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SOUND SPECTRUM STUDY

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A. ACCIDENT

Location: Tupelo, Mississippi
Date: June 3, 2023
Time: 0811 central daylight time (CDT)
Aircraft: Piper PA-31-325, N4077W

B. SUMMARY

B.1. The accident

On June 3, 2023, about 0811 central daylight time, a Piper PA-31-325, N4077W, was destroyed when it was involved in an accident near the Tupelo Regional Airport (TUP), Tupelo, Mississippi. The pilot and pilot rated passenger were fatally injured. The airplane was operated as a Title 14 *Code of Federal Regulations* Part 91 personal flight.

B.2. Objective and scope of the Sound Spectrum Study

The objective of this Video Study was estimating the speed of the aircraft engines based on the sound recorded by two cameras installed on airport buildings.

C. DETAILS OF THE INVESTIGATION

Two videos were used in the investigation. One was recorded by a camera installed on an airport hangar (camera 1). The video had 2688x1512 resolution and frame rate of 24 fps (frames per second). It recorded sound at the rate of 48,000 samples per second. The video lasted about 14 minutes. The airplane became visible in the video at video time 93.5 seconds. It was last seen at video time 135.3 seconds before it became obscured by an airport hangar. At about video time 140 seconds, the sound of a ground impact is heard in the video. At video time 142.5 seconds, smoke due to a post-crash fire can be first seen above the roof of a hangar.

The second video was recorded by a camera installed on a building in a rental parking lot (camera 2). The video had 2560x1920 resolution and frame rate of 20 fps. It recorded sound at the rate of 8000 samples per second. The video lasted about 14 minutes. The airplane became visible in the video at video time 38.15 seconds. It was last seen at video time 72.9 seconds before it became obscured by trees. At about video time 76 seconds, the sound of a ground impact is heard in the video. At video time 84.8 seconds, smoke due to a post-crash fire can be first seen above a tree line.

Figure 1 is an aerial view of the accident area. The figure shows the locations of the two cameras, the ADS-B ground track of the airplane, and the crash location. The ground track shows that the airplane was initially approaching the cameras, resulting

in the sound frequencies recorded by the cameras being higher than the frequencies emitted by the airplane due to the Doppler effect. Then the airplane was flying away from the cameras, resulting in the sound frequencies recorded by the cameras being lower than the frequencies emitted by the airplane. During the final segment of the flight, the airplane was again flying toward the cameras.

C.1. Engine speed estimation at locations free of the Doppler effect

There were two airplane locations for each camera where there was no Doppler effect. At these locations, the frequencies recorded by the cameras were equal to the frequencies emitted by the airplane. Figure 2 shows the geometry of the accident area and the times, in format MM:SS past 8 AM, when the airplane was at the marked locations. When the airplane was at location a, marked in Figure 2, the sound recorded by camera 1 was not affected by the Doppler effect because the airplane was moving perpendicularly to the line from camera 1 to the airplane.

When the airplane was at location b, the sound recorded by camera 2 was not affected by the Doppler effect because the airplane was moving perpendicularly to the line from camera 2 to the airplane. When the airplane was near location c, the sound recorded by both cameras was not affected by the Doppler effect because the airplane was moving perpendicularly to the lines from the cameras to the airplane.

Figure 3 is a frame from the video recorded by camera 2 when the airplane was at point c marked in Figure 2. The image of the airplane, located inside the red circle, is small because it was located about 3750 feet from the camera.

There was a need to locate the times in the two videos when the airplane was at locations a, b and c. The video times corresponding to locations a and b were assumed to be the times when the recorded sound intensities were highest. The video times corresponding to location c were estimated as follows. Figure 2 shows a line originating at the camera 1 location and passing tangentially to the ground track. The line touches the ground track at point e, corresponding to ADS-B time 8:11:11. A line originating at the camera 2 location and passing tangentially to the ground track also touches the ground track at the point corresponding to time 8:11:11.

