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VIDEO STUDY

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A. ACCIDENT

Location: Balch Camp, California
Date: September 9, 2023
Time: 13:45 Pacific daylight time
Aircraft: Bell 212 helicopter

B. SUMMARY

B.1. The accident

On September 9, 2023, at 13:45 Pacific daylight time, a Bell 212 helicopter, N873HL, was substantially damaged when it was involved in an accident near Balch Camp, California.

B.2. Objective and scope of the Video Study

The objective of this Video Study was estimating the speed of the helicopter main rotor based on the sound and visual information in a video recorded with a hand-held camera.

C. DETAILS OF THE INVESTIGATION

The analyzed video had 756×1344 resolution and frame rate of 30 frames per second. It recorded sound at the rate of 48,000 samples per second. The video lasted 52 seconds. The helicopter became visible in the video at video time 39.8 seconds and was losing altitude. The main rotor blades contacted tree branches at video time 49 seconds. Rotor blade damage is first seen at time 49.3 seconds. The helicopter impacted the ground at time 51.8 seconds.

The Bell 212 helicopter main rotor speed at 100% N₂ (the speed of the power turbines of the two engines) is 324 rpm. The main rotor has two blades, resulting in a blade passage frequency (BPF) of 648 blades/minute. The tail rotor speed at 100% N₂ is 1662 rpm. The tail rotor has two blades, resulting in a BPF of 3324 blades/minute.

C.1. Main rotor speed estimation based on sound spectrum analysis

Both the visual information and the video sound stream indicated that the main rotor speed was decreasing as the helicopter was descending toward ground impact. The spectrum of the recorded sound was estimated with the Fast Fourier Transform (FFT) algorithm. The algorithm used 65,536-point windows, resulting in windows that were 1.3653 seconds wide and in a frequency resolution of 44 cpm (cycles per minute).

Figure 1 shows the spectrum estimated in the processing window starting at video time 30 seconds. Eight spectral peaks are marked in the figure. Peaks B through H are harmonics of the main rotor BPF, from the second (peak B) to the eighth (peak H). Spectral peak T is the second harmonic of the tail rotor BPF. The visibility of the second harmonic of the tail rotor BPF was better than the visibility of the BPF and was used in the analysis below.

Spectra were estimated in 24 time windows with starting times from video time 23 seconds to video time 49 seconds. The second harmonic of the tail rotor BPF was used for the main rotor speed estimation in windows starting at 29 seconds through 49 seconds. The main rotor speed at times 23, 25 and 27 seconds was estimated based on the average spacing of the main rotor BPF harmonics (peaks B through H) because the second harmonic of the tail rotor BPF was less visible at these times. The ratios between the spectral peak frequencies indicated that the ratio between the tail rotor speed and the main rotor speed remained constant. This indicates that the tail rotor drive gear ratio remained constant. Consequently, either the tail rotor BPF or the main rotor BPF could be used for main rotor speed estimation.

Figure 2 shows the estimated main rotor speed. The blue markers and lines are the raw data and the red line is a 3rd order polynomial fit to the raw data. The figure shows that past video time 32 seconds the rotor speed is decreasing and that the rate of decrease increases over time.

C.2. Main rotor speed estimation based on the visual information in the video

The main rotor speed at 100% N₂ is 324 rpm or $324/60=5.4$ rotations per second. Since the video frame rate was 30 fps (frames per second), the main rotor rotation rate per video frame is $5.4/30=0.18$ rotations per frame. Over three frame intervals, the number of main rotor rotations is $0.18 \times 3=0.54$ rotations. The rotation angle of the main rotor over three frame intervals at 100% N₂ is $0.54 \times 360^\circ=194.4^\circ$.

Since the sound spectrum analysis showed that the main rotor speed was decreasing, an easy-to-estimate speed case would be one where the rotor rotates 180° over three frame intervals. The main rotor speed corresponding to that situation would be $324 \times 180/194.4=300$ rpm. Examination of the video reveals that it occurs between video frame 1352 and video frame 1355, corresponding to video times 45.066 seconds and 45.166 seconds. Figure 3 shows a segment of video frame No. 1352 and Figure 4 shows a segment of video frame No. 1355.

