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

October 5, 2020

Video Study

NTSB Case Number:
ERA20FA022

A. ACCIDENT

Location:	Ocala, Florida
Date:	October 31, 2019
Time:	1130 eastern daylight time
Aircraft:	Beechcraft BE-58

B. AUTHOR

Dan T. Horak
NTSB

C. ACCIDENT SUMMARY

On October 31, 2019, at 1130 eastern daylight time, a Beechcraft BE-58, N959CM, was destroyed when it was involved in an accident near Ocala International Airport - Jim Taylor Field (OCF), Ocala, Florida. The private pilot and a passenger sustained fatal injuries and one occupant in a motor vehicle was seriously injured. The airplane was operated as a Title 14 *Code of Federal Regulations* Part 91 personal flight.

D. DETAILS OF INVESTIGATION

The goal of this investigation was estimating the trajectory, altitude, speed and orientation angles of the airplane. Analysis was based on a video recorded by a camera installed in an electric car that was parked at a charging station. The video had 1060x720 resolution and frame rate of 30 fps.

The airborne airplane or part of it were visible in the video for 0.133 seconds ending at the time when the right wing touched the surface of a road. The shadow of the airplane was also visible during this time. Prior to that time, only the shadow of the airplane on the ground was visible. The total time when the shadow was visible sufficiently clearly to allow analysis was 1.25 seconds, ending at the time when the right wing touched the surface of a road.

Figure 1 shows a frame from the analyzed video that was recorded 0.3 seconds prior to ground impact. Only the shadow of the airplane on the ground is visible in the frame and is marked. The video frame is barrel-distorted because of the wide-angle lens of the camera. This distortion was mathematically removed prior to analyzing the video.

Figure 1. Frame from the Video Recorded 0.3 seconds before Ground Impact

Figure 2 shows an aerial image of the accident scene. The figure shows the location of the camera, the location of ground impact, and the final location of the airplane. The dotted line in the figure shows the azimuth direction of sunlight at the time of the accident. This azimuth angle was used in the analysis of the shadow of the airplane on the ground, as described below. The aerial image was rotated clockwise by 48.5º so that the road became horizontal in the figure (note the direction of north indicated by the white arrow). The rotation aligned the aerial image with the orientation of the video that was recorded with a camera oriented perpendicularly to the road.

