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

June 26, 2001

Cockpit Voice Recorder

Group Chairman's Sound Spectrum Study

By Anna W. Cushman

A. ACCIDENT

Location:	Aspen, Colorado
Date:	March 29, 2001
Time:	1902 mountain standard time (MST)
Aircraft:	Gulfstream III, N303GA
Operator:	AVJET Corporation
NTSB Number:	DCA01MA034

B. GROUP I: May 15, 2001

Chairman:	Anna W. Cushman Aerospace Engineer (CVR) National Transportation Safety Board
Member:	Dr. C. Kearney Barton Staff Scientist, Acoustical Engineering Gulfstream Aerospace Corporation
Member:	Tony James Air Safety Investigator Federal Aviation Administration
Declined Participation:	AVJET Corporation

GROUP II: May 16, 2001

Chairman:	Anna W. Cushman Aerospace Engineer (CVR) National Transportation Safety Board
Member:	Dave Keenan Aerospace Engineer (Powerplants) National Transportation Safety Board
Member:	Dr. C. Kearney Barton Staff Scientist, Acoustical Engineering Gulfstream Aerospace Corporation
Member:	Michael Weber Senior Air Safety Investigator Rolls-Royce Corporation
Member:	Tony James Air Safety Investigator Federal Aviation Administration

Declined Participation: AVJET Corporation

C. SUMMARY

On March 29, 2001 a Gulfstream-III, N303GA, collided with terrain about 0.4 miles northwest of Aspen-Pitkin County Airport in Aspen, Colorado. A Fairchild A100A tape cockpit voice recorder (CVR), serial number 54667, was recovered from the wreckage and sent to the audio laboratory of the National Transportation Safety Board. The CVR group meeting convened and a transcript was prepared for the 31-minute 40-second recording (reference the Group Chairman's CVR Factual Report and attached transcript). As part of the investigative process, it was determined that specific aspects of the accident recording needed further clarification and investigation. The sound spectrum group convened on May 15, 2001 and May 16, 2001. The sound spectrum group's specific tasks included:

1) Ascertaining sounds similar to gear retraction.
2) Verifying cockpit aural advisories and warnings.
3) Investigating the unidentified rumbling noise at the end of the recording.
4) Documenting the engine signatures recorded.

The sound spectrum group meeting convened on May 15, 2001 to address the first three items. On May 16, 2001 additional members joined the meeting to document the engine signatures recorded by the accident aircraft's CVR.

D. DETAILS OF INVESTIGATION

From the Group Chairman's CVR Factual Report, the Fairchild A100A tape CVR recording consisted of three channels of good quality audio information. The first channel contained the Captain's audio panel information. The second channel contained the audio information from the cockpit area microphone (CAM). The third channel contained the First Officer's audio panel information. The fourth channel did not contain any useful audio information, nor was it required by federal regulations.

1. SOUNDS SIMILAR TO GEAR RETRACTION

During the investigation a question arose as to whether there was evidence of landing gear retraction near the end of the CVR recording. In the CVR recording at 1859:30[1], the Captain calls for gear down, which is followed by the sound of two clunks and an increase of background noise. These sounds could be associated with landing gear movement or operation. In the first group meeting on May 15, 2001, the group was asked to ascertain whether there was evidence of landing gear movement at the end of the recording.

The group reviewed the section of the CAM channel recording that contained the "gear down" statement and the ensuing noises. The group also reviewed the end of the CAM channel recording beginning when the female electronic voice declares "one thousand" at 1901:28.6. The group performed an aural and spectral comparison of the "gear down" series of noises to the last thirty seconds of the recording. The comparison did not reveal any evidence of sounds associated with landing gear movement or operation at the end of the recording that was similar to the earlier "gear down" section. The sound spectrum group found that the last thirty seconds of the recording did not contain any acoustic evidence of landing gear movement or operation.

2. VERIFICATION OF COCKPIT AURAL ADVISORIES AND WARNINGS

Throughout the 30-minute CVR recording several aural advisories and warnings were transcribed, as shown in the transcript attached to the CVR Group Chairman's CVR Factual Report. In order to clarify and identify the audio advisories recorded on the accident aircraft recording, it was necessary to complete an inventory of all of the Gulfstream-III aural warnings and advisories, summarized in the following table:

[1] All times are expressed in mountain standard time (MST), unless otherwise noted.

