National Transportation Safety Board
Office of Research and Engineering
Washington, DC 20594

ERA23FA033

VIDEO & SOUND SPECTRUM

Specialist's Study
September 29, 2023

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A. ACCIDENT

Location: Keene, New Hampshire
Date: October 21, 2022
Time: 18:45 eastern daylight time (EDT)
Aircraft: Beech A24-R, private operator, N8020R

B. VIDEO & SOUND SPECTRUM SPECIALIST

Specialist Kyle Garner
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National Transportation Safety Board (NTSB)

C. DETAILS OF THE INVESTIGATION

A video group did not convene.

The NTSB received the following video files from five different cameras located near the airport and accident site:

Camera	Video Filename
Camera 1:	Takeoff Roll Approx 130.mp4
Camera 2:	Last Flight Segment.mp4
Camera 3:	Takeoff 820.mp4
Camera 4:	Garage_1666400081392_95270002U5AJFKTV.mp4
Camera 5:	GZBQ7566.3GPP

The video files were downloaded by non-NTSB personnel and forwarded to the NTSB for review.

1.0 Camera Information

Figure 1 is a Google Earth[1] overview of the location of the five cameras, Dillant–Hopkins Airport (KEEN[2]), and the approximate location of the accident aircraft's wreckage.

[1] The weather and lighting conditions in the Google Earth overview are not necessarily representative of the weather and lighting conditions at the time of the accident.
[2] KEEN is the ICAO identifier for Dillant–Hopkins Airport.

