

Acoustic Gunshot Analysis

The Kennedy Assassination and Beyond

When the FBI was not with Folio
 That was done by the FBI's Ramsey Committee that, unlike the
 FBI, was not with Folio

FBI LAW ENFORCEMENT BULLETIN

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The Cover: Forensic acoustic operations are important laboratory procedures which have been used in major investigations, including the Kennedy assassination. See article p. 1.

**Federal Bureau of Investigation
 United States Department of Justice
 Washington, D.C. 20535**

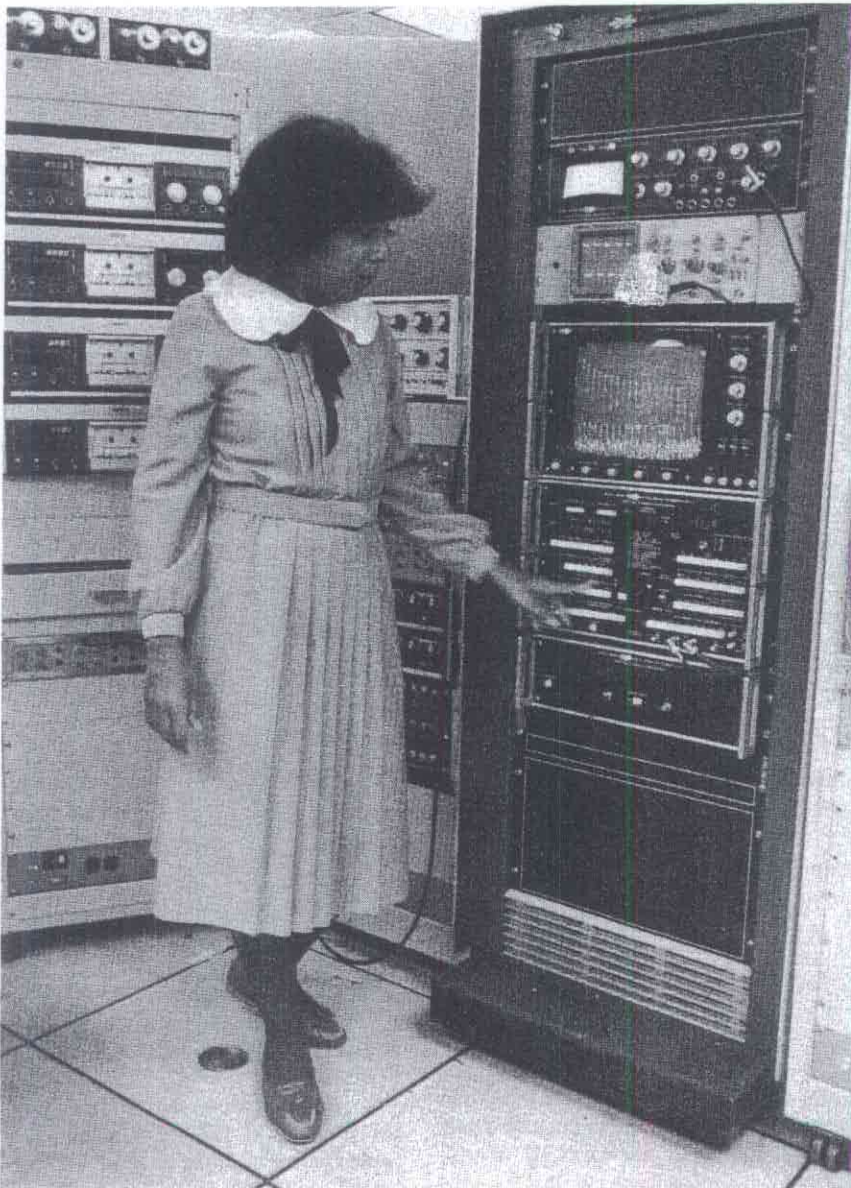
William H. Webster, Director

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 Assistant Editor—Kathryn E. Sulewski
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By

BRUCE E. KOENIG

*Special Agent
Technical Services Division
Federal Bureau of Investigation
Washington, D.C.*

Acoustic Gunshot Analysis

The Kennedy Assassination and Beyond

(Part I)



