

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Washington, D.C. 20594

May 27, 2021

Video Study

**NTSB Case Number:
ERA21FA142**

A. ACCIDENT

Location: Jupiter, Florida
Date: February 28, 2021
Time: 1230 EST
Aircraft: Luscombe 8E

B. AUTHOR

Dan T. Horak
NTSB

C. ACCIDENT SUMMARY

On February 28, 2021, at 1230 eastern standard time, a Luscombe 8E, N2601T, was substantially damaged when it was involved in an accident near Jupiter, Florida. One pilot sustained fatal injuries and the second pilot sustained serious injuries. 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 ground track, ground speed, altitude, orientation angles and engine speed of the airplane based on a video recorded by a viewer on the ground. The iPhone SE video was 29.8 seconds long, it had 3840x2160 resolution and frame rate of 30 fps. It recorded sound at the rate of 44,100 samples/second. The location of the camera is shown in Figure 1 that displays an aerial view of the accident area. The figure also shows seven ground track locations that were available from recorded ADS-B data. The airplane impacted the ground a short distance from the last ADS-B location.



Figure 1. Aerial Image of the Accident Area



Figure 2. Frame from the Video at Time 13 seconds

Camera Calibration

The estimation of the ground track, ground speed, altitude, and orientation angles of the airplane based on the video required a calibrated model of the optics of the camera that recorded the video. Such a model must be calibrated against references on the ground.

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 three location coordinates of the camera were known. The four angles had to be estimated as described next.

The estimation was based on references that were visible both in aerial images such as Figure 1 and in video frames such as the one in Figure 2. The references were the runway, buildings located along of the runway, and driveways. 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 four unknown angles 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 four angles were the optimal estimates of these parameters. At that point, the model of the camera optics was calibrated.

The HFOV angle remained constant during the video and, consequently, it had to be estimated only once. However, since the camera owner was filming a moving airplane and keeping its image near the center of the camera field of view, the yaw, pitch and roll camera orientation angles were different for each analyzed video frame. Consequently, the camera model had to be calibrated 14 times, once for each analyzed video frame.

Estimation of Airplane Locations, Speed and Orientation Angles

The calibrated camera optics model was then used to estimate the locations of the airplane at times corresponding to the 14 analyzed video frames. A wireframe model of the Luscombe 8E airplane was constructed, consisting of points on its nose, tail, rudder, stabilizers, wings, fuselage and landing gears. 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 at the time when the analyzed video frame was recorded.

Figure 3 shows the estimated locations of the airplane along the runway that is oriented in the west-to-east direction. The airplane was moving west-to-east. The camera was located about 1950 feet from the western end of the runway. Therefore, as seen in the figure, the airplane was in front of the camera at about video time 15 seconds.

The constant speed fit to the raw data in Figure 3 shows that the airplane was moving along the runway at the average speed of 43.7 knots.

