

National Transportation Safety Board

Office of Research and Engineering

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SOUND SPECTRUM

Specialist's Study

July 24, 2024

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A. ACCIDENT

Location: West Palm Beach, Florida
Date: March 5, 2023
Time: 2125 EST
Airplane: Diamond Aircraft DA40, N804ER

B. SOUND SPECTRUM SPECIALIST

Specialist Charles Cates
Mechanical Engineer/Recorder Specialist
National Transportation Safety Board (NTSB)

C. DETAILS OF THE INVESTIGATION

A sound spectrum group was not convened.

The NTSB Vehicle Recorder Division received eight video files from cell phones and security camera surveillance systems. Two of those files taken by a witness with a cell phone were deemed to be useful for a sound spectrum study to examine the aircraft's engine operating speed during its time aligned with the runway and in the moments prior to the crash. A brief description of the file is shown in table 1.

Table 1. Description of video files used in sound spectrum study.

Filename	Length	Audio Sample Rate	Notes
IMG_4102.MOV	0:14	44.1 kilo Hertz (kHz)	Captured aircraft flying past camera location.
IMG_4103.MOV	0:14	44.1 kHz	Captured crash sequence and moments leading up to it.

1.0 Data Description

Audio recovered from IMG_4102.MOV and IMG_4103.MOV were digitized at 44,100 samples/second and were analyzed for the documentation of engine sounds. The files were created by a witness' cell phone camera. The video was taken from a stationary location on the airport ramp about two-thirds of the way down the runway and 450 feet south of the runway. In IMG_4102.MOV, the camera followed the aircraft as it flew along the runway heading towards the camera and then as the aircraft flew past the camera location and continued along the runway heading. In IMG_4103.MOV, the camera followed the aircraft as it banked to the right and turned to the point where it was then headed back towards the camera location. The aircraft lost control in a steep right bank and rolled inverted, impacting terrain shortly

thereafter. Using these videos along with ADS-B data¹ it was possible to determine average aircraft ground speed and the relative flight path angle to the observer at various points along the runway and calculate the propeller speed recorded on the video at those locations, accounting for the Doppler shift² recorded in the audio.

1.1 Data Study

The spectrogram of the full duration of IMG_4102.MOV is shown in figure 1.

