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

GROUP CHAIRMAN'S SOUND SPECTRUM STUDY REPORT

CEN19MA190

By
Charles Cates

NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division

July 29, 2020

Cockpit Voice Recorder – Sound Spectrum Study

Group Chairman's Study Report
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1. EVENT SUMMARY

Location:	Addison, Texas
Date:	June 30, 2019
Aircraft:	Textron Aviation B300, Registration N534FF
Operator:	S&H Aircraft
NTSB Number:	CEN19MA190

On June 30, 2019, about 0911 central daylight time, a Textron Aviation B300, N534FF, was destroyed when it was involved in an accident near Addison, Texas. The airline transport pilot, the commercial co-pilot, and eight passengers sustained fatal injuries. The airplane was operated as a Title 14 *Code of Federal Regulations* Part 91 personal flight.

A solid-state cockpit voice recorder (CVR) was sent to the National Transportation Safety Board (NTSB) Vehicle Recorder Division for evaluation. A portion of the CVR recording was identified for further analysis in a dedicated study.

2. GROUP

A sound spectrum study group was convened remotely between NTSB and Hartzell Propeller specialists.

Chairman:	Charles Cates Mechanical Engineer National Transportation Safety Board
Member:	Les Doud Air Safety Investigator Hartzell Propeller/Hartzell Engine Technologies

3. DETAILS OF INVESTIGATION

The NTSB Vehicle Recorder Division received the following CVR:

Recorder Manufacturer/Model:	**L-3/Fairchild FA2100-1020**
Recorder Serial Number:	**001188762**

For details of the CVR and recovery of data, see the Cockpit Voice Recorder Group Chairman's Factual Report, available in this docket.

A sound spectrum study was completed on a portion of the cockpit area microphone (CAM) channel of the recording identified during the CVR group to investigate the possibility of determining the following:

- Ground and propeller speeds during the takeoff roll and accident sequence.
- Characteristics of sound of click.
- Determination of engine operation.

3.1 Description of Audio Events

See figure 1 (page 5) for a view of the sound spectrum from 25-210 Hz and figure 2 (page 8) for a view of the full audio range of the CAM channel, 0-8k Hz of the time period of interest for the study. Note that the times in the graph are not adjusted to the accident time, CDT, due to limitations of the acoustic analysis software, however adjusted times are provided in the text and tables.

At 2:03:17.2 in the CAM channel (9:10:12.4 CDT), a sound consistent with the engines advancing in power was recorded. During this time, a signal increasing in frequency and stabilizing was present in the sound spectrum. This signal was identified as the blade pass frequency of the propellers. At 2:03:40.1 (9:10:45.3 CDT), a reduction in broadband noise represented in the spectrum as a slight decrease in overall sound energy consistent with the aircraft taking off was audible. Between these two events, a series of multiple signals increasing in frequency with time and abruptly ceasing was present in the sound spectrum. Aircraft ground speed would have been too low for the CVR to capture the fundamental frequency of the landing gear tires, which would have been in the range of 0-30 Hz. Therefore, these signals were identified as harmonics of the fundamental frequency of the landing gear tires rolling on the runway. There was also a constant signal at 129 Hz that was identified as being consistent with avionics fan noise.

After taking off, the signal identified as the propeller blade pass frequency of the two four-bladed propellers was one tone. This is consistent with both propellers turning at approximately the same speed. About five seconds later, the sound of a click was recorded (not visible in figure 1)[1] and the tone then diverged in to two tones, consistent with one propeller turning slower than the other[2]. Stall warning tones were recorded from 2:03:46.5 (9:10:41.7 CDT) to 2:03:49.0 (9:10:44.2 CDT) and again from 2:03:50.9 (9:10:46.1 CDT) to the end of the recording that are visible in figure 2 and are referenced in the points of interest. At 2:03:54.2 (9:10:49.4 CDT), the lower propeller tone abruptly ceased to be visible in the spectrum, however, the first harmonic of that propeller tone was still visible until the point of impact, allowing for continued propeller speed calculations to be made.

3.2 Calculation of ground and propeller speeds

A sound spectrum study was conducted to determine propeller and ground speeds corresponding to the signals recorded by the CVR CAM channel. Figure 1 shows the

[1] Recorded clicks will be discussed in detail in Section 3.2.

[2] Based on the physical evidence of propeller slash marks on the hangar building the left propeller was the slower turning propeller.

sound spectrum for the time period of interest with ten sections annotated that were of interest to the study. A fast Fourier transform (FFT[3]) analysis was performed at each section to determine frequency components of the signals and calculate the speeds of interest. Relevant FFT parameters including FFT size, window type, and window overlap are included for each of the data points in Section 4.

The points of interest were as follows:

1. Beginning of engine acceleration to takeoff power.
2. Point where the engines were stabilized at takeoff power.
3. Point identified as the time the aircraft rotated for takeoff.
4. Point identified as the time the aircraft lifted off.
5. Time at which the aircraft stall warning was first heard.
6. Point at which the two propeller speeds were the furthest apart during the initial propeller speed dip.
7. Time at which the sound of the first stall warning ceased.
8. Time at which the aircraft stall warning sound was heard a second time.
9. Time at which the lower speed propeller fundamental frequency ceased to be visible in the spectrum.
10. The point of impact with the building.

For most points, a FFT sample size of 16,384 with 4x overlap (4,096 samples) provided a reasonably good level of tonal detectability with identification of transient signals. For point 5, the FFT sample size was increased to 65,536 with 4x overlap (16,384 samples) to find the point where the two propellers began to diverge in speed as closely as possible.

The equation used to convert the blade pass frequency in Hz to propeller speed in rpm (Np) is as follows:

$$Np = \left(\frac{f_{Blade\ Pass}}{number\ of\ blades}\right) \times 60$$

The propellers on the accident aircraft had four blades.

The landing gear tire frequencies were identified as harmonics of a once per revolution signal from the tires rolling on the runway and picked up by the cockpit area microphone. The equation used to convert the landing gear tire frequency in Hz to ground speed in knots (GS) is as follows[4]:

$$GS = \left(\frac{f_{Landing\ Gear}}{Harmonic\ Order}\right) \times Tire\ Circumference\ (inches) \times 0.04937364$$

The tire size for both the main and nose gear of the aircraft was 22x6.75-10, meaning tire diameters were approximately 22”. Therefore, the tire circumference for the study was estimated to be 69.115”. It is important to note that tire circumference can be variable due

[3] FFT analysis converts the sound spectrum from the time domain to the frequency domain to quantify the intensity of different frequencies at that time.
[4] This method was validated with flight test data from an exemplar aircraft operating at known ground speeds for rotation and liftoff.

to factors such as tire pressure, tread depth, and load. Because the actual tire circumference of the aircraft on the day of the accident is unknown the calculated ground speeds should be considered to have an error of up to +/-5%.