Figure 2 shows that just before time 8:11:11, the airplane had a small speed component toward the east and just past time 8:11:11 it had a small speed component toward the west. Frame-by-frame inspection of the videos made it possible to identify the frames and the corresponding video times when the east-west speed component was zero.

Figure 2 shows that the zero Doppler effect was expected at point c, when the time was about 8:11:03. Consequently, the video times when the airplane was at location c could be estimated as the video times $11-3=8$ seconds before the video times corresponding to the airplane location at ADS-B time 8:11:11 when the east-west speed component was zero.

Once the video times corresponding to airplane locations a, b and c were estimated, it was possible to estimate the engine speed at these Doppler-effect-free locations. The spectrum of the sound recorded by the cameras was analyzed with the Fast Fourier Transform (FFT). Camera 2 recorded sound at the rate of 8000 samples per second. The FFT algorithm used 8192-point windows, resulting in windows that were 1.024 seconds wide. The frequency resolution was 58.6 cycles per minute (cpm). Figure 4 shows the FFT intensity in twelve windows with starting times from 32 seconds to 43 seconds. The airplane was near location b, marked in Figure 2, at video time 39 seconds.

Figure 4 shows that the highest rms value of the sound signal was in the window starting at time 38 seconds and in the window starting at 39 seconds. Two spectral peaks, A and B, are marked in the figure in these two FFT intensity plots. The frequencies of the A peaks are 7383 cpm and 7265 cpm in windows starting at 38 seconds and 39 seconds, respectively. These are the blade passage frequencies (BPF). The frequencies of the B peaks are 9844 cpm and 9668 cpm. The average values of these spectral peaks are: $(7383+7265)/2=7324$ cpm and $(9844+9668)/2=9756$ cpm. Since the airplane propellers had three blades, the estimated engine speed of the airplane when it was at location b is $7324/3=2441$ rpm. Since $9756/7324=1.33$, spectral peak B is believed to be the sum of the blade passage frequency (BPF) of 7324 cpm and either the engine 2441 rpm or the second harmonic of the engine firing order.

Similar sound spectrum analysis was performed at airplane location a, based on the camera 1 recording, and at airplane location c based on the recordings of both cameras. The frequency resolution of the FFT algorithm used to analyze camera 1 sound recording was 44 cpm. Table 1 summarizes the results.

C.2. Engine speed estimation at locations affected by the Doppler effect

Two more airplane locations were of interest in the investigation. Point d shown in Figure 2 is at a location where the airplane was just past the start of its right turn. Point e is at a time shortly past which the airplane started its rapid descent toward ground. At point d, the airplane was flying away from the cameras and, therefore, the recorded frequencies were lower than the frequencies emitted by the airplane. At point e, the airplane was flying toward the cameras and, therefore, the recorded frequencies were higher than the frequencies emitted by the airplane. A Doppler

correction factor was defined as the number by which to multiply the frequencies of the recorded sound to transform them to the frequencies of the emitted sound.

The Doppler correction factor depends on the speed of sound and on the speed component of the airplane toward or away from a camera along the line from the camera to the airplane. The factor was estimated based on the ADS-B based airplane locations and speed. At point d, the factor was 1.18 for camera 1 and 1.14 for camera 2. At point e the factor was 0.88 for both cameras.

Sound spectrum analysis was performed at airplane locations d and e similarly to the analysis at the Doppler-free locations a, b and c. The frequencies of the spectral peaks were then corrected for the Doppler effect by multiplying them by the corresponding Doppler correction factor. Table 1 lists the estimated blade passage frequencies and speeds at the five analyzed locations. The data for Points d and e are after the correction for the Doppler effect.

Table 1. Summary of estimated blade passage frequencies and engine speeds

	BPF Frequency camera 1 (cpm)	Engine Speed camera 1 (rpm)	BPF Frequency camera 2 (cpm)	Engine Speed camera 2 (rpm)
Point a	7361	2454	NA	NA
Point b	NA	NA	7324	2441
Point c	7053	2351	7295	2432
Point d	7959	2653	7883	2628
Point e	7676	2559	7605	2535

Table 1 shows estimated engine speeds in the range expected from a normally operating Lycoming TIO-540 engine at all five analyzed airplane locations. The estimated engine speed can be expressed as 2550 ± 110 rpm.

