

NATIONAL TRANSPORTATION SAFETY BOARD

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

March 15, 2021

Video Study

NTSB Case Number:
CEN20LA167

A. ACCIDENT

Location: Houston, Texas
Date: May 2, 2020
Time: 0203 CDT
Aircraft: MD 369E helicopter

B. AUTHOR

Dan T. Horak
NTSB

C. ACCIDENT SUMMARY

On May 2, 2020, about 0203 central daylight time, a model 369E MD helicopter, N8375F, was destroyed when it was involved in an accident near Houston, Texas. The pilot sustained serious injuries and the other flight crewmember sustained fatal injuries. The helicopter was operated as a Title 14 *Code of Federal Regulations* Part 91 public aircraft flight.

D. DETAILS OF INVESTIGATION

The goal of this study was extracting information on motion and operation of the accident helicopter from a video. The video was recorded with a phone camera by a person in a residential building on Imperial Valley Drive, about 450 feet from the crash site. Figure 1 is an aerial view of the accident area. The camera location, the crash location and the ground track during the last 33 seconds that ended at the crash time are marked on the aerial view. The ground track is based on ADS-B data. Since the ground track and altitude were known, the primary objective was estimating the yaw angle and the yaw rate of the helicopter that could provide information on the cause of this accident.



Figure 1. Aerial View of the Accident Area

Analysis of the Visual Information in the Video

The estimation of the motion of the helicopter based on the video required a calibrated mathematical model of the camera optics. The mathematical model of camera optics requires seven parameters. Three are the X, Y and Z camera location coordinates. Three are the yaw, pitch and roll camera orientation angles, and the seventh parameter is the camera horizontal field of view angle (HFOV). The X and Y coordinates of the camera and the camera height above ground, Z, could be estimated from Google Earth aerial images and Street View images. The other four camera model parameters had to be estimated as described next.

The estimation was based on references that were visible both in aerial images of the accident area and in video frames. After the crash, the camera owner aimed the camera in the direction of the crash location and the video showed trees, bushes, lane lines and curbs located on Imperial Valley Drive. These details were used for estimating the camera HFOV angle. When the camera was aimed at the airborne helicopter, the video frames did not show enough references for estimation of the camera yaw, pitch and roll orientation angles. However, the helicopter locations were available from the ADS-B data and these locations were used for estimating the camera orientation angles.

While the ADS-B latitude and longitude locations were accurate, the ADS-B altitude data had resolution of 100 feet. Therefore, the ADS_B altitude data was interpolated to generate finer resolution. Figure 2 shows the ADS_B altitude above mean sea level (msl) data and the interpolated data. The useful portion of the video lasted only 9 seconds so that only the interpolated altitude past time 35 seconds in Figure 2 was used in the analysis.

