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VIDEO STUDY

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A. ACCIDENT

Location: Plano, Texas
Date: November 21, 2023
Time: 1748 Central Standard Time
Aircraft: Mooney M20C

B. SUMMARY

B.1. The accident

On November 21, 2023, at 1748 central standard time, a Mooney M20C, N1204X was destroyed when it was involved in an accident near Plano, Texas. The pilot was fatally injured. The airplane was operated as a Title 14 *Code of Federal Regulations* Part 91 personal flight.

B.2. Objective and scope of the Video Study

The objective of this Video Study was the estimation of the airplane altitude above ground level (AGL), vertical speed and stall speed increase due to bank angle. Analysis was based on a video recorded by a camera installed on a commercial building.

C. DETAILS OF THE INVESTIGATION

The video had 1920x1080 resolution and frame rate of 5 fps (frames per second). The video lasted about 20 minutes. The airplane was seen in the video for about 23 seconds. It entered the field of view of the camera at video time 12:18.97 and was last seen at video time 12:42.16. It is estimated that the airplane impacted the ground at about video time 12:44. Figure 1 shows a frame from the video recorded at video time 12:21.54. The airplane is marked in the figure. The frame is significantly barrel-distorted because of the wide-angle camera lens. The distortion was corrected mathematically before analyzing the video.

Figure 2 shows an aerial view of the accident area. The airplane was in the process of a go around while attempting to land at the Air Park-Dallas Airport (F69). The blue markers are the airplane ground locations available from ADS-B data. The blue numbers are the times corresponding to the ADS-B locations. Time is shown as seconds past ADS-B time 17:47.00. The figure also shows the location of the camera and the location of ground impact. The altitude available from ADS-B was not accurate. Therefore, the altitude was estimated based on the video as detailed below.

C.1. Estimation of airplane altitude and vertical speed

Airplane altitude was estimated using a method that is based on a mathematical model of the camera optics. In most video analysis cases, this method can estimate the three airplane location coordinates (X, Y and Z) and the three airplane orientation angles (yaw, pitch and roll) without any additional data coming from sources other than the video. However, in the analysis of this video, accurate video-based estimation of the airplane X and Y coordinates was not possible because of the distance from the camera to the airplane. Therefore, the X and Y location coordinates were taken from the ADS-B record. Once X and Y coordinates were available, it was possible to accurately estimate Z, the altitude of the airplane, based on video analysis.

The analysis of the video required a calibrated 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 video frames such as the one in Figure 1 and in aerial images such as the one in Figure 2. The references used for camera model calibration included markings on the ground, light poles, and buildings seen near the top of the video frame in Figure 1.

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 altitude of the airplane at times corresponding to fourteen video frames that were analyzed. The video time and the ADS-B time were synchronized based on the locations of the airplane as seen in video frames and the ADS-B locations marked in Figure 2. Once synchronized, it was possible to assign ADS-B time to each analyzed video frame.

A wireframe model of the Mooney 20C airplane was constructed, consisting of points on its nose, 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 was varied until it matched optimally the image of the airplane in the video frame. When optimal match was reached, the vertical location coordinate, Z, of the wireframe model was the optimal estimate of the vertical location of the accident airplane at the time when the analyzed video frame was recorded.

Figure 3 shows the estimated AGL altitude of the airplane. It is shown relative to the runway elevation. As mentioned above, the ground X-Y locations of the airplane were known from ADS-B data. In most accident cases, the airplane yaw, pitch and roll angles can also be estimated in the process used to estimate the altitude. In this case, however, estimating the angles was not possible because of the distance of the airplane from the camera and low visibility. The visibility at the time of the accident was low because the accident occurred after sunset. Consequently, the image of the airplane in the video did not show the details that are needed for estimation of the orientation angles with reasonable accuracy.

Figure 3 shows that the airplane was climbing at a moderate climb rate till about time 17:47:33. Past time 17:47:33, the climb rate was significantly higher, peaking at 20 feet/second or 1200 feet per minute in the time segment centered at about 35 seconds. There is no visible evidence in the video to explain the cause of the increased climb rate. There is more than one possible explanation for the higher climb rate. It could have been intentional to facilitate the go around maneuver. It also could have been caused by a mechanical failure. Unintentional pilot command caused by high acceleration affecting the pilot is not likely because the lateral acceleration before time 17:47:33 was only 0.26 g. However, a medical condition unrelated to acceleration is a possibility.

C.2. Estimation of the effect of the airplane bank angle on its stall speed

Figure 4 shows the ground distance, based on ADS-B data, flown by the airplane between time 17:47:23.1 seconds and time 17:47:39.7 seconds. The blue line is a constant-speed fit to the data points. The slope of the line indicates speed is 97.5 feet/second or 57.8 knots, near the stall speed of the Mooney M20C.

