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Audio Forensic Interpretation of the Trump Rally Assassination Attempt (July 13, 2024)

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This is a case study describing the rapid audio forensic assessment of recordings from the assassination attempt against presidential candidate Donald Trump in Butler, PA, on Saturday, July 13, 2024. Audio from the podium microphones revealed gunshot sound sequences of ballistic shock waves and muzzle blast sounds consistent with rifle bullets traveling at supersonic speed. Additional independent audio evidence was captured by cell phone videos recorded by individuals in the crowd at the time of the shooting. The acoustical consistency between the podium microphone signal and the audio from the numerous user-generated cell phone videos provided strong confidence of authenticity. Within a few hours of the incident, audio forensic analysis identified ten audible gunshots, with the first eight coming from a single position consistent with the subsequent identification of the would-be assassin's body and two other shots attributable to law enforcement officers.

0 INTRODUCTION

On Saturday, July 13, 2024, a shooting incident took place at an outdoor rally held by presidential candidate Donald J. Trump at the Butler Farm Show grounds in Butler, PA. Gunshot sounds were detected in audio from the venue's podium microphones, as well as from cell phone video recordings made by amateur bystanders who happened to be recording during the shooting incident. From the various audio recordings, gunshot sounds continued for approximately 16 s.

This paper describes audio forensic methods and analytical techniques used in the initial hours and days after the incident to answer scientific questions posed by news organizations reporting on the shooting. Unlike the relatively slow and methodical work typically done in acoustical research, this case study demonstrates the contemporary expectations of journalists and the public to receive authoritative information in the age of social media speculation with virtually instant promulgation.

The remainder of this paper is organized as follows. First, a brief summary is provided of the manner in which a forensic audio examiner works with a client to maintain scientific objectivity. Next, the characteristics and initial findings from the lectern microphone are summarized. Finally, the very unusual situation of having multiple user-generated recordings (UGRs) of the shooting sequence is considered, followed by a concluding summary.

1 STARTING AN AUDIO FORENSIC EXAMINATION

Audio forensics is used among the forensic sciences to evaluate evidence that may ultimately be used in a court of law or as part of a formal scientific inquiry [1]. Among the challenges of forensic examination is avoiding bias in the investigation. Whether the examination request comes from a prosecutor, defense attorney, potential litigant, or a journalist, the audio forensic examiner is ethically bound to use only the audio evidence presented, not extraneous nonaudio information or potentially prejudicial statements about the desired results of the investigation. In the adversarial legal process or in the story construction of a journalist, the audio forensic examiner is not an advocate for a particular conclusion or a particular side in a dispute. The examiner must therefore keep the investigators and advocates at arm's length to avoid either conscious or unconscious influence on the scientific examination.

In this case, for example, the request for forensic examination came from a series of professional journalists beginning just 35 min after the shooting incident took place in Butler, PA. Authorities at the scene were not releasing information, so the reporters asked whether recordings of gunshot sounds they had obtained from the scene could help understand the circumstances of the shooting incident. The reporters initially stated that witnesses had heard "small

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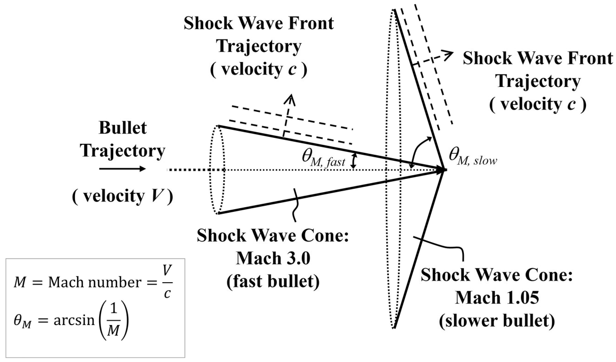

Fig. 1. Shock wave cone geometry for a supersonic projectile.

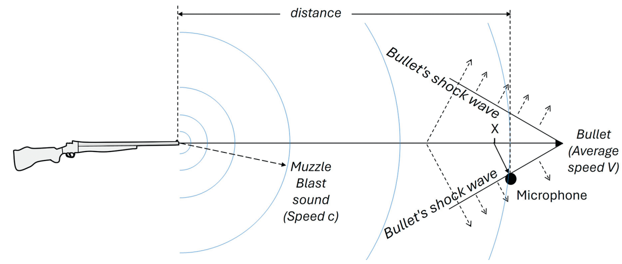

Fig. 2. A supersonic bullet traveling toward the microphone: the bullet's shock wave reaches the microphone before the sound of the muzzle blast.

arms fire" and that there was evidence of injuries at the venue. They made available to the present author various audio recordings obtained confidentially through their regular reporting process, then requested the audio forensic interpretation without further influence.