Table 1 provides the speeds calculated from the spectrum data. Section 4 provides the FFT data from each point of interest used to calculate the speeds provided in Table 1.

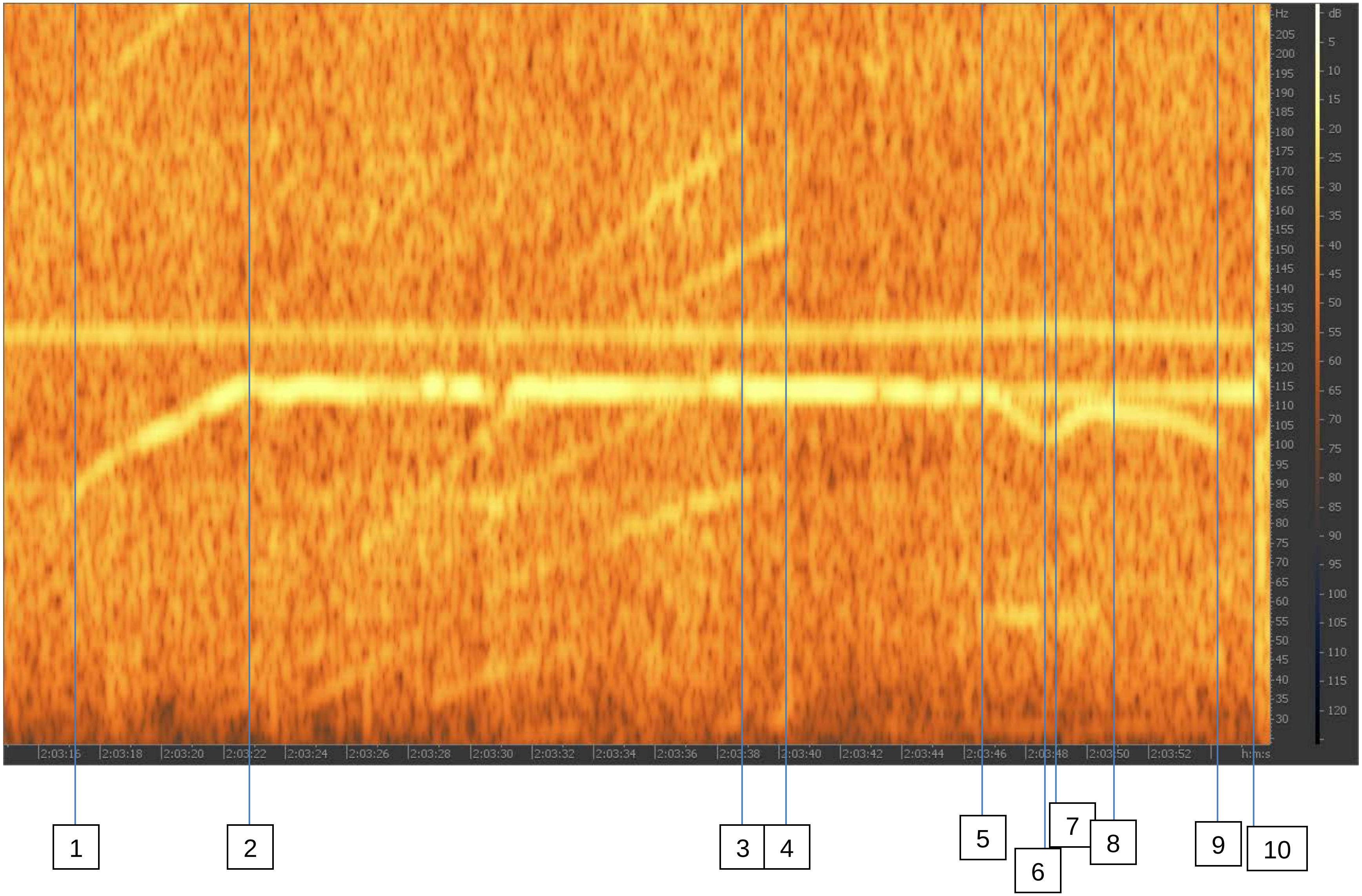


Figure 1. Image of CAM channel sound spectrum from 25-210 Hz of time period from engines advancing to takeoff power to end of recording, annotated with data point times of interest to the analysis.

Point	Time (Recorder)	Time (CDT)	Time from impact	Np 1 (rpm)	Np 2 (rpm)	Ground Speed (kts)	Note
1	2:03:17.2	9:10:12.4	0:00:38.2	1333.5		N/A	Beginning of engine acceleration to takeoff power
2	2:03:22.9	9:10:18.1	0:00:32.5	1729		N/A	Engines stable at takeoff power
3	2:03:38.8	9:10:34.0	0:00:16.6	1728		~101	Rotation
4	2:03:40.1	9:10:35.3	0:00:15.3	1714		~105	Lift off
5	2:03:46.5	9:10:41.7	0:00:08.9	1688	1707	N/A	Onset of initial stall warning, props began to diverge at 2:03:45.3
6	2:03:48.7	9:10:43.9	0:00:06.7	1545	1705	N/A	Point of largest difference in initial prop deviation
7	2:03:49.0	9:10:44.2	0:00:06.4	1560	1702.5	N/A	End of initial stall warning
8	2:03:50.9	9:10:46.1	0:00:04.5	1632	1705.5	N/A	Onset of second stall warning
9	2:03:54.2	9:10:49.4	0:00:01.2	1531.5	1708.5	N/A	Second prop fundamental abruptly stopped, first harmonic still visible until impact
10	2:03:55.4	9:10:50.6	0:00:00.0	1403	1704	N/A	Impact with building

Table 1. Propeller and ground speeds calculated from CAM channel data.

3.3 Characterization of clicks

The sound of a click was recorded two times during the accident flight, once at 2:03:40.7 in the CAM channel recording (9:10:41.0 CDT) and again at 2:03:49.3 (9:10:44.5 CDT). The first click occurred about one second prior to the first aircraft stall warning, which is shown in spectrum data as a tone at around 2k Hz starting at 2:03:46.5 (9:10:41.7 CDT)), and the second click occurred between the end of the first stall warning and the beginning of the second stall warning at 2:03:50.9 (9:10:46.1 CDT). Both clicks were broadband in nature, with sound energy captured from about 1.5k-8k Hz. Figure 2 shows this period of the spectrum. The clicks are represented as short duration (vertical) peaks in broadband energy intensity.

