

NATIONAL TRANSPORTATION SAFETY BOARD

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

July 31, 2020

Video Study

**NTSB Case Number:
WPR20LA157**

A. ACCIDENT

Location: Valley Center, California
Date: May 31, 2020
Time: 1757 PDT
Aircraft: Cub Crafters CCK-1865

B. AUTHOR

Dan T. Horak
NTSB

C. ACCIDENT SUMMARY

On May 31, 2020 at 1757 Pacific daylight time, an experimental Cub Crafters CCK-1865, N303KP, was substantially damaged when it was involved in an accident near Valley Center, California. The pilot sustained fatal injuries and the passenger was seriously injured. The airplane was operated as a Title 14 Code of Federal Regulations Part 91 personal flight.

D. DETAILS OF INVESTIGATION

The goal of this investigation was estimating the airplane speed, orientation angles and engine speed based on videos recorded by viewers on the ground. Two videos were used in the analysis. The locations of the two cameras are shown in Figure 1 that displays an aerial view of the accident area. The figure also shows the crash location and the ground track of the airplane during the last 84 seconds before ground impact. The ground track in Figure 1 was based on available ADS-B data.



Figure 1. Aerial Image of the Accident Area

The estimation of the speed and orientation angles of the airplane based on a video required a calibrated model of the optics of the camera that recorded the video. Such a model must be calibrated against references on the ground. Only the Camera

No. 1 video showed ground references. Therefore, this camera was used for estimating the speed and orientation angles of the airplane. This camera was located about 2800 feet from the crash location. The video lasted about 61 seconds, its resolution was 1920x1080, and the frame rate was 30 fps. The airplane impacted the ground at about time 57 seconds into the video.

Camera No. 2 was located about 160 feet from the crash location. It was pointed up at the airborne airplane most of the time and did not record ground references that could be used for the calibration of a camera optics model. However, because of its proximity to the airplane, it recorded clear propeller and engine sound that was used for estimating the speed of the airplane engine. The video lasted about 91.5 seconds, its resolution was 1920x1080, and the frame rate was 30 fps. The airplane impacted the ground at about time 91.5 seconds into the video. The sound in the video was recorded at the rate of 48 kHz.

Camera No. 1 Calibration

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 camera owner provided the GPS location and the height above ground of the camera. 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 such as Figure 1 and in video frames such as the one in Figure 2. The primary references used for calibration were the three power line poles, P1, P2 and P3, that are marked in Figure 1 and in Figure 2. Using Google Earth aerial images and Street View, the accurate locations of the three poles and the elevations of their crossarm members could be estimated. This made it possible to estimate accurately the camera HFOV, yaw, pitch and roll angles. The buildings seen in Figures 1 and 2 were used as secondary calibration references.

A computer program that simulates camera optics was used to project the references onto a frame from the video in an iterative process in which the four 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 four parameters were their optimal estimates. At that point, the model of the camera optics was calibrated.

Estimation of Airplane Locations, Orientation Angles and Speed

The calibrated camera optics model was then used to estimate the locations of the airplane at times corresponding to analyzed video frames. A wireframe model of the Cub Crafters CCK-1865 was constructed, consisting of points on its nose, tail, wings, fuselage and landing gear. An analysis program that used the camera model 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 airplane in the video frame. When optimal match was reached, the location (X, Y and Z) and the orientation angles (yaw, pitch and roll) of the wireframe model were the optimal estimates of the location and the orientation angles of the accident airplane.



Figure 2. Frame from Camera No. 1 Video

Figure 3 illustrates the geometry and timing used in the analysis. The ADS-B data and the two videos were not time-synchronized. To synchronize them, analysis time was set to zero seconds at time of ground impact. The ADS-B data was sampled at one data point per second. The locations of the airplane at these times are marked by the blue circles in Figure 3. Data was occasionally missed for one, two or three seconds as evident in the occasional wider gaps between the markers. It was assumed that the airplane impacted the ground one second after the last ADS-B data point. The coordinates in Figure 3 were set to (0,0) at the first shown ADS-B location.

Since the ground impact times in the two analyzed videos were 57 seconds and 90.5 seconds, the starting times of these videos were at -57 seconds and -90.5 seconds, respectively. The locations of the airplane at these times are marked in Figure 3. Airplane locations and orientation angles were estimated at ten times corresponding to ten Video No. 1 frames. The first analyzed frame was recorded at time $T = -11$ seconds. The location of the airplane at that time, based on ADS-B data, is marked in Figure 3. The last frame was recorded at time -2.67 seconds. The pitch angle of the airplane at that time was about -90° .