2 GUNSHOT ACOUSTICS SUMMARY

A conventional firearm uses a confined combustion of gunpowder to propel the bullet out of the gun barrel. The sound energy emanating from the barrel is referred to as the *muzzle blast*, which typically lasts for less than 3 ms. The sound of the rapid combustion is emitted from the gun in all directions, but most of the acoustic energy is expelled in the direction the gun barrel is pointing. Thus, the recorded sound will depend on the orientation of the firearm with respect to the microphone [2–4].

The muzzle blast acoustic wave propagates through the air at the speed of sound (e.g., $c = 343$ m/s at 20°C) and is partially reflected, absorbed, and diffracted by surrounding surfaces and obstacles. This inevitable mixture of sound due to the direct sound of the firearm and the overlapping acoustic reflections and reverberation creates a complicated pattern that depends on the firearm type, orientation, acoustical surroundings, and relative location of the microphone.

In addition to the sound of the muzzle blast, a bullet traveling at supersonic speed V, where $V > c$, creates another source of sound. The projectile's supersonic travel through the air causes a cone-shaped shock wave (miniature sonic boom) that propagates outward along the bullet's path. The sound of the ballistic shock wave can be detected down range along the bullet's path. The shock wave cone expands outward with its wavefront moving at the speed of sound and inner cone angle θ_M depending on the *Mach Number*, $M = V/c$, as given in Eq. (1) [3].

$$\theta_M = arcsin\left(\frac{1}{M}\right). \tag{1}$$

A projectile traveling at a speed much greater than the speed of sound will create a narrow shock wave cone, while a projectile traveling at a speed just barely above the speed of sound will have a broad shock wave cone, as shown in Fig. 1 [1].

The supersonic projectile carries the ballistic shock wave down range faster than the propagation of the muzzle blast sound. Therefore, a microphone located down range from the firearm will receive the bullet's shock wave "crack" sound prior to the arrival of the muzzle blast's "pop" sound, as depicted in Fig. 2 [6].

As the supersonic bullet travels down range, its supersonic speed V outpaces the sound of the muzzle blast, which is propagating at speed c, and therefore, the time gap between the arrival of the shock wave and the arrival of the muzzle blast increases down range. The result is a distinctive "crack-pop" sequence comprising two successive impulsive sounds, one due to the shock wave and one due to the muzzle blast [5].

The time lag (t_{diff}) between the ballistic shock wave arrival and the muzzle blast arrival depends on the speed of sound (c), the average speed of the bullet (V), and the distance between the firearm and microphone. Thus, given estimates of these parameters, the predicted distance between the firearm and microphone can be estimated from the measured time lag, as shown in Eq. (2) [6].

$$distance = \frac{t_{diff}}{\left(\frac{1}{c} - \frac{1}{V}\right)}. \tag{2}$$

A bullet decelerates as it travels through the air due to frictional losses. The deceleration depends on aerodynamic details of the bullet and other physical factors. It is typical to use experimental methods to characterize the muzzle velocity and deceleration characteristics of different types of ammunition.

An important detail is that the ballistic shock wave of a supersonic bullet propagates outward and forward along the bullet's trajectory. Therefore, an observer beside or behind the gun barrel will not receive the ballistic shock wave, while recordings from a position down range from the rifle will show evidence of the shock wave arrival (see Fig. 3).

An additional factor for interpreting gunshot sounds is the effect of the recording system and signal encoding format. The position and quality of the microphones built into consumer recording devices is often unknown, users may inadvertently cover the device's microphones with their fingers, and the perceptual audio coding used to process the audio may not be able to preserve precise timing and amplitude details with impulsive sounds such as gunshots.

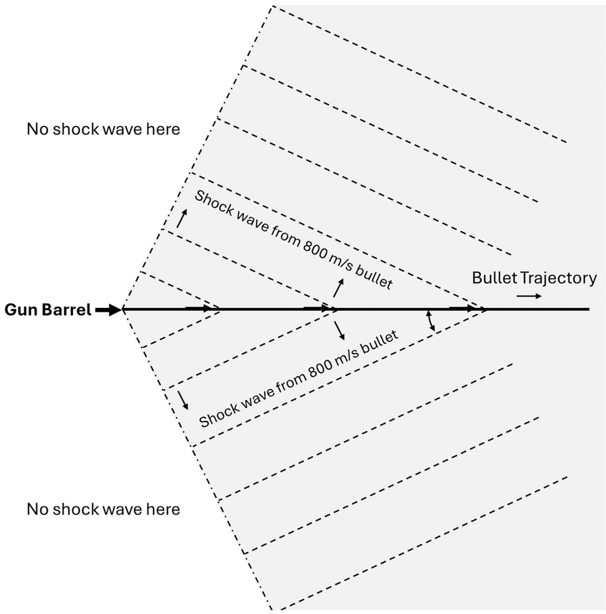

Fig. 3. The ballistic shock wave from a supersonic bullet propagates as an expanding cone trailing the bullet. Observers to the front of the gun barrel and down range along the bullet's path will detect the shock wave, while observers beside and behind the gun will not be in the shock wave's path. Once launched, the shock wave propagates at the local speed of sound.