Special Agent Koenig

Forensic analysis of tape recorded gunshots and other transient or impulsive sounds (i.e. doors slamming, explosion of fireworks, etc.) has been an important factor in the disposition of a number of widely publicized criminal, civil, and investigative matters in the past 20 years, including the Kent State University deaths in 1970, the attempted assassination of President Ronald Reagan in 1981, and the deadly confrontation in Greensboro, N.C., between members of the Ku Klux Klan, the Nazi Party, and the Communist Workers Party in 1979. However, in the last few years, such analysis has also been used to dramatically show and then refute the possible involvement of a second gunman in the assassination of President Kennedy in Dallas, Tex., on November 22, 1963.

To allow a better understanding of the scientific principles involved in acoustic gunshot analyses, the techniques presently used by the FBI to analyze recordings of gunshots and other transient sounds will be set forth, followed by a rather detailed description of the forensic acoustic studies conducted in the Kennedy assassination. This will include the reports of the House Select Committee on Assassinations (HSCA), which found a 95-percent or better chance of a second gunman being involved in the shooting of President Kennedy; a review by the Federal Bureau of Investigation refuting that claim; and the analysis conducted by the National Research Council, which conclusively invalidated the HSCA's result. The details of these reports will clearly show many of the complex problems and thinking involved in examinations of recorded gunshots.

The FBI's Forensic Capability

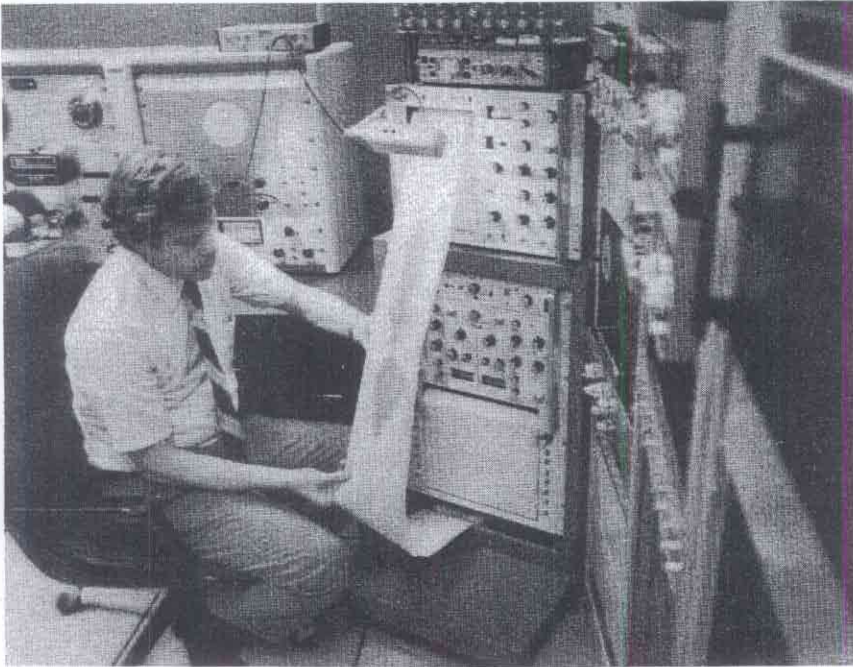
The FBI's Signal Analysis Unit in the Engineering Section of the Technical Services Division has been involved in forensic acoustics, waveform analysis, ballistics, and electronic engineering examinations of tape recordings since the 1950's. Forensic processes include voice intelligibility enhancement, authenticity determination, spectrographic voice comparisons, video enhancement, and copyright comparisons, with analyses of tape recorded gunshots and other impulsive sounds handled as a signal analysis matter.

Under the best recording conditions, this signal analysis examination can provide an accurate determination of which sounds represent gunshots and not some other impulsive sound (i.e. a door slamming), the number and time sequencing of the gunshots, the spatial location of where each gunshot occurred, and whether the fired projectiles were subsonic or supersonic. Subsonic projectiles travel at less than and supersonic at greater than the speed of sound (1130 feet per second at sea level and 71°F). However, matching a particular recorded gunshot sound to a specific weapon is normally not possible.

