National Transportation Safety Board
Office of Research and Engineering
Washington, DC 20594

CEN22FA331

VIDEO STUDY

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A. ACCIDENT

Location: North Fork, Idaho
Date: July 21, 2022
Time: 1642 MDT
Aircraft: CH-47D Chinook helicopter

B. SUMMARY

B.1. The accident

On July 21, 2022, at 1642 mountain daylight time (MDT), a Chinook helicopter crashed into the Salmon River while working on the Moose Fire northwest of Salmon, Idaho.

B.2. Objective and scope of the *Video Study*

The objective of this Video Study was estimating the speed of the helicopter rotors, the yaw, pitch and roll angles of the helicopter, the yaw rate of the helicopter, and the helicopter AGL altitude. The quantities were estimated with a method that used a model of the camera optics, as described below.

B.3. Summary of results

The rotors were rotating near their rated speed up to the helicopter impact with the water. The helicopter counterclockwise yaw rate was about 148 degrees/second when it impacted water.

C. DETAILS OF THE INVESTIGATION

C.1. Introduction

The analysis was based on a video that was recorded with a hand-held iPhone XR. The video had 1920x1080 resolution and a frame rate of 30 frames per second. The video lasted 38.7 seconds. The helicopter started a counterclockwise yaw rotation at about video time 13.5 seconds and its altitude started decreasing at about video time 18 seconds. It impacted the water at video time 26.2 seconds.

C.2. Estimation of helicopter angles, yaw rate and altitude

C.2.1. Camera calibration

The use of a model of camera optics for estimation of the helicopter angles, yaw rate and altitude required a set of calibrated model parameters. 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 approximate X and Y location coordinates of the camera were provided by the camera owner. The Z coordinate of the camera, its height above the surface of the Salmon River, was known approximately from Google Earth elevation data. The yaw, pitch and roll camera orientation angles and its HFOV were not known. Since the camera was hand-held, the yaw, pitch and roll angles were changing from video frame to video frame. Consequently, the accurate camera X, Y, Z coordinates and its HFOV angle had to be estimated once and the camera yaw, pitch and roll angles had to be estimated as many times as the number of analyzed video frames.

The estimation of camera model parameters is based on references that are visible both in aerial images and in video frames. The references must be objects and features that can be identified in aerial images. In this case, the available calibration references were the Salmon River shorelines and trees on both sides of the river. Figure 1 is an aerial view of the accident area. It shows the location of the camera and the location where the helicopter impacted water. The aerial view is shown rotated to approximately correspond to the images of the area as seen in video frames.

Figure 2 is a frame from the analyzed video. The frame was recorded at video time 15.7 seconds. The helicopter was already rotating at that time at a relatively low counterclockwise yaw rate of about 38 degrees/second. Its pitch angle was about 2º nose up (positive pitch) and its roll angle was about 2º left side down (negative roll).

A computer program that simulates camera optics was used to project the calibration references onto a frame from the video in an iterative process in which the seven parameters were varied so as to align the projected references with their images. When the projected references were aligned optimally with their images in the frame, values of the seven parameters were their optimal estimates. At that point, the estimated camera X, Y and Z coordinates and the HFOV angle were optimal for all the video frames that were to be analyzed.

The camera yaw, pitch and roll angles, however, were optimal only for the one specific frame that was used for calibration. These three angles had to be re-estimated for all the other video frames in a process where the camera X, Y and Z coordinates and the HFOV angle were fixed because they were already known. Since the total number of analyzed video frames was fifteen, camera calibration was performed fifteen times.

C.2.2. The estimation process

The calibrated camera optics models were then used to estimate the locations and orientations of the helicopter at times corresponding to the fifteen analyzed video frames. A wireframe model of the CH-47D Chinook helicopter was constructed, consisting of points on its nose, tail, fuselage, tires and rotor hubs. An analysis program that used the calibrated camera models was then used to project the wireframe model onto a video frame. The wireframe model was moved and rotated until it matched optimally the image of the helicopter in the video frame. When optimal match was reached, the location coordinates (X, Y and Z) of the wireframe model and its orientation angles (yaw, pitch and roll) were the optimal estimates of the location and orientation of the accident helicopter at the time when the analyzed video frame was recorded.

