30, M1; 3) Shotgun, Remington Model 11-48, 12 gauge; 4) Grenade Launcher, M79, 40 mm. The sound of these weapons firing were measured at ranges of 50 feet and 500 feet, both with aspect angles from the side, from the rear, and from the front. Live ammunition was used in all cases.

3. DESCRIPTION OF DATA ANALYSIS TECHNIQUES

3.1 Spectral Analysis with Cepstral Smoothing

A single gunfire impulse, or even the combination of impulses created in a reverberant environment, carries information that is frequency-dependent. We anticipate that different types of weapons have impulses with different frequency content. The analysis of an impulse or a series of impulses into frequency components is known as spectral analysis. The result of a spectral analysis is a graph known as an energy density graph or as an energy spectrum. Our procedure was to play the compensated data recordings into the analog to digital (A/D) interface of the BBN computer system, and to compute energy density graphs of selected portions of the data. The details of this procedure are described in Appendix B. A part of the nature of the spectral analysis of a single impulse is a rather uneven distribution of energy with frequency. This uneveness is an artifact caused by the arbitrary selection of a time segment of data. To smooth the data; i.e., to remove the artifacts, we have employed a technique called cepstral smoothing. This process is carried out on the BBN computer and is described in Appendix B.

3.2 Correlation Analysis

The spectral analysis is useful for determining which type of weapon is discharged, but in a reverberant environment it is not a good technique to determine when or how many weapons were fired. An analysis called correlation was used by us to determine the number of shots fired, and approximately the location from which these shots were fired.

There are two types of correlation analysis. The autocorrelation of an impulse is a mathematical measure of how well an impulse occurring at one time resembles itself occurring at a slightly later time. The crosscorrelation of two impulses is a mathematical measure of how well an impulse occurring at one time resembles another impulse occurring at a slightly later time. In both cases, the"slightly later time" between occurrences is a variable. Graphs of the correlation as functions of the variable "slightly later time" are called correlograms.

We computed and graphed correlograms by digitizing the impulsive data and computing in the BBN computer, as described in Appendix B.

3.3 Echo Pattern Analysis

The high frequency energy recorded by the Strubbe recorder is so badly attenuated, that only very low frequency energy remains. In this frequency range, the energy spectra of various weapons resemble one another to a rather close degree. Therefore an alternate analysis was developed, namely, the echo pattern analysis. To accomplish this, a re-creation of all features of the shooting episode important to low-frequency sound was conducted on February 18, 1974, at the site of the gunfire episode.

A series of test locations was chosen, and impulsive sound sources having sufficient low-frequency sound energy were discharged at each of these places. Two types of impulsive sources were used: an M1 rifle firing blank cartridges, and a cannon firing 10 gauge shotgun shells. These signals were recorded both at the location of the TV camera and at the location of the Campus Pet recorder. These signals were analyzed on the BBN computer to show the pattern of acoustic echos that would be recorded at each location for a test signal at each test location. These patterns were then crosscorrelated with the echo patterns on the equalized Strubbe tape recordings. Similarity (high crosscorrelation) of the time sequence of echos on the Strubbe recording with one of the echo patterns obtained during the reconstruction would indicate that the shot in question was fired from very near that test location.

3.4 Aural (Listening) Analysis

The entire equalized Strubbe recording was listened to through a high-fidelity amplifier and speaker system. We listened intently for evidence of events related to the shooting during the 10-minute periods before and after the main gunfire sequence.

3.5 Data Preserved

Appendix C is a list of the data files that have been created from the acoustic recordings. These files will be stored on magnetic tape until we are requested by U. S. Department of Justice to destroy them. Copies of numerical program will be preserved also to enable exact re-computation of the results contained herein.

4. RESULTS OF SPECTRAL ANALYSIS

4.1 Aberdeen Weapon Firings

The energy spectra of the four weapons fired at Aberdeen Proving Ground are shown in Fig. 1. The frequency range extends from 40 Hz to 2 kHz, and the energy spectra are plotted in decibels (dB), with a common arbitrary reference.

The energy spectra are shown for a single shot at 500 ft range and rear aspect. The 500 ft range was selected because this choice avoids impulse interference from ground reflections. The site of shooting is generally on a hilltop, so that ground reflections are not important.

Examination of the energy spectra in Fig. 1 shows that the shotgun blast contains about 4 dB more energy at 150 Hz than the rifle blast. The shotgun blast contains about 10 dB less energy at about 1500 Hz, however. The pistol blast contains about 13 dB less energy than the rifle blast at 150 Hz, but contains about the same energy as the rifle blast at 1500 Hz. The grenade launcher blast contains about 9 dB less energy at 150 Hz than the rifle blast, but contains about 15 dB more energy than any other weapon blast at about 500 Hz.

These differences are sufficient to distinguish with confidence between the discharge of the four weapons, provided interfering noise is not present. The 3 dB fluctuations in the data at frequencies above about 500 Hz are not significant.

4.2 Compensated WKYC-TV Recording

The energy spectrum of the ambient noise recorded by the TV camera during the time interval containing no shots and just prior to the last shot is plotted in Fig. 2. This energy spectrum represents a floor for the spectral analysis of shots on the TV recording. The energy spectra of recorded gunfire must exceed the ambient spectra to be visible.

