

NATIONAL TRANSPORTATION SAFETY BOARD

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

December 7, 2021

Video Study

**NTSB Case Number:
WPR22LA015**

A. ACCIDENT

Location: Alta Mesa Airpark, Wilton, California
Date: October 14, 2021
Time: 1600 Pacific daylight time
Aircraft: WSK Mielec AN-2TD

B. AUTHOR

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NTSB

C. ACCIDENT SUMMARY

On October 14, 2021 at 1600 Pacific daylight time, a WSK Mielec AN-2TD, N857PF, was substantially damaged when it was involved in an accident near Wilton, California. The pilot and one passenger sustained serious injuries and the other two passengers sustained minor 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, angle of attack of the wings, roll angle and engine speed of the airplane based on a video recorded by a bystander with an iPhone SE. The video was 67 seconds long, had 1280x720 resolution and frame rate of 30 fps. Sound was recorded at the rate of 44,100 samples per second. The airplane started its takeoff roll at video time 3 seconds. Liftoff was at about video time 40 seconds. At about time 52 seconds, the airplane reached its maximum altitude above ground level (AGL) and was descending past that time. Past time 56.5 seconds, the airplane was obscured from camera view by trees. At about time 60 seconds, the sound of ground impact can be heard in the sound channel of the video. There was a second video, also recorded with a hand-held camera, that was

used only for engine speed estimation, as described below. The second video recorded sound at a rate of 44,100 samples per second.



Figure 1. Aerial View of the Alta Mesa Airpark

Figure 1 shows an aerial view of the Alta Mesa Airpark. The camera location, the runway and the airplane crash location are marked in the figure. The airplane started its takeoff roll at the southern end of the runway, near the camera location. The camera was hand-held, and the camera holder was tracking the airplane as it moved north along the runway. To keep the airplane in the field of view, the camera holder was changing the yaw and the pitch orientation angles of the camera. The camera roll angle and the camera location were also changing slightly during the video. Figure 2 shows a frame from the video that was recorded at video time 47.5 seconds.



Figure 2. Video Frame Recorded at Time 47.5 seconds

Camera Calibration

The estimation of ground track, ground speed, altitude, angle of attack and roll angle of the airplane based on the video required a calibrated mathematical 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 approximately but not accurately enough to allow accurate estimation of the location and orientation of the accident airplane based on video frames. Therefore, all seven parameters had to be estimated in the calibration process. The HFOV was constant during the video and had

to be estimated only once. The other six camera parameters changed from frame to frame and had to be estimated eight times, once for each analyzed video frame.

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 runway, the runway markings, the buildings seen in Figure 2, and trees. 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 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 model of the camera optics was calibrated.

Estimation of Airplane Ground Track, Ground Speed, Altitude and Roll Angle

The calibrated camera optics model was then used to estimate the locations of the airplane at times corresponding to the eight analyzed video frames. A wireframe model of the AN-2TD airplane was constructed, consisting of points on its nose, tail, wings and horizontal stabilizer. 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 coordinates (X, Y and Z) of the wireframe model and its orientation angles (yaw, pitch and roll) were the optimal estimates of the location and orientation of the accident airplane at the time when the analyzed video frame was recorded.

Figure 3 shows the estimated ground track of the airplane. The ground track locations corresponding to the eight analyzed video frames are marked in the figure as are the times when the airplane was at these locations. The ground track starts at the location where the airplane started its takeoff roll. At analyzed point No. 1, the three airplane tires were still on the runway. Analyzed point No. 2 is just past liftoff. At point No. 7, the airplane reached its maximum AGL altitude and was already turning left.

The locations along the runway and the times when the airplane was at these locations made it possible to estimate the ground speed. It was 66 knots at time 40.5 seconds (point No. 2), just past liftoff. When the airplane reached its maximum altitude at time 52.3 seconds (point No. 7), the speed was down to 19 knots. The ground speed deceleration during these 11.8 seconds was constant at about 4 knots/second. Past time 52.3 seconds, the ground speed was increasing because the airplane was descending.

Figure 4 shows the estimated AGL altitude that peaked at 170 feet. Figure 5 shows the estimated airplane roll angle. It was close to zero degrees up to time 47.5 seconds (point No. 5). Past this time, the magnitude of the left-wing-down roll angle was increasing rapidly. Negative angles in Figure 5 indicate a left-wing-down roll direction.