3 THE FIRST OBSERVATIONS: LECTERN MICROPHONE

About 35 min after the shooting incident on July 13, 2024, journalists made available footage from news cameras that had been covering the rally in a routine manner. The news video showed what had happened on the podium, and the soundtrack captured the sounds recorded by lectern microphones. The reporters shared witness remarks from the scene that "small arms fire" had been heard, but no details were shared about the physical orientation of the rally venue, stage, bleachers, and audience configuration.

The lectern left and right channel audio and the corresponding spectrograms at the time of the first audible gunshots are shown in Fig. 4. The first step of formal audio forensic analysis, *critical listening*, identified that most of the gunshot sounds consisted of "crack-pop" sequences, indicating supersonic bullets on a trajectory generally toward the lectern microphones [7].

The audibly identified gunshot sounds were confirmed in the lectern audio using the standard audio forensic techniques of *waveform analysis* and *spectral analysis* [7]. The audio forensic interpretation was that the recording contained three audible gunshots (A, B, and C) in quick succession, then a barrage of five shots (D, E, F, G, and H), and then two more shots (I and J): a total of ten audible gunshots.

The first three shots from the lectern microphone recordings are depicted in Fig. 5. The time interval shown is 4.5 s, beginning with Mr. Trump uttering the words "take a look at what happened," then the sequence of three shots (labeled A, B, and C), and shouts from the Secret Service officers and crowd noise.

In the lectern recording, the time gap between shock wave and muzzle blast is approximately $t_{diff} = 217$ ms. The type of rifle and ammunition used was not known immediately after the incident, so as is customary in audio forensic analysis, a typical speed for a rifle bullet is assumed for initial calculations, subject to refinement later in the investigation. A typical assumption is $V = 800$ m/s.

The ambient air temperature at the time of the rally was above 30°C, giving the speed of sound estimate $c = 350$ m/s. Using the assumed average bullet speed, air temperature, and $t_{diff} = 217$ ms, Eq. (2) gives the estimate that the firearm causing shots A, B, and C was 135 m from the podium. Note that if the actual average supersonic bullet speed over the path from the firearm to the microphone was as slow as 600 m/s or as fast as 900 m/s (Mach 1.7–2.6),

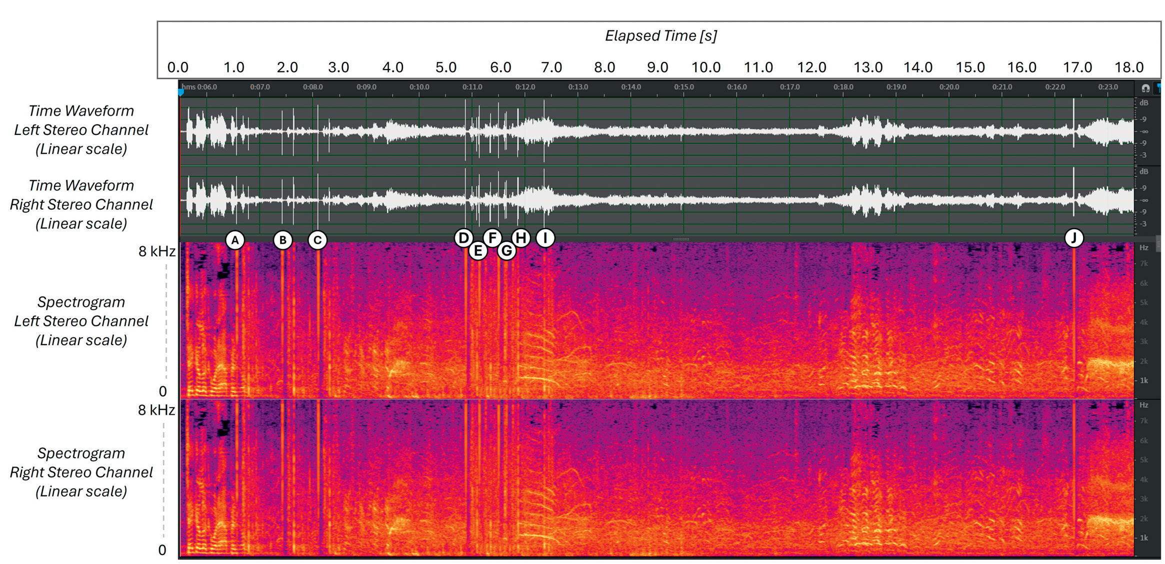

Fig. 4. Waveforms and spectrograms of lectern microphone audio, with manual indication of gunshot sounds (A–J).

