

# **NATIONAL TRANSPORTATION SAFETY BOARD**

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

December 21, 2020

## **Video Study**

**NTSB Case Number:  
WPR21LA011**

### **A. ACCIDENT**

Location: Spirit Lake, Idaho  
Date: October 6, 2020  
Time: 1533 Pacific Daylight Time (PDT)  
Aircraft: Rans S-7 Courier Amphibious Airplane

### **B. AUTHOR**

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NTSB

### **C. ACCIDENT SUMMARY**

On October 6, 2020 at 1533 Pacific Daylight Time, a Rans S-7 Courier amphibious airplane, N55893, was substantially damaged when it was involved in an accident near Spirit Lake, Idaho. The pilot sustained fatal injuries and the passenger 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, orientation angles and engine speed of the airplane based on a video recorded by a viewer on the ground. The iPhone XS video was about 37 seconds long, it had 1920x1080 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 the crash location.



**Figure 1. Aerial Image of the Accident Area**

### 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 buildings located north of the runway. 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.



**Figure 2. Frame from the Video Showing the Airborne Airplane**

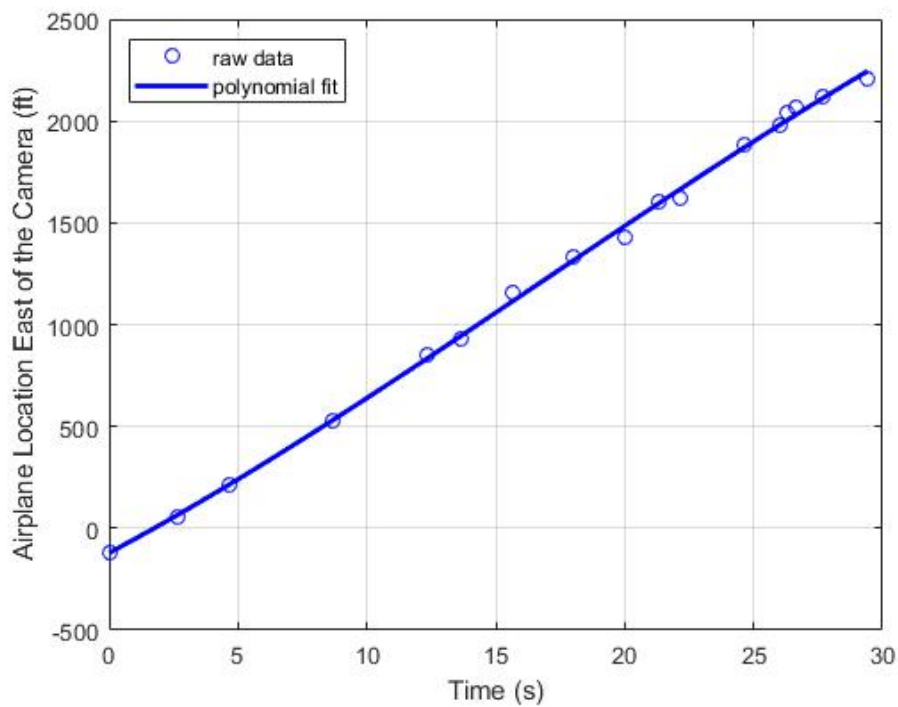
The HFOV angle remained constant during the video and, consequently, it had to be estimated only once. However, since the camera owner was filming a moving airplane and keeping its image near the center of the camera field of view, the yaw, pitch and roll camera orientation angles were different for each analyzed video frame. Consequently, the camera model had to be recalibrated 17 times, once for each analyzed video frame.