Figure 3. Estimated Ground Track of the Airplane

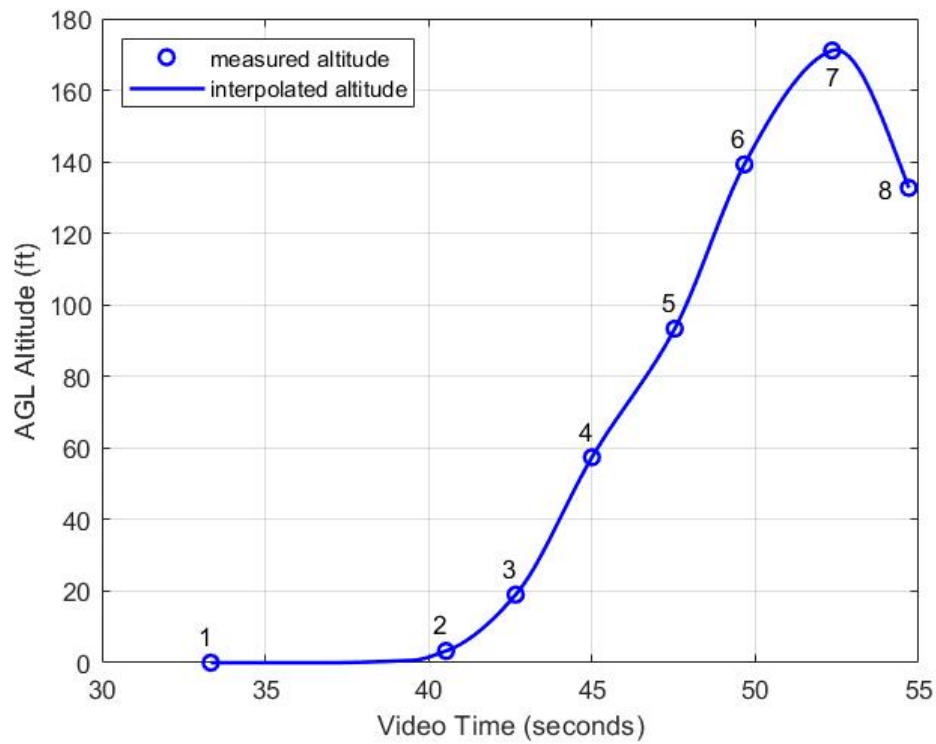


Figure 4. Estimated AGL Altitude of the Airplane

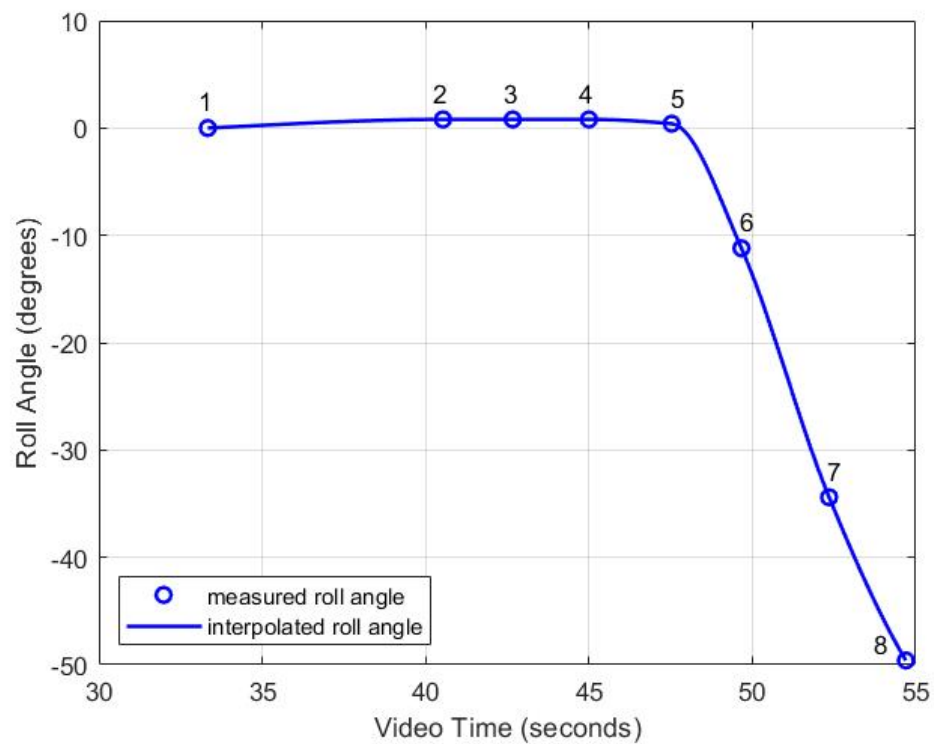


Figure 5. Estimated Roll Angle of the Airplane

Estimation of the Angle of Attack

The angle of attack is the difference between the pitch angle and the flight path angle (climb angle) of an airplane. This assumes no wind effects, as was assumed in this analysis. The AN-2TD has a high angle of attack of its wings when its three tires are on a horizontal runway. When the accident airplane was at the location where its takeoff roll started, near the camera, this angle was estimated as 12.5° based on the video. This value was validated by estimating it for several other AN-2 airplanes based on photographs. Their estimated angles were in the range between 11.5° and 13.5° .

