AFWAL-TM-79-10

TEST REPORT ON INFRARED WARNING RECEIVER (IRWR) FLIGHT VIBRATION MEASUREMENTS

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APRIL 1980

Final Report for 01 March 1979 – 01 September 1979

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
April 1980	Final	03/01/1979 – 09/01/1979

4. TITLE AND SUBTITLE
TEST REPORT ON INFRARED WARNING RECEIVER (IRWR) FLIGHT VIBRATION MEASUREMENTS

5a. CONTRACT NUMBER
In-house

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
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5d. PROJECT NUMBER
7500

5e. TASK NUMBER
50

5f. WORK UNIT NUMBER
14

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Analytical Structural Mechanics Branch (AFRL/VASM)
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8. PERFORMING ORGANIZATION REPORT NUMBER
AFWAL/FIBG/79-10

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Vehicles Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson Air Force Base, OH 45433-7542

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
AFRL/VASM

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFWAL-TM-79-10

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
This version of the report is the best quality available.

14. ABSTRACT
This test report presents data which define the vibration environments experienced by two infrared warning receiver (IRWR) units mounted on the HH-53 helicopter and the C-130E transport aircraft.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT:	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON (Monitor)
Unclassified	Unclassified	Unclassified	SAR	132	David Banaszak **19b. TELEPHONE NUMBER** *(Include Area Code)* (937) 904-6859

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

AIR FORCE WRIGHT AERONAUTICAL LABORATORIES

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TEST REPORT

ON

INFRARED WARNING RECEIVER (IRWR) FLIGHT VIBRATION MEASUREMENTS

REPORT NO: AFWAL/FIBG/79-10 DATE: April 1980

PROJECT NO: 75005014 PROJECT ORDER: ASD 8-1073P

TYPE OF TEST: Airborne Vibration Measurements

REQUESTED BY: 4950TW/FFAO

I. PURPOSE

This test report presents data which define the vibration environments experienced by two infrared warning receiver (IRWR) units mounted on the HH-53 helicopter and the C-130E transport aircraft.

These data were required to determine the effects of vibration on the receivers during a flight evaluation program. The environmental vibration and acoustic noise were measured at three receiver locations on each aircraft over a variety of flight conditions which represent the expected service environments of the receivers.

The data generated from the various flight configurations of the two aircraft were to be used for comparison of any irregularities in the output signal of the two contractor IRWR systems. Such irregularities might be attributed to vibration levels of the detecting device. Also, in the case of failure of one of the devices, the vibratory environment could be of major concern in determining possible reasons for failure and in considering methods for correction of the problems.

II. BACKGROUND

The 4950thTW/FFAO conducted a competitive fly-off of two contractor Infrared Warning Receiver (IRWR) systems. Test aircraft for this program were a C-130E transport and an HH-53C helicopter. Both IRWR systems were installed on each aircraft so that a direct comparison could be made between the two systems under identical operational conditions.

The IRWR system provided by Aerojet Electro-Systems was designated the AN/AAR-43. This sensor is a "staring" system that continuously monitors the field of view with nine fixed "eyes." The IRWR system provided by Cincinnati Electronics Corporation was designated the AN/AAR-44. This sensor is a scanning system with one detector and a rotating mirror.

The 4950th Test Wing requested that the FDL instrument both aircraft to provide vibration data for this evaluation. The request for support was received by the FDL Structural Vibration Branch (AFWAL/FIBG) on 26 May 1977 and the final plan was prepared on 3 April 1978. Four flight tests were conducted between March and September 1979.

Vibration and noise data were obtained for all flight conditions of interest for each aircraft. However, very few simultaneous data from the IRWR output and the vibration response were recorded. This made it impossible to adequately determine the correlation between the IRWR outputs and the vibration levels.

The IRWR sensor vibrations measured on these aircraft are not severe. The highest vibratory acceleration measured was on the AAR-43 sensor on the aft end of the C-130 at 250 knots airspeed and a 30° bank angle. The overall lateral acceleration for this condition ranged between 3 and 4 g's rms. The highest vibratory accelerations measured on the HH-53 helicopter sensors were also on the AAR-43 sensor at the aft end, which showed up to 2g rms during spiral descent.

The highest acoustic noise levels measured were on the C-130 aircraft, where the center-mounted AAR-44 experienced 140 dB at 250 knots and 30° bank angle. The highest noise levels measured on the HH-53 helicopter were on the center-mounted AAR-44, which showed 136 dB overall during spiral descent.

These vibration and noise levels are not expected to cause mechanical problems for IRWR sensors tested to MIL-STD-810C vibration and noise test spectra. However, the AAR-44 noise levels of up to 140 dB may result in fatigue damage to any sensitive electronic components in the AAR-44.

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PUBLICATION REVIEW

This test report has been reviewed and is approved.

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DISTRIBUTION:		
	4950thTW/FFAO	10
	AFWAL/FIBG	5
	AFWAL/FIB	2

APPENDIX A

Test Configuration, Instrumentation, Test Procedure, Data Analysis, and Test Results (all Tables and Figures are in Appendix B).

Test Configuration

The IRWR system provided by Aerojet Electro-Systems was designated the AN/AAR-43. This was a "staring" system that continuously monitored the field of view. Each of the four sensors for the AAR-43 was shaped like a quarter of a sphere (5.615 inch radius) and had nine sensor eyes distributed on the curved surface. Each eye contained two detectors; one was sensitive to visible light and the other was sensitive to infrared radiation. Four AAR-43 sensors were mounted by 4950th TW on each aircraft to cover the four aircraft quadrants, as shown in Figure 1 for the C-130E and in Figure 2 for the HH-53.

The IRWR system provided by Cincinnati Electronics Corporation was designated the AN/AAR-44. This was a scanning system that had one rotating IRWR sensor. The sensor contained a single lens system, a detector, and a six-sided rotating mirror. The entire sensor unit was rotated to obtain an azimuth scan, and the mirror within the sensor was rotated to obtain an elevation scan. The AAR-44 was mounted on the underside of the aircraft, as shown in Figure 1 for the C-130E and in Figure 2 for the HH-53.

More detailed descriptions of the two IRWR systems and the sensors can be found in the Reference.