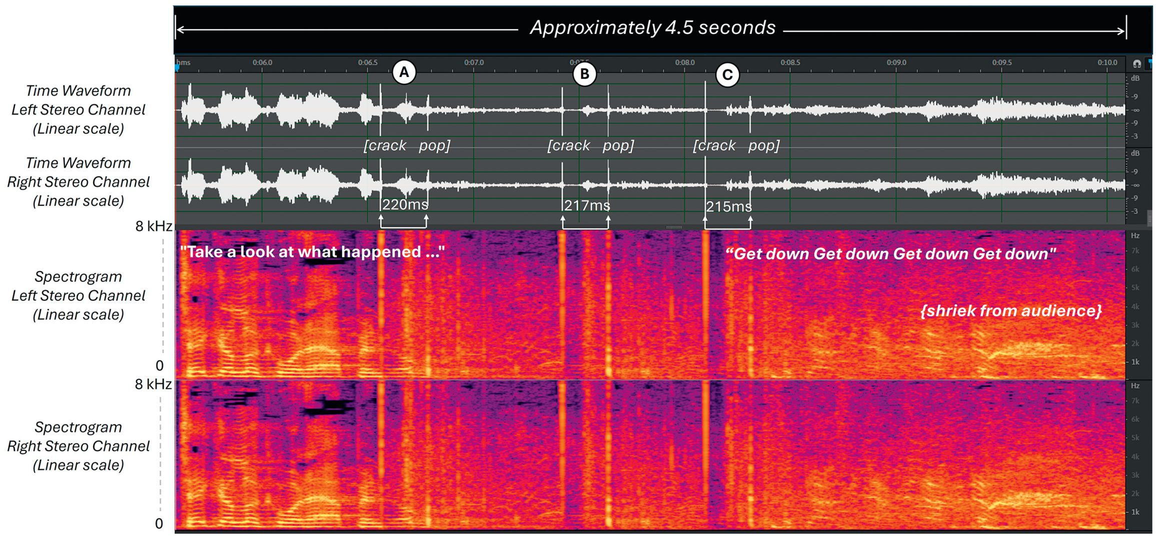

Fig. 5. Waveform and spectrogram of the first three audible shots (A, B, and C), from the lectern microphone.

the distance estimate would be between 182 and 124 m, indicating the importance of verifying the likely average bullet speed over the trajectory.

3.1 The Next Five Gunshots

After the sequence of three shots A, B, and C, there was a gap of about 2 s in the audio from the podium video, then a sequence of five shots in quick succession, labeled D–H in Fig. 6. The shock wave and muzzle blast crack-pop sequences for shots D–H were of similar amplitude and time lags to shots A–C, although the cadence of shots D–H was sufficiently rapid that the shock wave arrival of subsequent shots overlapped the muzzle blast arrival of prior shots. Audio forensic analysis of the signals from the lectern microphone indicated that the sounds of the first eight shots were indistinguishable acoustically and therefore likely to be from the same firearm and location, but a scientifically supported conclusion could not be justified from a single recording.

3.2 The Final Two Gunshots

Critical listening, waveform analysis, and spectral analysis identified two more gunshot sounds, designated I and J, in the podium recording (see Fig. 4). The character of these impulsive sounds differed from the eight shots A–H because no clear crack-pop sequence was observed for either I or J, and those two shots also differed from each other. The absence of the crack-pop sequence could indicate that the shots came from a firearm with ammunition that was not supersonic (e.g., a typical handgun) or that the orientation of the firearm(s) making those shots and the geometry of

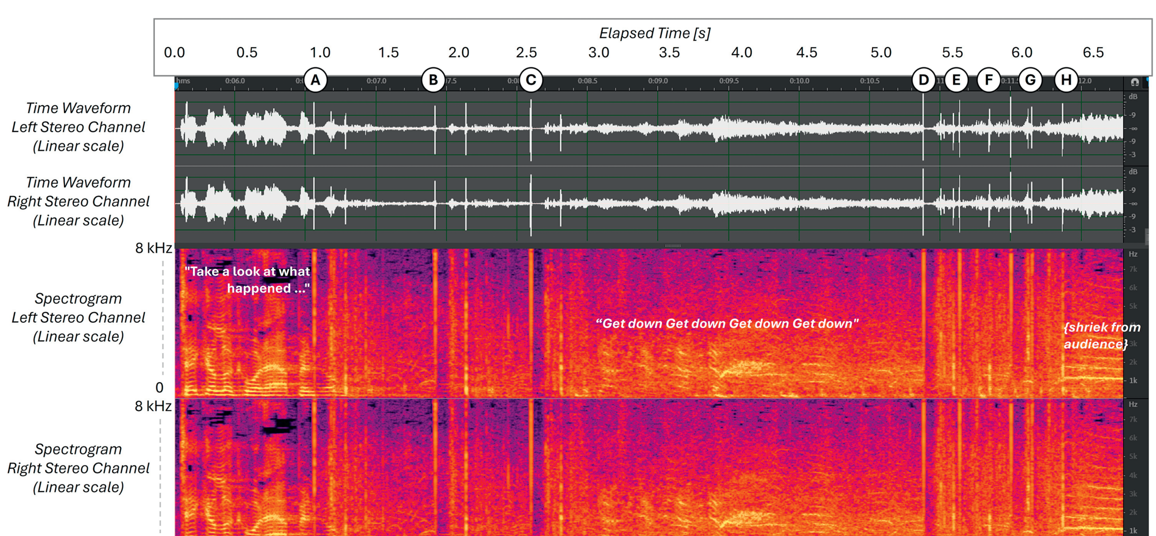

Fig. 6. Waveform and spectrogram of the first three audible shots (A, B, C), followed by the next five audible shots (D–H), from the lectern microphone.

