AN ANALYSIS OF RECORDED SOUNDS RELATING TO THE ASSASSINATION OF PRESIDENT JOHN F. KENNEDY*

(Prepared for Select Committee on Assassinations, U.S. House of Representatives, by Mark R. Weiss and Ernest Aschkenasy, Department of Computer Science, Queens College, City University of New York, February 1979)

*Materials submitted for this report by the committee's acoustics panel were compiled by HSCA staff member Gary T. Cornwell.

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ACKNOWLEDGMENT

The authors gratefully acknowledge the support and cooperation of the New York Police Department in providing both the facilities and personnel needed to make test recordings of gunshot sounds. We particularly appreciate the assistance of Sgt. Eugene McDonnell, Officer Mario Buda, and Officer Steve Baymack of the NYPD communications division, and Lt. Frank McGee and Sgt. John O'Brien of the firearms unit. We wish also to express our appreciation for the generous assistance of Dr. Ali Ghozati of the Queens College Department of Computer Science during the preparation of this report.

FOREWORD

On September 11, 1978, Dr. James Barger of Bolt Beranek and Newman, Inc. (BBN) presented to the House Select Committee on Assassinations the results of a BBN analysis of a Dallas Police Department (DPD) recording that had been made on November 22, 1963. One of the reported findings was that, with a probability of 50 percent, the recording contains sounds of a gunshot, or at least sounds as loud as a gunshot, fired from the so-called grassy knoll area of Dealey Plaza in Dallas; they were received by a microphone on a DPD motorcycle that was moving on Elm Street at a speed of about 11 mph in the same direction as the Presidential motorcade. On October 24, 1978, the committee authorized the authors of this report to conduct an independent examination of that portion of the recording to determine with more certainty whether the sounds in question were of such a shot. The analysis was completed by the middle of December 1978 and described in a public presentation to the committee on December 29, 1978. This report describes the method and results of that analysis.

1.0 INTRODUCTION AND SUMMARY

1.1 Background

On November 22, 1963, in Dallas, Tex., at the time that shots were being fired in the assassination of President John F. Kennedy, a radio on a Dallas Police Department (DPD) motorcycle that apparently had a stuck microphone was transmitting sounds over channel 1 of the DPD radio network that were being recorded at DPD headquarters. In an analysis of this recording, authorized by the House Select Committee on Assassinations, Dr. James Barger and his colleagues at Bolt Beranek and Newman, Inc. (BBN) isolated four groups of sound impulses and identified them as probable sounds of gunshots, and not merely random noise. They calculated that the statistical probabilities that these identifications were correct were, in order of increasing time of occurrence of the sounds, 88 percent, 88 percent, 50 percent, and 75 percent. BBN found that the probable cause of the first, second, and fourth of these groups of impulses were noises as loud as gunshots originating in the vicinity of the sixth floor southeast corner window of the Texas School Book Depository (TSBD) in Dealey Plaza. The probable cause of the third group of impulses was a similarly loud sound from the vicinity of the so-called grassy knoll area of Dealey Plaza. BBN also found that all of the groups of sounds were picked up by a microphone on a DPD motorcycle and that at the time of the third probable gunshot, the motorcycle was on Elm Street in Dealey Plaza, moving at a speed of about 11 miles per hour in the same direction as the motorcade. On October 24, 1978, the committee authorized the authors of this report to perform an independent examination of the sounds on the DPD recording to determine with a higher level of certainty if the third group of impulses was caused by the sounds of a gunshot from the grassy knoll.

1.2 Materials provided for the examination

At the time we began our analyses, we were provided with the following materials:

1. A high-fidelity tape-recorded copy of the original DPD recording.
2. A high-fidelity tape-recorded copy of the DPD tape recording that had been examined by BBN.
3. A high-fidelity tape-recorded copy of the sounds of gunshots that were recorded by BBN during an acoustical reconstruction experiment conducted in Dealey Plaza on August 20, 1978.
4. A topographical survey map of Dealey Plaza, plotted at a scale of 1 inch equal to 10 feet.
5. A map of Dealey Plaza, plotted at a scale of 1 inch equal to 40 feet, on which the locations of microphones used in the reconstruction experiment were indicated.
6. Aerial and ground level photographs of Dealey Plaza and relevant surrounding structures.

In addition, the committee staff provided to us various necessary items of informations, such as the heights of buildings in Dealey Plaza, the distance to objects not shown on the maps, the location of the DPD shooter during the BBN reconstruction experiment and the air temperature in Dealey Plaza at the time of the assassination and during the reconstruction experiment.

1.3 Preliminary review of the characteristics and sources of the recorded sounds

During 1963, communications that were transmitted on channel 1 of the DPD radio dispatching system were recorded continuously on a Dictabelt recorder. On November 22, 1963, a microphone on a mobile transmitter that was set to channel 1 apparently became stuck in the "on" position at about 12:28 p.m. and for about 5 minutes continuously transmitted sounds that it picked up. When we first listened to this interval on the DPD recording, we found that it contained a nearly continuous noise, with occasional speech, whistles, and clicks. Also recorded on the Dictabelt in this interval were the sounds that BBN identified as probable gunshots. To the ear, these sounds resembled static much more than they did a gunshot. However, as Dr. Barger testified in September, and as we independently verified, the equipment that was used in the DPD radio dispatching system was not designed to handle sounds as intense as a gunshot, and it was therefore likely to have recorded such sounds with very poor fidelity. Consequently, we recognized that these static-like sounds could be distorted gunshot sounds. On the other hand, such static-like sounds, theoretically could have been generated by a number of other sources, some acoustic, some related to electrical or mechanical disturbances in the DPD radio transmission, reception or recording equipment. Some test more discerning than the human ear was required to determine the probable cause of the sound impulses.

1.4 Basic principles and methods of analysis

To answer the basic question, "Was the third group of recorded sounds generated by a gunshot from the grassy knoll?" with a high level of certainty, these sounds needed to be examined for some characteristic that they would have had if they had been generated by such a gunshot, and would not be likely to have had if they had not been. Of the several characteristics that can be used, the most effective and most reliable one is the sequence of delay times of the muzzle-blast echoes.

The firing of a gun generates a very loud, very brief explosive blast at the muzzle of the gun. This sound, which typically lasts about five one-thousandths of a second (0.005 seconds, or 5 milliseconds), spreads out in all directions from the gun. If the muzzle blast strikes a wall of a structure, it will be reflected from the surface and will move away from it in a new direction. If the muzzle blast strikes the corner of a structure, it will be diffracted, that is, it will spread out from the corner in many directions. These reflected and diffracted sounds are the echoes of the muzzle blast. Like the muzzle blast, which they closely resemble, the individual echoes are very short in duration. The strengths of the echoes tend to diminish with time, the earliest ones being very loud and the later ones growing progressively weaker as they arrive from increasingly distant locations.

The time taken for the muzzle blast to be heard at some location depends solely on how fast the sound travels and how far the listener is from the gun. For example, at 65°F the speed of sound is 1123 ft/sec. A listener 112.3 feet away from a gun would hear its muzzle blast 0.1 second after the gun was fired. The time taken for the muzzle blast echoes to be heard also depends on the speed of sound and on the total distance each echo must travel, which is the total of the distance from the gun to the echo-producing object and then to the listener. Since the distance traveled by the muzzle blast to a listener must be less than the distance traveled by one of its echoes, the bang of the muzzle blast is always heard first. Then the echoes that are produced by the muzzle blast bouncing off the corners and surfaces of structures are heard.

If we now assume that the sound source (the gun) and the listener are located in a typical urban environment, with a number of randomly spaced echo-producing structures, it is possible to see that the pattern of sounds a listener will hear will be complex and unique for any given pair of gun and listener locations. For example, assuming a fixed location of a listener, the echoes that he hears and the times at which he hears them will be related uniquely to the location of the gun, since for each different location of the gun, even though the distances from the listener to the various echo-producing objects are the same, the distances from these objects to each gun location are different. Consequently, the times at which the echoes are heard will be different for each location of the gun. Similarly, assuming a fixed location of the gun, any change in the location of the listener will change the distances between him and the echo-producing structures, and thus the timing of the pattern of sounds he hears. If the listener is in motion as the muzzle blast and the various echo sounds reach him, the times at which he hears the muzzle blast and its echoes will be related uniquely to his location when he hears each sound.

A listener cannot tell, from the sounds of a gunshot, when the gun was fired. He can determine only the times that elapse between the muzzle blast and each of its echoes. These elapsed times are called the echo-delay times. Because the echo travel times are uniquely related to the locations of the gun and the listener, the echo-delay times are unique to any given pair of those locations. Hence, if we know the temperature (and thus, the speed of sound) and the location of the echo-producing structures, echo-delay times can be used to characterize the sounds of a gunshot for any pair of shooter and listener locations.

The "listener" that we have discussed, of course, could be either a human ear or a microphone. If a microphone receives the sounds and they are subsequently recorded, the recording becomes a picture of the event, not unlike a "fingerprint," that permanently characterizes the original gun and microphone locations.