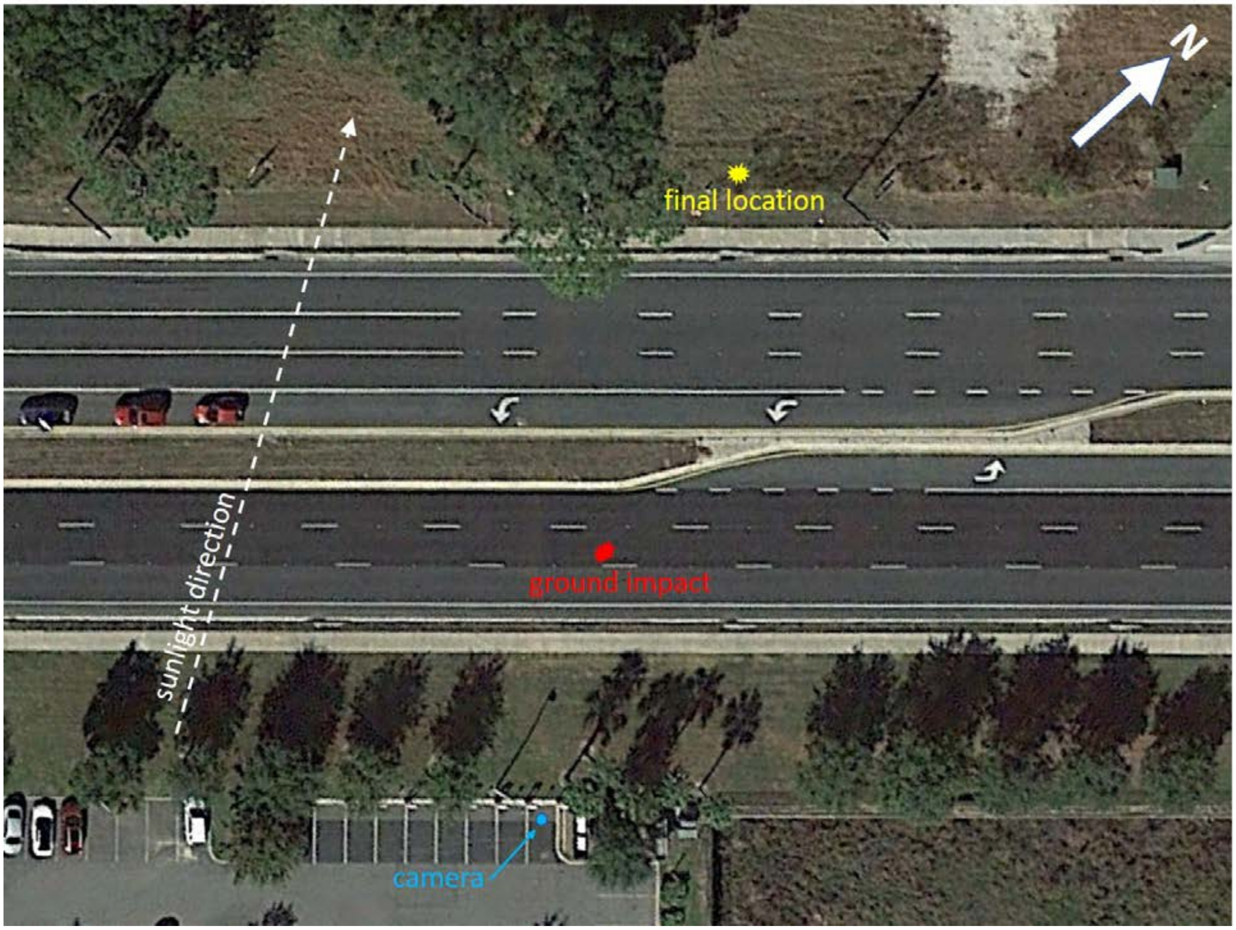

Figure 2. Aerial Image of the Accident Area

Camera Calibration

The analysis of this accident required a calibrated mathematical model of the camera optics. 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 (HFOV). The X and Y coordinates of the camera could be estimated from Google Earth aerial images and from video frames such as the one in Figure 1. The other five parameters had to be estimated.

The estimation was based on references that were visible both in aerial images and in video frames. The references used for calibration included the lane markings on the road, power line poles, trees, and details of the charging station seen in Figure 1.

A computer program that simulates camera optics was used to project the references onto a frame from the video in an iterative process in which the five 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 five parameters were their optimal estimates. At that point, the model of the camera optics was calibrated.

Analysis of Video Frames that Showed the Airplane or a Part of It

Five such video frames were available. The fifth frame showed the entire airplane at the time its right wing touched the ground. The other four only showed part of the airplane. The first of the five frames showed only part of its right wing.

A wireframe model of the Beechcraft BE-58 was constructed consisting of points on its nose, tail, wings and fuselage. 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 moved and rotated until it matched optimally the image of the airplane in the video frame. When optimal match was reached, the location (X, Y and Z) and the orientation angles (yaw, pitch and roll) of the wireframe model were the optimal estimates of the location and the orientation angles of the accident airplane.

Analysis of Video Frames that only Showed the Shadow of the Airplane

The NOAA Solar Calculator was used to determine that at the time of the accident the sun elevation angle was 40.8º and the sun azimuth angle was 148.2º. The azimuth direction of sunlight is shown in the rotated aerial view in Figure 2. Estimation of airplane location and orientation angles based on shadows has two main limitations compared to estimation based on images of the airplane.

