

NATIONAL TRANSPORTATION SAFETY BOARD

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

August 5, 2022

Video Study

**NTSB Case Number:
ERA21FA354**

A. ACCIDENT

Location:	Provincetown, Massachusetts
Date:	September 9, 2021
Time:	1527 EDT
Aircraft:	Cessna 402C, N88833

B. AUTHOR

Dan T. Horak
NTSB

C. ACCIDENT SUMMARY

On September 9, 2021, at about 1527 eastern daylight time, a Cessna 402C, N88833, was substantially damaged when it was involved in an accident while landing at Provincetown Municipal Airport (PVC), Provincetown, Massachusetts. The pilot and six passengers were seriously injured.

D. DETAILS OF INVESTIGATION

The goal of this investigation was estimating the distance along the runway, touchdown speed, ground speed and deceleration rate during the landing roll, as well as the acceleration during an attempted go-around of an airplane that crashed. Analysis was based on videos recorded by three airport cameras. Camera No. 1 and camera No. 2 had 1920x1080 resolution and frame rate of 12 fps. Camera No. 3 could not be calibrated accurately and was only used for estimating the time when the airplane hit trees during the attempted go-around. Figure 1 is an aerial view of the PVC airport. The aerial view is shown rotated to better correspond to the fields of view of the airport cameras. The figure shows the 3500 feet long runway and the locations of the three cameras that recorded the analyzed videos. The touchdown location is marked with the red circle.

The three segments along the runway where the airplane was in the fields of view of the cameras are marked by the three green lines. Camera No. 1 covered the beginning of the runway, camera No. 2 covered the middle section of the runway, and camera No. 3 covered the end of the runway. The field of view of camera 3 extended well beyond the end of the runway. There is an about 150 feet long runway segment that was not covered by either camera No. 1 or camera No. 2 and an about 400 feet long runway segment that was not covered by either camera No. 2 or camera No. 3.

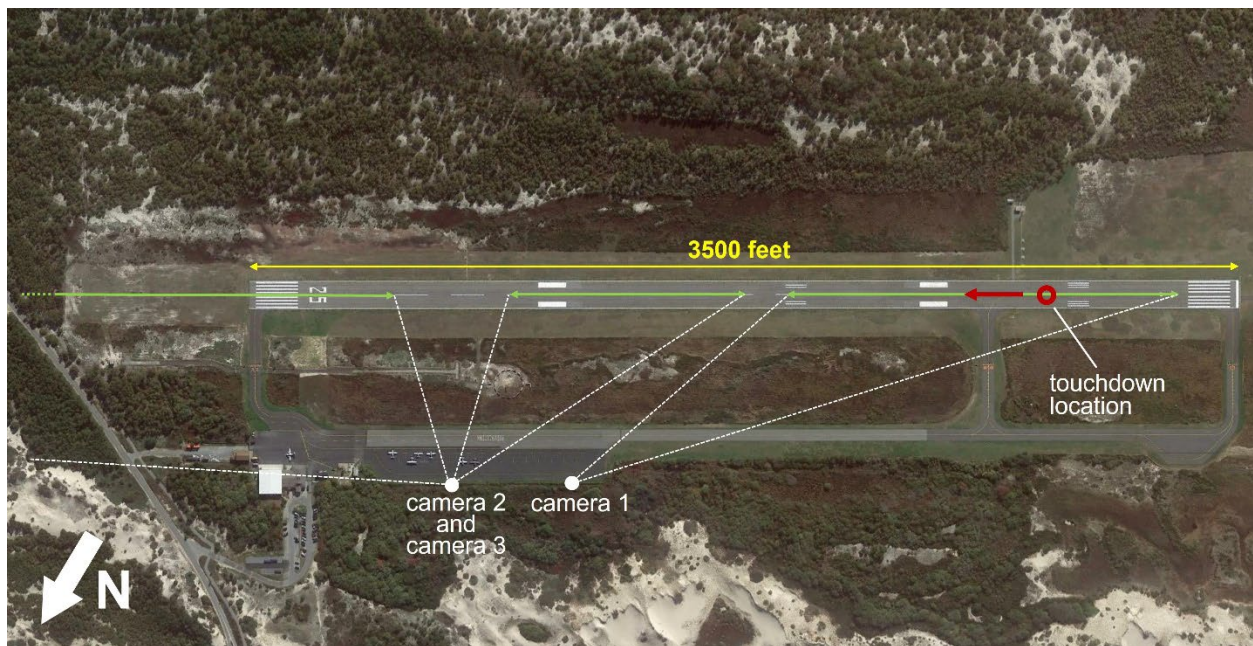


Figure 1. Aerial View of the Provincetown Municipal Airport

Figure 2 shows a segment from a video frame from video No. 1 that was recorded with camera No. 1. It shows the airplane shortly before exiting the field of view of the camera. The visibility of the airplane is poor because it was raining at the time of the accident.