Echo-delay times in such recordings can be measured easily and precisely by producing a graph of their waveforms on an oscillogram, or oscillograph. Such a graph is shown in figure 1. The narrow peaks represent individual sounds of brief duration (that is, impulse-sounds). The heights of the peaks correspond to the loudness of the impulse-sounds; the spacing between peaks corresponds to the time that elapses between them. The largest of the impulse peaks is the muzzle blast. The peaks that follow it are its individual echoes. The distance between the peak that is identified as the muzzle blast and each peak that represents an echo is a measure of the delay time of the echo. To convert this distance to a time measurement, it is multiplied by the time-scale of the graph. For example, the muzzle blast impulse in figure 1 and the sixth peak identified as an echo are 47 millimeters apart. Since the time-scale is 1 millisecond per millimeter (1 msec/mm), the measured echo-delay time is 47 milliseconds.

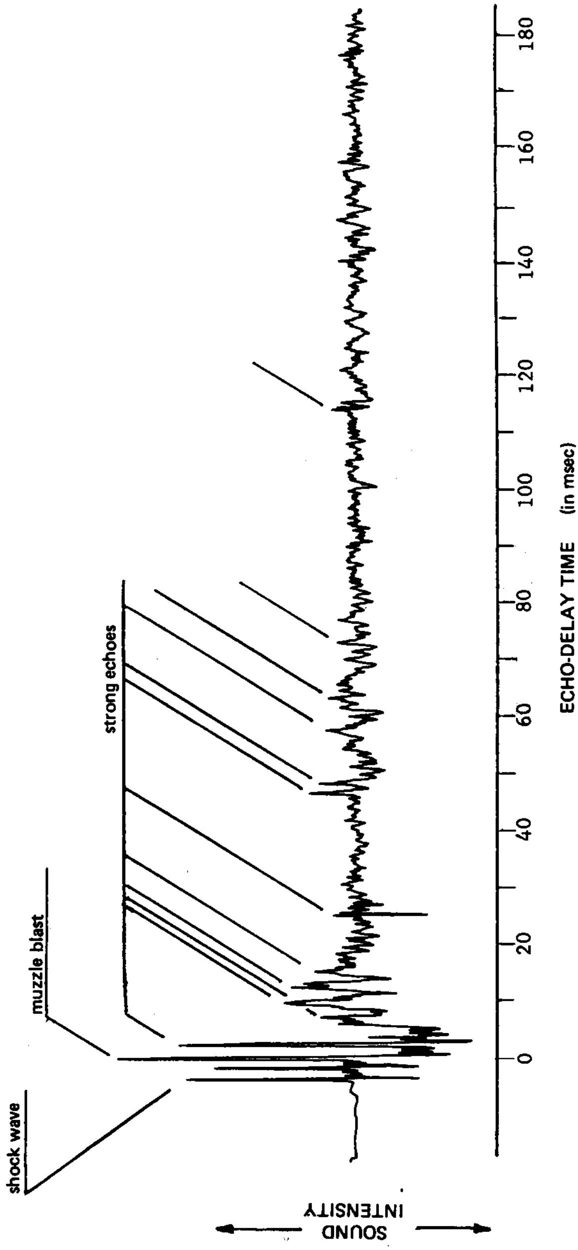

FIGURE 1 WAVEFORMS OF THE SOUNDS OF A GUNSHOT

It is easy to see how such a graph may be used for identification purposes. It provides a picture of the complex, random spacings of the echo-delay times. When the temperature of the air and the locations of the echo-producing objects are known, the graph is uniquely related to a particular pair of gun and microphone locations. This complex picture can be compared to other such graphs. If the random pattern of echo-delay times (the spacings between peaks) matches in any two such graphs, it may be concluded that the sounds and listener locations that produced both graphs were the same.

Of course, it may be that no second graph can be found that matches the first. Using the fingerprint identification process as an analogy, if a latent fingerprint taken from a knife found protruding from a murder victim's body is given to the FBI for identification, it may be that no matching "known" print is on file at FBI headquarters and that the murderer cannot be immediately identified. Furthermore, the police may proceed to take fingerprint samples from all of the suspects in the case and find that none match the one found on the murder weapon. In the end, the latent fingerprint may not be identified.

Applying the analogy to the graphs of sounds, our problem was to see if any of a number of assumed pairs of shooter and microphone locations would produce a pattern of sounds whose graph would match the graph of the sounds in question on the DPD tape. Before beginning the search, we knew that, just as in fingerprint identification cases, in the end we might find no match. If that occurred, of course, either of two conclusions would be required: (1) The real shooter and microphone locations could not be identified, or (2) the sounds on the tape were not produced by a gunshot in Dealey Plaza. On the other hand, if we found a shooter and microphone location that in combination would cause the same unique, random pattern of echo-delay times that were contained on the DPD tape recording, those sounds could be identified as probably being caused by such a gunshot.

For the sounds on the DPD recording, we knew what two of the four conditions that determine echo-delay time were at the time of the assassination. We knew what the speed of sound was and we knew where the major echo-producing objects were (and still are). We did not know exactly where to locate the gun, nor did we know through which sequence of locations on Elm Street to move the microphone. Therefore, we had to determine numerous hypothetical sequences of echo-delay times for gunshots that may have been fired from a variety of locations on the grassy knoll and picked up by microphones that moved through a variety of locations on Elm Street. This was accomplished in the only practical way possible—by predicting (i.e., mathematically calculating) the echo-delay time sequences that would be obtained for the various locations of a gun and a microphone.

After numerous comparisons between the echo-delay times for the sounds on the DPD recording and various predicted patterns for assumed motorcycle and shooter locations that did not match, a combination of motorcycle and shooter locations was found which mathematically produced a predicted pattern that showed strong similarities to the pattern of impulses on the DPD tape. However, to determine with a high level of certainty if these two sequences of echo-delay times, which were derived from different data, represented the same source, it was not enough to show that the sequences looked alike.

They had to be shown to be alike in an objective sense, that is, by use of a method of comparison that disregarded potentially misleading appearances. Such a method was provided by a computation of the binary correlation coefficient of the two sequences. The binary correlation coefficient of two sequences is a number that is exactly 1.0 if the sequences are identical and that rapidly approaches zero as they grow more dissimilar. As used in this analysis, the binary correlation coefficient takes into account the number of echo-delay times in each of the sequences and the number of echoes that coincide. Echoes in the two sequences are said to coincide if their delay times differ by a small amount. The smaller this amount, or "coincidence window," can be made while maintaining a high binary correlation coefficient, the greater will be the probability that the DPD sequence represents a gunshot from the grassy knoll.

1.5 Results of the analysis

Two different comparisons were made between the sequence of echo-delay times on the DPD tape and the most similar sequence of predicted echo-delay times. One of the comparisons was between those recorded sounds that were significantly louder than the average background noise and those predicted echoes that would have been recorded with comparable loudness. In the other comparison, the delay times of all of the recorded sounds and of all of the predicted echoes, up to a total delay of 50 milliseconds from the muzzle blast, were compared. The computed binary correlation coefficient was found to be 0.79 for the first comparison and 0.75 for the second.

In both of the comparisons described above, the coincidence window was set at ±1 millisecond. That is, a measured echo-delay time and a predicted one were said to coincide only if they were no more than 1 millisecond apart. For sequences that correlated at levels greater than 0.7 with a coincidence window of ±1 millisecond, the statistical probability was 95 percent or more that the sequences represented the same source—a sound as loud as a gunshot from the grassy knoll. Put alternatively, the probability that the sounds on the DPD recording were generated by sources other than a sound as loud as a gunshot originating from the grassy knoll is 5 percent or less.

1.6 Findings

The results of our analysis of sounds on the DPD recording permit the following findings:

1. The recording very probably contains the sound of a gunshot that was fired from the grassy knoll. The probability of this event is computed to be at least 95 percent.
2. The microphone that picked up the sounds of the probable gunshot was on Elm Street and was moving at a speed of about 11 miles per hour in the same direction as the motorcade. At the time the probable gunshot was fired, the microphone was at a point about 97 feet south of the TSBD and about 27 feet east of the southwest corner of the building. (For both distances, the uncertainty is about ±1 foot.)
3. The probable gunshot was fired from a point along the east-west line of the wooden stockade fence on the grassy knoll, about 8 feet (±5 feet) west of the corner of the fence.

1.7 Outline of the Report

The method and results of this analysis are described in detail in the sections of the report that follow. The sounds on the DPD recording are described in section 2. Following in section 3, is a discussion of the nature of the problems in this analysis and of the considerations that underlie the method of solution. Section 4 discusses the steps that were taken to implement the procedure for predicting echo-delay times and describes the method and results of a test of this procedure. Section 5 discusses the methods that were used to determine and to compare echo-delay times for the recorded and predicted sequences.