The energy spectrum of the last shot (shot No. 44 on the TV recording) is shown in Fig. 2. Segments of the graph corresponding to noise are omitted. This event is judged to be a rifle shot as a result of the cross-correlation analyses. Comparison of the energy spectra in Fig. 2 and Fig. 1 also shows that the last shot is probably a rifle.

Figure 3 shows the energy spectrum of shot number 6, which occurred at 2.402 seconds into the TV recording. The ambient noise energy spectrum was taken during a lull at 3.200 seconds into the TV recording. Comparison of Fig. 3 with Fig. 1 indicates that this weapon was a 45 caliber pistol.

Two energy spectra are shown in Fig. 4, corresponding to shots 28 and 29. These two shots are among 5 shots of a rapid-fire episode from a single weapon. These energy spectra are judged to correspond to a rifle discharge, both as a result of the correlation analyses and as a result of comparison to Fig. 1.

Figure 5 is the energy spectrum of shot number 43. Comparison to Fig. 1 indicates that the weapon was a shotgun.

4.3 Compensated Strubbe Recording

The energy spectrum of the last shot is shown in Fig. 6. The ambient noise level shown on Fig. 6 was taken during the lull just prior to the last shot. More of the energy spectrum for the last shot as recorded by Strubbe than as recorded by TV is obscured by noise. This is because sound must diffract around Johnson Hall to reach the Strubbe location. Also, comparison of the last shot recorded by Strubbe (Fig. 6) with the last shot recorded by WKYC-TV (Fig. 2) shows that the two different sound paths have different frequency characteristics. This is caused by the Fresnel diffraction pattern for sound diffracting around the corner and roof of Johnson Hall.

All energy spectra analyzed from the compensated Strubbe tape can be corrected for the Fresnel diffraction pattern by adding a correction equal to the difference between the energy spectra of Figs. 2 and 6. This difference cannot be determined at all frequencies because of data obscured by noise. Table 1 lists the correction factor at the frequencies at which it can be computed.

The energy spectrum shown in Fig. 7 is for the fourth shot. The ambient noise limit on this energy spectrum was taken just prior to the first shot. Also shown in Fig. 7 is an energy spectrum corrected for the diffraction pattern. Comparison of this corrected spectrum with Fig. 1 shows that the fourth weapon fired was probably a rifle.

TABLE 1: CORRECTION FACTOR FOR ENERGY SPECTRA MEASURED AT STRUBBE LOCATION

Frequency Hz	50	80	100	150	200	250	300	350	450	500	1300
Correction in dB	-3	3	6	9	7	5	0	-8	-5	0	-6

The energy spectrum of the third shot is shown in Fig. 8. The ambient noise limit was taken just prior to the first shot. Comparison of the corrected spectrum with Fig. 1 shows that the third weapon fired was probably a rifle.

The energy spectrum of the second shot is shown in Fig. 9. Comparison of the corrected spectrum with Fig. 1 shows that the second weapon fired:

1. is not a pistol, because there is too much low-frequency energy
2. is not a shotgun, because there is too much high-frequency energy
3. is not a grenade launcher, because there is not enough 500 Hz energy
4. is probably a rifle, except for the peak of energy at about 800 Hz.

Four separate rifle shots were fired at Aberdeen Proving Ground. The peak of 800 Hz energy appeared in one of them. *

The energy spectrum of the first shot is shown in Fig. 10. Comparison with Fig. 1 shows that the first weapon fired is probably a rifle. The low-frequency energy peak is about 3 dB lower for the first and second shots than for the third and fourth shots. This difference is the same as the difference in level among the test shots received at the Strubbe location and fired from the test positions 1-10 used in the echo-structure analysis (see p.15).

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* The energy spectra of weapon muzzle-blast impulses measured at Aberdeen and plotted in Fig. 1 are for a single shot from each weapon. Multiple shots were recorded and analyzed on an analog spectrum analyzer.

5. RESULTS OF CORRELATION ANALYSES

5.1 Compensated WKYC-TV Recording

The correlograms obtained by crosscorrelating three individual shot impulses with the entire compensated WKYC-TV recording are shown on Plate 1. The three shots used in the crosscorrelation analyses are:

1. Last shot, occurring at 9.98 seconds on the TV tape, believed to be a rifle.
2. Shot occurring at 5.75 seconds on the TV tape, believed to be a rifle.
3. Shot occurring at 6.73 seconds on the TV tape, believed to be a rifle.

The correlograms have been squared to simplify their reading, and the time scale is marked beneath each record in seconds.

The purpose of the correlograms is to clearly identify the number of shots and the time the shots were fired. Examination of Plate 1 reveals a total of 44 shots fired over an 8.19 second interval. Large values of correlation indicate that the weapon fired at the time of the large correlation is the same weapon as the weapon being used in the correlation. For example, we see that shots No. 13, 20, 23, 25, 27, 28, 29, 30 are apparently from the same weapon. Similarly, shots No. 11, 14, 21, 32, 35 are apparently from the same weapon. The last shot appears to be from the same weapon that fired shots No. 22, 24, 34, 36, 37, 41.

The results of this analysis are summarized in Table 2. The shots are numbered, and their time of occurrence is shown from an arbitrary mark before the TV tape recorder was turned on. The large values of correlation indicating that a given shot is the same as one of the three shots correlated with the TV tape are marked. The large values of correlation at the three shots used in the correlation analyses are market AUTO. Energy spectra for most shots were examined, and the judgement about weapon type is listed.