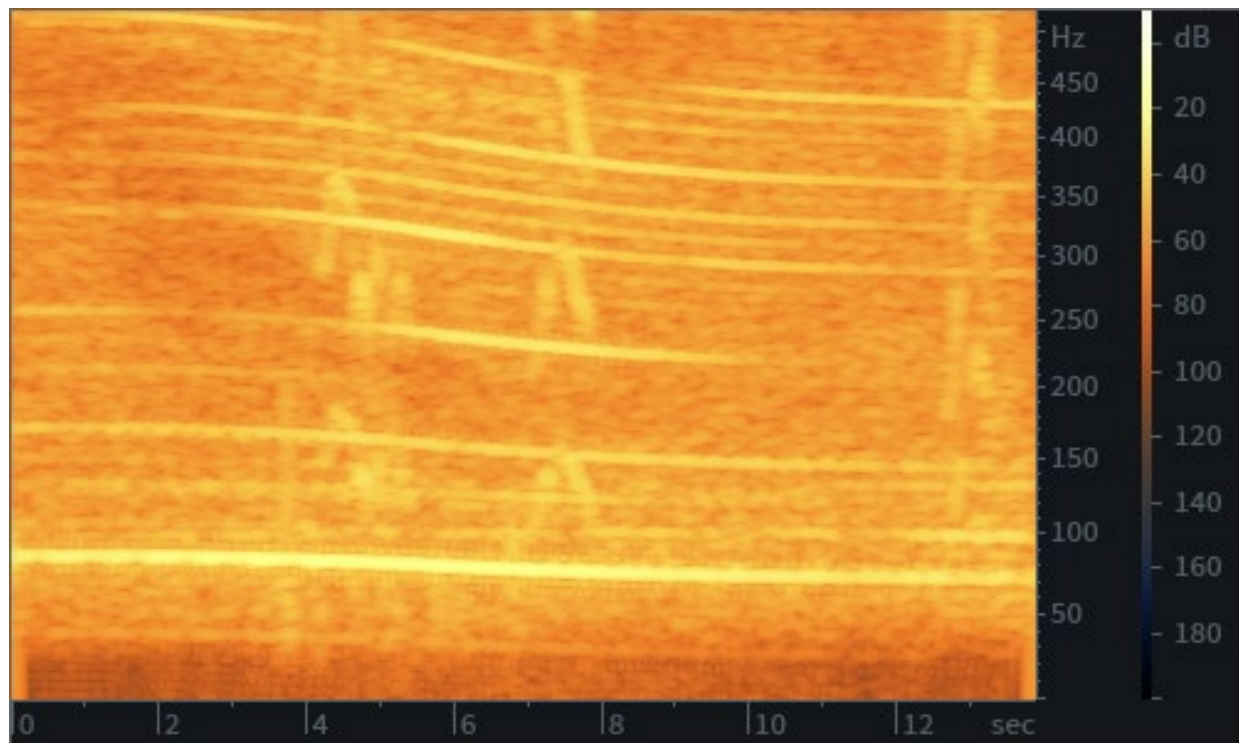


Figure 1. A color spectrogram showing audio from the full duration of IMG_4102.MOV.

For IMG_4102.MOV, the prominent higher amplitude tone visible between 50 and 100 Hz is the fundamental frequency of the propeller. An FFT³ was calculated at three time slices in the file to determine precise fundamental frequencies. The first time slice (Analysis Point 1) was at 0.24 seconds into the file with the aircraft approaching the viewpoint of the video. The second (Analysis Point 2) was at 6.07 seconds into the file with the aircraft's flight path perpendicular to the viewpoint of the video with a wind correction. The third (Analysis Point 3) was at 13.07 seconds (end of the file) with the aircraft moving away from the viewpoint of the video. The

¹ ADS-B data of the accident flight is available in the NTSB docket of this accident.

² Doppler shift is the change in observed frequency due to the relative motion of a sound source and the observer.

³ An FFT (Fast Fourier Transform) is a calculation to shift signal data from the time domain to the frequency domain, providing the individual spectral components of the signal.

effects of the Doppler shift were visible in the spectrogram as the decrease in frequency of the propeller signal over time.

Figure 2 shows spectrogram of the full duration of IMG_4103.MOV.

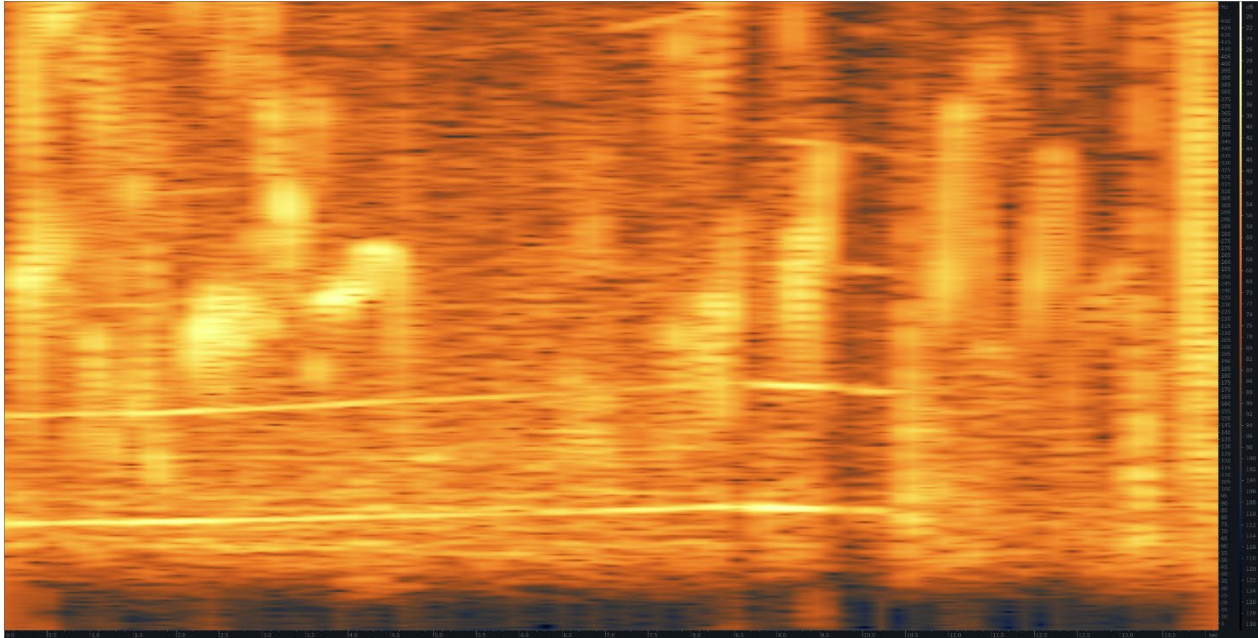


Figure 2. A color spectrogram showing audio from the full duration of IMG_4103.MOV

