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

April 19, 2016

Video Study

NTSB Case Number:
CEN15MA290

A. ACCIDENT

Location:	Frisco, Colorado
Date:	July 3, 2015
Time:	1339 MDT
Aircraft:	Airbus Helicopter AS350 B3e

B. AUTHOR

Dan T. Horak
NTSB

C. ACCIDENT SUMMARY

On July 3, 2015, at 1339 mountain daylight time, an Airbus Helicopter Inc. (formerly American Eurocopter) AS350 B3e helicopter, N390LG, impacted the upper west parking lot 360 feet southwest of the Summit Medical Center helipad (91CO), Frisco, Colorado. A post-impact fire ensued. Visual meteorological conditions prevailed at the time of the accident. The helicopter was registered to and operated by Air Methods Corp., and the flight was conducted under the provisions of 14 *Code of Federal Regulations* Part 135 on a company flight plan. The airline transport pilot was fatally injured and two flight nurses were seriously injured. The public relations flight was en route to Gypsum, Colorado.

D. DETAILS OF INVESTIGATION

The crashing helicopter was captured in a video for approximately one second before it impacted ground in the Medical Center parking lot. The video was recorded by a camera mounted on a light pole. The resolution of the video was 704x480. The frame rate was alternating between 10 fps and 15 fps from frame to frame so that no two consecutive frame intervals were equal. This resulted in average frame rate of 12 fps. The helicopter was approximately 100 ft from the camera.

Speed estimation of the helicopter was based on a mathematical model of the camera. The model was used to project reference points onto frames from the video and interactively align the projected points with their images in the frames. This approach was used first for calibrating the camera model and then for estimating helicopter trajectory and speed, as described next.

Camera Calibration

Mathematical model of camera optics requires seven parameters. Three are the X, Y and Z camera location coordinates. Three are the roll, pitch and yaw camera orientation angles, and the seventh parameter is the camera horizontal field of view (HFOV). The parking lot where the helicopter crashed was surveyed with a total station which provided accurate X, Y and Z camera location measurements. The other four parameters had to be estimated.

The estimation was based on 26 reference points that were surveyed and were visible in the video. These points included end points of white lines that marked parking spaces in the lot and points on light poles and sidewalk poles. A computer program was used to project these reference points onto a frame from the video in an iterative process in which the four parameters were varied so as to align the projected points with their images. When the projected points were aligned optimally with their images in the frame, values of the four parameters were their optimal estimates. At that point, the mathematical model of the camera was calibrated.

Helicopter Trajectory and Speed Estimation

Helicopter location and orientation in ground coordinates were estimated by projecting reference points located on it onto frames from the video using the calibrated camera model. Thirteen reference points on the helicopter were used. They included points on the nose, the horizontal and vertical stabilizers, the skid landing gear and the main rotor hub. The relative locations of these points were measured off schematic drawings of the helicopter in a coordinate system with origin at the nose of the helicopter.

A computer program similar to the one used for camera calibration was used for estimating location and orientation of the helicopter. The seven camera model parameters were fixed at their estimated values. The program was capable of moving the set of the thirteen helicopter reference points in the X, Y and Z directions, and orienting the set according to Euler yaw-pitch-roll sequence of rotations.

Twelve video frames were analyzed. The last one showed the helicopter impacting ground. The first one was the frame in which the full image of the helicopter was first visible. The helicopter was partially visible in four frames before the first analyzed frame. There was no need to analyze these four frames to derive an accurate estimate of the ground impact speed.

Analysis of each frame consisted of iterative movement (X, Y and Z) and rotation (roll, pitch and yaw angles) of the set of thirteen reference points until they optimally coincided with their images in the video frames. At that time, the X, Y, Z, roll, pitch and yaw were the optimal estimates of the helicopter location and orientation in ground coordinates.

