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VIDEO STUDY

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A. ACCIDENT

Location: Russell, Pennsylvania
Date: July 14, 2022
Time: 1940 eastern daylight time (EDT)
Aircraft: Flightstar II-SC, N6116U

B. SUMMARY

B.1. The accident

On July 14, 2022, about 1940 eastern daylight time a Flightstar II-SC, N6116U, was substantially damaged when it was involved in an accident at Shield Farm Airport (5PA6), Russell, Pennsylvania. The non-certificated pilot was seriously injured, and the passenger sustained minor injuries. The airplane was operated as a Title 14 *Code of Federal Regulations* (CFR) Part 91 personal flight.

B.2. Objective and Scope of the Video Study

The objective of this Video Study was estimating the pitch angle and angle of attack of the airplane, and the speed of the airplane engine. Analysis was based on a video recorded with a camera installed on the wing of the airplane.

B.3. Summary of results

The airplane developed a large wing angle of attack shortly after liftoff. The engine was operating near its rated speed throughout the flight segment recorded by the camera.

C. DETAILS OF THE INVESTIGATION

C.1. GPS-based data

The analysis was based on a video that was recorded with a camera mounted on the left wing of the airplane. The video had 1280x720 resolution and frame rate of 30 frames per second. It recorded sound at the rate of 44,100 samples/second. The video lasted 37 seconds.

Figure 1 shows a frame from the analyzed video. The gray rectangles in the figure mask the images of the pilot and the passenger. A GPS device in the airplane recorded the ground track of the airplane and its altitude during the flight at the rate of once per second. The camera and the GPS device were not time-synchronized. Figure 2 shows the ground track of the airplane superimposed on an aerial image of

the accident scene. The numbers along the ground track are seconds elapsed since 19:37:55, the time of the first airplane location recorded by the GPS device.

Figure 3 shows the ground speed and the altitude derived from the recorded GPS data. The ground speed was computed by dividing the distance between two adjacent GPS ground locations by the elapsed time that was one second. There were 44 GPS locations resulting in 43 ground speed estimates. However, as is evident in Figure 2, at time 25 seconds the airplane was already past the time when it impacted trees. Therefore, only the first 25 seconds are shown in Figure 3. The fluctuations of the ground speed are due to the finite accuracy of the GPS ground locations.

The altitude shown in Figure 3 was adjusted to be the altitude above ground level (AGL) relative to the altitude recorded when all three airplane tires were still on the ground during the takeoff roll. Both the ground speed and the AGL altitude in Figure 3 show steep declines past time 19 seconds that corresponds to time 19:38:14.

C.2. Estimation of airplane pitch angle and angle of attack

The camera used a wide field of view angle lens that resulted in significant barrel distortion of the video frames. The distortion was corrected mathematically before analyzing the video.

The pitch angle of interest was the wing pitch angle that can cause large wing angle of attack and stall if too large. There were three angles that had to be considered when estimating the wing pitch angle. The wing incidence angle was defined in this case as the wing pitch angle relative to horizontal when all three tires of the airplane were on a horizontal surface. Based on photographs of several Flightstar II SC airplanes it was estimated to be 7.5° . The camera, pointed along the wing, was attached to the wing with a 3.5° roll angle relative to horizontal. This resulted in the pitch angle of the wing in a video frame to be $7.5^\circ + 3.5^\circ = 11^\circ$ relative to the horizontal edge of the frame when all three tires of the airplane were on a horizontal surface.

The wing pitch angle relative to a horizontal surface when the airplane was on the runway and when it was airborne was estimated by subtracting from 11° the pitch angle at which known horizontal ground references appeared in video frames. For example, when all three airplane tires were still on the ground, horizontal references appeared at an angle of 3.5° relative to the horizontal edge of the frame and the estimated wing pitch angle was $11^\circ - 3.5^\circ = 7.5^\circ$. In Figure 2, the horizontal ground references appear at a large negative angle with respect to the video frame because the wing pitch angle was significantly larger than 11° .

The recorded GPS data and the video based on which the wing pitch angles were estimated had to be time-synchronized. The AGL altitude increase seen at about time 7 seconds in Figure 3 was used to align the video with the GPS data. The altitude increase was due to the rotation of the airplane as it was taking off and it had to correspond to an increase in the wing pitch angle at about the same time. Figure 4 shows the estimated wing pitch angle after the video time was synchronized with the GPS time.