For example, in the violent confrontation in Greensboro, N.C., the FBI acoustically examined over 100 impulsive-type sounds that had been recorded during the incident by high quality professional equipment. The analysis determined that 39 gunshots had been fired, the exact timing sequence of the gunshots over 88 seconds, which projectiles were sub- and supersonic, and the physical location of each gunshot (usually within ± 3 feet) fired by members of the Ku Klux Klan, the Nazi Party, and the Communist Workers Party. Unfortunately,

From other evidence it is not possible. From the evidence it is not possible that at the least probably improbable. The recording was by radio, with very low quality in both transmission and receipt and with a recording with not only poor equipment but made on a low quality test that had determined actual

“A good quality recording and microphone system has to have been used during an incident in order to differentiate between recorded gunshots and other impulsive sounds.”



aural examinations, very high resolution waveform analysis, and the presence or absence of precursor supersonic N-waves.

The actual number of impulsive sounds and their time sequence can be determined with lower quality recordings, even those over telephone lines and transmitting systems, as long as the microphones are not driven beyond their ability to reproduce very loud sounds. For example, a recent shooting incident was tape recorded using a police body transmitter system. When played by investigators, the recording revealed only six gunshot-like sounds, whereas physical evidence showed that one individual had fired one shot and the second person fired six shots from his revolver, for a total of seven gunshots. The original tape recording was submitted to the FBI to determine the actual number of gunshot-like sounds, and if possible, who fired the first shot. The examination revealed seven gunshot-like sounds using high resolution waveform analysis and that shots five and six were only 0.087 second apart. This information, therefore, reflected that the individual firing the one shot was responsible for either the fifth or sixth gunshot in the sequence, since tests showed that two consecutive shots could not be fired from that particular weapon in that short a time-span.

Determining the exact location of the source of an impulsive-type sound requires a very high quality tape recording made on site, knowledge of

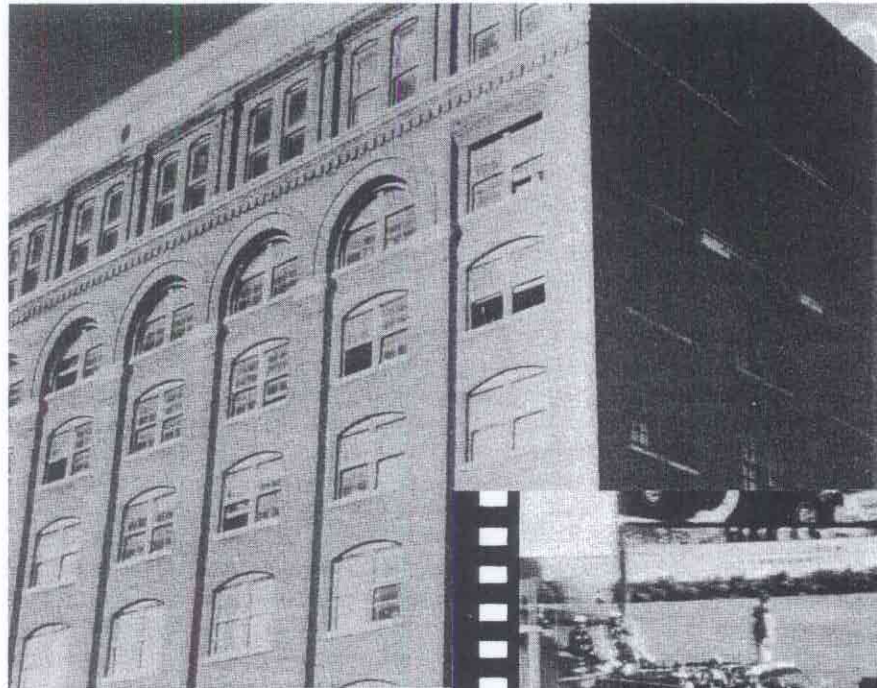
most forensic recordings of impulsive-type sounds are not recorded under the near perfect conditions encountered in Greensboro, N.C.

