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VIDEO STUDY

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TABLE OF CONTENTS

A. ACCIDENT	3
B. SUMMARY	3
B.1. The accident	3
B.2. Objective and scope of the <i>Video Study</i>	3
C. DETAILS OF THE INVESTIGATION	3
D. CONCLUSIONS	6
FIGURES	7

A. ACCIDENT

Location: Waldorf, Maryland
Date: July 9, 2023
Time: 1027 EDT (eastern daylight time)
Aircraft: Hughes 369D helicopter

B. SUMMARY

B.1. The accident

On July 9, 2023, at 1027 eastern daylight time, a Hughes 369D helicopter, N5027P, was substantially damaged when it was involved in an accident near Waldorf, Maryland. The commercial pilot and two observer crewmembers sustained minor injuries. The helicopter was operated by Haverfield Aviation, Inc. as a Title 14 *Code of Federal Regulations* Part 91 powerline inspection flight.

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 by a camera installed on a residential building.

C. DETAILS OF THE INVESTIGATION

Videos recorded by four cameras installed on a residential building were available. The sound streams recorded by the four cameras had equivalent information. One of the cameras provided the best view of the helicopter and was used in the analysis below. The analyzed video had 2688×1512 resolution and frame rate of 30 frames per second. It recorded sound at the rate of 16,000 samples per second. The helicopter became visible in the video 4.3 seconds before its tail touched the ground as it was crash-landing. It remained visible for 1.3 seconds after which it became obscured by a residential building. The helicopter became visible again 1.6 seconds before its tail touched the ground.

Figure 1 shows an aerial view of the accident area. The camera location and the location of the ground impact are marked in the figure. The yellow markers are at the locations recorded by ADS-B. The yellow lines connect adjacent ADS-B locations. The times when the helicopter was at the marked location are shown as time past 10 AM in MM:SS format. The MM:SS time format is also used throughout the text below. Under each time in Figure 1 is the speed computed as the average speed in the segment between the previous marker and the marker at which the speed is specified. The

specified speeds are the magnitudes of the 3D speed vectors and include contributions from the vertical speeds.

The times and the speeds are shown in yellow except for the time and speed at the last location that are shown in white. It is so because the last point is not based on ADS-B. The next ADS-B data past time 26:36 is at time 26:51. Analysis of the visual and sound information in the video and of the ADS-B data indicated that the helicopter crash-landed before time 26:51. The actual time of ground contact was estimated as 26:44 and the average speed of the helicopter between time 26:36 and time 26:44 was estimated as 36 knots.

The ADS-B data and the videos were not time-synchronized. The ADS-B time was considered to be the correct time and, therefore, the video time was shifted to coincide with the ADS-B time. The video time when the helicopter tail section first contacted the ground can be detected by stepping through the video frame-by-frame. The video time was shifted so that the detected time of ground contact became 26:44, the time of ground contact estimated above. The accuracy of this time synchronization was estimated as ± 2 seconds.

Figure 2 is a spectrogram display of the sound recorded by the camera. It is a color-coded plot of 59 spectra computed with the FFT (Fast Fourier Transform) algorithm. The algorithm used 16,384-point windows, resulting in windows that were 1.024 seconds wide and in a frequency resolution of 59 cpm (cycles per minute). The window starting times advanced by 0.5 seconds between time 26:20 and time 26:50. The color bar in the figure specifies the color-coding of the intensity of the spectra. Dark blue is the lowest intensity, and dark red is the highest intensity.

The rotational speed of the main rotor at the 103% N_2 (the speed of the engine power turbine) operating condition is 492 rpm. The main rotor has five blades so that its nominal BPF (blade passage frequency) is $5 \times 492 = 2460$ blades/minute. The second and third harmonic frequencies of the main rotor BPF at that engine speed are $2 \times 2460 = 4920$ cpm and $3 \times 2460 = 7380$ cpm, respectively.

The rotational speed of the tail rotor at 103% N_2 is $5.965 \times 492 = 2935$ rpm where 5.965 is the tail rotor gear ratio. The tail rotor has two blades, resulting in a nominal tail rotor BPF of $2 \times 2935 = 5870$ blades/minute. The second harmonic frequency of the tail rotor BPF is $2 \times 5870 = 11,740$ cpm.

Four measured frequencies of interest can be identified in Figure 2. The main rotor had five blades, and the figure shows the second and the third harmonics of the main rotor BPF. The tail rotor had two blades, and the figure shows its BPF and the

second harmonic of the BPF. Also marked in the figure is the second harmonic of the nominal tail rotor BPF, 11,740 cpm, corresponding to the normal operational speed of the engine at 103% N_2 (the speed of the engine power turbine).

The main rotor speed and the tail rotor speed are proportional to the rotational speed of the helicopter Rolls Royce 250-C20B engine output shaft when the helicopter is not in autorotation. When in autorotation, the main rotor speed and the tail rotor speed are related by their 5.965 gear ratio but are independent of the engine output shaft speed.