The first limitation is the loss of information when the 3D details of the airplane are reduced to a 2D shadow. In this specific case, it resulted in limited ability to accurately separate between effects of airplane pitch and airplane roll on the shadow. When the airplane rather than only its shadow is visible in a video frame, there is no confusion between airplane pitch and airplane roll.

The second limitation is the inability to estimate airplane altitude above ground based on the shadow. Airplane shadow on the ground is generated by parallel sun rays. Therefore, the shape of the shadow is independent of the airplane altitude above ground. A shadow at a specific location on the ground could have been generated by an airplane that is close to the location of the shadow and at a low altitude, or by the same airplane located far from the shadow and at a high altitude.

Consequently, when the airplane wireframe model is moved and rotated until its software-generated shadow optimally matches the shadow visible in a video frame, the estimated X-Y location of the airplane depends on the assumed airplane altitude. As the assumed altitude is varied, the estimated X-Y location moves along the sunlight direction shown in Figure 2.

Estimated Ground Track of the Airplane

Figure 3 shows the estimated ground track (measured as the location of the cg) of the airplane. Points 9 through 13 were estimated based on video frames where the image (not just the shadow) of the airplane was visible. The estimation process also estimated the altitudes of the airplanes so that there is no uncertainty caused by unknown altitudes, as is the case where only the airplane shadow is visible. At point 9, the airplane was estimated to be 28 feet above the ground (see Figure 4).