Instrumentation

The instrumentation system used by the Flight Dynamics Laboratory to collect data on both the C-130 and the HH-53 is illustrated in the block diagram of Figure 3. Vibration and acoustic data from eighteen accelerometers and three microphones were recorded by two tape recorders operating simultaneously. The HH-53 forward right AAR-43, the aft left AAR-43, and the AAR-44 were each instrumented with six accelerometers and one microphone. The C-130 aft right AAR-43, the forward left AAR-43, and the AAR-44 were each instrumentated with six accelerometers and one microphone.

The accelerometers used were Vibrametrics M1000A. The 5/8" Gulton microphones were used on the AAR-43 sensors, and 1/4" Gulton microphones were used on the AAR-44 sensors. The accelerometers contained built in emitter-followers and thus had low line loss, but the microphones had higher impedances and hence larger signal loss due to line length. The accelerometers at each location were oriented to obtain vertical, lateral, and longitudinal linear acceleration. The roll, pitch, and yaw angular acceleration were derived from appropriate pairs of accelerometers.

The microphone at each of the three IRWR sensor locations was used to determine the overall acoustic environment of each sensor.

The accelerometer locations are shown in Figures 4 and 5. Figures 6 and 7 are photos of the forward right AAR-43 mounting tray for the C-130. The AAR-43 quarter-sphere sensor fits into the opening indicated in the photos. The accelerometers were glued onto aluminum mounting blocks in order to obtain three-axis linear and three-axis angular vibration data on each sensor. The mounting blocks were glued to the back side of the mounting trays. The semicircles in Figures 4 and 5 represent the semicircular plane of the Aerojet sensor, which was parallel to the plane defined by the aircraft vertical and longitudinal axes. The HH-53 forward right and aft left and C-130 forward left AAR-43 sensors all used similar mounting trays. The 4950thTW cut openings in the trays to provide access to the back side of the trays for accelerometer mounting. The back side of the C-130 aft right AAR-43 was accessible by removing the panel on top of the C-130 beaver tail. Figure 8 shows six accelerometers for the C-130 aft right AAR-43. The accelerometers shown for the AAR-44 in Figures 4 and 5 are as viewed from the top. The accelerometers were glued directly to the sensor unit and each time the AAR-44 was removed, so were the accelerometers.

The microphones on the AAR-44 were located as shown in Figures 4 and 5. For the HH-53, a microphone was mounted 5" aft and 1/4" up from Accelerometer #6 by the forward right AAR-43. The diaphram was pointed downward and there was about 4.5" of open air space between the microphone diaphram and an obstruction. The other microphone was mounted 1/2" higher and 3.5" forward of Accelerometer #2 on the aft left sensor. The diaphram was facing downward and 7.5" of clear air space existed directly aft of the diaphram. For the C-130, a microphone was mounted 5" aft and 1" up from Accelerometer #1 on the forward left AAR-43 and a microphone was mounted 3.5" forward of and 1/5" lower than Accelerometer #1 on the aft right AAR-43.

For both IRWR systems, the accelerometer and microphone wires were connected to bulkhead Microdot connectors which routed the signals through the aircraft skin. The C-130 aft right sensor was the only location that did not require bulkhead fittings; here inline Microdot connectors were used to route the signals to the tape recording package.

In addition to the accelerometer and microphone signals, the two AAR-43 output signals, the AAR-44 output signal, time code, and voice were recorded on tape. The AAR-43 signals were recorded on Tape Recorder 1, the AAR-44 signal was recorded on Tape Recorder 2, and the aircraft time code and voice were recorded on both Tape Recorders 1 and 2. The IRWR output signals were provided to the recording system by the 4950th TW. Due to the large bandwidth of these signals, the tape recorders were operated at 60 ips so that the IRWR signals could be direct recorded at the same time that the accelerometer and microphone data were FM recorded.

A recorder track assignment versus input signals is shown in Table 1. The table also contains an explanation of the accelerometer and microphone numbering scheme used in this report.

The four amplifier systems, two tape recorders, power supplies, and power distribution box were mounted on a Wheaton table by 4950th TW personnel as shown in Figure 9. The table, including equipment and cables on it, was moved from one aircraft to the other as required by the test conditions. A separate remote control panel and its associated cables were installed in both aircraft, as shown in Figure 10. The four amplifier input signal cables and the aircraft power input cable were also installed in both aircraft. Thus, moving the instrumentation system on the Wheaton table required disconnecting and reconnecting the four amplifier input connectors, four remote control connectors, and the aircraft power input connector. The estimated weight of the Wheaton table plus equipment and cables was 196 pounds.

The 4950th TW installed the equipment and wiring in both aircraft, using wiring diagrams, equipment, connectors, and other supplies provided by AFWAL/FIBG. AFWAL/FIBG mounted the accelerometers and mounting blocks in both aircraft with the aid of the 4950th TW. The recording system was calibrated and checked out, both in the lab and in the aircraft, by AFWAL/FIBG. All other detailed electrical and mechanical requirements were coordinated between the 4950th TW and AFWAL/FIBG.

Test Procedure

Vibration data were recorded for a range of flight conditions which spanned the operational envelope of the IRWR systems in the two aircraft. The flight conditions included takeoff, climb, cruise, turns, descent, and landing for both aircraft. For the HH-53 helicopter there were additional test conditions covering transition and hover, both in and out of ground effect, and transverse and backward flight. The flight conditions were chosen to cover the range of dynamic pressure, engine speed and power (Tables 2 and 3).

The 4950th TW personnel aboard the aircraft loaded the tape recorders as required, turned the recording package on and off for the designated 30-second records, inhibited amplifier gains as needed, provided voice recordings of the flight conditions, and returned the recorded tapes to the Flight Dynamics Laboratory.