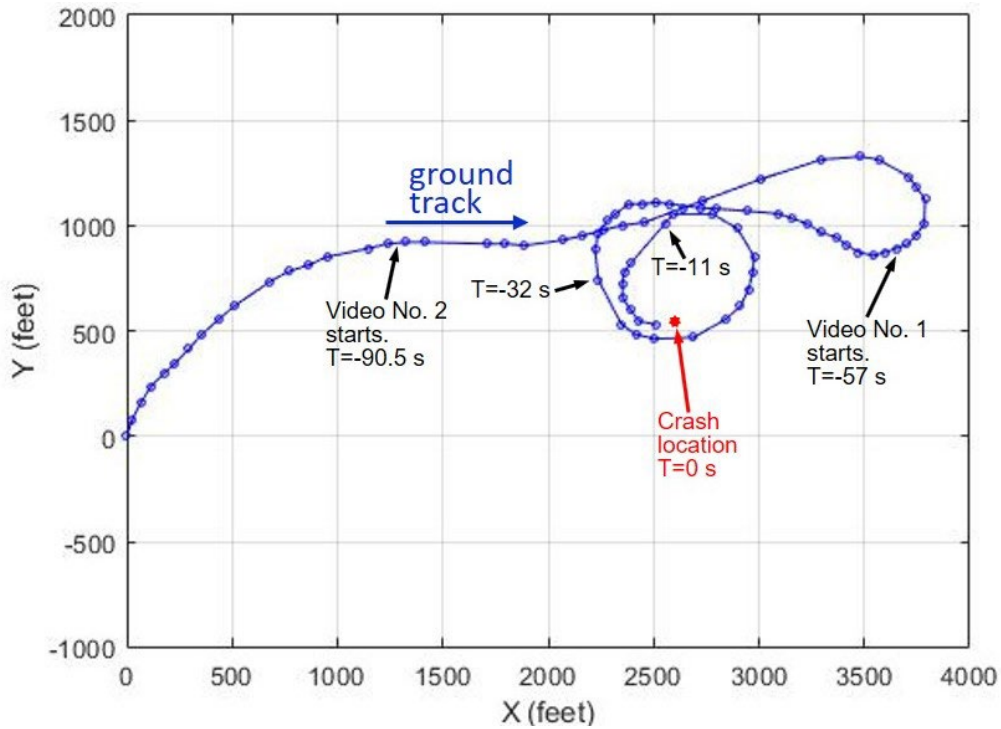


Figure 3. Geometry and Timing Used in the Analysis

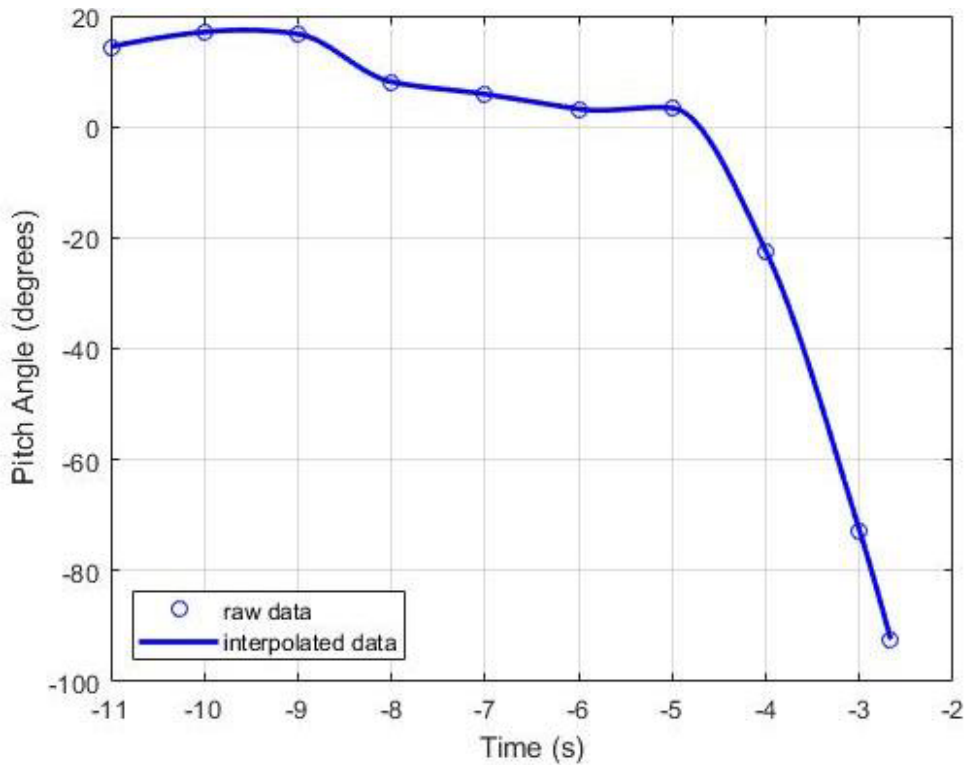


Figure 4. Estimated Pitch Angle of the Airplane

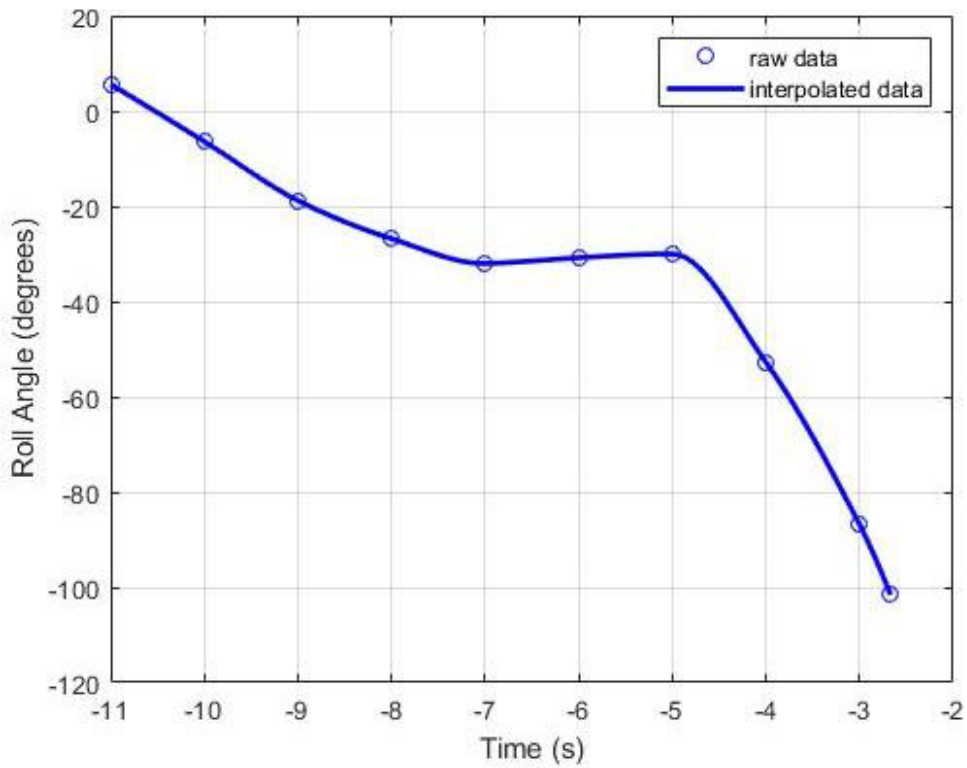


Figure 5. Estimated Roll Angle of the Airplane

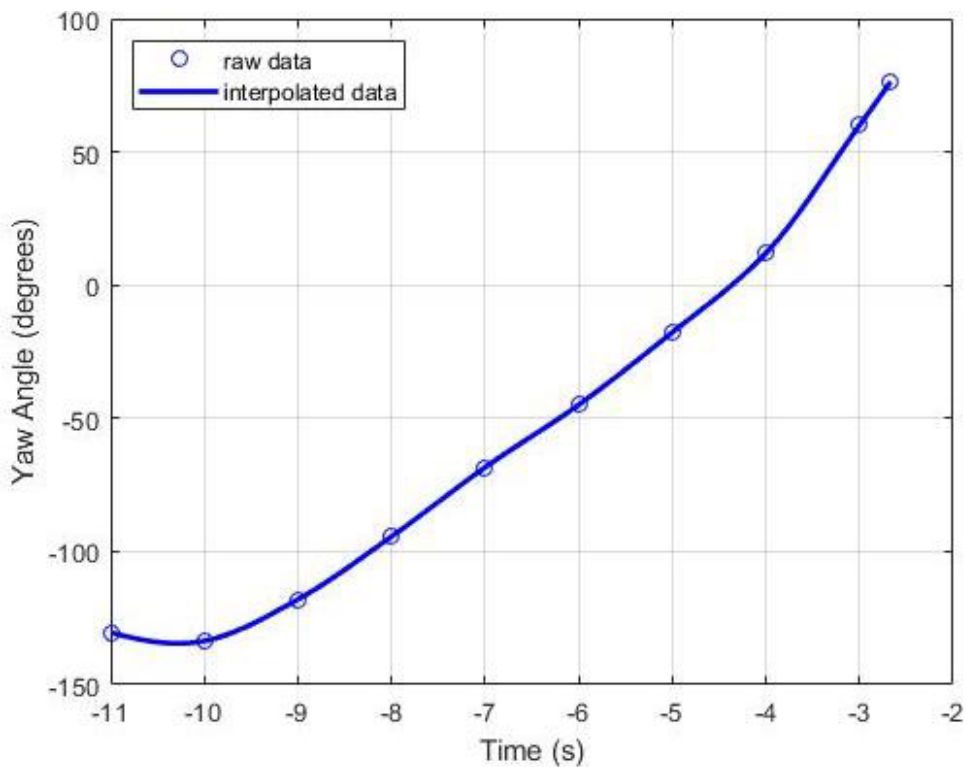


Figure 6. Estimated Yaw Angle of the Airplane

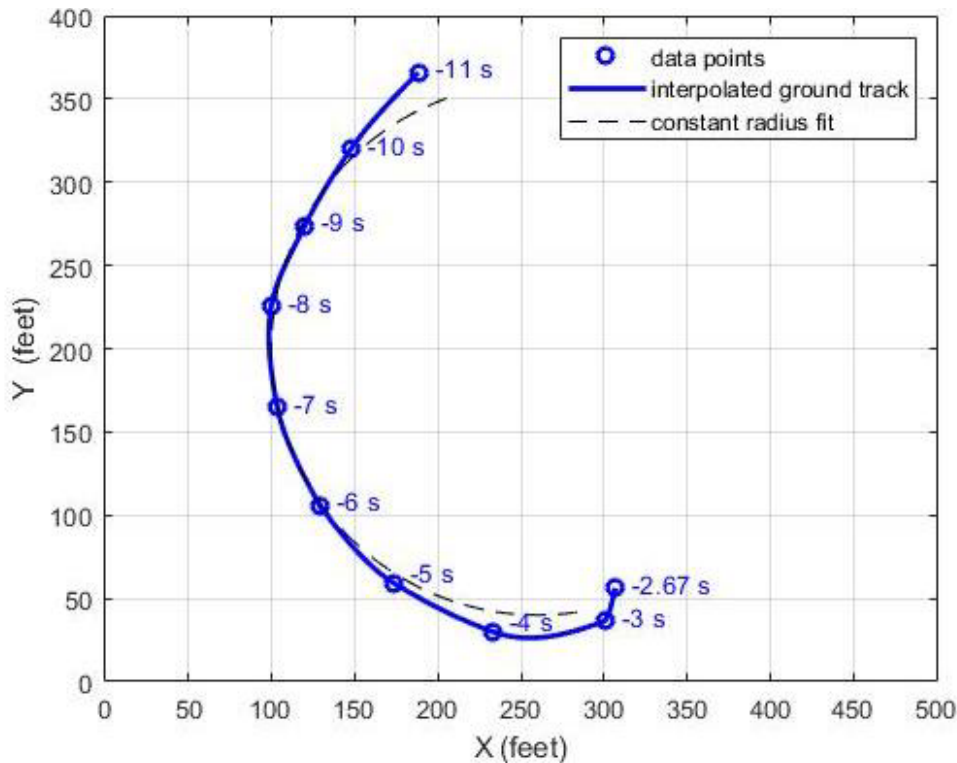


Figure 7. Estimation of Airplane Turn Radius

Figure 4 shows the estimated pitch angle during the analyzed time period. As can be seen in the figure, during the first six seconds, the pitch orientation did not indicate that a nose-down crash was imminent. Figure 5 shows the estimated airplane roll angle and Figure 6 shows the estimated airplane yaw angle.

The negative roll angle in Figure 5 indicates that the airplane was in a left turn during the analyzed time, as can be seen in the ADS-B ground track in Figure 3. The relatively constant yaw angle curve slope between time -10 seconds and -5 seconds indicates that the airplane was in a constant-radius turn. Figure 7 was used to estimate the radius of the turn. A circular arc was fitted to this segment of the video-based ground track. An arc with a 160-foot radius provided the best fit. Therefore, during these 5 seconds, the estimated radius of the turn that the airplane was executing was 160 feet.

Figure 8 displays the estimated AGL altitude of the airplane. It shows that the descent toward ground impact started at about time -7 seconds. Figure 9 shows the total speed, defined as the vector sum of the ground speed and the descent rate, and it also shows the ground speed. Only after time -4 seconds, when the airplane was already rapidly descending toward ground impact, is the total speed significantly higher than the ground speed due to the vertical speed component.