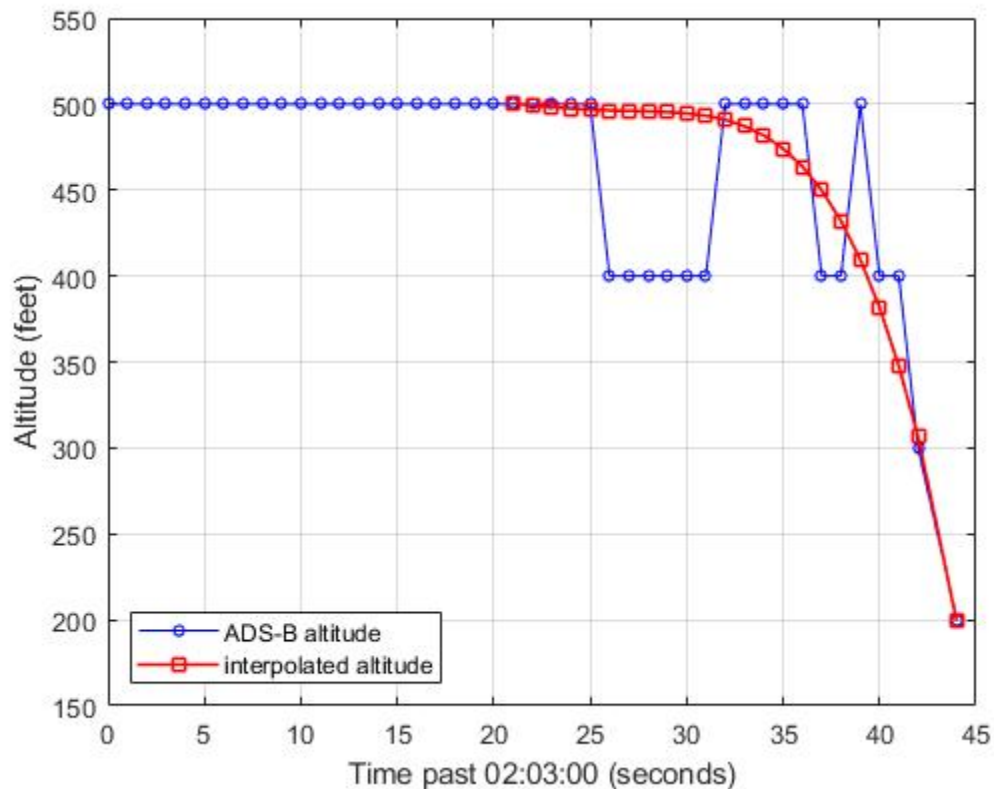


Figure 2. Helicopter Altitude Above Mean Sea Level

The analyzed video had 1280x720 resolution and frame rate of 30 frames per second. This was a nighttime accident and, consequently, only the external lights of the helicopter were visible in the video against the background of the dark sky. Figure 3 shows the locations of the external lights on the MD 369E helicopter. A model of the helicopter was constructed that consisted of the six external lights shown in Figure 3. They were the right-side green position light, the left-side red position light, the white landing/hover light, the white rear position light and the two red anti-collision strobe lights. Figure 4 is a section from a typical video frame that shows three of these external lights.

It was impossible to accurately estimate the camera roll angle, but it was possible to determine that it was within $\pm 5^\circ$ and that its effect on the estimation of the helicopter orientation angles was small. Therefore, it was assumed that the camera roll angle was zero.