Vibration data were collected on four flights, as summarized in the following table:

Date	Aircraft	Location	IRWR Operating Sensors	Comments
2 Mar 79	C-130	WPAFB	AAR-43 only	Cruise, 4K ft/220 Knots, climb
10 Apr 79	HH-53	WPAFB	AAR-43 only	Complete flight regime
1 May 79	HH-53	Eglin AFB	AAR-44 only	Complete flight regime
27 Sep 79	C-130	WPAFB	None	Complete flight regime

The 2 March 1979 C-130 flight was basically an instrumentation operational checkout flight and data were recorded for only two flight conditions -- takeoff and cruise at 4,000 feet, 220 knots. However, this represents the only data FIBG was able to obtain on the C-130 in which the AAR-43 sensors were operational. There was no AAR-44 output signal on this flight.

During the HH-53 flight on 10 April 1979, a dummy AAR-44 was instrumented with accelerometers and a microphone; but since the system was not operational, no output signal was recorded. Also, the forward right AAR-43 had the even sensor eyes covered and the rear left AAR-43 had the odd sensor eyes covered.

The 1 May 1979 flight of the HH-53 did not have the AAR-43 operating; hence, no AAR-43 output signals were obtained during this flight.

The last flight, the C-130 flight of 27 September 1979, represents the only flight where vibration data were collected for the complete C-130 flight regime, light gross weight conditions, as listed in Table 2. However, neither IRWR system was operational during this flight and thus FIBG was unable to record any IRWR output signals. A second flight was scheduled to obtain the flight conditions listed in Table 2 when at a heavy gross weight; however, FIBG determined that the 27 September 1979 flight contained sufficient data to define the vibration environment and that a second flight was unnecessary if the IRWR sensors would not be operating.

In summary, vibration and acoustic data were collected for all flight conditions on both aircraft. However, simultaneous collection of the IRWR output signals was very limited and inadequate for determining correlation between IRWR output signals and vibration levels in all but a limited number of situations. About 80% of the vibration data collected appeared to be of usable quality.

Data Analysis

The flight data were analyzed at the FIBG facility. The analog data tapes were played back and all data channels displayed on oscillograph strip charts to check data validity and to select areas for further analysis. A preliminary analog analysis of the vibration data was performed using an analog spectrum analyzer to determine the frequency range and resolution required for digital analysis. During this initial analysis, the flight test data were compared with the ground test data to establish noise floors and signal-to-noise ratios.

Selected flight conditions, shown in Table 4, were digitized for subsequent analysis using standard FFT (Fast Fourier Transform) techniques. The discretization parameters were chosen to provide a frequency range of 5kHz with a narrowband resolution of 3.3935 Hz for the C-130 data and 1.810 Hz for the HH-53 data (finer resolution for the more periodic helicopter data). In each selected area, sixteen transforms of data were digitized to provide for increased statistical confidence by ensemble averaging.

Power Spectral Densities (PSDs) were computed in G^2/Hz for the vibration acceleration data. Sound Pressure Level (SPL) spectra were computed in units of dB (ref .00002 pascals, or 20 $\mu N/m^2$) for the acoustic data. Angular PSDs were derived from selected pairs of linear accelerometers by phase matching, subtracting, and computing the PSD of the difference. This was then divided by the square of the separation distance, integrated twice, and scaled to obtain angular displacement in units of microradians^2/Hz. A flow chart for the data analysis procedures is shown in Figure 11.

Test Results

A group of flight conditions was selected for each aircraft that covered the range of dynamic environments experienced by the aircraft. Six conditions were chosen for the C-130 and five conditions were chosen for the HH-53, as shown in Table 4. The data for these flight conditions were analyzed over the 1.8 - 5000 Hz frequency spectrum, and the overall vibration levels in g rms and the overall sound pressure levels in dB (re 20μPa) are shown in Table 5 for the C-130 and in Table 6 for the HH-53.

The vibration and noise levels shown here are not overly severe, as compared to typical aircraft environments. The vibration environment of the AAR-44, at the midsection of each aircraft, is generally lower than the AAR-43 vibration. The AAR-44 vertical accelerations are all 1g rms or less, the longitudinals are around 0.5 g, and the laterals are even lower. The noise levels are 128-136 dB for the helicopter and 132-140 dB for the transport. These noise levels were measured when the AAR-44 was not operating, and therefore represent the engine and aerodynamic noise only. The 136-140 dB noise levels could possibly result in damage to sensitive electronic components in the AAR-44.

The AAR-43 experienced higher vibration environments in general, although the forward sensor on the HH-53 experienced even less vibration than the AAR-44. The AAR-43 sensors on the C-130 show the highest measured vibration. The 250-knot airspeed and the 30° bank produced significantly higher vibration than the other flight conditions. The forward sensor on the C-130 under these conditions showed about 1g vertical and 2.3g lateral vibration; the aft sensor also showed about 1g vertical vibration, but the lateral vibration reached 3.87g rms. The noise levels, however, did not reflect the increased vibration; the values ranged from 116-128 dB for the forward sensor and 118-126 dB for the aft sensor.

The overall vibration levels are significantly lower than the standard random test level of 0.04 g^2/Hz, and are not expected to cause mechanical problems unless the energy is concentrated at discrete frequencies near the sensor mechanical resonances. In order to evaluate the vibration over the entire spectrum, several of the vibration sensors were selected for spectral analysis, as shown in Table 7. One lateral, one vertical, and one longitudinal accelerometer were selected at each IRWR sensor location, along with the microphones and some derived angular vibration in roll, pitch, and yaw on the C-130.

The vibration and noise spectra are shown in Figures 12-100 in terms of acceleration spectral density, g^2/Hz, noise levels in dB re 20 μPa, and angular displacement spectral density in $\mu r^2/Hz$. The data are plotted from 10 to 5000 Hz in 3.3935-Hz bandwidth for the C-130 and 1.8311-Hz bandwidth for the HH-53. The data plots are grouped by aircraft, with the C-130 data shown first. For each aircraft, the data for individual sensors are grouped over all flight conditions and are shown from the forward to aft locations.

C-130 Vibration and Noise Results

The C-130 spectra are shown in Figures 12-59. Figures 12-15 show the lateral accelerometer 2F on the forward left AAR-43 for the six flight conditions and for the no-signal condition. This last condition is with instrument power on but with the aircraft engines turned off. It gives a measure of the noise in the instrumentation system. Of particular concern is the 400-Hz electrical supply frequency, which may sometimes be seen in the vibration data. Each of the data plots in this report should be compared with the corresponding no-signal record to determine the validity of individual spectral lines.