The stall speed of a banking airplane increases by a factor of $1/\sqrt{\cos(\varphi)}$ where φ is the airplane bank angle. The airplane bank angle in a steady-state turn is given by $\varphi = \tan^{-1}(a/g)$. The lateral acceleration, a , in the turn was 0.26 g, as mentioned above. Therefore, the estimated bank angle in the turn was about $\varphi = \tan^{-1}(0.26)=14.6^\circ$ and

the stall speed increase factor was $1/\sqrt{\cos(14.6^\circ)} = 1.017$. If it is assumed that the stall speed in straight flight is 55 knots, when the airplane is banking by 14.6° , the stall speed would increase to $1.017 \times 55 = 56$ knots. Therefore, the banking of the accident airplane increased its stall speed, but only by about 1 knot before the bank angle started to increase to higher values.

The airplane in the video undergoes a transient that starts at about ADS-B time 17:47:33. During the transient, the airplane transitions from what looks like controlled flight to flight with a large left-wing-down bank angle visible starting at about time 17:47:36.5 seconds. The airplane impacted the ground at about time 17:47:42. The visibility of the airplane between time 17:47:33 seconds and 3.5 seconds later at time 17:47:36.5 seconds is very low and its image in the video does not resemble the shape of an airplane. Therefore, the details of what happened during these 3.5 seconds could not be derived based on what is visible in the video.

Based on the information available from ADS-B data and from video analysis, it can be concluded that before the 3.5 second loss-of-control transient, the airplane speed was near its stall speed and the airplane was banking. At that time, the airplane stall speed was only slightly higher because of its bank angle than what it is in straight flight. However, it can be seen in the video that the bank angle was about to start a transient during which it quickly increased to almost 90° . As the bank angle was rapidly increasing during the 3.5 second transient, the stall speed was increasing rapidly. For example, when the bank angle was 45° , the stall speed increase factor was 1.19 and if the stall speed in straight flight was 55 knots, the increased stall speed was $1.19 \times 55 = 65.5$ knots, above the estimated ground speed of 57.8 knots.

This points to a process where once the 3.5 second loss-of-control transient started, the increasing bank angle was increasing the stall speed. The increasing stall speed moved the airplane wings deeper into the stall region that likely increased the bank angle and, therefore, increased the stall speed even higher. This process, where bank angle increases the stall speed and stall speed increases the bank angle can explain why the loss of control happened so quickly.

Additionally, when the airplane was transitioning from stable flight to a flight with a high bank angle, its vertical speed was as high as 1200 feet per minute. This high rate of climb could have contributed to the quick loss of control.

D. CONCLUSIONS

A video recorded with a camera installed on a commercial building was used for estimating the altitude, vertical speed and stall speed increase due to bank angle of an airplane that crashed shortly after starting a go-around maneuver. Analysis showed that during a short transient, the banking airplane transitioned from a stable flight at a speed close to the stall speed to flight with a large bank angle and crashed shortly thereafter.

