NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorders Division
Washington, D.C. 20594

August 29, 2000

Cockpit Voice Recorder

Addendum to Sound Spectrum Study

Specialist's Report
by Anna W. Cushman

A. ACCIDENT

Location:	Aberdeen, South Dakota
Date:	October 25, 1999
Time:	About 1713 universal coordinated time (UTC)*
Aircraft:	Learjet 35, N47BA
NTSB Number:	DCA00MA005

B. GROUP

Chairman:	Anna W. Cushman Aerospace Engineer (CVR) National Transportation Safety Board
Member:	James Cash Chief Technical Advisor, Transportation Data Recorders National Transportation Safety Board
Member:	Mike A. Cummins Senior Product Safety Specialist, Engines & Systems Honeywell
Member:	James B. Tidball Coordinator Bombardier/Learjet
Member:	Jeffrey L. Fetter Engineering Specialist Bombardier/Learjet
Member:	Tony Vecchio Director of Maintenance Sunjet Aviation
Member:	Ron Dass Chief Inspector Sunjet Aviation
Member:	Tony James Air Safety Investigator Federal Aviation Administration

* All times are expressed in universal coordinated time (UTC), unless otherwise noted.

C. SUMMARY

A sound spectrum group convened on November 1, 1999 to examine the cockpit voice recorder (CVR) recording for engine sounds and cockpit aural warnings contained in the last 30 minutes of N47BA's flight. The results of the initial sound group meeting can be found in the Group Chairman's report of the Cockpit Voice Recorder Sound Spectrum Study. A second sound spectrum meeting was convened on August 9, 2000. The purpose of the second meeting was to examine the results from a Learjet flight test. Specifically, background noise captured during several flight scenarios was evaluated and compared to the accident CVR recording.

D. DETAILS OF STUDY

In the course of the investigation there was an issue raised that N47BA's background noise level, as recorded on the cockpit area microphone (CAM) channel, was low, indicating that the cabin air system was not on. Because the background noise level was constant until the last two minutes of the recording, a basis for an acoustic comparison was missing – that is, the CVR recording did not contain any indisputable audible evidence that the cabin air was either off or on. The need to capture audio data in a controlled setting was evident. On June 19–20, 2000 the Safety Board, with Learjet, Inc. completed a flight test to obtain Lear 35 audio, as captured by the CAM and recorded by the aircraft's CVR.

Flight Test Parameters

The aircraft used for the test was a Lear 35 equipped with a Fairchild GA100 tape cockpit voice recorder. The CVR in N47BA was a solid state Universal CVR30. There are known differences in the CVR recordings between tape and digital units. One difference is the useable frequency response – the Federal Regulations specify a CVR recording bandwidth to 5000 Hz. The CAM is typically manufactured to have a frequency response higher than the requirement. Tape CVRs record the useable bandwidth that the area microphone captures, whereas the digital units roll off immediately above 5000 Hz, storing only the required bandwidth. Regardless, tape CVRs have a decreased ability to record above the requirement and do not necessarily record all CAM sounds above 5000 Hz. Another difference between the digital and tape recordings is evident during playback. Specifically, it is not uncommon to find timing variations due to a change in recording speed of the tape CVR recordings – that is, during normal operation, the speed by which the tape runs through the record head may vary. Digital units do not typically exhibit timing variations during normal operation.

The CAM channel from the accident recording was compared with the CAM channel from the flight test. To capture pure background noise on the CAM channel, the cockpit crew speaker was turned off during the flight test. Test condition annotations were made on the co-pilot's channel throughout the flight test. The pilot's radio channels from the flight test and accident recording were not evaluated.

In order to reduce the number of variables introduced into the acoustic environment, the flight test plan was created to match, as closely as possible, the flight conditions that existed during the last 30 minutes of N47BA's flight. From the initial sound spectrum group it was determined that the N47BA's engines were running at a setting of 98.6% N1. From the radar data it was evident that the aircraft was at a varying altitude above 41,000 feet. The flight test was completed at a 42,000-foot altitude, 220 KIAS, 0.76 MI, -31 °C, and at an engine setting of 95.3% N1. The flight test aircraft was not run at the 98.6% N1 accident aircraft setting due to possible long-term damage that could result from running the engines at the higher setting. There was another set of data obtained at 25,000 feet that was not originally planned, but provided useful information during the group evaluation. The following test matrix was completed on June 20, 2000 and evaluated by the sound spectrum group on August 9, 2000:

	CONDITION **Settings: 42,000 feet, 95.3% N1, 220 KIAS, 0.76 MI**	**Cabin Air ON**	**Cabin Air OFF**	**Cabin Air OFF, Emergency Air ON**
1	Background – No Warning Tones or Alerts	✓	✓	✓
2	Cabin Altitude Warning	✓	✓	✓
3	Altitude Alert	✓	✓	✓
4	Autopilot Disconnect	✓	✓	✓
	CONDITION **Settings: 25,000 feet, 220 KIAS, 0 ΔP (Cabin Air Pressure = Outside Air Pressure)**	**Cabin Air ON**	**Cabin Air OFF**	**Cabin Air OFF, Emergency Air ON**
5	Background – No Warning Tones or Alerts		✓	
6	Cabin Altitude Warning		✓	
7	Freon System ON (air conditioning)		✓	

Flight Test Results: Background Noise Evaluation

The initial focus in examining the data was to determine the difference in background noise levels of the three different scenarios: *Cabin Air OFF*, *Cabin Air ON*, and *Emergency Air ON*. Figure 1 shows the background noise level – without any warning tones or alerts – during the three flight conditions in the flight test. The *Cabin Air OFF* condition had two variants that were obtained at 25,000 feet: the *Freon ON* condition (air-conditioning system) and the *0 ΔP* condition. The *0 ΔP* condition was obtained when the cabin altitude air pressure equaled the outside air pressure. These additional flight conditions are shown with the *Cabin Air OFF* condition in Figure 2.

