

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Washington, D.C. 20594

January 28, 2022

Sound Spectrum Study

**NTSB Case Number:
WPR22FA055**

A. ACCIDENT

Location: Medford, Oregon
Date: December 6, 2021
Time: 1652 Pacific standard time (PST)
Aircraft: Piper PA-31

B. AUTHOR

Dan T. Horak
NTSB

C. ACCIDENT SUMMARY

On December 6, 2021, at 1652 PST, a Piper PA-31, N64BR, was substantially damaged when it was involved in an accident shortly after taking off from the Rogue Valley International - Medford Airport (MFR). The pilot and passenger were fatally injured.

D. DETAILS OF INVESTIGATION

The goal of this investigation was estimating the engine speed of the airplane based on a video recorded by a camera installed on a commercial building. The 90-seconds-long video did not record an image of the airplane, however, it recorded sound emitted by the airplane. The sound record started when the airplane was airborne and flying along the runway. The sound record ended past the time when the ground impact sound was heard. The airplane sound was audible in the recording up to the time of ground impact.

Ground Track and Doppler Effect Analysis

Figure 1 is an aerial view of the accident area. It shows the ADS-B ground track of the airplane, the crash location, and the location of the camera that recorded the analyzed sound. Figure 2 shows details of the ground track. The ADS-B time was synchronized with the video time and the time labels in the figure point to locations where the airplane was at those video times. The ADS-B record ended before ground impact.