The camera was located north of the crash location, looking approximately south. Therefore, a convenient coordinate system for specifying helicopter location and orientation when analyzing the video was

X	positive to west
Y	positive to south
Z	positive up
Yaw	0º when pointing west, positive counterclockwise
Pitch	positive when nose down
Roll	positive when right stabilizer down

Figure 1 shows the three angle estimates. Time is set to zero at the first analyzed point. The accuracy of these estimates is ±3º. Note that just before ground impact, at time 0.93 seconds, the pitch and roll angles were small.

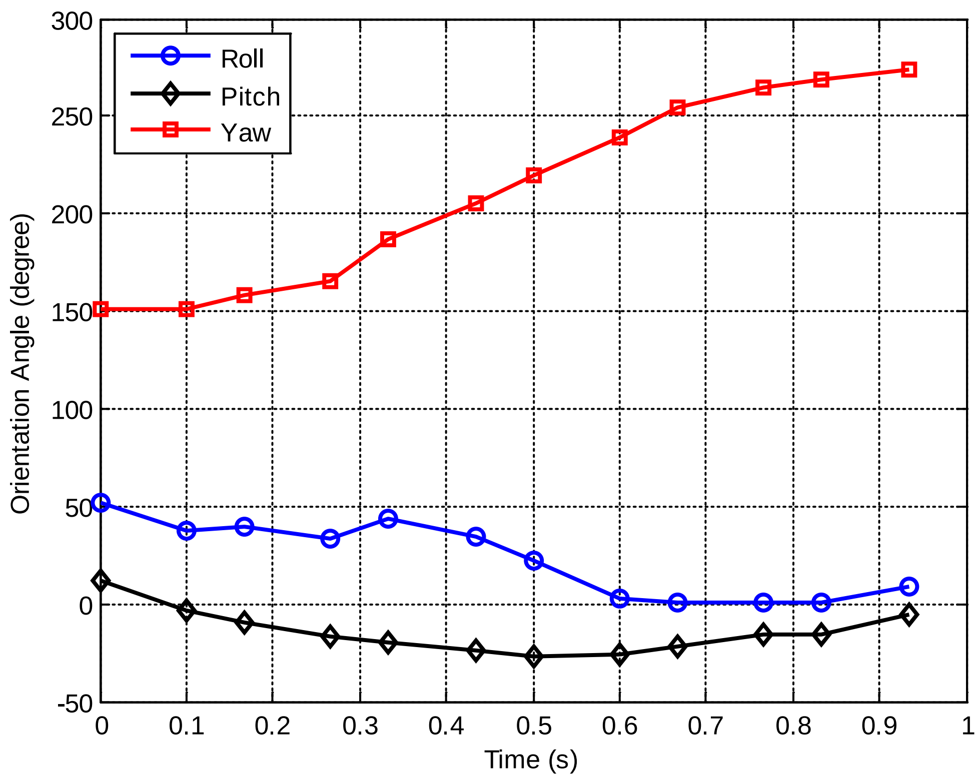

Figure 1. Estimated Helicopter Euler Orientation Angles

