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

October 21, 2021

Video Study

NTSB Case Number:
WPR21FA265

A. ACCIDENT

Location:	Albany, Oregon
Date:	July 9, 2021
Time:	20:51 PDT
Aircraft:	North Wing Mustang 3-15

B. AUTHOR

Dan T. Horak
NTSB

C. ACCIDENT SUMMARY

On July 9, 2021, about 2051 Pacific daylight time, an unregistered experimental, amateur-built North Wing Mustang 3-15 weight-shift-control trike, was substantially damaged when it was involved in an accident near Millersburg, Oregon. The noncertificated pilot and passenger were fatally injured. The aircraft 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, roll angle and engine speed of the aircraft based on a video recorded with a hand-held iPhone XS phone. The video was 41 seconds long, had 512x960 resolution and frame rate of 30 fps. The aircraft impacted the ground at video time 40.7 seconds.

The camera owner was changing the phone camera zoom and changing the camera orientation angles while the video was being recorded. Camera zoom changes change the camera horizontal field of view angle (HFOV). Some of the significant changes occurred when there were insufficient ground references based on which the changed camera HFOV and the changed camera orientation angles could be recalibrated. This reduced the accuracy with which the aircraft location could be estimated.

Furthermore, as the aircraft was nearing the end of flight while turning left and its roll angle was increasing toward 90º to the left, the video only showed the aircraft and the sky. During this flight segment, calibration of the camera orientation angles was impossible, further complicating the estimation of the aircraft location. The aircraft roll angle estimation accuracy was less dependent on the changing or unknown camera zoom and camera orientation angles.

Figure 1. Aerial View of the Accident Area

Figure 1 shows an aerial view of the accident area. The camera location and the location where the aircraft impacted ground are marked in the figure. The camera location was in the back yard of a house and was constant during the video.

Figure 2 shows the bottom 75% of the video frame recorded at video time 33.4 seconds. It shows the limited ground references available at that time for the calibration of the camera HFOV and orientation angles. The camera owner was pitching the camera up at that time and between video times 33.7 seconds and 37.3 seconds, only the aircraft and the sky were visible in the video. During this time, the aircraft left-wing-down roll angle increased from about 30º to about 87º. At video time 37.3, the aircraft was 3.4 seconds from ground impact.