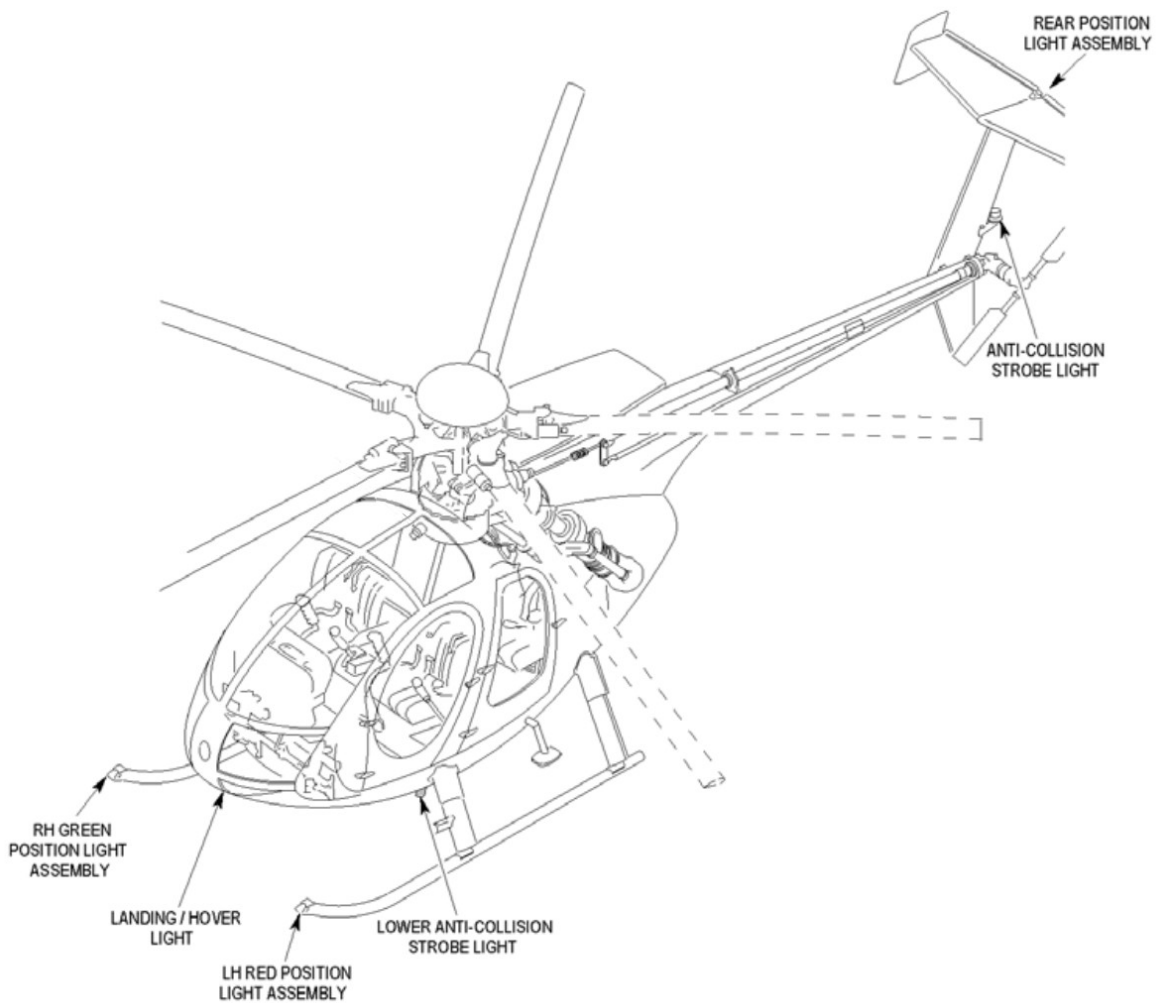


Figure 3. MD 369E External Lighting

With the ADS-B latitude and longitude data, the interpolated helicopter altitude and the camera roll set to zero, it became possible to estimate the camera yaw and pitch angles as follows. The camera optics model was used to superimpose the helicopter model on a video frame such as the one shown in Figure 4. The camera yaw and pitch angles were then varied until one of the position lights of the superimposed helicopter model coincided with the image of the corresponding helicopter light seen in the video frame. Once they coincided, the camera yaw and pitch angles were estimated. The camera pitch angle above horizontal varied from 50° when analysis started to 30° when analysis ended because the helicopter image became obstructed by the tree seen in Figure 4.

Once the camera orientation angles were estimated, it became possible to estimate the orientation angles of the helicopter. It was done by varying the yaw, pitch and roll angles of the helicopter model until it coincided with the image of the helicopter in the video frame. The alignment was based on the two or more lights that were visible in the video frame. Figure 4 shows a video frame where three lights were visible.



Figure 4. Section from Video Frame at Video Time 22.033 seconds

The longitudinal distance from the position lights that are mounted on the landing skids to the rear position light on the MD 369 helicopter is about 24 feet. This allowed for relatively accurate estimation of the yaw angle of the helicopter. The largest lateral distance between helicopter lights is the 6.45 feet that separate the red and the green position light that are on the landing skids. This relatively short distance limited the accuracy of estimating helicopter pitch and roll angles because they had a similar effect on how the lateral spacings of lights were seen in the video frames. This problem was amplified by the high pitch angle of the camera. This problem does not exist in analysis of fixed-wing aircraft because the two position lights are separated by the wingspan.

Consequently, it could only be determined that the pitch angle varied within $\pm 25^\circ$ and the roll angle varied within $\pm 40^\circ$. The exact values of the two angles at an analyzed time could not be estimated because there were more than one combination of pitch angle and roll angle that produced equally good match between the helicopter model and the helicopter image. Fortunately, the uncertainty of the pitch angle and the roll angle had only a small effect on the accuracy of the helicopter yaw angle estimate, the primary objective of this study.