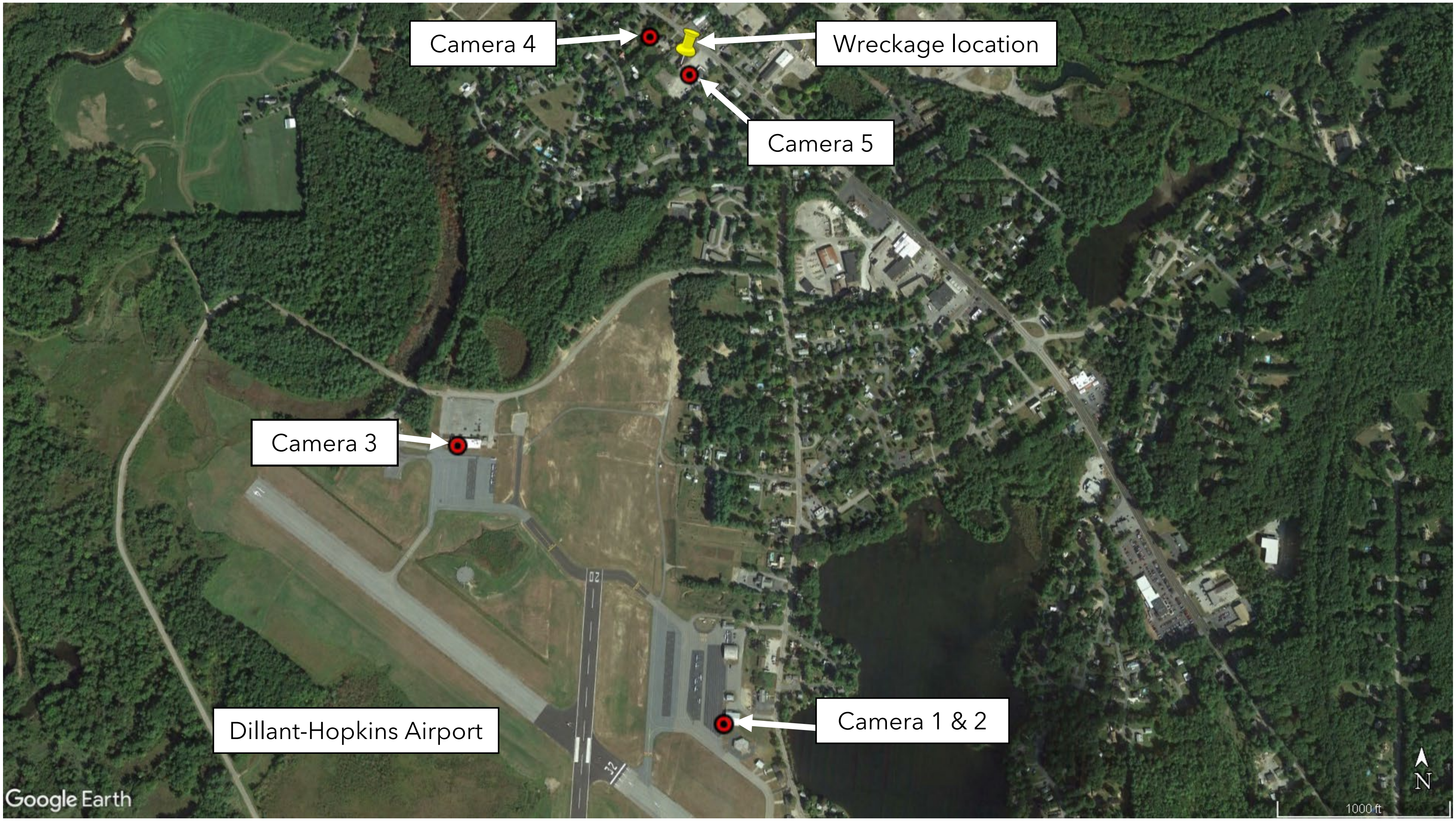

Figure 1. Google Earth overview of the location of the five cameras, departure airport, and the accident aircraft's wreckage.

2.0 Summary of events

2.1 Camera 1 – Airport Hangar

Camera 1 was mounted on the northwest corner of a hangar (42.901932° N, -72.266539° W) at KEEN and pointed toward the south. The video had a duration of 4 minutes and 42 seconds and included audio. A timestamp overlay indicated the video started at 18:42:07 EDT and ended at 18:46:49 EDT on the day of the accident.

At the start of the video, the accident aircraft's flashing beacon was visible at the approach end of runway 02. At about 18:43:30, a sound similar to the aircraft's engine speed increasing was noted and the aircraft began its takeoff roll, traveling towards the camera. At about 18:44:00, the aircraft rotated, lifted off the runway, and started a shallow climb out. At 18:44:16, sounds similar to an engine popping were noted and lasted about two seconds. At 18:44:19, the aircraft exited the field of view of the camera, near the intersection of runway 02/20 and runway 14/32, at an abnormally low altitude[3]. The remainder of the video was uneventful.

Audio from this camera is discussed further in section 3.2, camera 1 audio study.

2.2 Camera 2 – Airport Hangar

Camera 2 was mounted on the southwest corner of a hangar (42.901725° N, -72.266556° W) at KEEN and pointed toward the north. The video had a duration of 2 minutes and 24 seconds and included audio. A timestamp overlay indicated the video started at 18:44:30 EDT and ended at 18:46:54 EDT on the day of the accident.

At the start of the video, the accident aircraft was visible over the departure end of runway 02 at an abnormally low altitude[3]. The aircraft's engine was audible. A witness standing near a parked aircraft watching the accident aircraft depart was noted in the foreground of the video. About 30 seconds later, at 18:44:59, the aircraft was behind trees and no longer visible. At 18:45:09, the witness reacted to a sound similar to the accident aircraft impacting a structure. At 18:45:10, a large flash of light was noted north of the departure end of runway 02. The remainder of the video was uneventful.

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[3] Automatic Dependent Surveillance–Broadcast (ADS-B) data was not available for the accident flight, nor was an onboard recording device located in the wreckage. Witnesses from the airport indicated that the accident aircraft appeared to be between 50 and 200 feet above ground level (AGL) at the intersection of runway 02/20 and runway 14/32, which is about 5200 feet from the approach end of runway 02.

2.3 Camera 3 – Airport Terminal

Camera 3 was mounted on the south side of the terminal building (42.906389° N, -72.272778° W) at KEEN and pointed toward the southeast. The video had a duration of about 10 minutes and did not include audio. A timestamp overlay indicated the video started at 18:35:35 EDT and ended at 18:45:33 EDT on the day of the accident.