Figure 1. Aerial View of the Accident Area

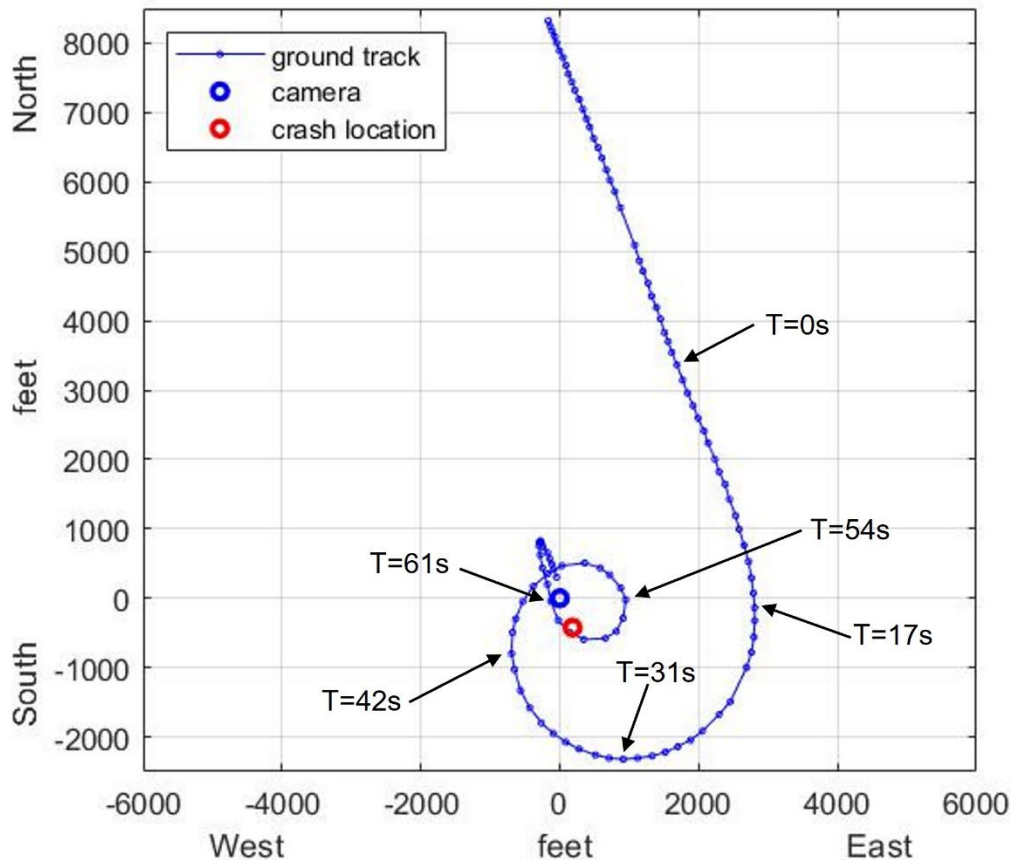


Figure 2. Details of Ground Track

The ground track location labeled T=0s is where the airplane was when the sound recording started. The airplane was closest to the camera at the location labeled T=61s. The airplane crashed at video time 79 seconds, after the ADS-B ground track data ended.

The ground speed of the airplane was about 115 knots at the location labeled T=0s and was about 150 knots when it was closest to the camera at the location labeled T=61s. As the ground track in the figure shows, the airplane first flew toward the camera, resulting in the recorded sound frequency being higher than the emitted frequency due to the Doppler effect. It then flew away from the camera, resulting in the recorded sound frequency being lower than the emitted frequency.

The ADS-B recording showed that the airplane altitude underwent three large climb-descent maneuvers between video time 25 seconds and the end of the ADS-B data at video time 73 seconds. These maneuvers resulted in high vertical speeds that contributed significantly to the Doppler effect. For example, during the last 6.5 seconds before the airplane was closest to the camera, the average descent speed was 5270 feet/minute or 62 knots.

At each ground track point shown in Figure 2, the magnitude of the Doppler effect depended on the magnitude of the relative speed between the airplane and the camera. The relative speed was estimated by considering the location of the airplane, the magnitude of its velocity vector and the direction of its velocity vector, all evaluated in a three-dimensional system of coordinates. The term 'Doppler multiplier' was defined to be a number by which to multiply a recorded frequency to get the frequency that was emitted by the moving airplane. Figure 3 shows the estimated Doppler multiplier as a function of video time.