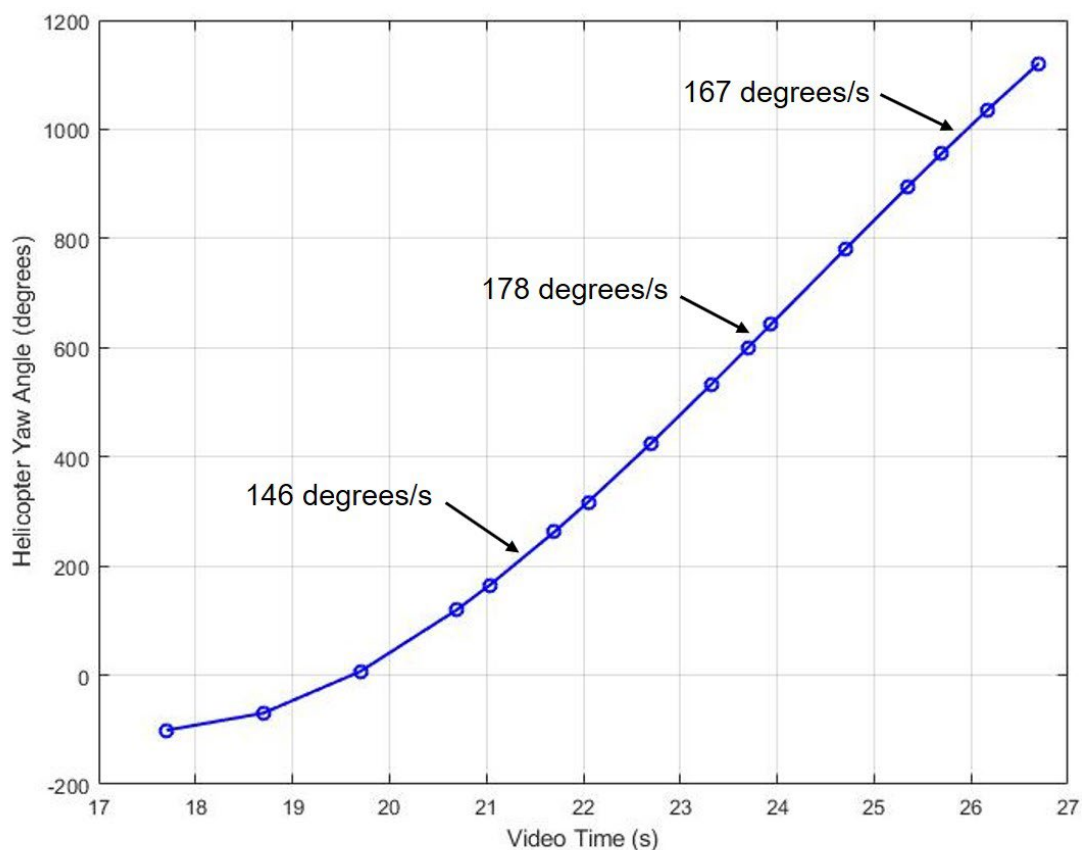


Figure 5. Estimated Helicopter Yaw Angles

Figure 5 is a plot of 16 helicopter yaw angles estimated based on 16 video frames over 9 seconds that started at video time 17.7 seconds. Past video time 27.5 seconds,

the helicopter was obstructed by the tree visible in Figure 4 and it impacted the ground about two seconds later. The yaw angles are positive in the clockwise direction when viewed from above. The yaw angles are with respect to a direction perpendicular to Imperial Valley Drive at the camera location. However, since the helicopter was spinning at a high rate during the nine analyzed seconds, the yaw angle relation to this reference direction is irrelevant because the large yaw angle of the spinning helicopter was unrelated to its relatively constant ground track angle.

Figure 5 shows the cumulative yaw angle as the helicopter was yawing clockwise. It executed 3.4 rotations (1224 degrees) about its vertical axis during the analyzed 9 seconds. The yaw rate is marked in the figure at three analysis times. A constant yaw rate fit to the raw data between video time 21.7 seconds and video time 26.7 seconds indicates that the average yaw rate during these last analyzed five seconds was 174 degrees/second.

Analysis of the Sound Information in the Video

The analyzed video contained an audio stream recorded at 44.1 kHz. Its spectral content was analyzed using the Fast Fourier Transform (FFT) algorithm. The video included two segments that recorded the airborne helicopter. The first segment lasted about 16 seconds during which the helicopter was not spinning. The segment that recorded the spinning helicopter lasted about eleven seconds, starting at video time 17 seconds. The analysis of the visual information in the video, described above, concentrated on nine of the eleven seconds when the helicopter was spinning.