The accident aircraft did not appear on the recording until 18:43:41 when its landing lights became visible as the aircraft was on its takeoff roll on runway 02. At 18:44:00, the aircraft rotated and lifted off the runway. At 18:44:33, the aircraft exited the field of view of the camera. The remainder of the video was uneventful.

2.4 Camera 4 – Residence

Camera 4 was located at a residence on the north side of KEEN, about 270 feet from the site of the wreckage, and had a view toward the south. The video had a duration of about 30 seconds and included audio. A timestamp overlay indicated the video started at 18:44:41 EDT and ended at 18:45:10 EDT on the day of the accident.

At the start of the video, 18:44:41, the accident aircraft's engine was audible. The engine noise became louder as the aircraft traveled toward the camera. At 18:44:56, the accident aircraft's landing lights were visible through the trees, and the aircraft was moving towards the camera. At 18:45:02, the aircraft appeared to be in a descent. At 18:45:05, the aircraft impacted a structure and three seconds later, at 18:45:08, a large fireball was noted. The video ended two seconds later, at 18:45:10.

Audio from this camera is discussed further in section 3.3, camera 4 audio study.

2.5 Camera 5 - Church

Camera 5 was located at a church on the north side of KEEN, about 90 feet from the site of the wreckage, and had a view toward the northwest. The video had a duration of 48 seconds and included audio. The video did not include a timestamp overlay.

At the beginning of the video, the accident aircraft's engine was audible, but the aircraft was not visible. At a video elapsed time of 00:09, the aircraft's landing lights and flashing beacon became visible. Sounds consistent with the aircraft impacting a structure were noted at video elapsed time 00:11. A large flash and subsequent fireball were noted three seconds later, at 00:14. The remainder of the video was uneventful.

3.0 Sound Spectrum Study

The audio portion of the videos from camera 1 and camera 4 were evaluated in an attempt to determine the operating speed of the aircraft's engine during takeoff and immediately before the accident[4].

The accident aircraft was equipped with one Lycoming I0-360-A1B four-cylinder, four-stroke direct drive piston engine, and a McCauley three-bladed constant speed propeller. An aircraft piston engine generates tones at several different frequencies, including the propeller blade passage frequency (BPF), the engine exhaust frequency, and the harmonics of those frequencies.

The Airplane Flight Manual Supplement[5] for the accident aircraft's propeller specified that the green arc range was between 2200 and 2700 revolutions per minute (rpm) and the radial red line was 2700 rpm. Further, the aircraft's Pilot Operating Handbook[6] (POIH) stated that the engine's takeoff and maximum continuous power setting was 2700 rpm.

For a three-bladed propeller, the expression relating engine rpm to the fundamental BPF is provided in equation 1:

$$RPM = BPF\left(\frac{blades}{sec}\right) * \frac{1}{3}\left(\frac{rev}{blades}\right) * 60\left(\frac{sec}{min}\right) \qquad \text{eq. 1}$$

Additionally, the expression for the fundamental engine exhaust frequency, f_{eng}, of a four-cylinder, four-stroke engine is provided in equation 2:

$$f_{eng} = \frac{RPM}{30} \qquad \text{eq. 2}$$

For example, at an engine operating speed of 2700 rpm, the propeller noise would be most evident at a BPF of 135 Hz and the engine exhaust noise at a frequency of 90 Hz.

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[4] Audio from camera 2 was not reviewed for the study due to the complications of evaluating the impact of the Doppler effect on the audio without knowing the speed of the aircraft during the accident flight. Camera 4 did not contain any audio data. Audio from camera 5 was of poor quality subsequently determined to be a screen recorded reproduction of the original video/audio file.

[5] Airplane Flight Manual Supplement for McCauley B3D36C429/82NPA-6 propellor, STC SA496CH, dated April 03, 1996.

[6] Beechcraft Sierra A24R POH, PN 169-590006-23, dated July 1994.

