

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



ERA24FA026

SOUND SPECTRUM STUDY

by Dan T. Horak

September 16, 2024

TABLE OF CONTENTS

A. ACCIDENT	3
B. SUMMARY	3
B.1. The accident	3
B.2. Objective of the Sound Spectrum Study	3
C. DETAILS OF THE INVESTIGATION	3
C.1. Sound spectrum analysis	4
C.2. Estimating possible Doppler frequency shifts	4
D. CONCLUSIONS	6
FIGURES	7

A. ACCIDENT

Location: Marion, Ohio
Date: October 31, 2023
Time: 11:23 eastern daylight time
Aircraft: Piper PA32-300

B. SUMMARY

B.1. The accident

On October 31, 2023, at 11:23 eastern daylight time, a Piper PA32-300, N44601, was destroyed when it was involved in an accident near Marion, Ohio. 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 of the Sound Spectrum Study

The objective of this study was the estimation of the speed of the airplane engine based on the sound in a video that was recorded with a camera mounted on a residential building.

C. DETAILS OF THE INVESTIGATION

The analyzed video was recorded with a camera installed on a residential building. It had 1920x1080 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 61 seconds. The airplane was not seen in the video but the sound it emitted was recorded and was audible in the video.

Figure 1 is an aerial view of the accident area. It shows the camera location and the location of ground impact. The yellow markers are the locations where data was available in an ADS-B record. Four markers are labeled with ADS-B times in format HH:MM:SS. The last available point was at time 11:22:27.

Figure 1 shows that the distance from the last available ADS-B location to the ground impact location is about 5000 feet. The distance from the 11:22:12 location to the 11:22:27 location is about 3000 feet. Therefore, the average ground speed between the 11:22:12 location to the 11:22:27 location was $3000/(27-12)=200$ feet/second or 118 knots.

The airplane heading between the 11:22:12 location and the 11:22:27 location in Figure 1 was toward the ground impact location. If the ground speed continued to

be 200 feet/second and the heading was unchanged up to the location of ground impact, it would have taken the airplane $5000/200=25$ seconds past time 11:22:27. Based on this ground speed assumption, the estimated ground impact time is 11:22:52. However, since the airplane impacted the ground in a steep nose-down attitude, the ground speed could have been lower as the airplane was approaching the location of ground impact.

C.1. Sound spectrum analysis

The sound in the video was analyzed with the FFT (Fast Fourier Transform) algorithm that used 32768-point windows. The windows were 0.6827 seconds wide and the frequency resolution was 88 cpm (cycles per minute). Figure 2 shows twelve spectra with window starting times between 0 seconds and 11 seconds in increments of one second. Spectral peaks due to the blade passage frequency (BPF) and the second harmonic of the BPF are marked in the figure.

The propeller had three blades. Therefore, the engine speed estimates were one third of the BPF frequencies in Figure 2. Figure 3 shows the estimated engine speeds based on BPF frequencies computed in processing windows with starting times between zero and 17.5 seconds in increments of 0.5 seconds. Past time 12 seconds in Figure 3, the estimated engine speed is marked as 'background noise.' It is marked so because there was an interfering sound signal at about 3000 cpm that was present even after the airplane crashed. The intensity of the interfering signal was very low.

The high engine speed estimates in Figure 3 could have been caused entirely or in part by frequency shifts caused by the Doppler effect. This possibility will be explored below in detail.

C.2. Estimating possible Doppler frequency shifts

The rated speed of the airplane Lycoming TIO-540 engine is 2700 rpm. Figure 3 shows maximum estimated speed of 4043 rpm as estimated based on the recorded BPF. This very high estimated engine speed could indicate extreme engine overspeeding, or a large frequency shift due to the Doppler effect, or a combination of engine overspeeding and Doppler frequency shift.

Deciding what was the cause of the high estimated engine speed was hindered by the ADS-B record ending at a distance of about 5000 feet from the ground impact location and at a time that was about 25 seconds before the estimated ground impact time. This gap in data availability made it impossible to accurately estimate the possible frequency shifts due to the Doppler effect because these shifts depended on the unknown speed with which the airplane was approaching the camera.

An eyewitness who observed the airplane as it was crashing stated that 'he observed the accident airplane flying south before it began a left circling turn.' The eyewitness stated further that 'the engine cut out and the airplane went nose down and impacted the ground.' It is not known if these statements are correct. If they are, then they imply that the airplane heading changed significantly past the 11:22:27 location in Figure 1. Without such a heading change, the airplane could not have been flying south and then execute a left circling turn just before impacting the ground at the location marked in Figure 1.

