

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



CEN23FA314

VIDEO STUDY

by Dan T. Horak

November 2, 2023

TABLE OF CONTENTS

A. ACCIDENT	3
B. SUMMARY	3
B.1. The accident	3
B.2. Objective and scope of the Video Study	3
C. DETAILS OF THE INVESTIGATION	3
C.1. Estimates based on the visual information in the videos.....	4
C.1.1. Estimation of engine and propeller speeds based on video 2.....	4
C.1.2. Estimation of airplane speed during ground roll based on video 1	5
C.2. Estimation of propeller speeds based on sound information in video 1	5
D. CONCLUSIONS	9
FIGURES.....	10

A. ACCIDENT

Location: Kearney, Missouri
Date: July 20, 2023
Time: 0934 CDT (central daylight time)
Aircraft: Piper PA-31P

B. SUMMARY

B.1. The accident

On July 20, 2023, about 0934 central daylight time, a Piper PA-31P airplane, N200RA, was destroyed when it was involved in an accident near Kearney, Missouri. The pilot sustained fatal injuries. The airplane was operated as a Title 14 Code of Federal Regulations Part 91 maintenance ferry flight.

B.2. Objective and scope of the Video Study

The objective of this Video Study was the estimation of the ground speed of the airplane during its ground roll, the ground speed at the time of rotation, and the speed of the two airplane engines and propellers. Analysis was based on the visual and sound information in two videos recorded with hand-held phones. The two phones were at about the same location along the runway (see Figure 1).

C. DETAILS OF THE INVESTIGATION

Two videos were used in the investigation. The first video ('video 1') was recorded with a hand-held iPhone 11 Pro Max ('camera 1'). It had 1280x720 resolution and frame rate of 30 fps (frames per second). It lasted about 107 seconds. The camera recorded sound at the rate of 44,100 samples per second. At video 1 time 33.07 seconds, the airplane was in front of the camera. When the video ended, the airplane was already airborne.

The second video ('video 2') was recorded with a hand-held iPhone 12 ('camera 2'). It had 3840x2160 resolution and frame rate of 60 fps. It lasted about 62 seconds. The camera recorded sound at the rate of 44,100 samples per second. At video 2 time 56.84 seconds, the airplane was in front of the camera. When the video ended, the airplane was still on the runway.

Figure 1 is an aerial view of the accident area. The location where the two cameras were located is marked in the figure. During the ground roll, the airplane was initially approaching the cameras, resulting in the sound frequencies recorded by the cameras being higher than the frequencies emitted by the airplane due to the Doppler

effect. Then the airplane was flying away from the cameras, resulting in the sound frequencies recorded by the cameras being lower than the frequencies emitted by the airplane.

C.1. Estimates based on the visual information in the videos

C.1.1. Estimation of engine and propeller speeds based on video 2

Video 1 had frame rate of 30 fps, which was too low to be usable for estimation of the propeller speeds based on the visual information in the video. Video 2 had frame rate of 60 fps, which made it possible to estimate the speed of the propellers. Figure 2 shows a frame from video 2 recorded at video 2 time 55.572 seconds. Note that blade A of the right propeller points up. Figure 3 shows the next frame of video 2. A blade on the right propeller is marked with B. The propeller was rotating clockwise when viewed from the front. The angle of blade B in Figure 3 is at an angle that is estimated at about 83° rotated clockwise with respect to blade A in Figure 2.

If it is assumed that blade B in Figure 3 is the same blade as blade A in Figure 2, the propeller rotational speed can be estimated as $(83^\circ/360^\circ)/(1/60) \times 60$ where $83^\circ/360^\circ$ is the fraction of one rotation corresponding to 83° rotation, $1/60$ is the frame spacing corresponding to the frame rate of 60 fps, and multiplying by 60 converts rotations/second to rpm. The formula simplifies to $10 \times 83 = 830$ rpm. This propeller speed is, obviously, too low considering that the airplane was able to take off. Therefore, the assumption that blade B in Figure 3 is the same blade as blade A in Figure 2 is incorrect.

If blade B in Figure 3 is not the same blade as blade A in Figure 2, blade B in Figure 3 must be the next blade that is located 120° counterclockwise from blade A, marked as C in Figure 2. Therefore, the propeller rotation during one frame spacing was $120^\circ + 83^\circ = 203^\circ$ rather than 83° . Using the simplified expression from above, the estimated propeller speed was $10 \times 203 = 2030$ rpm. It is estimated that the uncertainty of the 83° rotation was $\pm 2^\circ$. Therefore, the estimated right propeller speed was 2030 ± 20 rpm. The speed of the geared Lycoming TIGO-541-E1A engine corresponding to a propeller speed of 2030 rpm is $2030 \times 1.5 = 3045$ rpm. With the uncertainty added, it is 3045 ± 30 rpm.