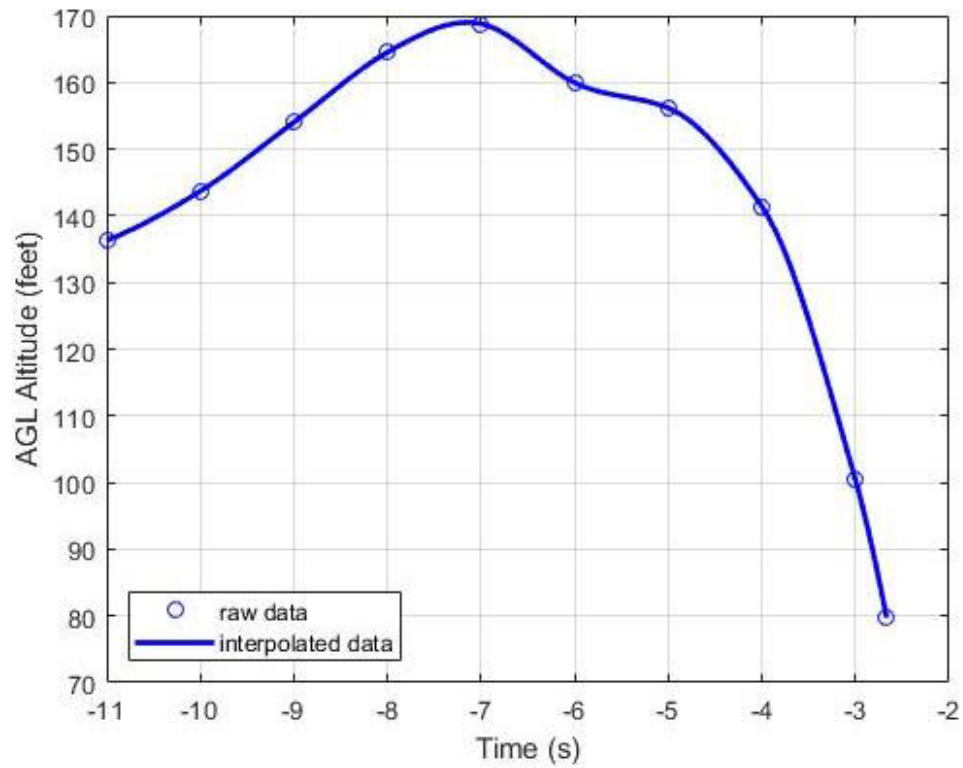


Figure 8. Estimated AGL Altitude of the Airplane

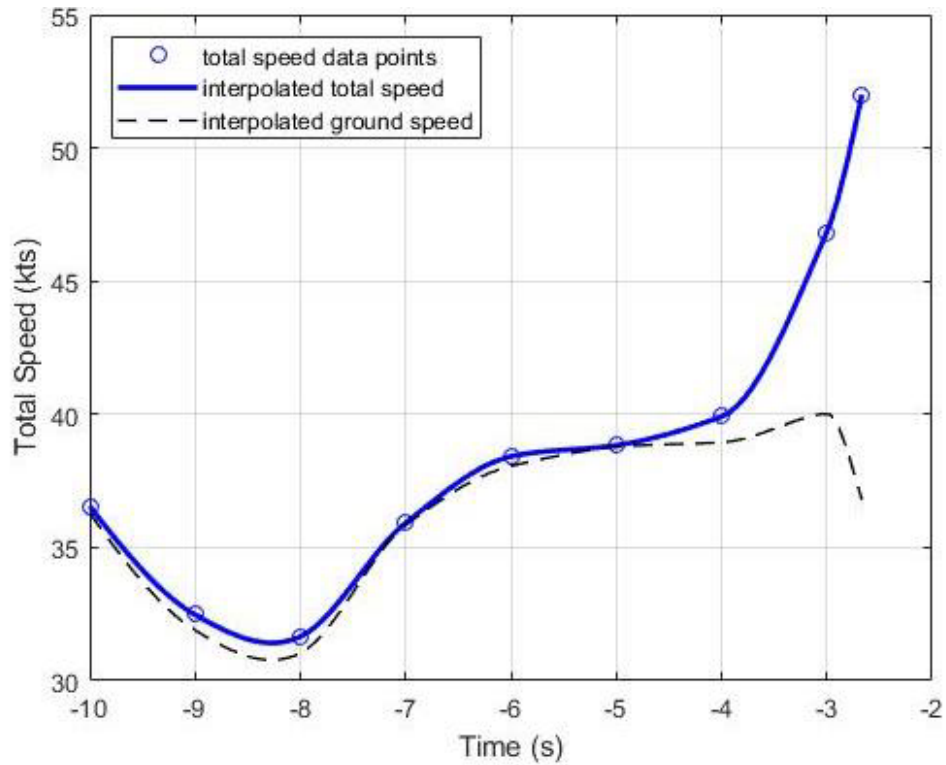


Figure 9. Estimated Total Speed and Ground Speed.

In a level turn, the stall speed increases as the roll angle of an airplane increases. Figure 10 shows the roll-adjusted stall speed of the airplane. Two curves are shown, one for assumed full-flaps, zero-roll stall speed of 32 mph (27.8 kts) and the other for no-flaps, zero-roll stall speed of 40 mph (34.8 kts). Video No. 2 shows that the flaps were deflected during the last 11 seconds of flight that ended in ground impact. The deflection angle could not be accurately estimated, but full deflection, at the third notch setting, was unlikely. Therefore, the actual stall speed is believed to be in between the two curves in Figure 10.

The stall speed curves in Figure 10 are not shown past time -4 seconds because the airplane was already starting its nose-down descent toward ground at that time. The estimated total speed curve from Figure 9 is also shown in Figure 10. It shows that near time -8 seconds, the airplane speed could have dropped below the stall speed.