A test was conducted in an exemplar B300 cockpit to see if the throttle movement could produce a similar click. The spectrum in figure 3 shows two clicks, the first from an unidentified flight deck switch being actuated at 1:02:41 in the recording from the exemplar aircraft, and the second from the throttle contacting the idle detent at 1:02:49. The switch panel is located on the lower portion of the panel near the throttle quadrant in the cockpit of the B300.

The test on the aircraft was conducted while on the ground with the avionics on and the engines not running, therefore the background noise environment was quieter on the test aircraft than the accident aircraft. The sound of the switch produced a larger range of frequencies than the sound of the throttle contacting the idle stop. The switch being actuated produced sound energy in frequencies ranging from about 2k-8k Hz, while the throttle contacting the idle stop produced sound energy in frequencies ranging from about 3.5k-8k Hz.

The accident recording was filtered to reduce the noise level and a comparison was made of the sound energy between the clicks heard on the accident flight and the clicks recorded in the ground test. It is possible that the background noise on the accident flight may have masked frequencies of the events in question, and therefore there is a high degree of uncertainty surrounding the comparisons. However, adjusted energy levels from the first click recorded during the accident flight sequence exhibited similar characteristics to the click recorded when the throttle contacted the idle stop in the test. Elevated sound energy was noted in frequencies ranging from about 3k-8k Hz, with peaks at about 5.5k and 6k Hz.

Adjusted energy levels from the second click recorded during the accident flight sequence exhibited similar characteristics to the click recorded upon actuation of a flight deck switch. Elevated sound energy was noted in frequencies ranging from about 1.5k to about 8k, with a concentration of energy between 3.5k and 5.5k Hz. Again, due to the background noise level differences there is a high degree of uncertainty in this spectral comparison.

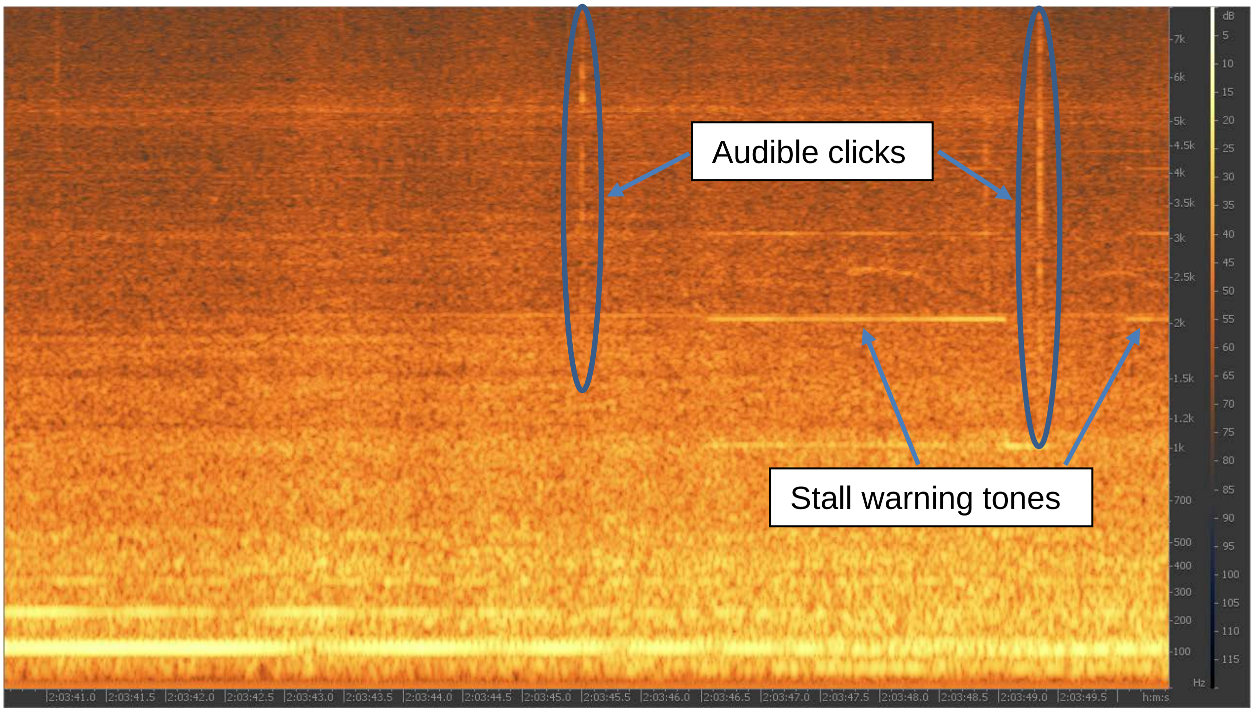


Figure 2. Sound spectrum from accident CAM recording showing two audible clicks under investigation.