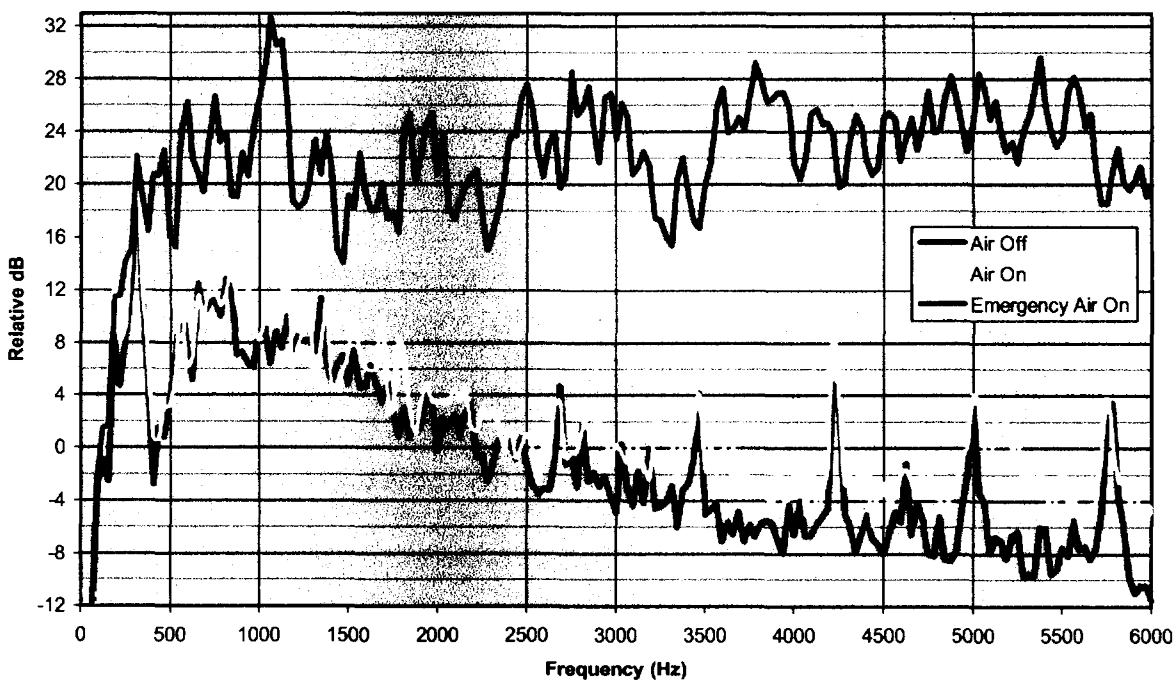

Figure 1: Flight test background noise levels – no warnings or alerts.

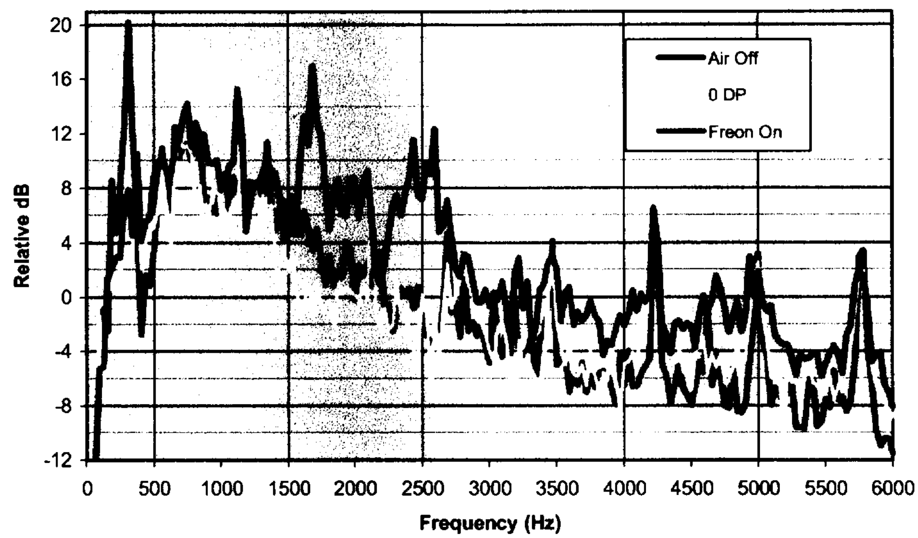

Figure 2: Flight test background noise of cabin air off flight conditions – no warnings or alerts.

The cabin altitude warning was evident throughout the accident recording until the last few seconds of the flight. Recorded during the flight test, Figure 3 shows the overall noise levels of the flight test conditions with the cabin altitude warning ON. The *Freon ON* condition was not captured with the cabin altitude warning.

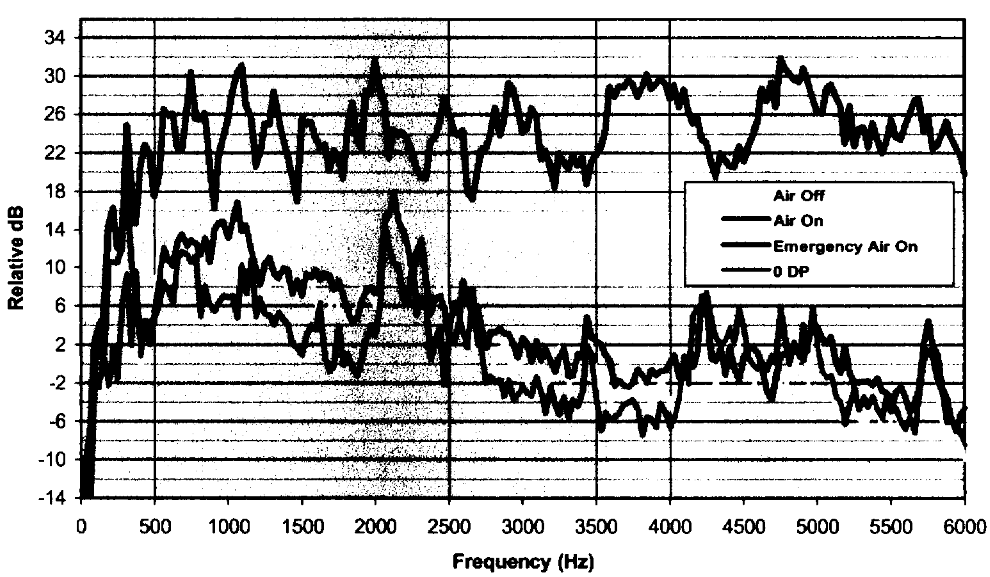

Figure 3: Flight test background noise levels with Cabin Altitude Warning.

Figure 4 shows a comparison of background noise levels with and without the cabin altitude warning. With the cabin altitude warning on or off, it was evident that the *Emergency Air ON* condition had a significantly higher noise level than the other scenarios.