This right propeller speed estimation was repeated at several locations past the location used above, with the same result. The process was then repeated for the left propeller. Its estimated speed was 2140 ± 20 rpm. Since the rated propeller speed of the PA-31P airplane is 2133 rpm, the analysis showed that the left propeller was rotating at about the rated speed, and the right propeller was rotating at about 100

rpm below the rated speed. The speed of the left engine corresponding to a propeller speed of 2140 rpm is 3210 rpm. With the uncertainty added, it is 3210 ± 30 rpm.

C.1.2. Estimation of airplane speed during ground roll based on video 1

Video 1 recorded the airplane past the time of liftoff. The centerline of runway 36 is marked with white stripes that are 120 feet in length. The gaps in between the stripes are 80 feet long. It was possible to estimate the locations of the airplane using the white stripes as a ruler. The estimated locations were those where the shadow of the left wing first touched a white stripe. The first location where it was possible to accurately estimate the location of the airplane is marked as M in Figure 1. The last location where it was possible to accurately estimate the location of the airplane is marked as N in Figure 1. Accurate estimation of airplane locations before M and past N was not possible because the hand-held camera was aimed parallel to the runway surface on which were the stripes.

A total of six locations were estimated with a total length of $5 \times (120 + 80) = 1000$ feet. The time elapsed between when the airplane was at location M and location N was 8.37 seconds, based on the frame rate of video 1. Analysis showed that the speed was constant at 119.5 feet/second (70.8 knots) during the 8.37 seconds.

By stepping through video 1 frame-by-frame, it was possible to determine that rotation occurred at video 1 time 41.71 seconds. The airplane was at location N at video 1 time 35.14 seconds. The visual information in video 1 did not provide information that could be used to estimate the location of rotation or the airplane speed at the time of rotation. Therefore, it was necessary to perform sound spectrum analysis of video 1, as described next.

C.2. Estimation of propeller speeds based on sound information in video 1

The visual information in video 1 showed that the airplane was moving at a constant speed at least up to location N marked in Figure 1, corresponding to video 1 time 35.14 seconds. If it could be shown that the speed remained constant at 119.5 feet/second (70.8 knots) up to rotation at video 1 time 41.71 seconds, then the rotation speed would be known, and the rotation location could be estimated by integration of the known speed. The strategy was to use the Doppler effect, as described next.

Spectrum of the sound stream in video 1 was computed with the Fast Fourier Transform (FFT) algorithm that used 65,536-point windows. The windows were 1.4861 seconds wide and the frequency resolution was 40 cpm (cycles per minute).

Figure 4 shows 12 spectra with windows starting at video 1 times from 27 seconds to 38 seconds. The airplane was in front of camera 1 at time 33.07 seconds. This is the reason why the spectra starting at 32 seconds and at 33 seconds look different from the other spectra. The two windows of interest were those starting at 31 seconds and 34 seconds. Four spectral peaks, D, E, F and G are marked on the spectrum that starts at 31 seconds. Their frequencies are 6864 cpm, 7227 cpm, 10336 cpm and 10861 cpm, respectively. Spectral peaks D and E are the blade passage frequencies of the two 3-bladed propellers. Spectral peaks F and G are the third harmonics of the engine rotational speed.

At the rated propeller speed of 2133 rpm, the blade passage frequency is $2133 \times 3 = 6399$ cpm. The two Lycoming TIGO-541-E1A engines on the PA-31P are geared. The engines rotate at 3200 rpm when the propellers rotate at 2133 rpm. Six cylinder, horizontally opposed engines usually generate sound signals at a frequency that is three times their rotational speed. At the rated engine speed, it is $3200 \times 3 = 9600$ cpm. Peaks D, E, F and G in the window starting at 31 seconds in Figure 4 are at frequencies higher than the frequencies corresponding to the rated propeller and engine speed. It is so because of the Doppler effect caused by the airplane approaching the camera.

Since the analysis based on video 2 showed that the left engine was rotating faster than the right engine, spectral peaks E and G correspond to the left propeller and engine and peaks D and F correspond to the right propeller and engine.

Four spectral peaks, D, E, F and G are also marked on the spectrum that starts at 34 seconds. Their frequencies are 5571 cpm, 5935 cpm, 8438 cpm and 8882 cpm, respectively. Peaks D, E, F and G in the window starting at 34 seconds in Figure 4 are at frequencies lower than the frequencies corresponding to the rated propeller and engine speed. It is so because of the Doppler effect caused by the airplane moving away from the camera.