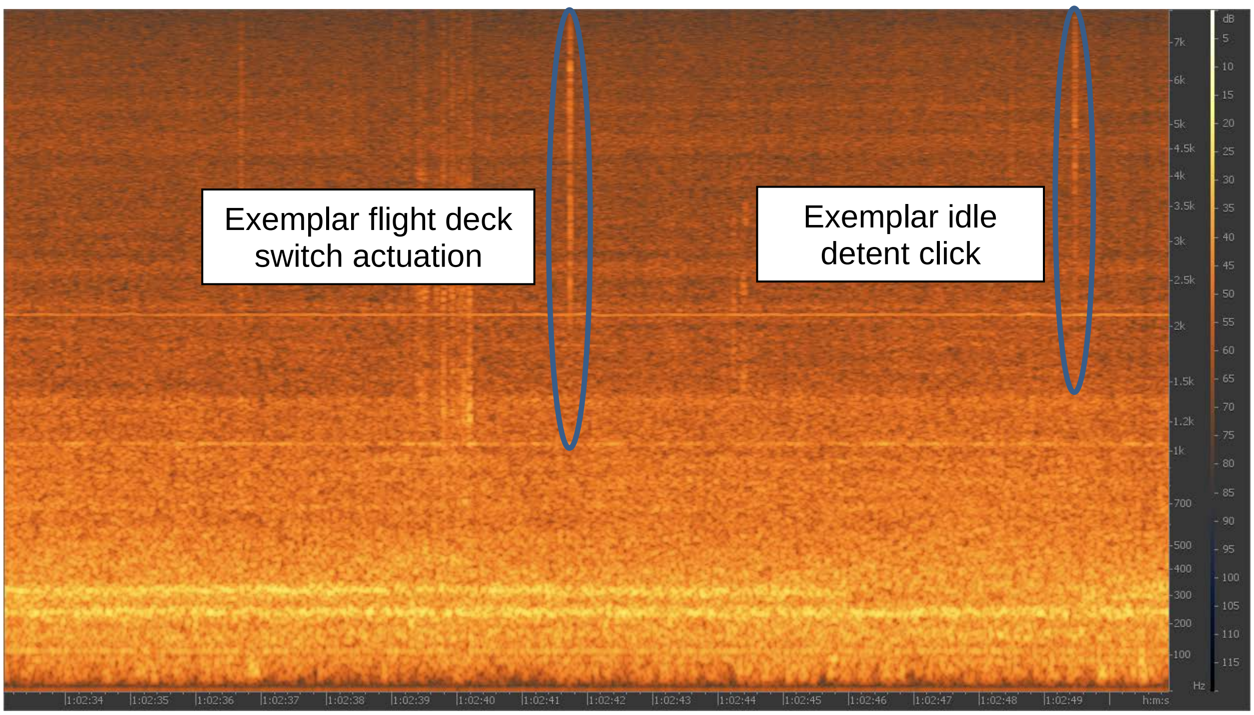


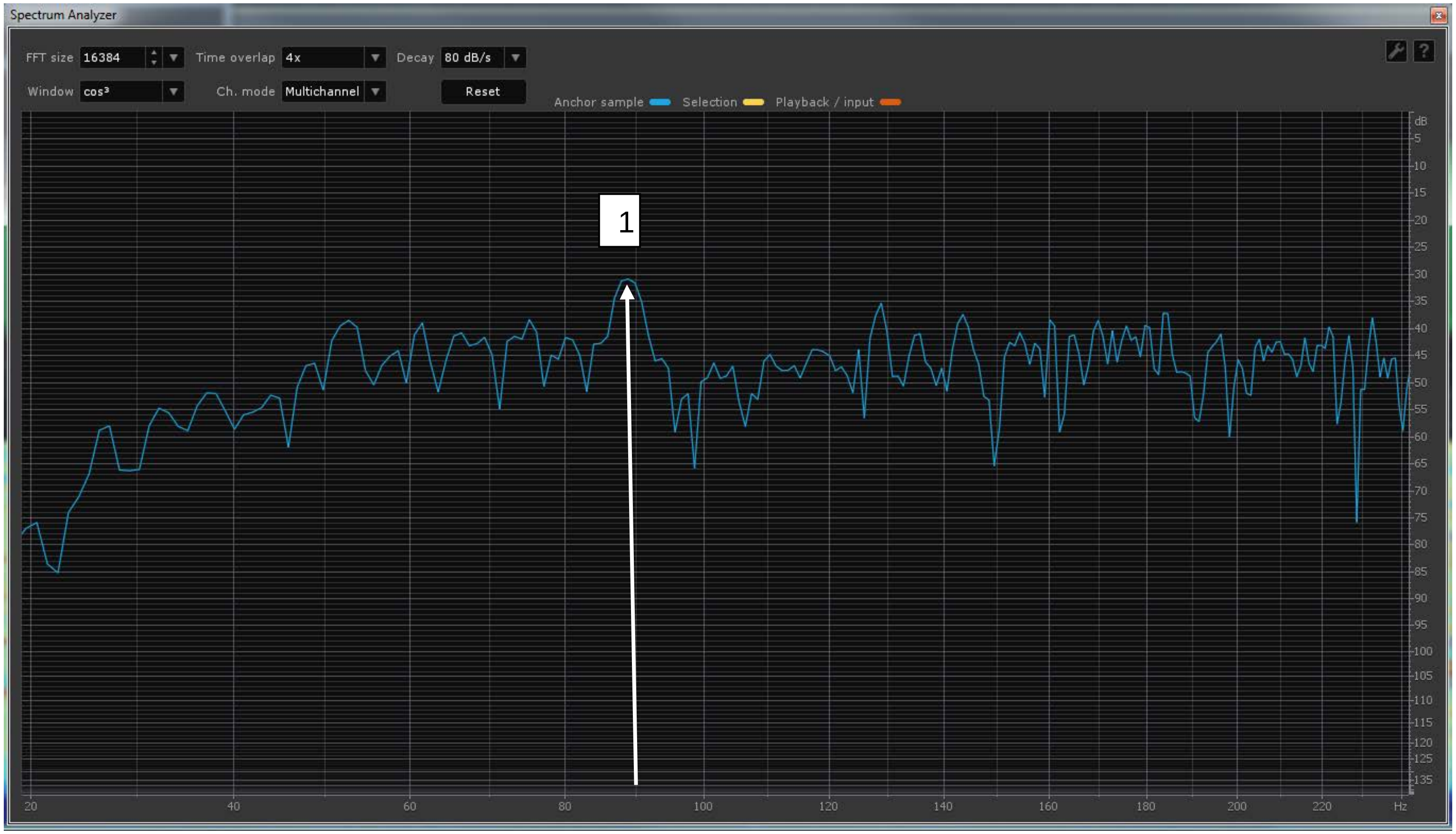
Figure 3. Sound spectrum from exemplar BE-300 aircraft CAM recording showing two audible clicks.

3.4 Engine operation noise

Sound spectrum work was performed to attempt to identify data pertinent to the operation of the engines in addition to the work performed to determine propeller speeds during the accident sequence. Data related to shaft speeds and gearbox ratios was provided by the engine manufacturer to see if those frequencies could be matched in the CAM channel of the CVR recording. Investigation of the recording showed that the frequencies in question were likely either masked by other sounds in the cockpit or were beyond the upper frequencies recorded by the CVR. No other engine information could be determined.