A good quality recording and microphone system has to have been used during an incident in order to differentiate between recorded gunshots and other impulsive sounds. Recordings over telephones and through radio transmitting systems (body, portable, and vehicular), or when the gunshot occurs close to the microphone, normally alter the signal sufficiently to prevent a meaningful determination. The actual examination to specify that a sound is a gunshot requires special



the approximate location of the microphone, and a scaled map of the area. Again, the use of recordings through telephone or transmitter systems is usually not possible. The examination uses the principle that impulsive sounds reflect and diffract off hard, relatively flat surfaces, like the sides of buildings, in a very predictable manner. This is analogous to a flashlight beam reflecting off a mirror in the dark or a bank shot in the game of billiards. These reflections and diffractions result in a waveform that contains the original impulsive sound followed by the echoes off flat surfaces in the locale. Thus, by carefully measuring the time delays of the set of echoes, a unique position can normally be determined for the original source of the impulsive sound. This examination is normally ineffective indoors (due to the very large number of echoes) and outdoors where few horizontal flat surfaces exist (such as the middle of a cornfield).

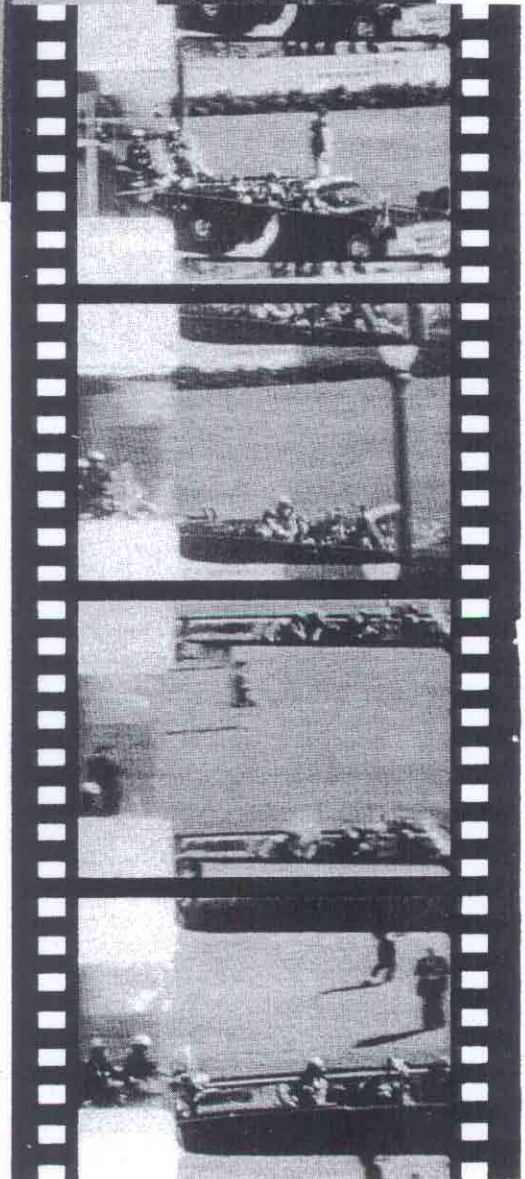
Ammunition is designed to be either sub- or supersonic when fired from a particular weapon due to the amount and type of gunpowder, the shape and weight of the projectile, and other factors. When a supersonic projectile is fired, the bullet will travel faster than the speed of sound, and thus, arrive at the target ahead of the sound of the muzzle blast. The supersonic speed of the bullet produces a characteristic shock wave, called an N-wave, that appears in the waveform as a precursor to the original muzzle blast, which itself is then followed by the echoes. The presence or absence of this N-wave on a high resolution waveform shows whether it is super- or subsonic, respectively.



Evidence submitted to the Technical Services Division for examination must be original recordings and have the appropriate supportive material enclosed.

Assassination of President Kennedy

On November 22, 1963, President John Fitzgerald Kennedy was assassinated while riding in a motorcade through Dealey Plaza in Dallas, Tex. The alleged assassin, Lee Harvey Oswald, supposedly fired three gunshots using a rifle while in the Texas School Book Depository (TSBD) Building at the intersection of Elm and Houston Streets in Dealey Plaza, which resulted in the death of our 35th President. However, Oswald was himself shot and killed soon after the assassination and could not be brought to trial.