The angle of attack of the airborne airplane estimated in this study was the angle of attack of its wings. It is this angle that causes stall rather than the angle of attack of the fuselage. The angle of attack of the wings is the difference between the pitch angle of the wings and the flight path angle (climb angle) of an airplane.

The flight path angle is given by $\tan^{-1}(\text{vertical speed}/\text{ground speed})$. The time period of interest for vertical speed estimation was between 40.5 seconds (point No. 2) and 49.7 seconds (point No. 6). At 40.5 seconds, the airplane was just past liftoff. At 49.7 seconds, the airplane was 2.6 seconds before reaching its maximum AGL altitude. Therefore, the 9.2 seconds between 40.5 seconds and 49.7 seconds are the period during which possible wing stall conditions developed.

A 3rd order polynomial fit was used to provide fine-time resolution of the estimated AGL altitude during this period. Differentiation of the 3rd order polynomial provided a 2nd order polynomial fine-time resolution estimate of the vertical speed.

As described above, ground speed was estimated to decrease from 66 knots at video time 40.5 seconds at the constant rate of 4 knots/second. With the ground speed and the vertical speed available, it was possible to estimate the flight path angle of the airplane via $\tan^{-1}(\text{vertical speed}/\text{ground speed})$.

A 2nd order polynomial was used to generate fine-time resolution of the estimated wing pitch angle between time 40.5 seconds (point No. 2) and time 49.7 seconds (point No. 6) based on the estimates of the pitch angle at these five times. The wing angle of attack was then computed via $\text{wing angle of attack} = \text{wing pitch angle} - \text{flight path angle}$.

Figure 6 shows the estimated wing angle of attack. The solid line shows the estimated angle of attack based on the polynomial fit to AGL altitude and the constant ground speed deceleration. The circular marker is at the maximum AGL altitude time of 52.3 seconds, where the flight path angle was zero and the wing angle of attack was equal to the wing pitch angle.

Figure 6 shows that the wing angle of attack was rapidly increasing past time 47 seconds and was above 20° after 52 seconds. At such high angles of attack, wing stall is likely. The reduced lift and the increased drag caused by stall could have contributed to the airplane reaching its maximum altitude at time 52.3 seconds.

