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VIDEO STUDY

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A. ACCIDENT

Location: Pembroke Pines, Florida
Date: August 4, 2023
Time: 1201 eastern daylight time
Aircraft: Cessna 172P

B. SUMMARY

B.1. The accident

On August 4, 2023, at 1201 eastern daylight time, a Cessna 172P, N697FL, was substantially damaged when it was involved in an accident at North Perry Airport (HWO), Pembroke Pines, Florida. The flight instructor and the front seat passenger sustained fatal injuries and the rear seat passenger was seriously injured. The airplane was operated as a Title 14 *Code of Federal Regulations* Part 91 sightseeing flight.

B.2. Objective and scope of the Video Study

The objective of this Video Study was the estimation of the airplane altitude, pitch angle and wing angle of attack. Analysis was based on the visual information in a video recorded with a camera installed on an airport building.

C. DETAILS OF THE INVESTIGATION

The video had 1920x1080 resolution and frame rate of 12 fps (frames per second). The video lasted about 49 seconds. The airplane entered the field of view of the camera at video time 27.56 seconds. The time stamp in the video at that time was 12:00:24. Examination of the video and of the available ADS-B record indicated that the video time stamp was running about one second behind ADS-B time. The resolution of the video time stamp was one second.

Rotation time was at video time 33.62 seconds (time stamp was 12:00:31). Past video time 36.52 seconds, the airplane is seen in the video initiating an increasing left-wing-down bank angle. Between time 37.52 seconds and time 43.50 seconds, the airplane visibility was low because of clouds. When the airplane became again clearly visible at time 43.80 seconds, it was rapidly descending, and it impacted the ground at video time 45.73 seconds (time stamp was 12:00:43).

C.1. Estimation of airplane altitude and pitch angle

Figure 1 is an aerial view of the accident area. Fifteen ADS-B locations are marked in the figure by filled yellow circular markers. Also marked are the locations of

the camera and the wreckage. Figure 2 is a frame from the video recorded at video time 37.27 seconds. The video time stamp on that frame was 12:00:34. The ADS-B time corresponding to video time 37.27 seconds was 12:00:35.58. Since the ADS-B time was considered to be the correct time, the analysis below and the corresponding figures will only use the ADS-B time.

The video frame in Figure 2 is significantly barrel-distorted because of the wide-angle lens of the camera. The distortion was corrected mathematically before analyzing the video.

The analysis of the video was based on a mathematical model of the optics of the camera that recorded the video. 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 were known. The Z coordinate (elevation above ground) of the camera was known approximately. The yaw, pitch and roll camera orientation angles and the HFOV were unknown. Consequently, the camera Z, yaw, pitch, roll and HFOV parameters were unknown and had to be estimated.

The estimation of camera model parameters is based on references that are visible both in aerial images such as the one in Figure 1 and in video frames such as the one in Figure 2. The references used for camera model calibration included markings on the ground, the taxiway, the runway and the building seen on the right in Figure 2.

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 five unknown camera model 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 camera model parameters were their optimal estimates. At that point, the camera optics model was calibrated.

The calibrated camera optics model was then used to estimate the locations of the airborne airplane at times corresponding to eight video frames that were analyzed. The first analyzed frame was recorded at ADS-B time 12:00:33.35. The last video frame was recorded at ADS-B time 12:00:38.77.

A wireframe model of the Cessna 172P airplane was constructed, consisting of points on its nose, fuselage, tail and wings. An analysis program that used the

calibrated camera model was then used to project the wireframe model onto a video frame. The wireframe model was then moved to ground coordinates X and Y, known from the ADS-B data, and its Z coordinate and the orientation angles were varied until it matched optimally the image of the aircraft in the video frame. When the optimal match was reached, the vertical location coordinate, Z, of the wireframe model and its orientation angles were the optimal estimates of the vertical location and orientation angles of the accident airplane at the time when the analyzed video frame was recorded.

Figure 3 shows the estimated AGL altitude of the airplane vs. ADS-B time. The altitude was that of the nose of the airplane. The altitude was set to zero when the three tires of the airplane were on the runway. The dotted segment of the altitude curve indicates that it had relatively low accuracy because the last shown altitude point was at a time when the airplane visibility was low due to clouds. The airplane is seen in the video initiating an increasing left-wing-down bank angle past video time 36.52 seconds that corresponds to ADS-B time 12:00:34.83. Therefore, it was desirable to estimate the wing angle of attack at that time.