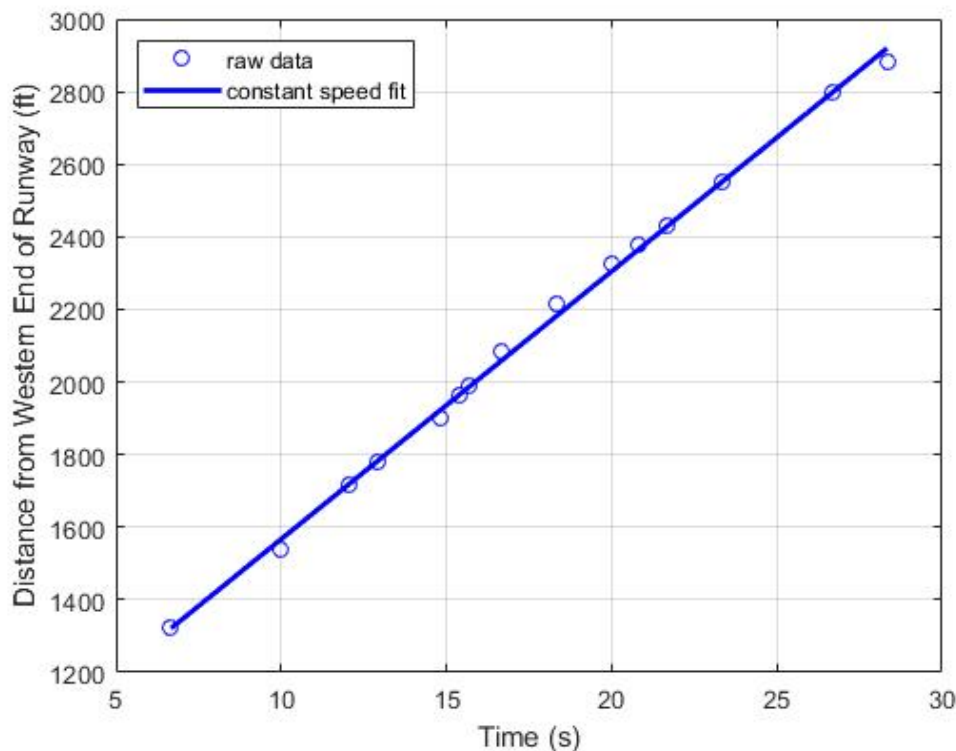


Figure 3. Estimated Airplane Distance from the Western End of Runway

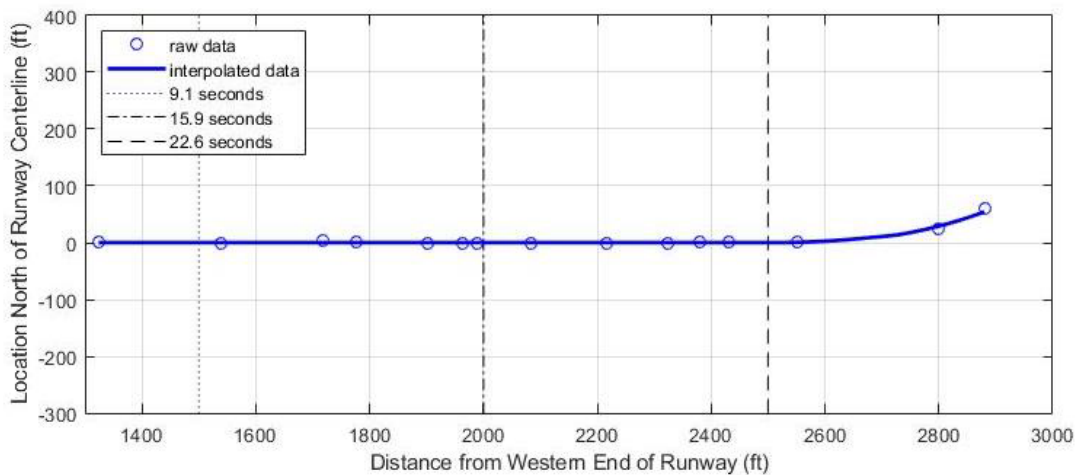


Figure 4. Estimated Airplane Ground Track

Figure 4 shows the estimated ground track of the airplane. The airplane was flying along the 3000-foot-long runway until about location 2600 feet. Past that location, it was turning left. Past the last data point in Figure 4, at runway distance 2880 feet, the airplane was obscured by a tree. The three vertical lines in the figure indicate the video times when the airplane was at locations 1500 feet, 2000 feet and 2500 feet along the runway.