4. SPECTRUM FFT DATA

4.1 Data Point 1

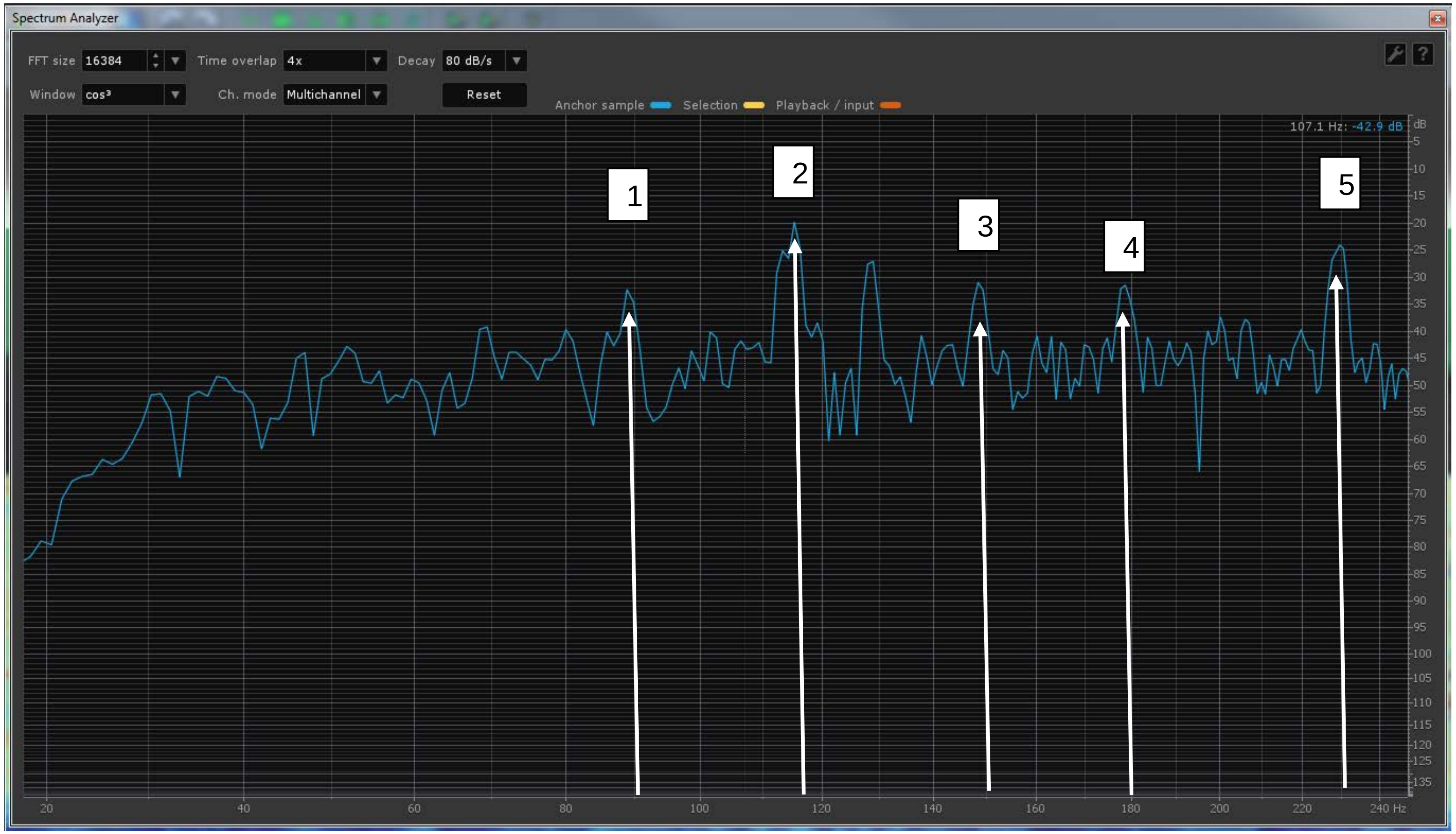


Peak 1 : 88.9 Hz, identified as Np

4.2 Data Point 2

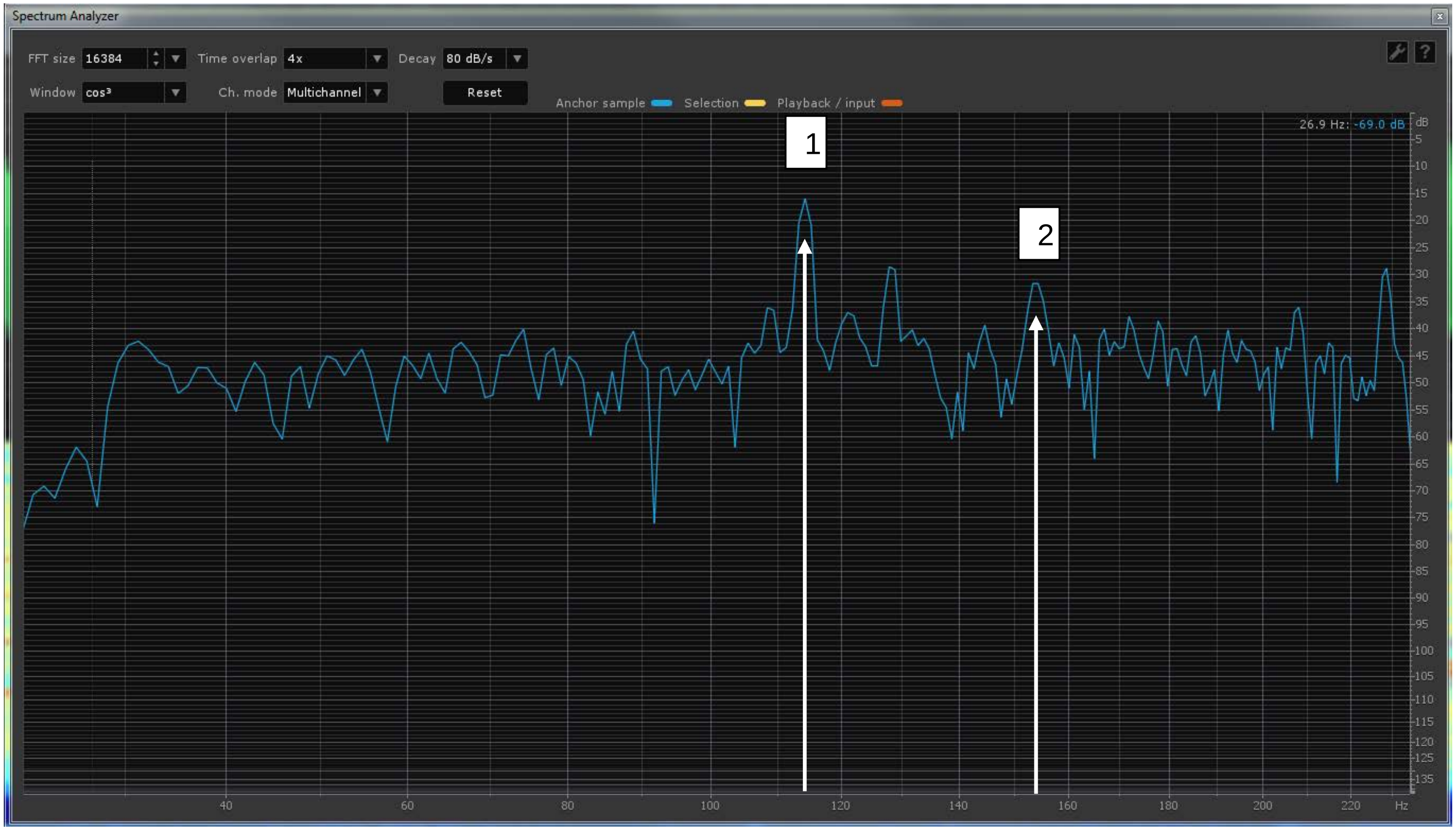
Peak 1 : 115.26 Hz, identified as Np

4.3 Data Point 3



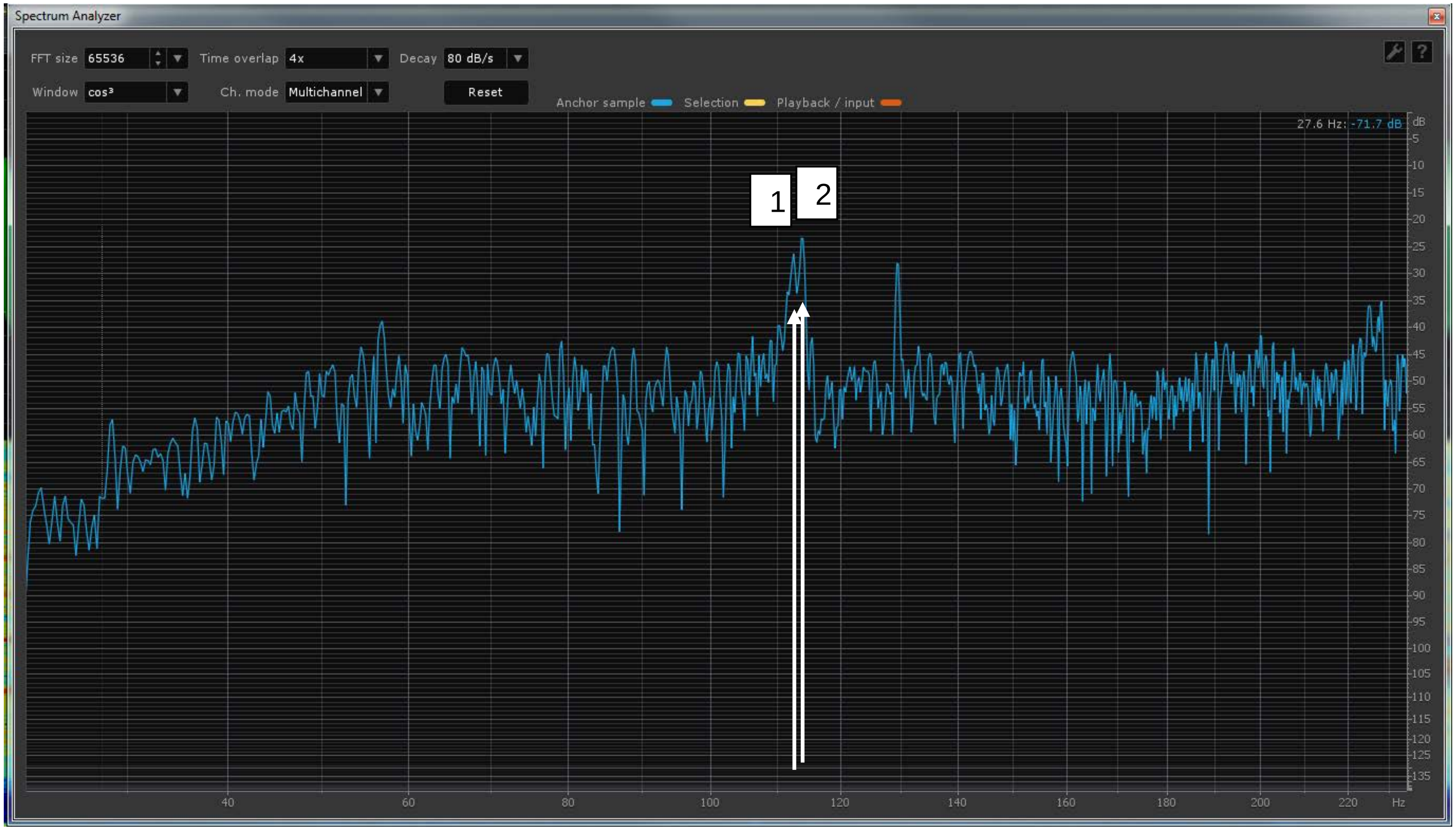
Peak 1: 89 Hz, identified as tire overtone