The wing angle of attack is the difference between the wing pitch angle and the flight path angle. The flight path angle is given by $\tan^{-1}(\text{vertical_speed}/\text{ground_speed})$. The vertical speed is the slope of the altitude vs. time curve in Figure 3. The red straight line in Figure 3 is a constant climb-rate fit to the data at the time when the airplane started banking to the left. The slope of the red line indicated a vertical speed of 13.5 feet/second or 810 feet/minute.

The ADS-B record listed geometric altitude with the resolution of 25 feet. Figure 4 is a plot of the geometric altitude after it was adjusted to be zero when the airplane was on the runway. The red line in the figure is an estimated constant climb-rate fit to the data. The slope of the red line is 13.5 feet/second, in agreement with the vertical speed estimated above through video analysis.

The ADS-B record included accurate ground track locations marked in yellow in Figure 1. To estimate the ground speed, ground track data was used to plot the total ground distance traveled between the last thirteen locations seen in the figure. Figure 5 is the plot of the total traveled distance vs. ADS-B time. The red line is a constant-speed fit to the data. The slope of that line is 103 feet/second or 61 knots.

C.2. Estimation of wing angle of attack

With the estimated vertical speed of 13.5 feet/second and the estimated ground speed of 103 feet/second available, the flight path angle of the airplane could be estimated as $\tan^{-1}(13.5/103)=7.5^\circ$. The wing angle of attack (AoA) is given by

$$\text{Wing AoA} = \text{airplane pitch angle} + \text{wing incidence angle} - \text{flight path angle}$$

In this analysis, the airplane pitch angle was measured relative to the airplane orientation when its three tires were on the runway. The estimated pitch angle past time 12:00:34 was $19^\circ \pm 1^\circ$. The wing incidence angle was defined to be the pitch angle of the wings relative to horizontal when the three airplane tires were on the runway. The incidence angle was estimated based on Cessna 172P photographs and schematics to be 3° . Consequently, neglecting uncertainties,

$$\text{Wing AoA} = 19^\circ + 3^\circ - 7.5^\circ = 14.5^\circ$$

The uncertainty of the estimated 19° airplane pitch angle was $\pm 1^\circ$. It is estimated that the combined uncertainty of the estimated wing incidence angle and the estimated flight path angle is about $\pm 1^\circ$. Therefore, the estimated angle of attack of the airplane wings when the airplane started banking to the left can be specified as $14.5^\circ \pm 2^\circ$.

The large wing angle of attack was caused primarily by the large airplane pitch angle. When the airplane started banking to the left, its ground speed was a constant 61 knots. The airplane performance was consistent with stall due to large wing angle of attack.

D. CONCLUSIONS

A video recorded with a camera installed on an airport building was used for estimating the altitude, pitch angle and wing angle of attack of an airplane that crashed shortly after takeoff. Analysis showed that when the airplane started banking to the left, the wing angle of attack was $14.5^\circ \pm 2^\circ$. The airplane impacted the ground about ten seconds after it started banking.

FIGURES



Figure 1. Aerial view of the accident area



Figure 2. Video frame recorded at video time 37.27 seconds
(ADS-B time 12:00:35.58)