Figure 2 shows large deviations from the normal operational speeds of the rotors. The second harmonic of the tail rotor BPF is used in the analysis. At time 26:20.5 and at time 26:38.5, the second BPF harmonic is 13,359 cpm. At the normal operational speed of the engine and when not in autorotation, that frequency, marked in the figure, is 11,740 cpm. The speed of the helicopter toward the camera that could generate a frequency increase from 11,740 cpm to 13,359 cpm due to the Doppler effect is 83 knots.

Figure 1 shows that at time 26:20.5, the helicopter would probably be near the center of the line connecting the data points at time 26:13 and at time 26:28. The speed of the helicopter would be about 97 knots. However, its speed toward the camera would be its speed multiplied by the cosine of the angle between its ground track and the angle from the camera to the helicopter location, which could reduce the speed to below the required 83 knots. There is a 15 second gap in the available ADS-B data between time 26:13 and time 26:28. The uncertainty due to this time gap makes the analysis of the cause of the high recorded frequency at time 26:20.5 inconclusive. It is possible that the helicopter was not in autorotation and the high frequency was caused by the Doppler effect. However, the possibility that the helicopter was in autorotation cannot be excluded.

At time 26:28.5, the second harmonic of the tail rotor BPF in Figure 2 is 9785 cpm. At the normal operational engine speed and not in autorotation, that frequency is 11,740 cpm. The speed of the helicopter away from the camera that could generate such a frequency decrease due to the Doppler effect is 138 knots. Figure 1 shows that at time 26:28.5, the helicopter speed was below 93 knots and its ground track was not directly away from the camera. Consequently, the Doppler effect could not have caused such a low recorded frequency.

If the speed at time 26:28.5 is assumed to be 93 knots and the angle between the ground track just before time 26:28 and the line from the camera to the marker at time 26:28 is taken into account, the Doppler frequency reduction factor is about 0.90.

Therefore, the emitted frequency that was recorded as 9785 cpm was $9785/0.90=10,872$ cpm. Since this frequency was the second harmonic of the 2-bladed tail rotor BPF, the corresponding main rotor speed was $10,872/4/5.965=456$ rpm. This speed is in the 410 cpm to 523 cpm recommended power-off main rotor speed range. At the normal operational speed of the engine at 103% N_2 , the main rotor speed is 492 rpm. The estimated main rotor speed of 456 rpm indicates that the helicopter was probably in autorotation.

Figure 1 shows that at time 26:38.5, the helicopter speed would be below 47 knots and it was not flying directly toward the camera. Consequently, it would be impossible for the Doppler effect to cause the recorded second harmonic of the tail rotor BPF to be as high as the recorded 13,359 cpm.

If the speed at time 26:38.5 is assumed to be 40 knots and the angle between the ground track just past time 26:36 and the line from the camera to the assumed helicopter location at time 26:28 is taken into account, the Doppler frequency multiplication factor is about 1.054. Therefore, the emitted frequency that was recorded as 13,359 cpm was $13,359/1.054=12,675$ cpm. Since this frequency was the second harmonic of the 2-bladed tail rotor BPF, the corresponding main rotor speed was $12,675/4/5.965=531$ rpm. This speed is slightly above the 410 rpm to 523 rpm recommended power-off main rotor speed range. This main rotor speed indicates that the helicopter was probably in autorotation.

The above analysis showed that the helicopter was probably in autorotation starting at time 26:28.5. Since ground contact time was estimated above as 26:44, it is estimated that the helicopter was in autorotation for at least 15.5 seconds before it crash-landed.

D. CONCLUSIONS

The speed of the main rotor of a helicopter that crash-landed was estimated based on the sound and visual information in a video. The video was recorded by a camera installed on a residential building. It was estimated that at least for the last 15.5 seconds before it crash-landed, the helicopter was in autorotation. The estimated main rotor speed during autorotation varied in the range between 456 rpm and 531 rpm.