Photographs from film showing the assassination of President Kennedy.

“During the past 20 years, [the] murder [of President John F. Kennedy] has probably generated more controversy than any other single criminal event in this country.”



President and Mrs. Kennedy moments before the fatal shot was fired.

These are not just random words by
 Andy J. Jacobs, et al.

During the past 20 years, this murder has probably generated more controversy than any other single criminal event in this country. Hundreds of articles, books, and scientific reports have been written concerning the assassination, covering a wide range of topics from the significance of bullet fragments found during the autopsy to who is buried in Oswald's grave. However, in recent years, the possible existence of another assassin in Dealey Plaza, besides Oswald, has become a major focus of interest in this ongoing controversy.

In September 1976, the HSCA of the U.S. House of Representatives, 95th Congress, was authorized a 12-member¹ committee to conduct a complete investigation into the circumstances surrounding the deaths of President Kennedy and Dr. Martin Luther King, Jr., including the possibility of additional assassins.

Acoustical Report of Bolt Beranek and Newman

In an attempt to cover all possible scientific leads concerning the assassination of President Kennedy, the HSCA asked personnel of Bolt Beranek and Newman, Inc. (BBN), in May 1978, to conduct an examination of two recordings made by the Dallas Police Department (DPD) of police radio traffic during the assassination. BBN, a Cambridge, Mass., acoustical firm, was asked to analyze the recordings to determine if they contained the sounds of gunfire involved in the shooting of the President, and if so, how many gunshots were recorded and from what locations did the gunshots originate.

BBN's report² of January 1979, to the HSCA reflects that the first recording is of DPD radio channel 1, which is a continuous recording on a Dictabelt of routine police radio traffic. The second recording is of auxiliary radio channel 2, which was intermittently recorded on a Gray Audograph disc and used by the DPD police officers assigned to the Presidential motorcade.³ However, after a preliminary examination, BBN decided to focus their attention on the channel 1 recording, instead of channel 2, for their analysis. *He avoids saying*

According to BBN, the police radio on a DPD motorcycle, which could have been in the Presidential motorcade, had its transmitting switch stuck open on channel 1 for approximately 5 minutes during the assassination. Therefore, the radio microphone would allegedly detect and transmit all sounds in the vicinity of the motorcycle, including the noises produced by the motorcycle itself.

BBN used filters to process the DPD channel 1 recording during the specified 5 minutes and displayed this signal in the form of a time-continuous waveform. An example of another type of time-continuous waveform is the pattern obtained when an electrocardiogram (EKG) displays a person's heartbeat.

The waveform display of channel 1 had five unique impulsive noise patterns thought to be different from motorcycle sounds, according to BBN. Their report reflects that four of these patterns appeared to be similar to the characteristics of a gunshot blast with a precursor supersonic N-wave. The other pattern was eliminated as a possible gunshot since it was different in amplitude and duration. The BBN report states that a rifle firing a supersonic bullet creates two sources of loud impulsive sounds—the muzzle blast and the shock wave of the projectile as it travels faster than the speed of sound.⁴ The shock wave is analogous to a jet fighter producing a sonic boom when it flies faster than the speed of sound. These two impulsive sounds, plus the echoes of these sounds reflecting and diffracting off such surfaces as the sides of buildings, the street, and automobiles, result in a particular pattern of sound impulse peaks.

However, tests performed by BBN on a radio system similar to that used by the DPD showed considerable distortion of loud impulsive sounds such as gunshots, which resulted in the elimination of impulse peaks, change in the position of peaks, and even the production of new peaks where no impulse peaks previously existed.⁵

Preliminary tests by BBN determined that the four chosen impulse patterns occurred at approximately

the same time as the known gunshots in Dealey Plaza and that no other sufficiently characteristic patterns were located in the pertinent 5-minute segment. Also, the time span between the first and fourth patterns did not contradict photographic evidence made during the assassination, the distorted patterns approximated test patterns of gunshots, and the amplitudes of the impulse patterns were in the same general range as test gunshots.⁶

On August 20, 1978, BBN fired a total of 12 test gunshots with weapons located only in the TSBD and on the so-called grassy knoll area in Dealey Plaza. Using 36 microphones located 18 feet apart on Houston and Elm Streets, BBN recorded these test gunshot blasts in an effort to reconstruct acoustically the impulse patterns recorded by the DPD radio system during the assassination of President Kennedy. Even though few physical changes had been made in Dealey Plaza since 1963, producing comparable test patterns was very difficult since the impulse patterns on the DPD recording were like "badly smudged fingerprints" due to the noisy environment in the vicinity of the transmitting DPD radio microphone, the poor quality of the DPD recording system, and a number of other problems.