It is evident in these figures that the two-bladed main rotor rotated by 180° and each figure shows a different blade. Therefore, the main rotor speed estimate at time 45.12 seconds is 300 rpm. Figure 2 shows that the polynomial fit to the sound-

spectrum-based rotor speed estimate indicates a speed of 302 rpm at that time. This is an accurate agreement between the two speed estimation methods considering that the sound spectrum analysis accuracy was limited by the 40 cpm FFT frequency resolution mentioned above.

Figure 2 shows that the main rotor speed was declining at a high rate past video time 45.12 seconds. The same method was used to estimate the main rotor speed between video frame 1471 and video frame 1474, corresponding to video times 49.033 seconds and 49.133 seconds. This was just before the time when the video showed blade damage that could have affected the rotor speed. Figures 5 shows a segment of video frame No. 1471 and Figure 6 shows a segment of video frame No. 1474. It is estimated that the rotor rotated about 168° between the corresponding video times. Therefore, the speed estimate at time 49.08 seconds is $324 \times 168 / 194.4 = 280$ rpm. This estimate also agrees with the sound-spectrum-based rotor speed estimate shown in Figure 2.

D. CONCLUSIONS

The speed of the main rotor of a helicopter that crashed was estimated based on the sound and the visual information in a video recorded with a hand-held camera. It was estimated that the rotor speed was declining during the analyzed 26 seconds that ended about 2.5 seconds before ground impact. The last estimated main rotor speed was 282 rpm.