There were several frequencies of interest when examining the sound spectrum. The nominal main rotor speed of the MD 369E helicopter is 490 revolutions per minute (rpm). Since the main rotor has five blades, its nominal blade passage frequency (BPF) is $BPF_{main}=2450$ cycles per minute (cpm). The nominal speed of the tail rotor is 2920 rpm. Since the tail rotor has two blades, its nominal blade passage frequency is $BPF_{tail}=5840$ cpm.

The spectrum of the sound generated by the two rotors could include the following frequencies.

BPF _{main}	2450 cpm	BPF of the main rotor
2×BPF _{main}	4900 cpm	2nd harmonic of the BPF of the main rotor
3×BPF _{main}	7350 cpm	3rd harmonic of the BPF of the main rotor
BPF _{tail}	5840 cpm	BPF of the tail rotor
2×BPF _{tail}	11680 cpm	2nd harmonic of the tail rotor BPF
3×BPF _{tail}	17520 cpm	3rd harmonic of the tail rotor BPF

Spectra were computed in 1.5-second-wide windows with a 65536-point FFT algorithm that had 40 cpm frequency resolution. Figure 6 shows spectra during the first segment of the video, when the helicopter was not spinning. Spectral peaks that could be associated with the frequencies listed above are marked in the figure. The peak at 2422 cpm corresponds to BPF_{main} and the peak at 4805 cpm corresponds to

2×BPFmain. The peak at 5733 cpm corresponds to BPFtail, the peak at 11470 cpm corresponds to 2×BPFtail and the peak at 17240 cpm corresponds to 3×BPFtail. Because of the close match between the blade passage frequencies and their harmonics and the measured frequencies, it can be concluded that during the first video segment, both the main rotor and the tail rotor were operating at their nominal operating speeds.