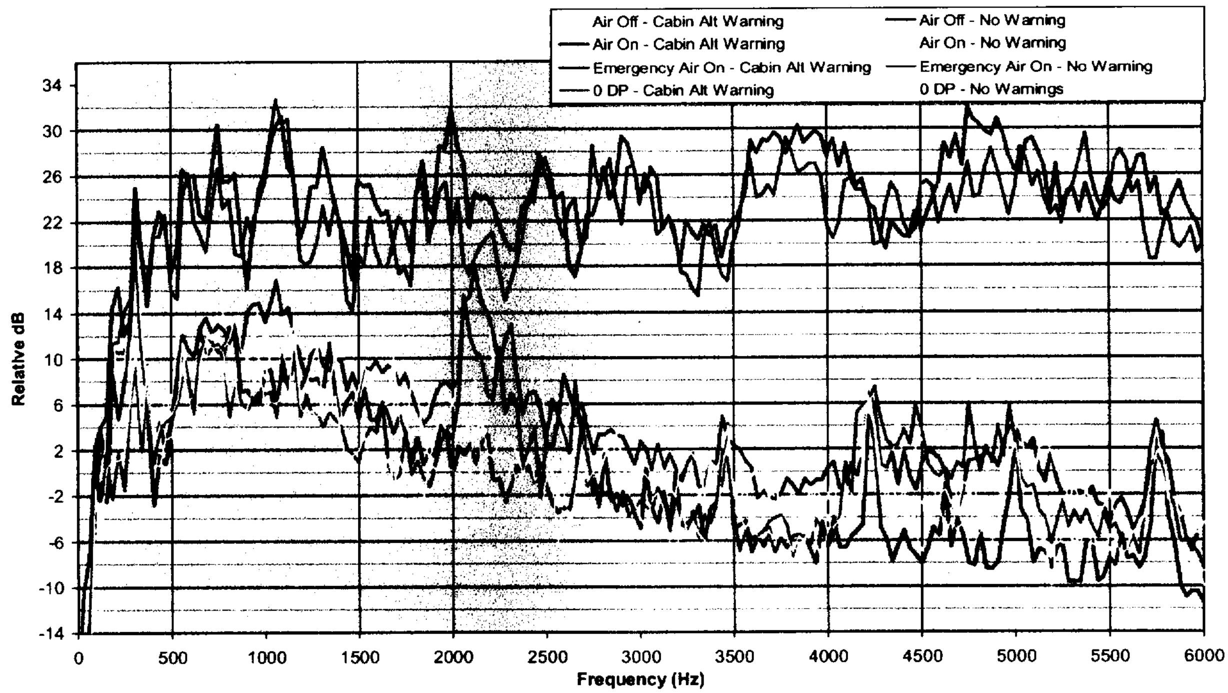

Figure 4: Flight test background noise levels - with and without cabin altitude warning.

Comparison of Emergency Air ON Flight Test Results to Accident Recording

In comparing the differences in the flight test background noise levels, it was apparent that the *Emergency Air ON* flight condition was noticeably loud with respect to the other flight conditions. Aural evaluation of the recording of the *Emergency Air ON* with the cabin altitude warning ON revealed that the cabin altitude warning was not discernable amongst the noise. The spectrum of the recording – shown as a voiceprint* in Figure 5 – also did not exhibit any characteristics of the cabin altitude warning, which had a 0.3 second cycle at about 2700 Hz. The accident recording, however, clearly showed the cyclic cabin altitude warning (Figure 6).

* *Color on the voiceprint represents relative magnitude of frequency strength – specifically, from low to high strength: white, blue, red, orange, yellow and teal. The flight test figures show a relative time, which is not correlated to any local time or accident time. The recordings from N47BA are correlated to the time (universal coordinated time) shown in the CVR transcript in the CVR Group Chairman's Factual Report.*

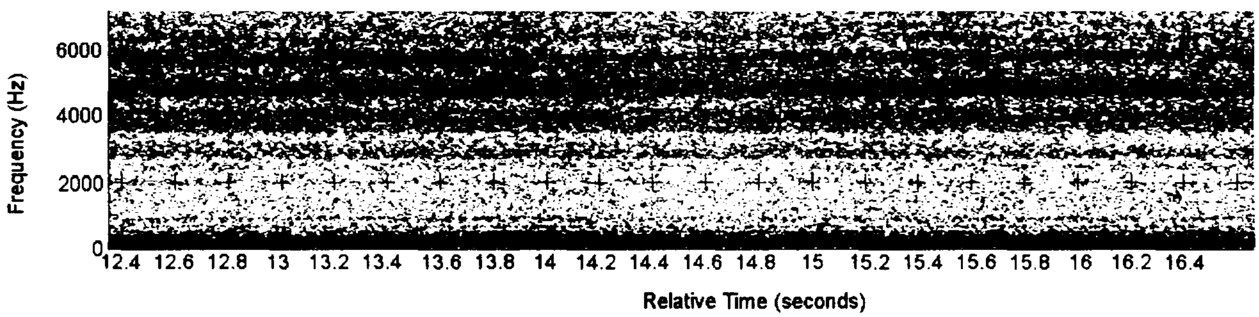

Figure 5: Voiceprint of Emergency Air ON with cabin altitude warning.

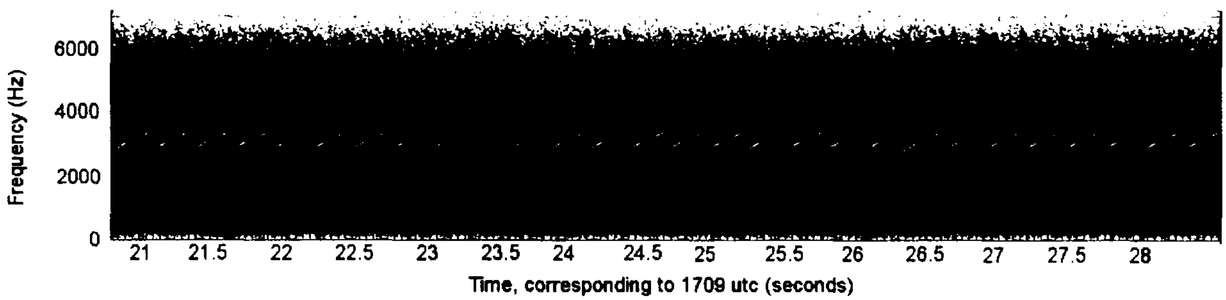

Figure 6: Voiceprint of Accident CAM recording.

Additional comparison of signal to background noise level is shown in Figure 7 and Figure 8 with the altitude alert. The tone was heard on the pilot's channel and correlated to the CAM channel of the flight test recording; Figure 7 shows that the altitude alert was not evident while the emergency air was operating. The altitude alert was recorded on the accident CVR CAM channel and is shown in the voiceprint in Figure 8.