The wing angle of attack is the difference between the wing pitch angle and the flight path angle. Flight path angle is given by $\tan^{-1}(\text{vertical speed} / \text{ground speed})$. The ground speed was calculated as described above and is plotted in Figure 3. Vertical speed is the slope of the altitude curve plotted in Figure 3. Figure 3 shows that the AGL altitude range during the flight was only between zero and 14 feet. This range is smaller than the estimated uncertainty of the GPS-based altitude measurement. Consequently, it is estimated that the accuracy of the computed flight path angle is relatively low and, consequently, the accuracy of the estimated wing angle of attack will be relatively low. This low accuracy of the estimated wing angle of attack will be accounted for below by assigning a relatively large uncertainty range to the estimated value.

Figure 5 shows the estimated wing pitch angle, the estimated flight path angle, and their difference, the estimated wing angle of attack. Because of the significantly barrel-distorted video frames and the inaccuracy of the recorded AGL altitude, the inaccuracy of the estimated wing angle of attack is set at $\pm 4^\circ$. Figure 5 shows that the estimated wing angle of attack was about 20° at time 12.2 seconds. Even if the inaccuracy at that time is at its negative maximum of -4° , the estimated wing angle of attack at that time is still about 16° , a high value.

After about time 15 seconds, the wing angle of attack was quickly reduced because the wing pitch angle decreased, and the flight path angle increased. However, after about time 17 seconds, the wing angle of attack started increasing again because the wing pitch angle was increasing, and the flight path angle became negative as the airplane was losing altitude. At time 19.1 seconds, the video shows that the elevator deflection started increasing. It reached maximum deflection at time 19.4 seconds, probably in an attempt to regain altitude as the airplane was approaching trees.

Figure 5 shows that shortly after the elevator deflection, at about time 20 seconds, the wing angle of attack reached 21.5° and it peaked at 22° at time 21.3 seconds. Figure 3 shows that past time 19 seconds, both the ground speed and the altitude were rapidly declining, consistent with wing stall. The last video frame, at time

22.7 seconds, shows tree branches in front of the airplane. It is assumed that at that time, impact with trees was imminent.

C.3. Estimation of engine speed

Engine speed was estimated via spectral analysis of the sound recorded by the camera. Spectrum was computed with a 65536-point Fast Fourier Transform (FFT) algorithm that computed spectra in 1.4861 seconds-wide windows, resulting in 40 cycles per minute (cpm) frequency resolution. A typical spectrum computed in a 1.4861 seconds-wide window is shown in Figure 6. There are six spectral peaks marked in the figure, A through F. The frequencies of these peaks and the overall characteristics of the spectrum remained constant throughout the flight of the airplane, indicating that the engine operational characteristics did not change during the flight.

The maximum speed of the two-cylinder, four-stroke HKS 700E airplane engine is 6200 rpm. The engine includes an integral gearbox with a 3.47 to 1 ratio. The airplane propeller had three blades. When the engine speed is N rpm, the blade passage frequency is $N \times 3/3.47$ blades per minute. Each of the two engine cylinders fires once per two engine shaft revolutions, at the rate of $N/2$ firings per minute. These firings can generate spectral peaks at the frequencies of $n \times N/2$ where $n=1, 2, 3, \dots$ specifies the harmonics of the cylinder firing rate.

Table 1 lists the frequencies of the six measured spectral peaks marked in Figure 6 and the spectral peak frequencies expected based on the above analysis if it is assumed that the engine speed was 6090 rpm. Assumed engine speed of 6090 rpm results in propeller blade passage frequency (BPF) of $6090 \times 3/3.47 = 5265$ blades per minute.

Table 1. Measured and expected spectral peak frequencies

Spectral Peak	Measured Frequency (cpm)	Expected Frequency (cpm)	Harmonic Specifier n
A	5249	5265	BPF
B	6097	6090	2
C	9125	9135	3
D	12193	12180	4
E	15221	15225	5
F	18290	18270	6

The measured spectral frequencies listed in Table 1 are as expected considering that the frequency resolution of the FFT algorithm was 40 cpm. The accurate agreement between measured and expected frequencies confirms that the engine

speed was 6090 rpm and that the gearbox operated properly. The engine speed and the proper operation of the gearbox remained constant throughout the flight.