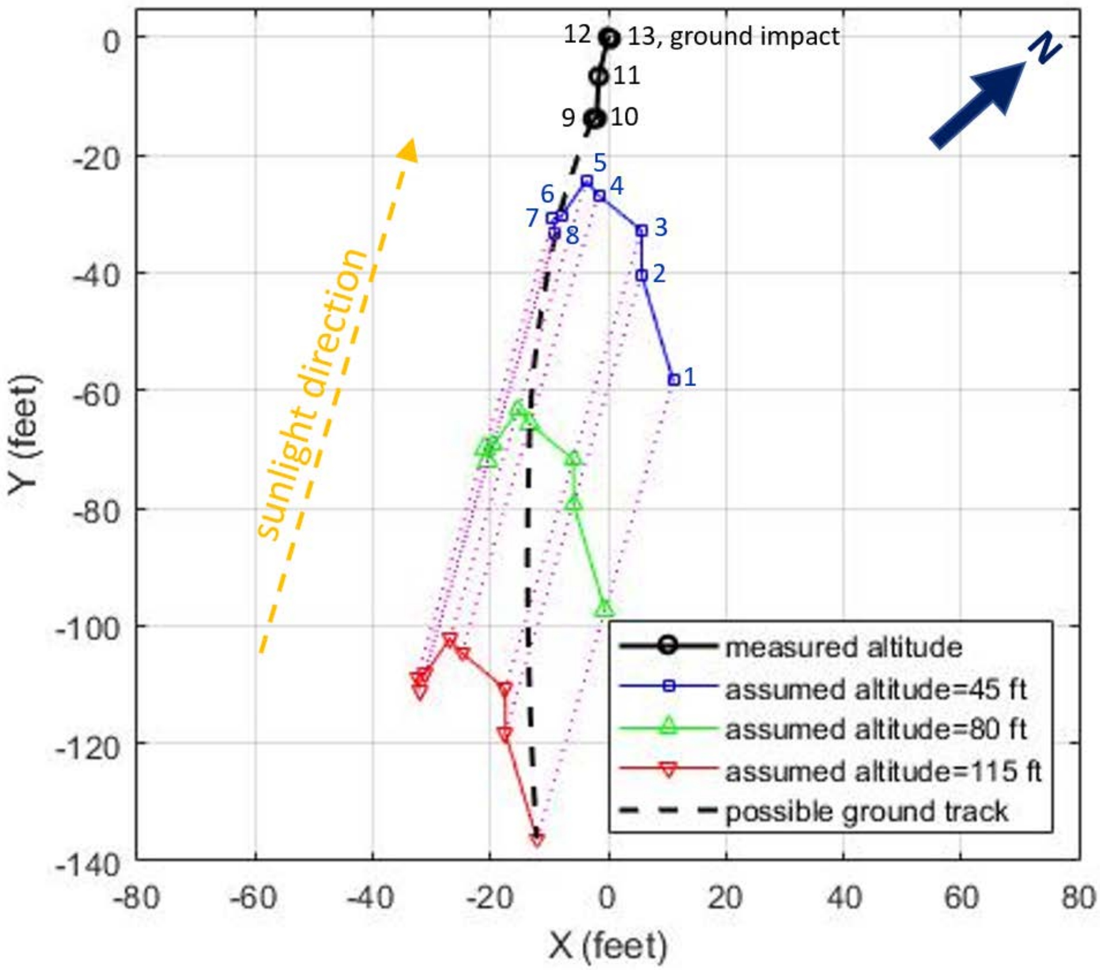

Figure 3. Estimated Ground Track of the Airplane

Points 1 through 8 were estimated based on airplane shadows. As explained above, the location of the shadow in the X-Y plane depends on the assumed altitude of the airplane. To deal with this uncertainty, ground track points 1 through 8 were estimated for three assumed altitudes, 45, 80 and 115 feet, shown in Figure 3 in blue, green and red, respectively. It is not likely that the airplane maintained constant altitude between points 1 and 8, i.e., it did not fly along the blue, green or red ground tracks.

It is reasonable to assume that at point 8 the airplane was at a relatively low altitude, such as 45 feet, shown in blue. It is also reasonable that at point 4 the airplane was at a higher altitude, such as 80 feet, shown in green, and at point 1, it was at an even higher altitude, such as 115 feet, shown in red. The hypothetical ground track shown by the broken black line in Figure 3 passes through these assumed points. While this hypothetical ground track is not based on measurable evidence, it does suggest that the airplane was flying approximately along the positive Y direction, i.e., approximately perpendicularly to the road seen in Figures 1 and 2.

Estimated Altitude, Speed and Orientation Angles of the Airplane

Figure 4 shows the estimated altitude above ground of the of the cg of the airplane. It is shown only at points 9 through 13, corresponding to video frames that allowed altitude estimation because they showed the airplane or part of it. At point 13, the right wing of the airplane was already touching the ground. It was not possible to estimate the altitude at earlier times because the corresponding video frames showed only the shadow of the airplane.