FIGURES

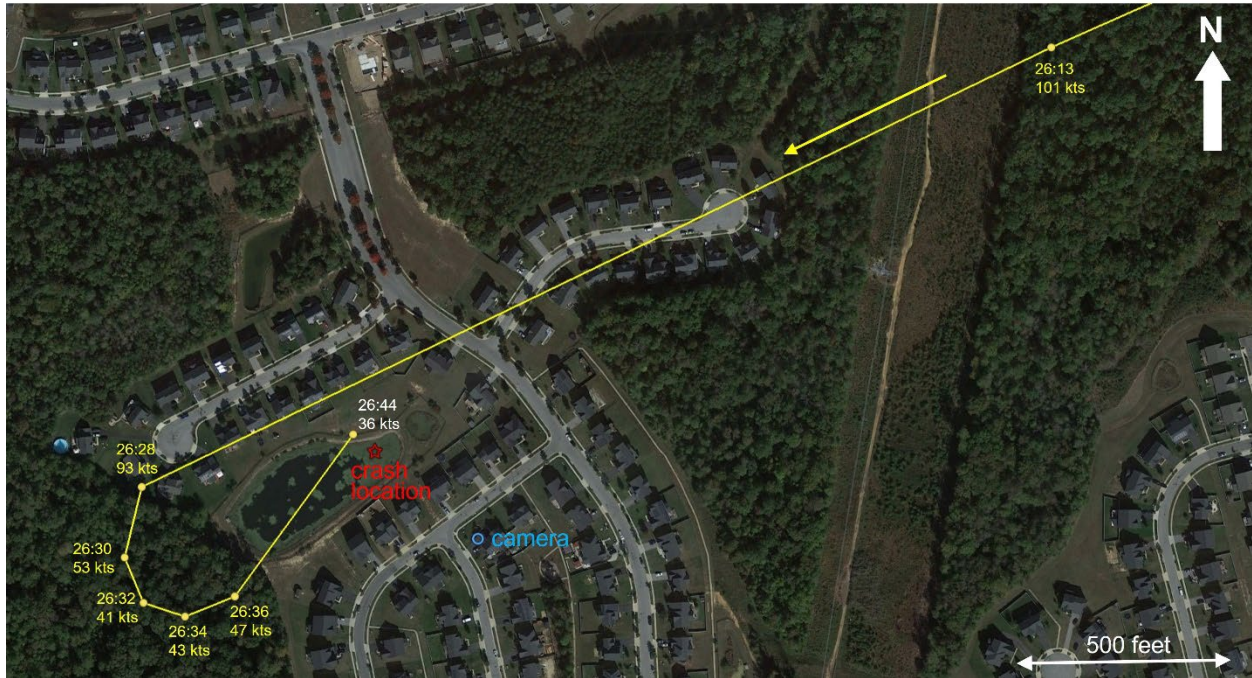


Figure 1. Aerial view of the accident area

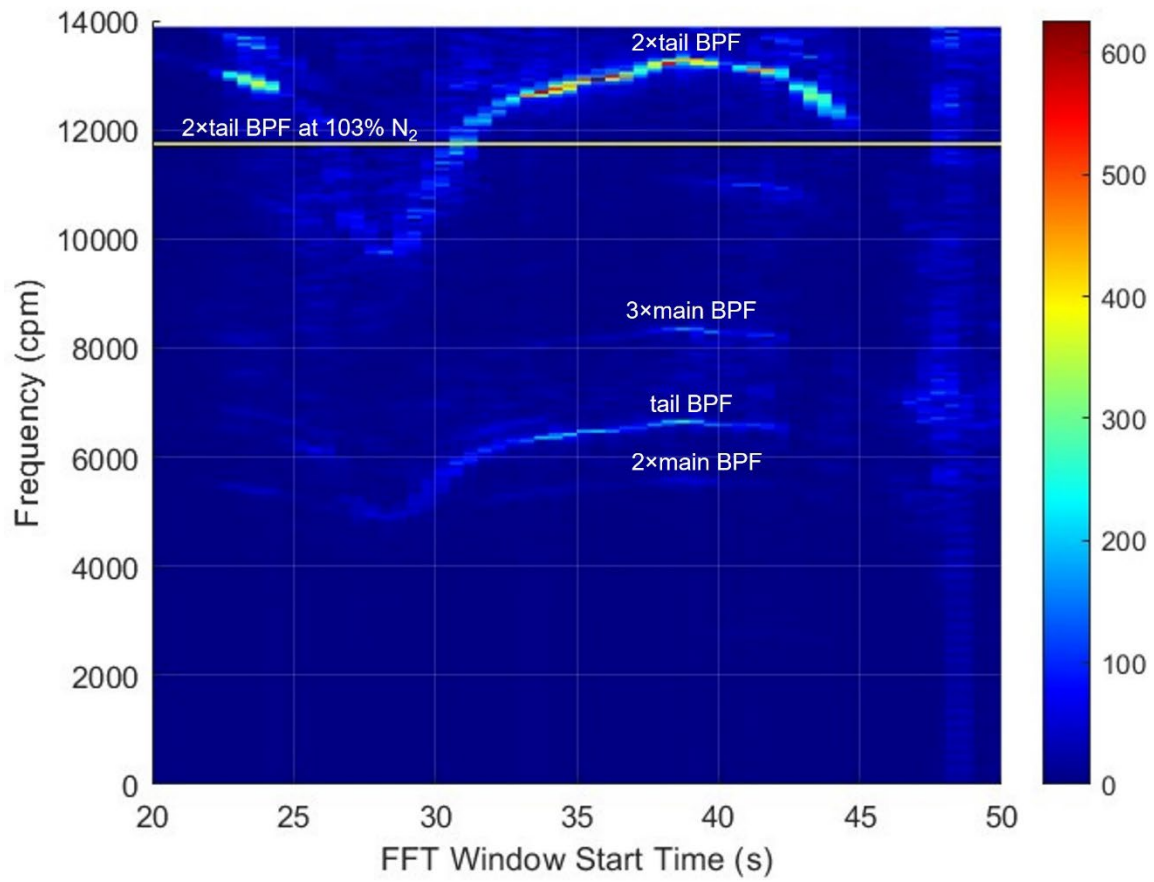


Figure 2. Spectrogram of recorded sound (time is seconds past 26:00)