Advisory/Warning	Aural Warning/Advisory Description	Tone Frequency/Cycle
Flight Profile Advisory (FPA) System	Female electronic voice: "check trim", "radio altitude", "check baro altitude check baro altitude check baro altitude"	-
	Altitude callouts - female electronic voice: "one thousand", "nine hundred", "eight hundred", "seven hundred", "six hundred", five hundred", four hundred", "three hundred", "two hundred"	-
	Altitude alert - 1000' above set altitude: single frequency tone, followed by female electronic voice, "check baro altitude check baro altitude check baro altitude"	4500 Hz, +/- 500 Hz
	Altitude alert - deviation from set altitude by 250': single frequency tone	4500 Hz, +/- 500 Hz
	Altitude alert - deviation from set altitude by 300': female electronic voice, "check baro altitude check baro altitude check baro altitude"	-
Ground Proximity Warning System (GPWS)	Male electronic voice: "five hundred", "two hundred", "sink rate", "bank angle"	-
Autopilot/Yaw Damper/Trim Disconnect Alert	Single frequency tone	2900 Hz, +/- 500 Hz
Configuration Alarm	Alternating dual frequency tone	1800 Hz and 3000 Hz, +/-20%
Gear Warning	Single mixed frequency tone	400 Hz and 4200 Hz, +/-20%
Stall Warning	Stick shaker motor operating speed: 800-1400 RPM or 13.3 Hz - 23.3 Hz	-
Overspeed alarm	"Cricket noise" with a cycle every 60 milliseconds	-
Cabin Altitude - Oxygen Warning	"Warble noise" - cyclic, increasing frequency tone	1600 Hz to 2500 Hz (+/-20%), every 0.0350 seconds
Engine/APU Fire Warning	"Bell noise"	525 Hz, +/- 150 Hz, 10-20 times per second

Table 1: Gulfstream-III aural advisories/warnings.

N303GA's CVR recording contains several advisories and warnings from the Flight Profile Advisory (FPA) system and Ground Proximity Warning System (GPWS). The two voice generators on board the accident aircraft are distinctly identifiable: the GPWS, with its male electronic voice, consistently recorded on the CAM channel only, and the FPA system, with its female electronic voice, regularly recorded on the flight crew channels and, at times, the CAM channel. The following table summarizes the accident recording's voice-generated advisories and warnings with each respective source audio channel:

Time (MST)	Aural Description	Voice Gender	CAM	CAPT	FO
1836:12	"check trim"	Female	X	X	X
1857:42	"radio altitude"	Female	X	X	X
1859:12	"radio altitude"	Female	X	X	X
1859:55	"radio altitude"	Female	X	X	X
1900:18	"radio altitude"	Female	X	X	X
1901:28.6	"one thousand"	Female	X	X	X
1901:31.4	"nine hundred"	Female	X	X	X
1901:34.0	"eight hundred"	Female	X	X	X
1901:38.3	"seven hundred"	Female	X	X	X
1901:41.5	"six hundred"	Female	X	X	X
1901:45.1	"five hundred"	Female		X	X
1901:45.1	"five hundred"	Male	X		
1901:48.6	"sink rate"	Male	X		
1901:48.9	"four hundred"	Female		X	X
1901:51.8	"sink rate"	Male	X		
1901:52.3	"four hundred"	Female		X	X
1901:53.7	"three hundred"	Female		X	X
1901:54.2	"two hundred"	Male	X		
1901:55.2	"two hundred"	Female			X
1901:57.2	"bank angle"	Male	X		

Table 2: Voice-generated warnings and advisories from N303GA's CVR recording.

Notably toward the end of the recording, it appears that the GPWS had priority over the FPA on the cockpit speaker system; there are several instances where the two systems were recorded concurrently or near-concurrently, and the GPWS was clearly recorded only on the CAM, while the FPS was clearly recorded only on the crew channels. Additionally, the "three hundred" recorded at 1901:53.7 was interrupted on the Captain's channel and recorded as "three hun-," followed by sounds indicative of a microphone key that continued until the end of the recording. Likewise, the "two hundred," which was recorded 1.5 seconds later on the First Officer's channel, and not recorded on the Captain's channel, is also an indication of a keyed microphone.