The lateral vibration of accelerometer 2F during the low-speed flight conditions (130 Kts) has a very low spectral density below 50 Hz. At 68 Hz there is a major peak corresponding to a propeller blade-passage frequency of 4100 rpm. Above 200 Hz, the spectrum is essentially flat at 10^{-4} g^2/Hz. For the higher speed flight (250 Kts), the entire spectrum is raised an order of magnitude. The high-frequency spectrum is normally 10^{-3} g^2 Hz, with peaks at 10^{-2} g^2/Hz near frequencies of 350 Hz. The 68 Hz frequency is a sinusoid and should be evaluated on a g rms basis rather than g^2/Hz. To convert, simply multiply the PSD by the bandwidth (3.3935 Hz) and take the square root. In Figure 12a, for example, the 68 Hz peak of 4 x 10^{-4} g^2/Hz corresponds to .037 g rms.

The vertical acceleration is much lower than the lateral, as shown for Sensor 3F in Figures 16-19. The longitudinal vibration, shown for Sensor 6F in Figures 20-23, is lower still, and is dominated at the higher frequencies by several discrete blade-passage frequencies and overtones. The forward microphone, MF, plotted in Figures 24-27, shows fairly low overall sound-pressure levels. The 400-Hz peak in the microphone data is probably instrument noise. The higher speed flight conditions add about 10 dB to the noise levels at the forward AAR-43 location.

The AAR-44 environments on the C-130 are shown in Figures 28-43. The vertical acceleration PSDs for Sensor 1C are shown in Figures 28-41, the lateral PSDs (Sensor 3C) in Figures 32-35, and the longitudinal PSDs (Sensor 6C) in Figures 36-39. The spectra are all distinctly lower in overall rms response than the forward AAR-43 location. The acoustic noise levels, shown in Figures 41-43, are about 16 dB higher than the forward location at 130 knots airspeed and are about 11 dB higher at 250 kts. At the higher flight speeds the noise levels are 139-140 dB, which may cause some difficulty for sensitive electronics.

The dynamic environments at the aft AAR-43 sensor on the C-130 are shown in Figures 44-59. The vertical acceleration PSDs are shown for Sensor 2A in Figures 44-47, the lateral PSDs (Sensor 3A) are shown in Figures 48-51, and the longitudinal PSDs (Sensor 6A) are shown in Figures 52-55. Overall, the lateral acceleration PSDs are about 50% higher at the aft AAR-43 sensor than at the forward AAR-43 sensor. The increase is due chiefly to the 69 Hz peak and to a general increase in the spectrum levels from 250 Hz to 750 Hz. In contrast, the vertical acceleration spectra show steady declines in PSD with increasing frequency from 100 Hz to 1000 Hz. The longitudinal vibration is highest at the aft (AAR-43) location, reaching about 1g rms at the 250 knot airspeed. The aft microphone data (MA), shown in Figures 56-59, are 13 dB lower than those at the center (AAR-44) sensor location. These aft levels are about the same as the forward sensor, even though the vibration levels are higher. The highest noise levels measured were 126 dB at 250 knots airspeed; these levels are not expected to cause any equipment problems.

HH-53 Vibration and Noise Results

The HH-53 spectra are shown in Figures 60-95 for five flight conditions and for the no-signal condition. The lateral vibration at the forward AAR-43 location is shown for Sensor 1F in Figures 60-62. The responses are less than 0.5g rms and are dominated by the rotor blade passage frequencies and by the narrowband engine frequencies. The vertical accelerations, shown for Sensor 4F in Figures 63-65, are no more than 0.25g rms and the spectra show a gradual decrease at frequencies from 100 Hz to 1000 Hz. The longitudinal accelerations, represented by Sensor 6F in Figures 66-68, are also very low, reaching less than 0.3g. The noise responses from microphone MF, shown in Figures 69-71, are a moderate 122-130 dB. The greatest response is at the 18-Hz rotor slapping frequency.

The center (AAR-44) sensor on the HH-53 showed higher vibration levels than the forward AAR-43, but lower than the aft AAR-43. The vertical accelerations for Sensor 2C are shown in Figures 72-74, the lateral accelerations (Sensor 3C) are shown in Figures 75-77, and the longitudinal accelerations (Sensor 6C) are shown in Figures 78-80. Only the vertical acceleration shows overall levels near 1g rms. The noise levels are relatively low, ranging from 126 to 136 dB for microphone MC, as shown in Figures 81-83.

The aft AAR-43 location showed the highest vibration levels on the helicopter. The lateral accelerations (Sensor 1A) are shown in Figures 84-86, the vertical accelerations (Sensor 3A) are shown in Figures 87-89, and the longitudinal accelerations (Sensor 6A) are shown in Figures 90-92. The microphone data (MA), shown in Figures 93-95, show sound pressure levels of 111-124 dB, lower than the forward or center locations. The HH-53 helicopter vibration levels are generally lower than the corresponding C-130 levels, and are not expected to cause any difficulty in sensor operation.

Derived Angular Accelerations

Several pairs of linear accelerometer signals on the C-130 were combined to produce a measure of the angular accelerations experienced by the sensors. The sensors chosen are shown in Table 7 and the results are shown in Figures 96-100 for the selected flight condition of 250 knots, 30° bank, and 1000 feet altitude. The results, shown in PSDs of microradians squared per hertz, are for information only and were not used to evaluate the sensor vibration environments.

REFERENCE

Noren, B L, Infrared Warning Receiver (IRWR) Phase I, DT&E Field Tests, Test Plan No. 78-2-11, 4950th Test Wing, Wright-Patterson AFB, Ohio, December 1978.