#### Estimation of Airplane Locations, Orientation Angles and Speed

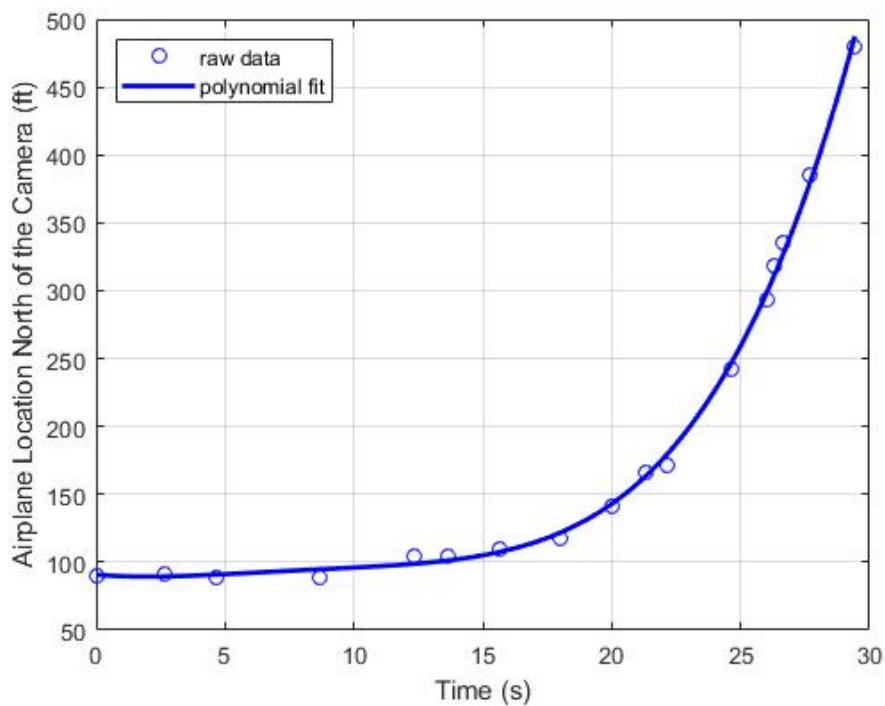
The calibrated camera optics model was then used to estimate the locations of the airplane at times corresponding to the 17 analyzed video frames. A wireframe model of the Rans S-7 airplane with its amphibious floats was constructed, consisting of points on its nose, tail, wings, fuselage and floats. 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 location of the airplane along the runway that is oriented in the west-to-east direction. The airplane was moving west-to-east. The location of the camera was set to 0 feet in the figure. Time was set to zero when the first video frame was analyzed, which was 5.33 seconds after the video started. Figure 4 shows the location of the airplane north of the camera. The location of the camera was

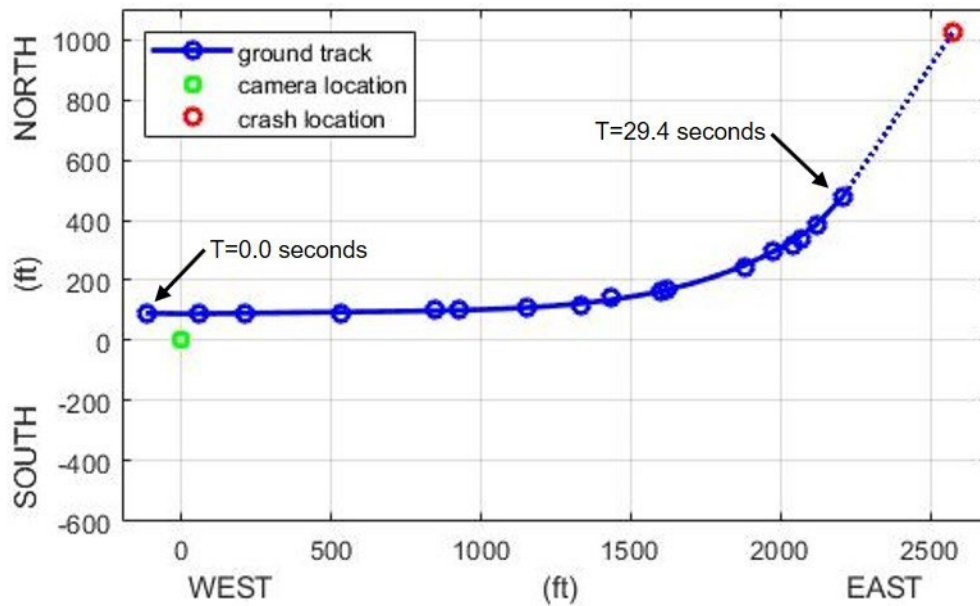
set to 0 feet in the figure. The blue lines in Figure 3 and Figure 4 are 3<sup>rd</sup> order polynomial fits to the 17 raw data points.



