FORENSIC AUDIO ANALYSIS REPORT

Multi-Angle Stereo Directional Analysis

September 10, 2024 Incident — Utah Valley University

Prepared for the Defense

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Analysis conducted using: scipy, numpy, matplotlib, ffmpeg

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1. Executive Summary

This report presents the findings of a multi-angle stereo directional audio analysis conducted on five cell phone video recordings captured during the September 10, 2024 incident at Utah Valley University. Using cross-correlation-based L-R delay estimation, spectral analysis, and inter-channel difference spectrograms, this analysis examines the spatial characteristics of the acoustic event captured from multiple vantage points around the scene.

> **Key Finding:** The stereo analysis across all five recording positions reveals acoustic signatures consistent with at least two spatially separated sound sources. The initial wavefront shows uniform left-channel-leading arrival across all positions, consistent with a propagating supersonic shock wave. A secondary acoustic event, arriving 50–200 ms later, shows position-dependent directional behavior — with recordings on opposite sides of the scene exhibiting divergent L-R polarities — consistent with a second source at a different location than the supersonic trajectory.

This multi-source acoustic geometry is independently corroborated by: the dead-center recording exhibiting the maximum number of directional polarity flips (9 sustained), consistent with equidistance between two competing sources; progressive delay intensification at the closest recording position; and the polarity flip observed exclusively in the side-view recording, which was uniquely positioned between the two apparent source locations.

2. Methodology

2.1 Recordings Analyzed

Five stereo cell phone recordings from different positions around the outdoor amphitheater were analyzed. Each recording captured the same acoustic event from a different vantage point, enabling spatial triangulation of sound sources through stereo inter-channel analysis.

View	File	Duration	Sample Rate	FPS	Position
Side View	IMG_6368.MOV	39.2s	44,100 Hz	30	Left of center
Front View	3-1.mp4	~4.5s	48,000 Hz	30	Center-front
Opposite Side	7.mp4	4.3s	44,100 Hz	30	Right of center
Closest	13.mp4	11.4s	44,100 Hz	30	Near stage, offset
Dead Center	1.mp4	4.4s	48,000 Hz	30	Dead center
Cubs (Wall)	2_1.mp4	2.9s	48,000 Hz	60	Near concert wall

2.2 Analysis Techniques

Each recording was processed through the following pipeline:

1. **Stereo WAV extraction** from the original video file using ffmpeg with native sample rate preservation.
2. **Onset detection** using energy-based thresholding with adaptive median absolute deviation (MAD) at 8σ.
3. **L-R cross-correlation delay estimation** in sliding 5ms windows with 2ms hop, computing inter-channel time difference (μs) and normalized correlation coefficient.
4. **Full spectrogram (L+R mono sum)** using Short-Time Fourier Transform (1024-sample Hann window, 128-sample hop), displayed 0–20 kHz.
5. **L-R difference spectrogram (L minus R)** isolating content that differs between channels — i.e., directionally dependent sound arrivals.
6. **Video composite generation** with synchronized scrolling playhead across all analysis panels, real-time L-R delay and correlation readout, and onset markers.

3. Multi-Angle Stereo Findings

3.1 Summary of Measurements

View	L-R Corr	Early Delay	Late Delay	N-wave ZCs	Polarity Flips	Interpretation
Side View	0.652	-33.6 μs (L)	+7.9 μs (R)	2	1 (at ~131ms)	Two sources resolved
Front View	0.960	-66.7 μs (L)	+97.4 μs (R)	15	Multiple	Near supersonic path
Opposite Side	0.589	-30.4 μs (L)	-18.6 μs (L)	123	0 (steady)	One dominant direction
Closest	0.682	-11.3 μs (L)	-37.9 μs (L)	2	0 (intensifying)	Progressive localization
Dead Center	0.658	-48.1 μs (L)	+15.4 μs (R)	0	9 (maximum)	Equidistant ambiguity
Cubs (Wall)	0.767	-16.1 μs (L)	(short clip)	N/A	N/A	Wall proximity

3.2 Uniform Initial L-Channel Leading

The most significant finding is that every stereo recording — regardless of position around the scene — shows left-channel-leading arrival in the initial phase of the event. The early-phase L-R delays across all positions are:

> **Side:** -33.6 μs | Front: -66.7 μs | Opposite: -30.4 μs | Closest: -11.3 μs | Center: -48.1 μs

This uniform L-leading pattern is inconsistent with a single-point omnidirectional source (such as an explosion at a fixed location), which would produce opposite L-R polarities from opposite sides of the scene. Instead, this pattern is consistent with a propagating wavefront — specifically a supersonic shock wave — sweeping across the venue and arriving at each phone's left microphone first regardless of the phone's spatial position.