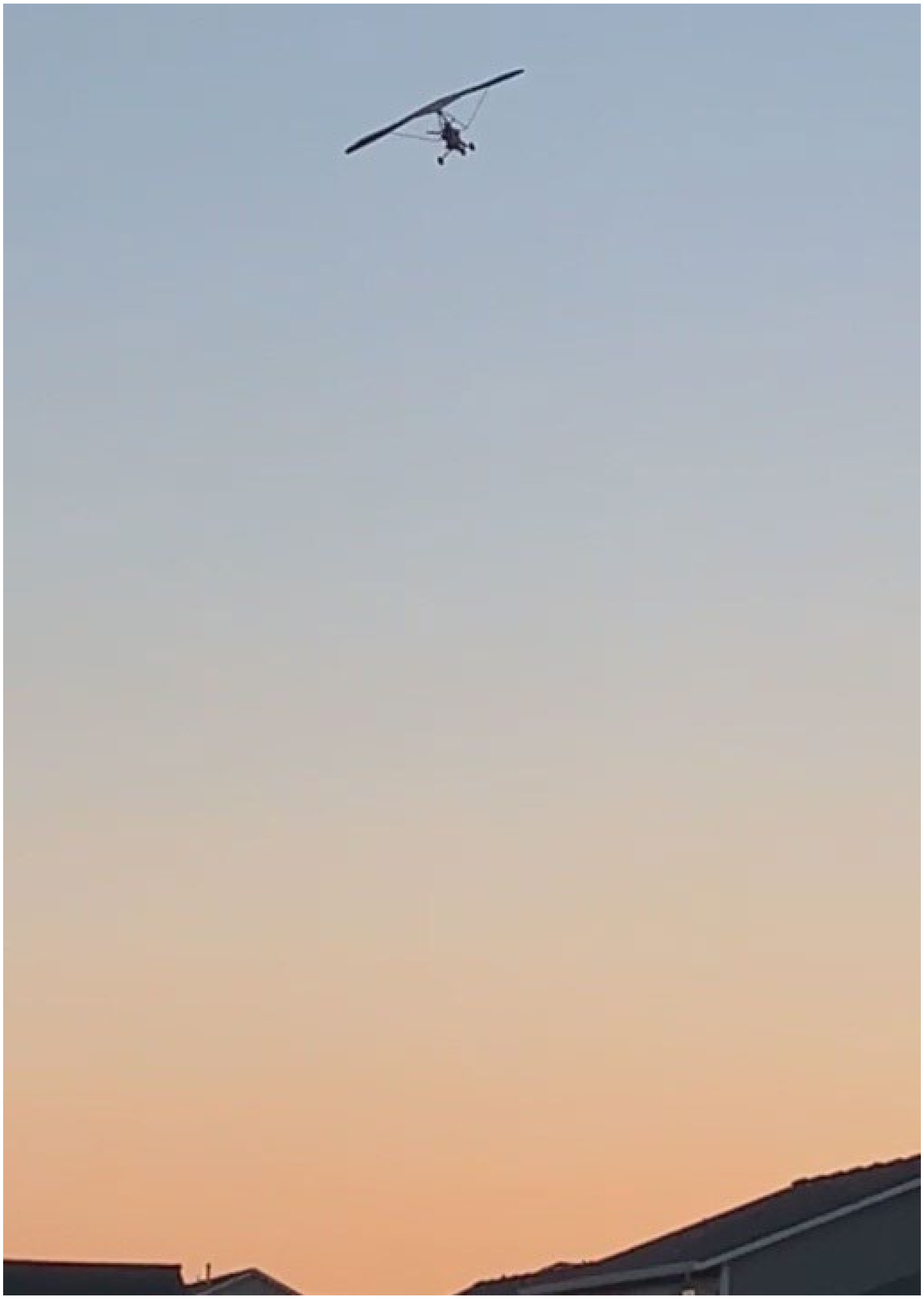

Figure 2. Bottom 75% of Video Frame Recorded at Video Time 33.4 seconds

Camera Calibration

The estimation of aircraft ground track, ground speed, altitude and roll angle 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 houses located west of the back yard where the camera was located, as marked in Figure 1. Figure 2 shows some of the roofs of these houses.

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.

As explained above, the camera zoom and orientation angles were changing during the video and references for accurate camera calibration were not available at all video times. However, there were sufficient references for accurate camera calibration during the six seconds preceding the aircraft turn to the left prior to ground impact.

Estimation of Aircraft Ground Track, Ground Speed and Altitude

The calibrated camera optics model was then used to estimate the locations of the aircraft at times corresponding to five frames. A wireframe model of the Mustang 3-15 aircraft was constructed, consisting of points on its nose, tail, wingtips, wing supports and tires. 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 aircraft in the video frame. When optimal match was reached, the location coordinates (X, Y and Z) and its orientation angles (yaw, pitch and roll) of the wireframe model were the optimal estimates of the location and orientation of the accident aircraft at the time when the analyzed video frame was recorded.

Figure 3 shows the estimated ground track of the aircraft. The five circular markers show the five locations that were estimated based on the five analyzed video frames. The numbers under these markers are the corresponding video times. The solid line is the interpolated ground track. Past video time 32.3 seconds, the camera could not be accurately calibrated. The broken line between time 32.3 seconds and ground impact time of 40.7 seconds is hypothetical and not based on analysis. However, the broken line is consistent with the video showing the aircraft flying approximately west at time 32.3 seconds and approximately east as it approached the ground impact location.