Camera Calibration

The estimation of the location of the airplane along the runway based on videos required calibrated mathematical models of the optics of the cameras that recorded the videos. Such models 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 X and Y location coordinates of the cameras were known. The height of the cameras above ground, Z, and the four angular parameters had to be estimated in the calibration process.



Figure 2. Segment of a Video No. 1 Frame Recorded at Time 11.7 seconds

The estimation was based on references that were visible both in aerial views such as Figure 1 and in video frames such as the one in Figure 2. The references were the taxiway, the runway, runway markings, runway lights, and other details seen in the videos. A computer program that simulates camera optics was used to project the references onto frames from the videos in an iterative process in which the five unknown camera 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 camera parameters were their optimal estimates. At that point, the models of the camera optics were calibrated. Since two of the three cameras were used in the analysis, the calibration process was performed twice.

Estimation of Airplane Locations, Speed, and Deceleration

The calibrated camera optics models were then used to estimate the locations of the airplane at times corresponding to the analyzed video frames. A wireframe model of the Cessna 402C airplane was constructed, consisting of points on its nose, tail, fuselage, wings, stabilizers and tires. An analysis program that used the calibrated camera models was then used to project the wireframe model onto a video frame. The wireframe model was moved along the runway until it matched optimally the image of the airplane in the video frame. When optimal match was reached, the location of the wireframe model along the runway was the optimal estimate of the location of the accident airplane at the time when the analyzed video frame was recorded.

Twelve airplane locations along the runway were estimated based on video No. 1 that was recorded with camera No. 1. Ten airplane locations along the runway were estimated based on video No. 2 that was recorded with camera No. 2. As mentioned above, camera No. 3 was used only for estimating the time when the airplane hit trees.

Figure 3 shows the distance of the airplane along the runway, measured from the runway threshold, vs. video No. 1 time. Analysis time was set to zero when video No. 1 started and video No. 1 time was used in this report even when discussing or displaying results based on video No. 2 or video No. 3. The dotted line in the figure is at the estimated touchdown time that was at 6.1 seconds into the video. Before 6.1 seconds, the airplane was still airborne. Because of the poor visibility due to rain and the distance from camera No. 1 to the touchdown location, both the estimated touchdown time and the estimated touchdown location have limited accuracy.

The figure shows three distance vs. time curves. The blue line is based on data derived from video No. 1 and the black line is based on data derived from video No. 2. The cyan line is a hypothetical distance vs. time curve from the end of the black line to a point at the location and time where and when the airplane impacted trees. The acceleration during this segment will be estimated below. The dotted magenta line is at the end of the 3500-foot long runway. The accuracy of the estimated distances along the runway is ± 30 feet.