3.1 Doppler Effect

The Doppler effect causes sound frequencies emitted from a source to appear higher to a stationary observer if the source is moving toward the observer, equal as the source passes the observer, and lower as the source moves away from the observer. The source frequency, f_s, is given by the following expression for a stationary observer[7]:

$$f_s = \frac{c - v_s \cos\theta}{c} f_o \qquad \text{eq. 3}$$

where f_o is the observed frequency, c is the speed of sound, v_s is the magnitude of the source velocity, and θ is the angle between the source velocity vector and the line-of-sight vector from the source to the observer.

The exact speed and ground track of the aircraft during the accident flight were not known, thus, moments in the audio files where the influence of the Doppler effect was minimal (i.e. θ at or near 0°) were identified for further analysis.

3.2 Camera 1 Audio Study

A three-dimensional (3D) spectrogram was generated, as shown in Figure 2, showing the frequency content of the sound from camera 1 and how it changes over time. The x-axis represents time in elapsed seconds of the video and the y-axis represents sound frequency in Hertz (Hz). The color represents sound intensity, with black being the lowest intensity sound and orange being the highest intensity.

The first portion of the spectrogram, marked 'Taxi', is consistent with the accident aircraft back-taxiing to the approach end of runway 02. The second portion, marked 'Takeoff Roll', is consistent with the aircraft accelerating for takeoff on runway 02. Of note in the spectrogram in the section marked 'Takeoff Roll' is the gradual upward and then downward slope of the lines of intense frequency as time passes. This pattern suggests that the influence of the Doppler effect should be considered.

The aircraft was closest to camera 1 during its takeoff roll near the intersection of runway 02/20 and runway 14/32 (about 5200 to 5400 feet from the approach end of runway 02) at a video elapsed time of 02:10 to 02:15 (18:44:18 to 18:44:23 EDT).

[7] Note that this formula is simplified and a result of several assumptions, including but not limited to: (1) the observer is stationary, (2) the source is moving toward the observer, (3) the source is in linear unaccelerated motion, (4) the source is far enough from the recording device that the elevation angle does not change appreciably, and (5) the source and the observer are close enough that the travel time of the sound in air can be ignored.

Figure 3 is the same spectrogram as Figure 2, with an overlay containing a two-dimensional (2D) plot of the spectrum from 02:10 to 02:15 video elapsed time. The two fundamental frequencies of note on the 2D spectrum are 81.0 Hz (engine exhaust) and 119.3 Hz (BPF). As the aircraft was closest to the camera during this time, the influence of the Doppler effect could be ignored. Using equation 1 and equation 2, these fundamental frequencies correspond to an engine speed of about 2400 rpm during that time.

As the aircraft moved further away from the camera, the signal-to-noise ratio was low enough that the fundamental frequencies were no longer discernable on the spectrogram after about 02:43 video elapsed time (18:44:51 EDT).