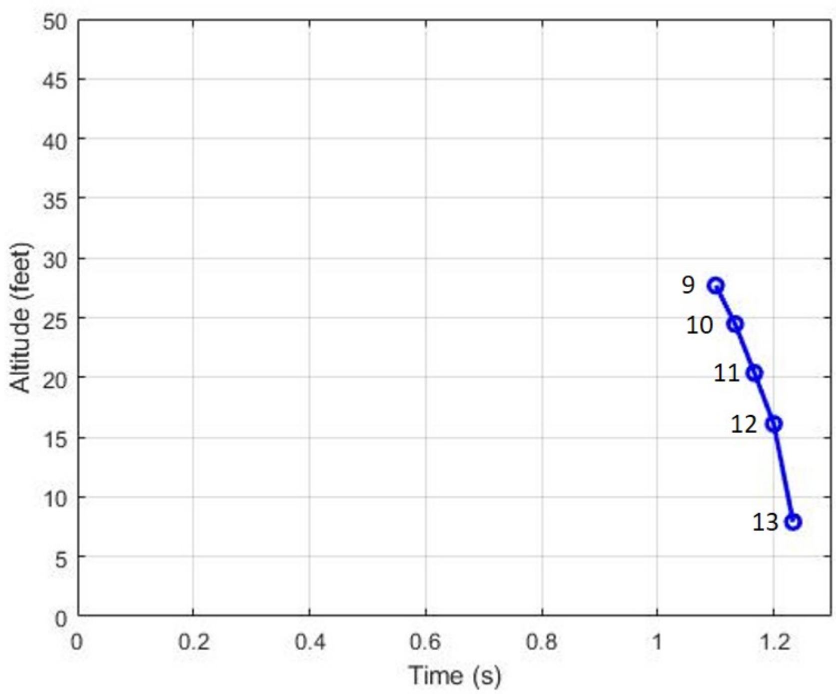

Figure 4. Estimated Altitude of the Airplane

The total time over which it was possible to estimate the altitude was only 0.133 seconds, as seen in Figure 3. The average descent rate during this time was 8900 feet per minute or 88 knots. The average ground speed during this time was 62 knots and the magnitude of the total speed vector was 107 knots.