2.0 DESCRIPTION OF THE RECORDED SOUNDS

The DPD recording contains a wide range of sounds—speech, clicks, whistles, motor noises, sirens and even the sound of a carillon bell. Mostly the recording contains sounds generated during normal communications on channel 1 of the DPD radio dispatching system. The speech transmissions usually were preceded and followed by sharp clicks. These were keying transients, probably generated by the switch on the transmitter microphones when they were turned on or off. Occasionally, a transmission was attempted while another one was in progress. When this occurred, the interference between the two transmitters usually generated a brief whistle, known as a heterodyne tone, that immediately followed the keying click of the oncoming microphone. At a time that the BBN analysis estimates to have been about 12:28 p.m., a microphone on a mobile unit apparently became stuck in the "on" position and began to transmit a continuous noise that is believed to be the sound of a motorcycle engine. For the first 2 minutes of the stuck-microphone transmission, the sound level of this noise is fairly constant. Occasionally, clicks and whistles can be heard through the noise, indicating attempts by other transmitters to use the channel. At several points, voices can be heard, but, being obscured by the noise, they cannot be understood. At 133 seconds after the start of the stuck-microphone transmission, the level of the noise drops by about 6 decibels (that is, to about one-fourth of its previous level). At almost the same moment a voice can be heard, communicating a brief but unintelligible message. This is followed about 3 seconds later by a series of randomly spaced, loud clicks and pops that lasts for at least 10 seconds. Some of the clicks occur singly, some in groups. Only one of them is accompanied by a heterodyne whistle and by an audible but unintelligible voice.

3.0 THE NATURE OF THE PROBLEM AND THE METHOD OF SOLUTION

3.1 Distortion of the relative intensities of the echoes

The sounds on the DPD recording that are thought to be those of gunshots begin about 5 seconds after the decrease in the level of the continuous noise and last for about 8 seconds. To the ear, these sounds resemble static, not gunshots. However, the equipment that was used in the DPD radio dispatching system in 1963 would have distorted the sounds of gunfire. The effect would have been to compress the peak amplitude of the sounds of the muzzle blast and of its strongest echoes, making them only slightly louder than those of some of the weaker echoes. Furthermore, if the microphone was on a DPD motorcycle in the motorcade, most of the many very weak echoes of the muzzle blast would have been obscured by the noise of the motorcycle engine (which is possibly the source of the continuous noise on the DPD recording). Consequently, the sounds of a gunshot would have been recorded as a sequence of very brief impulse-sounds (the muzzle blast and its loudest echoes), only a few of which would have been larger than the accompanying engine noise, and none of which would have sounded to the ear like gunshots after being distorted by the limiting circuitry of the DPD radio and recording equipment.

3.2 Waveforms of the sounds on the DPD recording

The waveforms of sounds in the DPD recording are shown in figure 2. The waveforms in the bracketed region include the group of impulse-sounds that the BBN analysis identified as a probable gunshot from the grassy knoll. This segment of the recording begins 144.9 seconds after the start of the stuck-microphone transmission and lasts for 0.36 seconds. The noise thresholds shown in the figure indicate the average peak levels of noise (mostly motorcycle noise) that can be heard immediately before and after this segment.

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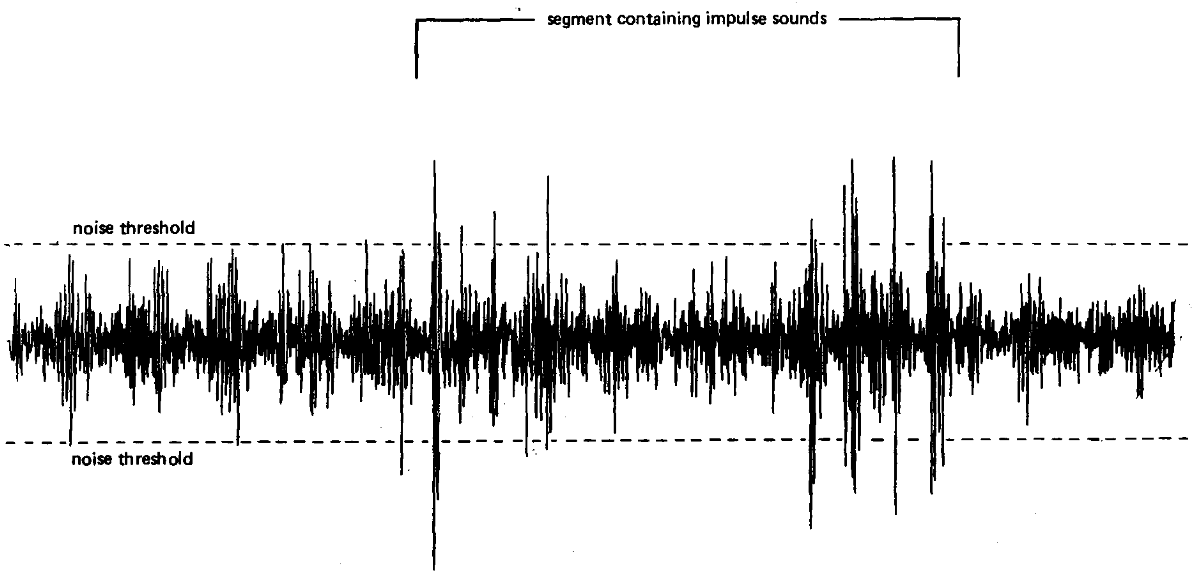

FIGURE 2 WAVEFORMS OF SOUNDS IN THE DPD RECORDING

Figure 3 shows the bracketed region in greater detail. The narrow peaks that exceed the thresholds, as well as many of those that do not, are the waveforms of the impulse-sounds that may be the sounds of a gunshot. Impulse peaks that are less than 1 millisecond apart are considered to be part of the same impulse. Altogether, 15 impulses exceed the thresholds. Five of them occur in the first 85 milliseconds following the one that is labeled as the muzzle blast. The remaining nine impulses occur in the 100-millisecond wide interval that begins about 280 milliseconds after the assumed muzzle blast.

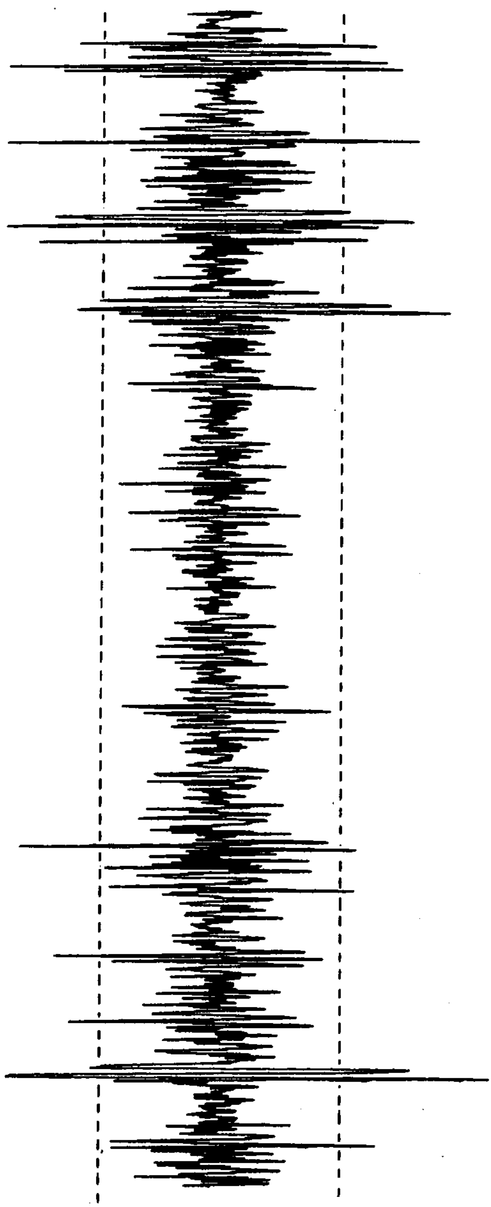

FIGURE 3 EXPANDED GRAPH OF WAVEFORMS OF SOUNDS IN THE DPD RECORDING

3.3 Possible sources of the impulse sounds

While it was possible that the louder impulse noises were the distorted sounds of a gunshot, it also is possible that they could have been generated in other ways. For example, they could have been the sounds of misfiring of the motorcycle engine. They could have been static-like impulse noises generated by the motorcycle's ignition system and picked up by the transmitter. The microphone that was stuck in the "on" position could itself have been the cause of impulses if from time-to-time it became unstuck and turned off briefly and then immediately turned on again. Impulse noises in the recording could also have resulted from scratches in the dictabelt on which the recording was made. Other components of the communication system could have been malfunctioning, producing electrical or mechanical disturbances that would have been recorded as clicks.

3.4 Method of the analysis

The essential questions to be answered were: "What is the source of the impulse-sounds in the DPD recording? Are they derived from the sounds of a gunshot that was fired from the grassy knoll and picked up by a microphone that was moving on Elm Street, or are they derived from one or more of the many other possible sources?" These questions could be answered with a high degree of certainty if the impulses could be shown to exhibit a characteristic that they would be expected to exhibit if they had been generated by a gunshot, and would not be likely to exhibit if they had not been. As explained in Section 1, such a characteristic is found in the unique pattern of time delays of echoes that buildings and other structures in Dealey Plaza would generate for a gunshot fired from the grassy knoll. If the impulse noises are the distorted sounds of a gunshot, their spacing should closely match that predicted for a shot fired from some location on the grassy knoll and "heard" by a microphone traveling along some path on Elm Street at 11 miles per hour. The closer the match between the actual and the predicted sequences, the greater the probability that the impulses are the sounds of a gunshot. If no shooter and microphone location can be found that can produce a sequence of echoes that closely matches the sequence of impulses on the tape recording, then it would have to be concluded that the impulses were not generated by sounds received by a microphone moving on Elm Street from a gun fired on the grassy knoll.