Notably, another signal was recorded during the flight test, but not evaluated – the autopilot disconnect. Because the cockpit crew speaker was turned off in the cockpit during the flight test, the autopilot disconnect was not recorded on the CAM channel during any of the flight conditions – the autopilot disconnect tone was distinctly recorded on the pilot's channels, but was not evident on the CAM. The autopilot disconnect tone was clearly identifiable on both the CAM and co-pilot channels of the accident recording.

Regardless, with its high noise level, it was evident that the emergency air system was not recorded on the accident CVR's CAM channel in the last 30 minutes of flight.

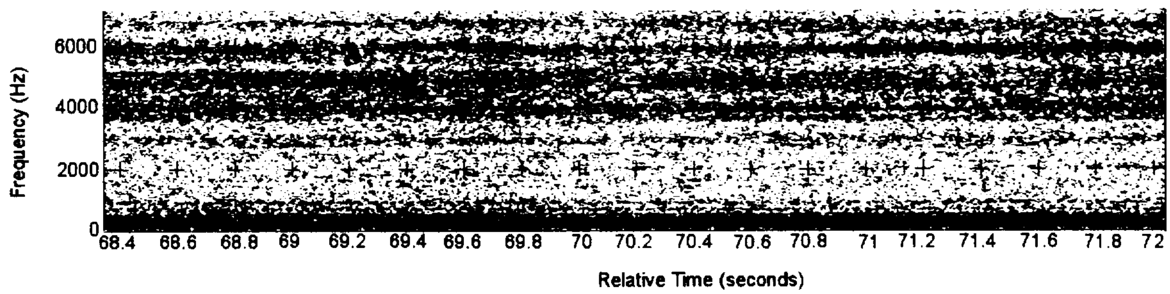

Figure 7: Voiceprint of Emergency Air ON with altitude alert.

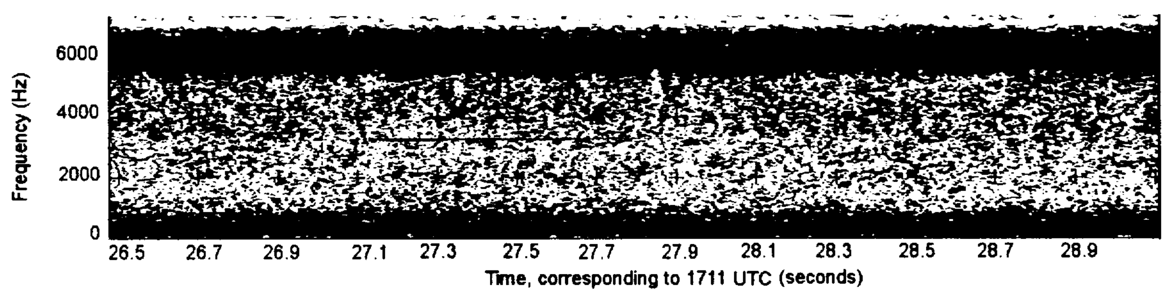

Figure 8: Voiceprint of accident recording altitude alert.

Comparison of Cabin Air OFF/ON Flight Test Results to the Accident Recording

To evaluate the results of *Cabin Air OFF* and *Cabin Air ON*, it was important to examine the recordings that most closely matched the conditions present in the accident recording; the test recordings evaluated contained the cabin altitude warning, when possible. Figure 9 shows the difference in noise levels between the *Cabin Air OFF* and *Cabin Air ON* flight test conditions. In comparing the background noise with the signal strength of the cabin altitude warning, there was no appreciable difference. The plot of the altitude alert (Figure 10) also does not show a considerable difference between the altitude alert signal (at approximately 2700 Hz) and background noise strength. Additionally, there were three engine harmonics visible above 4000 Hz, but were not considered due to the fact that similar harmonics did not appear in the accident recording. Regardless, both plots show that there was a minor difference between the two flight conditions – Cabin Air OFF generally had a lower noise level than Cabin Air ON, by 2-5 dB at select frequencies.

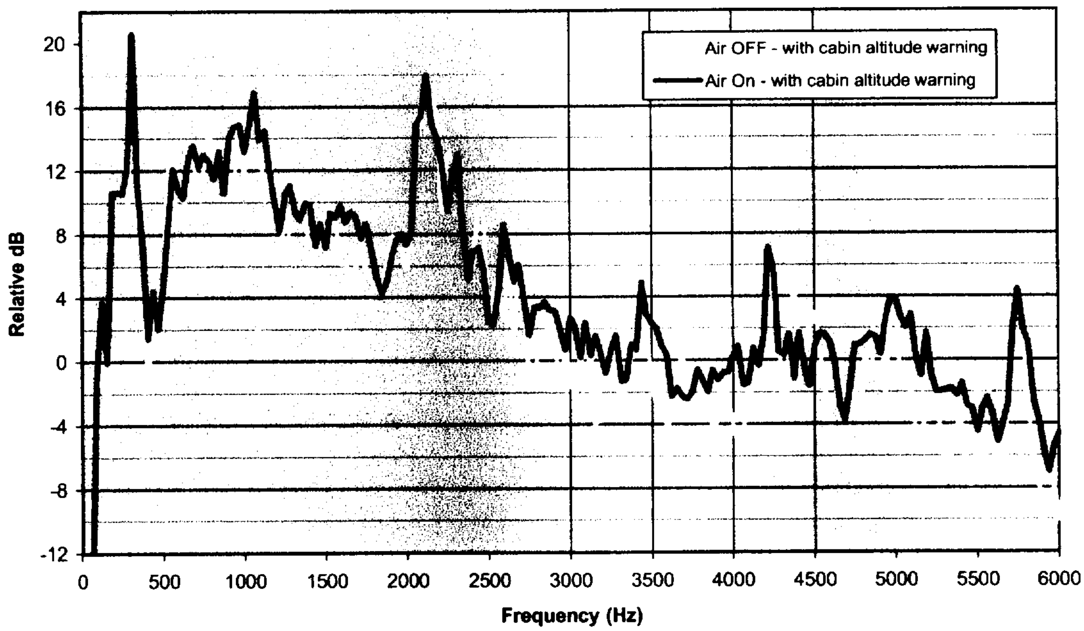

Figure 9: Flight test background noise levels with Cabin Air OFF and Cabin Air ON.