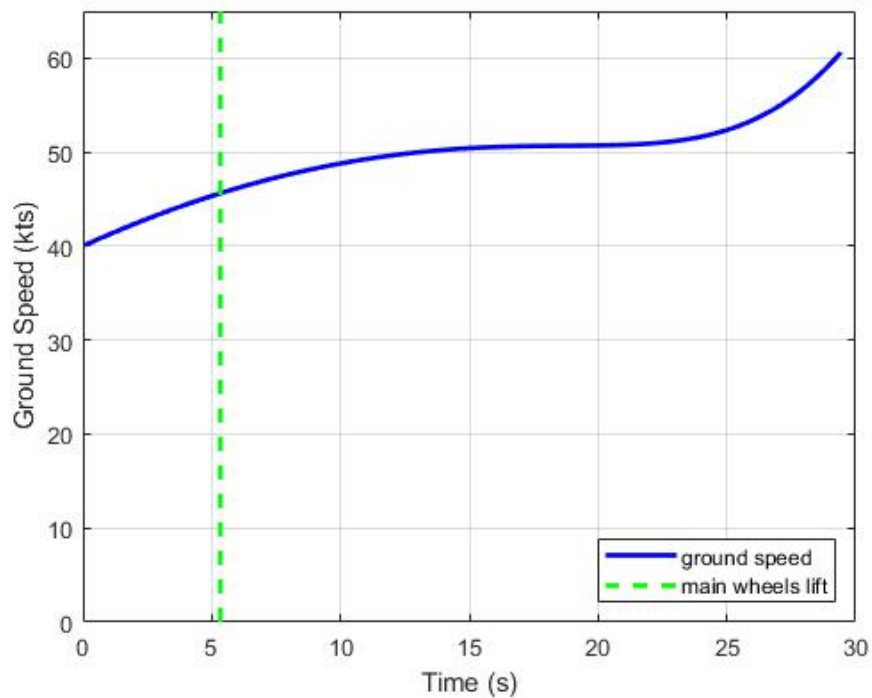
**Figure 3. Estimated Airplane Location East of the Camera**