The procedure for determining the probable cause of the specified group of impulses on the DPD recording thus consisted of three steps. First was to calculate the pattern of echo delays that would be produced by a gunshot from a variety of locations on the grassy knoll and recorded by a microphone moving along a variety of paths on Elm Street. Then, select the sequence of predicted echoes that most closely matched the actual recorded sequence of impulses. Finally, compute the probability that impulse sounds generated by sources other than the predicted gunshot could occur by chance in a sequence that would match the selected echo sequence as closely as did the actual DPD recording.

4.0 IMPLEMENTATION OF THE ANALYSIS

4.1 Preliminary considerations

The implementation of the three-step procedure of the analysis required the consideration of a number of questions. Each of these affected either the results of the analysis or the method by which the required echo-delay time sequences were obtained.

4.1.1 Source of the gunshot sounds

If a gun was fired from the grassy knoll during the assassination, the would-be assassin reasonably could have used either a rifle or a pistol, since the target would have been less than 150 feet away. Since rifles typically fire bullets that travel faster than the speed of sound, the firing of a rifle generates two intermixed echo sequences composed of the echoes of the muzzle blast and the echoes of the continuously generated shock wave that is created by a bullet in supersonic flight. On the other hand, most pistol bullets do not fly at supersonic speeds. A pistol that fires a subsonic bullet generates only the set of echoes of the muzzle blast. Since we did not know what type of gun, if any, had actually been used on November 22, 1963, we sought only to compare the DPD tape with predicted sequences of echoes of muzzle blasts which would have been present regardless of the type of weapon fired.*

4.1.2 Placement of the gun on the grassy knoll

The BBN analysis indicated that the gun was in the vicinity of the grassy knoll. During the acoustic reconstruction experiment that was conducted by BBN in Dealey Plaza on August 20, 1978, shots were fired from behind the wooden stockade fence on the grassy knoll. This location was consistent with available eyewitness and earwitness testimony. It was a reasonable one since it afforded good visibility of Elm Street while providing good cover for the shooter of a gun. At any other location on the grassy knoll either the visibility or the cover would have been substantially poorer. However, it is uncertain exactly where a shooter would have stood behind the fence, since equally good locations can be found up to 25 feet along the fence either north or west of its corner.

4.1.3 Placement of the microphone on Elm Street

The BBN analysis placed the stuck microphone on Elm Street in the vicinity of the fourth microphone in the third array of microphones that were set up in Dealey Plaza during the acoustic reconstruction experiment. As illustrated in figure 4, the microphones were located in the center of the street at points 18 feet apart along the route of the Presidential motorcade, from the intersection of Houston and Main Streets to the location of the Presidential limousine on Elm Street in Zapruder frame 312. The sounds of a gunshot from the grassy knoll received by each of these microphones were recorded during the experiment. Later, BBN determined the degree of match between the

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*The DPD recording does contain a series of impulses that precede the large impulse ultimately determined to be the muzzle blast. The probability that these earlier impulses were the sounds of supersonic shock wave was discussed by Dr. Barger in his testimony before the committee on Dec. 29, 1978. See Vol. V of the hearings before the select committee, 94th Cong., 2d session (Washington, D.C.: U.S. Government Printing Office, 1979).

recordings from each of these microphones and the impulse noises on the DPD recording by calculating their binary correlation coefficients. A coincidence window of ±6 milliseconds was used for these comparisons. Only one of the 36 comparisons yielded a correlation coefficient greater than 0.5 when compared with the segment of the DPD tape that is here at issue. That one—for the sounds received by microphone 4 in array 3—was at a level of 0.8, indicating a strong similarity between the echo sequence that was heard at that test location in Dealey Plaza and the impulse sequence on the DPD recording.

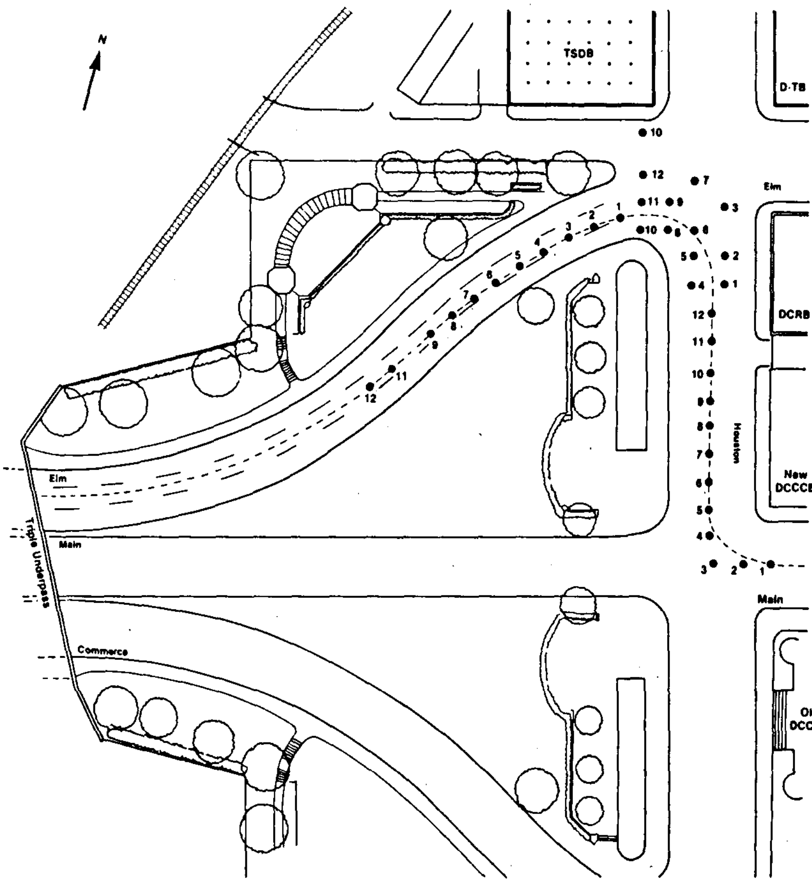

FIGURE 4 MICROPHONE LOCATIONS AT DEALEY PLAZA

The low values of the binary correlation coefficients that were calculated for all of the other microphones indicate that there is no other microphone location either on Elm Street or on Houston Street at which a sequence of echoes caused by a shot from the grassy knoll could be heard that was even moderately similar to the sequence of impulses on the DPD recording. It was therefore clear that for the purpose of analysis the microphone location in Dealey Plaza for which echo sequences had to be obtained was in the vicinity of microphone 4 of array 3. This region extends along Elm Street from halfway between microphones 3 and 4 to halfway between microphones 4 and 5, and from curb to curb (since the presumed motorcycle with the stuck microphone could be anywhere to the right or left of the center of the street).

4.1.4 Selection of the coincidence window

To compare sequences of impulses and echoes by use of the binary correlation coefficient, it was necessary first to determine how many echoes coincided with impulses. Ideally, if the microphones that were used in the acoustic reconstruction experiment could have been spaced very closely along the route of the motorcade, say, 1 foot apart, and spread from curb to curb, impulses and echoes that were within 1 millisecond of one another could have been considered coincident. For practical reasons, the microphones were located in the middle of the street and spaced 18 feet apart. Also, only one of many possible shooter locations was used. To take into account these practicalities, the coincidence window for BBN's analysis was made ±6 milliseconds. If a window of ±1 millisecond had been used, there would have been few points of coincidence in any comparison, and all of the calculated binary correlation coefficients would have been small, since the chances would have been small that a microphone and a shooter would have been arbitrarily located in precisely the correct positions to receive a sequence of echoes that coincided with the sequence of impulses to within 1 millisecond. By increasing the coincidence window to ±6 milliseconds, the number of coincident impulses and echoes was increased. However, so was the possibility that an impulse generated by a source other than a gunshot would appear to coincide with an echo. The major consequence of this was the value of 50 percent computed as the statistical probability that the impulses under examination were caused by the sounds of a gunshot.

To increase the certainty in our findings above a 50-percent level, we had to be able to reduce the coincidence window to as low a value as possible, preferably to ±1 millisecond or less. Theoretically, this could be accomplished by placing microphones 1 foot apart in the region of interest and conducting additional test firings in Dealey Plaza from various locations on the grassy knoll. With respect to the microphone location problem alone, the relevant area on the street would be 720 square feet. Therefore, if, as in the BBN acoustic reconstruction experiment, microphones were placed in arrays of 12 each, a total of 60 arrays would be required for each position of a gun fired on the grassy knoll. Clearly, this approach was impractical.

4.1.5 Prediction of echo sequences

The only practical way to obtain the needed echo sequence was to predict them analytically. Using fundamental principles of acoustics, it was possible to compute the time it would take for the sound of a muzzle blast to travel from a gun at any assumed point on the grassy knoll to a microphone at any assumed point on Elm Street. Knowing where the echo-producing objects were in Dealey Plaza, it was also possible to compute the time it would take for echoes of the muzzle blast to travel from the gun to the microphone. Subtracting the muzzle-blast travel time from the echo travel times yielded the required sequence of echo-delay times.