It was impossible to determine if the recorded sound signals were generated by one or two engines because two engines operating at the same speed generate sound spectral peaks that are identical to those generated by a single engine at that speed. It can only be concluded that at least one of the engines was operating normally.

D. CONCLUSIONS

The sound emitted by an airplane that crashed a short time after takeoff was used for estimating the speed of the airplane engines. The sound streams in videos recorded by two cameras mounted on airport buildings were used in the analysis. The spectrum of the recorded sound showed that at least one of the airplane engines was operating at the speed of 2550 ± 110 rpm when the airplane was flying along the runway and when it was in a right turn that ended in ground impact.

FIGURES

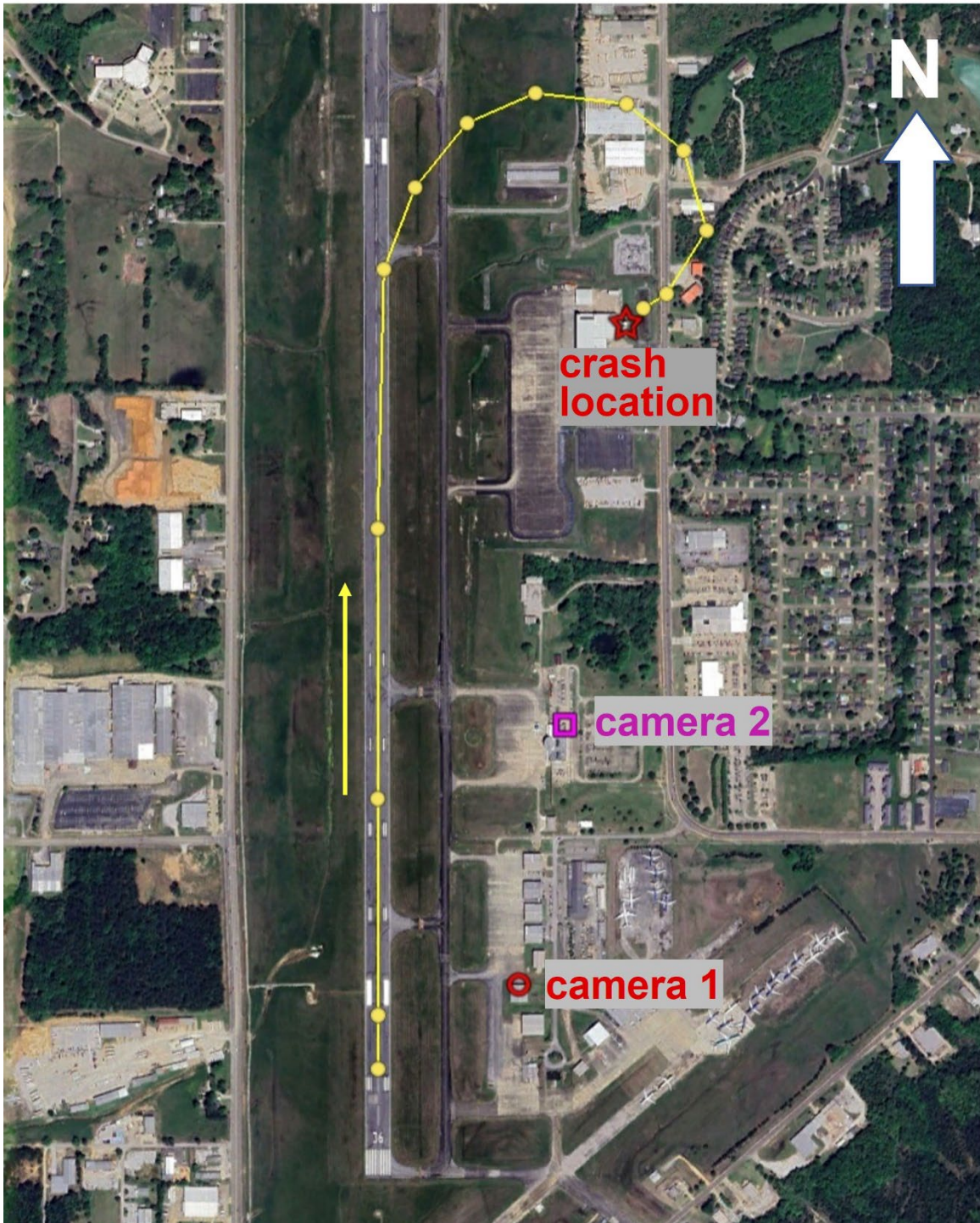


Figure 1. Aerial view of the accident area

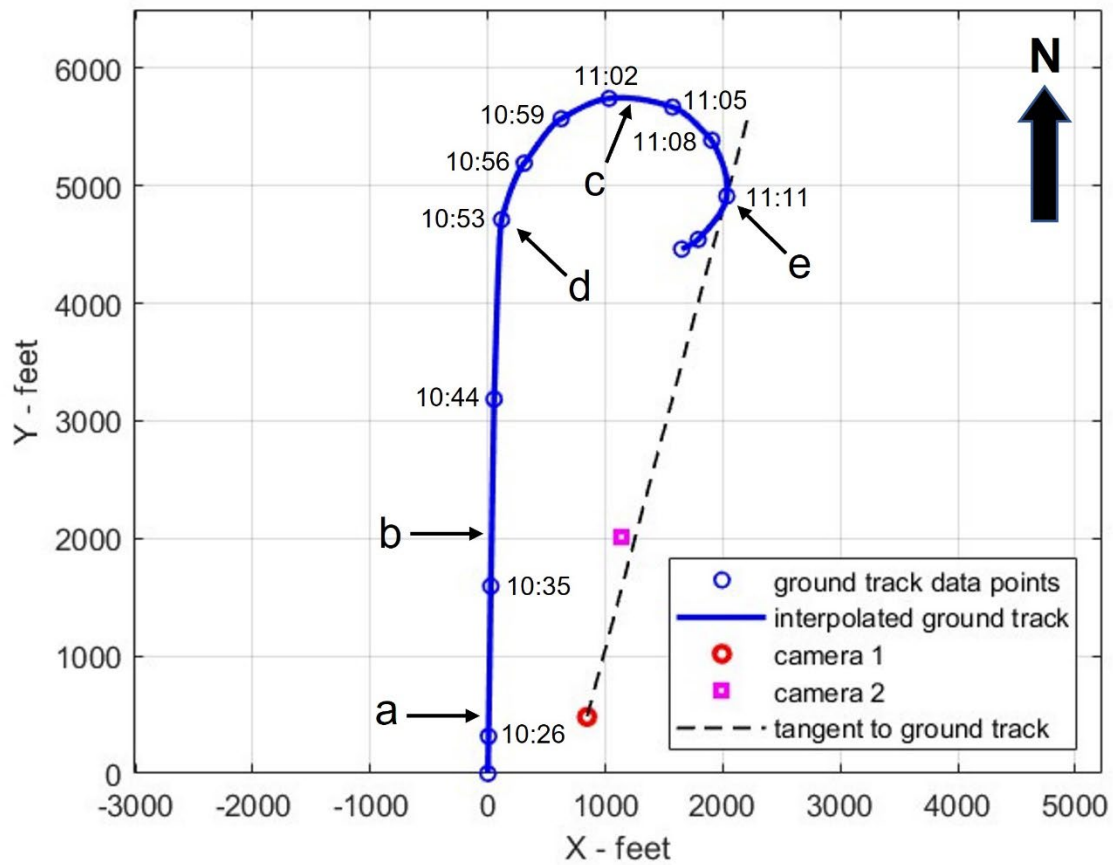


Figure 2. Geometry of the accident area. Times are shown as MM:SS past 8:00:00.