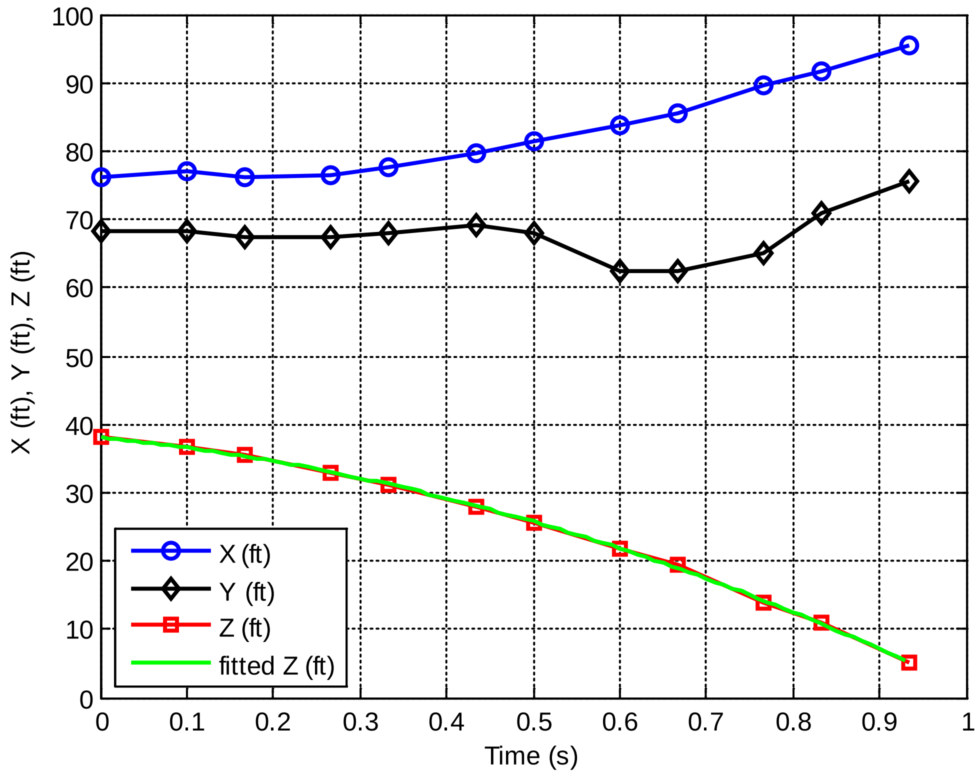

Figure 2. Estimated Helicopter Locations

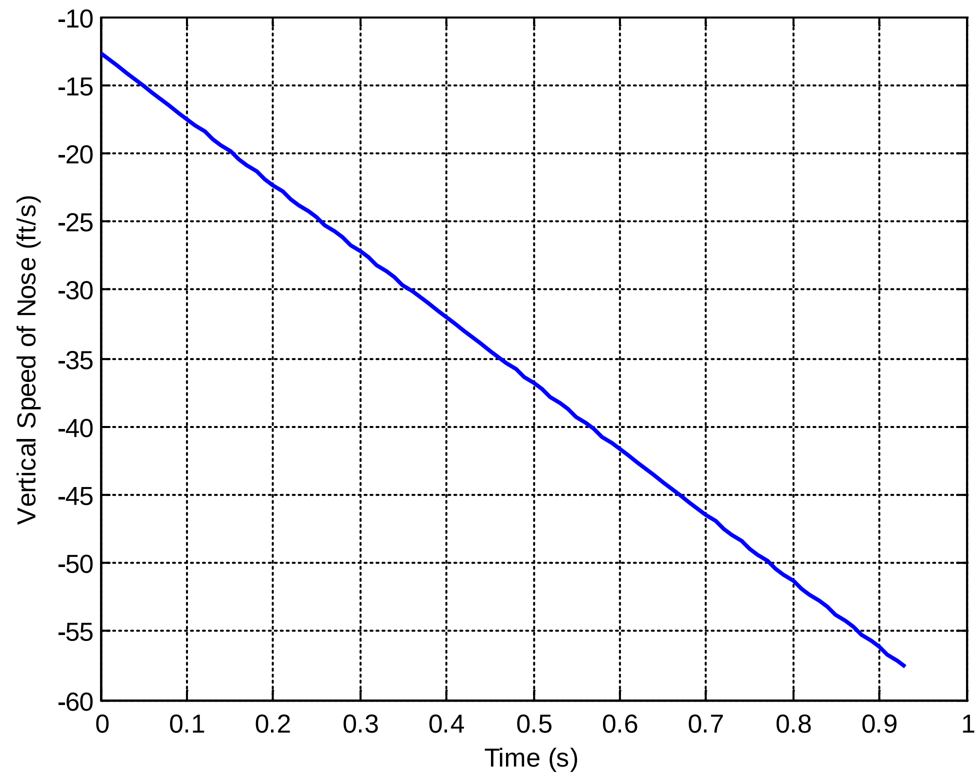

Figure 3. Estimated Helicopter Vertical Speed

Figure 2 shows the estimated locations of the helicopter in ground coordinates. The locations are those of the helicopter nose. The accuracy of these estimates is ±3 ft. The last point in the figure is just before ground impact. The coordinate of interest is Z, the vertical location. A second order polynomial curve was fitted to it and matched it very accurately, as seen in Figure 2. The two curves virtually overlap. The vertical speed, computed based on the polynomial fit, is shown in Figure 3. It was 58 ft/s just before ground impact.