Using the 12 different test gunshots from the TSBD and the grassy knoll and the 36 different microphone locations used by BBN, a total of 432 gunshot patterns were recorded ($12 \times 36 = 432$). These 432 test gunshot patterns were then compared to the impulse patterns isolated on the channel 1 DPD recording using a statistical analysis technique. This comparison provided a total of 15 possible matches, which was not particularly

significant since the average expected number of statistically false matches for such a comparison is 13, due to the random noise impulses present throughout the DPD tape.

BBN then stated that at least 6 of the 15 correlations were false matches, because 1 gunshot would have been fired at the wrong target, 1 would have occurred only 1.05 second after earlier correlations, which is too fast a firing rate for the tested rifle, 3 would have required a motorcycle with the open microphone to travel at 16 mph, and 1 would have required the motorcycle to travel at 55 mph. The motorcade was thought to have been traveling at approximately 11 mph. The remaining nine correlations sufficiently matched the four designated impulse patterns on the DPD recording to show a DPD microphone location varying between 120 and 160 feet behind the Presidential limousine. Further, the BBN analysis found that the four impulse patterns may have been gunshots fired as follows:

- "1. time 0.0 sec[ond]—one shot from the TSBD . . .
- "2. time 1.6 sec[onds]—one shot from the TSBD . . .
- "3. time 7.8 sec[onds]—one shot from behind the fence on the grassy knoll . . .
- "4. time 8.3 sec[onds]—one shot from the TSBD. . ."⁷

The BBN conclusions were presented in oral testimony to the HSCA on September 11, 1978, reflecting that the radio on the DPD motorcycle in the Presidential motorcade had received and transmitted the four specified impulse sounds and that each of these impulse sounds was possibly a gunshot. Due to the false matches produced by the statistical technique, the probabilities, according to BBN, that each impulse pattern is a gunshot are:

- Time 0.0 second—88 percent
- Time 1.6 seconds—88 percent
- Time 7.8 seconds—50 percent
- Time 8.3 seconds—75 percent

BBN stated that the probability that all four impulse patterns are gunshots is only 29 percent.⁸

Acoustical Report of Weiss and Aschkenasy

On October 24, 1978, the HSCA authorized Mark R. Weiss and Ernest Aschkenasy, Department of Computer Science, Queens College, City University of New York, to conduct an independent analysis of the alleged third gunshot recorded on channel 1 of the DPD radio system to determine with greater accuracy whether it was indicative of a gunshot from the grassy knoll.

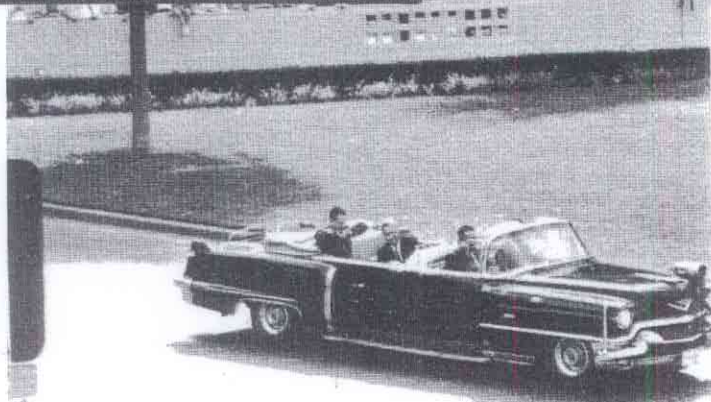
To conduct their analysis, Weiss and Aschkenasy received from the HSCA high quality magnetic tape copies of the DPD recording, a high quality tape copy of the gunshot sounds recorded by BBN during the acoustical reconstruction tests performed in Dealey Plaza on August 20, 1978, a topographical survey map of



Above: Model of Dealey Plaza showing the route of the Presidential motorcade.

