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VIDEO STUDY

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A. ACCIDENT

Location: Corona, California
Date: December 16, 2023
Time: 1951 PST (Pacific Standard Time)
Aircraft: Van's RV-8

B. SUMMARY

B.1. The accident

On December 16, 2023, about 1951 Pacific Standard Time, a Van's Aircraft RV-8, N6948L, sustained substantial damage when it was involved in an accident in Corona, California. The pilot was fatally injured. The airplane was operated as a Title 14 *Code of Federal Regulations* Part 135 on-demand flight.

B.2. Objective and scope of the Video Study

The objective of this Video Study was the estimation of the airplane speed, altitude above ground level (AGL), roll angle and engine speed. Analysis was based on the visual information in video No. 1 recorded with Camera 1 installed on an airport building and on the sound in video No. 2 recorded by a bystander with Camera 2.

C. DETAILS OF THE INVESTIGATION

Video No. 1 had 3860x2160 resolution and frame rate of 20 fps (frames per second). The video lasted about 60 seconds. The airplane entered the field of view of the camera at time 11:49:23 as indicated by the time stamps in the video. This time corresponds to video time 4.10 seconds. Rotation was at about time 11:49:27, corresponding to video time 8.00 seconds. The airplane was last seen in the video at time 11:50:07, corresponding to video time 47.75 seconds.

Video No. 2, recorded with an iPhone, had 1280x720 resolution and frame rate of 30 fps. It recorded sound at the rate of 44,100 samples per second and lasted 14.5 seconds. The airplane was not seen in this video.

C.1. Estimation of airplane speed

Figure 1 is an aerial view of the accident area. Fourteen ADS-B locations are marked in the figure by filled yellow circular markers. Also marked are the locations of the two cameras, the crash location, and the runway location where the airplane rotated. The speed of the airplane at the time of rotation and liftoff was estimated based on the runway markings seen in video No. 1 and in Figure 1. The centerline of

the runway was marked with 120-foot-long white lines followed by 80-foot-long gaps. Using these distances and the time it took to move these distances, it was estimated that the ground speed at the time of rotation and liftoff was about 71 knots. Figure 2 is a frame from the video recorded at the time of rotation. The image is barrel-distorted due to the wide field-of-view angle of the camera lens. The distortion of the video frames was corrected mathematically before analyzing the video.

Once the airplane was airborne and was flying away from the camera, for about 16 seconds it was not possible to estimate its speed based on the video because of the distance from the camera to the airplane. However, since there was an ADS-B record, speed estimates based on ADS-B became possible past time 19:49:43.

Figure 3 is a plot of the flown distance of the airborne airplane based on ADS-B data. The first data point, at time 19:49:43, corresponds to point B marked in Figure 1. The flown distance at that point is the distance from point A to point B, which are shown in Figure 1. The ground speed of the airplane is the slope of a line passing through the data points in Figure 3. The red line in Figure 3 is a constant-speed fit to the data points between time 19:49:48 and time 19:51:10, the last time when ADS-B data was recorded. The estimated ground speed is 58 knots, 13 knots lower than the speed at the time of rotation and liftoff.

C.2. Estimation of airplane altitude and roll angle

Airplane altitude and roll angle estimation was 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 video No. 1, 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, and its roll angle based on video analysis.

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 hangar 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 1 optics model was calibrated.

The calibrated camera optics model was then used to estimate the locations of the airborne airplane at times corresponding to thirteen video frames that were analyzed. The first analyzed frame corresponded to location A marked in Figure 1. The last video frame corresponded to the last available ADS-B airplane location.

A wireframe model of the RV-8 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 and the yaw, pitch and roll orientation angles were varied until it matched optimally the image of the aircraft in the video frame. When 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 4 shows the estimated AGL altitude of the airplane. It is shown relative to the runway elevation by the blue solid line and relative to the crash location by the black broken line. Figure 5 shows the estimated roll angle of the airplane. Positive roll angle indicates right-wing-down orientation.

C.3. Estimation of engine speed

Video No. 2 was recorded by a bystander with Camera 2, an iPhone. The airplane was not seen in the video, but its sound was recorded. The camera holder stated that the recording started when the airplane was near the end of the runway and

that there was an idling airplane near the camera location. Consequently, the recorded sound included components from both the RV-8 and from an idling airplane.