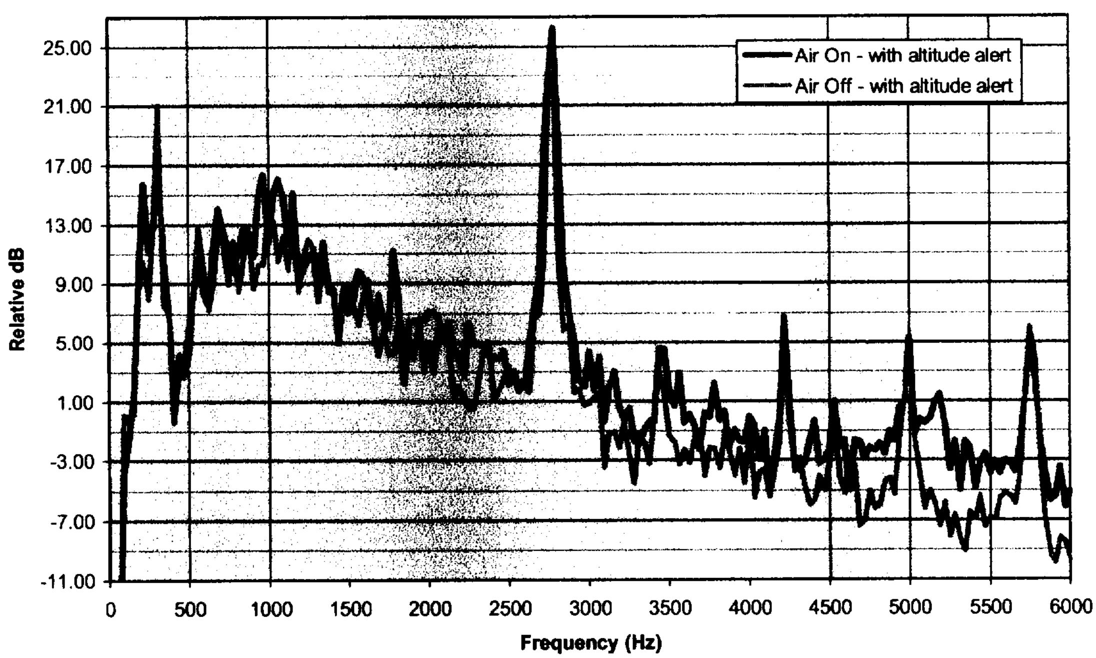

Figure 10: Flight test background noise levels with altitude alert.

The difference between cabin air OFF and ON was also evident in the voiceprint of the transition from cabin air OFF to ON in the flight test (Figure 11). At a relative time of 28 seconds the cabin air was ON and the intensity of the noise was higher than at 30.5 seconds where the cabin air was OFF. The relative difference between OFF and ON was discernable, but not considerable – that is, when comparing the two flight conditions side by side it was possible to determine which flight condition existed. However, when examining a recording without a reference, it would be difficult to determine its flight condition. The accident CVR recording did not contain any changes in background noise level prior to the last 2 minutes of the recording. Figure 12 shows the accident recording with the flight test conditions – the results were inconclusive, as there was no basis for comparing the two separate audio sources.

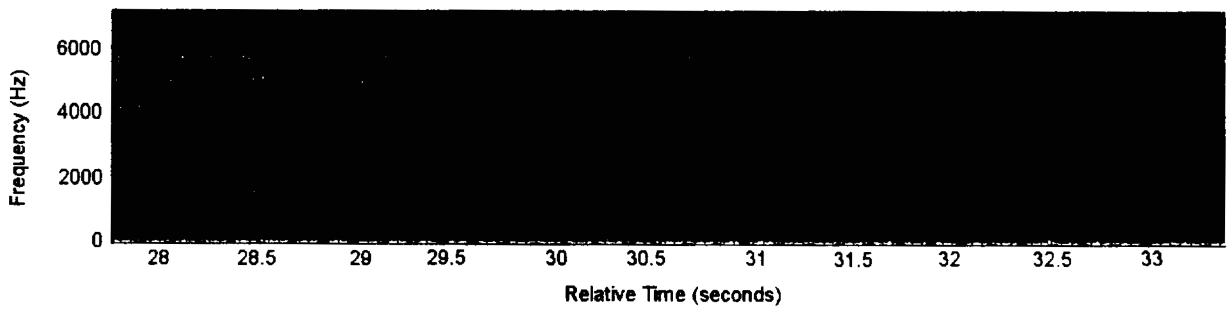

Figure 11: Voiceprint of the flight test transition between Cabin Air OFF and Cabin Air ON.

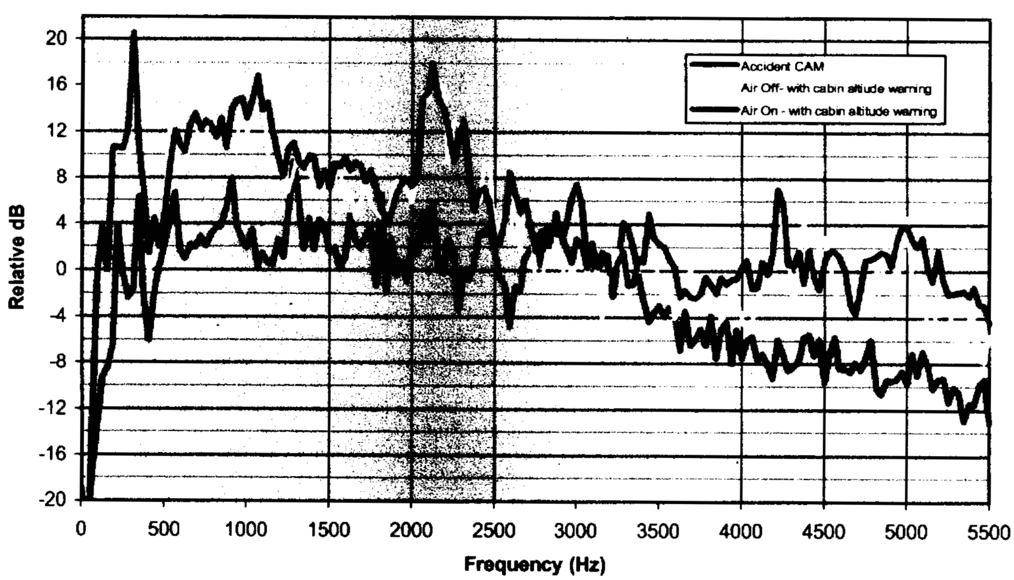

Figure 12: Background noise levels of Cabin Air OFF, ON, and accident recording.

Comparison of 0 ΔP Flight Test Results to the Accident Recording

When the group convened on August 9, 2000 it was discussed that the lower engine harmonics are typically embedded in the background noise during normal, pressurized flight operations. The *0 ΔP* (with the cabin air OFF) flight condition was evaluated for engine harmonics in the lower range (less than 2000 Hz) and compared to the accident recording.