Figure 3. Video frame recorded by camera 2 at time 8:11:03

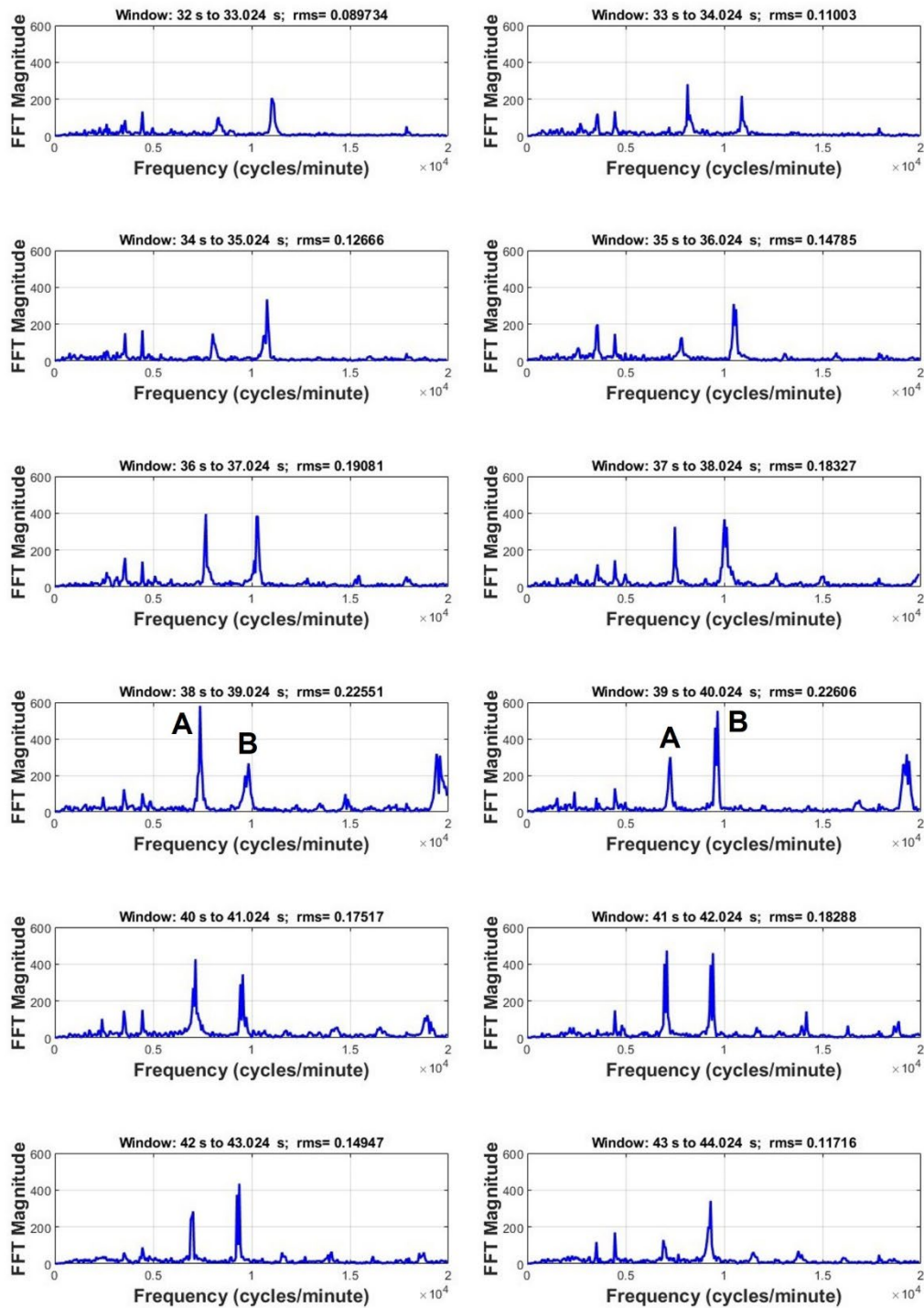


Figure 4. Sound spectra in windows starting at time 32 seconds (camera 2)