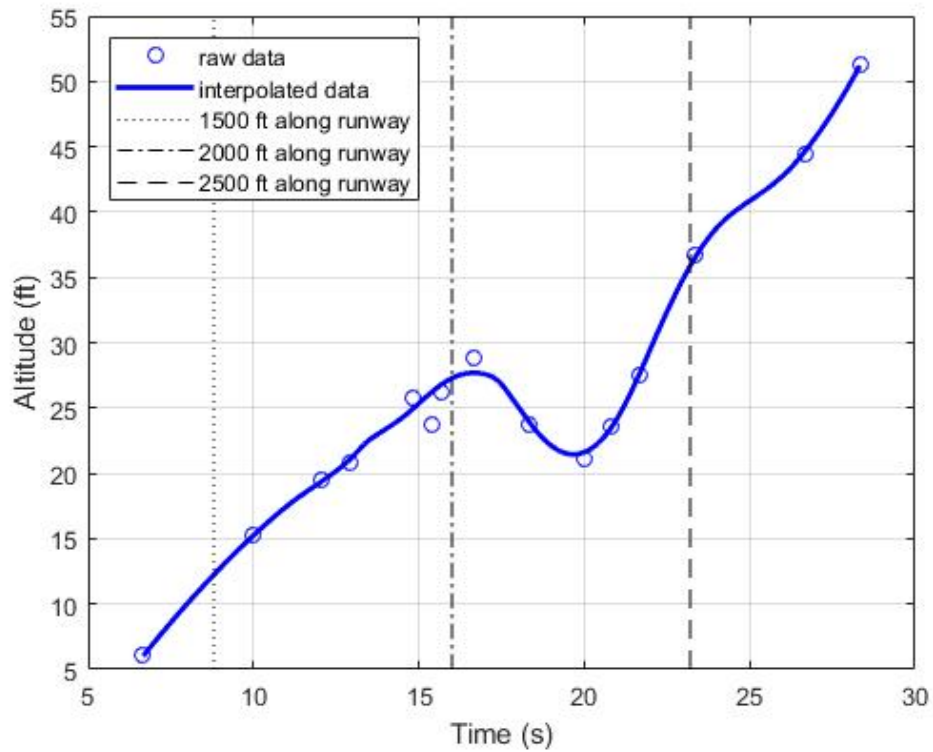


Figure 5. Estimated Airplane Altitude above the Runway

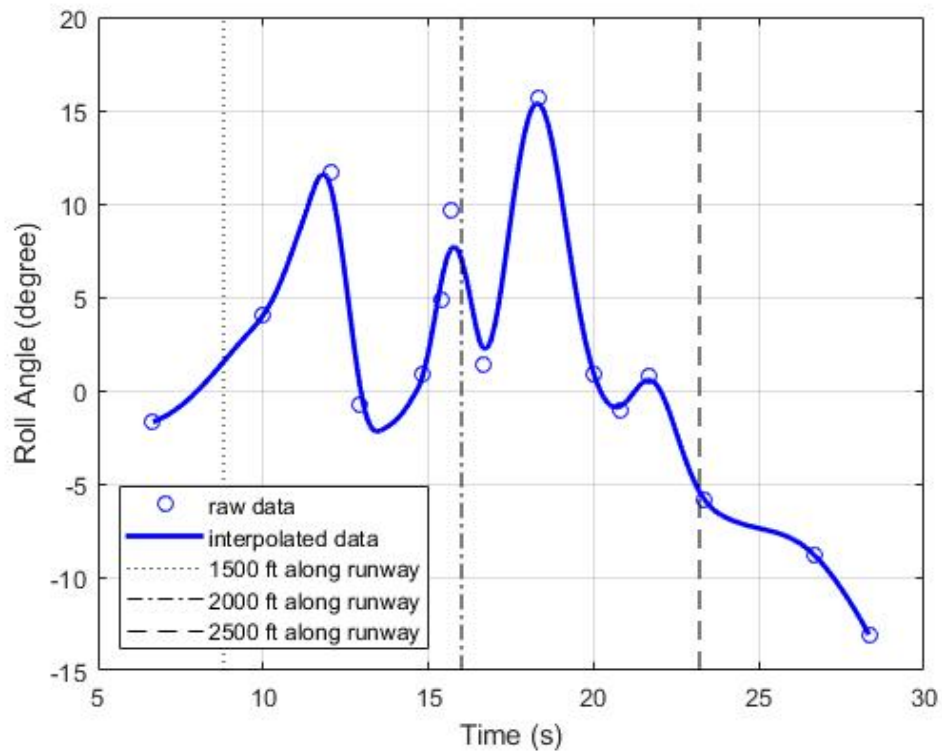


Figure 6. Estimated Airplane Roll Angle

Figure 5 shows the estimated altitude of the airplane above the runway. The altitude was measured as the height of the airplane nose above the runway surface. The three vertical lines in the figure are at video times when the airplane was at locations 1500 feet, 2000 feet and 2500 feet along the runway. The interpolated data curve in the figure was generated by first interpolating between the raw data points and then smoothing the data to filter out altitude jumps caused by the ± 2 foot uncertainty of the estimated raw data points.

Figure 6 shows the estimated roll angle of the airplane. The figure shows two large right-wing-down roll transients, one at about time 12 seconds peaking at about 12° and one at about time 18 seconds peaking at about 15° . The interpolated data curve in the figure was generated by first interpolating between the raw data points and then smoothing the data to filter out roll angle jumps caused by the $\pm 2^\circ$ uncertainty of the estimated raw data points.

Estimation of Engine Speed

The airplane was powered by a Continental C90 Series engine and the propeller had two blades. It is estimated that the normal engine speed during takeoff would be about 2400 rpm, resulting in blade passage frequency (BPF) of about 4800 cycles per minute (cpm). The sound due to the blade passage was recorded in the sound stream in the video. Spectral analysis of the sound was used to estimate the speed of the engine as the airplane was moving along the runway.