**Figure 4. Estimated Airplane Location North of the Camera**



**Figure 5. Estimated Ground Track**

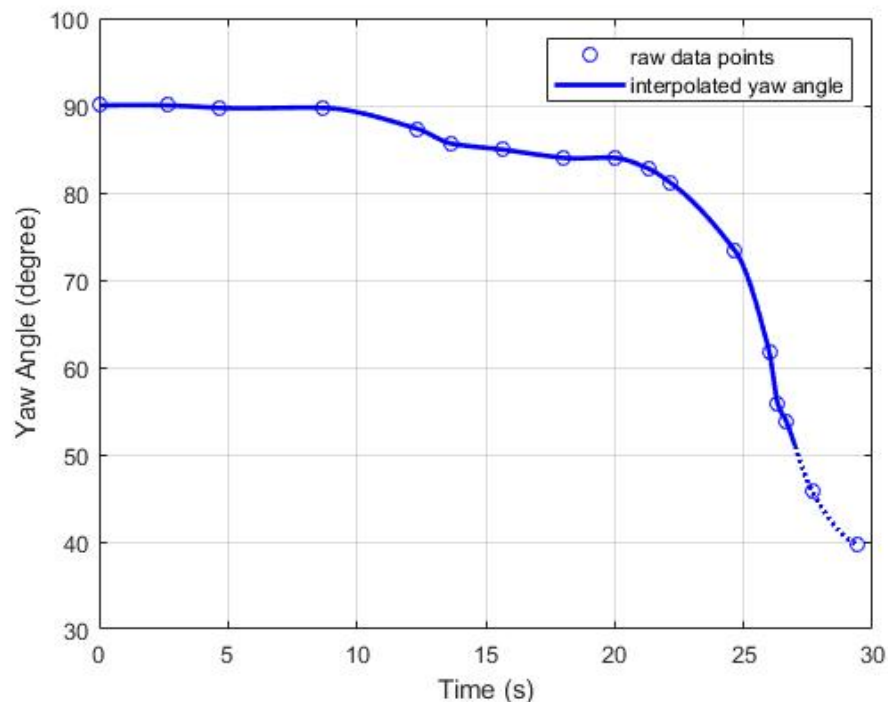


**Figure 6. Estimated Ground Speed**

Figure 5 shows the estimated airplane ground track. The solid blue line is based on the polynomial location fits in Figure 3 and Figure 4. The dotted line connects the last airplane location that could be estimated with the known crash location.

Figure 6 shows the estimated ground speed of the airplane. The airplane had four wheels mounted on the amphibious floats. The vertical broken line marks the time when the two main (rear) wheels lifted, at about time 5.3 seconds. The airplane was airborne past that time.

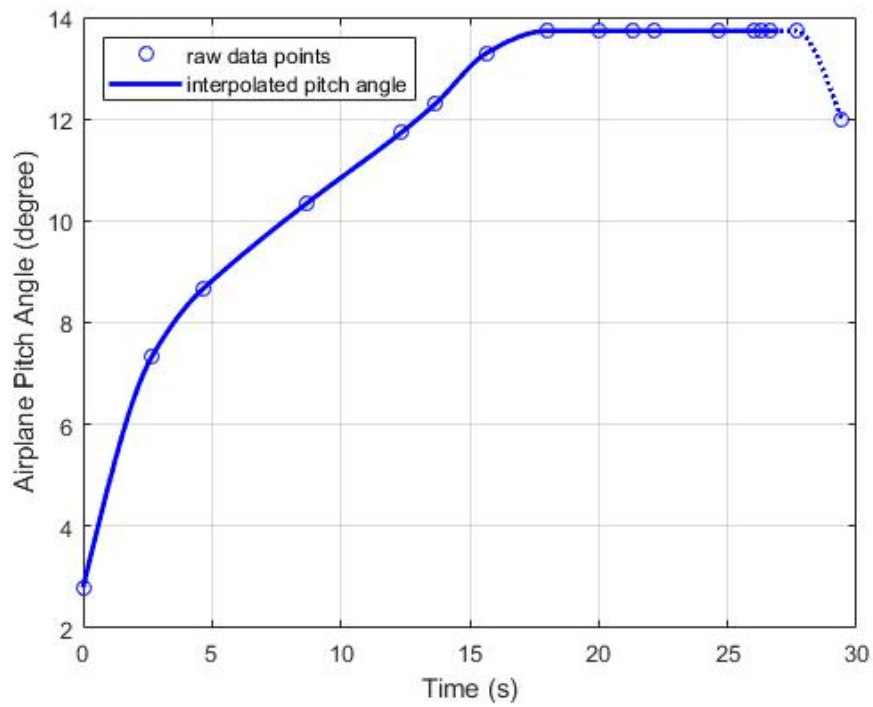
Figure 7 shows the yaw orientation of the airplane. Yaw angle is zero when airplane nose points to north and it increases clockwise. At time zero, the yaw angle was  $90^\circ$  because the airplane nose was pointed to the east. Past time 27 seconds, the angle is represented by a dotted line to indicate reduced accuracy because of reduced visibility of the airplane in the video.