The principles of acoustics that underlie this approach are described in detail in BBN Report. No. 3497 that was submitted to the committee in January 1979.* The essential principles can be summarized as follows:

1. Most sounds spread out in all directions from the source of the sound.
2. If the medium (in this case, air) through which sound travels is uniform, sound will travel in straight lines from the source and at the same constant velocity in all directions of travel.
3. The time taken for sound to travel from one point to another can be computed by dividing the distance between the points by the speed of sound. For example, at a speed of 1,100 feet per second, it will take 0.5 second for sound to travel a distance of 550 feet. Conversely, the distance traveled by a sound can be computed by multiplying the travel time by the speed of sound.
4. Sound traveling through air will reflect from the surfaces and diffract from the corners of structures such as buildings, walls and columns.

4.2 Information needed to predict echo-delay sequences

Before the echo travel times could be calculated, it was necessary to determine three things: (1) Which objects in Dealey Plaza would produce echoes in the region of interest on Elm Street for a gun fired from the vicinity of the grassy knoll; (2) how far these objects were from the locations of the gun and of the microphone; and (3) what was the speed of sound under the conditions for which the echo travel times were to be predicted. When the required information had been obtained, it was used first to determine the accuracy of the echo procedure. Then it was used to predict echoes for comparison with the impulses in the DPD recording.

4.2.1 Identification of echo-producing objects

The objects in Dealey Plaza that would generate relevant echoes were identified with the aid of a topographical survey map of the plaza that was drawn to a scale of 1 inch equal to 10 feet. Most of these objects were corners of buildings or of walls that, as illustrated in figure 5, produced muzzle blast echoes in the selected region on Elm Street by diffracting the incident sound of a muzzle blast that was generated in the vicinity of the grassy knoll. Two of the objects, the wall of the DCRB and the curved wall at the reflecting pool, produced echoes by reflecting such a sound. In all, we were able to identify 22 objects that would generate echoes of sufficient strength that they would have been recorded on the Dictabelt recording. (See table 1.)

4.2.2 Measurement of distances in Dealey Plaza

The distances of the echo-producing objects from positions of a gun and a microphone were determined by direct measurement on the

*This report follows the present report.

survey map. By comparing the known widths of buildings in Dealey Plaza with measurements made on the map, we found the distances measured on the map to be accurate to about 0.5 foot. We measured distances on the map in millimeters, to the nearest half-millimeter. This simplified the making of measurements by providing a decimal

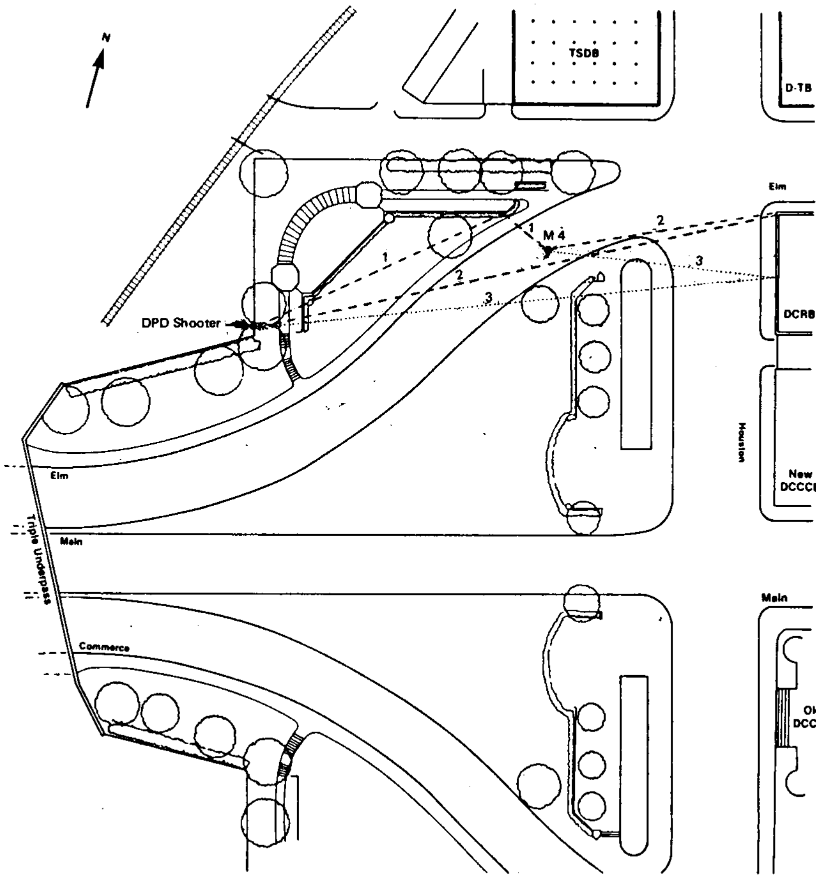

FIGURE 5 PATHS OF THREE MUZZLE BLAST ECHOES

scale. To simplify the calculation of the travel time of the echoes, we converted the speed of sound to an equivalent value for map distances that were measured in millimeters. For example, a speed of sound of 1,123 feet per second was converted to 2,852 millimeters per second for map measurements made in millimeters.

4.2.3 The speed of sound

The speed of sound in air is primarily a function of the temperature of the air. At a temperature of 65° Fahrenheit, it is 1,123 feet per second, and at 90° Fahrenheit it is 1,150 feet per second. To a first order approximation, in this temperature range the speed of sound increases at a rate of 1 foot per second per degree Fahrenheit. By comparison, humidity has a negligible effect on the speed of sound in air. Similarly, small variations in the temperature at different locations in Dealey Plaza would have a negligible effect on the average speed of sound over the path lengths of the echoes.

According to records of the weather bureau in Dallas, as obtained by the committee staff,* the temperature in Dallas at 12:30 p.m. on November 22, 1963 was 65° Fahrenheit. This was substantially confirmed by a photograph that was taken in Dealey Plaza at about that time. In it, a sign on top of the TSBD can be seen on which the time is indicated as 12:40 and the temperature in Dealey Plaza as 68° Fahrenheit. Even if the temperature that was supplied by the weather bureau varied from the temperature in Dealey Plaza by 3° Fahrenheit, the resulting error of 3 feet per second is less than 0.27 percent of the speed of sound at 65° Fahrenheit. For most of the echoes, the resulting error in the computed echo-delay time would be less than 0.25 millisecond. Even for the echoes that travel the longest echo paths, the error would be less than 1 millisecond. In either case, the error is within the accuracy required for the echo prediction procedure. As is explained later in this report, temperature differences up to ±10° Fahrenheit would have had negligible effect on the final results and would not substantially have changed the final conclusion nor the degree of confidence (the final statistical probability) that can be appropriately assigned to it.

Wind also will affect the speed of sound, increasing or decreasing it by an amount that depends on the speed of the wind and on the angle between the direction of the wind and the direction the sound travels. However, the delay time of an echo, which is determined by subtracting the muzzle blast travel time from the echo travel time, will be affected by wind only to the extent that the wind affects the echo and muzzle blast travel times differently. This in turn depends on the difference between the direction of the echo path and the direction of the direct muzzle blast path. For a gunshot fired from the grassy knoll and heard on Elm Street, the travel of most echoes is in approximately the same direction as the directly received muzzle blast. Consequently, the effect of wind on the delay times of these echoes is comparatively small, becoming significant only for windspeeds greater than 40 miles per hour. The weather bureau recorded winds in Dallas on November 22, 1963, as ranging only between 13 knots and 17 knots, which is roughly equal to 15 to 20 miles per hour.**

4.3 Accuracy of the echo prediction procedure

Before proceeding to predict sequences of echoes for comparison with the sequence of impulses on the DPD recording, the accuracy of

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* See addendum A to the acoustics reports.

**The actual recordings made at Dallas Love Field were 13 knots at 11:55 a.m., 13 knots at 12:30 p.m., and 17 knots at 1:00 p.m. See addendum B to the acoustics report.

the echo prediction procedure was tested. Given the estimated accuracy of the map, we expected to be able to predict echo-delay times to within ±1 millisecond for specified locations of a gun and a microphone. However, it was essential to verify that this accuracy would be achieved in practice and that the identified echo-producing objects would generate significant echoes in the region of interest on Elm Street.

To test the procedure, we predicted the delay times of the echoes that would be received by a microphone at the location of microphone 4 of array 3, as shown in figure 5, for a shot fired from the grassy knoll by the DPD shooter during the acoustic reconstruction experiment. We then compared the predicted echo-delay times to echo-delay times actually recorded on the BBN tape recording of the shot that was fired by the DPD shooter. At the time that the test shot was fired, the temperature in Dealey Plaza was approximately 90° Fahrenheit. Accordingly, the value used for the speed of sound was 1,150 feet per second. As discussed in section 4.1.5, the echo-delay time is computed by subtracting the muzzle blast travel time (185.2 msec.) from the echo travel time. The muzzle blast travel time is obtained by dividing the distance between the gun and the microphone in Dealey Plaza (213 feet) by the speed of sound.

For echoes produced at the corners of structures, the measurement procedure was simple and direct. For example, the path of echo 2 in figure 5 consisted of two segments. As measured on the map, the segment from the shooter to the diffraction point was 499 millimeters and from that point to the microphone was 92 millimeters. The total path length, 591 millimeters, when divided by the sound-speed constant (2921 mm/sec) yielded an echo travel time of 0.2024 second (202.4 msec). Subtracting the muzzle blast travel time from the echo travel time yielded an echo-delay time of 17.2 milliseconds.