If the witness statements are correct, the airplane could have been flying toward the camera at a high speed, which could have caused large Doppler frequency shifts that resulted in the high recorded blade passage frequencies. This segment of the airplane ground track is not shown in Figure 1 because the ADS-B data ended at the 11:22:27 location. In the absence of latitude, longitude and altitude data it was impossible to evaluate the actual Doppler frequency shifts when the airplane was flying past the 11:22:27 location. To overcome the unavailability of ADS-B trajectory and speed information, an alternative strategy was employed to decide if the engine speed stayed below 2700 rpm and the high estimated engine speed of 4043 rpm was caused by the Doppler effect.

An analysis was performed to place upper limits on the possible Doppler frequency shifts by estimating the shifts under extreme assumptions. For the purpose of the analysis, the term Doppler multiplier was defined to be the number by which a frequency is multiplied due to the Doppler effect when it is recorded by the camera. The airplane ground speed at the time of the last ADS-B data point was 200 feet/second, as estimated above. It was known that the airplane had to descend from the pressure altitude of 5625 feet to the ground elevation at the impact location that was 950 feet. It was assumed that in addition to the ground speed, the airplane was descending toward ground impact at the high vertical terminal velocity of 150 mph or 220 feet/seconds.

Under these extreme assumptions, the total speed of the airplane was $\sqrt{200^2 + 220^2} = 297$ feet/second. The Doppler multiplier was 1.36 and the adjusted speed estimate was $4043/1.36=2973$ rpm. The Doppler-adjusted estimated engine speed of 2973 rpm was higher than the rated engine speed of 2700 rpm. Furthermore, the adjusted 2973 rpm engine speed estimate was based on the assumption that the airplane was flying with the 297 feet/second speed directly toward the camera, which is unlikely. If the airplane was not flying directly toward the camera, the Doppler multiplier would have been less than 1.36 and the adjusted engine speed estimate would have been higher than 2973 rpm.

Consequently, since even extreme assumptions could not explain the very high BPF-based estimated engine speed of 4043 rpm as being entirely due to the Doppler effect, it was concluded that at least part of the high speed estimate was due to the engine overspeeding. It is likely that the Doppler effect also contributed to the high speed estimate. It was not possible to estimate the maximum engine speed because spectral analysis could not estimate the frequency of the emitted blade passage frequency. It could not separate the recorded frequency into a frequency emitted by the propeller blades and a frequency shift due to the Doppler effect.

D. CONCLUSIONS

The speed of the engine of an airplane that crashed was analyzed via spectrum analysis of the sound recorded in a video. It was estimated that shortly before ground impact, the engine speed exceeded significantly its rated speed of 2700 rpm. The accurate maximum speed could not be estimated because the analysis was based on a recorded propeller blade passage frequency that was affected by Doppler frequency shifts of unknown magnitude.