Figure 13 shows the plot of background noise levels of the flight test conditions from 0 to 2000 Hz. The unpressurized *0 ΔP* flight conditions, including the *Freon ON* condition, exhibited similar characteristics.

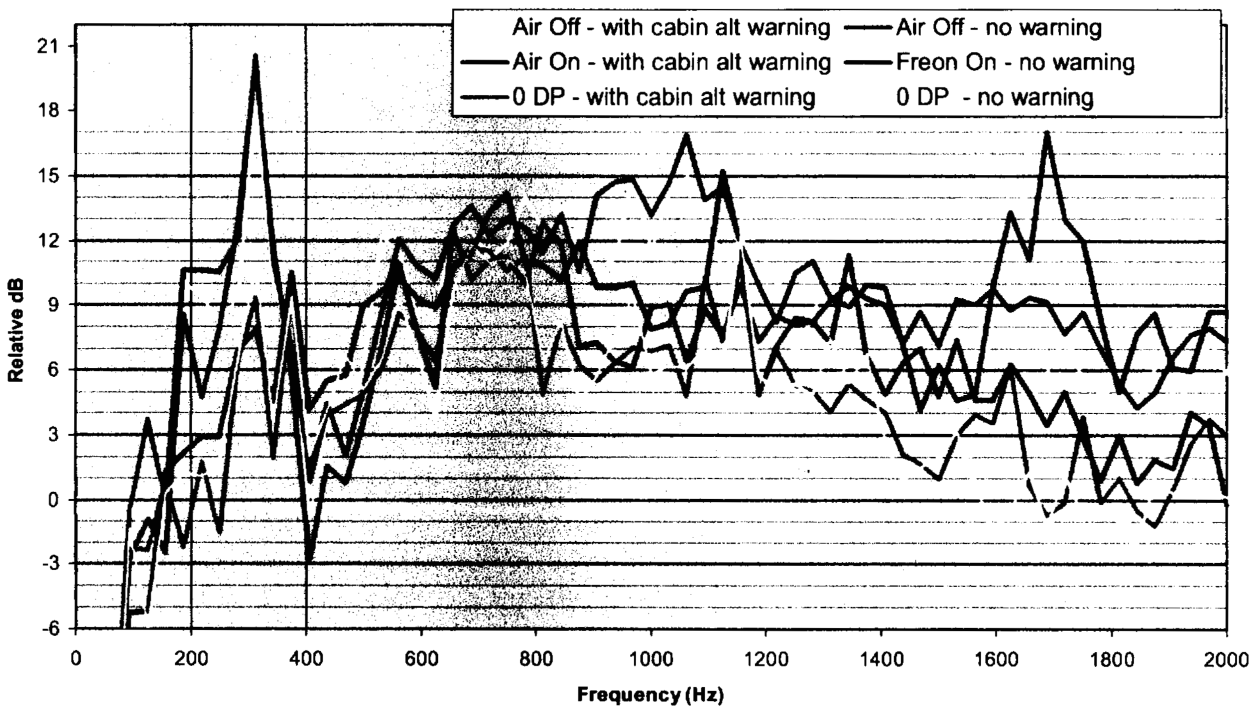

Figure 13: Background noise levels of Cabin Air OFF, ON, 0 ΔP, and Freon ON below 2000 Hz.

The following two plots (Figure 14 and Figure 15) show the background noise levels below 2000 Hz for the accident CVR and the flight test conditions.

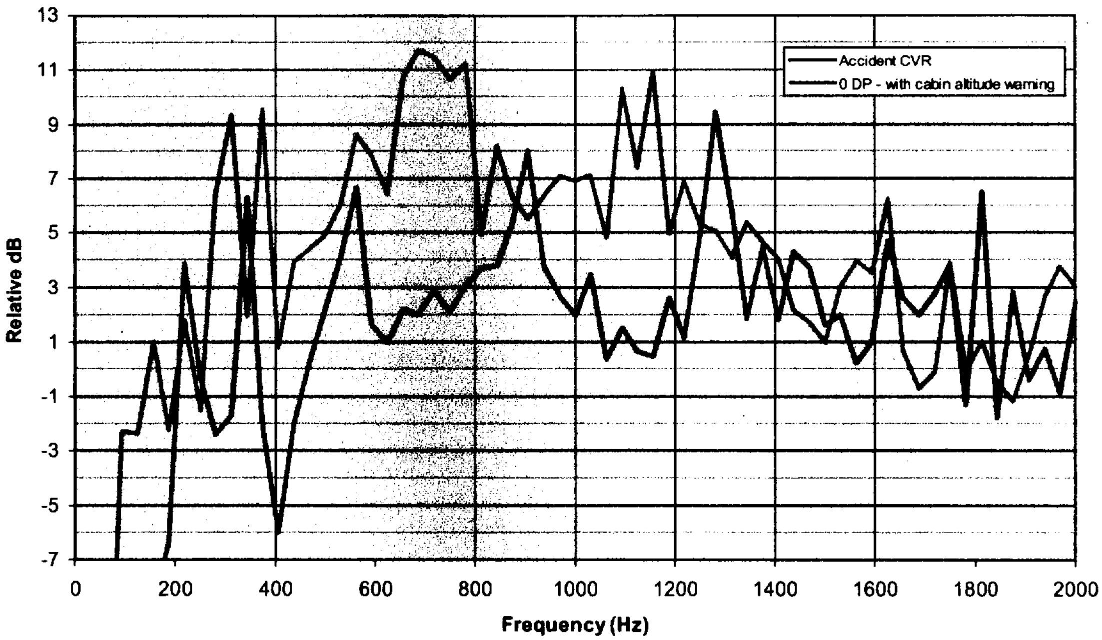

Figure 14: Background noise level below 2000 Hz for accident CVR and 0 ΔP flight test condition.