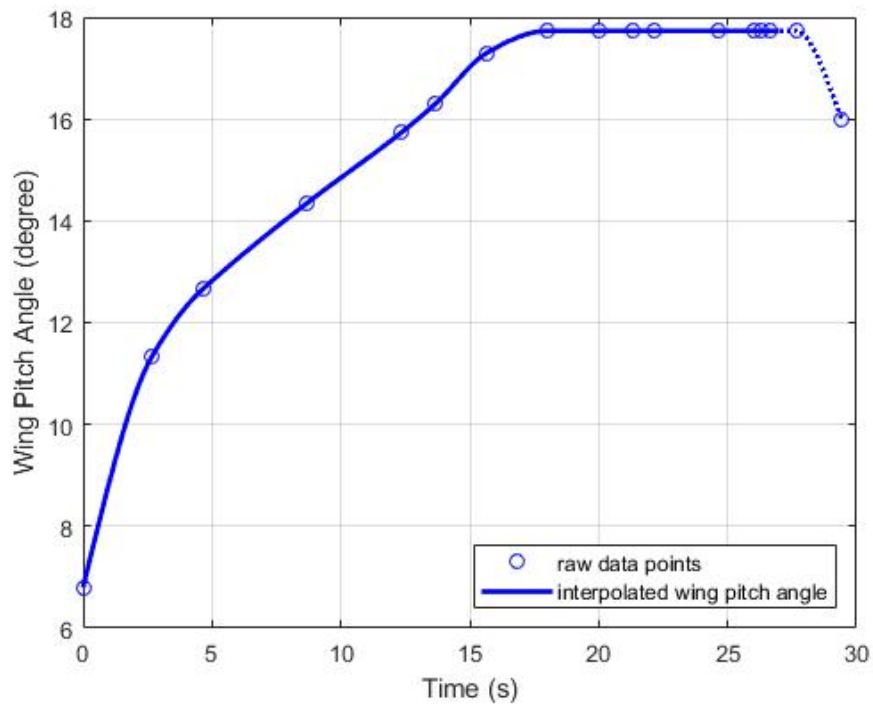
**Figure 7. Estimated Yaw Angle of the Airplane**

Figure 8 shows the estimated pitch angle of the airplane. The angle is defined as zero when the longitudinal axis of the airplane is horizontal. The angle increases as the nose starts pointing up. The dotted line segment indicates reduced angle estimation accuracy.

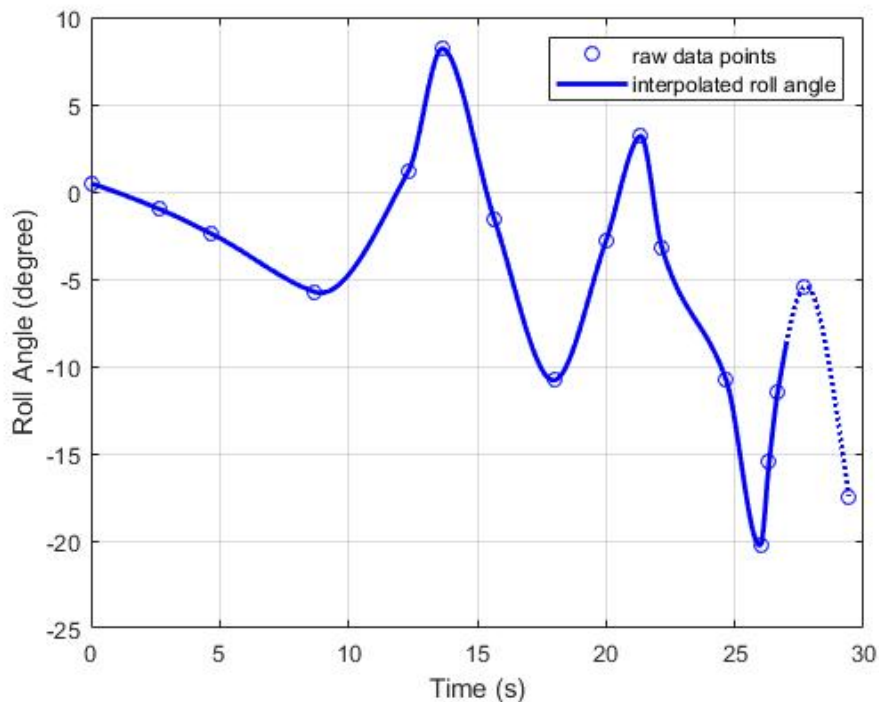
The wing incidence angle, i.e., the angle between the wing airfoil chord and the longitudinal axis of the airplane was estimated as about  $4^\circ$  based on the images of the airplane in the video. Figure 9 shows the estimated pitch angle of the wings. It is  $4^\circ$  higher than the pitch angle of the airplane shown in Figure 8.