Peak 2: 115.22 Hz, identified as Np
Peak 3: 148.6 Hz, identified as tire overtone
Peak 4: 178.6 Hz, identified as tire overtone
Peak 5: 230 Hz, identified as Np overtone

4.4 Data Point 4



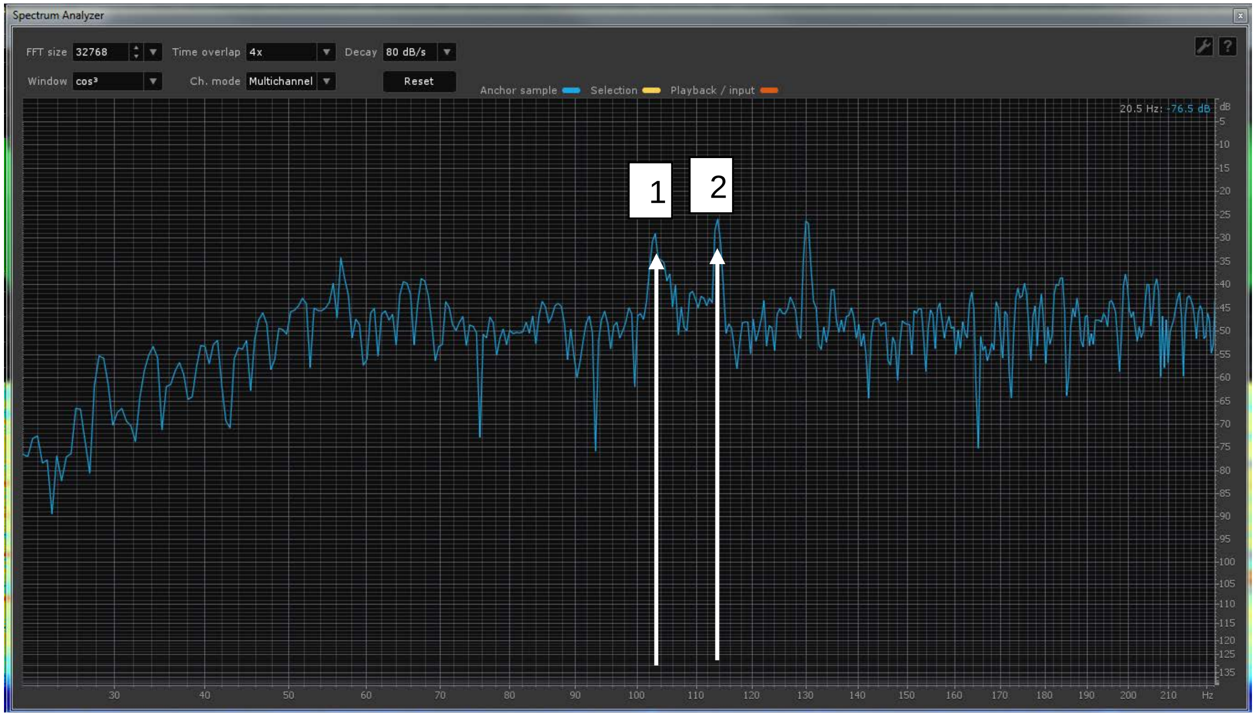
Peak 1: 114.24 Hz, identified as Np
Peak 2: 154 Hz, identified as tire overtone