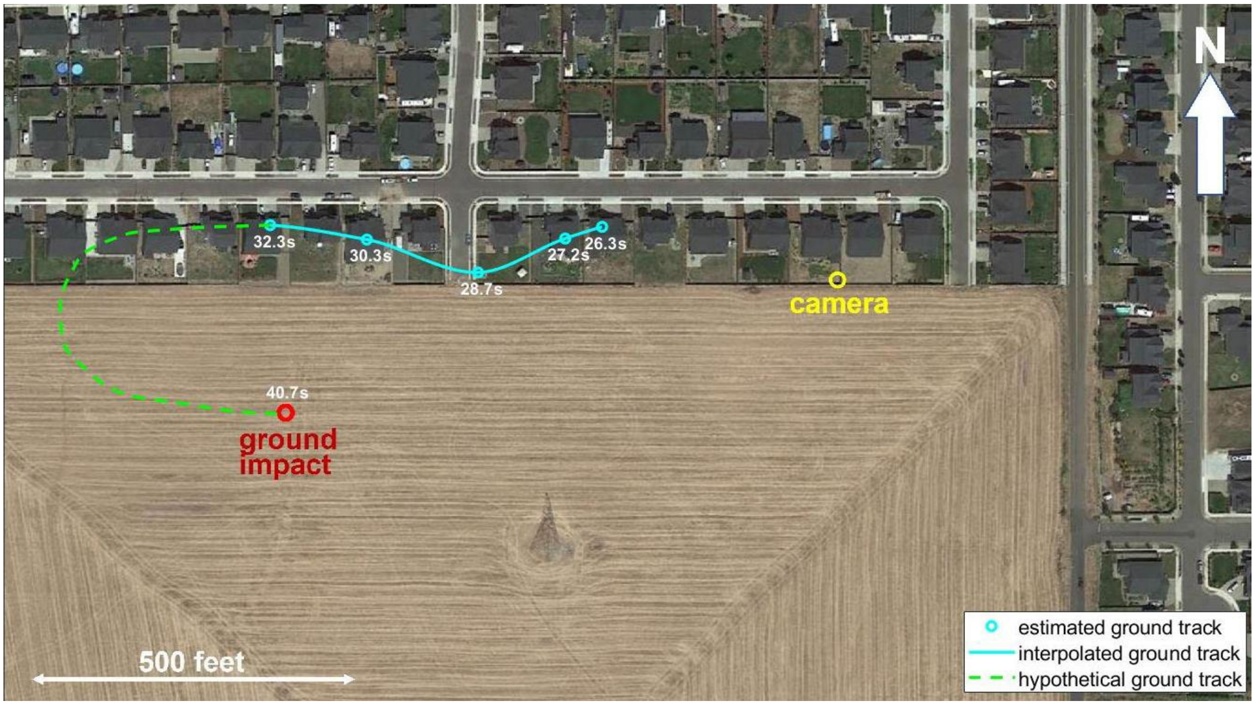

Figure 3. Estimated Ground Track of the Aircraft

The estimated aircraft ground speed during the six seconds between time 26.3 seconds and time 32.3 seconds, was 59 mph (51 kts). The estimated ground speed during the 3.6 seconds between time 28.7 seconds and time 32.3 seconds, was 61 mph (53 kts). Accounting for the unavoidable analysis uncertainty, it is estimated that the aircraft speed leading into the left turn that resulted in ground impact was 60±3 mph (52±3 kts).

The estimated AGL altitude of the aircraft was constant at 233±10 feet during the analyzed six seconds between time 26.3 seconds and time 32.3 seconds. During the 8.4 seconds from time 32.3 seconds to the ground impact time of 40.7 seconds, as the aircraft descended from AGL altitude of 233 feet to ground level, the average descent rate was 1664 feet/minute.

Estimation of Aircraft Roll Angle

Estimation of the aircraft roll angle was less dependent on the camera calibration parameters than the estimation of the aircraft ground track and altitude. It was so because the estimated aircraft roll angle depended significantly only on the calibrated camera roll angle.

Experience with several past accidents where hand-held cameras were used to track flying aircraft showed that camera holders keep the camera roll angle within ±5º from horizontal. The camera owner who recorded the video analyzed in this report also kept the camera roll angle within ±5º during the analyzed six seconds. Therefore, it was assumed that the camera roll angle was zero degrees at times where camera calibration was impossible and an uncertainty of ±5º was assigned to the estimated aircraft roll angles.