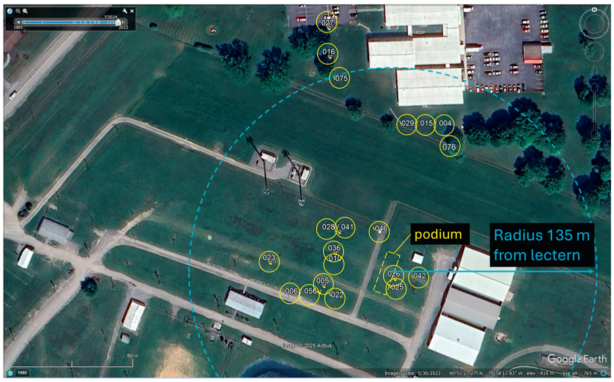

Fig. 7. Example geolocation information for several of the UGRs (i.e., arbitrary identification 005, 023, 028, etc.).

the venue was such that the shock wave and muzzle blast did not both impinge on the microphone (refer to Fig. 3).

At this point, just a few hours after the incident on July 13, 2024, the author's audio forensic investigation determined that eight very similar crack-pop sequences took place in the span of about 6 s and that the timing of those sequences indicated that the shots likely came from a single firearm (rifle with supersonic ammunition) at an estimated distance of approximately 135 m from the podium, with distance uncertainty due to the unknown characteristics of the ammunition used. The other two audible shots (I and J) could not be fully understood from only the lectern recordings.

4 ADDITIONAL OBSERVATIONS: THE AMATEUR BYSTANDER VIDEOS

Within a few hours of the incident, the professional journalists began to receive videos sent to them or posted online by attendees at the rally who happened to have been recording with their handheld smartphones during all or some portion of the shooting incident. These UGRs were from locations all over the rally venue. Some of the recordings were from many minutes before the first audible shot, while others included the sound of the gunshots from the users' camera locations.

The reporters were manually able to "geolocate" many of the camera positions in the UGRs by recognizing reference points from the rally scene in still frames from the video. Each UGR was assigned an arbitrary identification number and then made available to the author for analysis. To maintain objectivity, the UGRs were handled as evidence, with no additional commentary from the reporters.

The location of several of the UGRs that contained sounds relevant to the audio forensic investigation are shown in Fig. 7, superimposed on a Google Earth image of the rally location.

4.1. Initial Review of Several User-Generated Recordings

As the UGRs were received over the next 48 h, the audio forensic analysis process proceeded by performing critical listening, waveform analysis, and spectral analysis of each available recording.

One of the first recordings received, ID "076," was recorded from a location near a chain link fence north of the podium. The video showed law enforcement officers looking toward the roof of a tan metal-sided building and several audible utterances of individuals shouting "he has a gun!" in the moments before the gunshots are audible. The waveform and spectrogram of UGR 076 are shown in Fig. 8.

Another UGR, this one with ID "006," was recorded from an entirely different location southeast of the podium area. The waveform and spectrogram of UGR 006 are shown in Fig. 9.

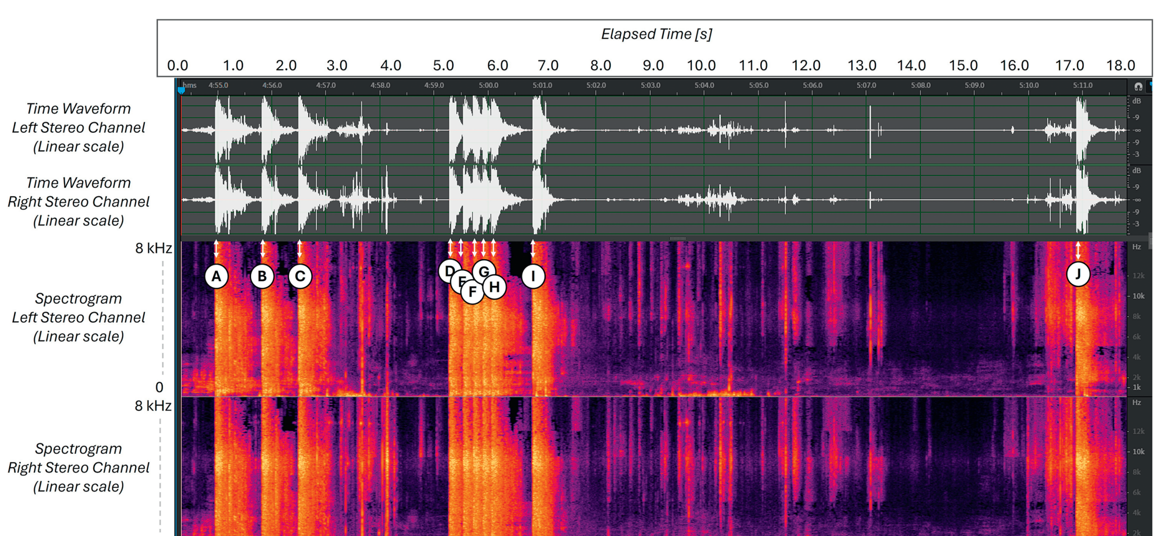

Fig. 8. Waveform and spectrogram from UGR 076.