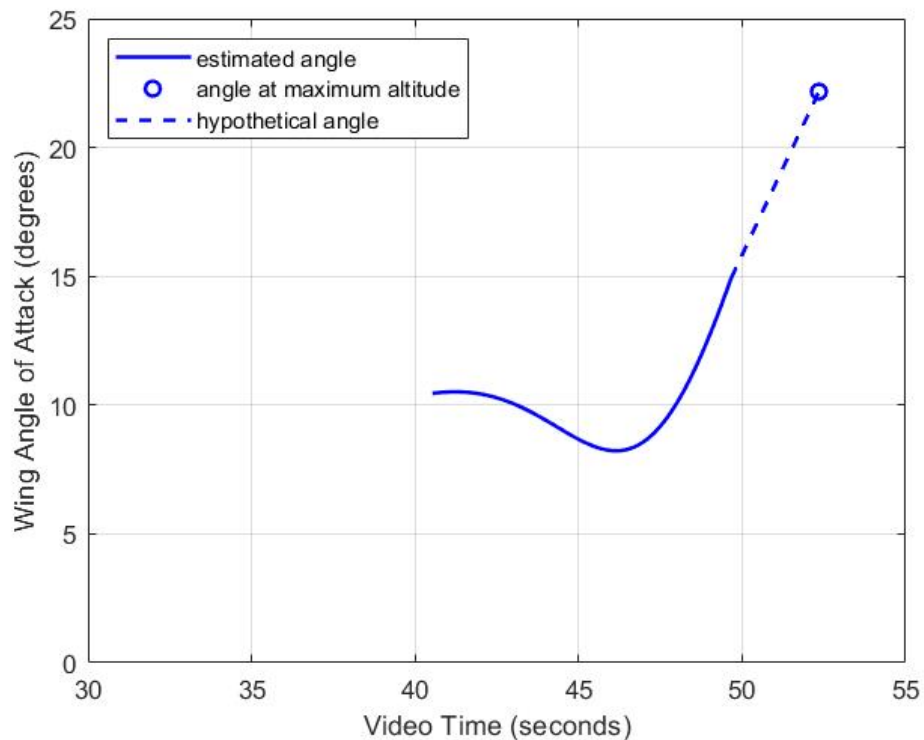


Figure 6. Estimated Wing Angle of Attack

Estimation of the Engine Speed

Engine speed was estimated by spectrum analysis of the sound channel in the video. The WSK Mielec AN-2TD uses a Shvetsov ASz-62IR engine designed to run at 2200 rpm at takeoff. The engine has a propeller speed reduction gearbox with a $11/16=0.6875$ ratio. The airplane uses a 4-bladed propeller. Therefore, the designed propeller speed at takeoff is $2200 \times 0.6875 = 1512.5$ rpm. Consequently, the blade passage frequency (BPF) is $1512.5 \times 4 = 6050$ blades/minute.

The Shvetsov ASz-62IR is a nine-cylinder four-stroke radial engine. In such engines, each cylinder fires once per two revolutions of the crankshaft. When the engine operates at the 2200 rpm speed, each cylinder fires at the rate of 1100 firings/minute. The firing order is 1-3-5-7-9-2-4-6-8 so that only one cylinder fires at a time.

Consequently, assuming that the engine was operating at 2200 rpm, the frequencies of interest in the sound spectrum were

- 2200 cycles per minute (cpm) - engine rotational speed
- 1100 cpm – engine cylinder firing rate
- 6050 cpm – blade passage frequency
- $N \times 6050$ cpm – harmonics of the blade passage frequency, where $N=2, 3, 4, \dots$

Spectra were computed with a 65536-point Fast Fourier Transform (FFT) algorithm that resulted in 1.5-seconds-wide processing windows and frequency resolution of 40 cpm. The time range of interest was from 35 seconds to 52 seconds, i.e., from the time the airplane was approaching takeoff speed to the time when its wing angle of attack became dangerously large. The starting times of the processing windows were advancing in steps of one second, resulting in the processing windows overlapping by half a second.

Figure 7 shows the spectrum computed between 43.5 seconds and 45 seconds. At this time, the airplane was airborne and climbing, as seen in Figure 4.