The estimated nose vertical acceleration was constant -1.5 g, as evident by the straight line in Figure 3. It had to be constant because of the second order polynomial curve fit. During the analyzed 0.93 seconds, the helicopter was undergoing 3D translation and rotation with the rotor spinning. Therefore, one should not expect the nose acceleration to be -1.0 g.

Figure 1 shows a small pitch rate at the time of ground impact. The polarity of the pitch rate is positive, meaning that it reduces the magnitude of the vertical speed of points aft of the helicopter nose relative to the nose speed. However, the pitch rate was relatively small and was difficult to estimate at time of ground impact because the helicopter nose was pointed toward the camera. Additionally, just before the fuselage impacted ground, the skid landing gear impacted ground, collapsed, and probably altered the fuselage pitch rate. The magnitude and polarity of this effect were not measurable from the video. Consequently, since it was not possible to estimate it accurately, the possible pitch rate contribution to vertical speed was accounted for in the tolerance of the ground impact speed estimate and it was specified as 58±5 ft/s.

Comments about Ground Impact

Fuel tank resistance to impacts can be tested by dropping it from varying heights onto a hard surface, measuring the acceleration at impact time with an accelerometer attached to the tank, and observing the damage the impact caused. The fuel tank resistance to impact can then be specified by the highest acceleration that did not cause tank rupture. Note that the measured acceleration depends on the elevation from which the tank was dropped, type of surface onto which it was dropped, the orientation with which it impacted the surface, and the attachment point of the accelerometer.

Information derived by analyzing this accident cannot generate acceleration information that could be directly compared to the impact resistance measured during such fuel tank testing. There are three main reasons for it.

1. The frame rate of the video is not sufficiently high for measuring accelerations caused by impact with ground.
2. The AS350 B3e fuel tank is internal to the fuselage so that even if acceleration of the fuselage was measurable from the video, fuel tank acceleration that could be compared to accelerometer measurements during drop-testing could not be derived from it.

3. Upon ground impact, the accident helicopter fuselage was heavily damaged, and probably exerted multi-directional forces on the fuel tank. It is possible that these forces damaged the tank and caused the fuel leak. The standard fuel tank drop test does not test against such forces.

However, the accident helicopter impacted ground with small roll and pitch angles and the impact speed was accurately estimated from the video. Therefore, information from this accident may be useful in estimating the maximum ground impact speed that the helicopter can withstand without causing fuel tank leaks.

Figures 4, 5 and 6 illustrate the severe fuselage damage caused by ground impact. Figure 4 is at time of impact, with the fuselage still intact. Figure 5 shows the helicopter 0.33 seconds after ground impact. It has already rolled approximately 90 degrees to right. Figure 6 shows the helicopter one second after ground impact.

Figure 4. Accident Helicopter at Time of Ground Impact

<u>Climb Rate after Takeoff</u>

The Ambulance Bay camera captured the first eight seconds of flight of the helicopter and was used for estimating its vertical speed. The camera was calibrated based on dimensional information measured in Google Earth images. Figure 7 shows the estimated elevation above ground of the helicopter. Two fixed-speed lines were fitted to the elevation data, one over the last 5.4 seconds and the other over the last 2.9 seconds. The slopes of these lines can be viewed as the lower and upper bounds on the estimated climb rate. They are 5.1 ft/s and 6.1 ft/s, respectively. Therefore, the estimated vertical speed shortly after takeoff is 5.6±0.5 ft/s.