**Figure 8. Estimated Pitch Angle of the Airplane**



**Figure 9. Estimated Pitch Angle of the Wings**



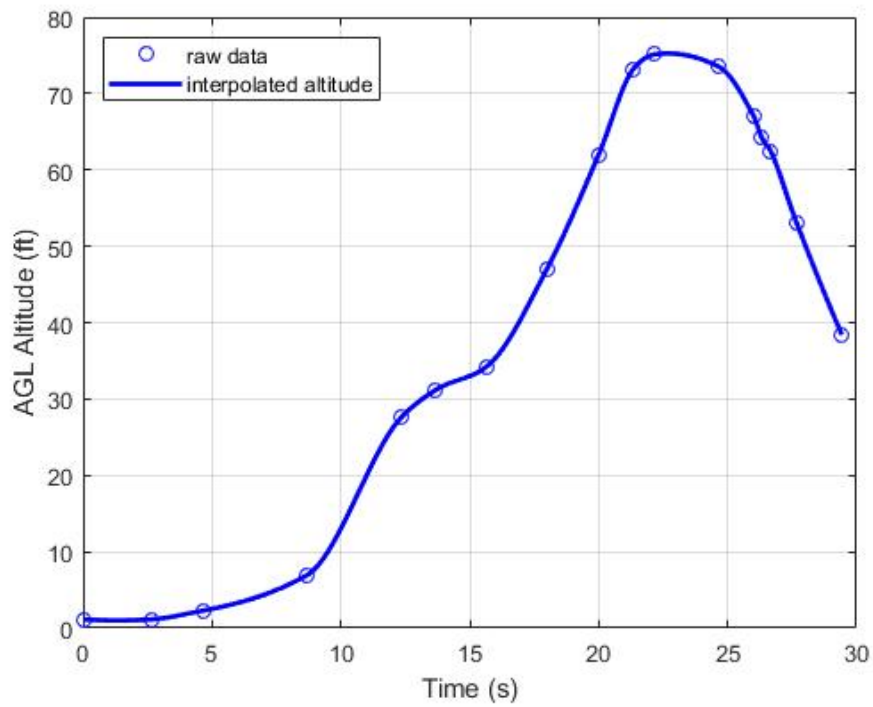
**Figure 10. Estimated Roll Angle of the Airplane**

Figure 10 shows the estimated roll angle of the airplane. Positive roll corresponds to right wing down. The figure shows large roll angle swings past time 10 seconds. Between time 13.67 seconds and time 18 seconds, roll angle decreased by  $19^\circ$ , going from  $+8.2^\circ$  to  $-10.8^\circ$ . The angle then increased to  $+3.2^\circ$  at time 21.33 seconds and then decreased to  $-20.2^\circ$  at time 26 seconds.

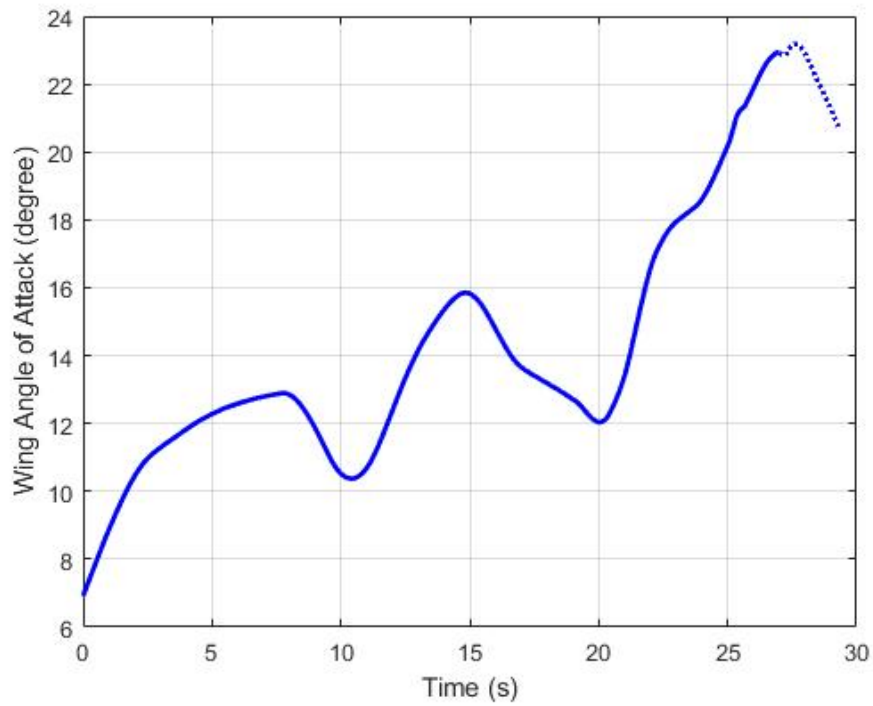
Figure 11 shows the estimated AGL altitude of the airplane. Altitude is set to zero when all four airplane wheels are on the runway. The figure shows the altitude of the nose of the airplane above the altitude where the nose was when all four wheels were on the runway. The maximum altitude that the airplane reached was about 75 feet above the runway, at about time 22 seconds. The airplane was losing altitude past that time.