APPENDIX B

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TABLE 1. RECORDER TRACK ASSIGNMENTS

Tape Recorder Track Number	Recorder Number 1		Recorder Number 2	
	Signal	Recording Method	Signal	Recording Method
1	1F	FM	1C	FM
2	6F	FM	5A	FM
3	2F	FM	2C	FM
4	1A	FM	6A	FM
5	3F	FM	3C	FM
6	2A	FM	6C	FM
7	4F	FM	4C	FM
8	3A	FM	MF	FM
9 (C-130)	A Output	DR	C Output	DR
9 (HH-53)	F Output	DR	C Output	DR
10 (C-130)	F Output	DR	MA	FM
10 (HH-53)	A Output	DR	MA	FM
11	5F	FM	5C	FM
12	4A	FM	MC	FM
13	Commutator	FM	Commutator	FM
14	Time Code	FM	Time Code	FM
15	Intercom	FM	Not Used	--
16	Not Used	--	Intercom	FM

NOTES: Signal 1F is Accelerometer Number 1 on Forward (AAR-43) IRWR Sensor.

MC is Microphone on Center (AAR-44) IRWR Sensor.

6A is Accelerometer Number 6 on Aft (AAR-43) IRWR Sensor.

FM = Frequency Modulation @ 60 ips, Bandwidth = 0 - 20kHz.

DR = Direct Record, 300-250kHz.

A Output, F Output = 5.5 Vrms, 192kHz Bandwidth.

C Output = 0-3.5V, 160kHz Bandwidth.

TABLE 2. C-130 VIBRATION TEST MATRIX

	ALTITUDE (FEET) AGL	AIRSPEED (KNOTS)	ROLL ANGLE (DEGREES)	CONDITION
1	200	125-130	0	Simulated Air Drop
2	500	125-130	0	Simulated Air Drop
3	1000	125-130	0	Simulated Air Drop
4	2000	125-130	0	Simulated Air Drop
5	5000	125-130	0	Simulated Air Drop
6	200	130-150	0	Simulated Air Drop
7	500	130-150	0	Simulated Air Drop
8	1000	130-150	0	Simulated Air Drop
9	2000	130-150	0	Simulated Air Drop
10	5000	130-150	0	Simulated Air Drop
11	200	210	30	In Route to Air Drop
12	500	210	30	In Route to Air Drop
13	1000	210	30	In Route to Air Drop
14	2000	210	30	In Route to Air Drop
15	5000	210	30	In Route to Air Drop
16	200	250	30	In Route to Air Drop
17.	500	250	30	In Route to Air Drop
18	1000	250	30	In Route to Air Drop
19	2000	250	30	In Route to Air Drop
20	5000	250	30	In Route to Air Drop

TABLE 3. H-53 VIBRATION TEST MATRIX.

GROSS WEIGHT	ROTOR RPM	GROSS WEIGHT	ROTOR RPM	ALTITUDE (FT AGL)	AIRSPEED (KNOTS)	ROLL ANGLE (DEGREES)	CONDITION
INTERNAL FUEL	100	FULL FUEL	105	10	0	0	Hover-In Ground Effect
"	100	"	105	300	0	0	Hover-Out of Ground Effect
"	100	"	105	10	0	0	Hover Turn-In Ground Effect
"	100	"	105	300	0	0	Hover Turn-Out of Ground Effect
"	100	"	105	0-500	0-100	0	Normal Takeoff
"	105	"	105	0-500	0-100	0	Maximum Performance Takeoff
"	100	"	105	0-500	0-100	0	Rolling Takeoff
"	100	"	105	100-2000	80	0	Normal Climb
"	100	"	105	100-2000	80	0	Climb-Maximum Rate of Climb
"	100	"	100	5000	80-130	0	Accelerate to Cruise
"	100	"	100	5000	130	0	Cruise
"	100	"	100	5000	130	60	Left Turn - 360°
"	100	"	100	5000	130	60	Right Turn - 360°
"	100	"	100	5000	162/150	0	Maximum Airspeed
"	100-125	"	100-125	5000-1000	90	60	Autorotation-Turning
"	100-125	"	100-125	5000-1000	100	60	Spiral Descent
"	100	"	100	5000-1000	162/150	0	Descent-Maximum Airspeed
"	100	"	105	500-0	80-0	0	Normal Approach
"	105	"	105	500-0	80-0	0	Steep Approach
"	100	"	100	50	30-35	0	Sideward and Rearward Flight

TABLE 4. C-130 AND HH-53 FLIGHT CONDITIONS SELECTED FOR ANALYSIS.

C-130 (6 Conditions)	HH-53 (5 Conditions
130-150 Kts, 0° Bank Angle:	
1. 200 Ft Altitude	1. Hover in-ground-effect
2. 1000 Ft Altitude	2. Maximum Performance Takeoff
3. 5000 Ft Altitude	3. Cruise, 5000 Ft, 130 Kt
250 Kts, 30° Bank Angle:	4. Spiral Descent, 5000-1000 Ft, 100 Kt
4. 200 Ft Altitude	
5. 1000 Ft Altitude	5. Autorotation, 5000-1000 Ft, 90 Kt.
6. 5000 Ft Altitude	

TABLE 5. C-130 OVERALL VIBRATION AND NOISE LEVELS

C-130

SENSOR	200 Ft 130 Kt/0°	1000 Ft 130 Kt/0°	5000 Ft 130 Kt/0°	200 Ft 250 Kt/30°	1000 Ft 250 Kt/30°	5000 Ft 250 Kt/30°	NO SIGNAL
1F (Lat)	1.06	1.05	1.15	2.30	2.36	2.38	.05
2F (Lat)	.44	.45	.46	2.21	2.22	2.28	.02
3F (Vert)	.17	.17	.18	.91	.95	1.00	.03
4F (Vert)	---	---	---	---	---	---	---
5F (Lat)	---	---	---	---	---	---	---
6F (Long)	.06	.06	.05	.06	.06	.05	.01
MF	116	116	117	128	128	128	99
1C (Vert)	.11	.11	.12	.86	.92	.92	.01
2C (Vert)	.08*	.08*	.10*	.60	.65	.65	.04
3C (Lat)	.04	.04	.05	.05	.04	.04	.01
4C (Lat)	.04	.04	.04	.04	.04	.04	.01
5C (Vert)	---	---	---	---	---	---	---
6C (Long)	.09	.09	.11	.61	.62	.64	.001
MC	132	132	132	139	140	139	116
1A (Lat)	.66	.67	.78	3.43	3.54	3.87	.07
2A (Lat)	.64	.65	.76	3.09	3.19	3.52	.06
3A (Vert)	.65	.49	.58	.99	1.00	1.08	.01
4A (Vert)	.51	.38	.45	.83	.83	.92	.02
5A (Lat)	.38	.36	.44	1.56	1.56	1.69	.04
6A (Long)	.24*	.24*	.30*	.95	.99	1.08	.15
MA	118	119	119	126	126	126	88

NOTES: - Data Not Obtained
* Data affected by instrument noise.