Left: Photograph of re-enactment conducted as part of the investigation into the assassination.

Above left: Photograph of the re-enactment through a rifle scope from the Texas School Book Depository.



Dealey Plaza (scale: 1 inch to 10 feet), a map of Dealey Plaza (scale: 1 inch to 40 feet) with microphone locations used by BBN in their gunshot reconstruction tests, and aerial and ground-level photographs of Dealey Plaza and the surrounding areas. The HSCA also provided them with additional information, such as building heights in Dealey Plaza, distances not shown on the maps, the location of shooters during the BBN reconstruction experiment, and the air temperature during the assassination and reconstruction experiment.

Weiss and Aschkenasy's report states:

"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. . . . 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."⁹

The static-like sounds on the DPD recording could be distorted gunshot sounds, since the DPD radio system would have compressed the sound of the muzzle blast and its strongest echoes, making them only slightly louder than the background static. For example, if the open microphone was on a motorcycle in the motorcade, most of the weak echoes of a muzzle blast would have been obscured by the noise of a motorcycle engine (which could be the source of the continuous noise on channel 1). Thus, the sounds of a gunshot could have been recorded as a sequence of impulse sounds (the muzzle blast and its echoes), only a few having a larger amplitude than the engine noise and none of which would have sounded like gunshots after being changed by the circuitry of the DPD radio and recording equipment.

The report states that the higher impulse sounds on the DPD recording could be generated by a number of

sources, including misfiring of a motorcycle engine, noise produced by the motorcycle's ignition system, radio on-and-off clicks, scratches on the Dictabelt, and electrical or mechanical disturbances in the system. Weiss and Aschkenasy, in an effort to differentiate these sounds from a gunshot, asserted that the most effective and most reliable characteristic to determine if a sound is a gunshot is the presence or absence of echoes from the muzzle blast. These echoes are the result of firing a gun, which produces a loud impulse sound that spreads out and is heard in every direction. This sound is then reflected and diffracted off any structures in the area, producing echoes which arrive at the microphone later than the direct muzzle blast impulse. Weiss and Aschkenasy contended that the specified impulse pattern on the DPD recording had these echoes, thus reflecting that it was a gunshot. However, in public testimony before the Committee on December 29, 1978, Weiss stated that it is "... not so much the echo pattern as the evidence of a supersonic shock wave" that would characterize a gunshot sound and eliminate other sounds like the backfire of a motorcycle. Weiss further stated he does not know of any other sound that might resemble the pattern he determined to be a gunshot due to the presence of the supersonic shock wave and the muzzle blast impulses.¹⁰ It is not known which characteristic Weiss and Aschkenasy actually used in their analysis.

In their report to the House Select Committee on Assassinations, Weiss and Aschkenasy stated:

"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.

"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."¹¹

Using the topographical map of Dealey Plaza and the BBN reconstruction results (test gunshots fired only from the TSBD and the grassy knoll), Weiss and Aschkenasy attempted to predict a pairing of a shooter and a microphone that would produce a sound pattern that would match the specified impulse pattern of the DPD recording. To calculate these predicted echo patterns of a particular shooter and microphone location in Dealey Plaza, three pieces of information were needed:

"(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."¹²

First, the topographical map revealed many of the reflecting and diffracting surfaces within Dealey Plaza. Second, direct measurement on the map determined the distances from the gun to the reflecting and diffracting surfaces and then to the microphone location. Third, the speed of sound was determined to be approximately 1,123 feet per second, principally by using the known air temperature near Dealey Plaza on November 22, 1963, of approximately 65° F (the speed of sound varies with changes in air temperature).