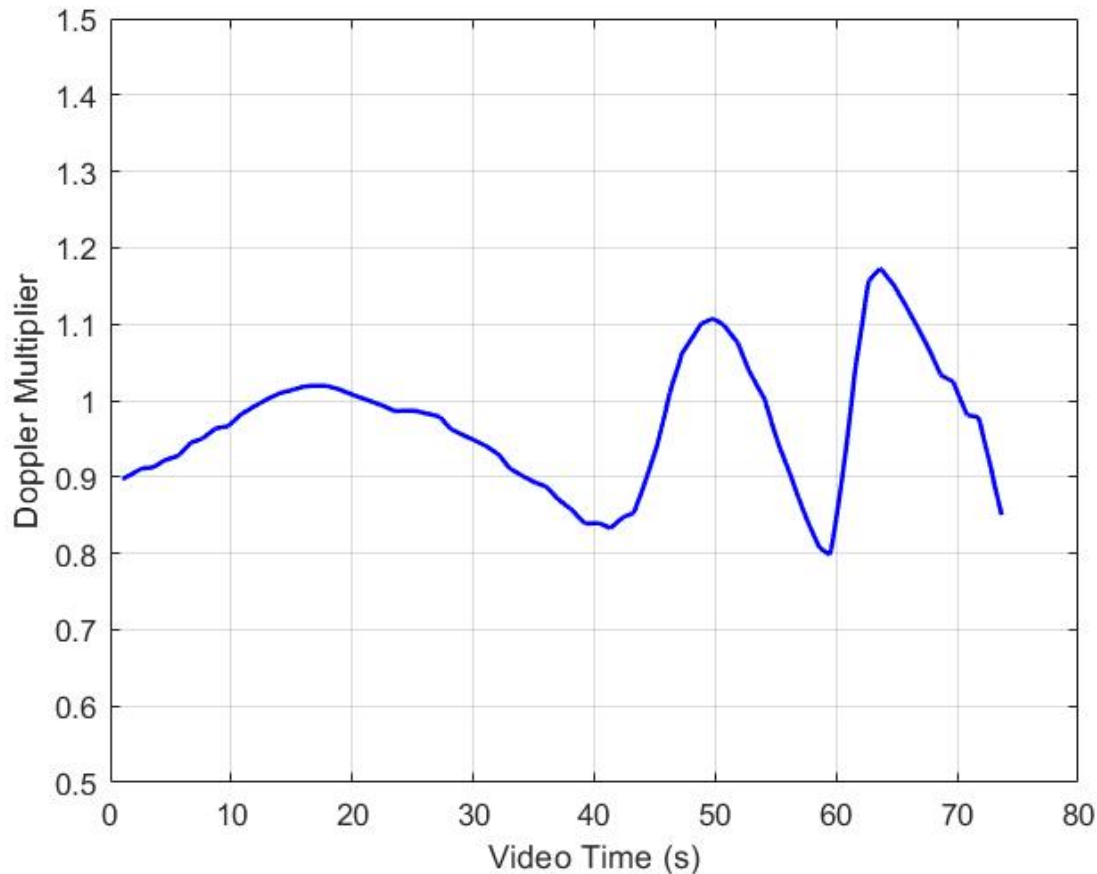


Figure 3. Doppler Multiplier

Sound Spectrum Analysis

The spectrum of the sound recorded by the camera was analyzed with a 4096-point Fast Fourier Transform (FFT) algorithm. Since sound was sampled at the rate of 8000 samples/second, the FFT processing window was 0.512 seconds wide and the frequency resolution was 117 cycles/minute.

The rated speed of the Lycoming TIO-340 engines on the airplane is 2500 rpm. At this speed, the possible spectral peak frequencies due to engine rotation are 2500 cycles per minute (cpm) and the harmonics at 5000 cpm, 7500 cpm, 10,000 cpm, etc. The

propellers had three blades, resulting in a blade passage frequency (BPF) of $3 \times 2500 = 7500$ cpm. The second harmonic due to BPF would be at 15,000 cpm. In the four-stroke cycle, six-cylinder engines, each cylinder fires once per two engine shaft revolutions, resulting in possible spectral peaks at $2500/2 = 1250$ cpm and harmonics at 2500 cpm, 3750 cpm, 5000 cpm, etc. In the complex sound pressure field generated by the two engines and the two propellers, there could also be spectral peaks corresponding to sums or differences of any of the above frequencies.

Figure 4 is the spectrum in the time window between video time 50 seconds and video time 50.512 seconds. Five spectral peaks are marked in the figure. Figure 3 shows that the Doppler multiplier at video time 50 seconds was 1.1. Table 1 lists the frequencies of the five peaks in Figure 4 and the frequencies after they were multiplied by 1.1 to account for the Doppler effect.