The system tones generated by the FPA and other systems from the accident recording are shown in Table 3. Notably, there are two system tones that the CVR group was not able to describe during the group meeting. The first tone, at 1856:22, has a frequency of 2973 Hz. This frequency falls within the range of the autopilot/yaw damper/trim disconnect tone. The other unidentified tone at 1900:31 appears to be an altitude alert tone, due to its frequency of 4123 Hz. Because the tone occurs by itself, without the female voice, "check baro altitude check baro altitude check baro altitude," it could have been triggered by an aircraft deviation of more than 250 feet from set altitude. The sound spectrum group on May 15, 2001 confirmed the frequencies of the tones and alerts shown in Table 3.

Time (MST)	Recorded Frequency	Alert/Warning Identification	Aural Description	CAM	CAPT	FO
1840:22	416 Hz and 3rd, 8th, 9th, 10th and 11th harmonics	gear warning	single tone, with two mixed frequencies: 400 Hz and 4200Hz, +/-20%	X		
1842:16	4150 Hz	altitude alert	single frequency tone (4500 Hz +/- 500 Hz), followed by female voice: "check baro altitude check baro altitude check baro altitude"	X	X	X
1846:59	4158 Hz	altitude alert	single frequency tone (4500 Hz +/- 500 Hz), followed by female voice: "check baro altitude check baro altitude check baro altitude"	X	X	X
1848:48	416 Hz and 3rd, 8th, 9th, 10th and 11th harmonics	gear warning	single tone, with two mixed frequencies: 400 Hz and 4200Hz, +/-20%	X		
1849:11	4159 Hz	altitude alert	single frequency tone (4500 Hz +/- 500 Hz), followed by female voice: "check baro altitude check baro altitude check baro altitude"	X	X	X
1852:38	4158 Hz	altitude alert	single frequency tone (4500 Hz +/- 500 Hz), followed by female voice: "check baro altitude check baro altitude check baro altitude"	X	X	X
1854:04	416 Hz and 3rd, 8th, 9th, 10th and 11th harmonics	gear warning	single tone, with two mixed frequencies: 400 Hz and 4200Hz, +/-20%	X		
1856:12	416 Hz and 3rd, 8th, 9th, 10th and 11th harmonics	gear warning	single tone, with two mixed frequencies: 400 Hz and 4200Hz, +/-20%	X		
1856:22	2973 Hz	tone unidentified in transcript (autopilot / yaw damper / trim disconnect tone)	single frequency tone: 2900 Hz +/- 500 Hz	X	X	X
1856:57	4157 Hz	altitude alert	single frequency tone (4500 Hz +/- 500 Hz), followed by female voice: "check baro altitude check baro altitude check baro altitude"	X	X	X
1857:57	4152 Hz	altitude alert	single frequency tone (4500 Hz +/- 500 Hz), followed by female voice: "check baro altitude check baro altitude check baro altitude"	X	X	X
1858:34	4155 Hz	altitude alert	single frequency tone (4500 Hz +/- 500 Hz), followed by female voice: "check baro altitude check baro altitude check baro altitude"	X	X	X
1859:37	416 Hz and 3rd, 8th, 9th, 10th and 11th harmonics	gear warning	single tone, with two mixed frequencies: 400 Hz and 4200Hz, +/-20%	X		
1859:59	4152 Hz	altitude alert	single frequency tone (4500 Hz +/- 500 Hz), followed by female voice: "check baro altitude check baro altitude check baro altitude"	X	X	X
1900:31	4123 Hz	tone unidentified in transcript (altitude alert)	single frequency tone: 4500 Hz +/- 500 Hz	X	X	X
1900:47	4153 Hz	altitude alert	single frequency tone (4500 Hz +/- 500 Hz), followed by female voice: "check baro altitude check baro altitude check baro altitude"	X	X	X
1901:21	1764 Hz / 2989 Hz	configuration alarm	alternating dual frequency tone: 1800 Hz/3000 Hz, +/-20%	X	X	X

Table 3: System tones recorded on N303GA's CVR.