FIGURES



Figure 1. Video frame recorded at video time 12:21.54



Figure 2. Aerial view of the accident area

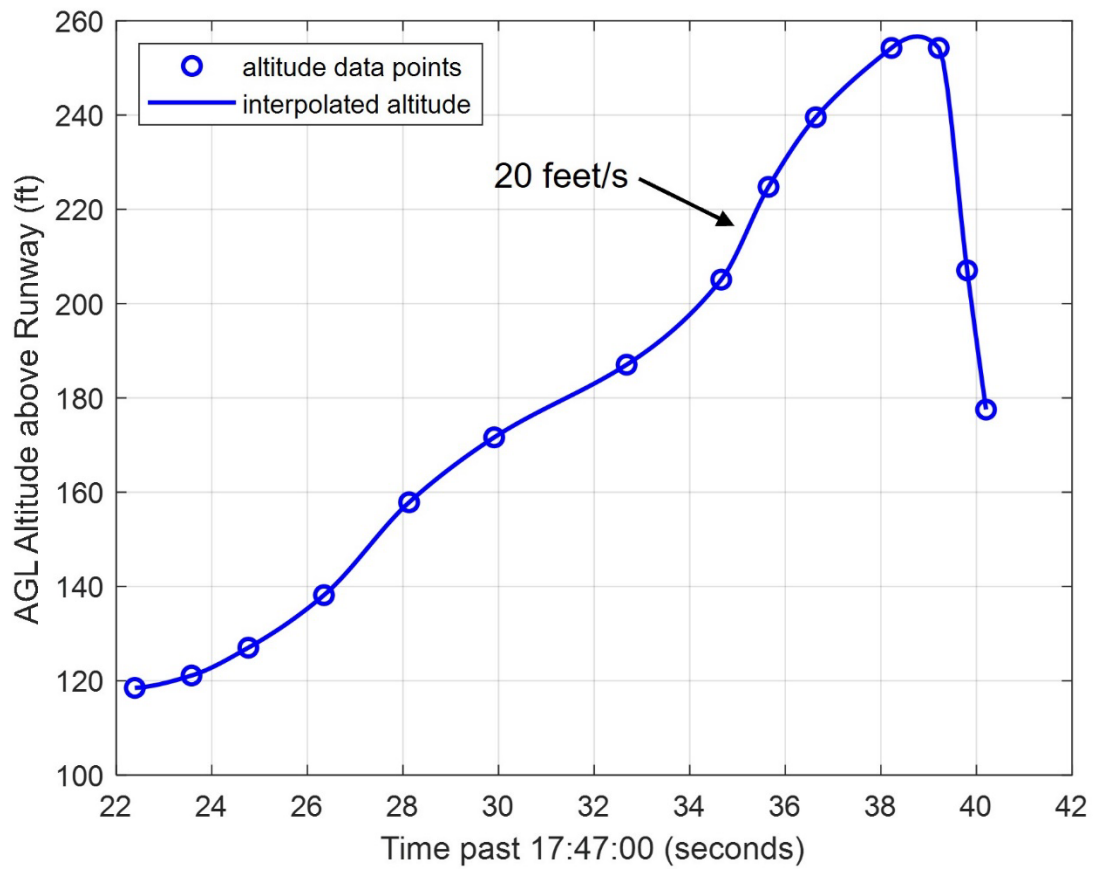


Figure 3. Estimated altitude of the airplane

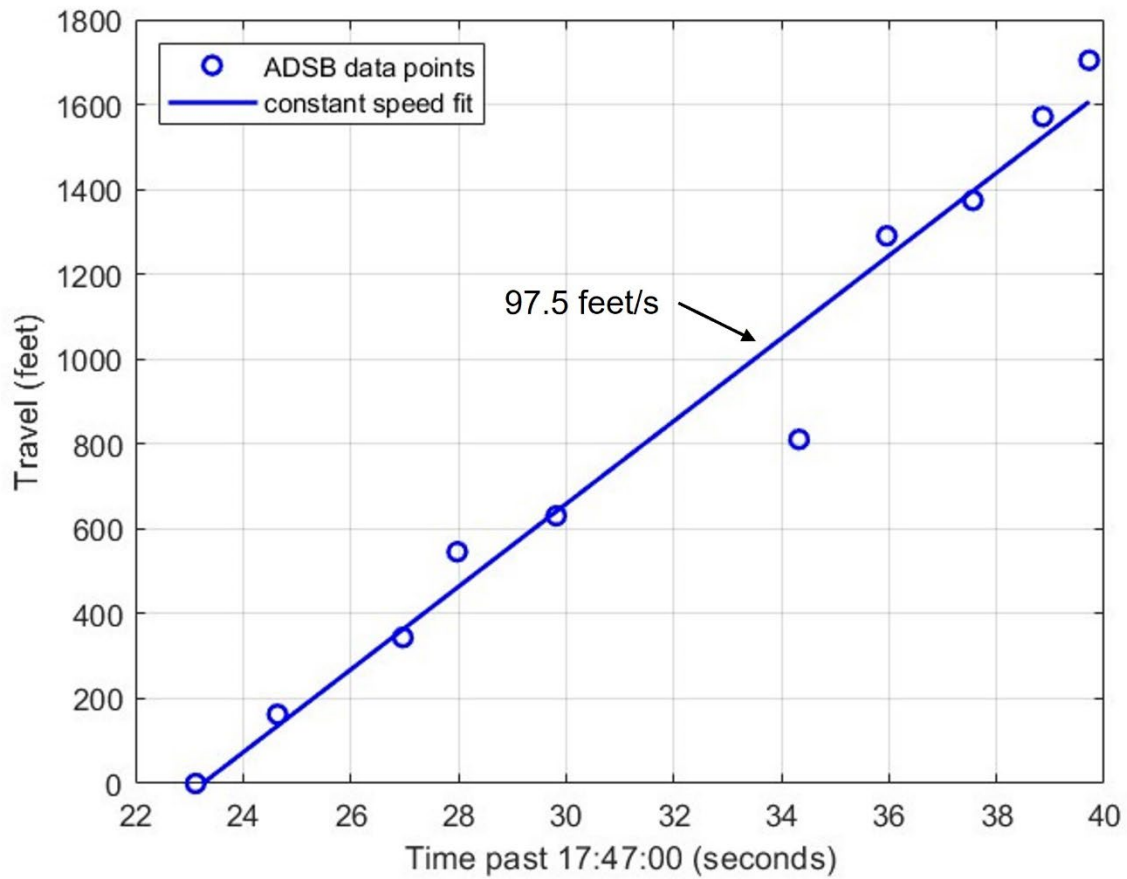


Figure 4. ADS-B based ground travel and ground speed of the airplane