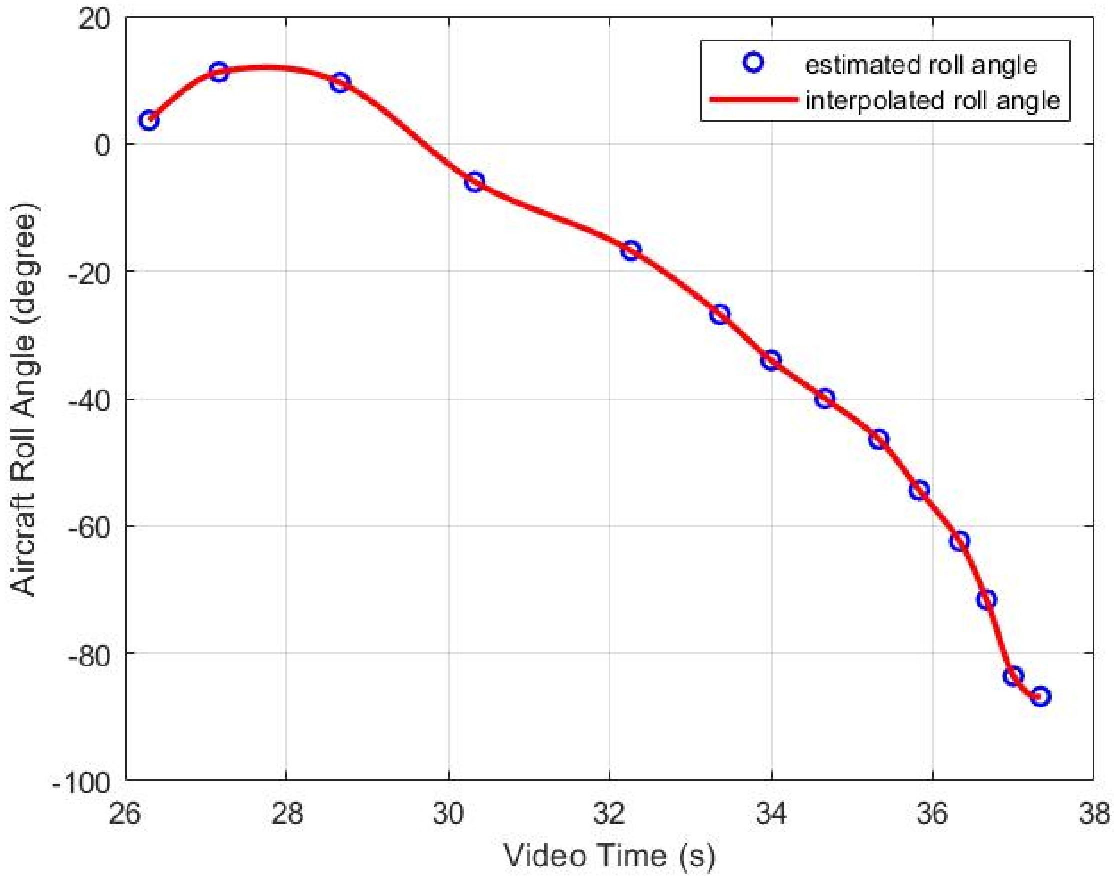

Figure 4. Estimated Aircraft Roll Angle (negative angle is left wing down)

Figure 4 shows the estimated aircraft roll angle between video time 26.3 seconds and video time 37.3 seconds. Negative roll angle in the figure corresponds to left wing down. The accuracy of the estimated roll angles is ±5º. The figure shows that the aircraft roll angle increased from left wing down of 17º to left wing down of 87º during the five seconds past video time 32.3 seconds, the last time when camera calibration was possible. The aircraft impacted the ground at video time 40.7 seconds.

Estimation of Engine Speed

The sound channel in the video was recorded at the rate of 44,100 samples/second. It was analyzed with a 65536-point Fast Fourier Transform (FFT) algorithm, resulting in 40.4 cycles per minute (cpm) frequency resolution. Since during the video the aircraft was first flying toward the camera, then away from the camera, and again toward the camera when it was crashing, the recorded frequency was affected by the Doppler effect. The recorded frequency could be up to about 8% higher than the emitted frequency when the aircraft was flying toward the camera and up to about 8% lower than the emitted frequency when it was flying away from the camera, based on the estimated 60 mph speed of the aircraft.

At about video time 22 seconds, the video shows that the aircraft was approximately above the camera so that the recorded sound was not affected by the Doppler effect at that time. At that time, there were spectral peaks at 6540 cpm and at 13,080 cpm. It is estimated that these were the blade passage frequency (BPF) and its second harmonic. Accounting for the Rotax 912 engine gearbox ratio of 2.43 and the three propeller blades, the engine speed at video time 22 seconds is estimated to be 6540/3×2.43=5297 rpm.

During the video, taking the Doppler effect into account, the estimated engine speed remained in the range between 5100 rpm and 5500 rpm except past time 38 seconds, during the last 2.7 seconds before ground impact. It is possible that during this time period the engine speed increased up to 6000 rpm.

Figure 4 shows that at video time 36 seconds, the magnitude of the roll angle was high (60° left wing down) and increasing rapidly. At that time, the engine speed was still within the normal 5100 rpm to 5500 rpm range. Therefore, it is estimated that the steep bank angle was not a result of engine failure.

There was also a video recorded by the passenger in the aircraft. It ended about six seconds before ground impact. Spectrum analysis of the sound channel in this video showed spectral peaks at 6660 cpm and 13,320 cpm. Assuming that these were the BPF and its second harmonic, the estimated engine speed was 5395 rpm. The range of estimated engine speeds during this video was between 5105 rpm and 5544 rpm, in close agreement with the estimates based on the video recorded by the camera held by the observer on the ground. The engine speed estimates based on the passenger video were not affected by the Doppler effect since the camera was on the aircraft.

E. <u>CONCLUSIONS</u>

The ground track, ground speed, altitude, roll angle and engine speed of an experimental aircraft that crashed were estimated based on a video recorded with a hand-held phone. The estimated ground speed of the aircraft when it initiated a left turn was 60±3 mph (52±3 kts). Its AGL altitude was 233±10 feet at that time. Its left-wing-down roll angle increased to almost 90º about six seconds after initiating the turn. The aircraft impacted the ground about nine seconds after initiating the turn. The engine speed was within its normal range when the magnitude of the aircraft roll angle was already large and was increasing at a high rate.