3. UNIDENTIFIED RUMBLING NOISE AT THE END OF THE RECORDING

The CVR transcript shows an unidentified rumbling noise at 1901:52.7. The noise blends into the background after 1901:57.5. The third task of the sound spectrum group meeting on May 15, 2001 was to investigate this noise and further clarify its origins. The spectrogram[2] of the last seven seconds of the CAM channel recording reveals a cyclic, broadband noise that begins at approximately 1901:52.7 (see Figure 1). The noise has a cycle of approximately 16.5 Hz.

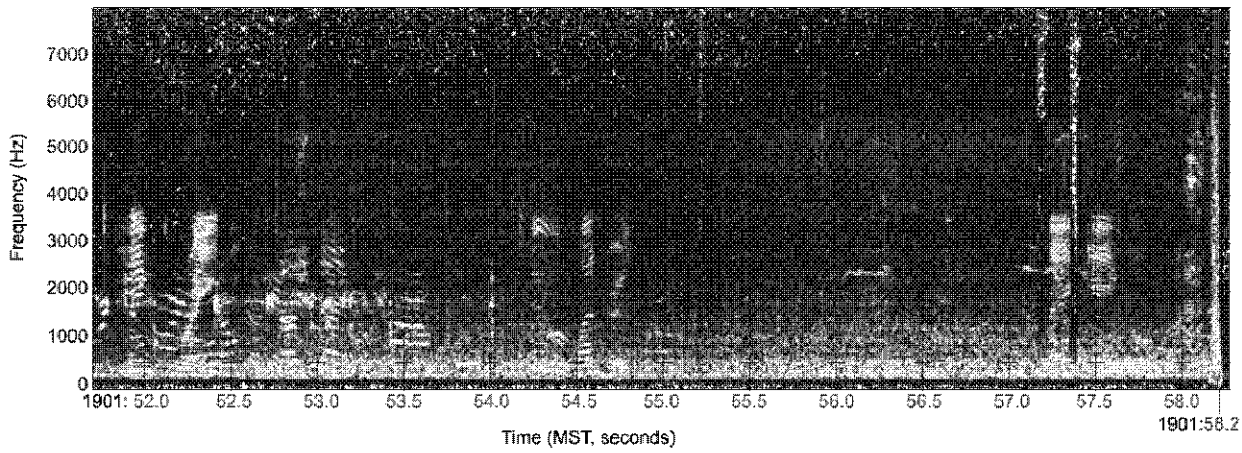

Figure 1: Sound spectrum of the last portion of the N303GA CVR CAM recording.

The stick shaker from a similar Gulfstream-III stall warning system was recorded during a static ground test. There are two stick shaker systems that control each crew control column. The following plots (Figures 2-5) are spectrograms of the stick shaker from the test aircraft CVR CAM channel recordings.

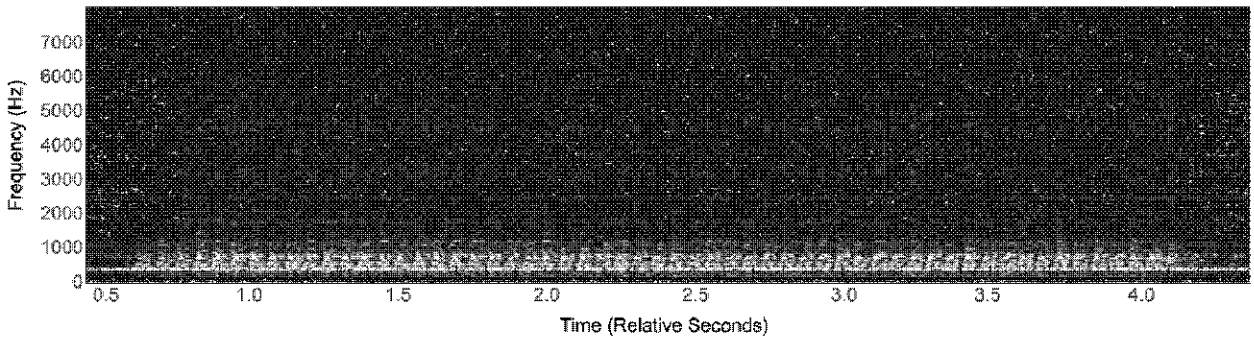

Figure 2: Stall warning test (system 1) - engines off.

