NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Washington, D.C. 20594

February 13, 2018

Video Study

NTSB Case Number:
ERA17FA274

A. ACCIDENT

Location:	Charlottesville, Virginia
Date:	August 12, 2017
Time:	1649 EDT
Aircraft:	Bell 407 helicopter

B. AUTHOR

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NTSB

C. ACCIDENT SUMMARY

At 1649 EDT a Virginia State Police Bell 407 helicopter (N31VA) crashed in a residential area, 7 mi SW of Charlottesville - Albemarle Airport (KCHO), Charlottesville, Virginia. The two crew members on board sustained fatal injuries. There were no ground injuries.

D. DETAILS OF INVESTIGATION

The goal of this study was extracting information on motion of the accident helicopter from a video and from still photographs. The video was recorded by a security camera mounted on a building near the intersection of Ivy Road and Copley Road in Charlottesville. The still photographs were taken by a resident from a back yard of a house on Courtyard Drive in Charlottesville.

Analysis of the Video

The video had 1024x768 resolution and frame rate of 30 fps. The descending helicopter was visible for a period of about 10 seconds. The helicopter was located about

6250 feet southwest of the camera and, consequently, the image of the helicopter was only about 2x2 pixels when it was visible.

Analysis of the video consisted of first mathematically removing the barrel distortion from the video frames. The distortion was caused by the relatively wide field of view angle of the camera. The camera was then calibrated using reference points on roads, trees, buildings and power line poles. All the reference points were 400 feet or closer to the camera. The calibration resulted in estimated values of the camera 3D location, camera 3D orientation, and its horizontal field of view angle (HFOV).

Figure 1 shows a frame from the video after barrel distortion correction with superimposed red markers at the locations that were used for estimating the helicopter altitude. These points were not spaced evenly in time or in altitude. They were selected because the image of the helicopter was clearly visible in these video frames. It was assumed that the ground distance from the camera to the helicopter was 6250 feet, corresponding to the distance from the camera to the crash site. With a calibrated camera and assumed ground distance to the helicopter, it was possible to estimate the above sea level (MSL) altitude of the helicopter at each of the 11 points marked in Figure 1.

Figure 1. Frame from the Video with Marked Analyzed Points

Figure 2 is a plot of the MSL altitude of the helicopter at the 11 points marked in Figure 1. The time was set to zero at the first point. A second order polynomial fit to the 11 points generates a curve that matches the curve in Figure 2 very closely. The maximum difference between the 11 points and the fitted curve, not shown in Figure 2, is less than 10 feet.