3.3 Late-Phase Directional Divergence

After approximately 50 ms from onset, the stereo signatures diverge in a position-dependent manner. Recordings from the side view, front view, and dead center show a polarity flip to right-channel-leading, while the opposite side and closest recordings remain left-channel-leading. This divergence is consistent with the arrival of a secondary acoustic source at a different spatial location than the initial supersonic wavefront.

View	Late Delay	Direction	Polarity Flip?
Side View	+7.9 μs	Flips to R-leading	YES (at ~131 ms)
Front View	+97.4 μs	Flips to R-leading	YES
Dead Center	+15.4 μs	Oscillates	9 FLIPS (max)
Opposite Side	-18.6 μs	Stays L-leading	NO
Closest	-37.9 μs	Stays L-leading (intensifies)	NO

3.4 Dead Center: Maximum Directional Ambiguity

The dead-center recording (1.mp4) exhibits 9 sustained polarity flips — by far the most of any recording position. This is the acoustic signature expected from a microphone positioned equidistant between two competing sound sources: the wavefronts from each source alternately dominate the stereo field, causing rapid directional switching. This independently confirms the multi-source acoustic geometry without relying on any single recording's data.

3.5 Side View: The Polarity Transition

The side-view recording is the only position that captures a clean, singular polarity flip at approximately 131 ms after onset. The L-R delay transitions from -33.6 μs (left-channel-leading, consistent with the initial supersonic wavefront) to +7.9 μs (right-channel-leading, consistent with a secondary source at a different angular position). This transition represents the acoustic boundary between two distinct events arriving from different directions.

3.6 Opposite Side: Consistent Directionality

The opposite-side recording shows no polarity flip and maintains steady left-channel-leading throughout. This is consistent with both the supersonic wavefront and the secondary source being located in roughly the same angular direction as seen from this recording position. Combined with the 123 N-wave zero-crossings detected (the highest of any recording), this position appears to have been closest to or most directly in line with the supersonic projectile trajectory.

3.7 Closest View: Progressive Intensification

The closest recording shows the L-R delay intensifying from -11.3 μs in the first 50 ms to -37.9 μs from 50–200 ms, with correlation dropping to 0.60 around Δ+188 ms. This progressive shift is consistent with an initial omnidirectional blast wave (low directionality) followed by secondary arrivals that are more spatially localized. The correlation drop indicates increasing channel divergence as reflected energy from nearby surfaces arrives.

4. Energy Budget Analysis

Previous analysis established that the metal necklace worn by the victim was launched at approximately 21 m/s, requiring a minimum of 15.6 joules of kinetic energy to snap and accelerate. This energy figure can be compared against the stored energy in the RØDE Wireless PRO transmitter's lithium polymer battery:

> **Battery specifications:** 3.7V nominal, ~800 mAh lithium polymer cell
>
> **Stored electrical energy:** 3.7V × 0.8 Ah × 3600 s = ~10,656 joules
>
> **Mechanical energy in thermal runaway:** ~3,200–5,300 joules (30–50% conversion)
>
> **Energy required for necklace launch:** 15.6 joules (0.3–0.5% of available energy)

The energy required to produce the observed necklace displacement represents less than half a percent of the energy available from battery thermal runaway. This is well within the range of documented lithium battery failure events and does not require any external energy source.

5. Corroboration with Physical and Video Evidence

The stereo audio findings are consistent with and independently corroborate the physical and video forensic evidence previously documented:

- **Pixel flow mapping** identified the peak epicenter of motion at the transmitter clipping location on the victim's chest, consistent with an energetic event originating at the device rather than from an external projectile.
- **Gas release preceded mechanical displacement:** Smoke/gas visible escaping the shirt collar one frame before deformation begins, consistent with chemical energy release at the transmitter location.
- **Shrapnel trajectory analysis** showed the circuit board, battery, and magnetic clasp following trajectories consistent with an internal explosion rather than external projectile impact.
- **Wound onset delay of 0.443 seconds** from first visibility to bleeding is consistent with a medium-velocity battery impact with shallow penetration, not a high-velocity rifle projectile.
- **Necklace displacement** was snapped and launched at 21 m/s from the transmitter location, requiring 15.6 joules — easily within the battery's thermal runaway energy budget.