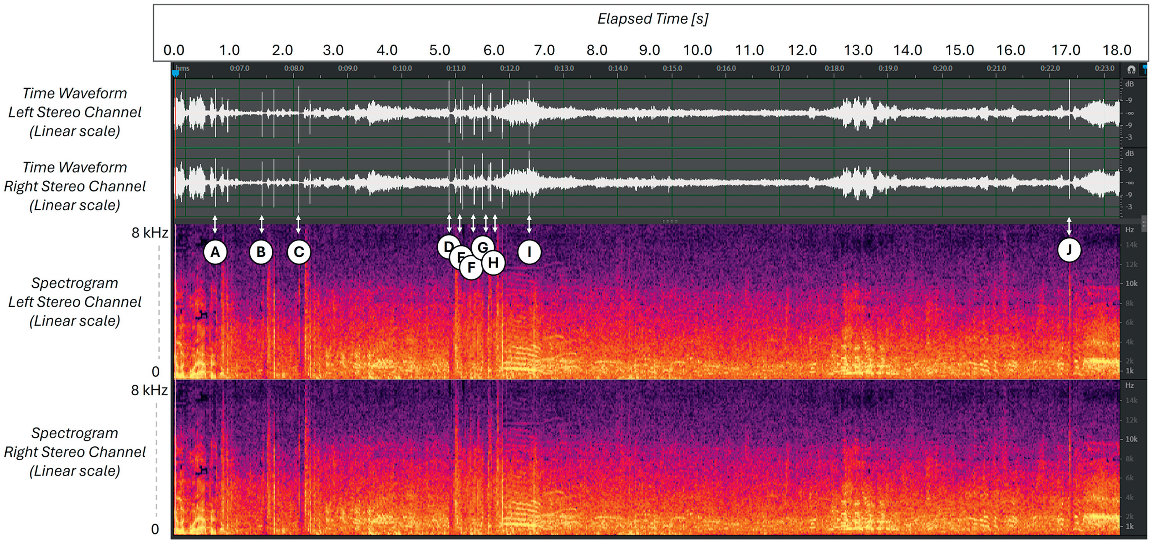

Fig. 9. Waveform and spectrogram for user generated recording 006.

Table 1. Timing comparison in seconds for audible shots in recording 076 and 006.

Shot ID	Recording 076	Recording 006	Difference
A	0.000	0.000	0.000
B	0.859	0.858	0.001
C	1.538	1.535	0.003
D	4.329	4.317	0.012
E	4.584	4.573	0.011
F	4.768	4.787	–0.019
G	4.945	4.938	0.007
H	5.104	5.085	0.019
I	5.869	5.801	0.068
J	15.927	15.794	0.133

Audio forensic observations from UGR 076 (north location) and UGR 006 (southeast location) gave the timing comparison shown in Table 1, each referenced to the time of shot A. Even though the two recording locations were separated by approximately 150 m, the timing comparison of each of the first eight shots (A–H) relative to shot A is within 20 ms.

Considering the facts that the recordings contain noise and shouting, the audio was processed with a perceptual audio coder (MP4), and the mobile phones were moving somewhat during the recording interval as the individuals making the recordings turned and took a few steps, the audio forensic interpretation of the relatively small timing discrepancies in this comparison indicated that the first eight shots were indeed likely from the same shooting location.

4.2. Reviewing More of the User-Generated Recordings

As additional UGRs became available, it was possible to determine the relative onset timing of the audible gunshots compared to the first muzzle blast sound in each recording. For example, a visual comparison of five UGRs is shown in Fig. 10, with the alignment based on the first muzzle blast sound in each recording (shot A).

As was noted in the initial comparison of recordings 076 and 006, the relative timing of shots A–H is found to be consistent among the UGRs. The audio forensic conclusion from these observations was that shots A–H each came from the same location, so that the relative time-of-arrival of the sound at each microphone was the same. The observation that shots I and J exhibit different time lags in different recordings indicates that those two shots were not from the same location as shots A–H and, furthermore, were not from the same location as each other.

Within a few days, more UGRs became known, and ultimately 13 of the UGRs captured all ten audible shots. A graphical depiction of the relative time-of-arrival of each shot is shown in Fig. 11. The small timing difference (within 20 ms) for shots A–H among the 13 UGRs provided additional support for the audio forensic conclusion that the first eight audible shots came from a single location.