D. CONCLUSIONS

The wing pitch angle and the wing angle of attack of an airplane that crashed shortly after takeoff were estimated based on a video recorded with a camera mounted on the left wing of the airplane. It was estimated that the wing angle of attack exceeded 20° shortly before the airplane impacted trees. The sound stream in the video was used to estimate the speed of the engine. It was found that it operated at 6090 rpm, near the rated speed, throughout the flight.

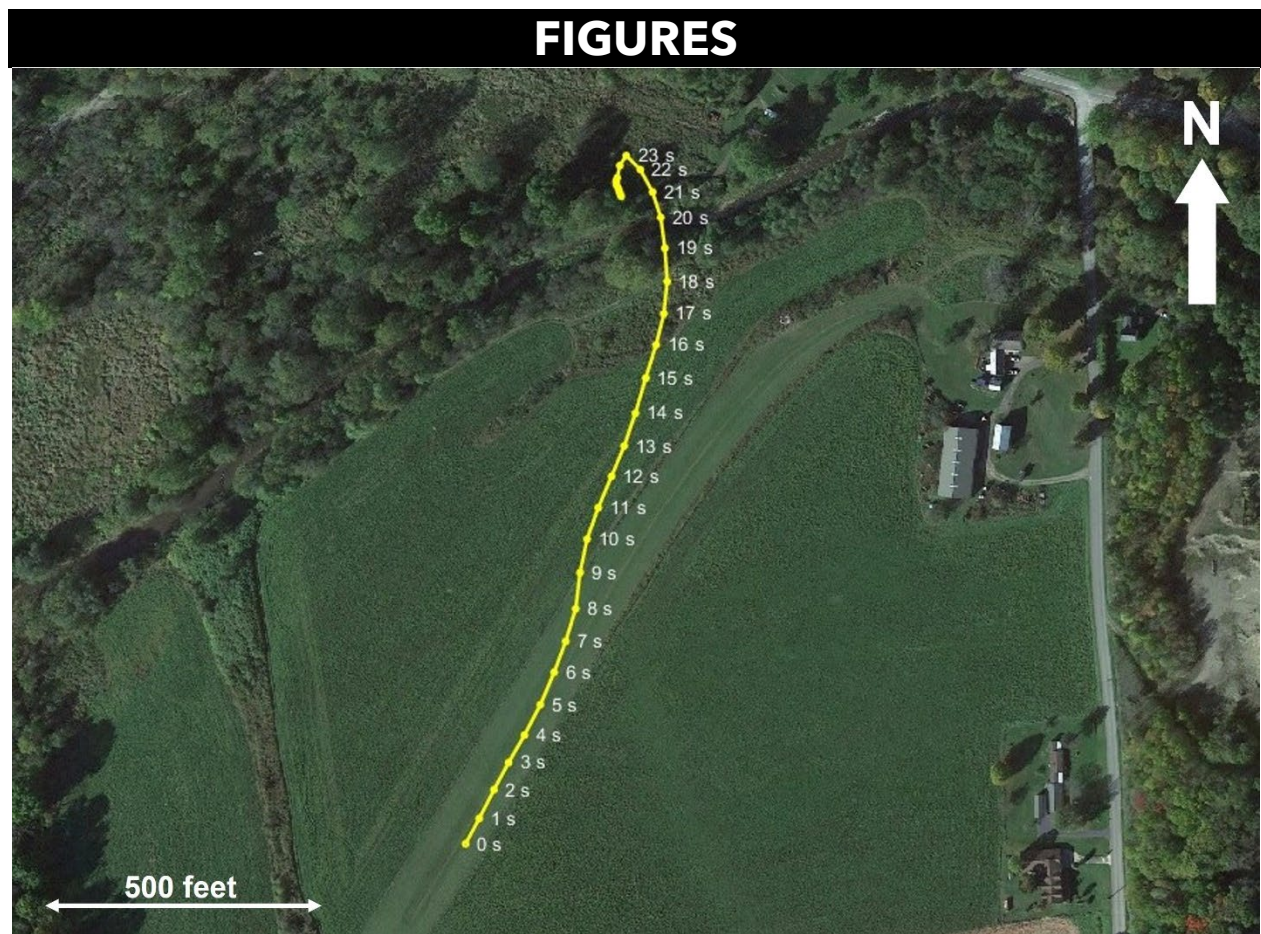


Figure 1. Aerial view of the accident area (the numbers are seconds past 19:37:55)



