

NATIONAL TRANSPORTATION SAFETY BOARD

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

March 8, 2021

Video Study

**NTSB Case Number:
ERA20FA074**

A. ACCIDENT

Location: Mechanicsburg, Pennsylvania
Date: January 9, 2020
Time: 2029 eastern standard time (EST)
Aircraft: Robinson R66 helicopter

B. AUTHOR

Dan T. Horak
NTSB

C. ACCIDENT SUMMARY

On January 9, 2020, about 2029 eastern standard time (EST), a Robinson R66 helicopter, N450MC, experienced an in-flight break-up near Mechanicsburg, Pennsylvania. The private pilot and one passenger were fatally injured and the helicopter was destroyed. The helicopter was operated under the provisions of title 14 *Code of Federal Regulations Part 91* personal flight. Night visual meteorological conditions prevailed at the time and no flight plan was filed for the flight. The flight originated about 1958 EST from Martin State Airport (MTN), Baltimore, Maryland, and was destined for Buffalo Niagara International Airport (BUF), Buffalo, New York.

D. DETAILS OF INVESTIGATION

The goal of this investigation was extracting information from a Nest Doorbell Camera video that recorded the final seconds of the flight of the helicopter. The video had 1152x864 resolution and frame rate of 15 fps. It lasted 22.8 seconds. The helicopter became visible in the video at 8.5 seconds. It was last seen in the video at 15.3 seconds. The camera also recorded the sound of the helicopter that was audible during the first 19 seconds.

Available Automatic Dependent Surveillance – Broadcast (ADS-B) data included accurate ground track and altitude of the helicopter sampled at the rate of once per second. Therefore, it was not necessary to estimate these quantities based on the visual information in the video. Consequently, this report analyzes only the sound information in the video. The ADS-B data showed that when the video recording started, the barometric altitude of the helicopter was a constant 1800 feet and the ground speed was constant at about 125 knots. Therefore, the video happened to record the entire transition from stable flight to ground impact of the helicopter.

Analysis of Sound Signal Intensity

The sound was sampled at the rate of 16,000 samples per second. Figure 1 shows the sound signal intensity. The ground track of the helicopter indicated that it was flying approximately toward the camera. Because of the decreasing distance between the helicopter and the camera, it was expected that the sound signal intensity would increase with time.

However, the large increase starting at about 11 seconds and lasting till about 13 seconds could not be explained by the decreasing distance between the helicopter and the camera. Since the main rotor impacted the ground about 150 feet away from the airframe impact location, it is likely that the large signal level between 11 seconds and 13 seconds is due to the event that resulted in the separation of the main rotor from the airframe.