Figure 3 shows the estimated yaw angle of the helicopter. The markers are the raw data points and the curve is a second-order polynomial fit to the raw data. The angle is zero when the helicopter nose points to the north. The negative yaw angles in the figure mean that the helicopter was yawing counterclockwise in top view. The yaw angle starts at about +90º and ends at about -840º at time 26.2 seconds when the helicopter contacted the water. This yaw angle range corresponds to about 2 ½ counterclockwise rotations.

Figure 4 shows the estimated helicopter yaw rate. It was derived by differentiating the second-order polynomial fit from Figure 3. Figure 4 shows that the magnitude of the negative (i.e., counterclockwise) yaw rate is increasing. At the time of water contact, the estimated yaw rate was about -148 degrees/second.

Figure 5 shows the estimated pitch angle of the helicopter. Pitch angle was defined as zero when all four tires are on a horizontal surface. Positive pitch angle corresponds to a nose-up orientation. Figure 6 shows the estimated roll angle of the helicopter. Positive roll angle corresponds to a right side down orientation.

Figure 5 and Figure 6 show that the pitch angle and the roll angle reach their maximum negative values at about time 19.2 seconds. Figure 7 shows the helicopter at that time. Its pitch angle is about -11º and its roll angle is about -22º. Figure 5 and Figure 6 also show that just before water contact, when the yaw rate is high, both the pitch angle and the roll angle reach high positive values.

Figure 8 shows the estimated AGL altitude of the helicopter. AGL was set to zero at the elevation of the water in the Salmon River. The altitude of the helicopter was defined as the altitude of its nose above water.

C.3. Estimation of rotor speeds

The rated speed of the helicopter two rotors is 225 rpm. The rotors have three blades so that the rotor blade passing frequency of each rotor is 225×3=675 blades/minute or 11.25 blades/second. Since the frame rate of the video was 30 frames/second, the blades per frame rate was 11.25/30=0.375 blades/frame. Therefore, every three video frames each one of the three rotor blades should rotate 0.375×3=1.125 revolutions with respect to the helicopter fuselage, which translates to 405º or one full revolution and 45 additional degrees.

Because of the angular orientation of the helicopter with respect to the camera, it was not possible to accurately estimate the rotational speeds of the helicopter rotors based on the orientation of the rotor blades relative to the fuselage. However, it was possible to determine at some video times that a helicopter blade rotated somewhat beyond one full rotation every three video frames.

For example, the clockwise-rotating rear rotor rotated about 405° every three video frames at time 12.1 seconds, before the helicopter started yawing. It also rotated about 405° over three frames at time 20.1 seconds, when the helicopter was already yawing, and it rotated about 405° over three frames at time 26.2 seconds, when the helicopter was contacting the water.

The counterclockwise-rotating front rotor was also rotating near the rated speed. It is seen in the video rotating about 405° over three frames at time 21.8 second, when the helicopter was already yawing, and also at time 25.4 seconds, about 0.8 seconds before water impact. This visual-information-based analysis showed that the rotors were rotating approximately at the rated speed up to the time of water impact.

The rotor speeds were also estimated via spectrum analysis of the sound stream in the video. The camera recorded sound at the rate of 44,100 samples/second. A 65536-point Fast Fourier Transform (FFT) algorithm was used to compute the spectrum, resulting in time windows that were 1.4861 seconds wide and a frequency resolution of 40 cpm (cycles/minute). Figure 9 shows the computed spectra in time windows starting from video time 7 seconds to video time 23.5 seconds. The spectral peaks that are clearly seen up to the analysis window starting time of 14.5 seconds are separated by 686 cpm, indicating a rotor speed of 686/3=229 rpm. Autocorrelation analysis of the spectra detected a significant presence of spectral peaks spaced by 686 cpm up to the window starting time of 19 seconds.

Past time 21 seconds, spectral peaks separated by constant frequencies were not significant. It is estimated that when the helicopter yaw rate was relatively low and the descent rate was low, the wakes of the two rotors combined in a fashion that caused the acoustic pressure field at the camera location to include evenly-spaced spectral components. As the yaw rate and the descent rate of the helicopter increased, the pressure field became much less structured and the evenly-spaced spectral peaks were no longer visible.