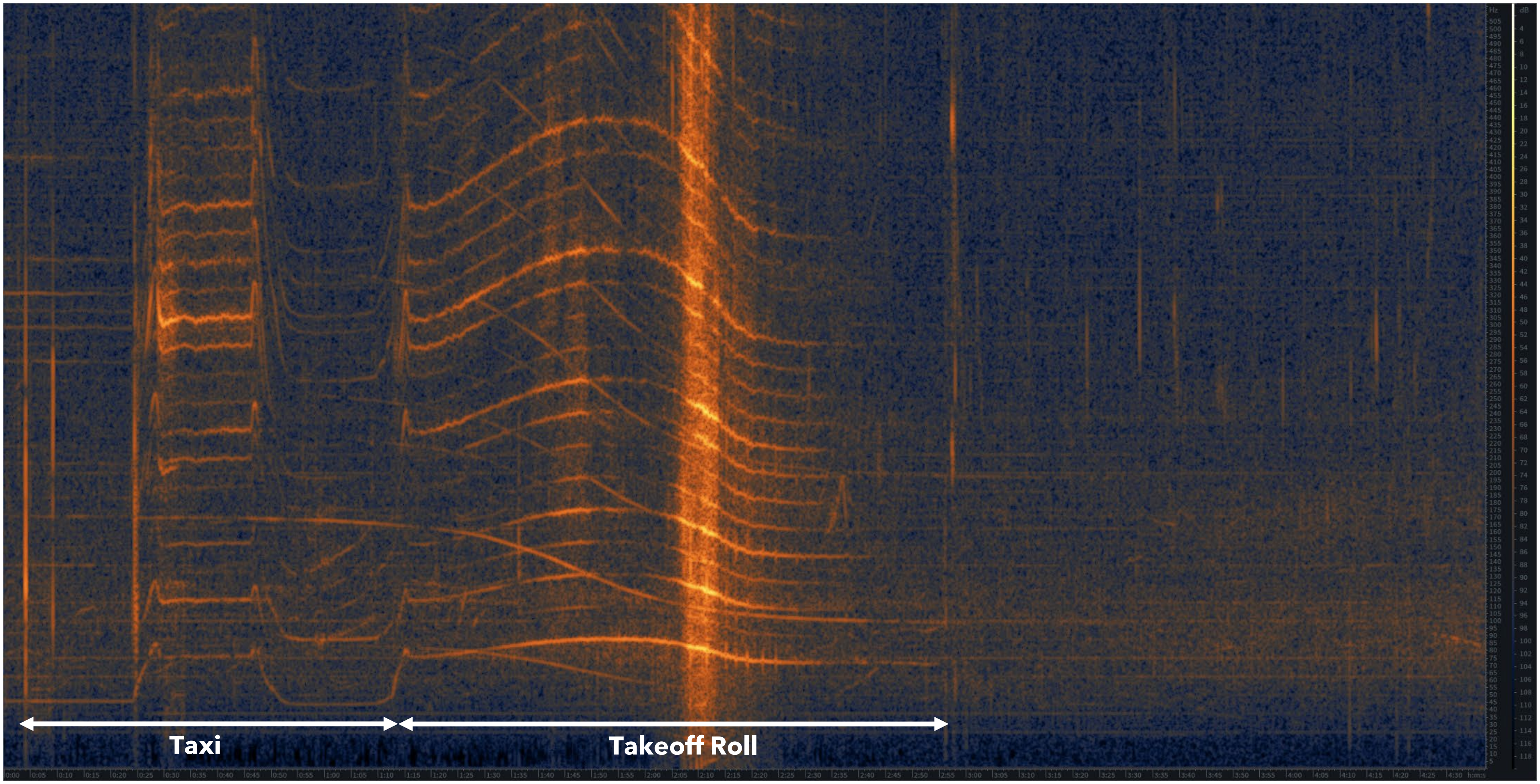

Figure 2. 3D spectrogram of audio from camera 1.