Figure 1 shows that the recorded frequencies due to blade passage will be affected by the Doppler effect. When the airplane was far from the camera and was approaching it, the recorded sound frequencies will be increased by a factor of 1.07. As the airplane was flying away from the camera and was far from it, the recorded sound frequencies will be scaled down by a factor of 0.94. When the airplane is closer than 200 feet from the camera, the Doppler multiplier transitions smoothly from 1.07 to 0.94, and is 1.00 when the airplane is in front of the camera.

Figure 7 shows six sound spectra computed in windows that were 1.5 seconds wide. The starting times of the six windows were all before the airplane reached the camera so that the Doppler factor was about 1.07 for all of them. The Fast Fourier Transform (FFT) algorithm used 65536 points and the frequency resolution was 40 cpm. The window starting at time 9 seconds shows BPF of 4845 cpm, that after Doppler shift correction corresponds to engine speed of $4845/2/1.07=2264$ rpm. The window starting at time 11 seconds shows BPF of 4118 cpm, that after Doppler shift correction corresponds to engine speed of $4118/2/1.07=1924$ rpm. This indicates an engine speed decrease of 340 rpm in about 3 seconds.

Spectral analysis and Doppler shift correction were performed in 1.5-second-wide time windows over the duration of the video. Figure 8 shows the estimated engine speed vs. time. The Figure shows that starting at time 10 seconds, engine speed was decreasing for about 7.5 seconds. This period included two sudden speed decreases.

The decrease starting at about time 10 seconds was by about 290 rpm. The decrease at about time 17 seconds was by about 330 rpm. The speed was above 2250 rpm only between time 7 seconds and time 10 seconds. The speed reached a minimum of 1530 rpm at about time 18 seconds and then climbed to about 1860 rpm at the last data point at about time 29 seconds.