TABLE 6. HH-53 OVERALL VIBRATION AND NOISE LEVELS

HH-53

	HOVER IGE	MAX TAKEOFF	CRUISE	SPIRAL DESCENT	AUTO-ROTATION	NO SIGNAL
1F (Lat)	.37	.27	.50	.43	.38	.04
2F (Lat)	---	.13	.31	.27	.19	.01
3F (Vert)	.16	.03*	.04*	.04*	.03*	.03
4F (Vert)	.27	.15*	.25	.27	.18*	.10
5F (Lat)	.37	---	---	---	---	.02
6F (Long)	.31	.19	.27	.29	.21	.01
MF	126	122	131	130	127	106
1C (Vert)	.87	.86	.85	.93	1.00	.17
2C (Vert)	.51	.50	.52	.62	.53	.02
3C (Lat)	.04	.04	.04	.04	.04	.01
4C (Lat)	.03	.03	.04	.04	.03	.01
5C (Vert)	.56	.54	.55	.67	.63	.04
6C (Long)	.47	.43	.44	.50	.53	.01
MC	128	127	126	136	131	106
1A (Lat)	1.22	1.00	1.07	1.46	.77	.06
2A (Lat)	1.69	1.60	1.68	2.07	1.57	.06
3A (Vert)	.39	.41	.37	.60	.30	.08
4A (Vert)	.38	.37	.35	.61	.30	.02
5A (Lat)	---	---	---	---	---	---
6A (Long)	.37	.31	.35	.52	.31	.01
MA	123	120	111	123	124	90

NOTES: - Data Not Obtained
* Data affected by instrument noise.

TABLE 7. SENSORS SELECTED FOR SPECTRAL ANALYSIS.

AIRCRAFT	FORWARD	CENTER	AFT
C-130	2F Lat	1C Vert	2A Lat
	3F Vert	3C Lat	3A Vert
	6F Long	6C Long	6A Long
	MF	MC	MA
	1F-2F Roll	1c-2C Roll	1A-2A Roll
		3C-4C Yaw	3A-4A Pitch
HH-53	1F Lat	2C Vert	1A Lat
	4F Vert	3C Lat	3A Vert
	6F Long	6C Long	6A Long
	MF	MC	MA

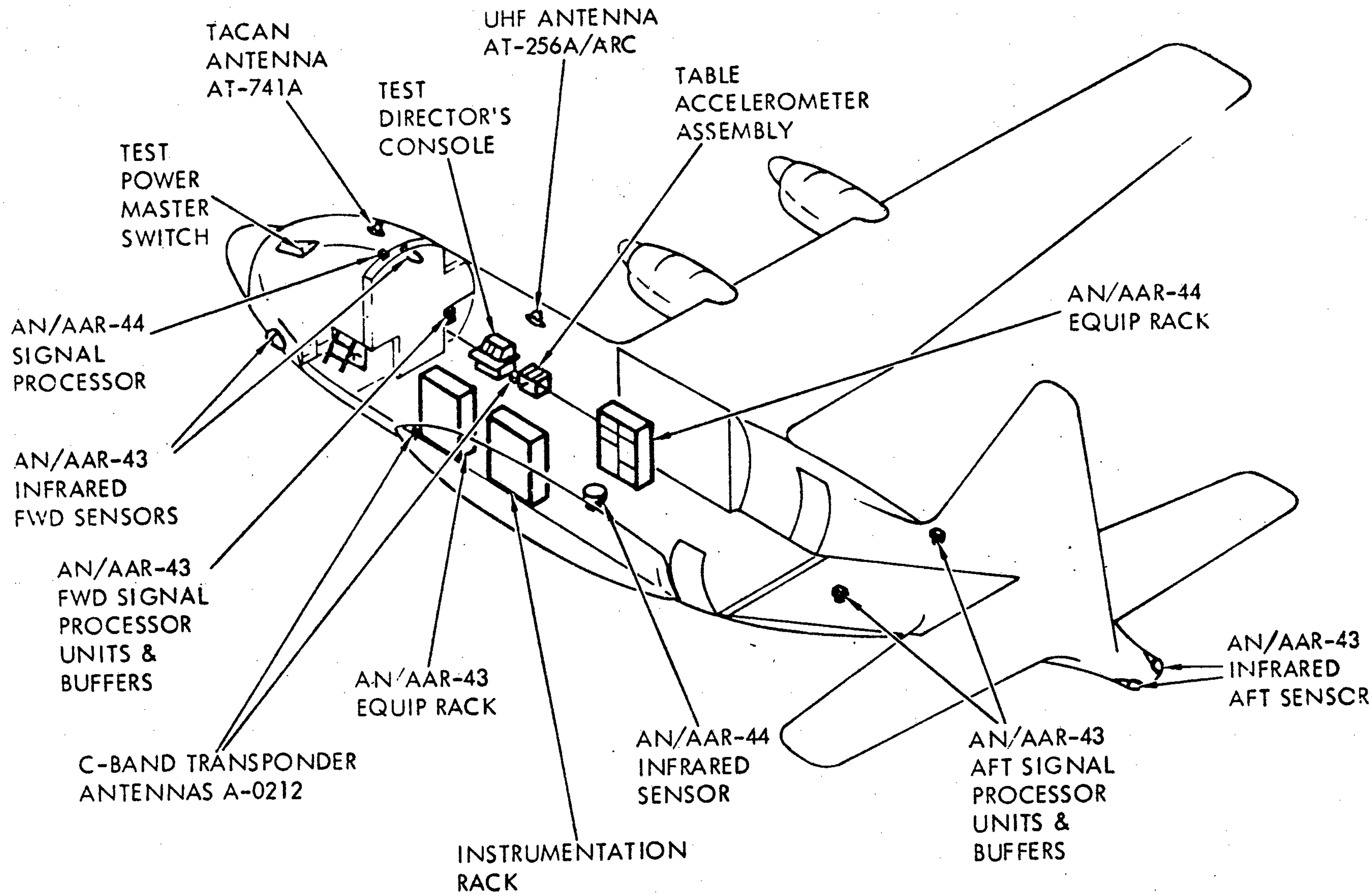


Figure 1. C-130E Installation.