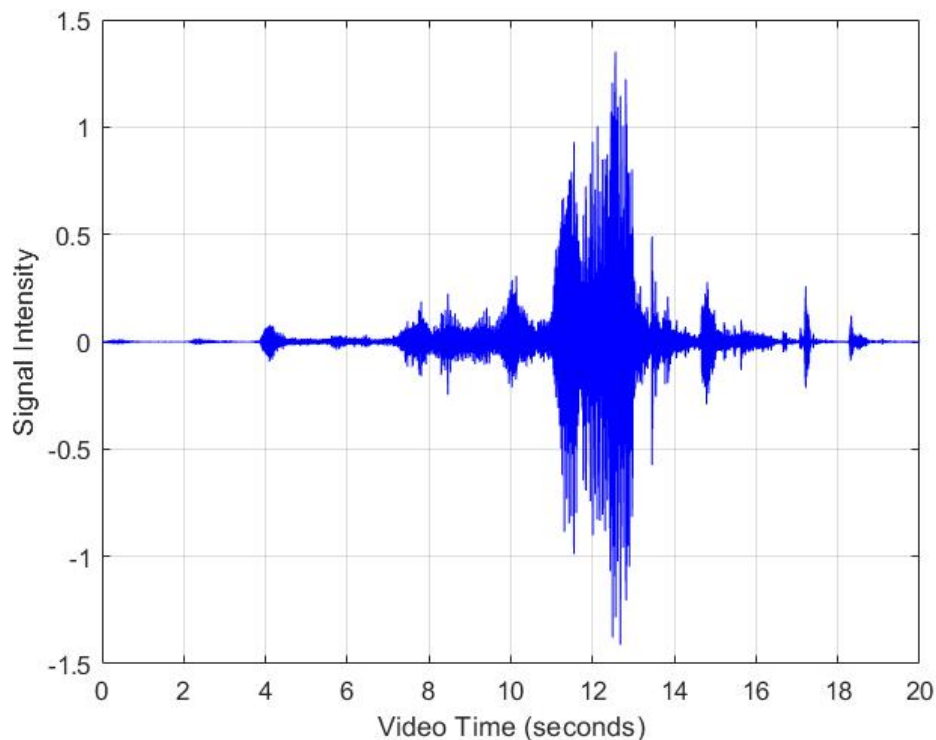


Figure 1. Sound Signal Recorded by the Camera

Analysis of Sound Spectrum

The spectrum of the sound signal was analyzed to generate more information on the signal seen in Figure 1. Spectra were computed with a 16384 point Fast Fourier Transform (FFT) algorithm in 20 time windows between video time 1 second and video time 21 seconds. Each time window was $16384/16000=1.024$ seconds wide. The FFT frequency resolution was 58.6 cycles per minute (cpm). The FFT algorithm did not use signal windowing. It was verified that a Hanning window had only small effect on the computed spectra and it would not have affected the conclusions in this report that are based on the spectra.

Figure 2 shows the spectra between time 1 second and time 11 seconds. Figure 3 shows the spectra between time 11 seconds and time 21 seconds. Four main peaks can be seen in the spectra in Figure 2. They are marked in red on two of the plots. In the processing window that starts at time 8 seconds, the frequencies of peaks A, B, C and D were 6094 cpm, 12070 cpm, 18050 cpm and 24080 cpm, respectively.

According to the theoretical analysis and experimental results in Reference 1, spectral peak A is expected to be the tail rotor blade passage frequency (BPF) and peaks B, C and D its harmonics. The rated (100%) engine output shaft speed of the RR300 engine in the R66 helicopter is 6016 rpm. The rated main rotor speed is $R=408$ rpm and the rated tail rotor speed is $T=2427.4$ rpm. Therefore, the frequency of peak A, generated by the blade passage rate of the 2-bladed tail rotor, is expected to be $2T=4855$ cpm. The helicopter was approaching the camera at a high speed, resulting in the recorded frequencies to be about 1.25 times larger than the emitted frequencies due to the Doppler effect. When the measured frequencies of peaks A, B, C and D are divided by 1.25, they yield 4875 cpm, 9656 cpm, 14440 cpm and 19264 cpm, respectively. These values correspond to $2T$, $2 \times 2T$, $3 \times 2T$ and $4 \times 2T$ with accuracy better than the frequency resolution of the FFT algorithm.

Furthermore, Reference 1 found experimentally that in addition to the spectral peaks due to the tail rotor BPF, there could be spectral peaks due to the interaction of the wake of the tail rotor with the wake of the main rotor. These peaks are expected at the frequencies given by $N \times 2T + M \times 2R$, where $2R=816$ cpm is the main rotor BPF, N represents the tail rotor harmonic order and M represents the main rotor harmonic order. Figure 4 shows an enlarged view of the spectrum in the window that starts at time 8 seconds in Figure 2.

Four of the spectral peaks are marked in the figure. The tail rotor BPF, $2T$, scaled up by the Doppler effect, corresponds to the peak at 6094 cpm. Its second harmonic, $2 \times 2T$, scaled up by the Doppler effect, corresponds to the peak at 12070 cpm. The peak at 7090 cpm corresponds to $2T+2R$, scaled up by the Doppler effect and the peak at 10140 cpm corresponds to $2T+4 \times 2R$, scaled up by the Doppler effect. Examination of the other spectral peaks in Figure 4 reveals that all the peaks defined by $N \times 2T + M \times 2R$ for $N=1$ and 2 and $M=1$ through 5, scaled up by the Doppler effect, agree with the predicted values with accuracy better than the frequency resolution of the FFT algorithm.