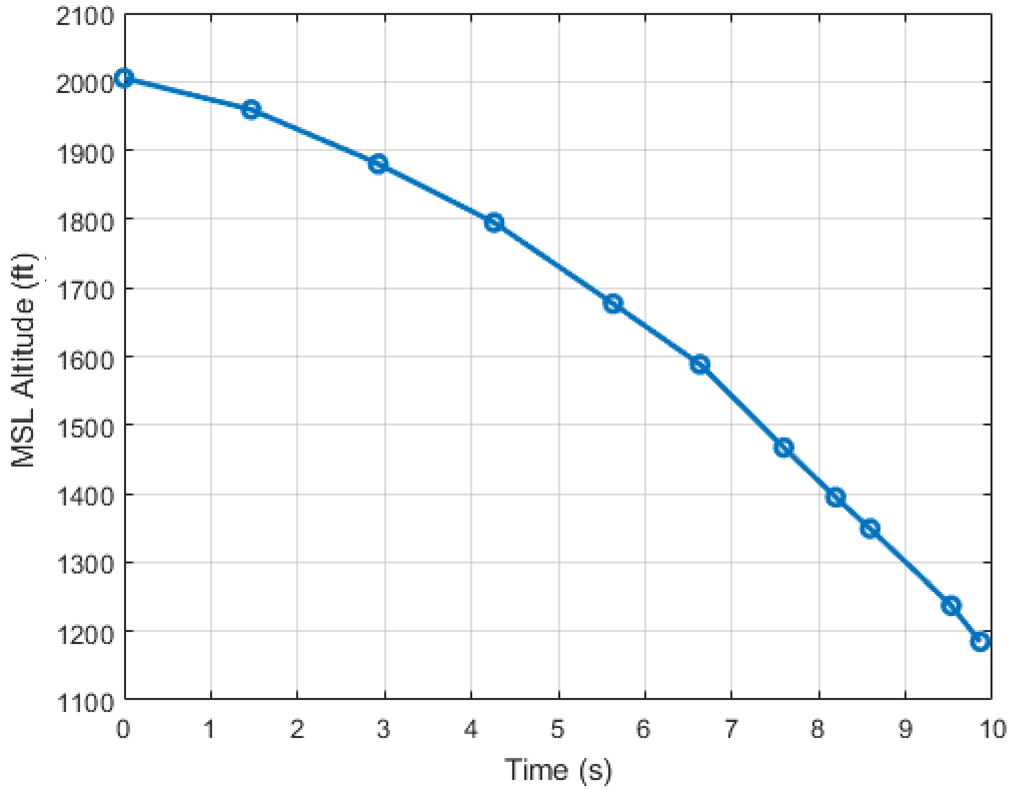

Figure 2. Estimated Above Sea Level Altitude of the Helicopter vs. Time

The accurate fit with a second order polynomial indicates that the helicopter was descending with a constant acceleration. Figure 3 shows a plot of the helicopter vertical speed vs. time. At the beginning of the 10 second interval, its descent speed was about 25 ft/s (1500 feet/minute). At the end of the interval, the speed was about 142 ft/s (8520 feet/minute). The constant acceleration was 0.37 g. In a mostly free fall, the acceleration would have been close to 1.0 g. The relatively low acceleration of 0.37 g indicates that the descending helicopter was generating lift but not enough lift to maintain altitude. The accuracy of the 0.37 g acceleration estimate is about ±10%, resulting in acceleration estimate of 0.37±0.04 g.

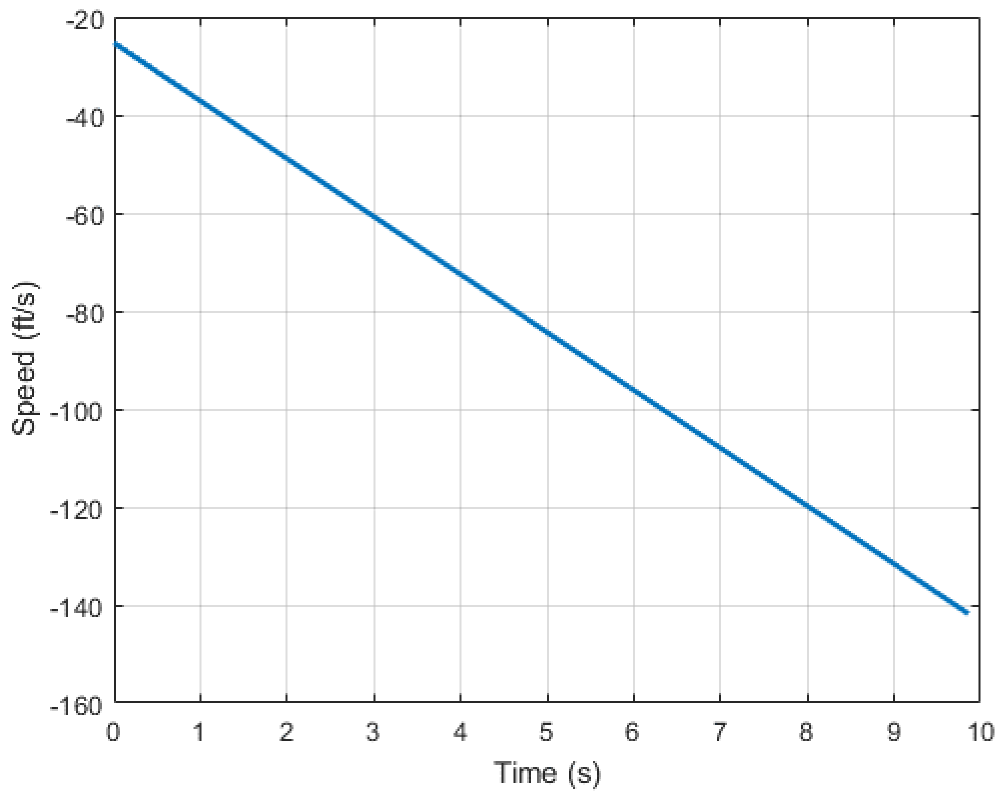

Figure 3. Estimated Vertical Speed of the Helicopter vs. Time

<u>Analysis of Photographs</u>

The photographs were taken by a person located about 7200 feet south of the crash site. The hand-held camera was a Canon EOS 50D with a Canon EF 75-300 mm zoom lens. The resolution of the photographs was 4752x3168.

The owner of the camera allowed NTSB to calibrate it. Calibration revealed that the camera in the ‘ContinuousDrive’ mode and set at the ‘Continuous, High’ rate acquires still photographs at the rate of 5.7 photographs per second. The Canon EOS 50D User Manual specifies the ‘Continuous, High’ speed as ‘Max. approx. 6.3 shots/sec.’ The photographs of the accident helicopter were acquired with the zoom lens set at 300mm. The horizontal field of view (HFOV) angle with the zoom set at 300mm was experimentally measured at NTSB as 4.3º.

The camera Exif data included the time when each photograph was taken with resolution of one second. The ‘CreateDate’ time entry for the first three photographs was 15:54:33. The ‘CreateDate’ time entry for the fourth photograph was 15:54:34. The hour and minute numbers did not correspond to the time of the accident because the camera clock time was not set correctly. However, only the seconds matter in the following analysis.