The relative timing of shots I and J showed a greater difference among the 13 UGRs, with a discrepancy among the UGRs of more than 200 ms for shot I and more than 400 ms for shot J. The audio forensic conclusion is that shots I and J came from different locations than shots A–H.

4.3 Interpretation of Shots I and J

At this point in the investigation, the professional reporters sought an explanation for audible shots I and J. It became known from witnesses and official reports that a Secret Service counter-sniper had shot the assassination suspect, so there was an assumption that one of those two audible shots was from a Secret Service rifle.

Comparison of shot sounds I and J in the 13 UGRs showed significant differences in signal amplitude and apparent presence or absence of a crack-pop sequence. As noted in Fig. 3, the presence of a ballistic shock wave depends on the trajectory of the bullet with respect to the microphone. The UGRs from the area west of the podium, such as 006 and 023, did not show a discernable and consistent crack-pop sequence for shots I and J, while recordings

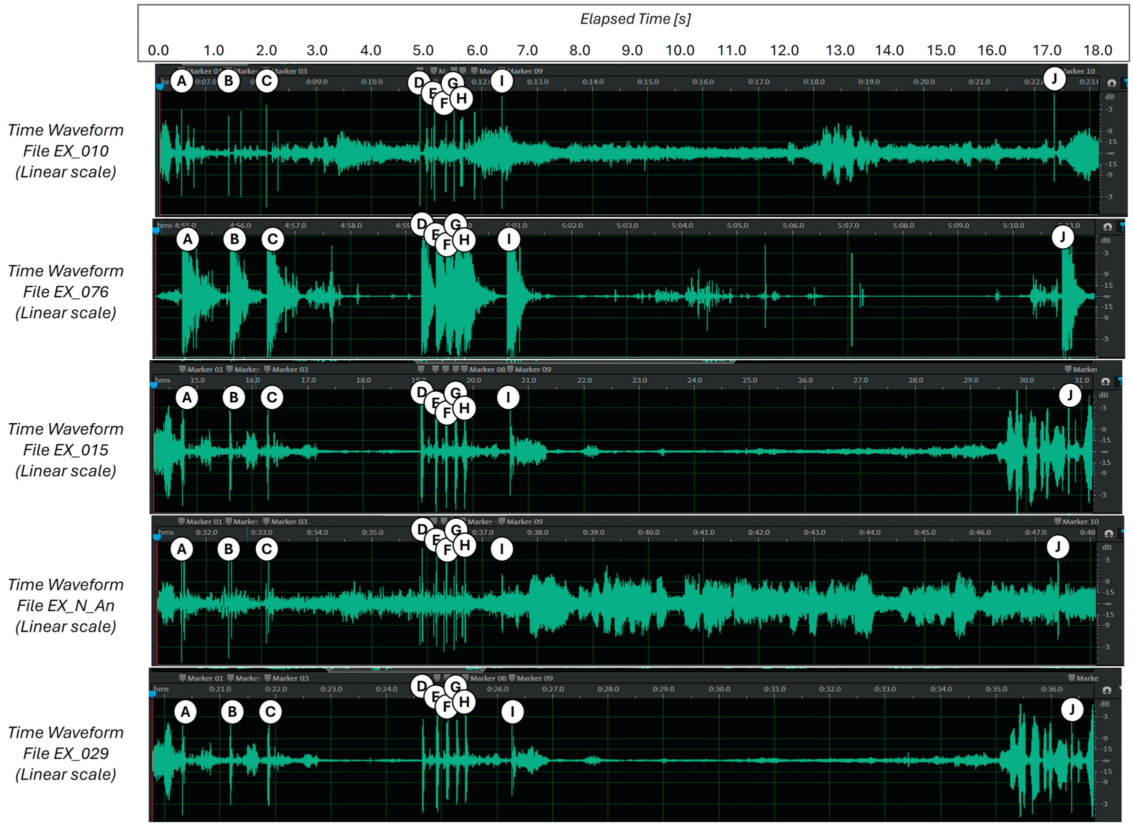

Fig. 10. Five example concurrent UGRs of the gunshot sequence. The eight identified gunshot sounds A–H show onset synchrony, while shots I and J are asynchronous. The conclusion is that shots A–H came from a single location, while shots I and J were from two other (and different) locations.

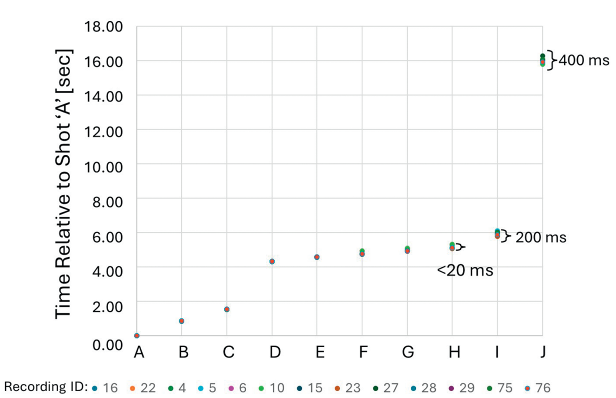

Fig. 11. Relative timing comparison for sequence of ten shots A–J observed at 13 locations. The first eight shots (A–H) have consistent relative timing. Shots I and J have notably different relative timing among the recordings.

such as UGR 076 from north of the podium showed some evidence of a shock wave and muzzle blast combination. However, the interpretation was not as clear and consistent as had been observed for the initial shots A, B, and C from the lectern microphone recording.