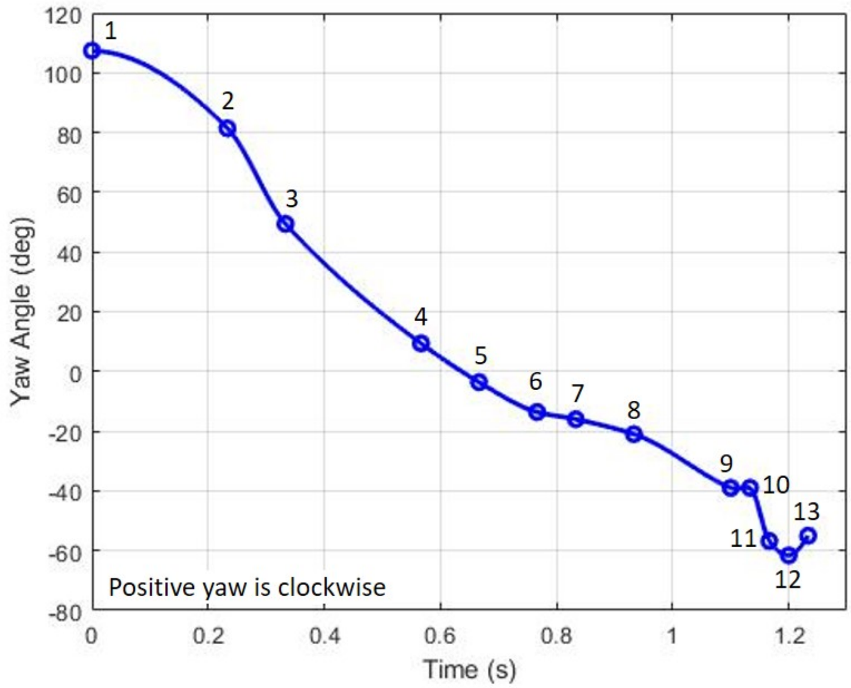

Figure 5. Estimated Yaw Angle of the Airplane

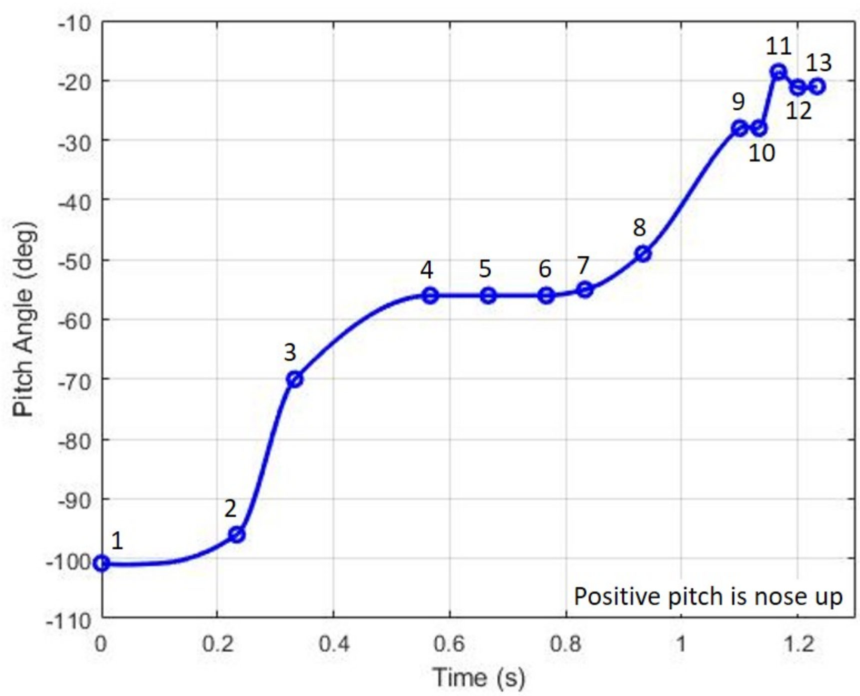

Figure 6. Estimated Pitch Angle of the Airplane

Figure 5 shows the estimated yaw angle of the airplane. Yaw is defined as zero when the airplane fuselage is oriented along the road, pointing to right in Figure 2. Yaw angles are positive clockwise from the zero direction. If the yaw angles were measured clockwise from north, the angles in Figure 5 would be higher by 41.5º. The figure shows that the airplane was rotating counterclockwise at the average rate of about 130 degrees per second. The yaw angles were estimated based on the image of the airplane and its shadow at points 9 through 13 and based on the shadow only at points 1 through 8.

Figure 6 shows the estimated pitch angle of the airplane. The figure shows that the airplane was in a nose-down orientation during the analyzed time period. Figure 7 shows the estimated roll angle of the airplane. The figure shows that the airplane was in a right-wing-down orientation during the analyzed time period.

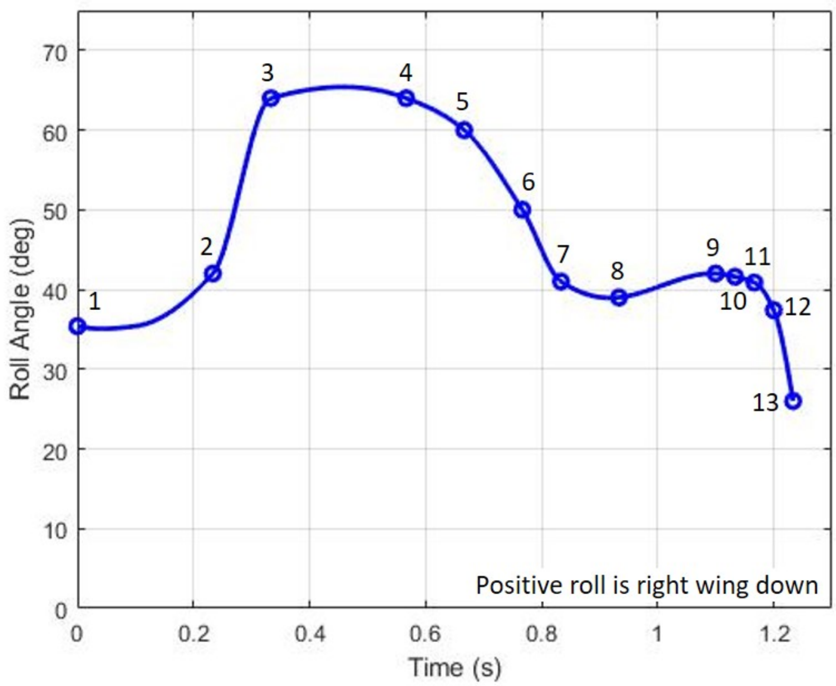

Figure 7. Estimated Roll Angle of the Airplane

The deflection of the rudder just before ground impact was estimated by adding a movable rudder to the wireframe model described above. The rudder deflection angle was then varied until it optimally matched the image of the rudder in a video frame. The deflection angle was estimated as 20º±4º to the left.

E. <u>CONCLUSIONS</u>

A video recorded by a camera installed in a parked car was used for estimating the ground track, altitude, speed and orientation angles of an airplane that crashed. Analysis was based on images of the airplane seen in the video and on images of the shadow of the airplane on the ground that were seen in the video.