Since there was a relatively small difference between photographs 1, 2 and 3, it is assumed that they were taken in the ‘Continuous, High’ mode at the rate of 5.7 fps. Figure 4 is photograph No. 3. The fourth photograph shows the helicopter nose oriented to the right in contrast to its orientation to the left in photograph No. 3 shown Figure 4. This excludes the possibility of the fourth photograph being part of the 5.7 fps burst because such a yaw angle change in 1/5.7 seconds would require an unrealistic helicopter yaw rate of above 800 degrees per second.

Figure 4. Photograph No. 3 that Was Used in the Analysis

Consequently, it was concluded that the fourth photograph was taken in single-shot mode. It is not possible to estimate the minimum time that elapsed between the third and fourth photographs. As shown above, the minimum time assumption results in an unrealistically high yaw rate estimate. The maximum time can be estimated as follows. The time stamps differ by one second, 33 vs. 34, as stated above. Assume that the three-photograph burst started as early as possible to be stamped at 33 seconds, i.e., at 33.000 seconds. It lasted 2/5.7=0.35 seconds, implying that the third photograph was taken at 33.35 seconds. Assume that the fourth photograph was taken as late as possible to be stamped 34 seconds, i.e., at 34.999 seconds. Therefore, the maximum time difference is 34.999-33.35=1.649 seconds. This estimated maximum time difference will be used below for estimating the minimum yaw rate of the helicopter.

The HFOV angle of the camera was calibrated and known to be 4.3º. The location of the camera was known to be in the back yard of its owner. Therefore, it was possible to construct a model of the camera optics. The only important camera model parameter that was unknown at this stage was its pitch angle above horizontal. The pitch angle was estimated as follows.

The estimated helicopter ground track and above mean sea level (MSL) altitude were known from radar data. A 3D wireframe model of the helicopter was constructed and its image was mapped with the camera model onto photograph No. 3. The distance of the wireframe model from the camera and the camera pitch angle were then iterated until the mapped wireframe model optimally matched the image of the helicopter in the photograph.

Optimal match was achieved when the MSL altitude of the wireframe model was 2100±150 feet, its distance from the camera was 7200±500 feet, and the camera pitch angle was 11.6º above horizontal. This altitude and distance from the camera place the helicopter near the most northern point of the radar-based ground track and close to the location where the helicopter tail was found. It is estimated that the times when the four still photographs were taken are between radar-based time 16:48:22 and radar-based time 16:48:27 (assuming that radar-based ground track, altitude and time are exact), and close to time zero in Figures 2 and 3. This time, about 20 seconds before ground impact, corresponds approximately to the time when the helicopter started the descent that ended in ground impact.

Optimal match of the wireframe model with the image of the helicopter in a photograph also estimated the yaw and roll angles of the helicopter at the time a photograph was taken. Table 1 lists the estimated angles. The time was set to zero when photograph No. 1 was taken. This time is unrelated to the time shown in Figures 2 and 3. Positive roll angle corresponds to right side down. Increasing yaw angle indicates clockwise yaw rotation when viewed from above. The yaw angle data in Table 1 indicates that the helicopter was rotating clockwise when viewed from above. Zero yaw angle corresponds to the nose of the helicopter pointing to the right in the photographs.

Table 1. Estimated Orientation Angles of the Helicopter

	Time (second)	Yaw Angle (degree)	Roll Angle (degree)
Photograph No.1	0.00	-174	-57
Photograph No.2	0.175	-158	-59
Photograph No.3	0.35	-143	-53
Photograph No.4	≤2.00	9	-30

The estimated yaw rate during the first 0.35 seconds (from the time photograph No. 1 was taken to the time No. 3 was taken) is (-143+174)/0.35=89 degrees/second. The lower limit on the yaw rate estimate between the times corresponding to photographs No. 3 and photograph No. 4 is (9+143)/(2.00-0.35)=92 degrees/second. The lower limit on the roll rate estimate between the times corresponding to photographs No. 3 and photograph No. 4 is (-30+53)/(2.00-0.35)=14 degrees/second. The accuracy of the angular rate estimates is about ±5%.

The helicopter tail structure appears undamaged in the last available photograph (No. 4). At that time, the helicopter was already experiencing a high yaw rate.

E. <u>CONCLUSIONS</u>

Motion of a helicopter that crashed was analyzed based on a video and on a sequence of still photographs. The video indicated that the helicopter was descending with the estimated acceleration of 0.37±0.04 g.

The photographs indicated that the estimated yaw rate of the helicopter about 20 seconds before ground impact was at least 92±5 degrees/second. The helicopter started its descent that ended in ground impact approximately at the time when this yaw rate was estimated. The helicopter tail structure appears undamaged in the photographs.