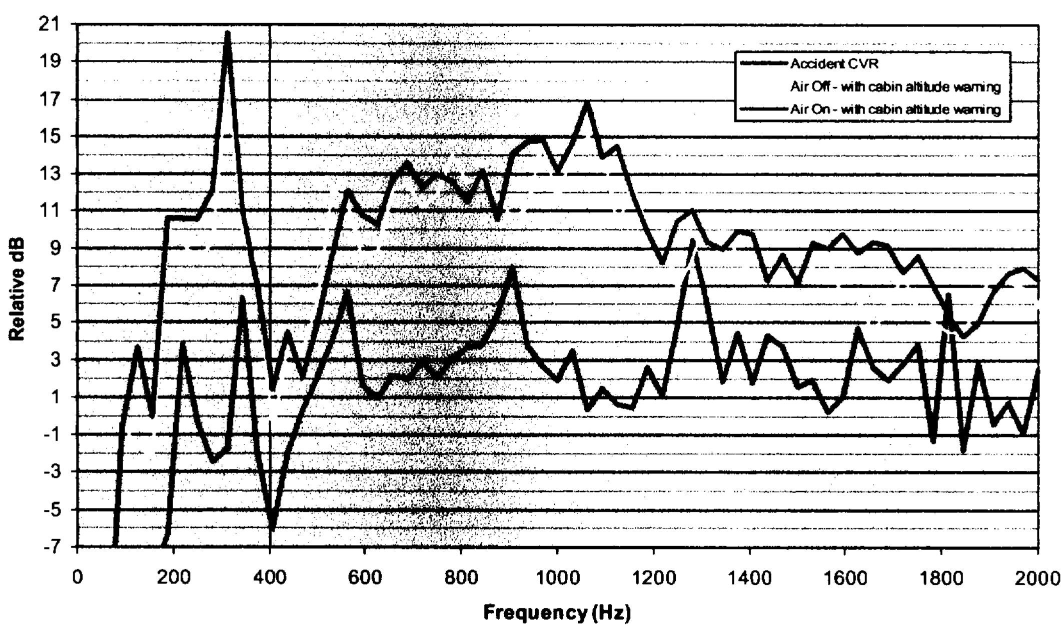

Figure 15: Background noise level below 2000 Hz of accident CVR and Cabin Air OFF/ON flight test conditions.

Overall Energy Distribution of Accident CVR Recording

In the final two minutes of the N47BA's flight there were several changes in the background noise level. The changes were attributed to the changing flight characteristics of the aircraft. From the Group Chairman's Cockpit Voice Recorder Sound Spectrum Report, approximately two minutes before the end of the recording, a signature associated with one of the engines decreased in frequency and strength. This was an indication that one engine had spooled down. Immediately after the spool down, several warnings and alerts were recorded on the CVR, along with increasing and changing background noise levels. The spool down of one engine did not significantly impact the overall background noise level, as shown in Figure 16.

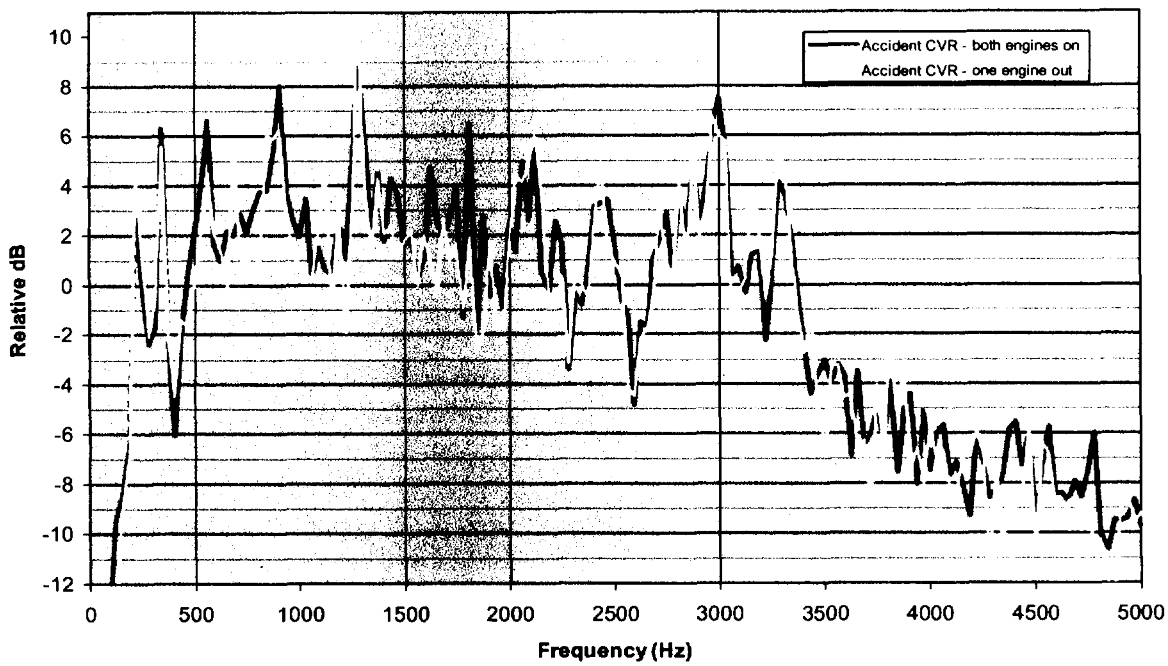

Figure 16: Background noise level of accident CVR with both engines operating and one engine operating.

The following voiceprints (Figure 17 and Figure 18) show a general comparison in background noise level between both engines operating and one engine operating. Note the cyclic change in frequency strength at 340 Hz from bright red to dark red in Figure 17. The 340 Hz signal was associated with the aircraft's engines in the Group Chairman's Cockpit Voice Recorder Sound Spectrum Report. The frequency strength remained constant after one engine spooled down, as seen in Figure 18. This is a spectral representation of the N1 drone (periodic increase and decrease in sound) that was referenced in the Group Chairman's Cockpit Voice Recorder Factual Report and Sound Spectrum Study.

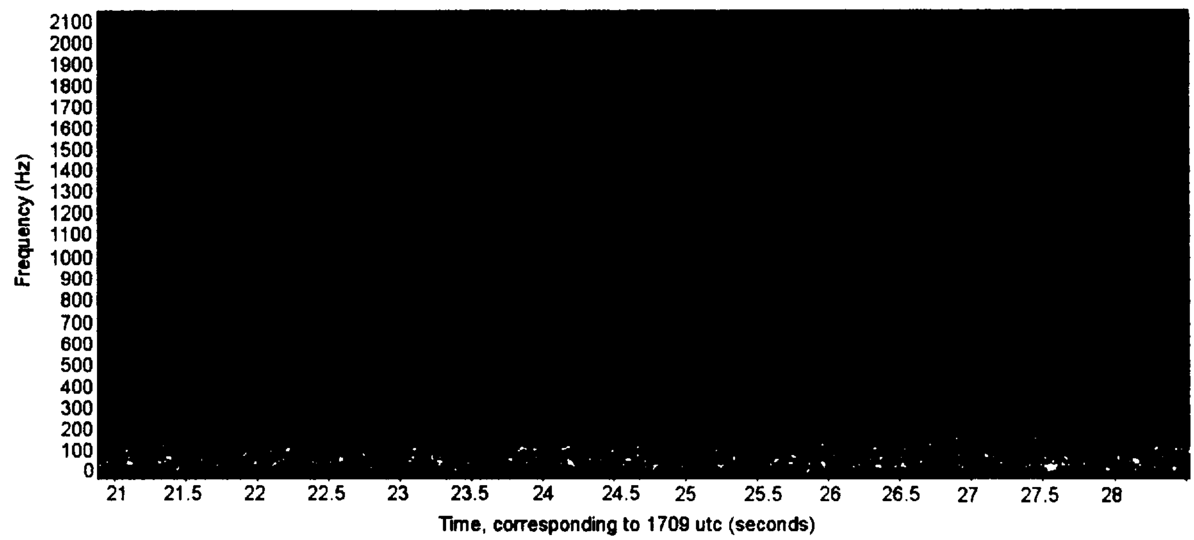

Figure 17: Voiceprint of accident CVR with both engines running.