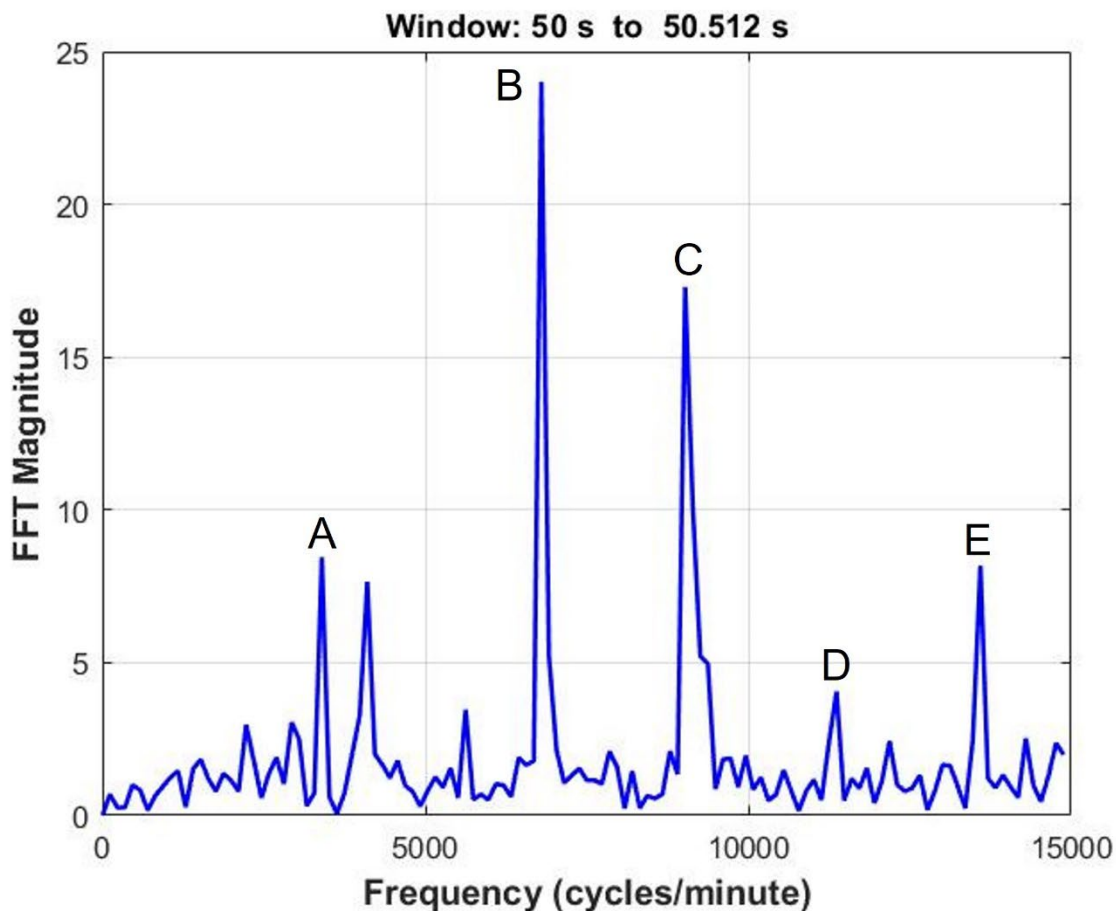


Figure 4. Sound Spectrum at Video Time 50 seconds

The Doppler-adjusted frequencies of spectral peaks A through E in Table 1 are very close to 3750 cpm, 7500 cpm, 10,000 cpm, 12,500 cpm and 15,000 cpm, respectively. These adjusted frequencies all point to engine rotational speed of 2500 rpm, as detailed above. The analysis shown in Figure 4 and in Table 1 was performed for 0.512-seconds-wide FFT processing windows starting from video time zero through

video time 78.5 seconds, in half-second increments. Throughout this period, there were spectral peaks pointing to an engine speed near 2500 rpm. The largest peaks in most analyzed time windows were near 7500 cpm and near 10,000 cpm.

Table 1. Measured Sound Spectrum Peaks

Spectral Peak	Unadjusted Frequency (cpm)	Doppler-Adjusted Frequency (cpm)
A	3398	3738
B	6797	7477
C	9023	9925
D	11370	12507
E	13590	14949

Figure 5 summarizes the engine speed analysis. The estimated Doppler-adjusted engine speed was in the range of 2500 ± 100 rpm, as expected from properly operating engines. The speed fluctuation between 2400 rpm and 2600 rpm are within the expected estimation errors due to ADS-B location errors and the 117 cpm resolution of the FFT algorithm. They do not indicate a fluctuating engine speed.