Another issue when the bullet trajectory is not directly toward the microphone is depicted in Fig. 12. This has been studied in prior investigations (e.g., see [6, Sec. 6], for a discussion of the bullet trajectory geometry and timing considerations).

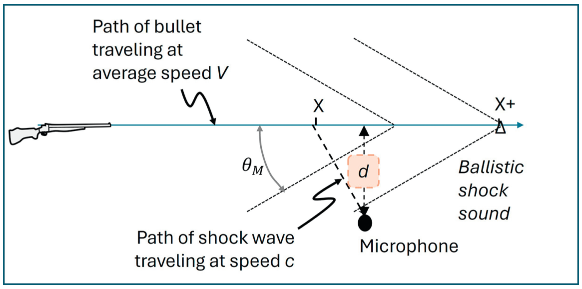

Fig. 12. Shock wave geometry for bullet trajectory a distance d from the microphone.

Ultimately, the audio forensic conclusion was that because shots I and J were not fired directly toward any of the recording devices, the crack-pop observation and timing [Eq. (2)] based on the geometry of Fig. 2, which is based on the assumption that the bullet trajectory is very close to the microphone, was simply not valid for shots I and J.

5 CONCLUSION

This case study described how audio forensic analysis was applied immediately after the Trump assassination attempt in Butler, PA, on Saturday, July 13, 2024. From the audio forensic standpoint, the case included an unprecedented number of concurrent UGRs of gunshots from the scene of a tragic criminal shooting incident. These UGRs provided essential corroborative information that lessened the likelihood of manipulated audio surfacing on social media sites or unfounded claims gaining traction on the internet. Had anyone come forward with a recording that purported to have a different sequence of gunshot sounds, it would be hard to explain in light of the numerous—and consistent—UGRs available in this case. While the multiple audio recordings available from this incident largely prevented hoaxes from confusing the situation, the potential for forged material remains a challenge for future sensational incidents with fewer concurring recordings.

In the weeks and months since the incident, physical evidence and witness reports from the scene have confirmed that a single shooter with an AR-15–style rifle fired eight shots from the roof of a building approximately 130 m north of the podium. A law enforcement officer standing on the ground northeast of the podium fired one rifle shot toward the perpetrator on the roof (shot I), and then a Secret Service counter-sniper officer on the roof of a structure southeast of the podium fired one rifle shot (shot J) that killed the suspect [8, pp. 84–86].

The FBI described the perpetrator's firearm as a DPMS Panther Arms–produced AR-15–style rifle with a 16-in (41 cm) barrel, chambered in 5.56 $\times$ 45 mm NATO. Although the exact ammunition type and bullet weight has not been disclosed, the description is .223 Remington caliber cartridges with a Hornady ammunition headstamp [9, p. 125]. Published velocity information for an example 223 Hornady BTHP Match 75 grain bullet indicates a muzzle speed of 841 m/s, slowing uniformly to 749.5 m/s at a distance of 135 m [10]. The average example bullet speed is therefore 795 m/s, which agrees remarkably well with the original audio forensic assumption of 800 m/s. Should additional information become available regarding the exact nature of the perpetrator's ammunition, this calculation can be revisited. These updated findings are consistent with the initial audio forensic observations of shots A–H being from one location approximately 135 m from the podium and two additional shots (I and J) coming from two other locations.

6 ACKNOWLEDGEMENT

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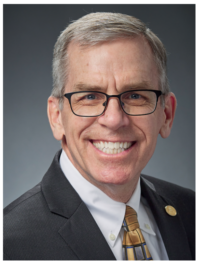
THE AUTHOR



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Robert C. Maher is a Professor of Electrical and Computer Engineering, Montana State University in Bozeman, MT. He joined the faculty in August 2002, after prior work in both academia and industry. He holds a B.S. degree from Washington University in St. Louis, M.S. degree from the University of Wisconsin-Madison, and Ph.D. from the University of Illinois-Urbana, all in Electrical Engineering. His research and teaching interests are in digital signal processing, with particular emphasis on audio forensic analysis. Dr. Maher is a Fellow of the AES, and he formerly served as Associate Technical Editor (2007–2024) and Deputy Editor-In-Chief of the *Journal of the AES* (2022–2024). He is a Senior Member of IEEE, member of the Acoustical Society of America, and Associate Member of the American Academy of Forensic Sciences. He is the author of the book *Principles of Forensic Audio Analysis* (Springer, 2018).