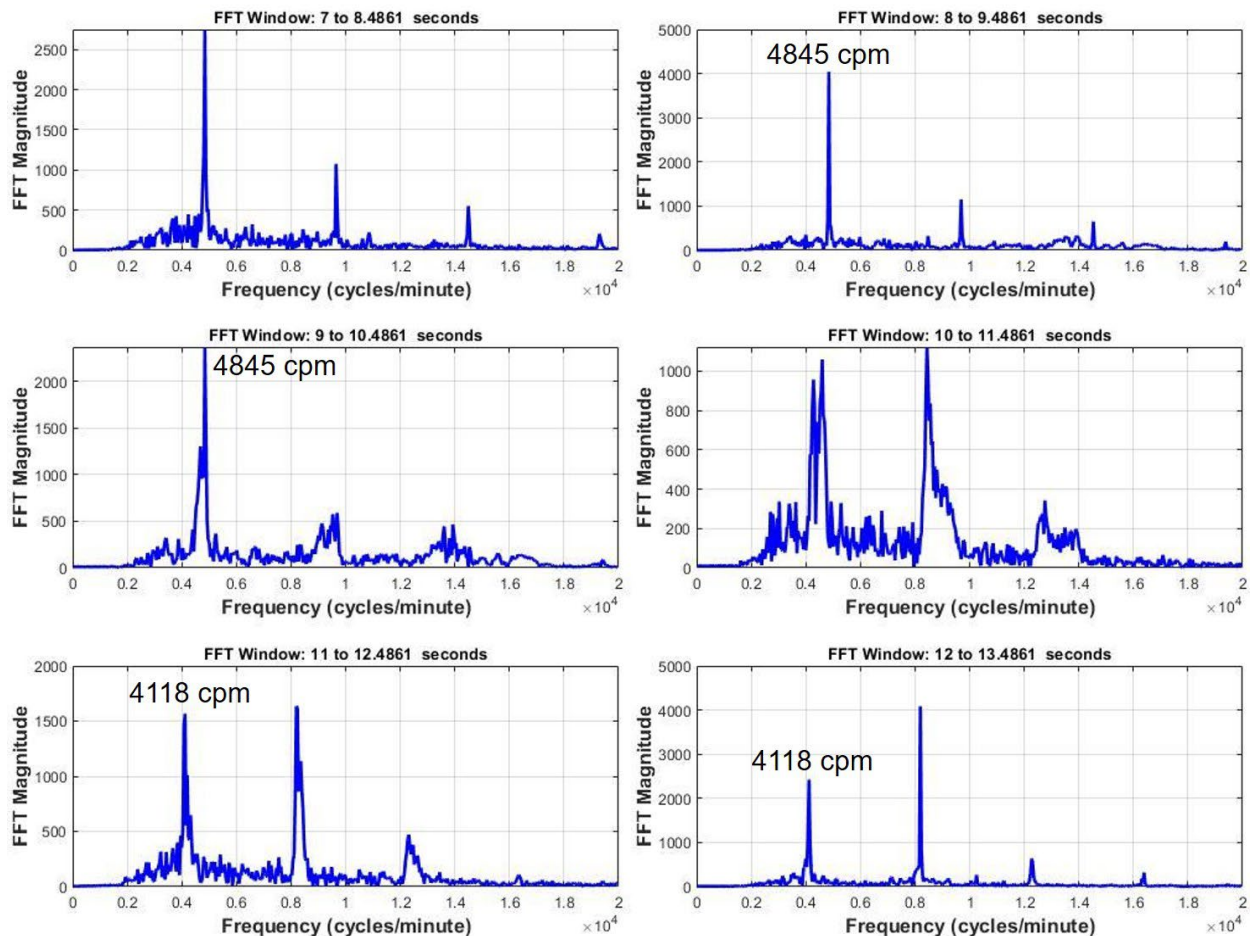


Figure 7. Spectrum of the Recorded Sound

Other Observations

The video shows that the left engine cowl was open and flapping up and down as the airplane was flying. The open cowl could be seen in the video starting at time 11.2 seconds and could have been open even earlier. At time 11.2 seconds, the airplane was about 1340 feet from the eastern end of the runway.

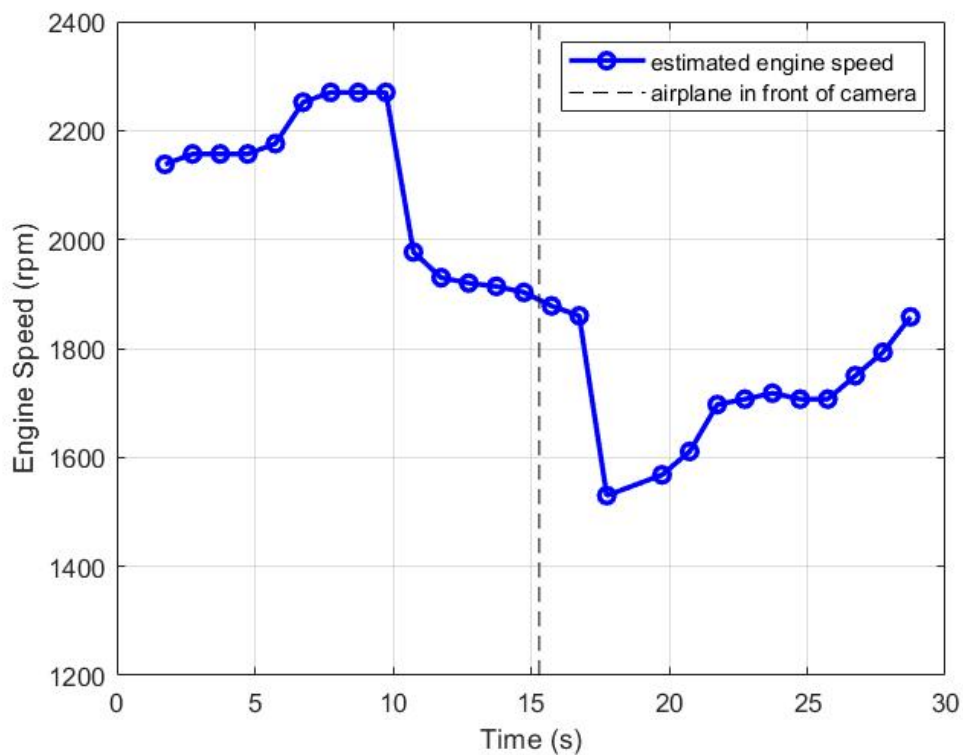


Figure 8. Estimated Engine Speed

E. CONCLUSIONS

The ground track, ground speed, altitude, roll angle and engine speed of an airplane that crashed shortly after takeoff were estimated based on a video recorded by a viewer on the ground. Both the visual and the sound information in the video were used in the analysis. The analysis showed that the airplane was flying with its left engine cowl open and the engine speed was substantially below the normal engine speed for takeoff of about 2400 rpm.