Figure 2. Frame from the analyzed video

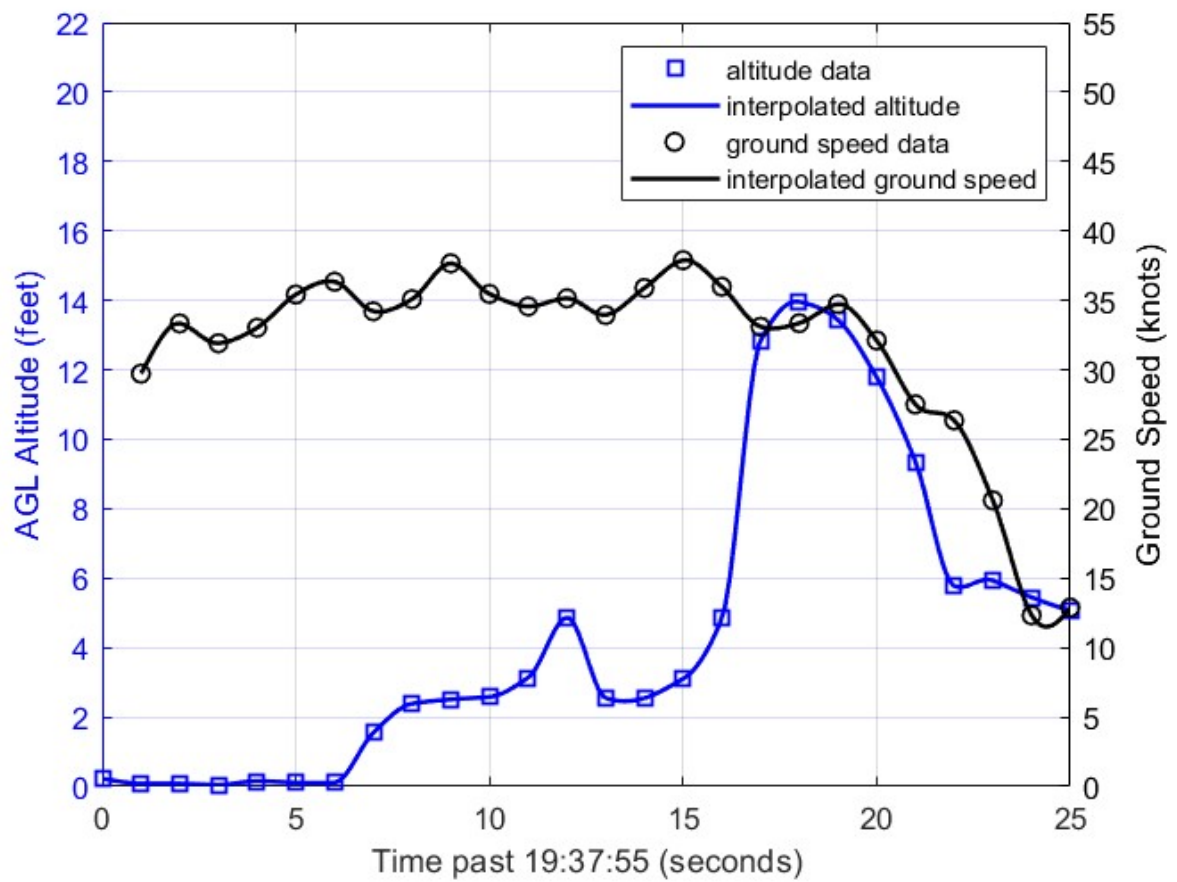


Figure 3. Airplane ground speed and AGL altitude