TABLE 2: RESULTS OF CORRELATION ANALYSIS

Shot No.	Time	shot at 5.75 sec.	shot at 6.73 sec.	last shot	weapon
1	1.79				rifle
2	1.80				-
3	1.92				rifle
4.	2.13				rifle
5	2.23				pistol
6	2.40				pistol
7	2.64				rifle
8	2.66				-
9	2.74				-
10	2.82				-
11	2.86		x		rifle
12	2.91				-
13	2.99	x			rifle
14	3.39		x		rifle
15	3.61				rifle
16	3.70				rifle
17	3.80				rifle
18	4.16				rifle
19	4.18				rifle
20	4.32	x			rifle
21	4.45		x		rifle
22	4.62			x	rifle
23	4.86	x			rifle
24	4.95			x	rifle
25	5.29	x			rifle
26	5.48				shotgun
27	5.55	x			-
28	5.75	AUTO			rifle
29	5.95	x			rifle
30	6.16	x			-
31	6.31				rifle
32	6.41		x		rifle
33	6.43				-
34	6.50			x	rifle
35	6.73		AUTO		rifle
36	6.91			x	rifle
37	6.95			x	-
38	7.13		x		rifle
39	7.18		x		-
40	7.55				pistol
41	7.67			x	rifle
42	7.88				-
43	8.03				shotgun
44	9.98			AUTO	rifle

5.2 Compensated Strubbe Recording

The correlograms obtained by crosscorrelating the first three shot impulses with the entire compensated Strubbe recording are shown on Plates 2 and 3. The correlograms have been squared to simplify their analysis, and the time scale is marked below each record in seconds. Table 3 summarizes the results.

TABLE 3: RESULTS OF CORRELATION ANALYSIS ON STRUBBE RECORDING

Shot No.	Time	First	Second	Third
1	2.65	AUTO		
2	2.98		AUTO	
3	3.37			AUTO
4	3.63			
5	3.82			
6	3.93			
7	3.99			
8	4.59			
9	4.76			
10	5.00			
11	5.16			
12	5.25	x		
13	5.34		x	
14	5.62	x		
15	5.73	x		
16	5.85			x
17	5.95			
18	6.10			
19	6.29			
20	6.41		x	
21	6.60			x
22	6.83			
23	6.99	x		

Remaining shots recorded on TV tape

Table 3 shows that the first weapon fired probably fired again about four times, the second weapon probably fired twice more, and the third weapon probably fired twice more. Table 3 shows that 23 shots were identifiable in the interval between the beginning of firing and the time when the WKYC-TV camera was turned on. We count, therefore, a total of 67 shots fired during the gunfire sequence.

6. RESULTS OF ECHO PATTERN ANALYSIS

6.1 Location of Test Sites

A series of fourteen test sites was chosen. The location of these sites is shown on the scale drawing, Fig. 11. Sites 1-10 (excluding site 6) correspond to locations occupied by the National Guardsmen during the shooting incident. These sites were chosen after careful analysis of photographs taken at about the time of the shooting. Site 6 corresponds to the possible location of impulsive sound located in front of the line of Guardsmen. Sites 11-14 correspond to possible locations of impulsive sound caused by that part of the crowd of spectators and students in the vicinity of casualties.

Also shown on Fig. 11 is the location of our microphone intended to be at the same place as the WKYC-TV camera, and the location of Mr. Strubbe's room in Johnson Hall.

6.2 Measurement of Echo Patterns

At least three impulsive sound sources were detonated at each of the 14 test sites. An M-1 rifle containing blank cartridges was fired once at a 45 degree angle to the vertical and once horizontal to the ground. Next a 10 gauge blank shotgun shell was detonated in a starter's cannon. These impulses were designated by the number of the test site followed by a suffix V (45 degrees from vertical), H(horizontal), S(10 ga. cannon).

The windows were opened in Johnson Hall according to photographs taken during the shooting incident. The door to Strubbe's room was normally closed during the test firing sequence. At test sites 5, 10, and 11 the three shot sequence was repeated with the door open.

Preliminary analysis of the echo patterns on the Strubbe recording showed that a significant path of sound arrived about 100 ms later than the first arrivals. Photographs of the vicinity of Johnson Hall showed a VW microbus in the second (from Johnson Hall) stall of the parking lot in front of Strubbe's room. Several sedans were parked beyond. This pattern of parked cars was reproduced for the test shots.

Photographs of the Guardsmen show a shoulder-to-shoulder rank along a line extending over the locations of our test sites. Such a dense line of people will act as a significant acoustic baffle for impulsive sounds originating in front of the line, as in a muzzle blast from a rifle pointed in the horizontal plane. The office of the Chief of Campus Police provided us with twenty persons who deployed about each test site at the time of firing, in the manner of the Guardsmen during the shooting incident.

No attempt was made to re-create the locations of individual persons, temperature or humidity conditions, leaves on trees, or wind conditions because sound at frequencies below 300 Hz and propagating over distances of a few hundred feet is not sensitive to these details.

The recording apparatus used to record the test sounds at the WKYC-TV camera location and at the Strubbe recorder location are described in Appendix A. These recordings were digitized and analyzed on the BBN computer as described in Appendix B.