For an echo produced by a specular reflection, it was necessary first to locate the point at which the reflection would occur. Such reflections occur at that point on an echo-producing surface at which the total length of the echo path to that surface is a minimum. At that point, the reflecting surface will be tangent to an ellipse for which the locations of the gun and the microphone are the locii and the total length of the echo path is equal to the sum of the radii. The required ellipse was easily generated by the following procedure. First, a non-extensible string was cut to a length greater than the probable length of the echo path on the topographical map. One end of the string was tied to a pin at the location of the gun and a portion of the string near its other end was wrapped tightly around a pin at the location of the microphone. The string was then pulled toward the reflecting surface by the point of a pencil. With the string drawn taut, the pencil was moved so that its point drew an arc on the map in the region of the line that represented the reflecting surface. The length of the string was then adjusted until the arc was just tangent to the line. The point at which the arc touched the line was the desired point of reflection. The path from the gun to the point of reflection and then to the microphone (the echo path) was then measured. The total distance of the echo path divided by the speed of sound was the echo travel time. Subtracting from it the muzzle blast travel time yielded the echo-delay time.

TABLE 1.— *List of structures in Dealey Plaza that would have produced echoes of sufficient strength to have been recorded on the DPD tape*

Object No.:	*Identification*
1	South shelter: South door, east post.
2	South shelter: East door, south post.
3	South shelter: East door, north post.
4	North shelter: South door, west post.
5	North shelter: South door, east post.
6	North shelter: East door, south post.
7	North shelter: East door, north post.
8	Wall "A." [1]
9	Wall "A": Corner 1.
10	Wall "A": Corner 2.
11	Column "A" [2]: Southwest corner.
12	Wall "B" [3]: Corner 1.
13	Wall "B": Corner 2.
14	Column "B" [4]: West corner.
15	Wall at the north end of the reflecting pool.
16	DCRB: Southwest corner.
17	DCRB: Northwest corner.
18	DCRB: West wall (front of building).
19	DCRB: Roof edge on west wall.
20	DCRB: Southwest corner.
21	New DCCCB: Northwest corner.
22	DCRB—New DCCCB: Alley wall between buildings.

[1] Wall "A" is a concrete wall on the north side of Elm St. that runs in an east-west direction. Corners 1 and 2 are at the east end of the wall. The direction of the wall changes from east to northeast at corner 1, and from northeast to north at corner 2.

[2] Column "A" is a concrete column on the north side of Elm St. near the intersection with Houston St.

[3] Wall "B" is a concrete wall on the south side of Elm St. near the reflecting pool. It runs in a generally north-south direction. Corners 1 and 2 are at the northern end of the wall. The direction of the wall changes from north to northeast at corner 1 and from northeast to east at corner 2.

[4] Column "B" is a concrete column on the south side of Elm St., at the northern end of Wall "B."

TABLE 2.—*List of echo paths used in the predictions of echo-delay times*

Path No.:	*Echo producing objects (Identification numbers)*
1	1
2	2
3	9
4	2, 8
5	10
6	5
7	4
8	6
9	7
10	12
11	13
12	14
13	3, 13
14	3, 14
15	3, 15
16	16
17	8, 13
18	19
19	18
20	21
21	22
22	4, 19
23	6, 19
24	20
25	17
26	23

TABLE 3.—MEASURED AND PREDICTED DELAY TIMES OF ECHOES FOR A GUNSHOT FIRED ON AUG. 20, 1978

[In milliseconds]

Echo path	Echo travel time	Echo-delay time [1]		Deviation
		Predicted	Measured	
1	192.3	7.0	7.3	0.3
2	196.0	10.8	11.2	.4
3	198.6	13.4	13.1	.3
4	201.7	16.5	16.9	.4
5	202.4	17.2	16.9	.3
6	213.0	27.8	28.3	.5
7	213.0	27.8	29.8	2.0
8	215.4	30.1	29.8	.3
9	218.1	32.9	32.9	0
10	228.4	43.2	42.3	1.1
11	229.4	44.7	45.6	.9
12	232.5	52.3	52.9	.6
13	243.4	58.2	60.0	1.8
14	252.7	67.5	68.3	.8
15	259.9	74.7	76.9	2.5
16	267.1	81.9	82.5	.6
17	267.4	82.2	83.1	.9
18	451.6	266.7	266.6	.1
19	455.0	269.8	269.2	.6
20	458.1	272.9	272.2	.7
21	469.2	284.0	282.3	1.7
22	482.8	297.6	297.7	.1
23	482.8	297.6	297.7	.1
24	487.2	302.0	303.2	1.2
25	497.8	312.6	313.0	.4
26	541.3	356.1	354.0	2.1

[1] For the calculated locations of the gun and the microphone, the muzzle blast travel time is computed to be 185.2 ms.

Using the methods described above, 26 echo paths were defined for 22 echo-producing objects.[*] For some of these paths, the muzzle blast sound bounced off more than one echo-producing object. The echo-producing objects and echo paths are listed in tables 1 and 2. The travel times and the delay times for the predicted echoes are listed in table 3. Also listed are the echo-delay times determined by analysis of the time waveforms of the sounds received at microphone 4 of array 3 for the shot fired by the DPD shooter from the grassy knoll. These waveforms, which are shown in figure 6, were obtained by playing back the recording of the sounds that were picked up by the microphone, modifying the reproduced signal so as to approximate the effect that a microphone of the type used by the DPD in 1963 would have had on the signal, and then graphing the resulting signal. A 60-Hz tone that was recorded in one segment of the recording made during the testing in August 1978 made it possible to calibrate the time scale of the graph at 1 millisecond per millimeter. The first waveform appearing in the graph, the large peak at the left-hand side, corresponds to the supersonic shockwave of the rifle bullet. The second large peak is the waveform of the muzzle blast. Following it, with generally diminishing heights, are the waveforms of the echoes of the muzzle blast. The delay time of each echo was determined by direct measurement of the distance from the leading edge of the muzzle blast waveform to that of the echo. The numbered peaks shown in this figure correspond to the predicted echoes identified in table 3.

The deviations between the predicted and measured echo-delay times listed in table 3 were in part due to small errors in the locations of the

*At the time of the presentation of our findings on Dec. 29, 1978, 22 echo paths had be defined. After that date, four additional paths were defined.

gun and the microphone. The microphone location was determined from a map of Dealey Plaza that showed where microphones were to be placed during the reconstruction experiment. However, the scale of the map, 1 inch equal to 40 feet, limited the measurement accuracy to about plus or minus 2 feet. Therefore, the actual location of the microphone may have deviated from the indicated one by a foot or two. Similarly, there were no measurements taken of the exact location

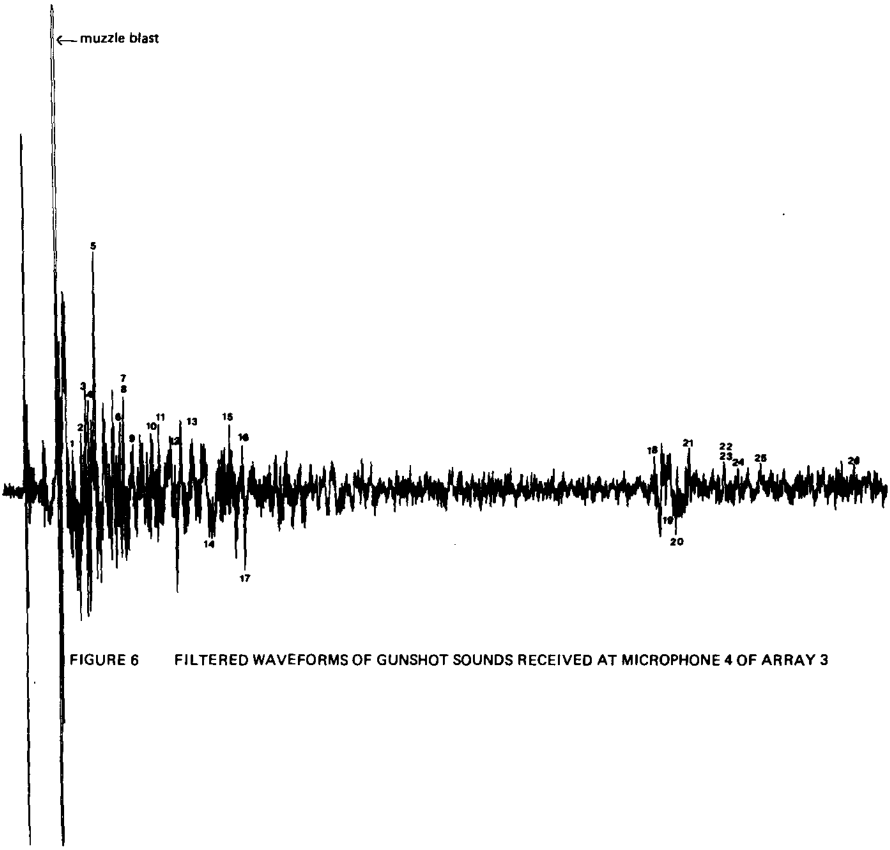

FIGURE 6 FILTERED WAVEFORMS OF GUNSHOT SOUNDS RECEIVED AT MICROPHONE 4 OF ARRAY 3

where the DPD shooter stood as he fired each shot from the grassy knoll. Consequently, it was likely that the gun and the microphone locations that were used for the echo-delay time predictions were slightly in error and that if these positions were adjusted correctly, the resulting predictions would be closer to the measured echo-delay time.