The spectral peaks corresponding to the engine sound, peaks F and G, were tracked up to the window starting at video 1 time 48 seconds, past the time of rotation. Table 1 shows the frequencies. Since peaks F and G are due to combustion noise, this indicates that both engines were operating at least till that time and that the right engine was rotating more slowly than the left engine.

Past the time when the window starting at 48 seconds ended, the spectral peaks were no longer visible. It was because the increasing distance of the airplane from the cameras caused the intensity of the peaks to be lower than the background noise intensity.

The visual information in video 1 showed that both propellers were rotating at least till about time 60 seconds, when the airplane was already past the runway and airborne. After video 1 time 60 seconds, the propeller blades could not be seen due to the finite resolution of the video.

The time windows in Table 1 were when the airplane was moving away from the camera. Therefore, the frequencies in the table were lower than the frequencies emitted by the engines due to the Doppler effect. At window starting times 34 seconds and 36 seconds, the airplane was still close to the camera. Since the camera was located east of the runway, the relative speed between the airplane and the camera was not equal to the ground speed of the airplane. The relative speed was the ground speed multiplied by the cosine of the angle between the runway and the line from the camera to the airplane. This reduced the relative speed and reduced the Doppler effect. Therefore, the frequencies at window starting times 34 seconds and 36 seconds are somewhat higher than the other frequencies.

Table 1. Frequencies of spectral peaks corresponding to engines

Window starting time (s)	Peak F, right engine, (cpm)	Peak G, left engine, (cpm)
34	8438	8882
36	8478	8801
38	8278	8761
40	8278	8721
42	8358	8721
44	8318	8681
46	8358	8681
48	8358	8681

Past time 38 seconds, the relative speed between the airplane and the camera could be assumed to be equal to the ground speed of the airplane. The frequency resolution of the FFT algorithm was 40 cpm. Therefore, the numbers in Table 1 change by 40 cpm or 80 cpm when time advances by 2 seconds.

Because rotation was at video 1 time 41.71 seconds, engine speeds between windows starting time 38 seconds and 42 seconds were of main interest. If analysis showed that the average airplane ground speed during this period was 119.5 feet/second (70.8 knots), it could be concluded that the speed remained constant from location N to the location of rotation. The average of peak F frequencies in the corresponding three lines in the table was 8304 cpm. The average of peak G frequencies was 8734 cpm.

The left engine speed was estimated above, based on the visual information in video 2, as 3210 rpm. When this speed is Doppler-adjusted based on the assumed ground speed of 119.5 feet/second (70.8 knots), it becomes 2906 rpm. Its third harmonic is $2906 \times 3 = 8718$ cpm, close to the 8734 cpm average of the peak G frequencies in Table 1, supporting the assumed ground speed.

The right engine speed was estimated above, based on the visual information in video 2, as 3045 rpm. When this speed is Doppler-adjusted based on the assumed ground speed of 119.5 feet/second (70.8 knots), it becomes 2757 rpm. Its third harmonic is $2757 \times 3 = 8271$ cpm, close to the 8304 cpm average of the peak F frequencies in Table 1, supporting the assumed ground speed.

To assess the validity of the observation that the airplane continued to the location of rotation at the speed of 119.5 feet/second (70.8 knots), the following hypothesis was tested. It was assumed that the airplane was accelerating and reached 78 knots at the location of rotation. The Doppler-adjusted left engine speed of 3210 rpm that was based on video 2, assuming a ground speed of 78 knots, is 2878 rpm. Its third harmonic is 8632 cpm, 102 cpm less than the 8734 cpm average of the peak G frequencies in Table 1.

The Doppler-adjusted right engine speed of 3045 rpm that was based on video 2, assuming a ground speed of 78 knots, is 2730 rpm. Its third harmonic is 8190 cpm, 114 cpm less than the 8304 cpm average of the peak G frequencies in Table 1.

The assumed rotation speed of 70.8 knots resulted in close agreement between the estimated propeller speeds based on visual and sound information in the videos. The alternative assumption of 78 knots did not result in a close agreement. Therefore, it was concluded that rotation occurred at the ground speed of about 70.8 knots. Winds at a location that is 2 NM from the accident site were reported as 4 knots from 330°. Under the extreme assumption that the air speed was the ground speed with 4 knots added to it, the resulting estimated air speed of 74.8 knots was significantly lower than the rotation speed of 83 knots recommended by Piper. Since the time between when the airplane was at location N in Figure 1 and the time of rotation was known, and assuming constant ground speed of 70.8 knots, rotation location was estimated as 3080 feet from the beginning of the paved surface of runway 36. This location is marked in Figure 1.