[2] Color on the spectrogram (sometimes referred to as a voiceprint plot) represents a relative magnitude of frequency strength – specifically, from low strength to high strength: white, blue, red, orange, yellow, and teal. The time shown in the audio test plots is a relative CVR time, not correlated to the accident recording.

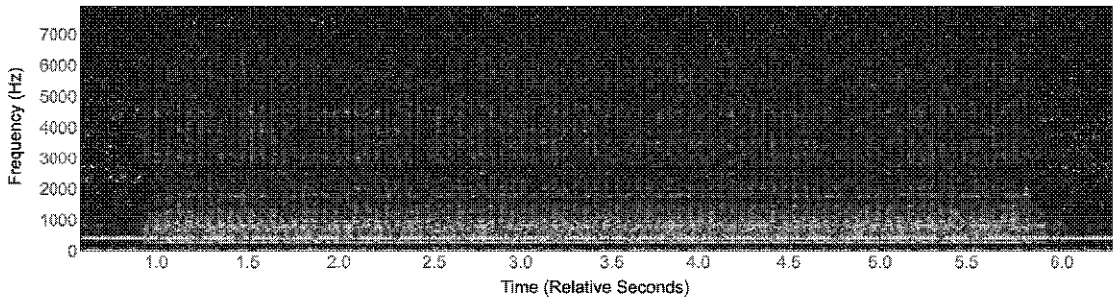

Figure 3: Stall warning test (system 2) - engines off.

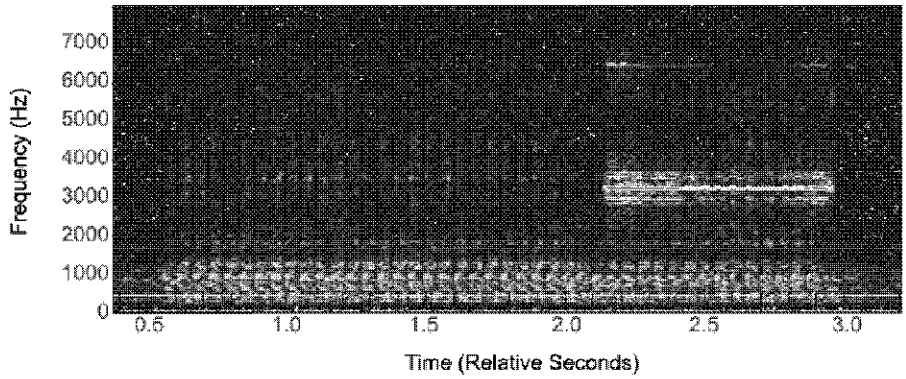

Figure 4: Stall warning (system 2) with pusher - engines on, hydraulics on.

Upon evaluating the test data, it was evident that the spectrograms contained characteristics similar to the rumbling noise on the accident recording. Specifically, the stick shaker tests revealed a broadband cyclic noise of medium intensity. The cycle of the test stick shaker was 16.1 Hz for system 1, and 17.2 Hz for system 2. The stick shaker motor has a specification for operating between 800 and 1400 RPM or 13.3 Hz to 23.3 Hz.

Because the stick shaker has a broad range of operating speeds and the noise encompasses the entire frequency range (as opposed to a specific single frequency), it is not possible to definitively conclude that the stick shaker produced the rumbling noise in the N303GA recording. However, historically CVR recordings of cyclic noises are generally produced by an on board aircraft system or a repeatable external factor, such as runway seams. Therefore, given the cyclic nature of the rumbling noise and its resemblance to the test stick shaker recording in its intensity across the bandwidth, the unidentified rumbling noise at 1901:52.7 is likely to have been N303GA's stick shaker.

4. ENGINE SIGNATURE DOCUMENTATION

On May 16, 2001 additional members were required to document and interpret the signatures from the engine of N303GA. In reviewing the spectrogram of the last six minutes of the CAM recording, it became apparent that there was a signature recorded in the lower frequency range between approximately 260 Hz and 510 Hz. According to the manufacturer, a signature recorded by the CAM in this frequency range is typically associated with the engine-driven hydraulic pump. Given that the signature found on the recording is the product of the hydraulic pump, it is possible to derive the corresponding speed of the engine (N2). For instance, a signature of 259.3 Hz correlated to the hydraulic pump, yields an engine speed of approximately 52.9% N2. Figure 5 shows the engine speed (%RPM N2) for the last six minutes of the recording, with select CVR transcript events, and Figure 6 shows the last one minute and 38 seconds of the recording.