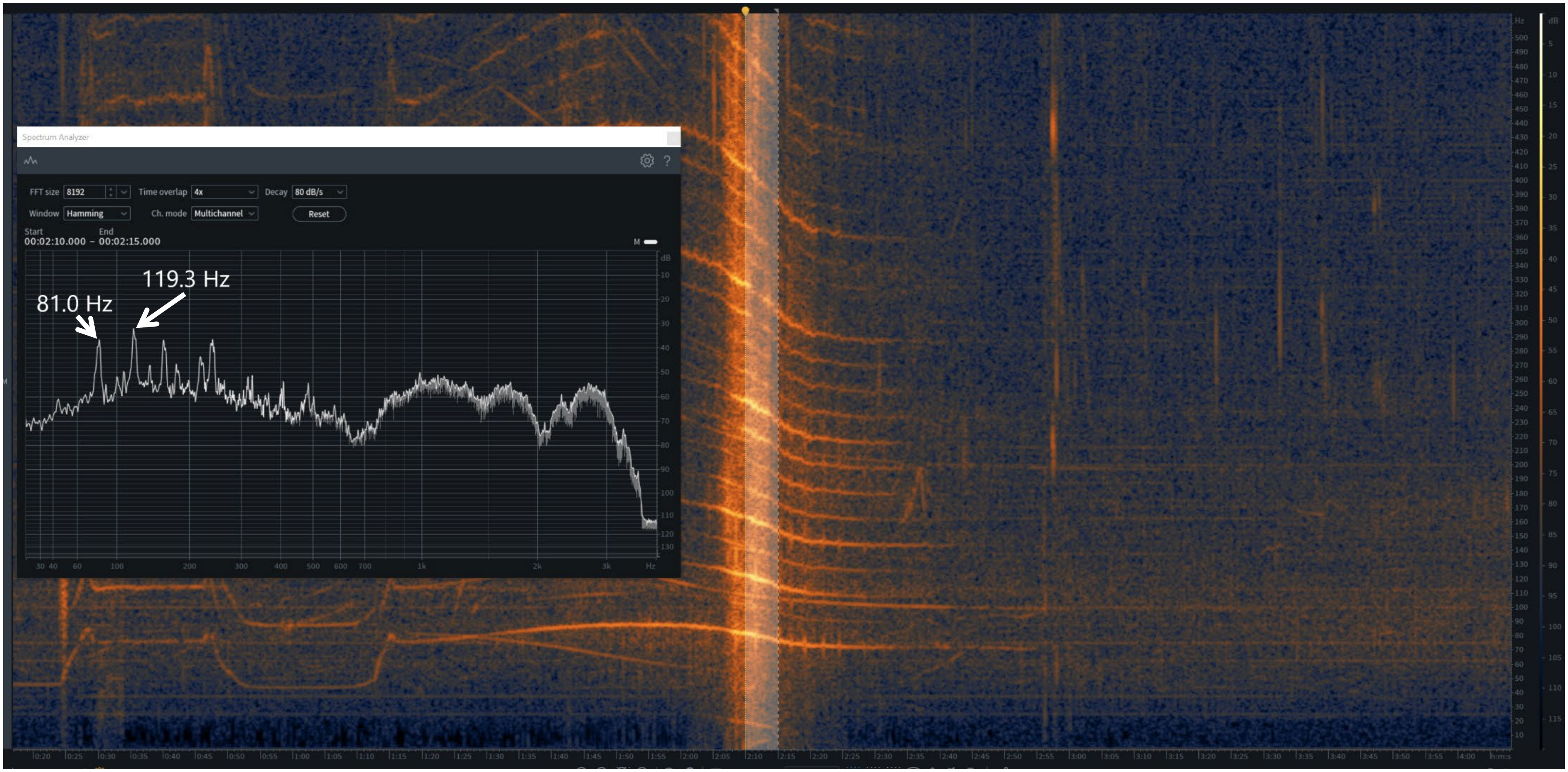

Figure 3. 2D spectrogram of audio from 02:10 to 02:15 video elapsed time (18:44:18 to 18:44:23 EDT) – camera 1.

3.3 Camera 4 Audio Study

Figure 4 is a 3D spectrogram showing the frequency content of the sound from camera 4. The x-axis represents time in elapsed seconds of the video and the y-axis represents sound frequency in Hertz (Hz). The color represents sound intensity, with black being the lowest intensity sound and orange being the highest intensity.

The accident aircraft's landing lights were visible through the trees at 00:14 video elapsed time (18:44:56 EDT). Broadband noise consistent with the aircraft impacting a structure is noted in the spectrogram at a video elapsed time of about 00:23 (18:45:05 EDT).

Figure 5 is the same spectrogram as Figure 4, with an overlay containing a 2D spectrogram from 00:20 to 00:23 video elapsed time (18:45:02 to 18:45:05 EDT). The two fundamental frequencies of note on the 2D spectrogram are 82.1 Hz (engine exhaust) and 119.3 Hz (BPF). As the aircraft was closest to the camera during this time, the influence of the Doppler effect could be ignored. Using equation 1 and equation 2, these fundamental frequencies correspond to an engine speed of about 2400 rpm immediately before the aircraft impacted a structure.

3.4 Conclusions

The calculated engine rpm at two moments during the accident flight: (1) as the aircraft departed runway 02 at KEEN and (2) immediately before the aircraft impacted a structure, appeared to be consistent with the engine operating at or near 2400 rpm, which is below its published takeoff and maximum continuous power setting of 2700 rpm.