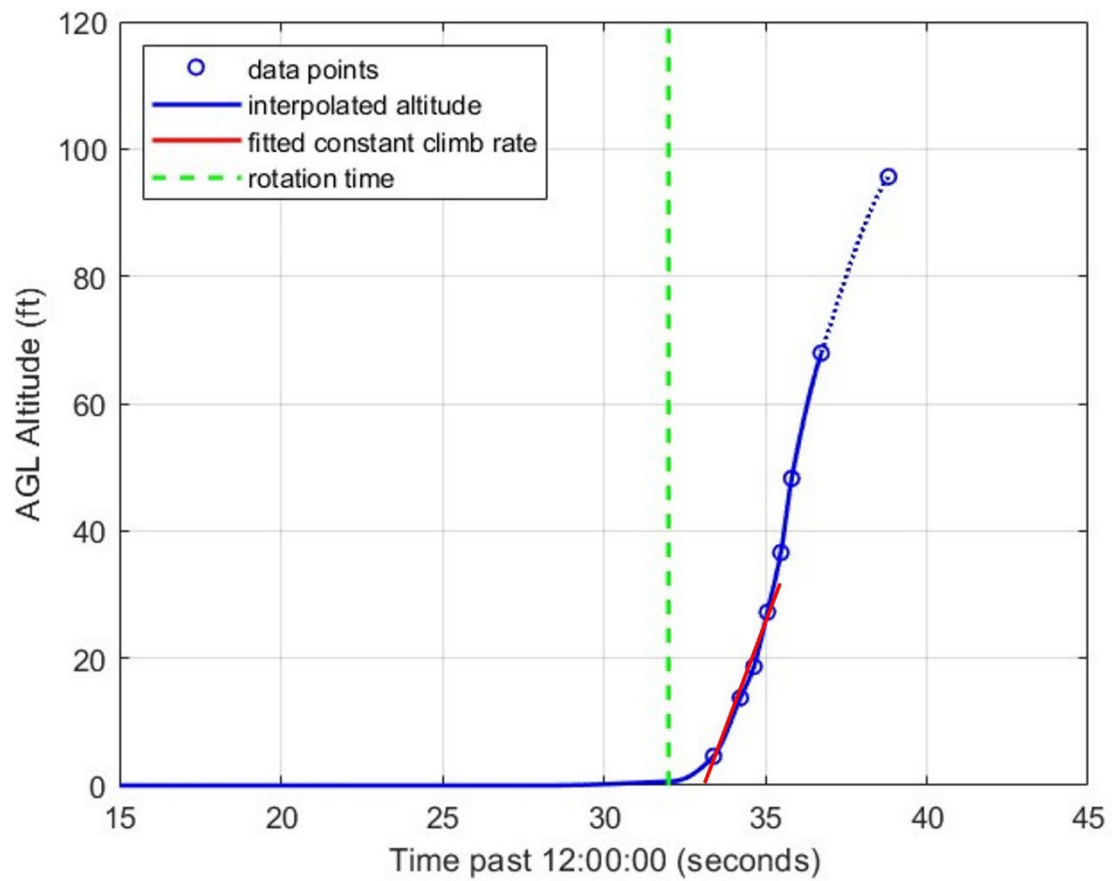


Figure 3. Estimated video-based altitude of the airplane vs. ADS-B time

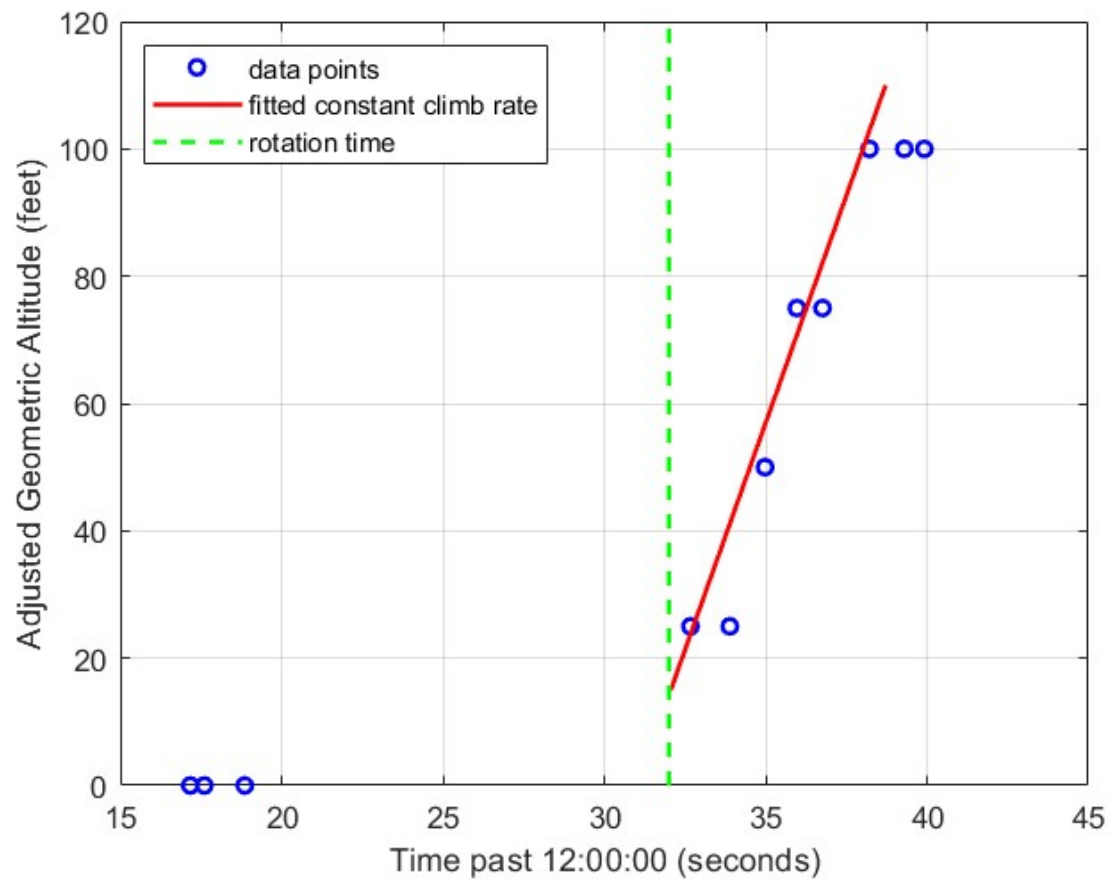