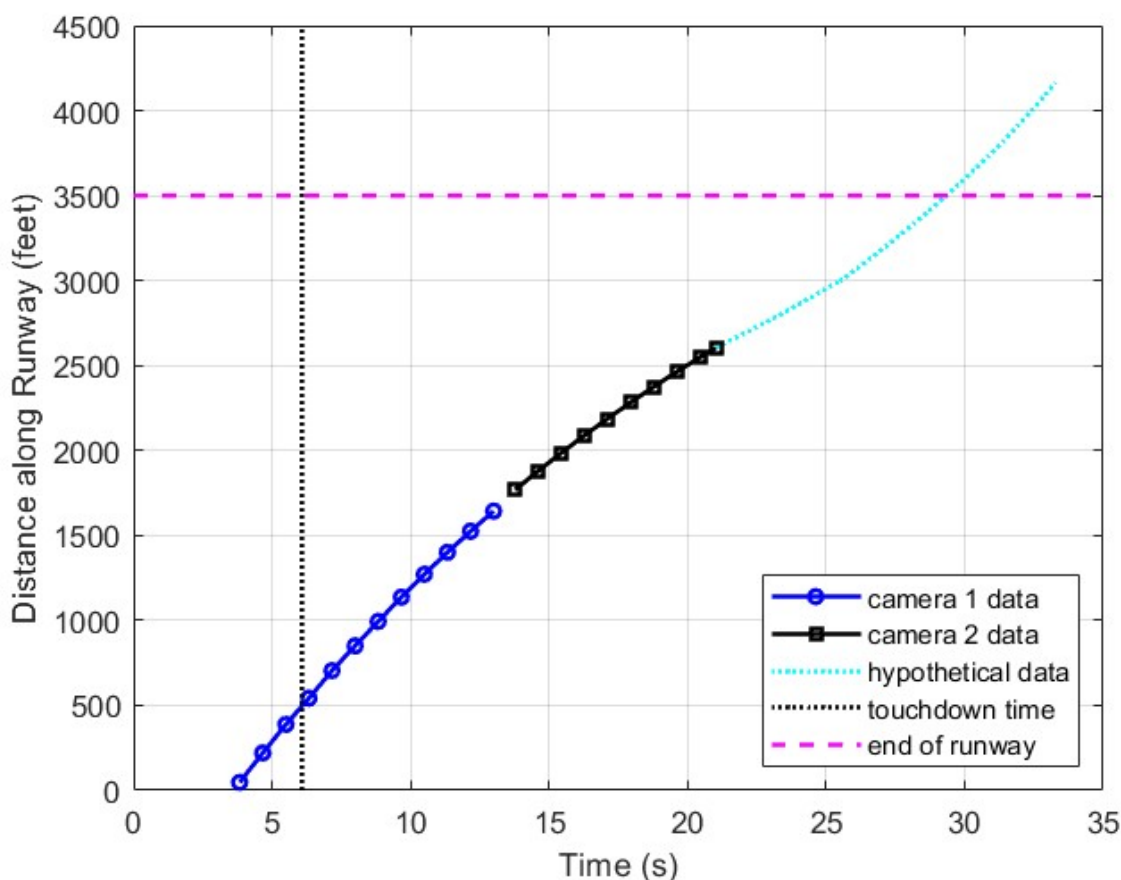


Figure 3. Estimated Airplane Distance along the Runway

Figure 3 shows that the airplane was airborne up to about time 6 seconds when it touched down. Past about time 27 seconds, the airplane became airborne again during an attempted go-around.

The deceleration of the airplane in the segment covered by camera No. 1, the blue curve, was increasing slowly with time. The deceleration in the segment covered by camera No. 2 was constant at 5.15 ft/s^2 or 0.16 g . It was verified by fitting a second-order polynomial curve to the distance data that resulted in an accurate fit of the curve to the data represented by the black square markers in Figure 3.

Figure 4 shows the ground speed of the airplane along the runway in the two segments where speed estimation was possible based on the camera No. 1 and camera No. 2 videos. The gap between the speed curves is due to the gap in coverage that was mentioned above. The figure shows that the ground speed at touchdown time was 104 knots. The accuracy of the estimated ground speed is ± 1.5 knots.