Submitted by:

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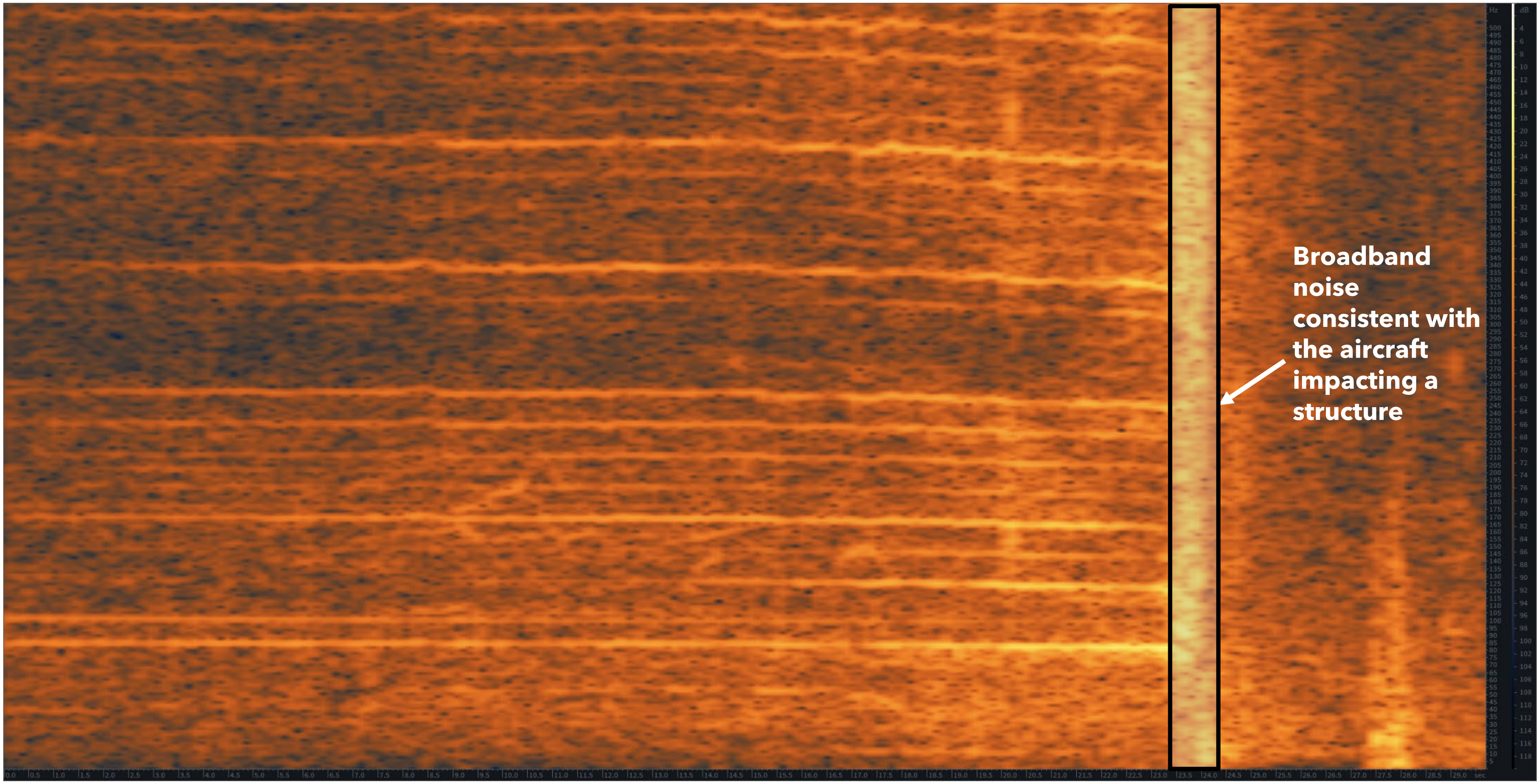

Figure 4. 3D spectrogram of audio from camera 4.