The absence of the evenly-spaced spectral peaks does not indicate that the speed of the rotors changed from the estimated 229 rpm past time 21 seconds. As the analysis based on the visual information in the video indicated, the speed remained approximately constant up to the time of water impact

D. CONCLUSIONS

The yaw, pitch and roll angles, the yaw rate, and the AGL altitude of a helicopter that crashed into a river were estimated based on the visual information in a video recorded with a hand-held camera. The estimated counterclockwise yaw rate of the helicopter at the time it impacted the water was 148 degrees/second. The rotor speeds of the helicopter were estimated based on the visual information and the sound in the video. The rotor speeds were found to be close to the rated speed of 225 rpm up to the time of water impact.

FIGURES

Figure 1. Aerial View of the Accident Area

Figure 2. Video Frame Recorded at Time 15.7 seconds

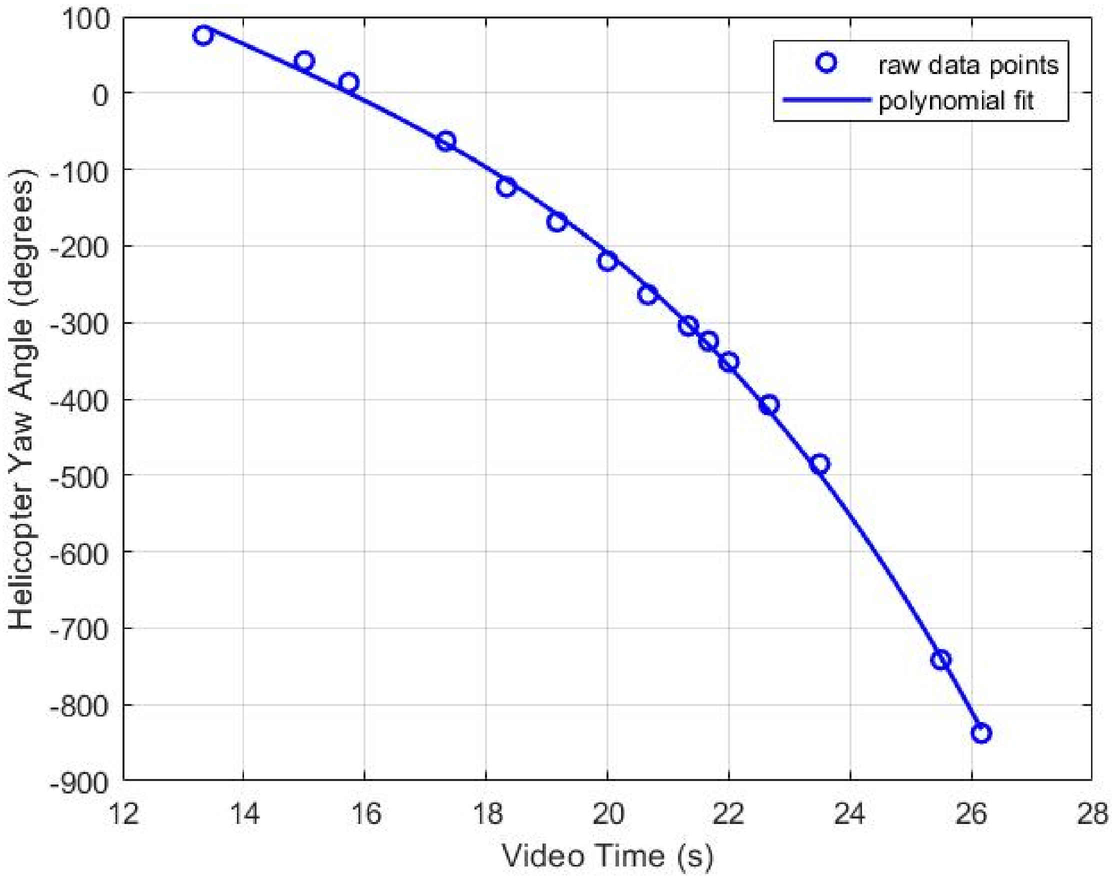

Figure 3. Estimated Helicopter Yaw Angle

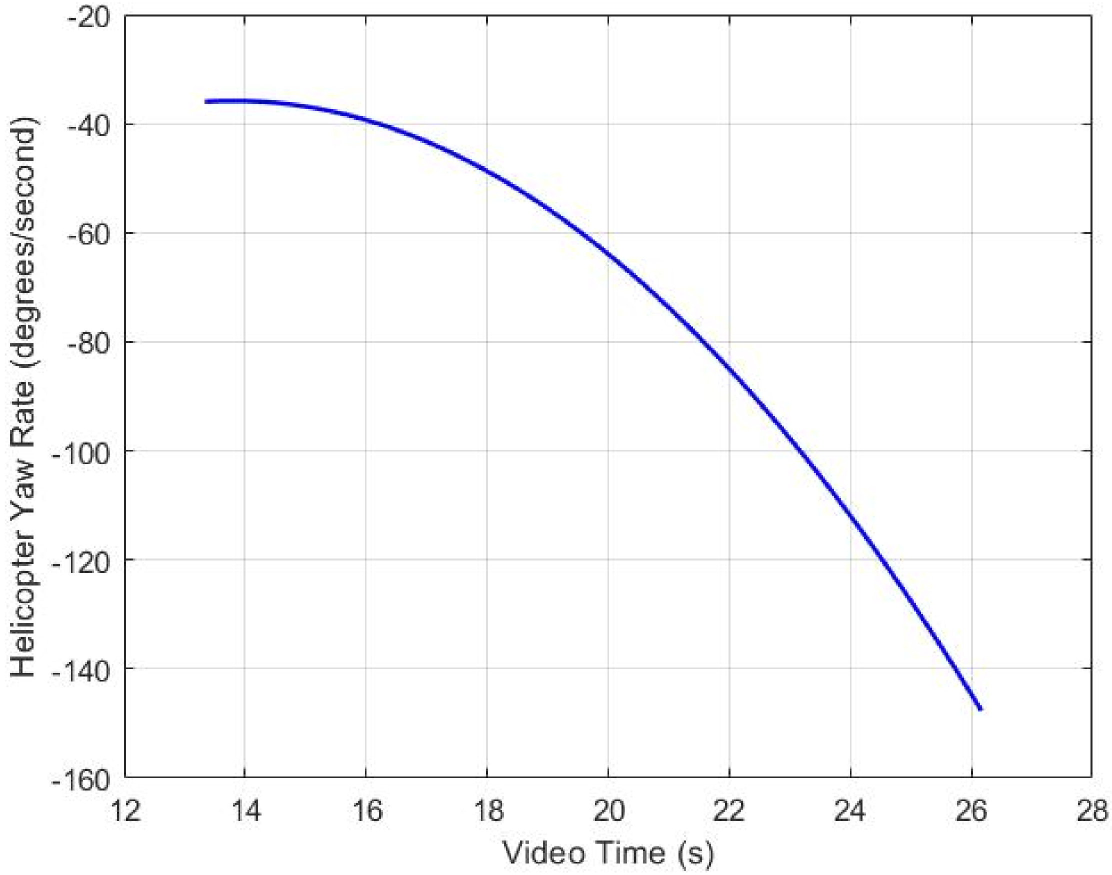

Figure 4. Estimated Helicopter Yaw Rate

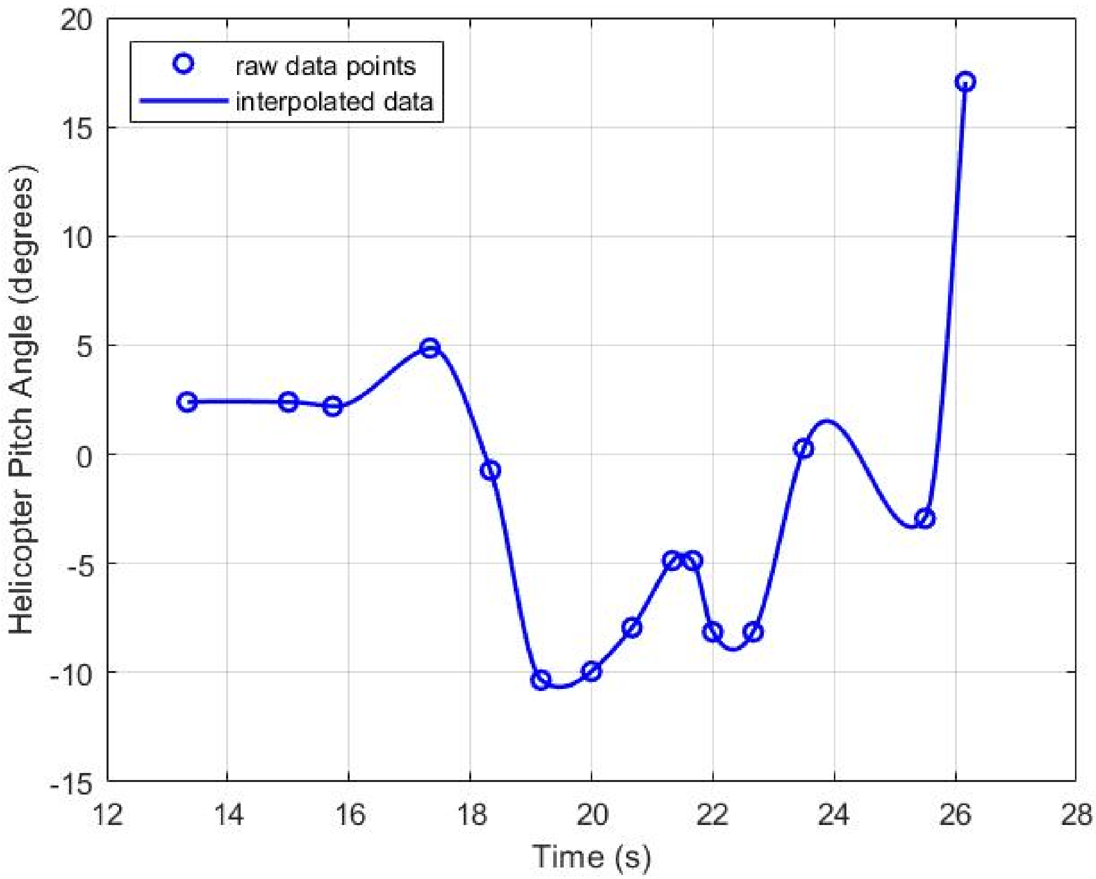

Figure 5. Estimated Helicopter Pitch Angle (positive is nose up)