The estimated vertical speed of the airplane is the slope of the estimated altitude of the airplane shown in Figure 11. The flight path angle (or climb angle) of the airplane is the angle between the velocity vector of the airplane and the horizon. It is computed by  $\tan^{-1}(\text{vertical speed} / \text{ground speed})$ .

The angle of attack of the wings is given by the difference between the wing pitch angle shown in Figure 9 and the flight path angle. Wind direction and speed also affect the angle of attack, but since they were not known, they were not taken into account. Figure 12 shows the estimated wing angle of attack. The accuracy of the estimate is about  $\pm 1.5^\circ$ . The airplane angle of attack is smaller by  $4^\circ$  than the wing angle of attack.



**Figure 11. Estimated AGL Altitude of the Airplane**



**Figure 12. Estimated Wing Angle of Attack**

Figure 12 shows that past time 12 seconds, the wing angle of attack continued climbing dangerously close to the stall angle of attack of the Rans S-7 NACA 2412 wing airfoil. It is possible that wing stall actually occurred near time 15 seconds and it caused the large  $19^\circ$  roll angle change between time 13.67 seconds and time 18 seconds seen in Figure 10. Figure 12 shows that the wing angle of attack decreased to about  $12^\circ$  by time 20 seconds but then increased toward stall values.

At time 25 seconds, the estimated wing angle of attack was  $20^\circ$ , above the wing airfoil stall angle of attack. Figure 11 shows that past time 25 seconds, the airplane was losing altitude. It impacted the ground about 650 feet from the ground location corresponding to the last altitude data point in Figure 11.