The sound spectral peaks listed in Table 1 show that the frequencies of peaks F and G remained approximately constant past the time of rotation. This indicates that the airplane speed remained constant at approximately 70.8 knots at least through the time covered by the window that starts at video 1 time 48 seconds.

D. CONCLUSIONS

Two videos that recorded an airplane that crashed shortly after takeoff were analyzed. The airplane speed during its ground roll, the ground speed at the time of rotation, the location of rotation, and the speed of the two airplane engines and propellers were estimated. Analysis was based on the visual and sound information in the two videos. Analysis showed that the left propeller was operating at the rated speed, and the right propeller was operating at about 100 rpm below the rated speed. Rotation was at a ground speed of about 70.8 knots corresponding to an estimated air speed of about 74.8 knots which was significantly below the rotation speed recommended by Piper.

FIGURES

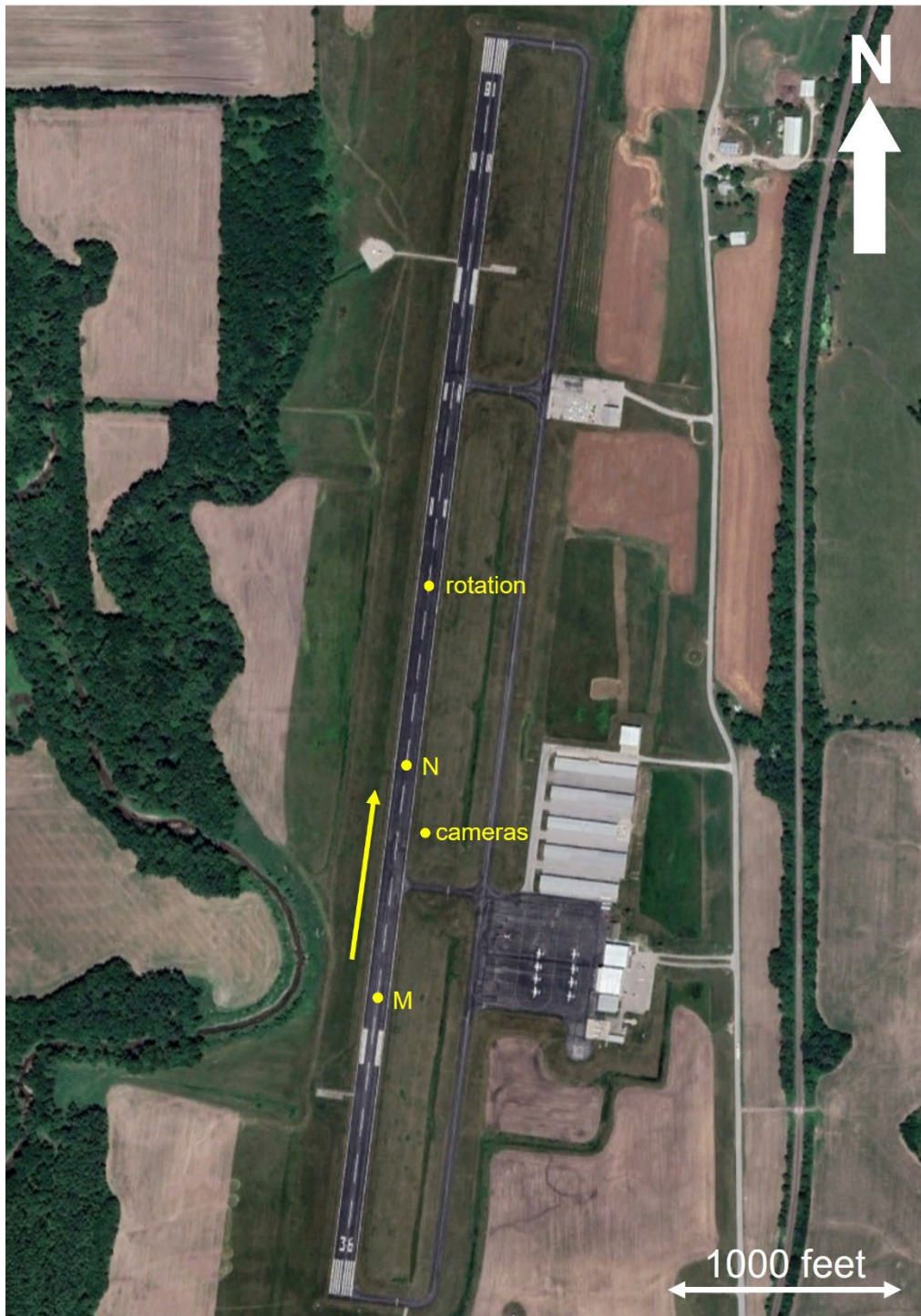


Figure 1. Aerial view of the accident area



Figure 2. The airplane at time 55.572 seconds (video 2)