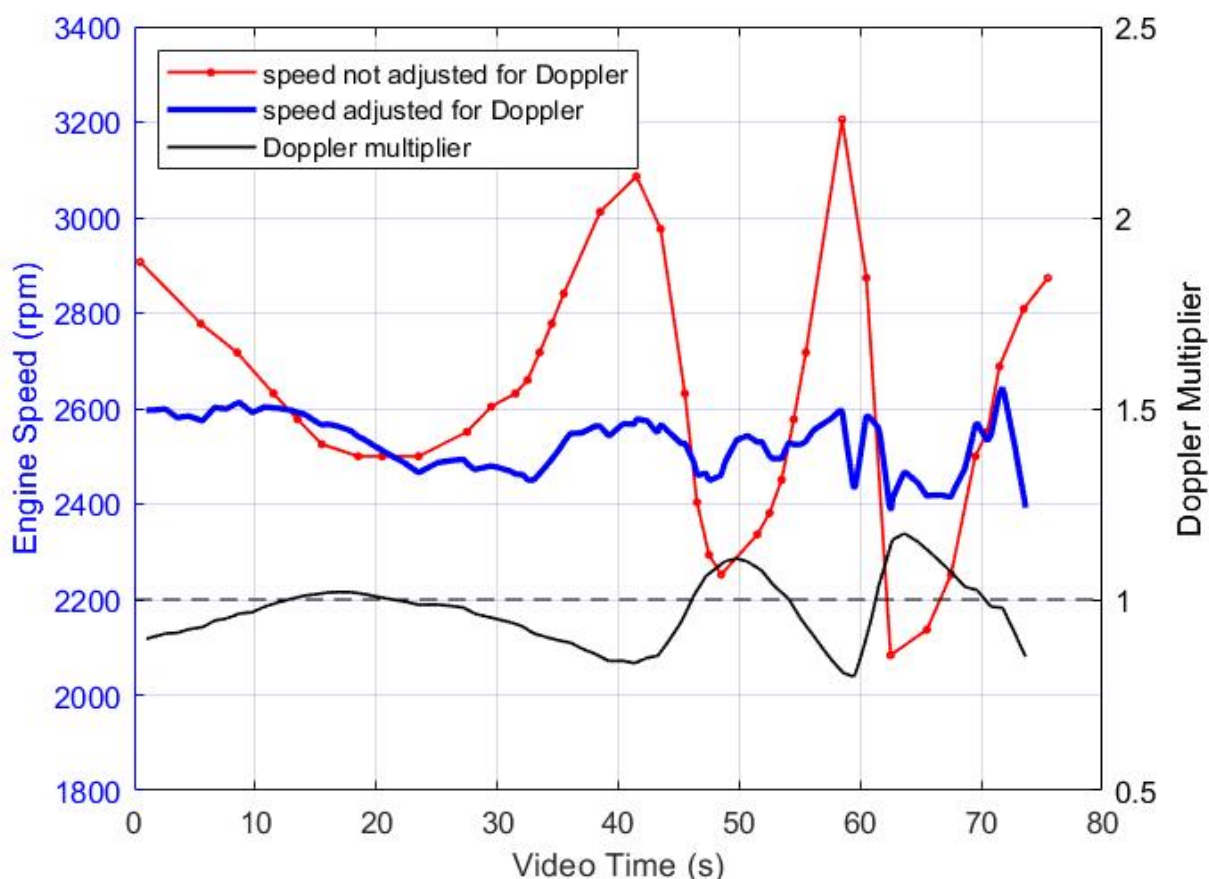


Figure 5. Estimated Engine Speed

The estimated Doppler-adjusted engine speed in Figure 5, the blue curve, ends at video time 73 seconds. Past that time, Doppler adjustment was impossible because the ADS-B record ended at 73 seconds. The engine(s) continued operating up to time 79 seconds, when the sound of ground impact is heard in the video. It was not possible to determine through spectrum analysis if the analyzed sound was generated by one engine or by two engines operating at the same speed.

E. CONCLUSIONS

The engine speed of an airplane that crashed after taking off was estimated through spectral analysis of sound recorded by a camera on a commercial building. The estimated engine speed was constant in the range of 2500 ± 100 rpm during the analyzed time, indicating properly-operating engines. Based on sound analysis alone, it was not possible to determine if the analyzed sound was generated by both engines operating at the same speed or by one engine.