4.5 Data Point 5



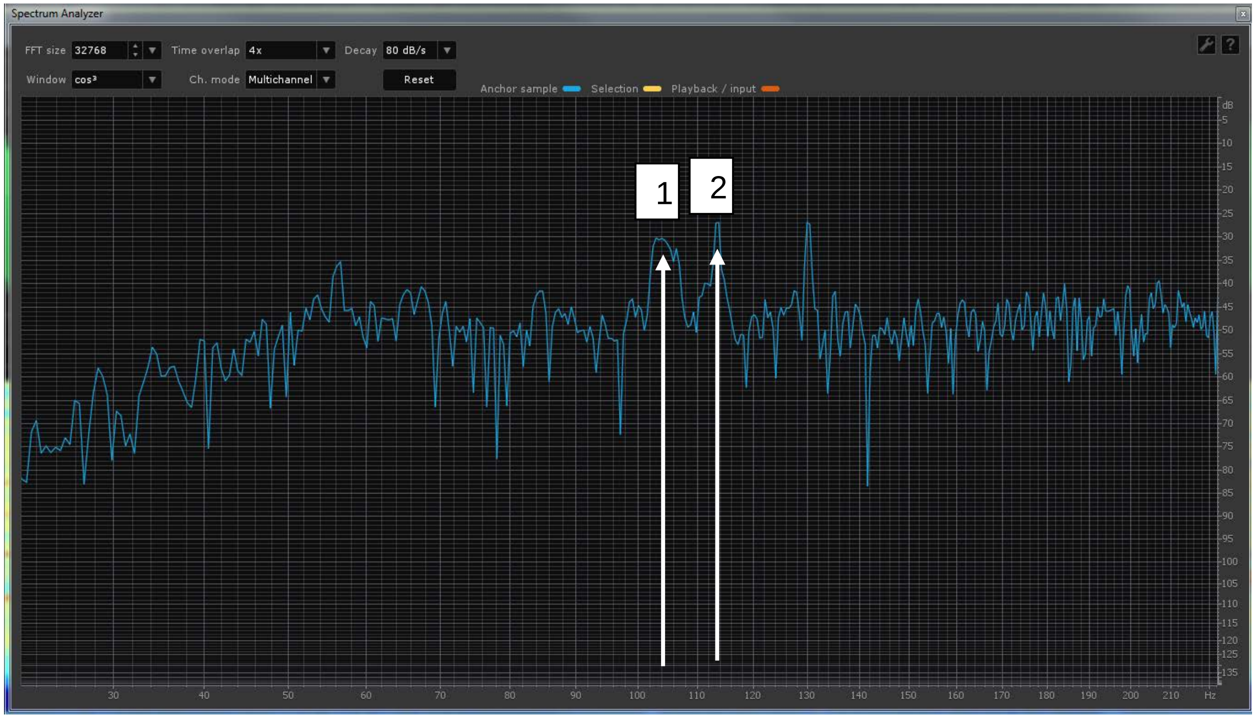
Peak 1: 112.56 Hz, identified as Np 1
Peak 2: 113.8 Hz, identified as Np 2

4.6 Data Point 6



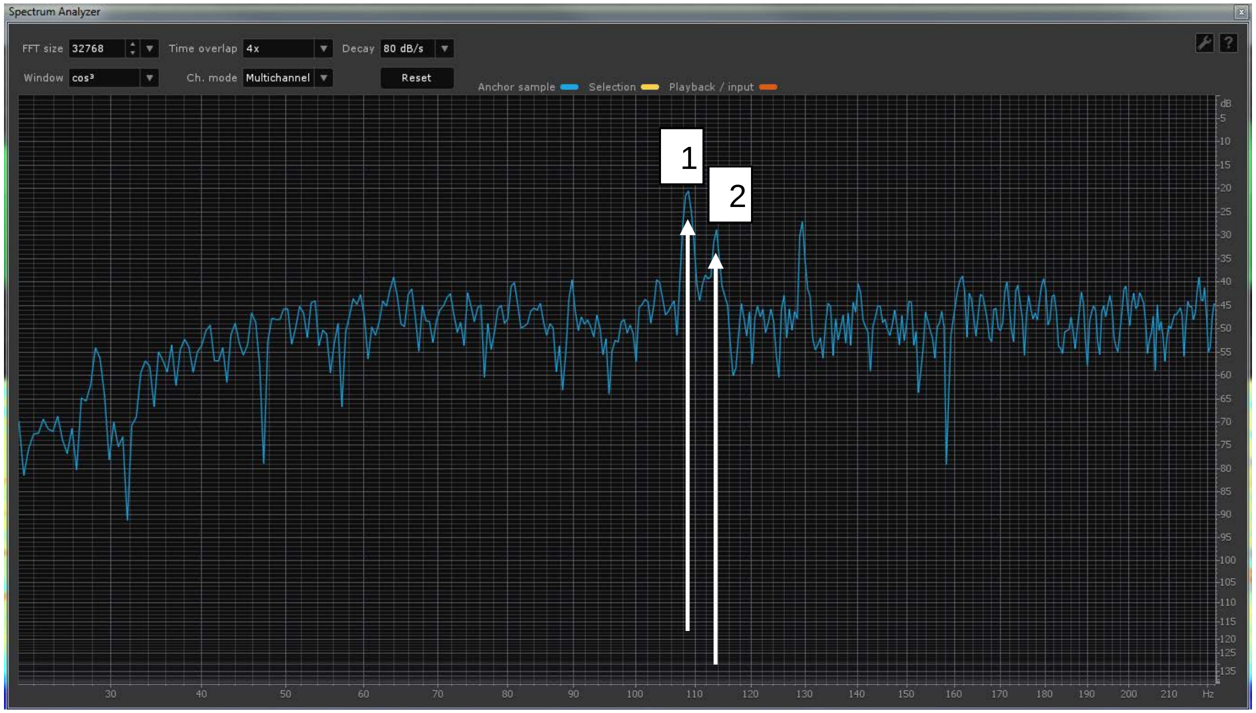
Peak 1: 102.99 Hz, identified as Np 1
Peak 2: 113.66 Hz, identified as Np 2