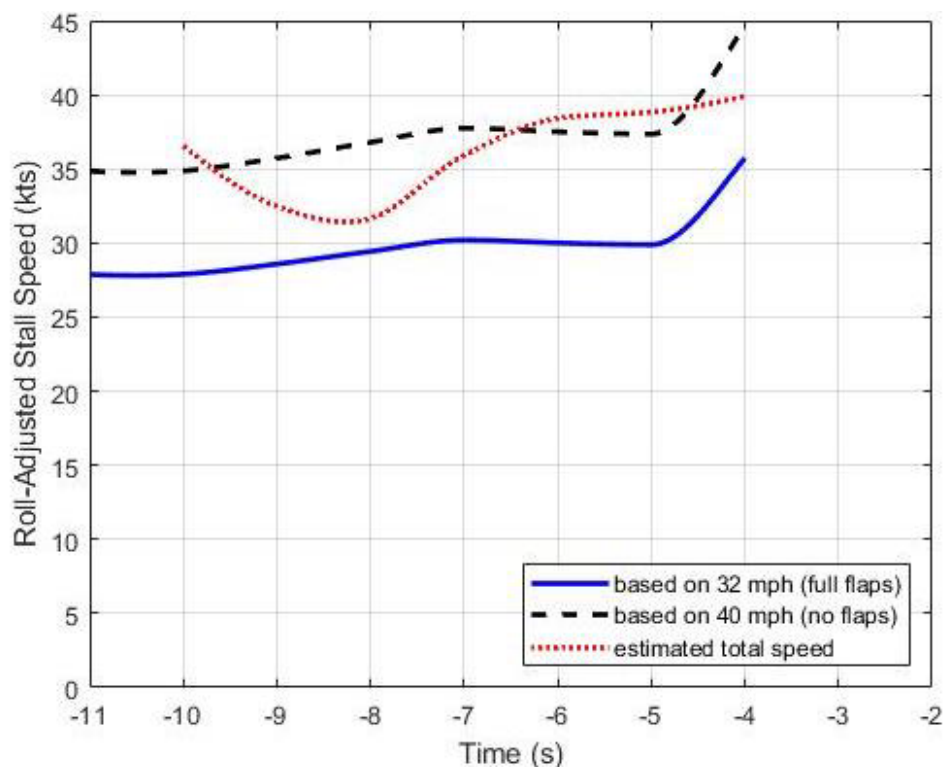


Figure 10. Roll-Adjusted Stall Speeds

Estimation of Engine Speed

Camera No. 2 was close to the airplane and recorded a clear signal of its sound. The sound was sampled at 48 kHz. The recorded signal was down-sampled to 24 kHz and the Fast Fourier Transform (FFT) algorithm was used to compute its spectrum. The FFT algorithm used 32768 points, resulting in a 1.37 second time window and frequency resolution of 44 cycles/minute (cpm).

Figure 1 and Figure 3 show that there had to be a significant Doppler effect resulting in shifting of the frequencies recorded by the camera relative to the frequencies emitted by the airplane. The ground track in Figure 3 shows that when the airplane was near $X=3750$ feet and near $X=2200$ feet, it was flying directly toward the camera, resulting in the recorded frequencies being higher than the emitted frequencies. Then, when the airplane was near $X=3000$ feet, it was flying directly away from the camera, resulting in the recorded frequencies being lower than the emitted frequencies. Shortly before ground impact, near $X=2300$ feet, the airplane was flying again directly toward the camera, resulting in the recorded frequencies being higher than the emitted frequencies.

The Doppler effect was zero only when the ground track was perpendicular to the line from the camera to the airplane. The Doppler frequency shift was removed from the recorded sound signal as follows. The speed of the airplane along the ground track was estimated by smoothing the speed curve computed across adjacent ADS-B data points. The direction of the velocity vector of the airplane was estimated by computing the slope of the ground track in Figure 3. The direction of the line from the camera to the airplane was known because the camera location was known and the ADS-B locations of the airplane were known.

With the speed and the two directions available, it was possible to compute the speed component along the line from the camera to the airplane. This was the speed causing the Doppler frequency shift. The Doppler frequency shift due to this speed was computed along the ground track and the FFT frequency axis was adjusted to offset the shift. All the airplane sound analysis described below was performed using Doppler-corrected FFT spectra.

Figure 11 shows the sound spectrum in a time window starting at time -62.5 seconds. The highest spectral peak is at 4150 cycles/minute. It is either due to the blade passage frequency of the two-bladed propeller, or it is the second harmonic of the engine 2075 rpm speed, or a combination of both. Spectral peaks at the second and the third harmonic frequencies are also clearly visible.

The Cub Crafters specifies the continuous power speed of the CC340 engine as 2100 rpm at the altitude of 2000 feet MSL. The airplane was at about 1850 feet MSL, indicating that the engine was operating at the recommended speed. However, the engine speed remained near the recommended value for only about 11 seconds. Except for the last ten seconds before ground impact, the speed estimated based on the Camera No. 2 video was below 1800 rpm. Figure 12 shows the estimated engine speeds during the 90 seconds that Camera No. 2 was recording the sound.

The red markers in Figure 12 are at times when the speed could not be estimated because the sound intensity was low and there were no clearly identifiable spectral peaks. It is believed that at these times the engine speed was low, probably below 1600 rpm. The expected blade passage frequency if the engine speed was the recommended 2100 rpm was 4200 blades/minute. The frame rate of the video was 30 fps or $30 \times 60 = 1800$

frames/minute. Therefore, there were expected $4200/1800=2.33$ blade passes per video frame. Consequently, engine speed could not be measured by counting blade passes.