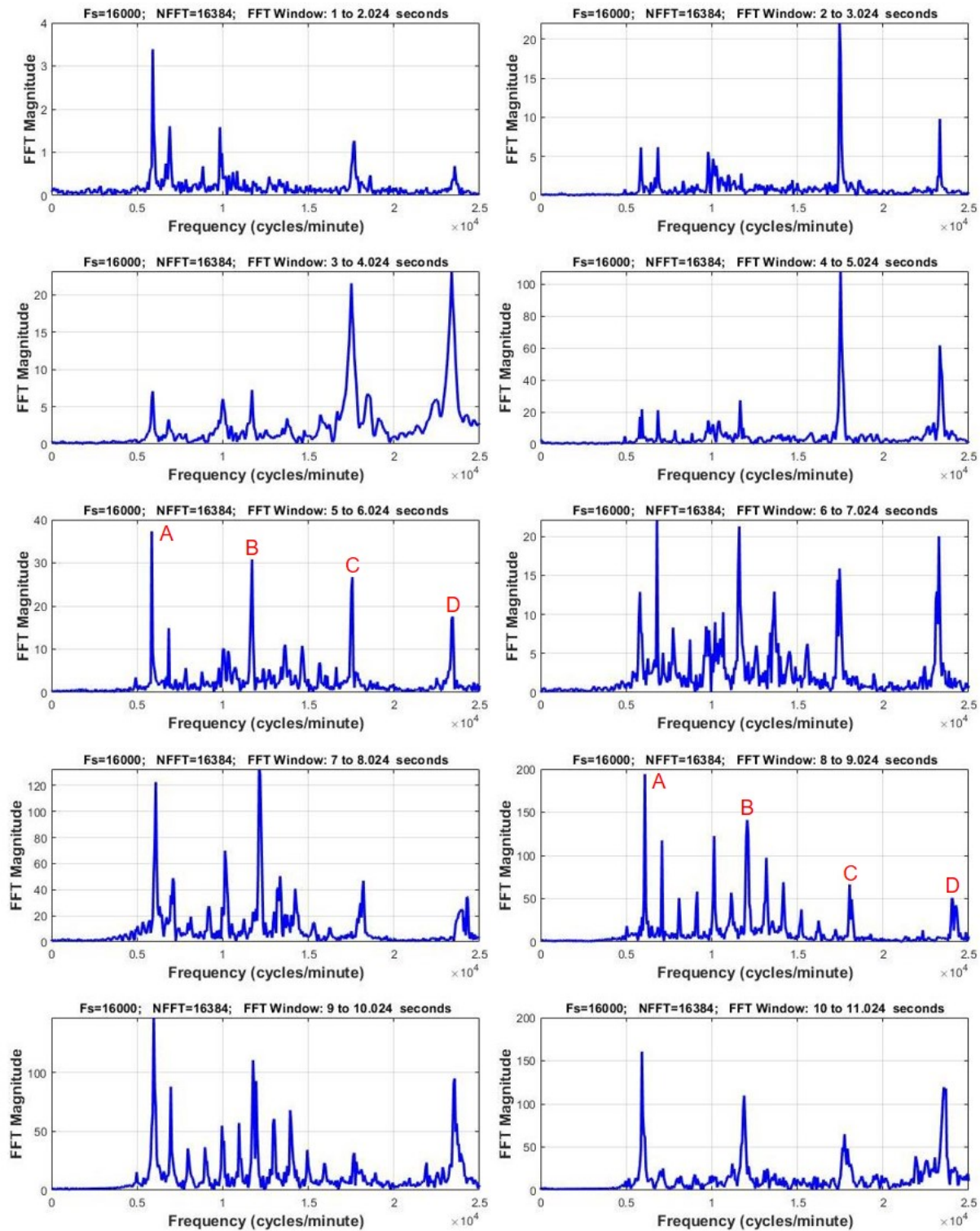


Figure 2. Sound Signal Spectrum from Time 1 second to Time 11 seconds

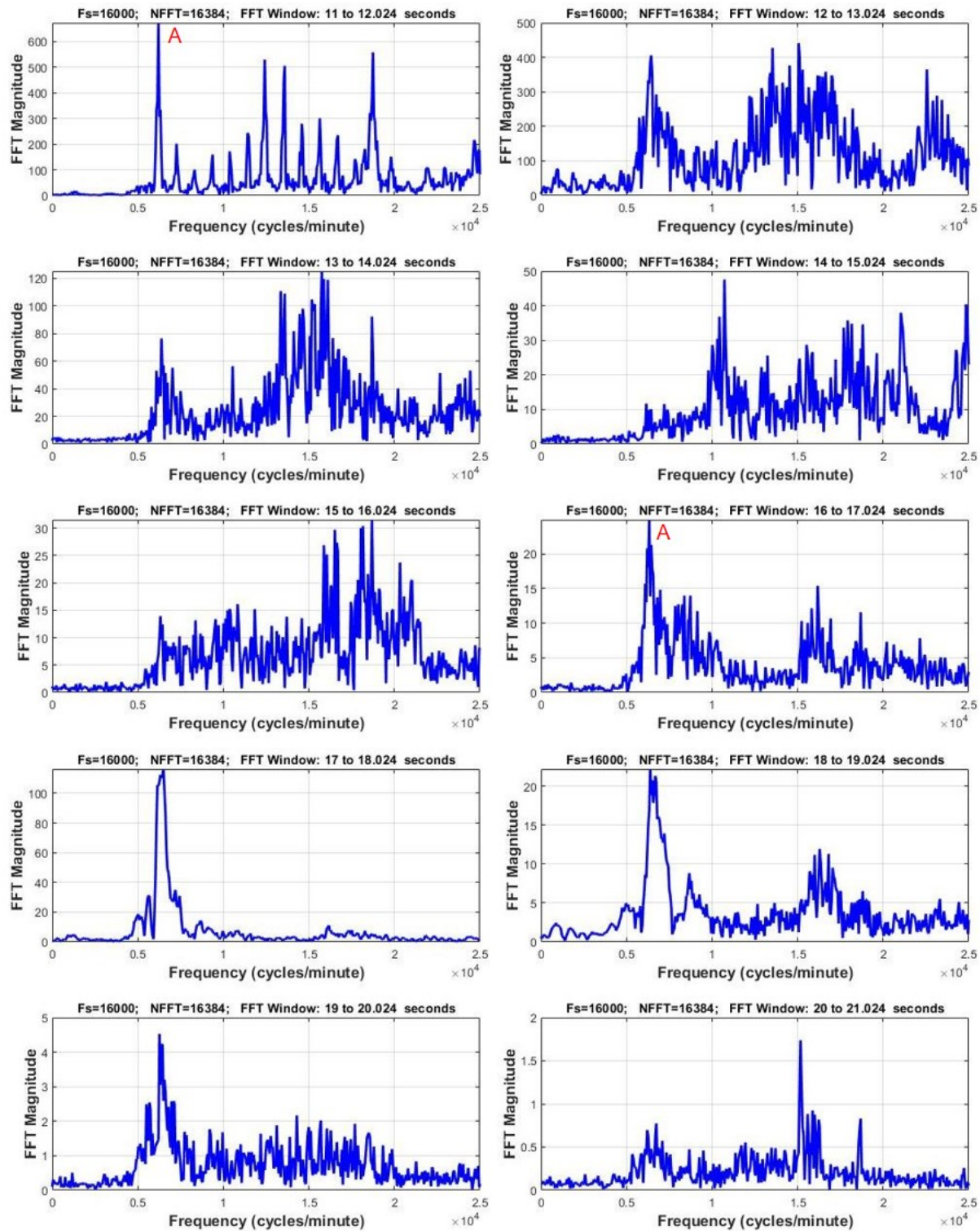


Figure 3. Sound Signal Spectrum from Time 11 seconds to Time 21 seconds

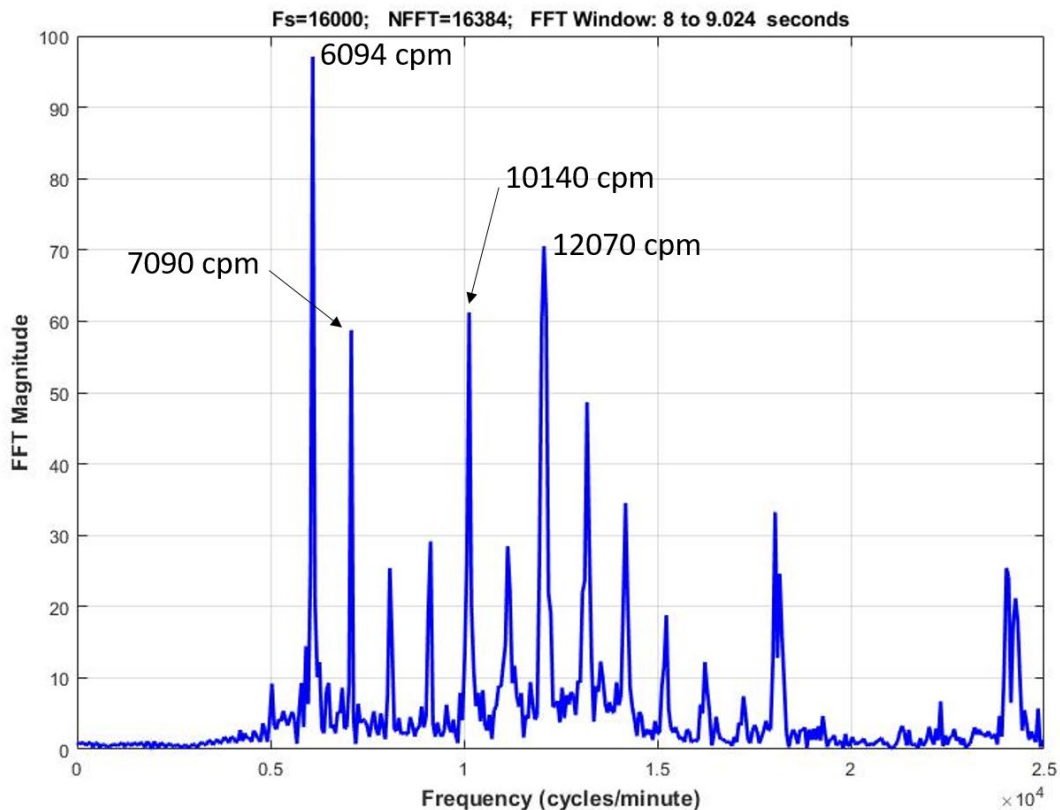


Figure 4. Sound Signal Spectrum from Time 8 seconds to Time 9 seconds

The accurate agreement between the spectral peaks computed in this Video Study and the frequencies predicted based on Reference 1 is viewed as a strong indication that the computed spectral peaks can be used for estimating the rotational speeds of the tail rotor and the main rotor of the accident R66 helicopter.

Figures 2 and 3 show that portions of the pattern of spectral peaks generated by the interaction of the tail rotor wake and the main rotor wake are present through video time 12 seconds. This indicates that both rotors were rotating at the expected speeds up to video time 12 seconds.

Past time 12 seconds, the contribution of the main rotor to the sound spectrum is no longer there, indicating that the event corresponding to the large transient shown in Figure 1 probably caused significant damage to or separation of the main rotor.