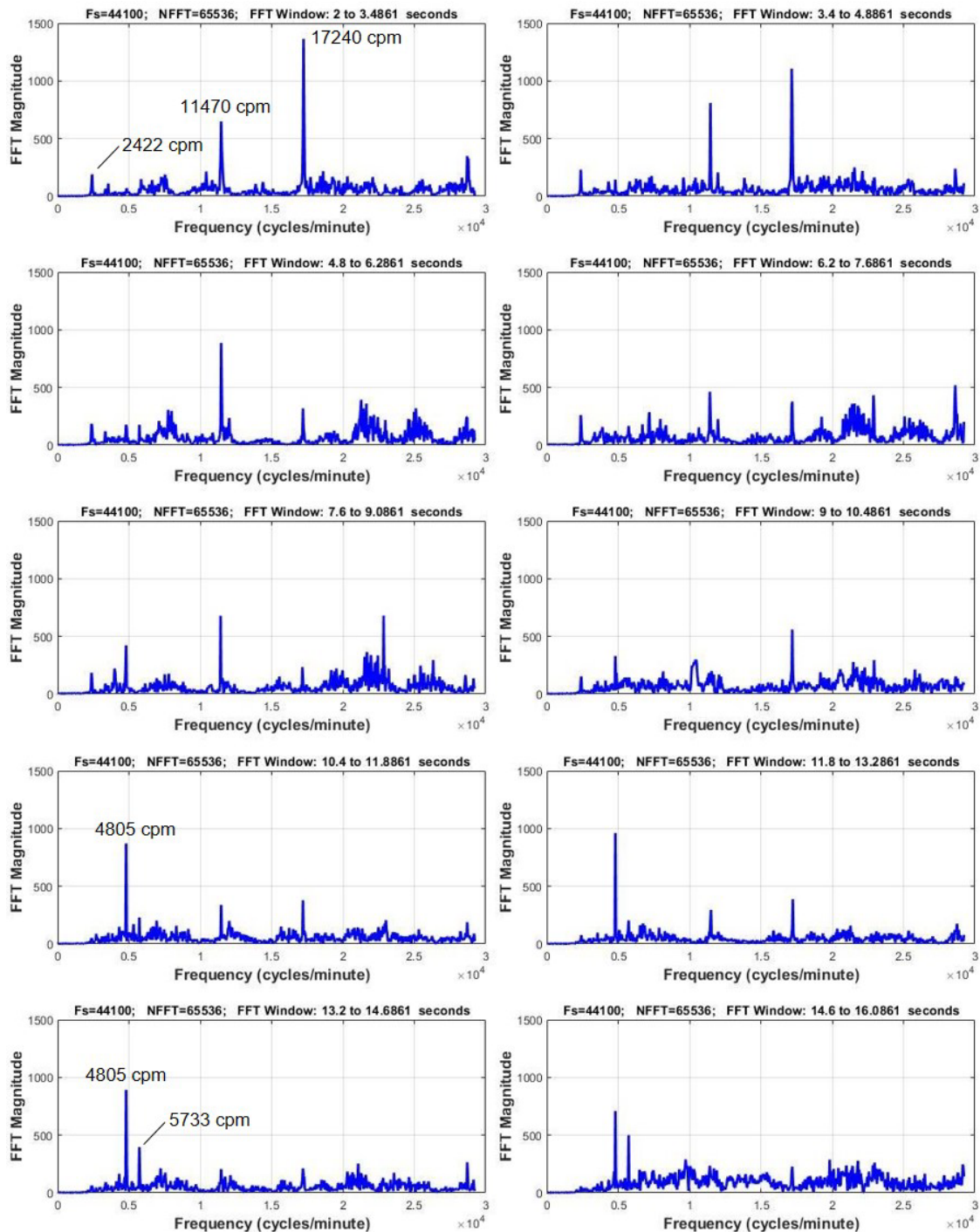


Figure 6. Sound Spectrum up to Video Time 16 seconds

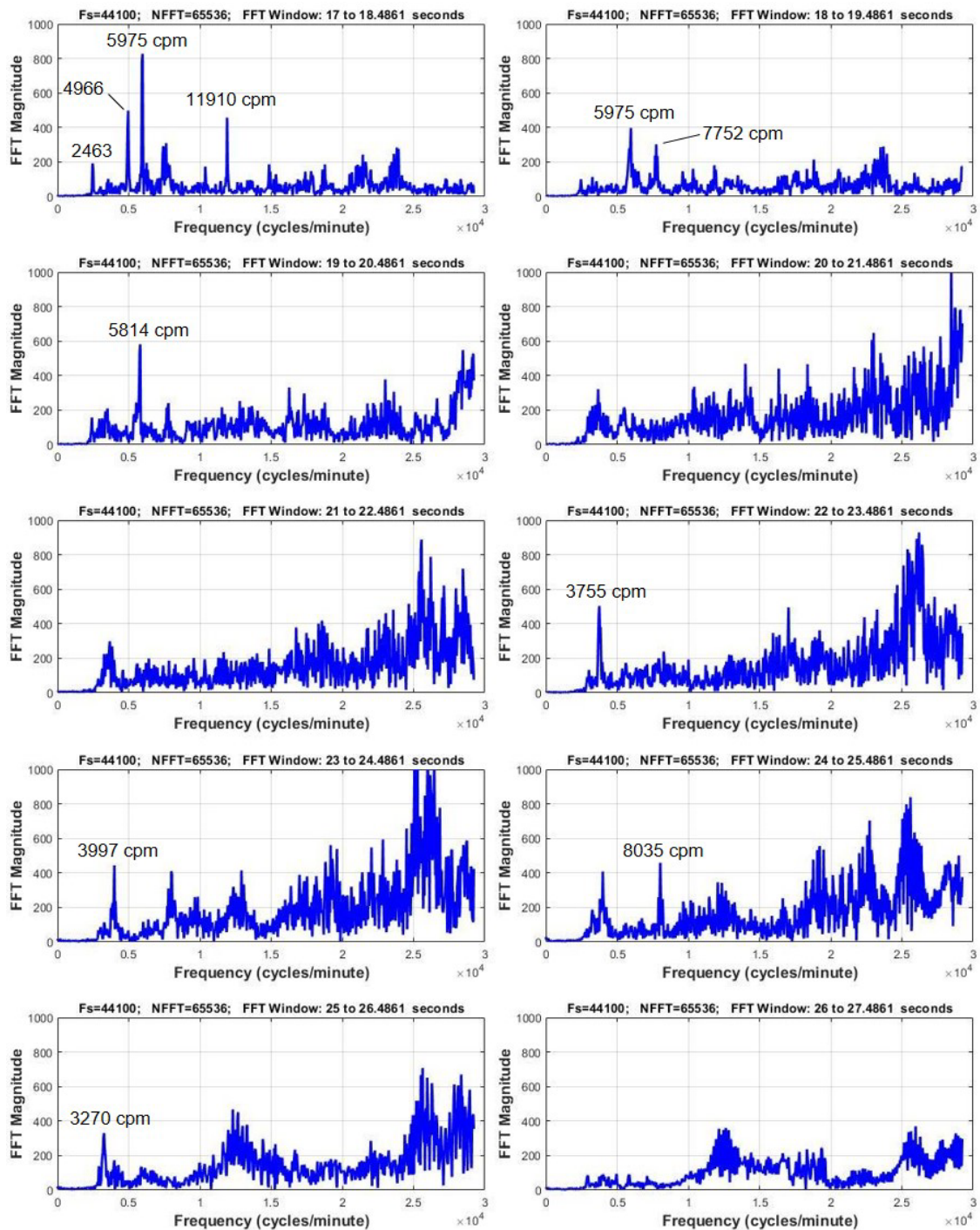


Figure 7. Sound Spectrum past Video Time 17 seconds

Figure 7 shows spectra during the second segment of the video, when the helicopter was spinning. Spectral peaks between times 17 seconds and 20.5 seconds that could be associated with the frequencies listed above are marked in the figure. The peak at 2463 cpm corresponds to BPFmain and the peak at 4966 cpm corresponds to $2 \times \text{BPFmain}$. The peak at 5975 cpm corresponds to BPFtail and the peak at 11910 cpm corresponds to $2 \times \text{BPFtail}$. These frequencies are slightly higher than the corresponding frequencies in the first video segment, pointing to slightly higher engine output shaft speed.

The spectrum in the processing window that starts at video time 18 seconds includes a peak at 7752 cpm. This peak could correspond to frequency $3 \times \text{BPFmain}$. The spectrum in the processing window that starts at video time 19 seconds includes a peak at 5814 cpm that is believed to correspond to BPFtail. This could point to decreasing engine output shaft speed that resulted in BPFtail decreasing from 5975 cpm at video time 18 seconds to 5814 cpm at video time 19 seconds.

After video time 20 seconds, about three seconds after the helicopter emerged from being covered by the roof seen in Figure 4 and two seconds before the helicopter was at the location shown in Figure 4, the characteristics of the sound spectrum changed. There were no longer spectral peaks that could be associated with blade passage frequencies due to rotors rotating at their nominal speeds.