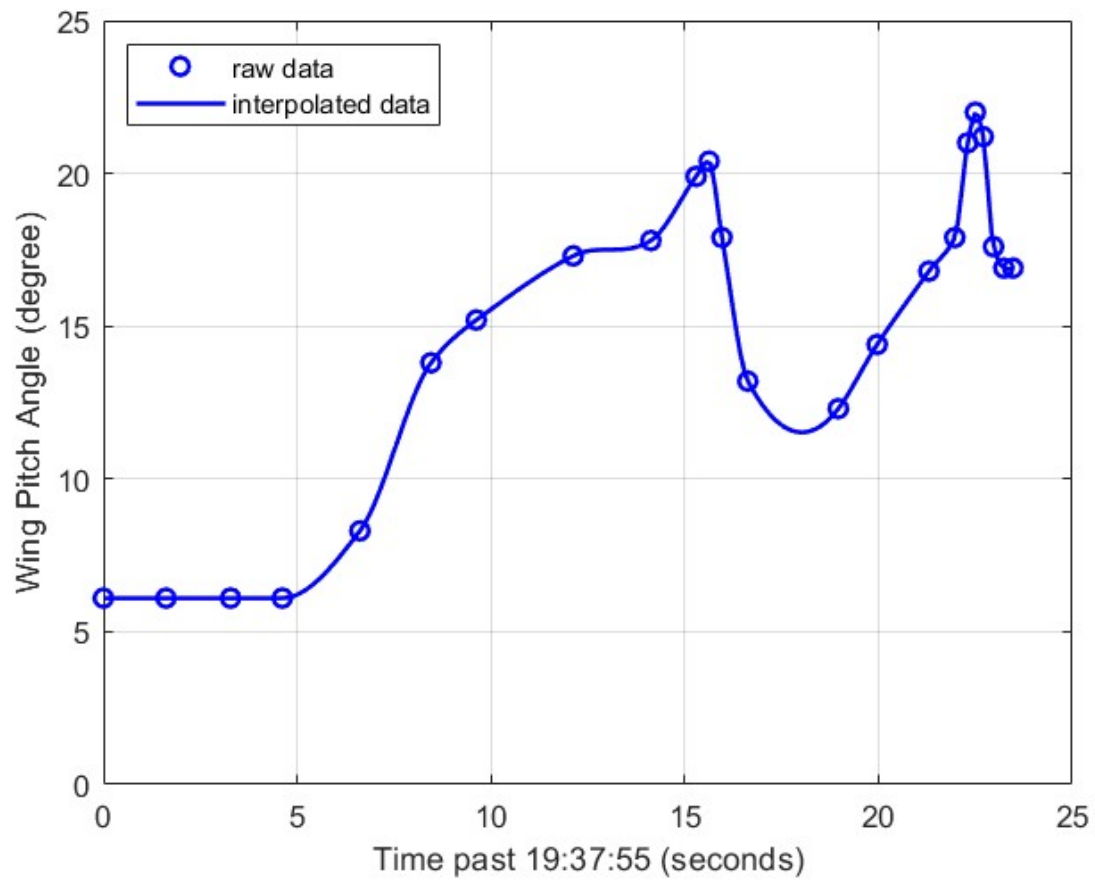


Figure 4. Estimated wing pitch angle

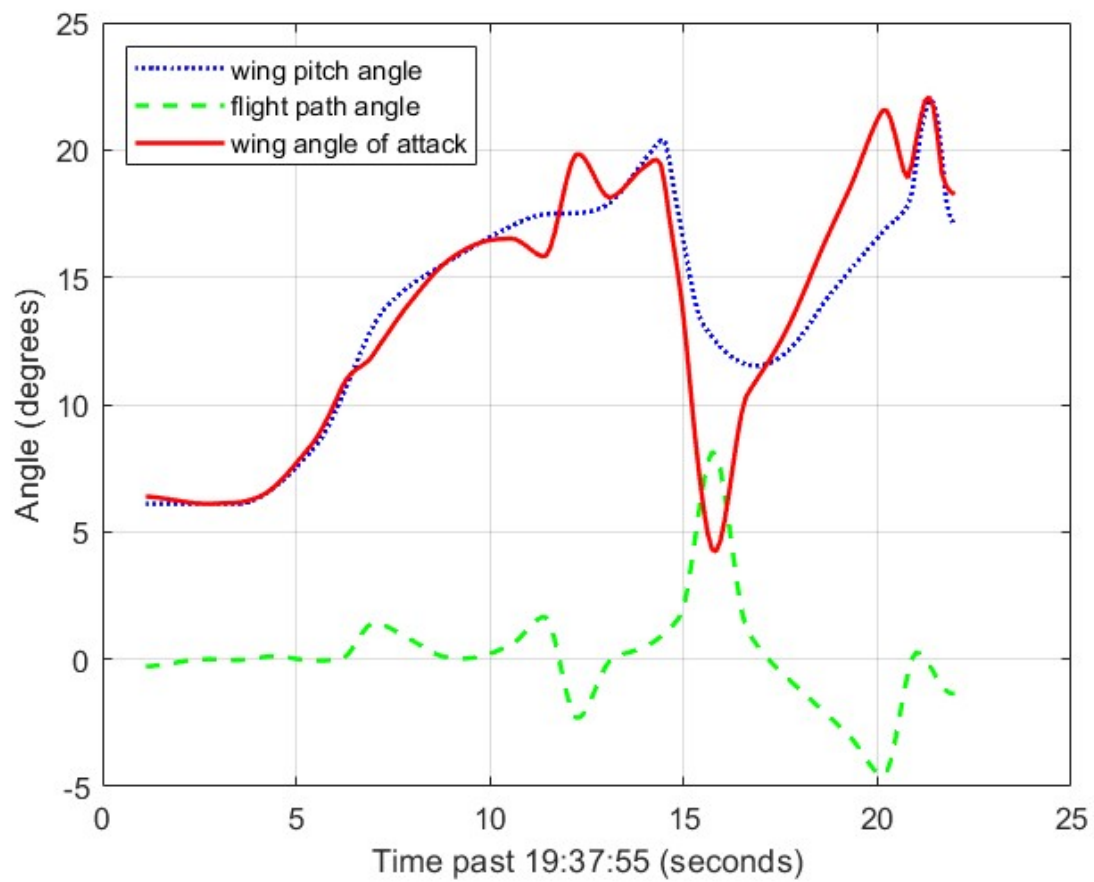