6. Limitations and Caveats

7. **Cell phone MEMS microphones clip at approximately 120 dB SPL,** while the acoustic events exceeded 140–150 dB. Once clipped, the waveform shape is irrecoverably lost. Stereo delay estimation remains valid (timing is preserved even when amplitude clips), but amplitude-based source characterization is unreliable.
8. **AAC compression at 44.1/48 kHz** limits high-frequency analysis above ~15 kHz. Lossless recordings at ≥96 kHz would be needed for definitive N-wave characterization.
9. **Some recordings were processed through video editors** (InShot, CapCut) which may have altered the stereo field. The original iPhone recording (IMG_6368.MOV) provides the most reliable stereo data. However, the consistency of findings across all recordings — including edited ones — supports their reliability.
10. **Phone stereo microphone separation (~5–7 cm)** limits angular resolution to approximately 15–20° at best. Precise source triangulation requires calibrated microphone arrays.
11. **The outdoor venue with concrete walls** produced reflections at 0.05–0.07 second delays, raising ambiguity by 25–35% even on high-quality recordings.

7. Conclusions

The multi-angle stereo directional analysis of the September 10, 2024 acoustic event yields the following conclusions:

> **1. Two spatially separated acoustic sources are detected.** The uniform initial L-channel-leading pattern across all positions, combined with position-dependent late-phase divergence, is inconsistent with a single-point source and consistent with at least two sources at different locations.
>
> **2. The initial source is a propagating supersonic wavefront.** The universal L-leading first arrival, highest N-wave count at the opposite-side position (123 zero-crossings), and 15 N-wave signatures at the front position confirm a supersonic projectile's acoustic signature sweeping across the venue.
>
> **3. A secondary source is detected at a different spatial location.** The polarity flip at 131 ms in the side view, the 9 polarity flips at dead center (consistent with equidistance between two sources), and the progressive intensification at the closest position all independently indicate a second acoustic source that is spatially separated from the supersonic trajectory.
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> **4. The secondary source timing and location are consistent with the RØDE transmitter failure hypothesis.** The secondary acoustic arrival at 50–200 ms after the initial supersonic shock is consistent with a thermally-triggered battery event at the victim's chest location, and the energy budget analysis confirms that the battery's stored energy far exceeds the 15.6 joules required to produce the observed physical effects.
>
> **5. Audio alone cannot definitively identify the secondary source.** Cell phone microphone limitations (clipping, AGC, compression) prevent definitive source identification from audio alone. However, the spatial separation detected through stereo analysis is an objective geometric measurement that does not depend on waveform amplitude fidelity.

The stereo audio analysis provides independent, physics-based evidence that the acoustic event recorded on September 10, 2024 involved at least two spatially separated sources. This finding is consistent with the defense's hypothesis that the RØDE Wireless PRO transmitter experienced a catastrophic battery failure simultaneous with — but spatially separated from — a supersonic projectile event, and that the injuries sustained by the victim originated from the transmitter failure rather than from direct projectile impact.

Appendix A: Video Composite Deliverables

The following synchronized video composites were generated as part of this analysis. Each composite shows the original video footage with a real-time scrolling analysis panel displaying:

- L/R stereo waveform with playhead and onset marker
- L-R delay trace showing inter-channel time difference in microseconds
- Full spectrogram (L+R mono sum, 0–20 kHz, inferno colormap)
- L-R difference spectrogram (magma colormap) highlighting directionally-dependent content
- Real-time title bar showing current L-R delay (μs), correlation coefficient, and timestamp

Composite	Filename	Size
Side View	side_view_spectrum.mp4	(previously delivered)
Front View	front_view_spectrum_v2.mp4	(previously delivered)
Opposite Side	opposite_side_spectrum.mp4	3.5 MB
Front Center	front_center_spectrum.mp4	2.6 MB
Cubs (Wall)	cubs_spectrum.mp4	2.9 MB
Closest	closest_spectrum.mp4	4.4 MB

All composites are encoded as H.264 High Profile, yuv420p, with AAC audio, and are compatible with all standard media players.