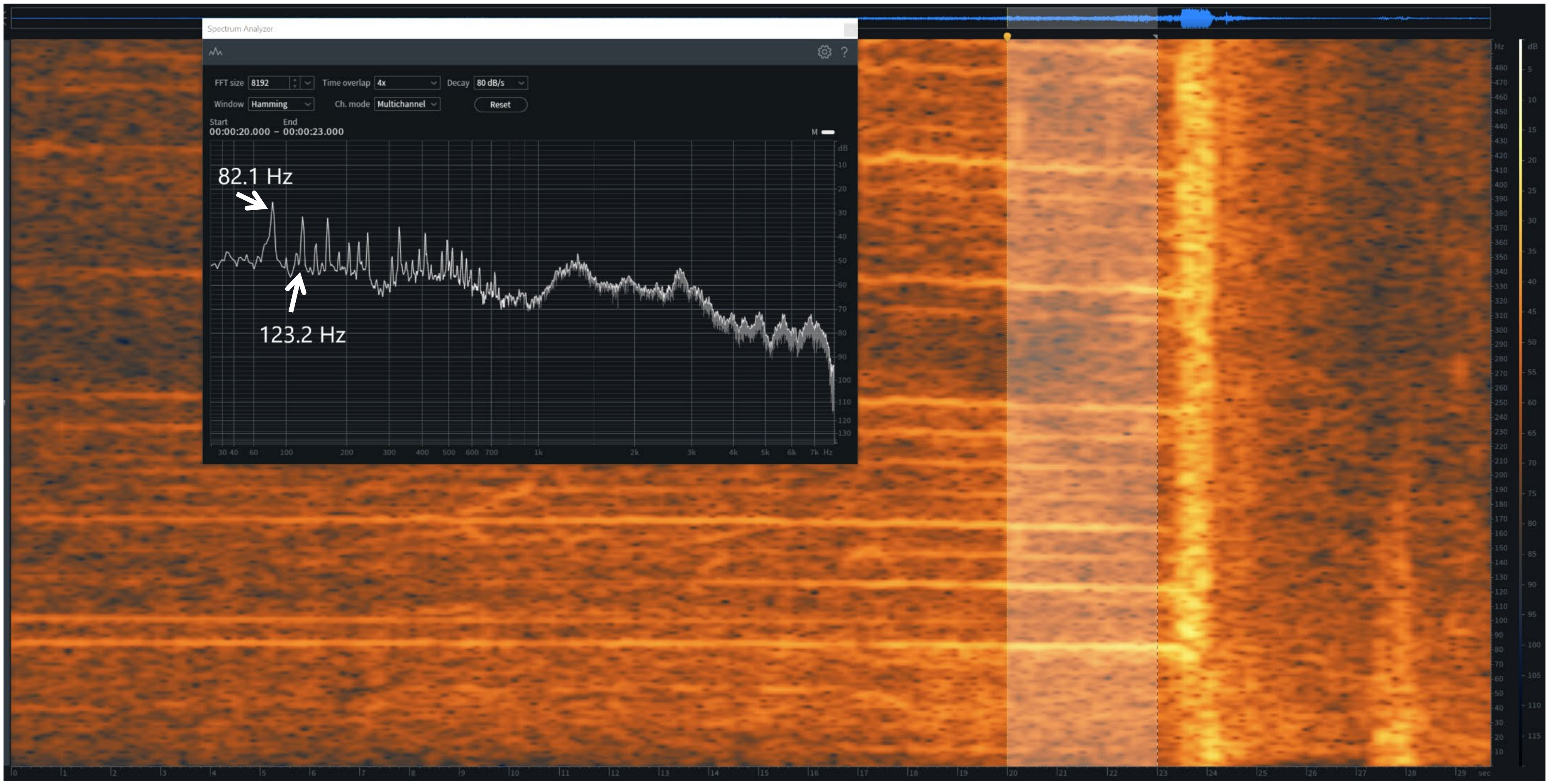

Figure 5. 2D spectrogram of audio from 00:20 to 00:23 video elapsed time (18:45:02 to 18:45:05 EDT) – camera 4.