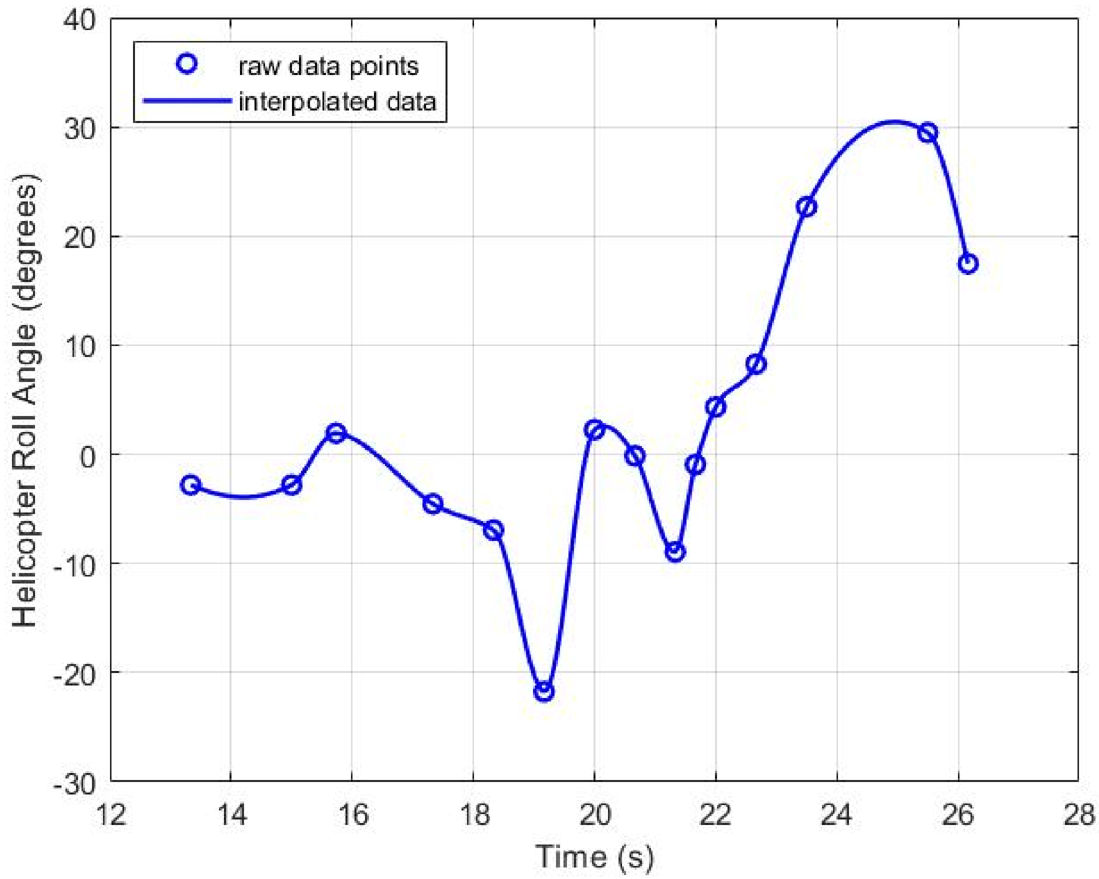

Figure 6. Estimated Helicopter Roll Angle (positive is right side down)