To make a comparison of predicted echo patterns to the specified pat-

tern on the DPD recording, the errors in the speed of sound determination and the time accuracy of the DPD recording had to be determined. Weiss and Aschkenasy used a ± 1.0 -percent error for the speed of sound due to temperature variations ($\pm 10^\circ$ F) and a -4.0 -percent to -6.0 -percent error for speed variations on the DPD Dictabelt recorder, since the average speed of the recorder over a 15-minute segment was 5.0 percent too slow. These two errors combined to give a maximum possible time error range of -3.0 percent to -7.0 percent. Weiss and Aschkenasy then stated that since any value within this maximum error range is valid, it was possible to choose a value that created the best match between the alleged gunshot impulse and predicted echo sequences. A -4.3 -percent error factor was picked since it gave the best match.

Weiss and Aschkenasy, using a statistical technique and by physically measuring on the topographical map of Dealey Plaza with string, determined that the specified impulse pattern on the DPD recording of channel 1 was "a sound as loud as a gunshot from the grassy knoll" area of Dealey Plaza, with a probability of 95 percent or higher.

The complete findings of Weiss and Aschkenasy concerning the specific sounds on the DPD recordings are:

"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 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."¹³

In his testimony in the public hearing before the HSCA on December 29, 1978, Weiss mentioned two additional findings that were not in his report of February 1979. Weiss stated that the specified pattern found to be a gunshot from the grassy knoll was most likely supersonic and fired by a rifle. However, in their report, Weiss and Aschenasy stated they did not know the type of gun used. Weiss also testified that the weapon fired from the grassy knoll was aimed in the general direction of President Kennedy's limousine.

Aschkenasy stated at that public hearing that he was so sure of their results that "if someone were to tell me that the motorcycle was not in Dealey Plaza, and he was, in fact, somewhere else, and he was transmitting from another location . . . I would ask to be told where that location is, and once told where it is, I would go there, and one thing I would expect to find is a replica of Dealey Plaza at that location. That's the only way that it can come out."¹⁴ Based primarily on the acoustical analyses

performed by both BBN and Weiss and Aschkenasy that there were gunshots in Dealey Plaza from both the TSBD building (where Lee Harvey Oswald allegedly fired three gunshots) and the grassy knoll area (one gunshot) during the assassination of President Kennedy, the HSCA found, in part, that "scientific acoustical evidence establishes a high probability that two gunmen fired at President John F. Kennedy."¹⁵

Having considered in part I the analyses of BBN and Weiss and Aschkenasy of recorded sounds relating to the assassination of President John F. Kennedy, the conclusion will report on a review and the findings of the Federal Bureau of Investigation and the analysis conducted by the National Research Council. **FBI**

(Continued next month)

Footnotes

¹ The members were Louis Stokes—Chairman (Ohio), Richardson Preyer (North Carolina), Walter E. Fauntroy (District of Columbia), Yvonne Brathwaite Burke (California), Christopher J. Dodd (Connecticut), Harold E. Ford (Tennessee), Floyd J. Fithian (Indiana), Robert W. Edgar (Pennsylvania), Samuel L. Devine (Ohio), Stewart B. McKinney (Connecticut), Charles Thone (Nebraska), and Harold S. Sawyer (Michigan).

² *Appendix to Hearings Before the Select Committee on Assassinations, U.S. House of Representatives, 95th Cong., 2d Sess., Volume VIII, Washington, D.C., 1979, pp. 41-42.*

³ Dictabelts and Gray Audograph discs were used with early dictating equipment to record voice information; a stylus imprinted grooves on their plastic surfaces, much like a poor quality phonograph record, which could then be played back at a later time.

⁴ *Appendix, pp. 41-43, 52-55.*

⁵ *Appendix, pp. 76-77.*

⁶ *Appendix, pp. 43-45.*

⁷ *Appendix, p. 46.*

⁸ *Appendix, pp. 47-48.*

⁹ *Appendix, p. 11.*

¹⁰ Broadcast of public hearing over radio station WETA-FM in Washington, D.C.

¹¹ *Appendix, p. 7.*

¹² *Appendix, p. 19.*

¹³ *Appendix, p. 10.*

¹⁴ *Supra note 10.*

¹⁵ *Report of the Select Committee on Assassinations, U.S. House of Representatives, Findings and Recommendations, 95th Cong., 2d Sess., U.S. Government Printing Office, Washington, D.C., 1979, p. 58.*