Figure 5. Accident Helicopter 0.33 Seconds after Ground Impact

Figure 6. Accident Helicopter One Second after Ground Impact

<u>Yaw Rate after Takeoff</u>

The Flight for Life camera ('FFL camera') video captured the flying helicopter for approximately ten seconds after takeoff and its shadow for two additional seconds. The average yaw rate over the first eight seconds was approximately 22 degrees per second, counterclockwise in top view, and the average rate over the last four seconds was approximately 45 degrees per second. This resulted in average rate during the first twelve seconds of flight of approximately 30 degrees per second. These yaw rates were estimated by viewing the video and the accuracy of the estimates is approximately ±10%.

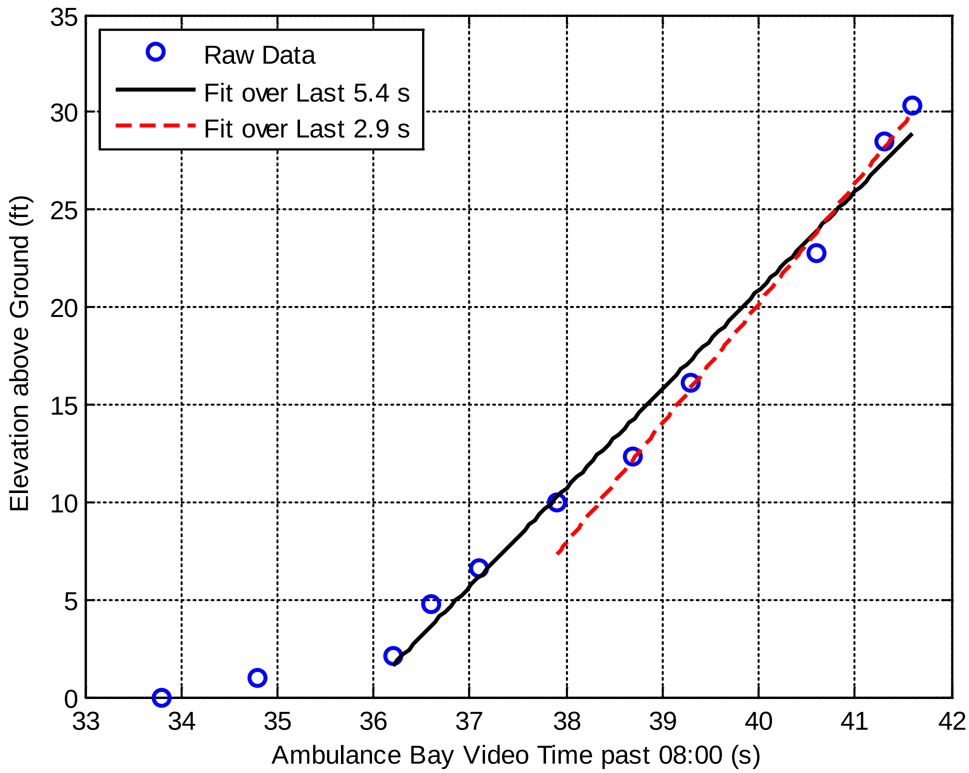

Figure 7. Estimated Helicopter Elevation above Ground after Takeoff

E. CONCLUSIONS

Video captured by a camera mounted on a light pole in a parking lot was used for estimating trajectory and speed of a crashing helicopter. It was estimated that the helicopter impacted ground with small pitch and roll angles at the speed of 58±5 fps (40±3 mph).

It was further estimated that the average yaw rate of the helicopter during the first twelve seconds of flight was 30±3 degrees per second, reaching the maximum value of 45 degrees per second toward the end of the twelve second period.

The estimated helicopter climb rate shortly after takeoff was 5.6±0.5 ft/s. Toward the end of the analyzed first eight seconds of flight, the climb rate reached the maximum value of 6.1 ft/s.