Figure 7. Video Frame Recorded at Time 19.2 seconds

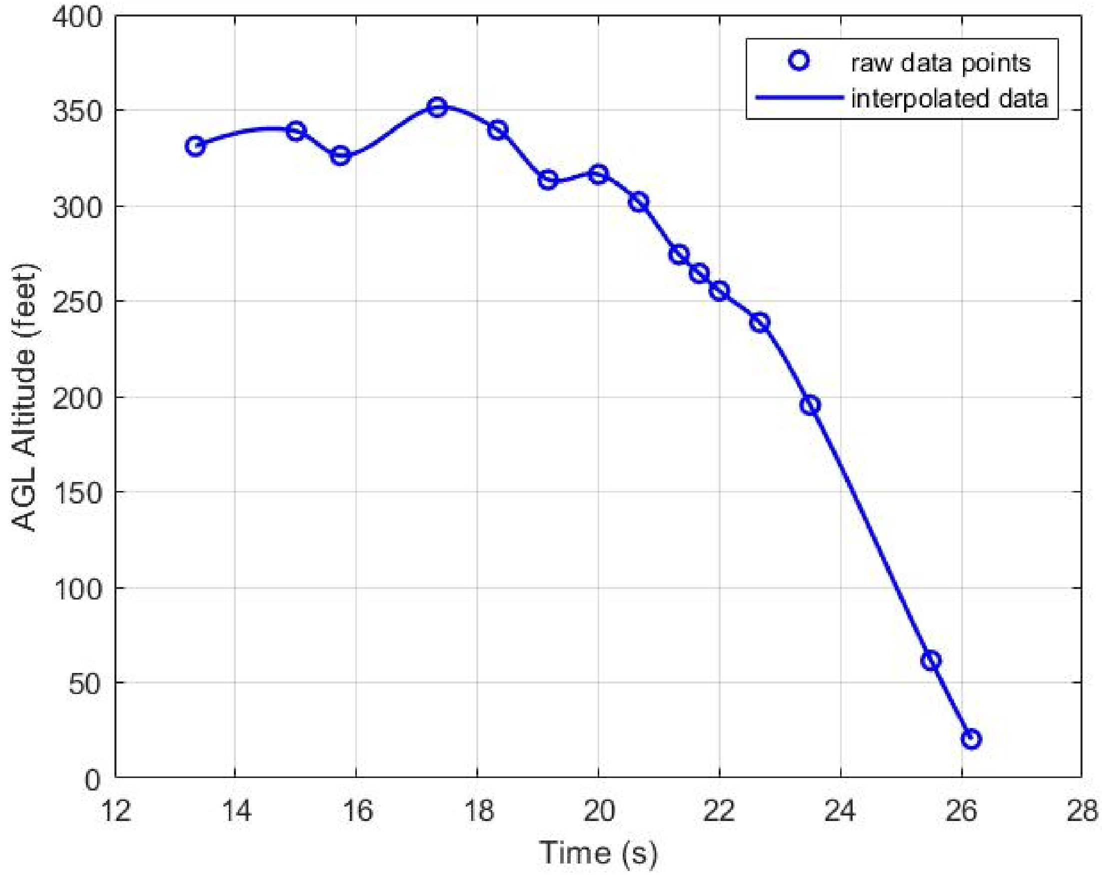