An analysis of the data listed in table 3 shows that the assumed locations were sufficiently accurate for the purpose of this test. The average absolute difference between the predicted and measured echo-delay times was 0.8 millisecond. The standard deviation of predicted delay times about this average was 0.7 millisecond. These results are well within the accuracy required of the echo prediction procedure.

5.0 COMPARISON OF THE SEQUENCE OF IMPULSES ON THE DPD RECORDING WITH SEQUENCES OF PREDICTED ECHOES

5.1 Prediction of echoes for November 22, 1963

Using the techniques described in section 4, we predicted echoes and echo-delay times for gunshot sounds that would have been heard in Dealey Plaza at 12:30 p.m. on November 22, 1963. The predictions were made given the following conditions: (1) The air temperature was 65° F (with a possible error of 3° F); (2) the gun was somewhere along the wooden stockade fence on the grassy knoll; (3) the microphone was somewhere in the region of interest on Elm Street (see section 4.1.3) and moving with the motorcade at a speed of about 11 miles per hour; and (4) the echo-producing objects were the same as those identified in table 1.

The procedure that was used to predict echoes required a few more steps than the method described in section 4. Since the conditions required the microphone to be moving on Elm Street at a speed of 11 miles per hour, the location of the microphone on the map had to be moved in a similar manner. First, a location was specified on the map at which the microphone received the muzzle blast. Then, the microphone was moved along a path corresponding to the path it would have traveled on Elm Street during the time it received all of the predicted muzzle blast echoes. The location of the microphone at the time it would have received each particular echo was determined by calculating the distance the microphone would have moved from the initial position at a constant speed of 11 miles per hour during an interval equal to the echo traveltime. Small deviations about this estimated distance (for example, ±1 millimeter) did not materially affect the predicted echo travel time. The predicted echo-delay times were then obtained by the procedure described in section 4.

5.2 Correction of time delay measurements

The delay times of the impulse sounds on the DPD recording were measured directly from a graph of the sequence of impulse waveforms, such as the one shown in figure 3. To simplify the measurement of time intervals, the graph was plotted with a time scale of 1 millisecond per millimeter (1 msec/mm). However, before the measurements could be used, they had to be multiplied by a time-correction factor to correct for an error in the speed of the DPD Dictabelt machine. As was shown in the BBN analysis, the DPD recorder was running slow at the time the recording was made. Consequently, when the recording is played back at the faster, correct speed, the recorded impulse sounds will be heard closer together than they actually were at the time the recording was made. This error could be corrected by multiplying the time intervals measured on the graph by a time-correction factor. The BBN analysis showed that between 12:22 p.m. and 12:37 p.m., the average speed of the recorder was 0.95 of correct speed. The actual speed at any time during this interval could have been from 0.94 to 0.96 of true speed. Accordingly, the time-correction factor could range from 1.04 to 1.06.

An adjustment in the measurement of impulse delay times would also be necessary if the temperature in Dealey Plaza at 12:30 p.m. on

November 22, 1963, was not 65° F, as was initially assumed. The computed delay time of each predicted echo would be in error by about 0.1 percent for each 1° F difference between the true temperature and the assumed value of 65°F. The effect on the predicted echoes would be to scale their spacing from what they should be. For example, if the true temperature was less than 65° F, then the predicted echoes would be closer together than they should be. Conversely, if the true temperature was more than 65° F, the computed echoes would be spaced more widely than they should be. Since it was not likely that the assumed temperature differed from the true temperature by more than 10° F, the factor for correcting temperature errors would range only from 0.99 to 1.01. Assuming that the differences in temperature and recorder speed occurred in such a way as to compound one another, the combined factor that would correct for both recorder speed and temperature at the same time could range from 1.03 to 1.07. Because we knew that the range of the correction was 1.03 to 1.07, theoretically we could use any value between 1.03 and 1.07 to adjust the measured time intervals between the impulses on the DPD recording.

Because any value between 1.03 and 1.07 was theoretically valid, it was permissible to choose the value between those limits that created the best match between the impulse and echo sequences. By fitting the DPD tape recorded impulse sequence to our predicted echo sequences, we found that a time-correction factor of 1.043 gave the best match, and we therefore used that factor.

TABLE 4.—MEASURED DELAY TIMES OF IMPULSES AND PREDICTED DELAY TIMES OF GUNSHOT ECHOES FOR NOV. 22, 1963

[In milliseconds]

Echo path	Echo travel time	Echo delay time	Impulse delay time	Deviation
1	202.4	6.5	6.3	0.2
2	206.8	10.9	10.5	.4
3	211.0	15.1	14.7	.4
4	214.7	18.8	19.3	.5
5	217.0	21.1	20.1	1.0
6	224.3	28.4	27.4	1.0
7	225.2	29.3	30.3	1.0
8	227.1	31.2	31.6	.4
9	230.6	34.7	34.1	.6
10	244.1	48.2	48.7	.5
11	241.5	45.6	45.4	.2
12	250.3	54.4	54.2	.2
13	255.2	59.3	59.7	.4
14	266.0	70.1	69.4	.7
15	273.4	77.5	77.4	.1
16	281.8	85.9	85.3	.6
17	276.7	80.8	80.2	.6
18	473.9	278.0	278.6	.6
19	479.8	283.9	283.7	.2
20	479.8	283.9	283.7	.2
21	489.1	293.2	292.1	1.1
22	506.8	310.9	310.5	.4
23	507.9	312.0	312.4	.4
24	509.6	313.7	313.1	.6
25	524.0	328.1	327.5	.6
26	565.0	369.1	369.2	.1

[1] For the calculated locations of the gun and the microphone, the muzzle blast travel time is computed to be 195.9 ms.

5.3 Comparison of the impulse and echo sequences

The sequence of predicted echo-delay times that best matched the sequence of impulse-delay times, computed as described above, is listed in table 4. The numbered peaks shown in figure 7 correspond to the predicted echoes identified in table 4. The average absolute difference between the impulse-delay times and the corresponding echo-delay times is 0.5 millisecond, and the standard deviation of impulse-delay times about this average is 0.3 millisecond.

The location of the gun and the path of the microphone for which these predicted echoes were obtained are shown in figure 8. The microphone is initially located 97 feet south of the TSBD and 27 feet east of the southwest corner of the TSBD. The path of the microphone, as it received the muzzle blast and its echoes, extends for about 6 feet