FIGURES

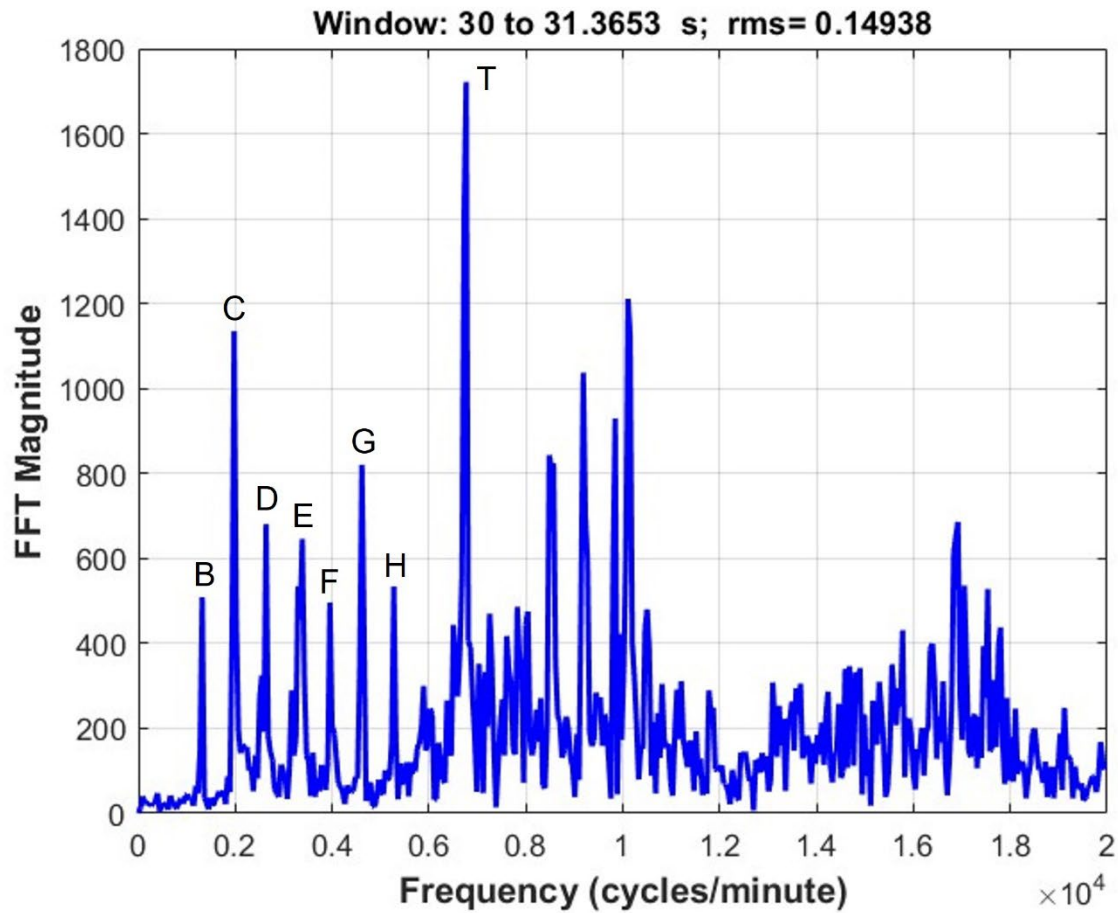


Figure 1. Sound spectrum estimated in the window starting at 30 seconds

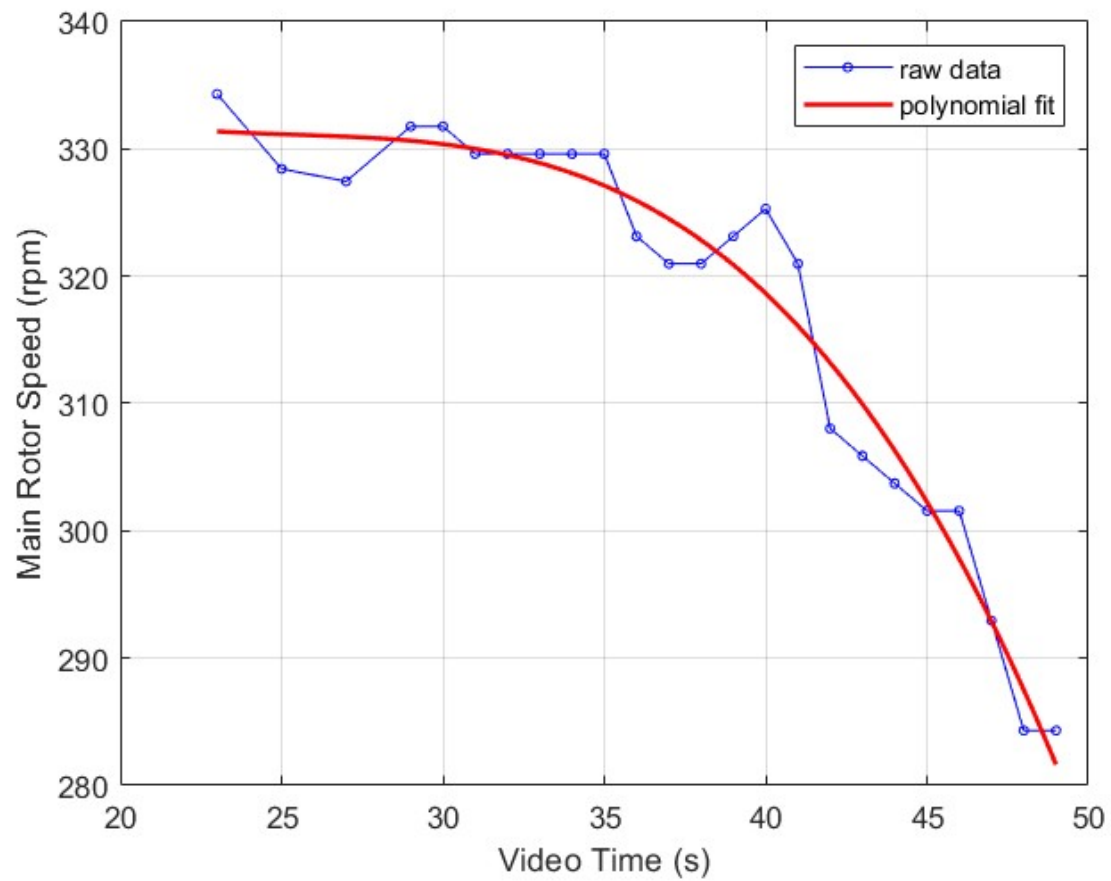


Figure 2. Estimated main rotor speed based on sound spectrum analysis



Figure 3. Segment of video frame No. 1352



Figure 4. Segment of video frame No. 1355



Figure 5. Segment of video frame No. 1471



Figure 6. Segment of video frame No. 1474