For IMG_4103.MOV, the prominent tone between 50 and 100 Hz is the fundamental frequency of the propeller. The aircraft is further from the observer and there is other background noise in this video so the fundamental and overtones are not as prominent as they are in IMG_4102.MOV. Two time slices from this video were selected for analysis of the engine speeds. The first (Analysis Point 4) was at 0.05 seconds into the file with the aircraft in a right bank and the flight path at an angle away from the viewpoint. The second (Analysis Point 5) was at 7.25 seconds into the file with the aircraft in a steep right bank and flight path headed back towards the viewpoint. Point 5 represents the time immediately prior to the initial loss of control and inverted roll of the aircraft. The effects of the Doppler shift were visible in the spectrogram as the increase in frequency of the propeller signal over time as the aircraft turned to the right and began to approach the location of the stationary observer.

Figure 3 shows the ADS-B data from the time of the sound spectrum study plotted on a map overlay in Google Earth. The location from which the videos were taken is displayed as a black and white square on the map and the points of the five time slices from the two videos are annotated as numbers on the path. Note that atmospheric and lighting conditions in Google Earth are not representative of those conditions at the time of the accident.



Figure 3. ADS-B data plotted in Google Earth with video location and studied points annotated.

Knowing the fundamental frequency of the observed (recorded) audio taken from a stationary position, the frequency of the source (the propeller on the moving airplane) can be determined using a form of the Doppler shift equation:

$$f_{source} = \frac{f_{observed}(c - v_{source})}{c}$$

where f is the frequency of the propeller source signal (*source*) and the observed recorded signal (*observed*), c is the speed of sound, and v is the component of the aircraft's velocity moving directly towards or away from the observer, adjusted for winds. Winds at the time of the accident were reported as 5 knots (kts) at 110 degrees, essentially in line with the runway. The velocity component moving towards or away from the observer was calculated from the ADS-B positions, the known fixed point of the observer, and the flight path and speed of the aircraft as follows:

$$v_{source} = (\text{wind corr. ADS} - B \text{ Groundspeed}) \times [\cos(\text{relative flight path angle})]$$

Speed of sound in knots is calculated with the following equation:

$$c = 643.885 \times \left(\frac{T}{273.15} \right)^{0.5}$$

where T is the air temperature in degrees Kelvin. METAR reported temperature at the time of the accident was 24 degrees Celsius (°C), therefore the speed of sound used in this study is c=671.55 kts.

The propeller was a 2-bladed model, so propeller speed in revolutions per minutes (rpm) was calculated from the fundamental frequency in Hertz as follows:

$$n_{prop} = \frac{f_{source}}{2} \times 60 \frac{sec}{min}$$

Table 2 shows the results of the study including the speeds and frequencies used in the formulas above. In brief, the propeller speed was constant at 2,389 rpm (near the Continuous Operating setting of 2,400 rpm) as the aircraft approached and passed the observer along the runway heading (Analysis Points 1 and 2). At the end of the runway (Analysis Point 3, the end of the first video IMG_4102.MOV) the propeller rpm had reduced slightly. As the aircraft continued through its right turn (Analysis Point 4, second video IMG_4103.MOV) the propeller rpm continued to decrease slightly. At the initial point of the upset (Analysis Point 5, also of second video IMG_4103.MOV) propeller rpm was calculated as 2,282 rpm. Throughout the videos, the propeller speed sound was smooth and consistent with normal engine operation.

Table 2. Data and results from the video study of doppler effect.

Analysis Point	Video Time (sec)	Nearest ADS-B Time (UTC ⁴)	ADS-B Average Groundspeed (kts)	Speed Adjusted for Winds (kts)	Speed Component Towards Observer (kts)	Video Fundamental Frequency (Hz)	Frequency Accounting for Doppler Shift (Hz)	Calculated Propeller Speed (rpm ⁵)
1	0.24 s	02:24:05.598	69.3	64.3	53.0	86.47	79.64	2,389
2	6.07 s	02:24:12.032	70.6	65.6	0.0	79.63	79.63	2,389
3	13.07 s	02:24:19.065	62.2	57.2	-50.3	73.70	79.22	2,377
4	0.05 s	02:24:31.987	64.4	60.9	-18.0	75.65	77.68	2,330
5	7.25 s	02:24:39.084	69.4	73.7	71.2	85.10	76.07	2,282

⁴ ADS-B data is presented in Coordinated Universal Time (UTC). Subtract five hours from UTC to get local eastern standard time.

⁵ According to the Aircraft Type Certificate Data Sheet (TCDS) the "Maximum Take-Off" setting is specified as 2,700 rpm and the "Continuous Operation" setting is specified as 2,400 rpm.

Submitted by:

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