Figure 3. The airplane at time 55.588 seconds (video 2)

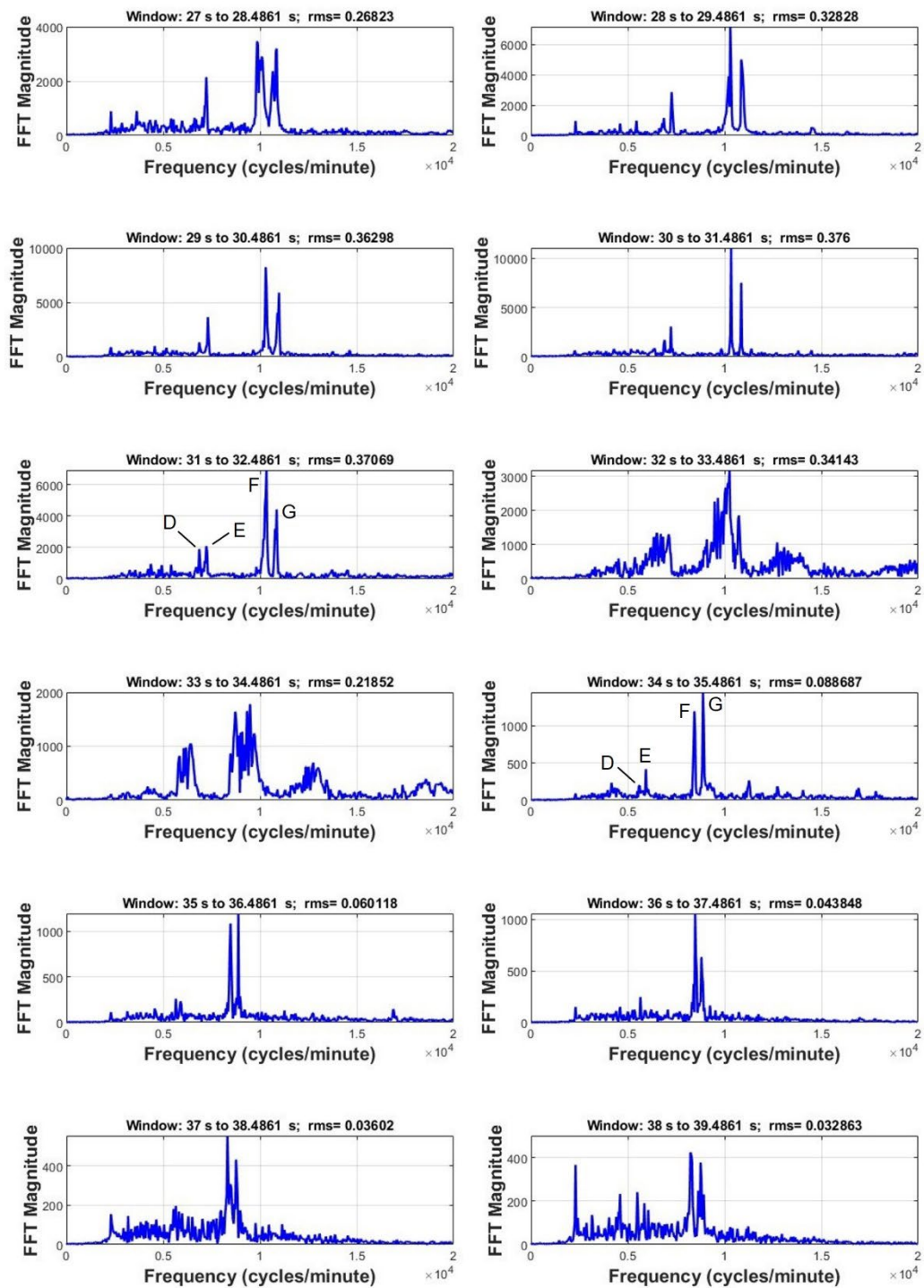


Figure 4. Sound spectra in windows starting at time 27 seconds (video 1)