6.3 Test Site Echo Patterns

The recorded signals measured at the location of the WKYC-TV camera and at the location of the Strubbe recorder were squared and plotted as a function of time at 10 inches/sec. The results for measurements at the Strubbe location for test sites 1-10 are shown on Plate 4. The results for test sites 11-14 are shown on Plate 5. Each spike is to be interpreted as representing the arrival of the test-sound impulse at the microphone over a single path. The height of each spike is proportional to the sound energy arriving over that path. The maximum energy of each test signal has been normalized on Plate 5 to a constant value to facilitate viewing. The relative energies in decibels of the strongest sound path from each site are listed in Table 4.

Echo patterns from test sites near the corner of Taylor Hall generally show two nearly equal energy paths arriving first. Our measurement of propagation time between firing of the test shot and arrival time of the first impulses indicates that these early arrivals are via diffraction over the roof of Johnson Hall and around the North West corner. About 90 ms later a second major echo arrives. This echo is reflected from the VW microbus, which has a direct line of sight to the test sites. The difference between test sites 1-6 can only be recognized by the precise difference between these two major arrival paths.

Echo patterns from test sites 7-10 are more complex. Added to the diffracted paths are reflections from Taylor Hall. Great differences are seen between different test sites.

Echo patterns from test sites 11-14 are grossly different, being of much greater total time duration. The pattern from location 11 shows arrivals of nearly equal energy separated in time by more than one sound. Thus, sound arriving over the second path has travelled 1100 feet further than over the first path, which is itself only about 500 feet long.

The energies of the strongest path to the Strubbe location are within a range of 3 dB for test sites 1-10. The energies of the strongest path to the Strubbe location from test sites 11-14 are about 15 dB lower than from test sites 1-10.

6.4 Correlation of Test-Site Echo Patterns With Strubbe Recording

The eye can be used to judge similarities between the test-site echo patterns and the pattern of echos on the Strubbe recordings of the relatively isolated shots: namely, the first three and the last. Our mathematical measure of similarity, the cross-correlation, can be used more reliably, however.

To cross correlate the echo patterns, they were first squared and boxcar integrated for 1 ms. This process represents each echo pattern in terms of the time sequence of energy arrival, and removes all phase information. These patterns were then cross-correlated according to the methods described in Appendix B. The resulting correlograms are displayed in Plates 6, 7, and 8. The amplitudes of each correlogram are normalized to the same peak value, to facilitate viewing. The values of the peak cross-correlation for each of the test shots correlated with the first three and last shot on the equalized Strubbe recording are tabulated in Table 4.

A reliable measure of similarity between any test shot echo pattern and between any shot echo pattern recorded by Strubbe contains three characteristics:

1. large peak crosscorrelation,
2. a single peak for each shot,
3. a peak that occurs at the actual time of the onset of echo pattern on the Strubbe recording.

TABLE 4: VALUES OF CROSSCORRELATION BETWEEN TEST SITE ECHO PATTERNS AND FOUR SHOTS RECORDED BY STRUBBE

Test Site No.	gain relative to Test Site 1(dB)	first shot	second shot	third shot	last shot
1 H	0	264	556	688	847
3 V	2	283	439	745**	822
3 H	3	308**	564**	769**	820
4 V	-3	286	523	669	762
4 H	-1	281	536	716	818
5 VO	-2	276	550**	728	777
5 VC	-5	-	524	640	903
6 V	-2	274	546	720	770
7 V	-1	276	441	663	883
7 S	0	-	433	619	928**
8 V	-3	-	460	582	981**
9 H	-3	266	546	677	750
10 V	-2	273	495	645	793
11 V	-18	-	-	-	704†
12 VC	-13	-	583†	637†	805†
13 S	-18	-	565†	674†	861†
14 S	-18	-	695†	603†	938†

The table indicates with ** the values of peak cross-correlation that are largest for each shot and whose peaks occur at the proper time for each shot. The test sites corresponding to these data have echo patterns that most closely resemble the particular shot echo pattern recorded by Strubbe against which the test site echo pattern was crosscorrelated. The values of crosscorrelation from test sites 11-14 are excepted from the above comparison because the energy from these test sites is about 15 dB lower than from test sites 1-10, while all shots recorded by Strubbe had energy within about an 8 dB range.

The values of crosscorrelation with the first shot are maximum for test site 3 H. This would indicate the first shot was fired about half-way between Taylor Hall porch and the shelter, in a horizontal position. Examination of the correlogram on Plate 6 shows that two peaks occur in the correlogram near the time of the first shot. A single peak would result from a near-perfect match with the test site echo pattern. No test site gives a single peak. Therefore the site 3 H is the best match, although no test site gives a perfect match.

The values of crosscorrelation with the second shot are maximum for test sites 5 VO and 3 H. This would indicate that the second shot was fired between sites 5 and 3, which are only 10 feet apart. The weapon was high if at 5 or high or low if at 3*. The door to Strubbe's room would have to be open. Examination of the correlograms on Plate 6 shows that one single clean peak occurs at the time of the second shot, a near-perfect match.

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* see next paragraph

Values of crosscorrelation with the third shot are maximum for test sites 3 V and 3 H. This would indicate that the third shot was fired near test site 3. The echo patterns cannot distinguish between high and low muzzle positions at test site 3. Examination of the correlograms on Plate 6 shows that two large and distinct peaks occur at the time of the third shot. This would indicate that what has been considered to be one shot (the third) is actually two fired only about 20 ms apart. The low-frequency energy in the energy spectra of what was though to be the third shot was found to be about 3 dB greater than for the first and second shots (See Figs. 8, 9, 10). The energy spectra of two similar impulses would be 3 dB greater than the energy spectra of one.