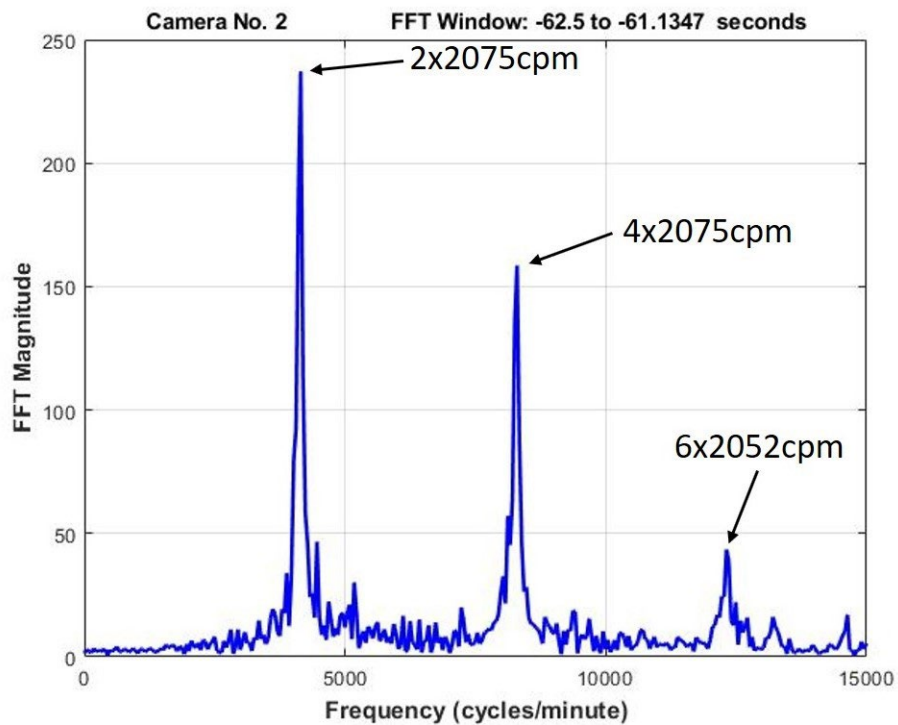


Figure 11. Sound Spectrum at Time -62.5 seconds

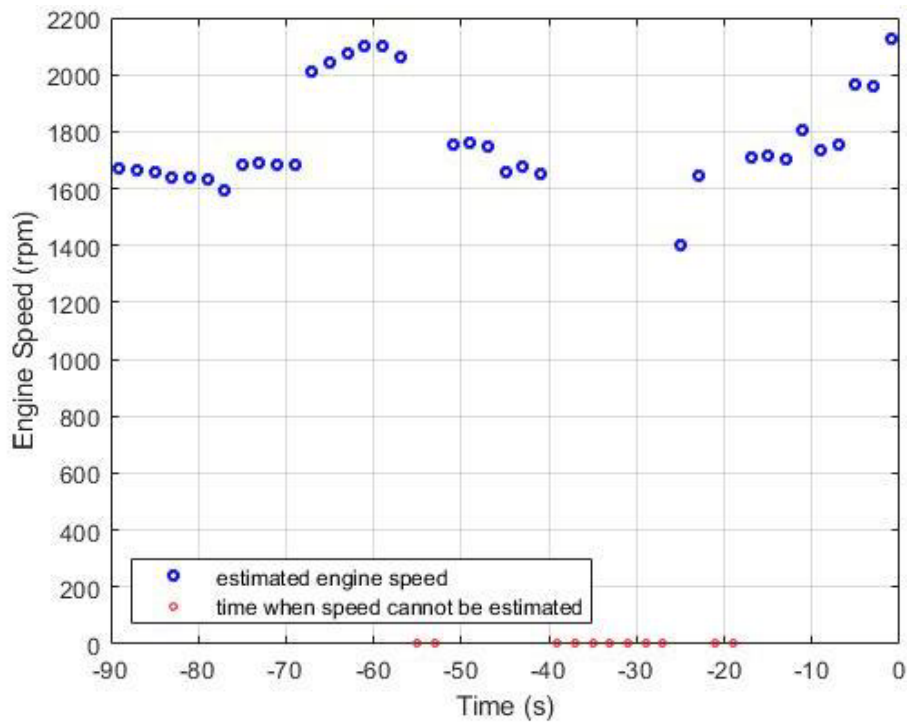


Figure 12. Estimated Engine Speed

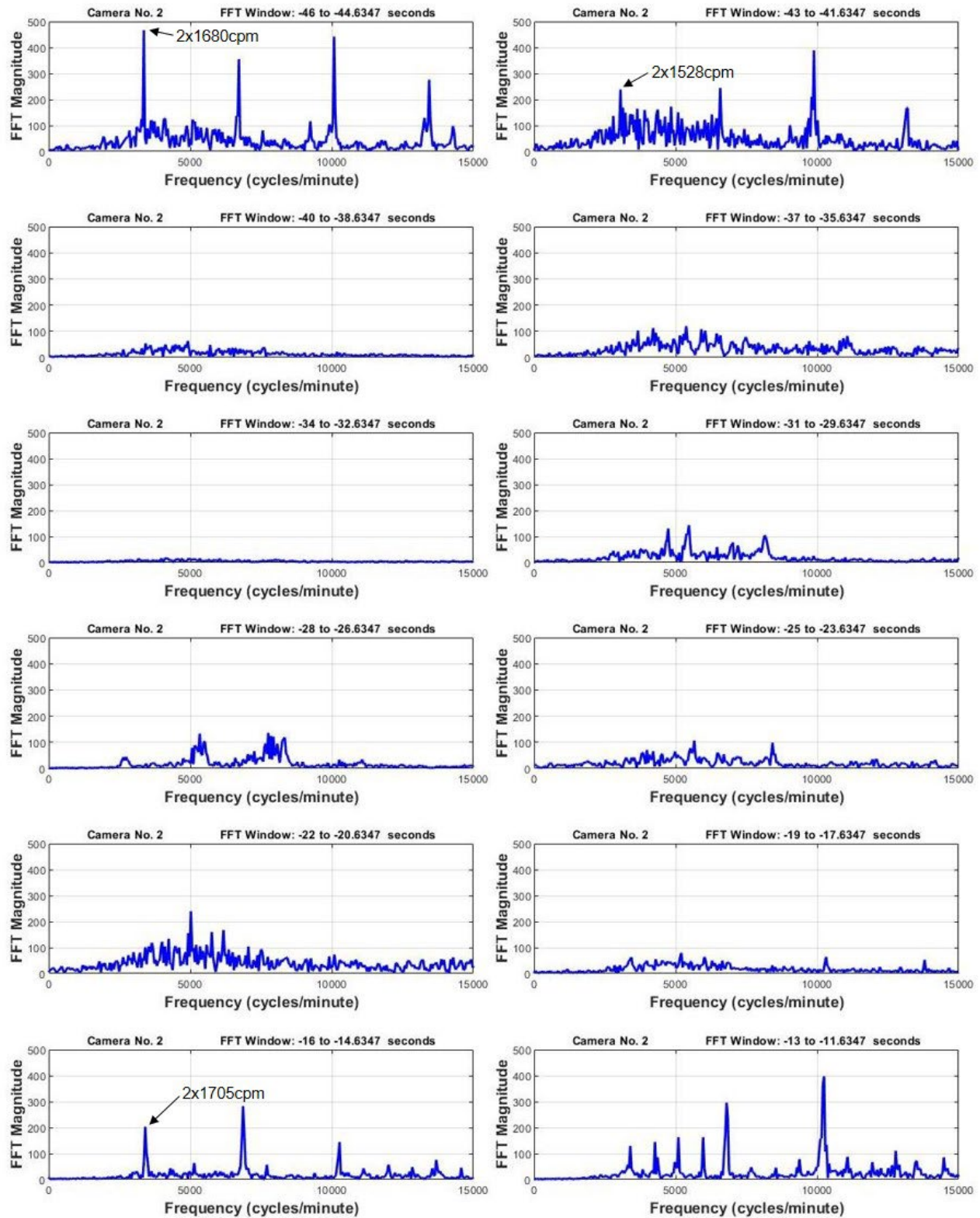


Figure 13. Sound Spectra between Time -46 seconds and Time -11 seconds

At two times in the video, near time -39 seconds and near time -32 seconds that is marked in Figure 3, the propeller blades look as if they were not moving. One possible explanation is that the engine was not rotating. However, it could not be the case because the engine was still emitting audible sound. The only other explanation is that the engine speed was near 900 rpm, resulting in a blade passage frequency of 1800 blades/minute.

Since the video frame rate was 1800 frames/minute the video recorded the propeller twice per each engine revolution which made the two-bladed propeller look as if it was not rotating. Figure 13 shows twelve sound spectra computed in time windows that started at times separated by 3 seconds. The figure covers a period of about 35 seconds that includes the two times when the propeller appears to be not spinning in the video.

The spectrum for FFT period starting at time -43 seconds and the spectrum for FFT period starting at time -16 seconds look like the spectrum in Figure 11 but the peaks are at lower frequencies. In between these times, the FFT magnitudes are low and the peaks due to the engine speed and/or the blade passage are not as obvious as those in Figure 11. The spectrum for FFT period starting at time -34 seconds is the extreme case where the engine sound is almost inaudible. It is believed that the engine speed at that time was near 900 rpm.

Birds Seen in Camera No. 2 Video

Two birds that crossed the field of view of the camera were recorded in the Camera No. 2 video. The first one is seen in the video at about time -58.5 seconds. It did not fly near the airplane. The second bird was at a high altitude and its image in the video was only a dark dot. The dot is seen crossing the image of the airplane in the video because at that time, both the airplane and the bird were on the same line-of-sight from the camera. However, the bird was much farther from the camera than the airplane. The dark dot seems to be falling down, but it is only because the camera was pointed up at the airplane. The dot did not change its speed or its heading when it crossed the image of the airplane, providing further proof that there was no interaction between the airplane and the bird.

E. CONCLUSIONS

The trajectory, orientation angles and speed of an airplane that crashed were estimated based on a video during the last 11 seconds of flight. A second video was used to estimate the engine speed during the last 90 seconds of flight. The estimated engine speed was low during most of the analyzed 90 seconds.