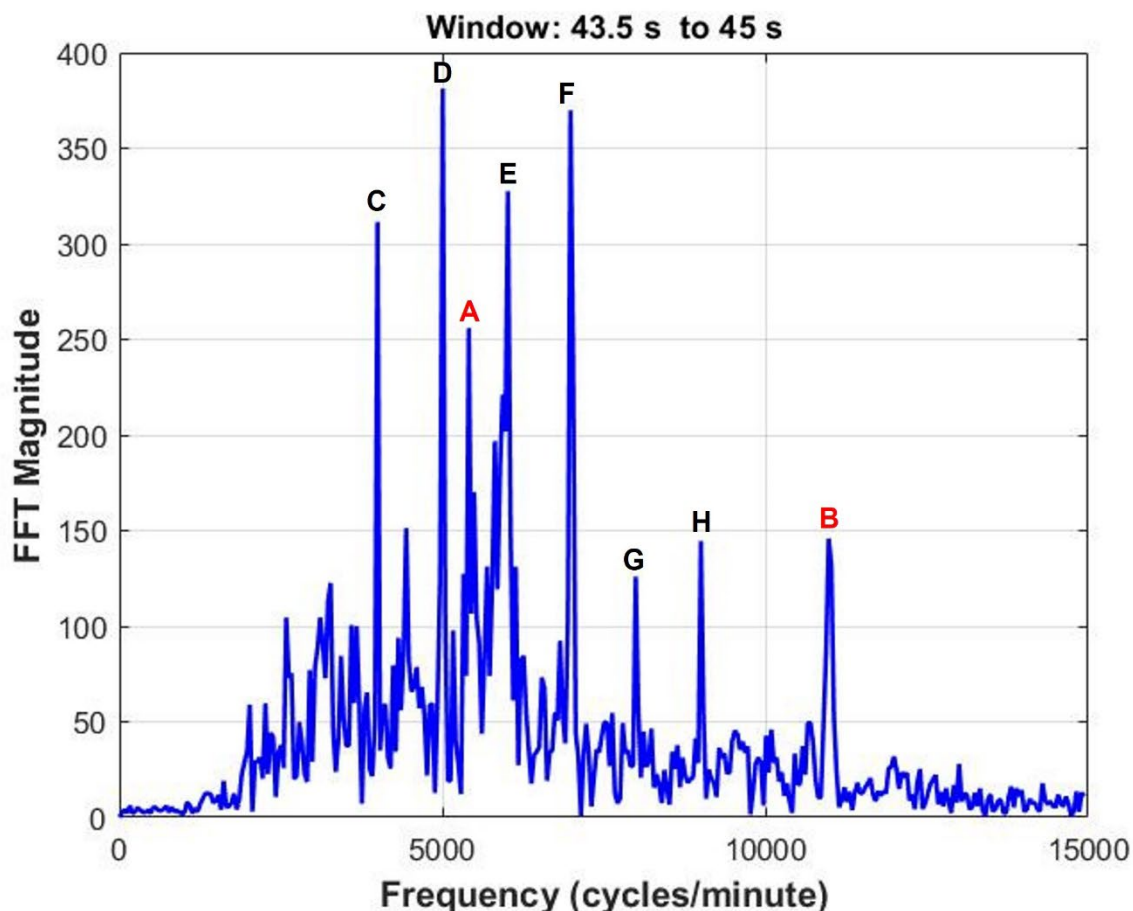


Figure 7. Sound Spectrum in Window Starting at Video Time 43.5 seconds

Spectral peak A at 5410 cpm is due to the blade passage frequency (BPF). Peak B at 10,980 cpm is its second harmonic. The 40 cpm frequency resolution is a smaller fraction of the second harmonic frequency of the BPF than it is relative to the BPF. Therefore, the BPF estimate is taken as half of the second harmonic, or 5490 cpm.

The airplane was moving away from the camera at a speed estimated as 51 knots at video time 44.25 seconds, the time at the center of the spectrum processing window. This speed results in a Doppler factor of 0.93, meaning that the recorded speed was 93%

of the emitted frequency. Therefore, the estimated BPF of the propeller was $5490/0.93=5903$ blades/minute. Since the BPF of the AN-2TD is 6050 blades/minute when the engine speed is 2200 rpm, the estimated engine speed is $2200 \times 5903/6050=2147$ rpm.

Spectral peaks C, D, E, F, G and H are spaced by the average spacing of 1002 cpm. It is estimated that these spacings are due to the firing rate of the nine engine cylinders. At the engine speed of 2200 rpm, ignition takes place in each of the nine cylinders at the rate of 1100 firings/minute. The sound spectrum of short-duration acoustic impulses that occur at the rate of 1100 impulses/minute consists of spectral peaks at frequencies $N \times 1100$ cpm, where $N=1, 2, 3, 4, \dots$, etc.

When the observed spectral peaks are adjusted by the above Doppler factor of 0.93, the estimated firing rate of the cylinders was $1002/0.93=1077$ firings/minute. Since the cylinder firing rate of the AN-2TD is 1100 firings/minute when the engine speed is 2200 rpm, the estimated engine speed is $2200 \times 1077/1100=2154$ rpm, in close agreement with the speed estimated as 2147 rpm based on the blade passage frequency.

The second video of the airborne accident airplane was recorded by a bystander standing near the northern end of the runway. The times of the two videos could be approximately synchronized based on the sound of ground impact. Based on the visual information in the second video and based on the time of maximum intensity of the sound recorded by the second camera, it was estimated that the airplane was closest to it at about the time that corresponds to 56 seconds in the first video.

At that time, the sound frequencies recorded by the second camera were not affected by the Doppler effect because there was no relative speed between the airplane and the camera. As can be seen in Figure 3, at that time the airplane was near the most northern point of its ground track. As can be seen in Figure 4, at that time the airplane was already descending toward ground impact. The frequency corresponding to BPF was 6055 blades/minutes based on spectrum analysis of the sound recorded with the second camera, resulting in an engine speed estimate of $2200 \times 6055/6050=2202$ rpm.

E. CONCLUSIONS

The ground track, ground speed, altitude, angle of attack and roll angle of an airplane that crashed shortly after takeoff were estimated based on a video recorded with a hand-held phone. The ground speed of the airplane went as low as 19 knots shortly after it started a left turn and a rapid descent toward ground impact. At that time, the airplane reached its maximum AGL altitude of 170 feet and the angle of attack of its wings was estimated to be 22.5° .

Engine speed, estimated via spectrum analysis of sound recorded by two cameras, was 2150 rpm several seconds after liftoff and 2200 rpm when the airplane was already descending toward ground impact. The specified engine speed at takeoff for the WSK Mielec AN-2TD is 2200 rpm.