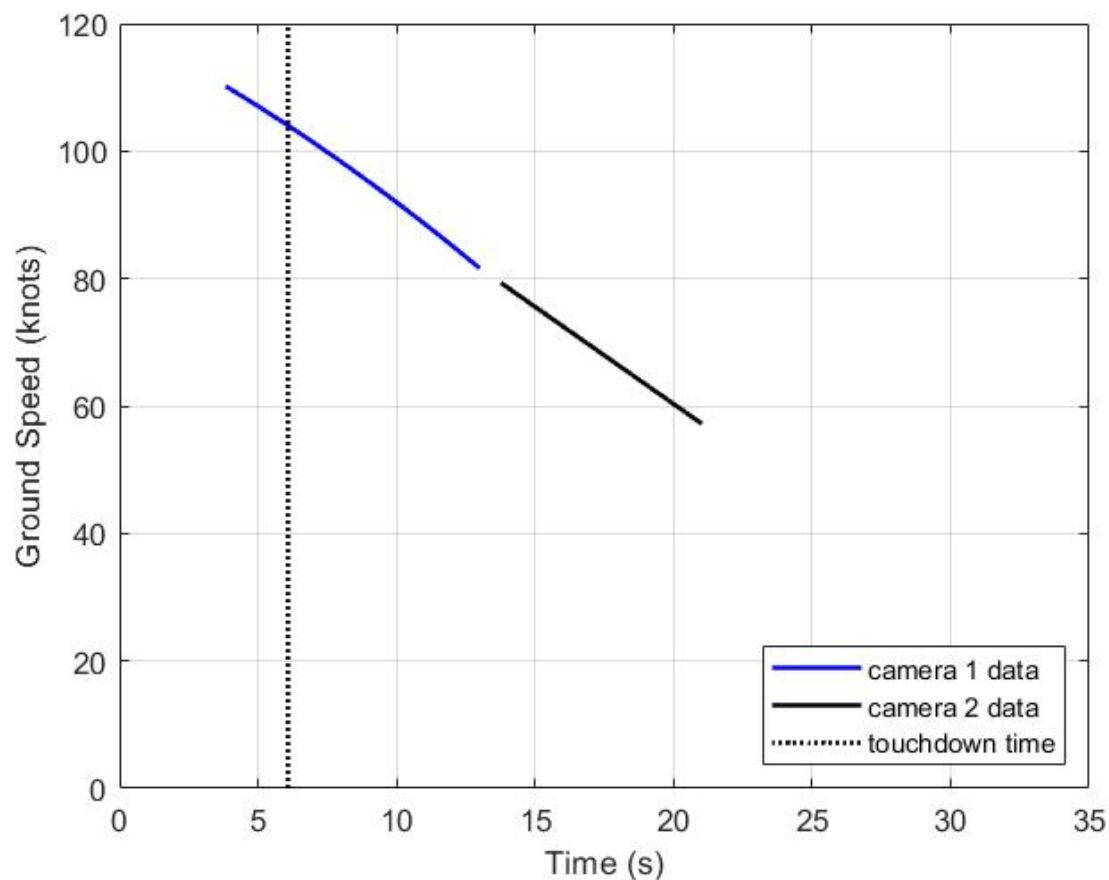


Figure 4. Estimated Ground Speed of the Airplane

The airplane was decelerating at the rate of 5.15 ft/s² or 0.16 g when it was at the end of the speed segment based on camera No. 2, at time 21 seconds. Its speed was 57.2 knots, or 96.54 feet/second, at that time. If the airplane stayed on the runway and continued decelerating at the rate of 5.15 ft/s², the stopping distance from where it was at time 21 seconds would have been

$$\text{stopping distance} = V^2/(2 \times a) = 96.54^2/(2 \times 5.15) = 905 \text{ feet}$$

At time 21 seconds, the airplane was about 896 feet from the end of the runway. The estimated stopping distance of 905 feet places the airplane nose 9 feet past the end of the runway. Because of the ± 1.5 knots accuracy of the estimated speed and the ± 30 feet accuracy of the estimated distances, the actual stopping location could have been anywhere between about 68 feet before the end of the runway and 88 feet beyond the end of the runway.

The estimated stopping locations are shown in Figure 5. The blue circular marker is at the estimated location where the airplane was when exiting the field of view of camera No. 2. The airplane was 896 feet from the end of the runway, its estimated ground speed was 57.2 knots, and it was decelerating at 0.16 g. The green dotted line, located 68 feet before the end of the runway, marks the location where the airplane would have stopped if the stopping distance was the shortest under the assumptions explained above. The red dotted line, located 88 feet beyond the end of the runway, marks the location where the airplane would have stopped if the stopping distance was the longest under the assumptions explained above.