The statements of the camera holder were assumed to be accurate and were used in the analysis of the spectrum of the sound recorded in the video. The RV-8 was flying away from the camera. Therefore, it was assumed that during the last second of the recording, when the RV-8 was far from the camera, the sound spectrum included mostly spectral peaks due to the idling airplane. These spectral peaks were present throughout the 14.5 second duration of the video and were neglected during the first few seconds of the video when the intensity of the RV-8 sound was high.

The sound spectrum computed in a 65536-point time window between video No. 2 time 4.00 seconds and video No. 2 time 5.48 seconds is shown in Figure 5. The frequency resolution was 40 cycles per minute (cpm). Four spectral peaks, A, B, C and D are marked in the figure. Their frequencies are 4670 cpm, 9340 cpm, 14010 cpm and 18680 cpm, respectively. It is assumed that the frequency of peak A, 4670 cpm, is the blade passage frequency (BPF) of the 2-bladed propeller and the other peaks are harmonics of the BPF.

Since the RV-8 was flying away from the camera, the frequency recorded by the camera was reduced due to the Doppler effect. The Doppler frequency reduction factor was estimated to be 0.935 based on the airplane speed and the angle between its velocity vector and the line from Camera 2 to the airplane. Taking the Doppler frequency reduction factor into account, the engine speed shortly after liftoff was estimated to be $4670/(2 \times 0.935) = 2497$ rpm.

D. CONCLUSIONS

A video recorded with a camera installed on an airport building was used for estimating the speed, altitude and roll angle of an airplane that crashed shortly after takeoff. Analysis showed that the ground speed of the airplane was declining after liftoff and it was able to climb to only about 92 feet above the runway before it crashed.

The airplane engine speed shortly after liftoff was estimated based on the sound in a video recorded by a bystander with an iPhone. The estimated engine speed was about 2500 rpm.