Values of crosscorrelation with the last shot are maximum for test sites 7 S and 8 V. This would indicate that the final shot was fired somewhere between test sites 7 and 8, and with the muzzle high. Examination of the correlograms on Plate 7 shows a single and distinct peak at the time of the last shot on both of the test site correlograms. This indicates a good match.

7. FINDINGS

7.1 The First Shot

We find that the first shot was not fired by a 45 caliber pistol, an M-79 grenade launcher, or a shotgun. The energy spectra of the muzzle blast of these weapons are incompatible with the energy spectrum of the first shot. The energy spectrum of the first shot is compatible with the energy spectrum of the muzzle blast of an M-1 rifle. The first shot was not fired from near our test sites 1 or 7-14. Of the remaining sites, site 3 is the best candidate. The match for the first shot with site 3 is not as good as the matches achieved for the second, third, and last shot.

7.2 The Second Shot

We find that the second shot was not fired by a 45 caliber pistol, an M-79 grenade launcher, or a shotgun. The energy spectrum of the second shot is compatible with the energy spectrum of the muzzle blast of 1 of 4 test shots with an M-1 rifle. The second shot was probably fired from a position near the line connecting our test sites 3 and 5. The muzzle was probably high.

7.3 The Third Shot

We find that the third shot was not fired by a 45 caliber pistol, an M-79 grenade launcher, or a shotgun. The energy spectrum of the third shot is compatible with the energy spectrum of one or two M-1 rifle muzzle blasts fired nearly simultaneously. The third shot (possibly two shots) was probably fired very nearly at the location of our test site 3. The muzzle was probably low.

7.4 The Last Shot

We find that the last shot was fired by an M-1 rifle. It was located somewhere between our test sites 7 and 8, and the muzzle was probably high.

7.5 Rapid-Fire Sequence

We find that 5 shots were fired from an M-1 rifle in a 0.87 second period beginning 3.50 seconds after the first shot on the TV recording. This rifle was located somewhere near our test site 1.

7.6 Aural Investigation

We find that no sounds resembling gunfire were recorded on the Strubbe recording apart from the gunfire sequence beginning with two shots separated by 0.24 seconds and extending for a period of 12.53 seconds. The recording was continuous for at least 10 minutes before the gunfire sequence.

7.7 Number of Shots

We find that a minimum of 67 shots were fired during the gunfire sequence. Apart from the first four shots, the first 4.34 seconds of the sequence have not been studied to determine which weapons were fired. The last 8.19 seconds have been so studied. We find the following minimum number of shots from each weapon type:

M-1 rifle: 32

45 caliber pistol: 3

12 gauge shotgun: 2

M-79 grenade launcher: 0

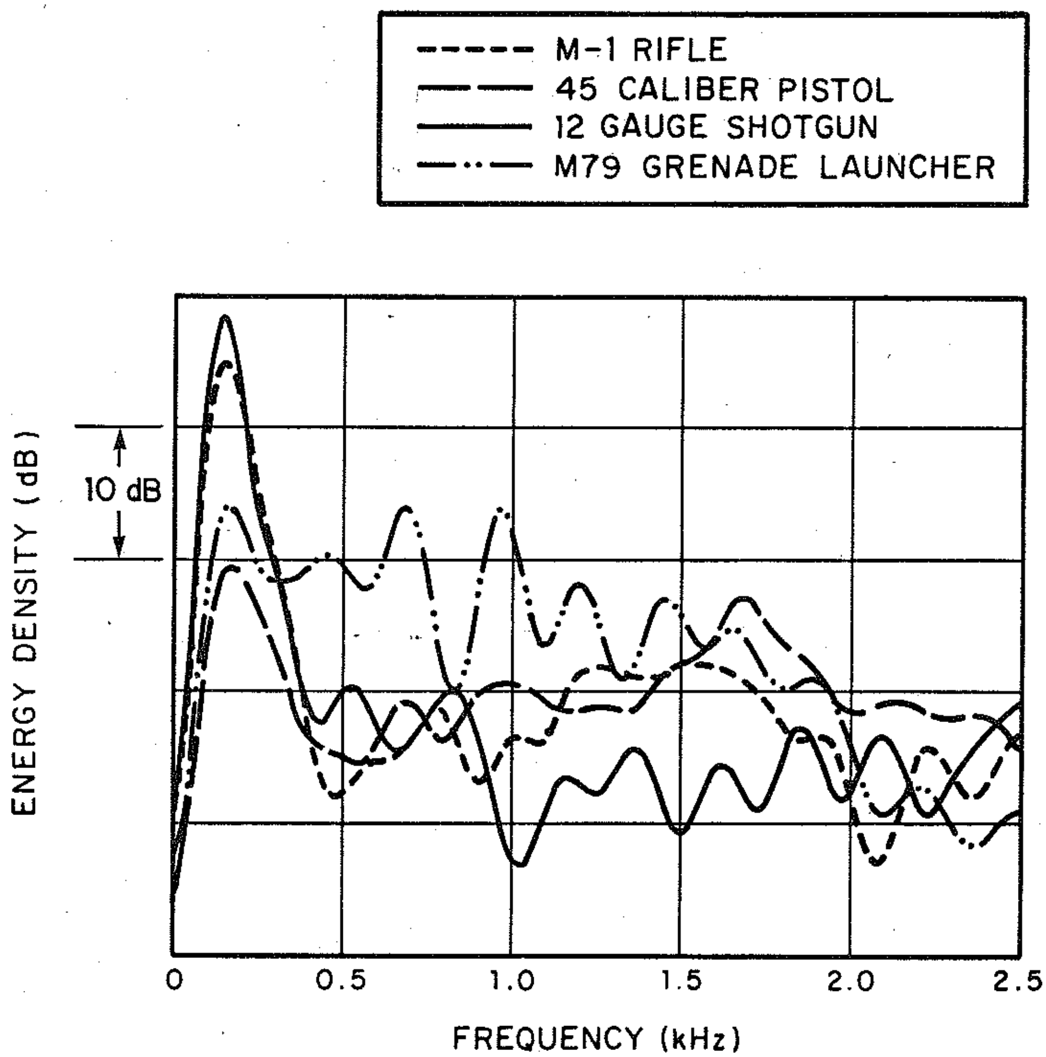

Fig. 1: Energy Spectra of Weapons Test-Fired at Aberdeen Proving Ground