4.7 Data Point 7



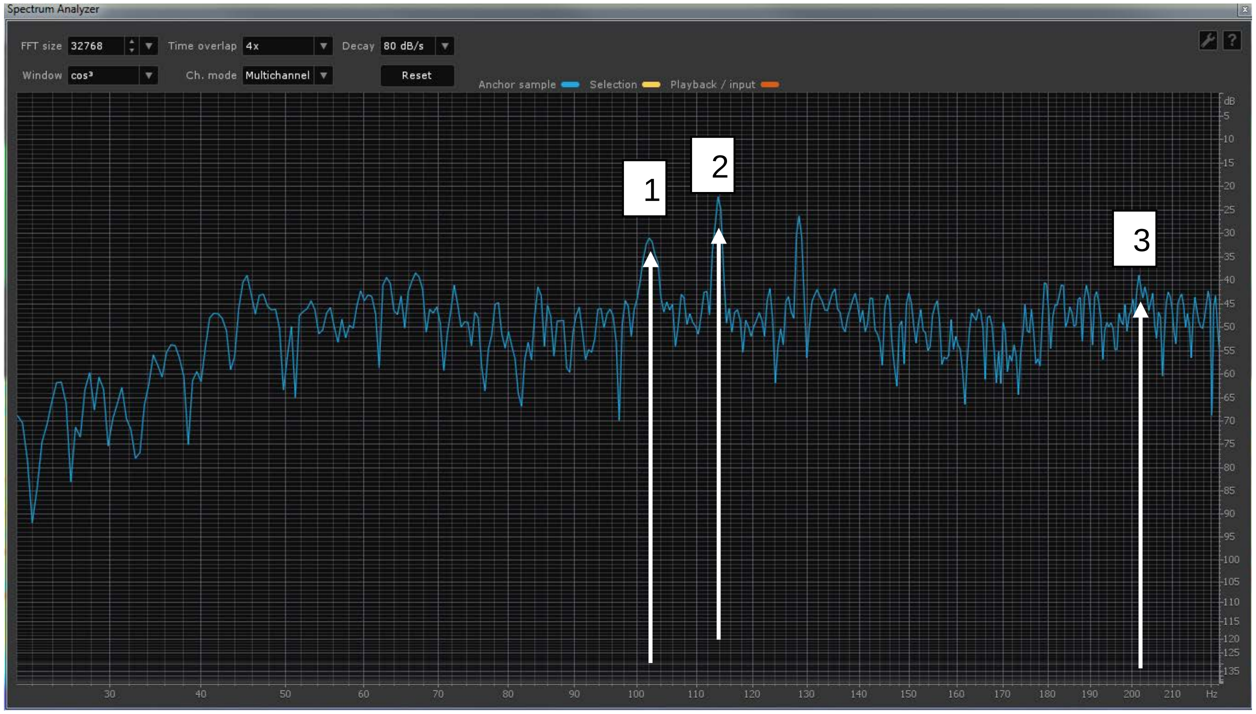
Peak 1: 104 Hz, identified as Np 1
Peak 2: 113.5 Hz, identified as Np 2

4.8 Data Point 8



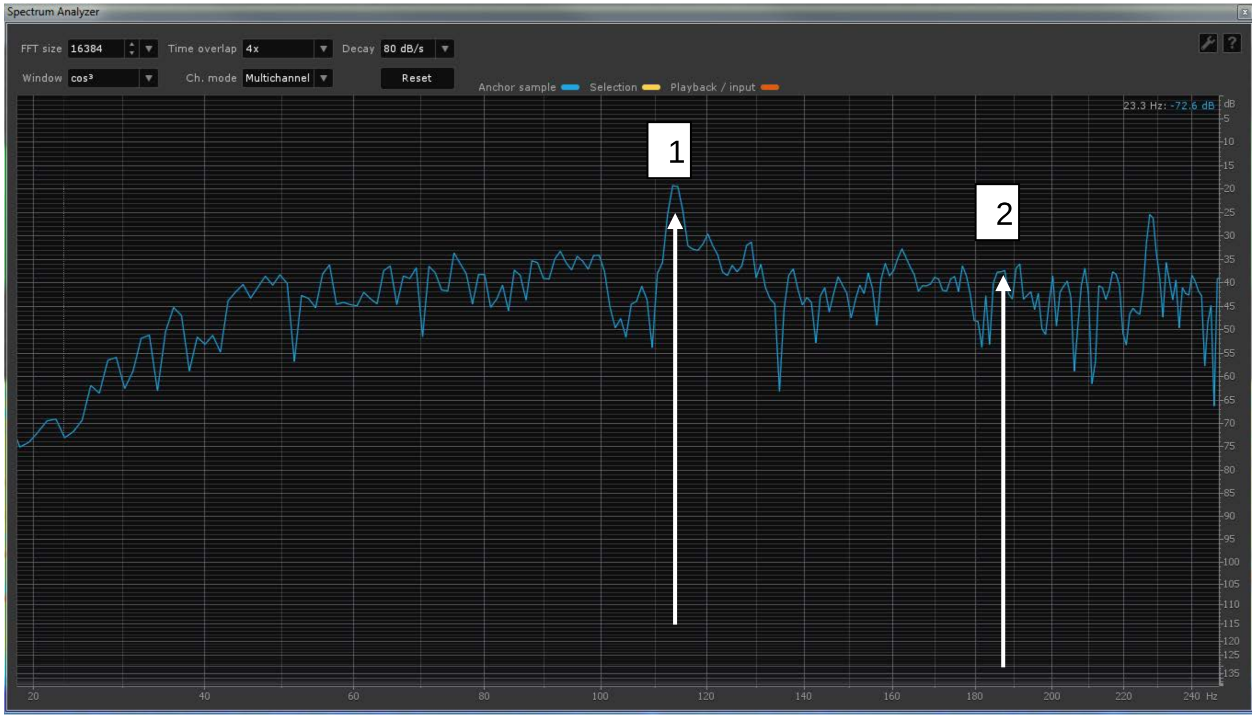
Peak 1: 108.8 Hz, identified as Np 1
Peak 2: 113.7 Hz, identified as Np 2

4.9 Data Point 9



Peak 1: 102.1 Hz, identified as Np 1
Peak 2: 113.9 Hz, identified as Np 2
Peak 3: 201.6 Hz, identified as Np 1 overtone

4.10 Data Point 10



Peak 1: 113.6 Hz, identified as Np 2
Peak 2: 187.09 Hz, identified as Np 1 overtone