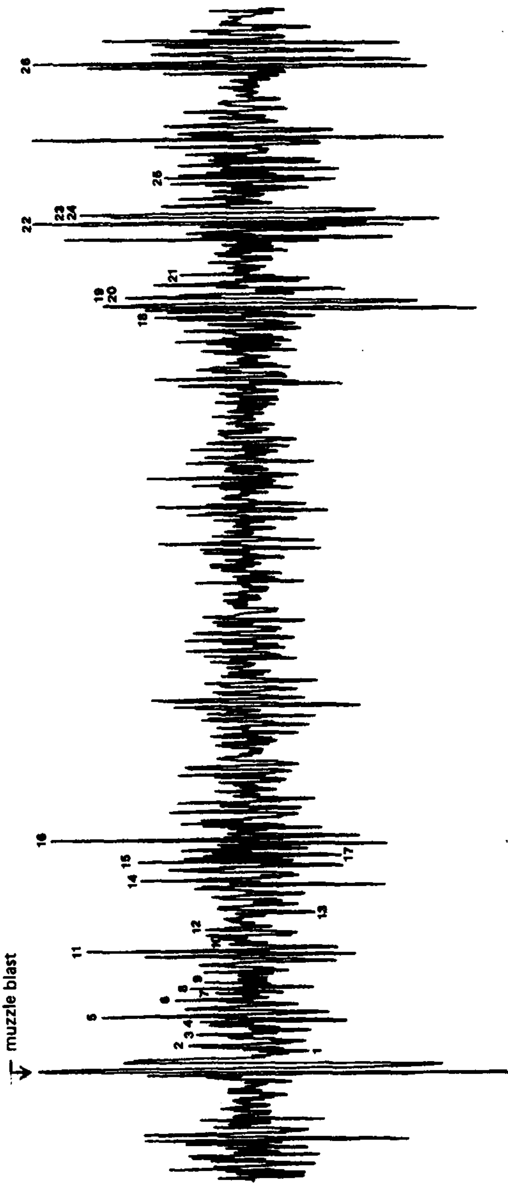

FIGURE 7 IMPULSES ON THE DPD RECORDING ASSOCIATED WITH ECHOES

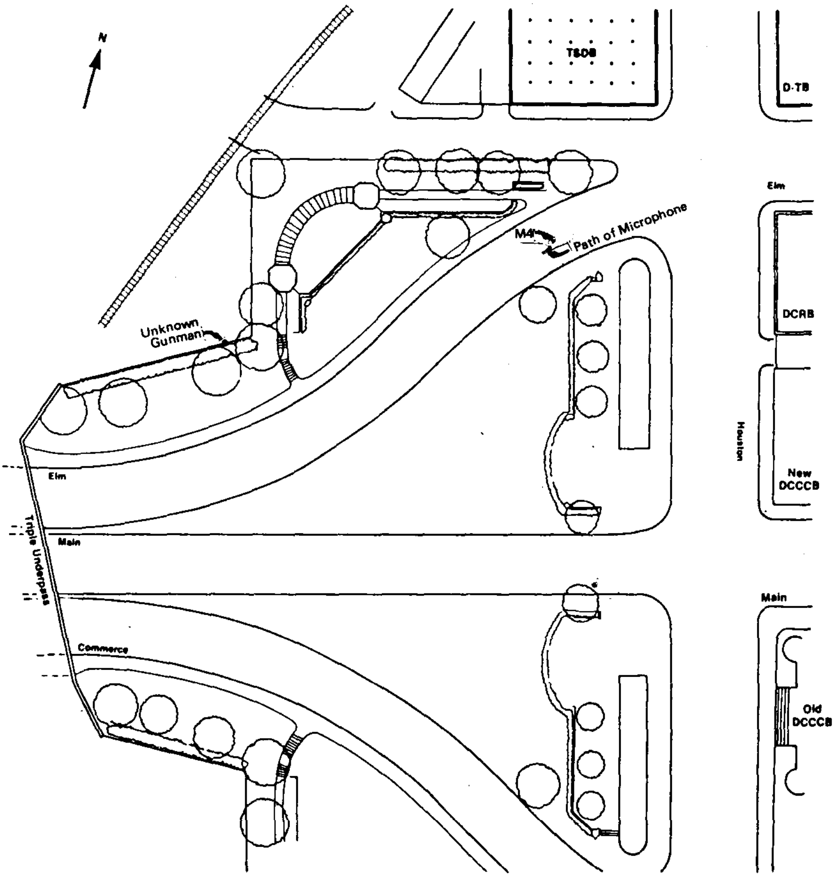

FIGURE 8 LOCATION OF THE GUN AND PATH OF THE MICROPHONE COMPUTED FOR NOVEMBER 22, 1963

along Elm Street. The uncertainty in the initial position is ±1 foot, which corresponds to the accuracy of measurements made on the topographical survey map. The gun is located about 8 feet to the left of the corner of the wooden stockade fence on the grassy knoll. If the gun is moved along the fence from this location, the delay times of the muzzle blast echoes changes. However, for movements up to ±5 feet, these changes can be reduced to less than 1 millisecond by making a small adjustment in the initial location of the microphone.

The data in table 4 suggest that the sequence of impulses on the DPD recording is very similar to the sequence of predicted echoes. A visual comparison indicates that almost all of the impulses and echoes coincide within a window of ±1 millisecond. However, such an examination can be deceptive. It does not take into account the impulses that do not coincide with echoes, or the echoes that are not matched by impulses of even minimal amplitude. For these reasons, a more appropriate method of comparison was to compute the binary correlation coefficient of the sequences.

5.4 Factors affecting the selection of impulses and echoes for correlation

Ideally, a correlation of the impulses and the predicted echoes would have included all of the impulses evident in the waveforms of figure 7 and all of the predicted echoes. However, some of the impulses must have represented components of the background noise. To minimize the number of noise impulses that might be included in the correlation calculation, only those impulses that were greater than the average peak level of the background noise were counted. This required limiting the predicted echoes that were included in the correlation calculation to those that would have been recorded at a level above that of the background noise. To identify these echoes and impulses, it was necessary to consider, first, the relative strengths of predicted echoes near the microphone, and then the way in which the DPD radio dispatching system would have altered both the relative strengths of the echoes as recorded and the recorded level of the background noise.

5.4.1 Relative strengths of echoes near the microphone location

The relative strengths of the predicted echoes at locations along the path traveled by the microphone would be similar to those of the actual echoes of a muzzle blast that were recorded during the acoustical reconstruction experiment at the nearby location of microphone 4 in array 3 (see fig. 5). The strengths of echoes received at these nearby locations would not differ by more than a few decibels. Therefore, the relative strengths of the predicted echoes in the vicinity of the moving microphone could be taken to be the same as those received by microphone 4.

5.4.2 Effects of the DPD radio dispatching system on the relative strengths of recorded echoes

The DPD radio dispatching system contained a circuit that would have greatly affected the relative strengths of the recorded echoes of a muzzle blast. This circuit, the automatic gain control (AGC), limited the range of variations in the levels of signals by reducing the levels of received signals when they were too strong and increasing their levels when they were too weak. It responded very rapidly to a sudden increase in the level of a signal, but comparatively slowly to a sudden reduction in a signal level. Consequently, the response of the AGC to the sound of a muzzle blast would greatly reduce the recorded levels of echoes and background noise received shortly afterward. Progressively during the next 100 milliseconds, the AGC would allow the recorded levels of received signals to increase until full amplification was finally restored. The effect on the predicted echoes would be to make the recorded levels of late-arriving echoes very nearly the same as those of the early ones. Concurrently, the recorded background noise would gradually rise to its level before the muzzle blast was received.

A different but also significant effect on the relative strengths of the recorded echoes would have been caused by the motorcycle windshield. On the DPD motorcycles, the microphone was usually mounted on a bar directly behind the windshield. Sounds arriving from the front of the motorcycle would have diffracted around the windshield and in doing so would have lost strength. As determined by experiment, the windshield of a 1960's Harley Davidson motorcycle attenuated gunshot sounds received from in front of the motorcycle by from 3 decibels to 6 decibels. The amount of attenuation depended on how close the microphone was to the windshield. Obviously, sounds received from the sides and rear of the motorcycle would not be affected by the windshield.

5.5 Correlations of impulse and echo sequences

The selection of impulses for the calculation of the binary correlation coefficient depends directly on the noise level to which the heights of the impulses are compared. This level can be set, as in figure 2, at the average peak level of the recorded noise immediately adjacent to the recorded impulses. This approach, however, presumes that the noise level is the same during the impulse segment as it is in the adjacent segments of the recording. As was discussed above, the level of the noise recorded during the first 50 milliseconds following a muzzle blast will be greatly reduced. Consequently, an alternative would be correspondingly to lower the level to which the impulses are compared during this 50-millisecond period.

Both approaches to setting the amplitude comparison level were used, each in a separate calculation of the binary correlation coefficient. For the first calculation, the amplitude comparison level was set as in figure 2. Taking all of the factors discussed in section 5.4 into account, we found that 13 gunshot sounds (the muzzle blast and 12 of the predicted echoes) would have been loud enough to have been recorded at a level above the background noise. Eleven of these sounds coincided, within a ±1-millisecond window, with impulses that exceeded the amplitude comparison level. Including the leading impulse, which was identified as the muzzle blast, a total of 15 impulses exceeded this level. The binary correlation coefficient was calculated as the number of gunshot sounds and impulses that coincided (11) divided by the square root of the product of the number of selected impulses (15) and the number of selected gunshot sounds (13). For these data, the binary correlation coefficient was calculated to be 0.79.

For the second calculation of the binary correlation coefficient, the delay time range over which impulses and echoes were compared was limited to the first 50 milliseconds following the muzzle blast, since this was the range in which the AGC would have had greatest effect. (It is also the range in which most of the echoes arriving from the front of the motorcycle occurred.) In this calculation, the amplitude comparison level was reduced to one-fourth of its value during the previous calculation, which placed it at a level just above that of very small peaks among the waveforms of the recorded impulses. Eighteen impulses exceeded this level. So would have the muzzle blast and all 11 echoes that were predicted to occur in the delay time range up to 50 milliseconds. Eleven of these sounds coincided, within ±1 millisecond, with one or another of the selected impulses. These data—11 coincident impulses and echoes, 12 gunshot sounds, and 18 impulses—resulted in a computed binary correlation coefficient of 0.75.

5.6 The probability that the recorded impulses are not gunshot sounds

The high degree of correlation between the impulse and echo sequences does not preclude the possibility that the impulses were not the sounds of a gunshot. It is conceivable that a sequence of impulse sounds, derived from nongunshot sources, was generated with time spacings that, by chance, corresponded within one one-thousandth of a second to those of echoes of a gunshot fired from the grassy knoll. However, the probability of such a chance occurrence is about 5 percent.* This calculation represents a highly conservative point of view, since it assumes that impulses can occur only in the two intervals in which echoes were observed to occur, these being the echo-delay range from 0 to 85 milliseconds and the range from 275 to 370 milliseconds. However, if the impulses in the DPD recording were not the echoes of a gunshot, they could also have occurred in the 190-millisecond timespan that separated these two intervals. Taking this timespan into account, the probability becomes considerably less than 5 percent that the match between the recorded impulses and the predicted echoes occurred by chance. Thus, the probability is 95 percent or more that the impulses and echoes have the same source—a gunshot, or a sound at least as sound as a gunshot, from the grassy knoll. Stated differently, the odds are less than 1 in 20 that the impulses and echoes were not caused by a gunshot from the grassy knoll, and at least 20 to 1 that they were.

*See the BBN report No. 3947.