Peaks appeared at 3755 cpm, at 3997 cpm and at its possible second harmonic at 8035 cpm, and at 3270 cpm. It is not clear what was the source of these frequencies. One possibility is that these were $2 \times \text{BPFmain}$ and/or BPFtail generated when the engine output shaft was operating significantly below its nominal speed.

Till video time 27.5 seconds, the line of sight from the camera to the helicopter was unobstructed. Only past this time a tree started obstructing the view of the helicopter. Therefore, path obstruction was not the cause of the changes in the sound spectrum past video time 20 seconds.

The spectra in Figure 7 that correspond to video times past 20 seconds show significant content at frequencies above 15000 cpm, unlike the spectra before time 20 seconds. This high-frequency content is due to the camera owner's voice. It was verified by splicing together signal segments where the owner's voice is not heard and computing the spectrum of the spliced signal. The computed spectrum showed the same spectral peaks as those marked in Figure 7 but without the high-frequency content above 15000 cpm.

E. CONCLUSIONS

Orientation angles of a helicopter that crashed were estimated based on a video recorded with a phone camera. The video indicated that the average helicopter yaw rate during the last five analyzed seconds that ended about two seconds before ground impact was 174 degrees/second in the clockwise direction.

Spectral analysis of the helicopter sound when the helicopter was not spinning at a high yaw rate detected spectral peaks at frequencies that corresponded to main rotor and tail rotor blade passage frequencies at the nominal operating speeds of the rotors. When the helicopter was spinning at a high rate, the frequencies of the spectral peaks were lower than those corresponding to the blade passage frequencies at the nominal operating speeds of the rotors.