Figure 4. Estimated ADS-B based altitude of the airplane vs. ADS-B time

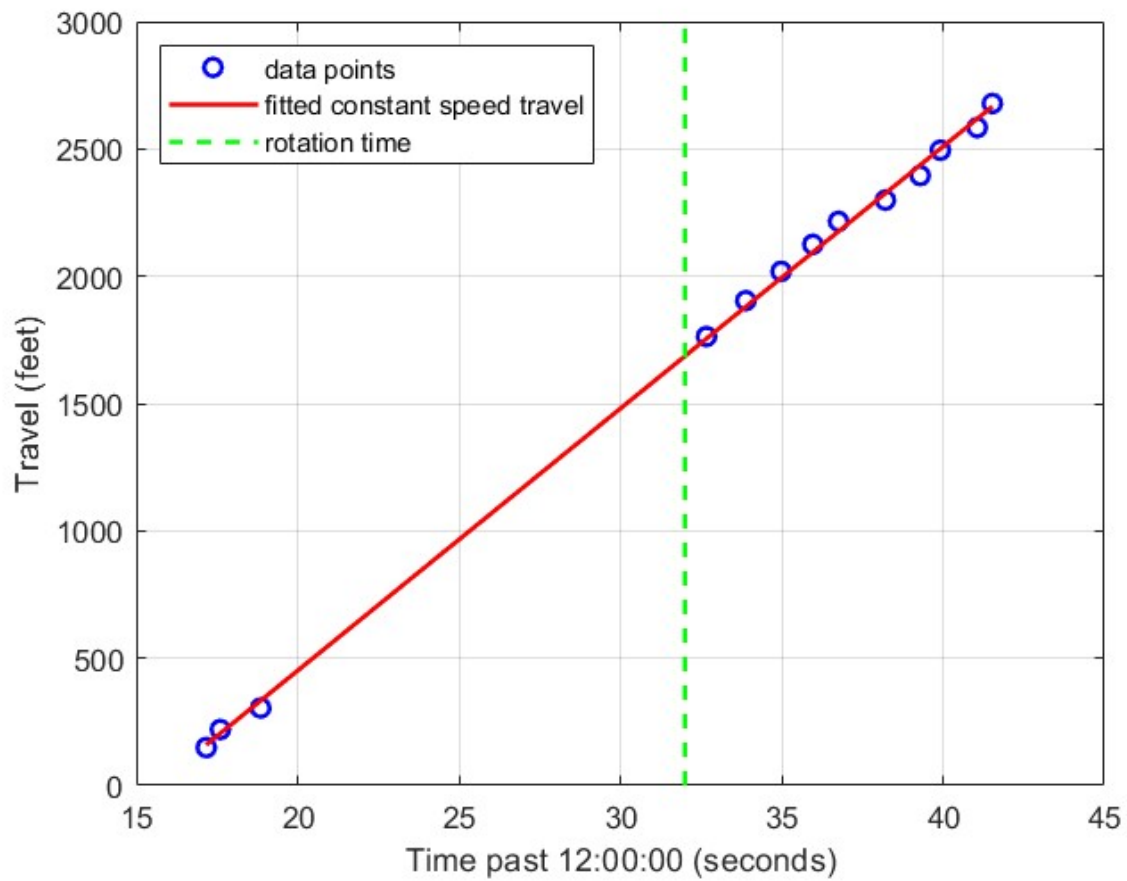


Figure 5. Ground travel of the airplane vs. ADS-B time