FIGURES

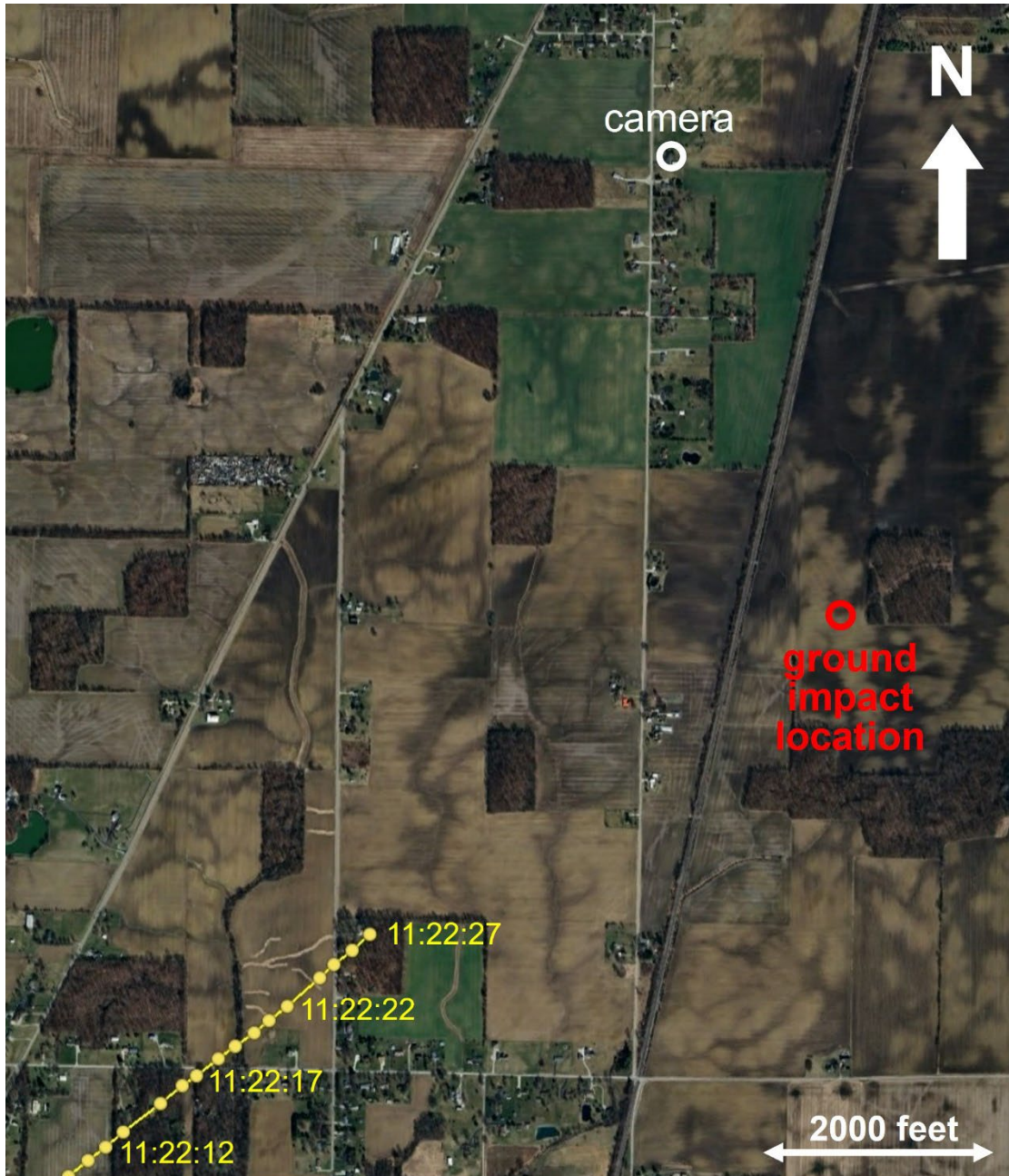


Figure 1. Aerial view of the accident area

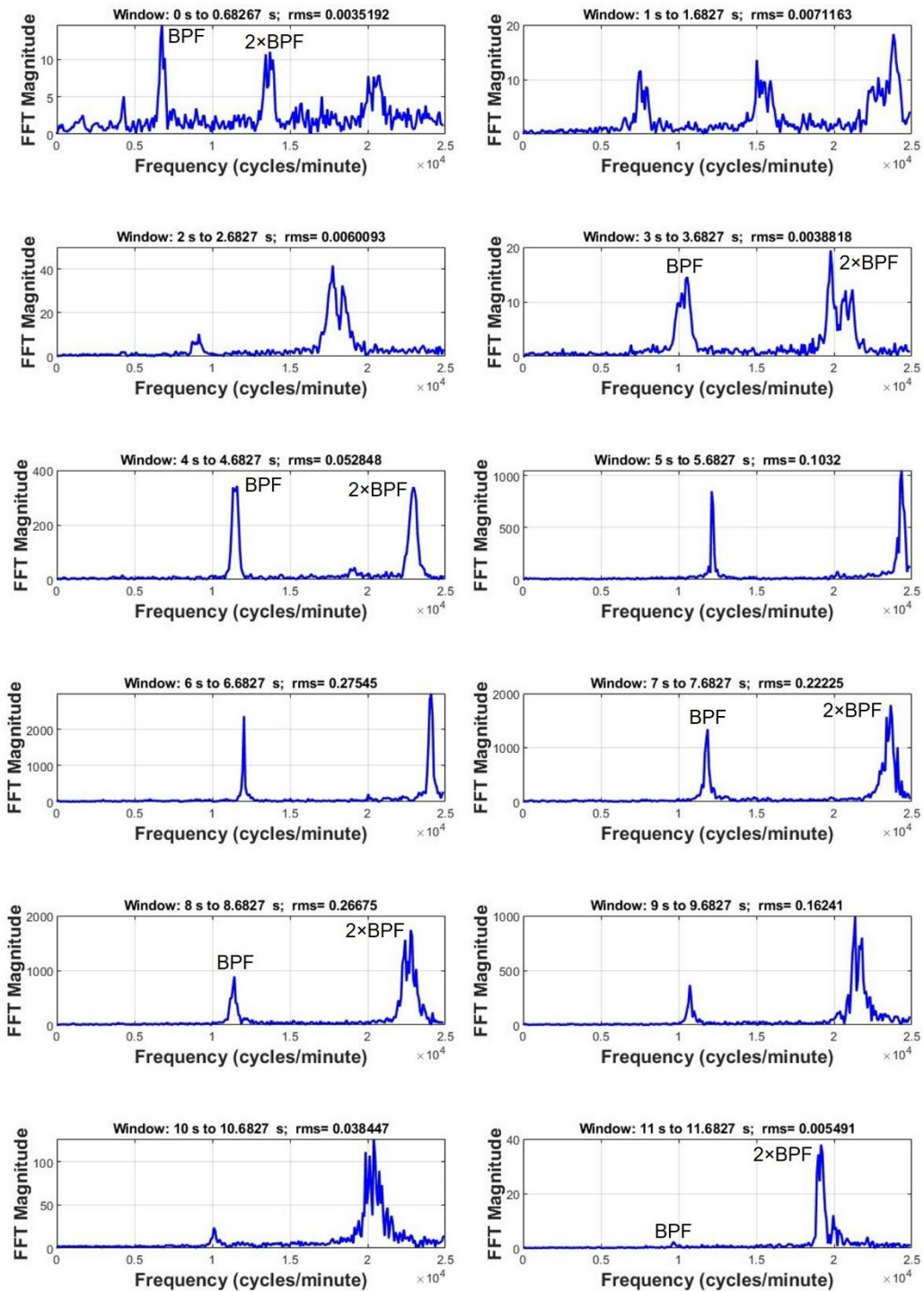