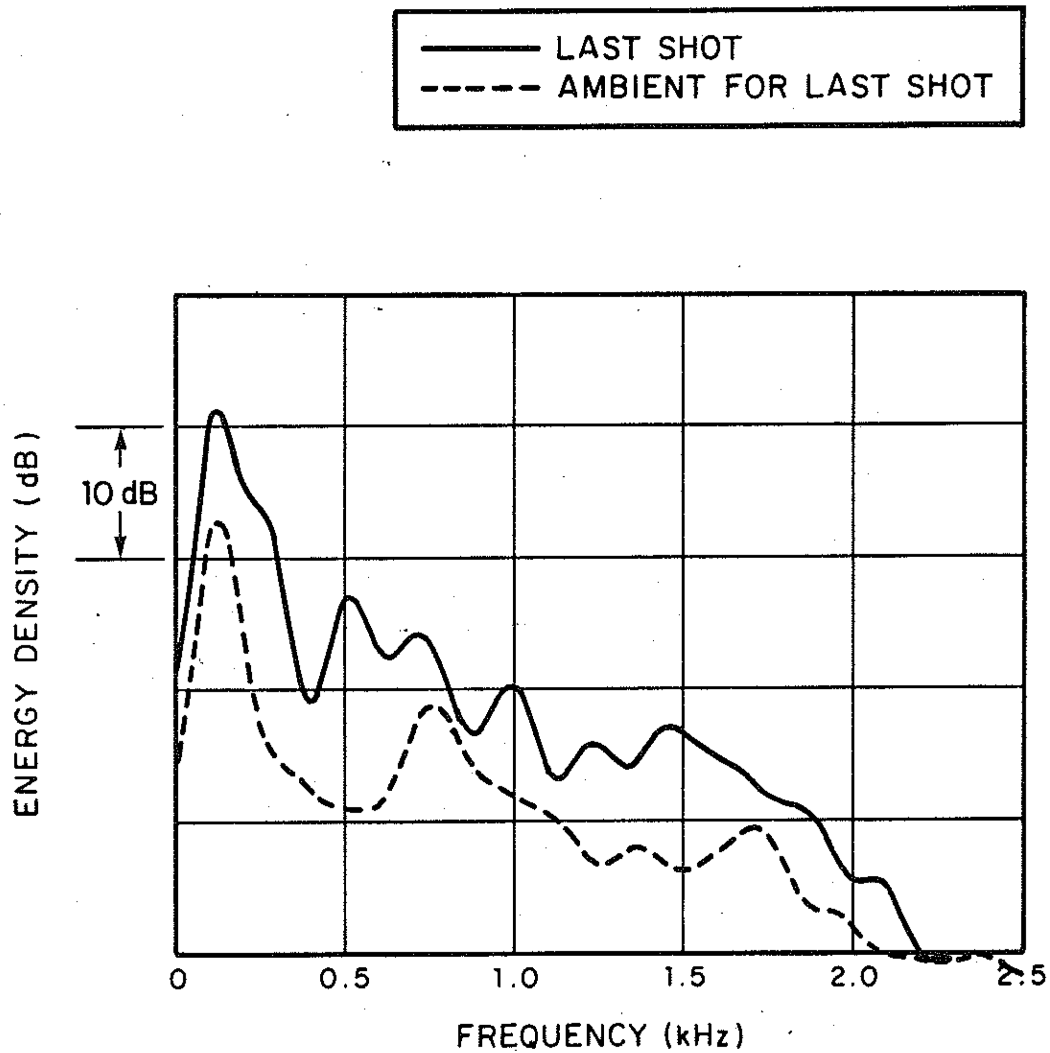

Fig. 2: Energy Spectrum of Last Shot on Compensated WKYC-TV Recording

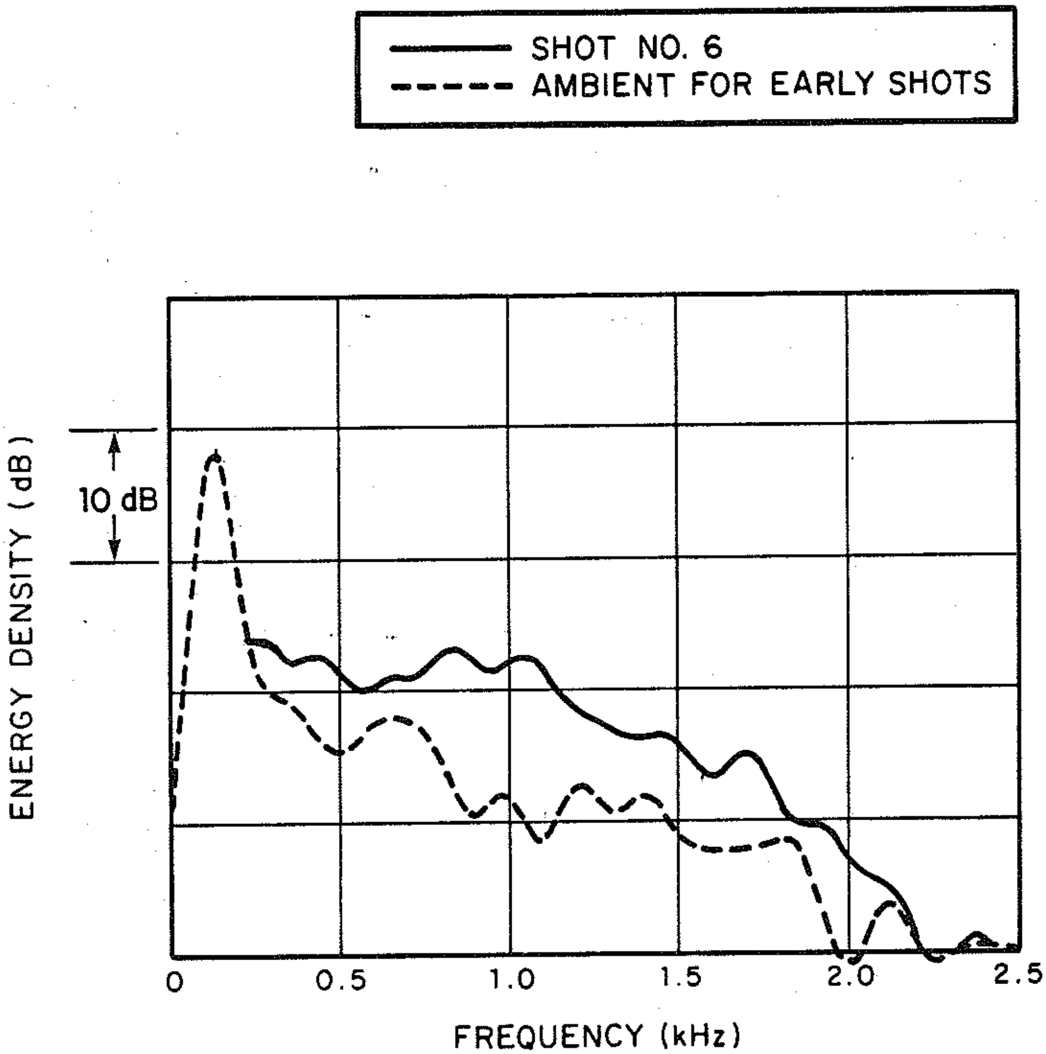

Fig. 3: Energy Spectrum of Shot 6 on Compensated WKYC-TV Recording