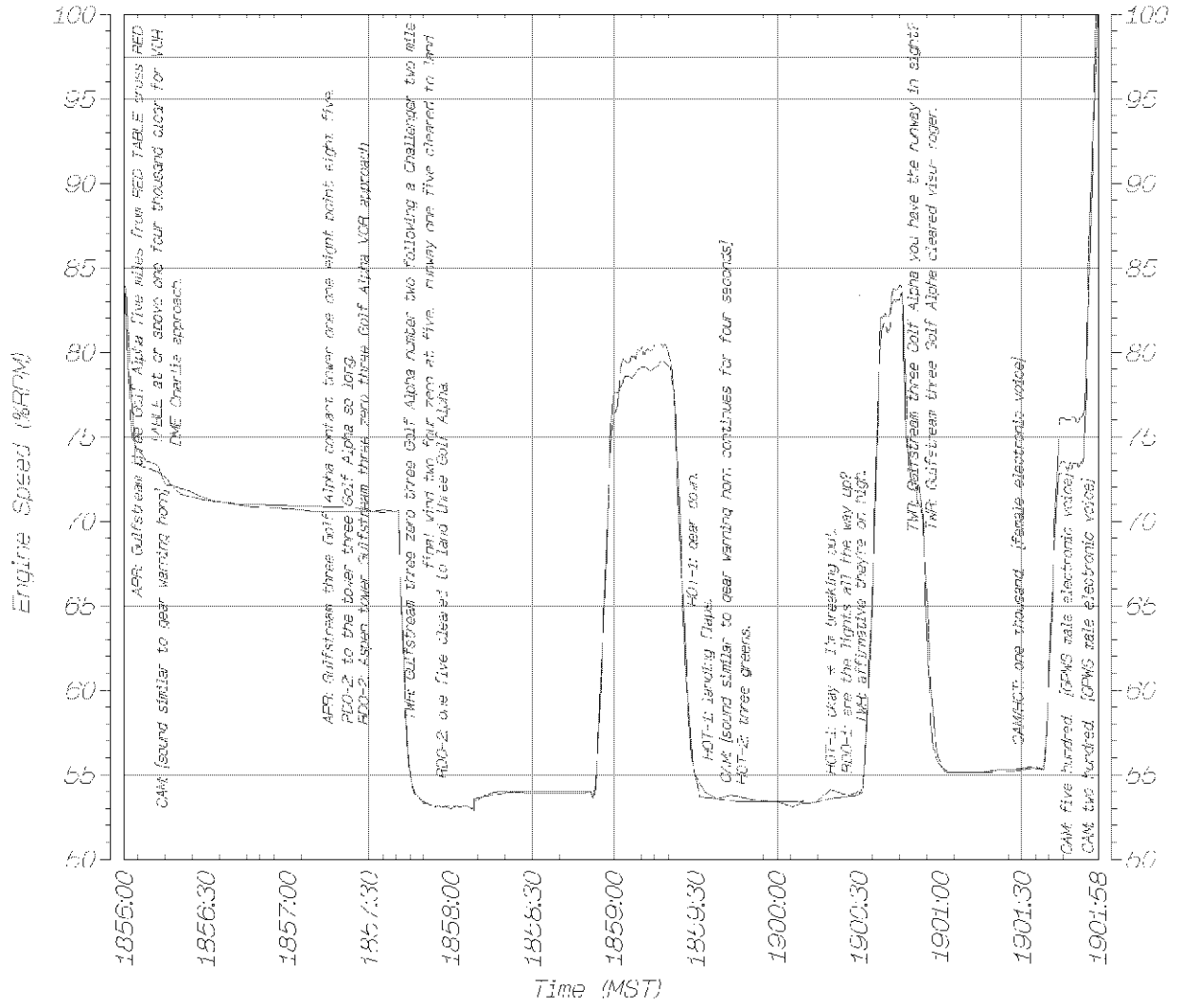

Figure 5: Engine signatures for the last 6 minutes of the N303GA CVR recording.