Figure 8. Estimated Helicopter AGL Altitude

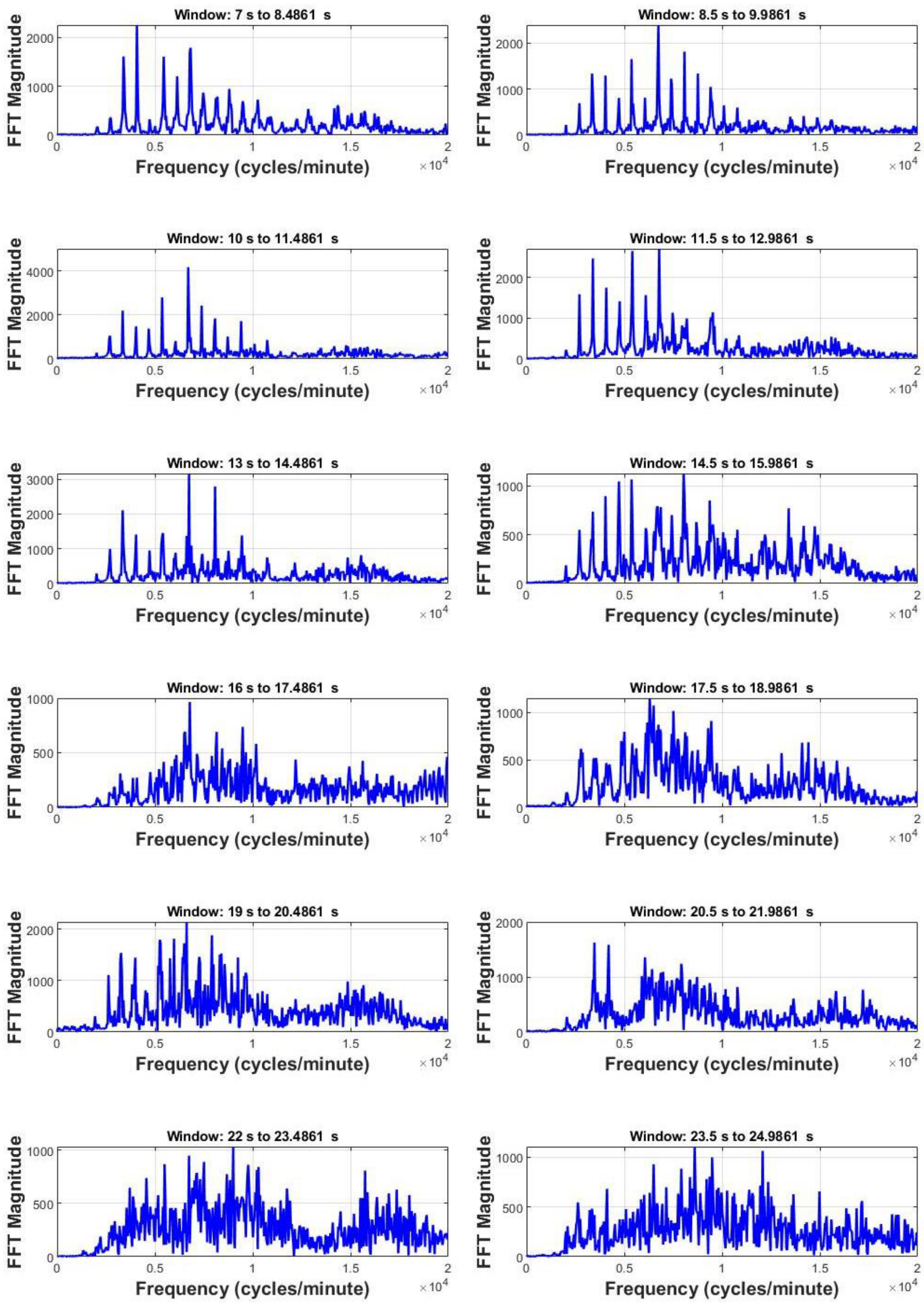

Figure 9. Helicopter Sound Spectra