Figure 2. Sound spectra

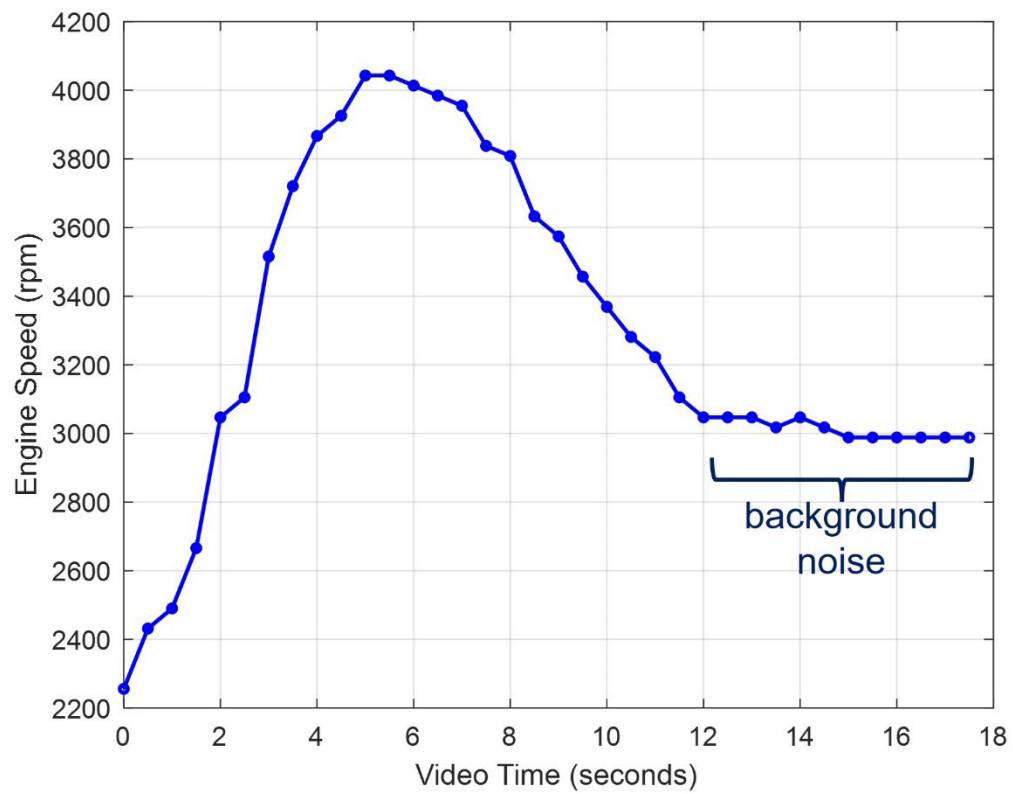


Figure 3. Engine speed estimates based on recorded blade passage frequency