The spectral peak that is believed to correspond to the tail rotor BPF is still present past time 12 seconds. At time 16 seconds, its frequency is 6328 cpm, about 4% higher than what it was before time 12 seconds. This increase agrees with recorded engine data that show an increase of the power turbine speed N2 shortly before the crash, possibly caused by the decreased resistive torque applied by the damaged or missing main rotor.

Figure 4 shows that the frequency range between the tail rotor BPF at $2T=6094$ cpm and its second harmonic at $2 \times 2T=12070$ cpm is evenly divided into six segments by the five spectral peaks that have contributions from the main rotor BPF. It is so because $2T/2R=5.95$, almost 6.

Figures 2 and 3 show that spectral peaks that are affected by the main rotor wake are clearly seen only in the 1-second-long windows that start at times 8 seconds, 9 seconds and 11 seconds. It is probably so because some of the spectral details of the three-dimensional pressure field due to the interacting rotor wakes are lost by the time the pressure field reaches the camera microphone that was 2000 feet or farther from the moving helicopter that generated the pressure field.

E. CONCLUSIONS

The sound of a crashing helicopter recorded by a doorbell camera installed on a residence was analyzed. The analysis detected a large sound transient that lasted about two seconds, probably caused by the main rotor separating from the airframe. The transient event significantly changed the spectral characteristics of the engine sound.

Before the large sound transient, the spectrum included peaks that corresponded to the first four harmonics of the tail rotor blade passage frequency and peaks that could be associated with the interaction of the tail rotor wake with the main rotor wake. This was consistent with both main and tail rotors operating at their normal rotational speeds. After the transient, only peaks related to the tail rotor could be identified in the spectrum.

F. REFERENCE

1. Leverton, John W., Pollard, John S. and Wills, Christopher R., Westland Helicopters Ltd., "Main Rotor Wake / Tail Rotor Interaction", Vertica 1, 213-221, 1977.