Figure 5. Estimation of wing angle of attack

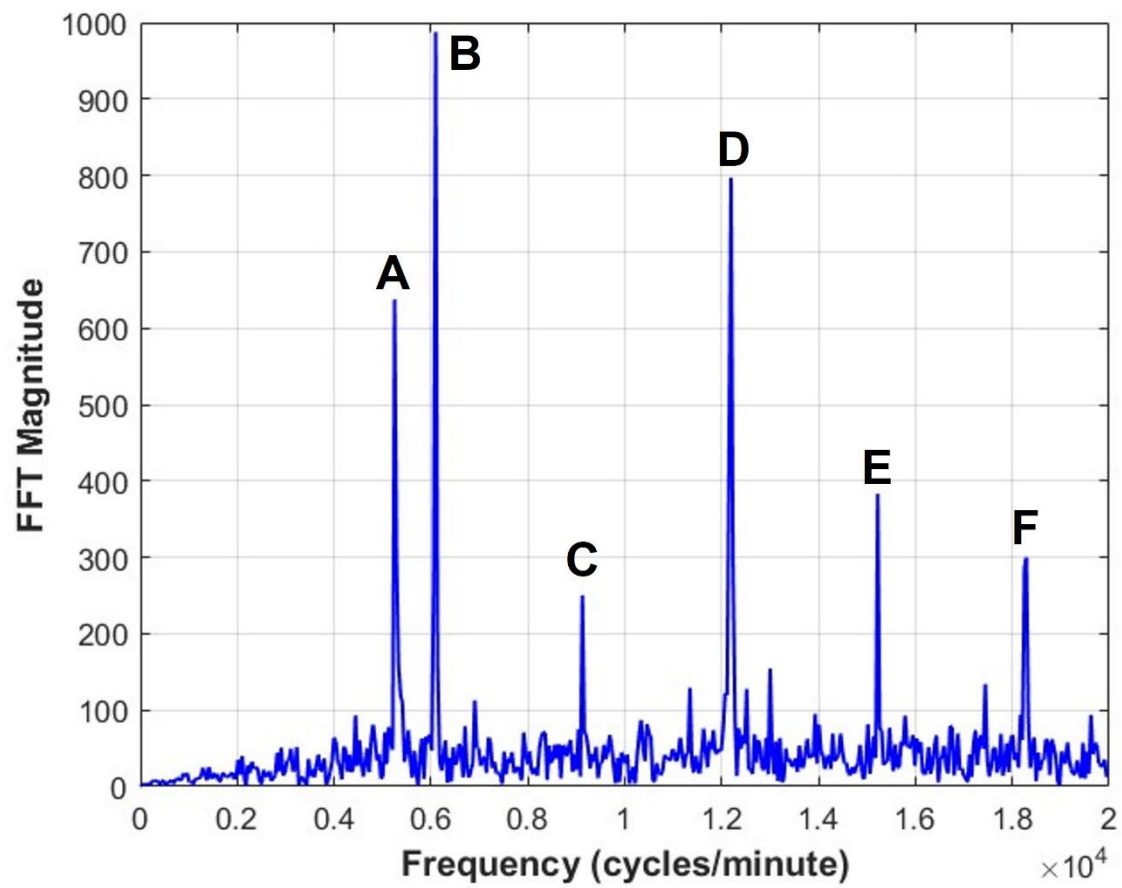


Figure 6. Engine sound spectrum