### Estimation of Engine Speed

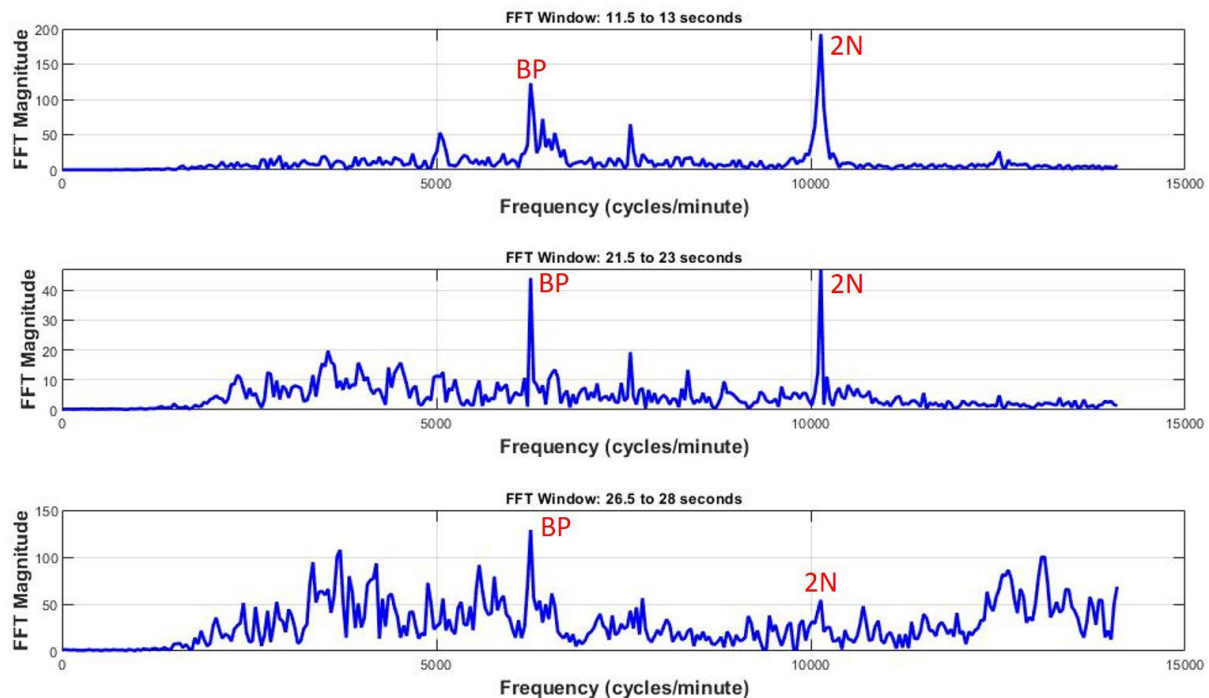
The airplane was powered by a Rotax 912 ULS engine with a reduction gearbox. The rated engine speed is  $N=5800$  rpm. The gearbox reduction ratio is 2.43:1, resulting in rated propeller shaft speed of  $5800/2.43=2387$  rpm. The airplane propeller had three blades, resulting in blade passage frequency of  $2387 \times 3 = 7161$  blades/minute.

The spectrum of the sound recorded in the analyzed video showed largest peaks at the second harmonic of the airplane engine speed and at the blade passage frequency. The ratio of these frequencies is  $2 \times N / (3 \times N / 2.43) = 1.62$ . This ratio should remain constant even when both frequencies are affected by the Doppler effect when the airplane was moving away from the camera.

Figure 13 shows the spectra of the recorded sound at three analysis times. The spectra were computed in 1.5-second wide windows with a 65536-point Fast Fourier Transform (FFT) algorithm, resulting in 40.4 cycle/minute resolution. The analysis windows started at times 11.5 seconds, 21.5 seconds and 26.5 seconds. Two peaks are marked in each plot. BP marks the blade passage frequency and  $2N$  marks the second harmonic of the engine speed. At all three times, these frequencies were BP=6258 cycles per minute (cpm) and  $2N=10130$  cpm. The frequency ratio was  $10130/6258=1.62$ , indicating that the engine reduction gearbox and the propeller were intact.

The airplane was moving away from the camera at about 50 knots at the three times when the spectrum was computed, resulting in the recorded frequencies being about 93% of the emitted frequencies due to the Doppler effect. Therefore, the estimated engine speed was  $(10130/2)/0.93=5446$  rpm, about 94% of the rated engine speed of 5800 rpm.

Figure 13 shows that the engine and the propeller were operating properly in the time window between 26.5 seconds and 28 seconds. Figure 11 shows that the airplane started losing altitude at about time 25 seconds. This indicates that the engine and the propeller were not the cause of the altitude loss.



**Figure 13. Spectrum of the Recorded Sound**

### Other Observations

There was a flagpole with two flags near a building located north of the runway. It can be seen on the left in Figure 2. The relatively small deflections of the flags indicated that the cross component of the wind was to the left relative to the airplane that was moving along the runway. Wind speed could not be estimated based on the flag deflections.

The deflections of the control surfaces of the airplane could be seen until about analysis time 11 seconds. The flaps were deflected down and the ailerons showed no deflections until that time.

### **E. CONCLUSIONS**

The ground track, ground speed, altitude, orientation angles 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 angle of attack of the airplane wings reached high values before and after the airplane started losing altitude. The engine and the propeller were intact when the airplane was losing altitude.