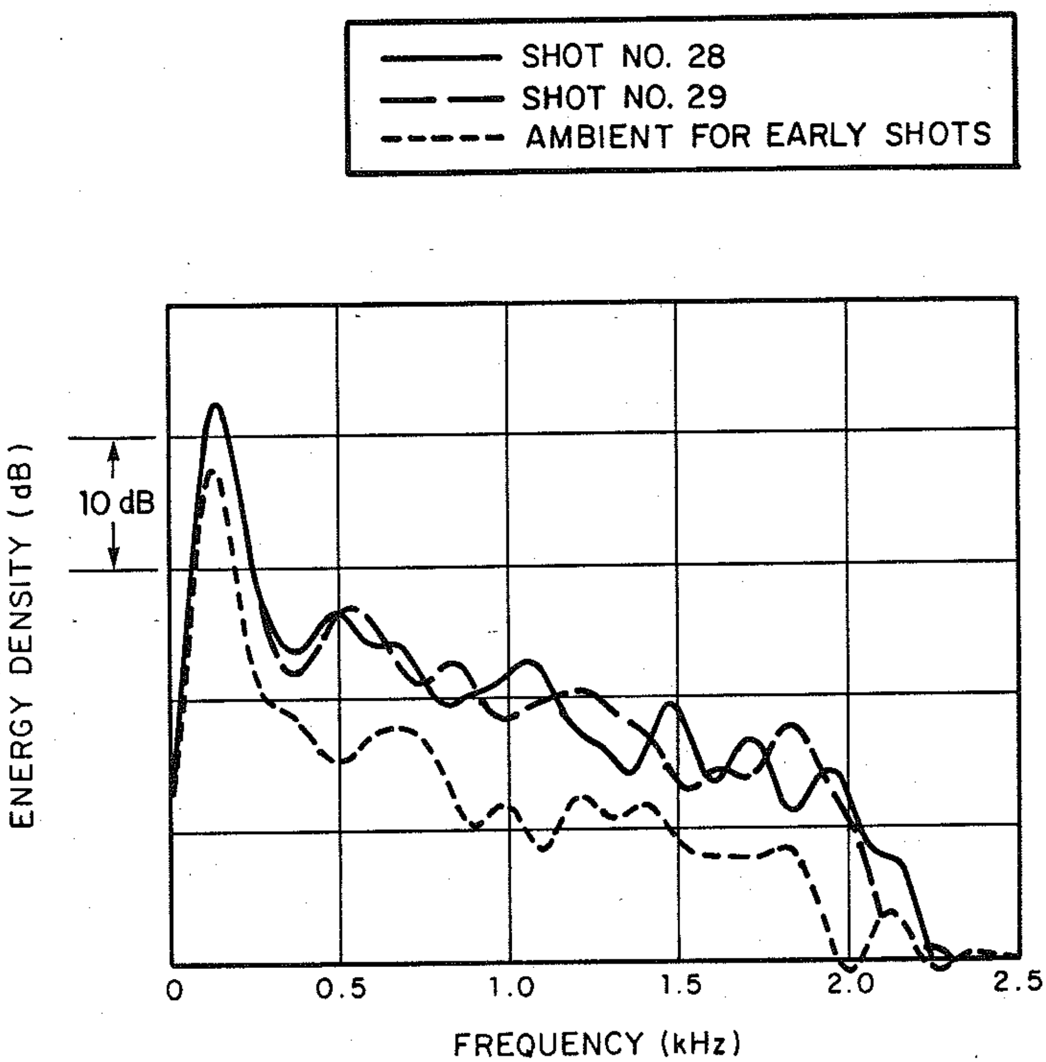

Fig. 4: Energy Spectra of Shots No. 28 and 29 on Compensated WKYC-TV Recording

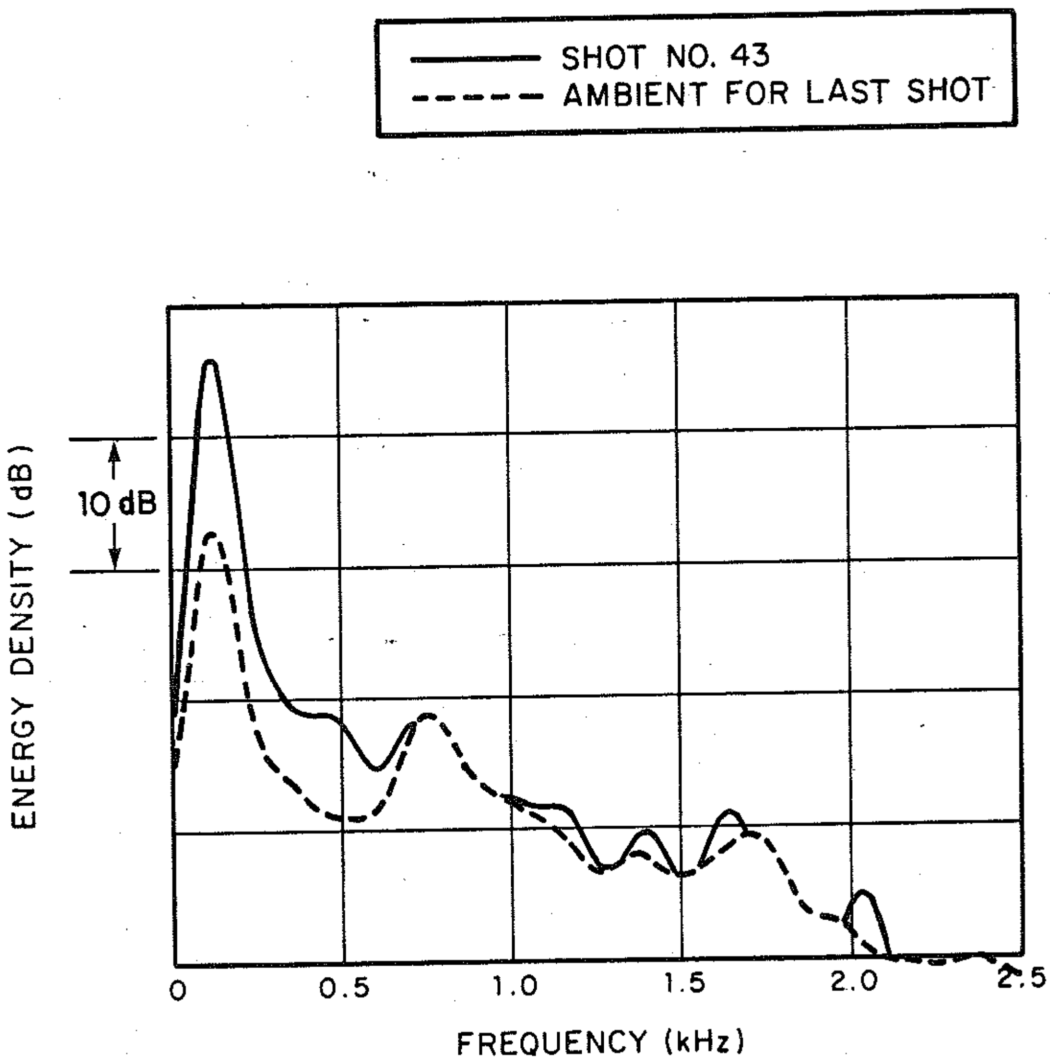

Fig. 5: Energy Spectrum of Shot No. 43 on Compensated WKYC-TV Recording