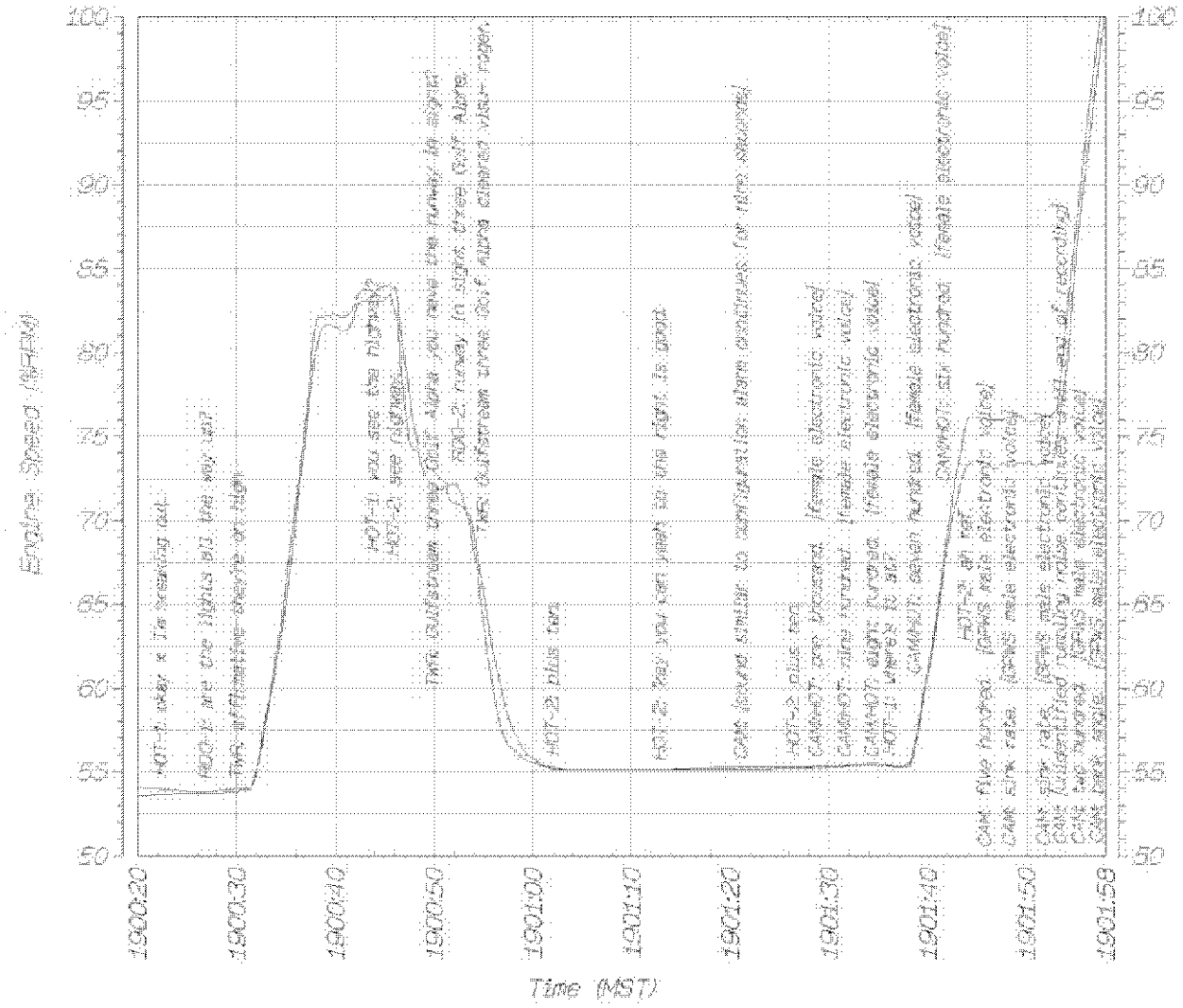

Figure 6: Engine signatures from N303GA - the last 1 minute 38 seconds of the recording.

Notably there are two separate signatures, which indicate that the two engines were operating independently. Moreover, it is not possible to determine which engine created a specific signature. Regardless, it is apparent that if the engine-driven hydraulic pump produced the signature recorded on the CAM channel, the engine speed reflected in the plots shows an %RPM range from about 53% N2 to 102% N2 during the last six minutes of the N303GA CVR recording.

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