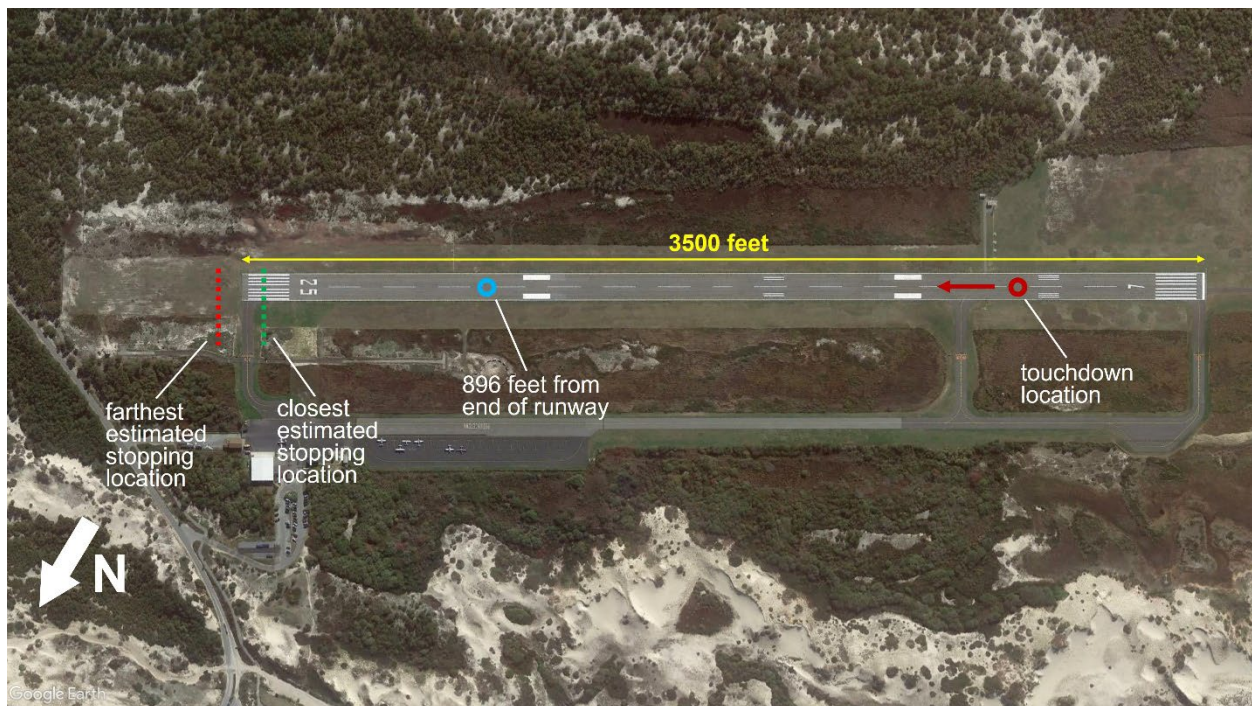


Figure 5. Estimated Stopping Location of the Airplane

Estimation of Airplane Acceleration during Attempted Go-Around

A short time after exiting the field of view of camera No. 2, the pilot decided to abort the landing and attempt a go-around. The following is an estimate of the airplane acceleration, a , during the attempted go-around.

The following are known from the analysis of camera No. 2 video

$T_1=21.02$ s time at the end of camera No. 2 coverage

$X_1=2604$ feet airplane runway location at the end of camera No. 2 coverage

$V_1=96.54$ ft/s ground speed of airplane at the end of camera No. 2 coverage

The following is known from video No. 3 that was not analyzed because camera No. 3 could not be calibrated accurately

$T_2=33.28$ s time when airplane hit trees

The following was measured in Google Earth

$X_2=4163$ feet location along runway where airplane hit trees (past end of runway)

Assuming constant acceleration motion,

$$X_2 - X_1 = V_1 \times (T_2 - T_1) + a \times (T_2 - T_1)^2 / 2$$

Therefore, the estimated acceleration, a , is

$$a = 2 \times (X_2 - X_1 - V_1 \times (T_2 - T_1)) / (T_2 - T_1)^2 = 5.0 \text{ ft/s}^2 = 0.155 \text{ g}$$

The estimated ground speed of the airplane when it hit the trees is

$$V_2 = V_1 + a \times (T_2 - T_1) = 157.8 \text{ ft/s} = 93.5 \text{ knots}$$

E. CONCLUSIONS

The distance along the runway, ground speed, touchdown speed and deceleration rate of a landing airplane were estimated based on videos recorded by two airport cameras. The estimated touchdown ground speed was 104 ± 1.5 knots. The estimated deceleration rate of the airplane as it was moving past the midpoint of the runway was constant at 0.16 g . It was estimated that if the airplane continued moving along the runway at that deceleration rate, it would have stopped somewhere between a short distance before the end of the runway and a short distance past the end of the runway. It was also estimated that the acceleration of the airplane during the attempted go-around was 0.155 g .