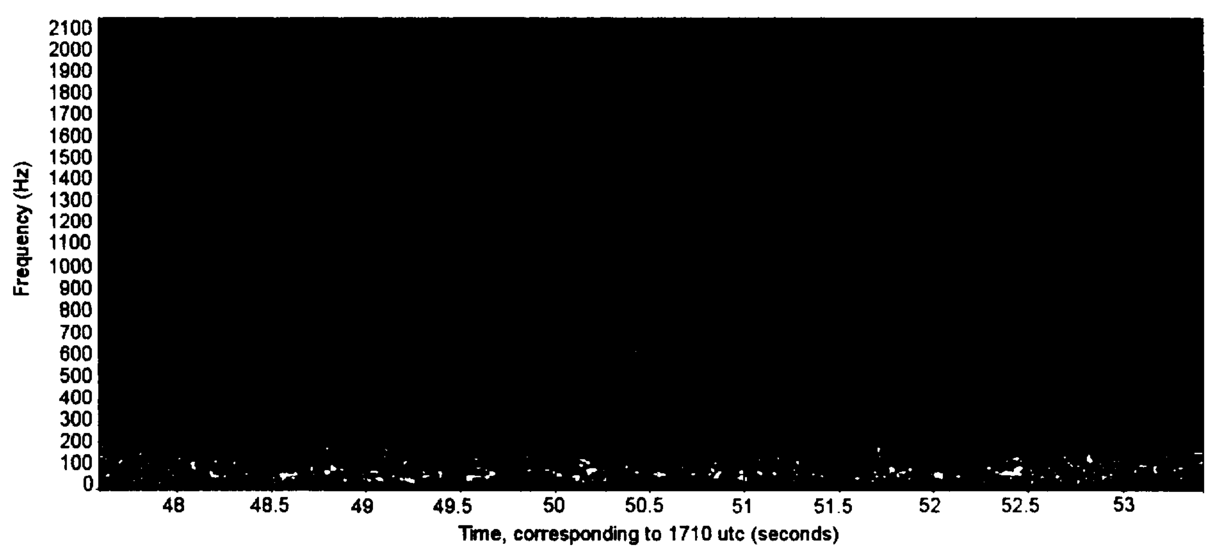

Figure 18: Voiceprint of accident CVR immediately after one engine spooled down.

The overall energy distribution of a recording is a direct indication of the overall background noise level. There are factors that can contribute to the energy level and need to be accounted for. In the accident recording, the stick shaker and other aural warnings raised the energy level. Figure 19 shows the total energy of the last two minutes of the accident recording with overlays of CVR transcript events.

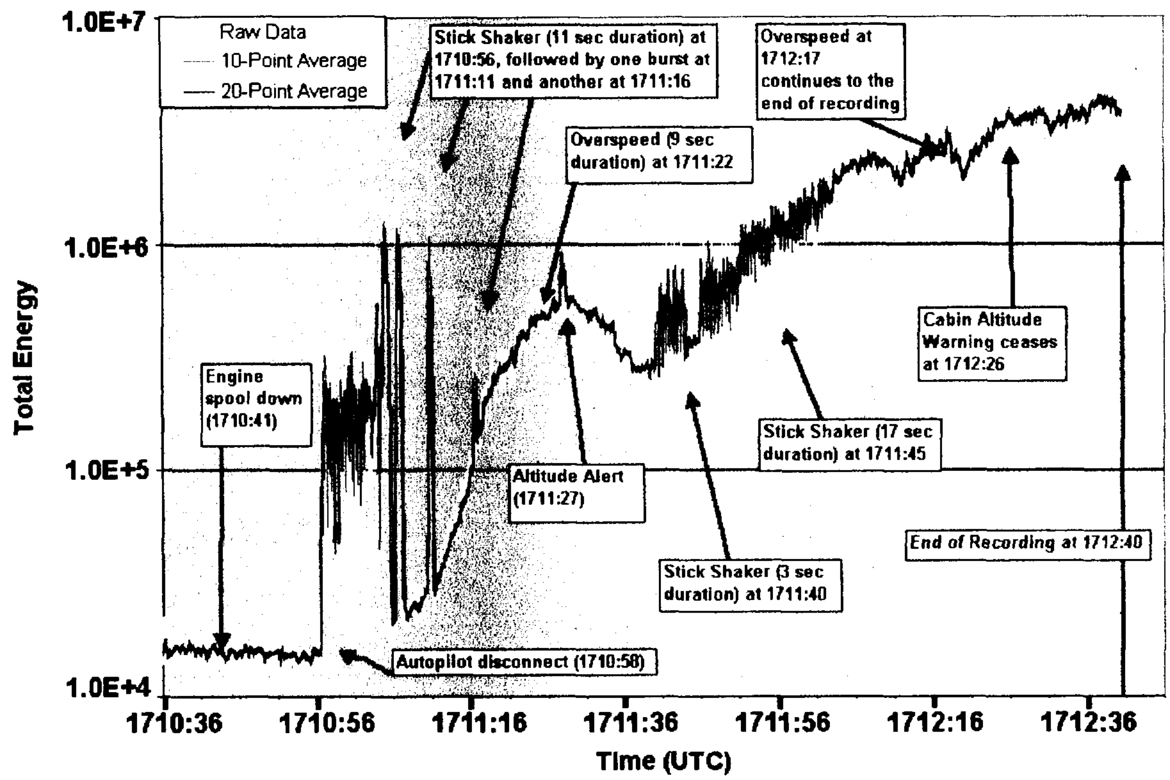

Figure 19: Total energy distribution of the last two minutes of the accident CVR recording.

[redacted]

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