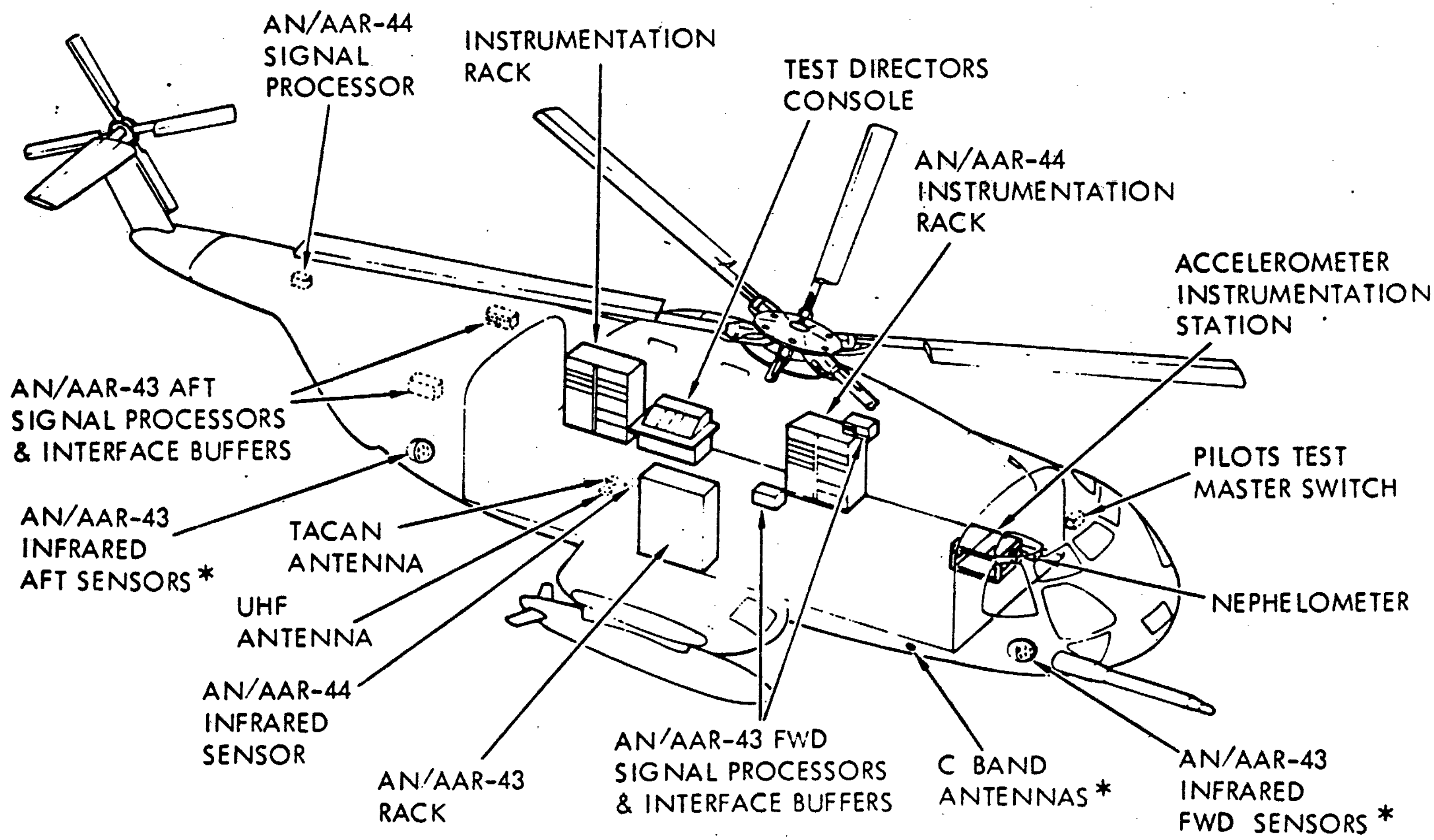


Figure 2. HH-53C Installation.