Installed

FIGURES



Figure 1. Aerial view of the accident area



Figure 2. Video frame recorded at the time of rotation

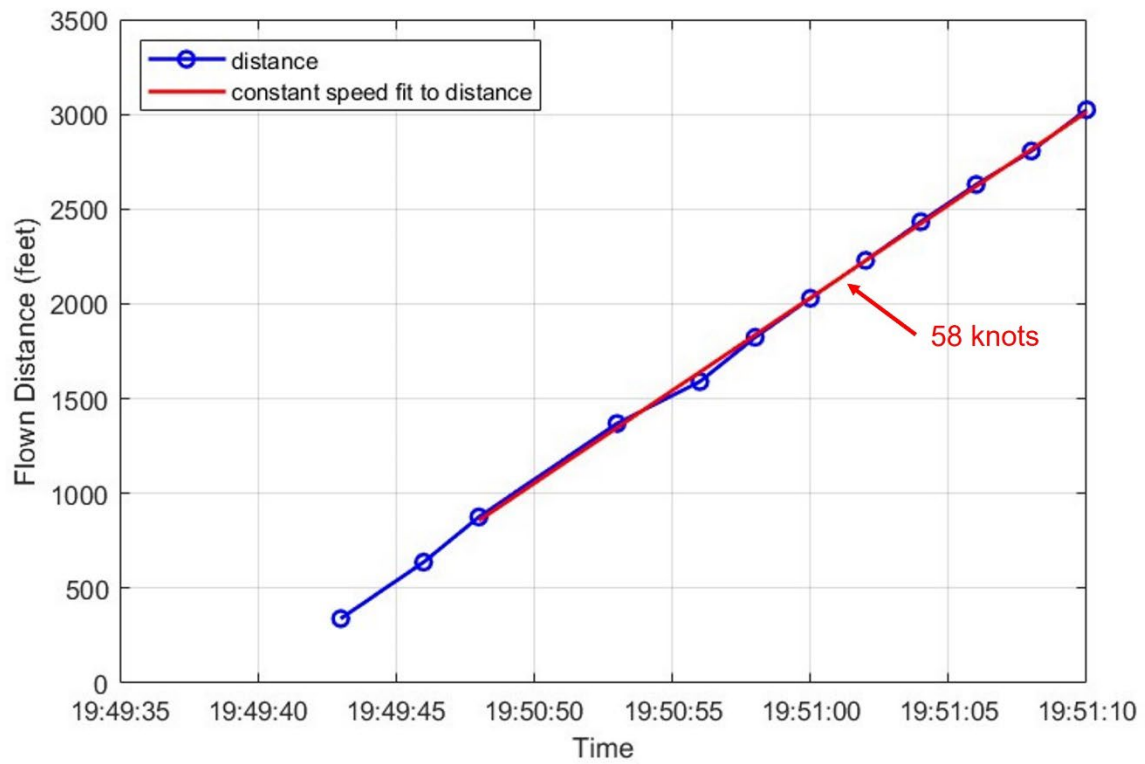


Figure 3. Flown distance and estimated speed

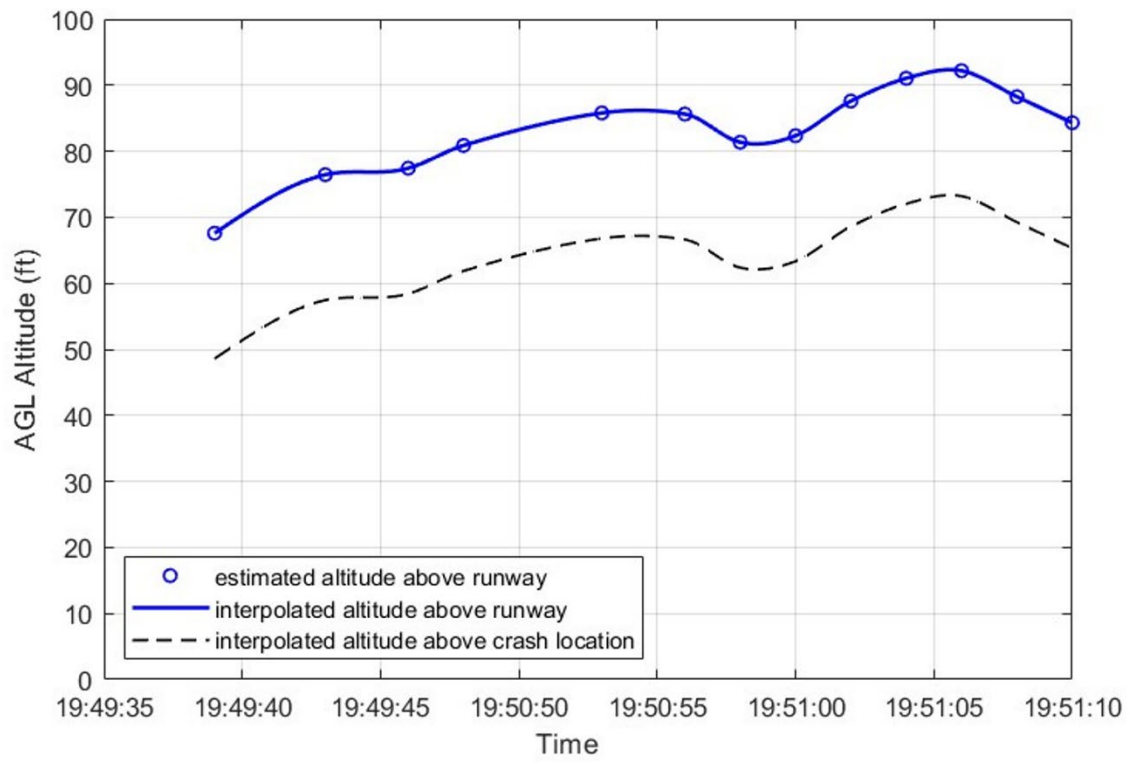


Figure 4. Estimated AGL altitude of the airplane

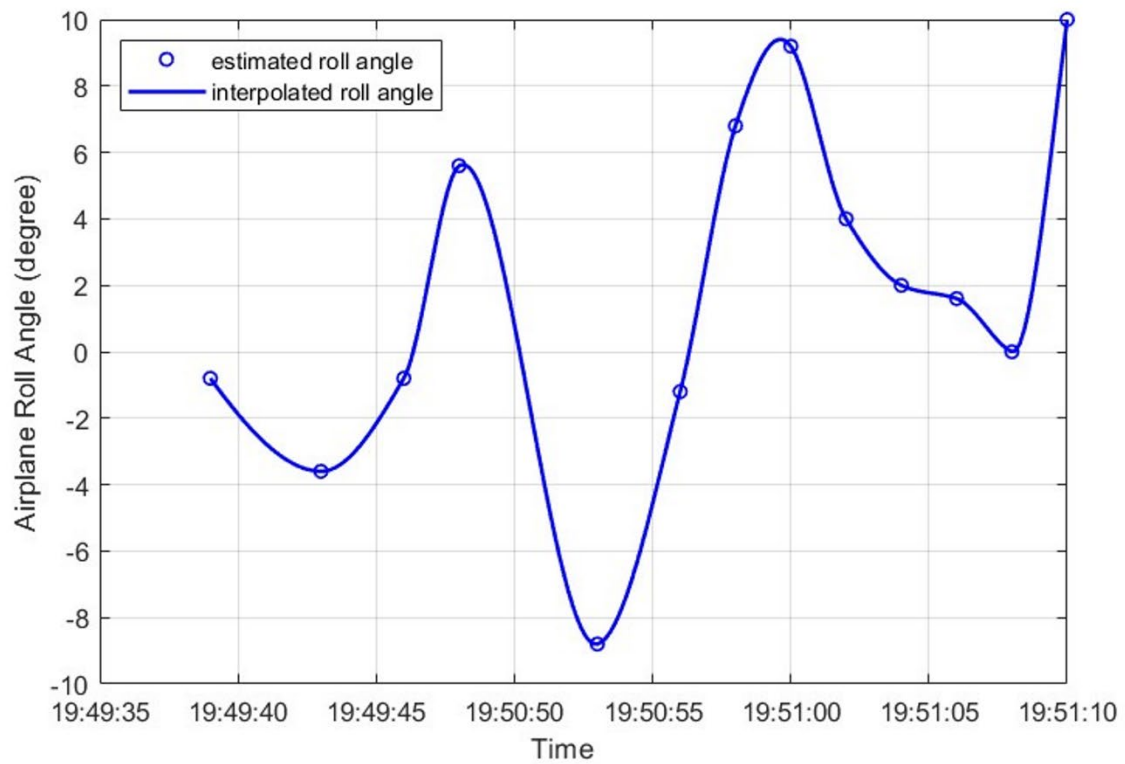


Figure 5. Estimated airplane roll angle

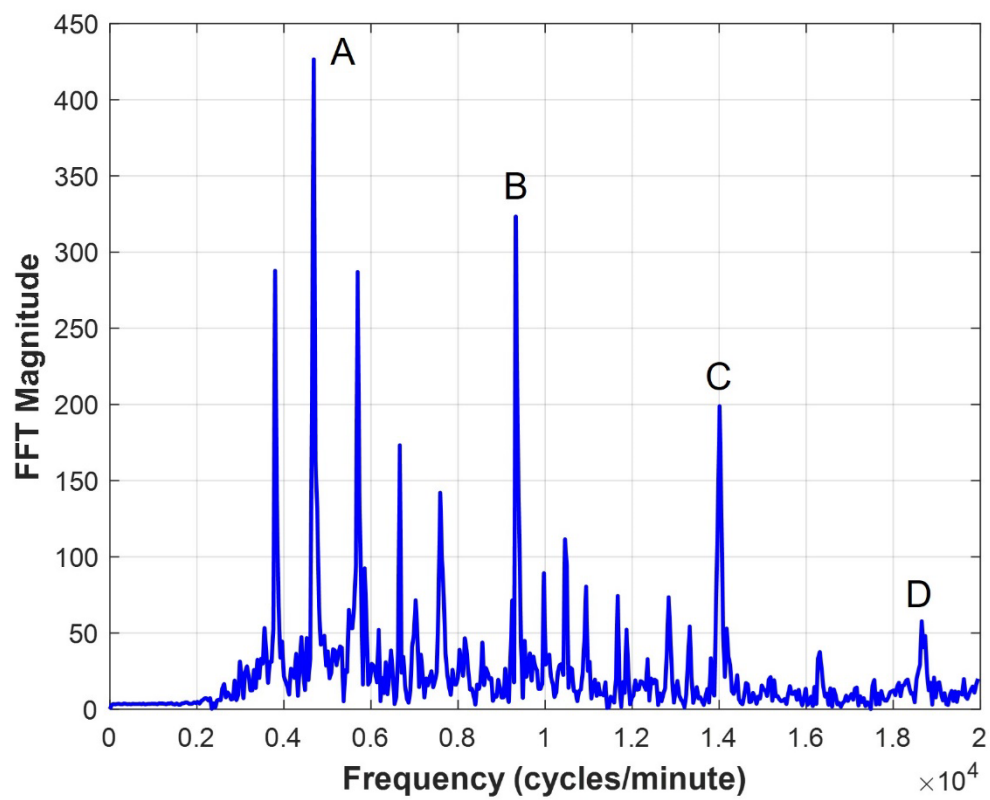


Figure 6. Sound Spectrum at Video 2 time 4 seconds