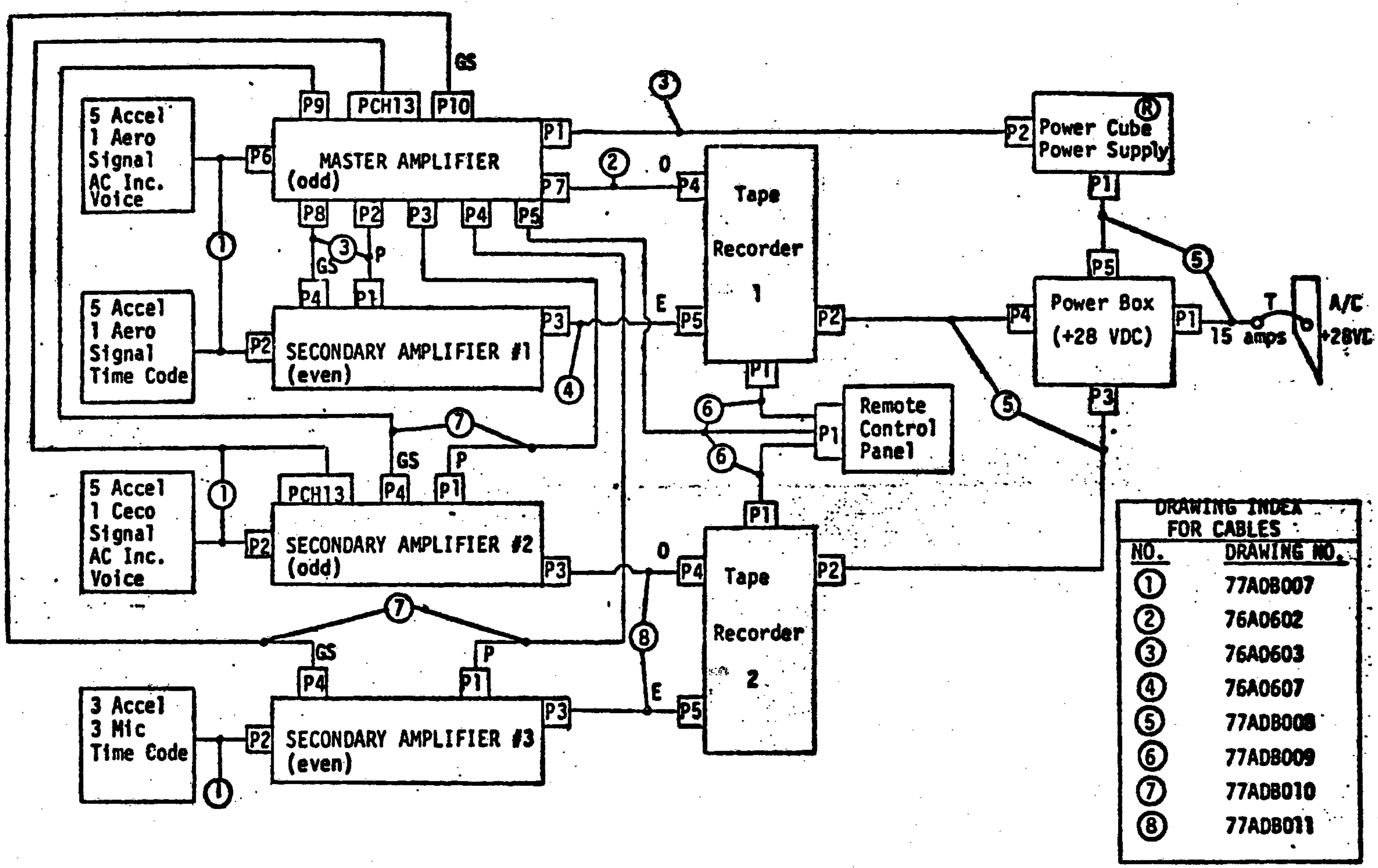
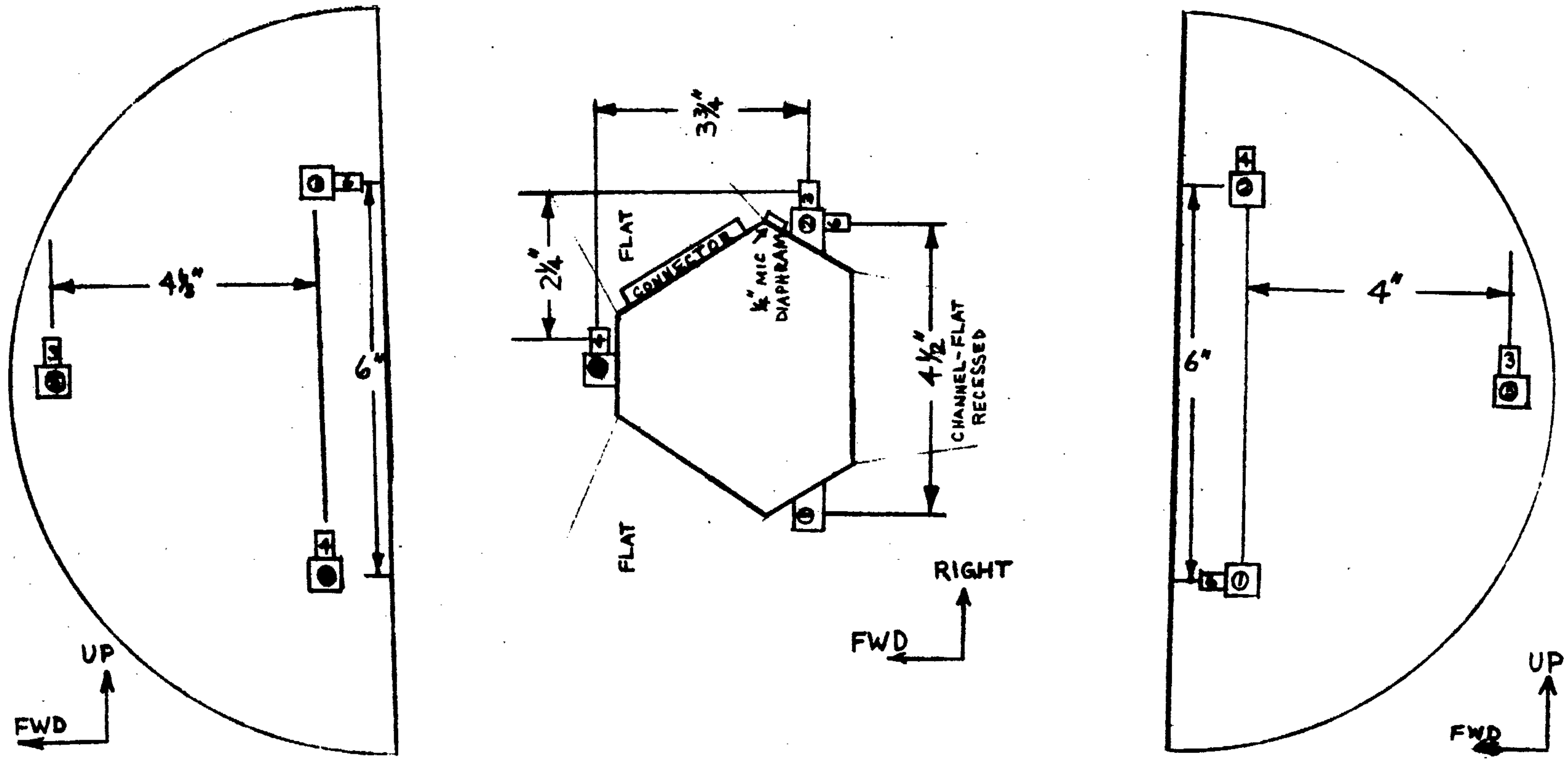


Figure 3. Vibration Instrumentation Block Diagram.

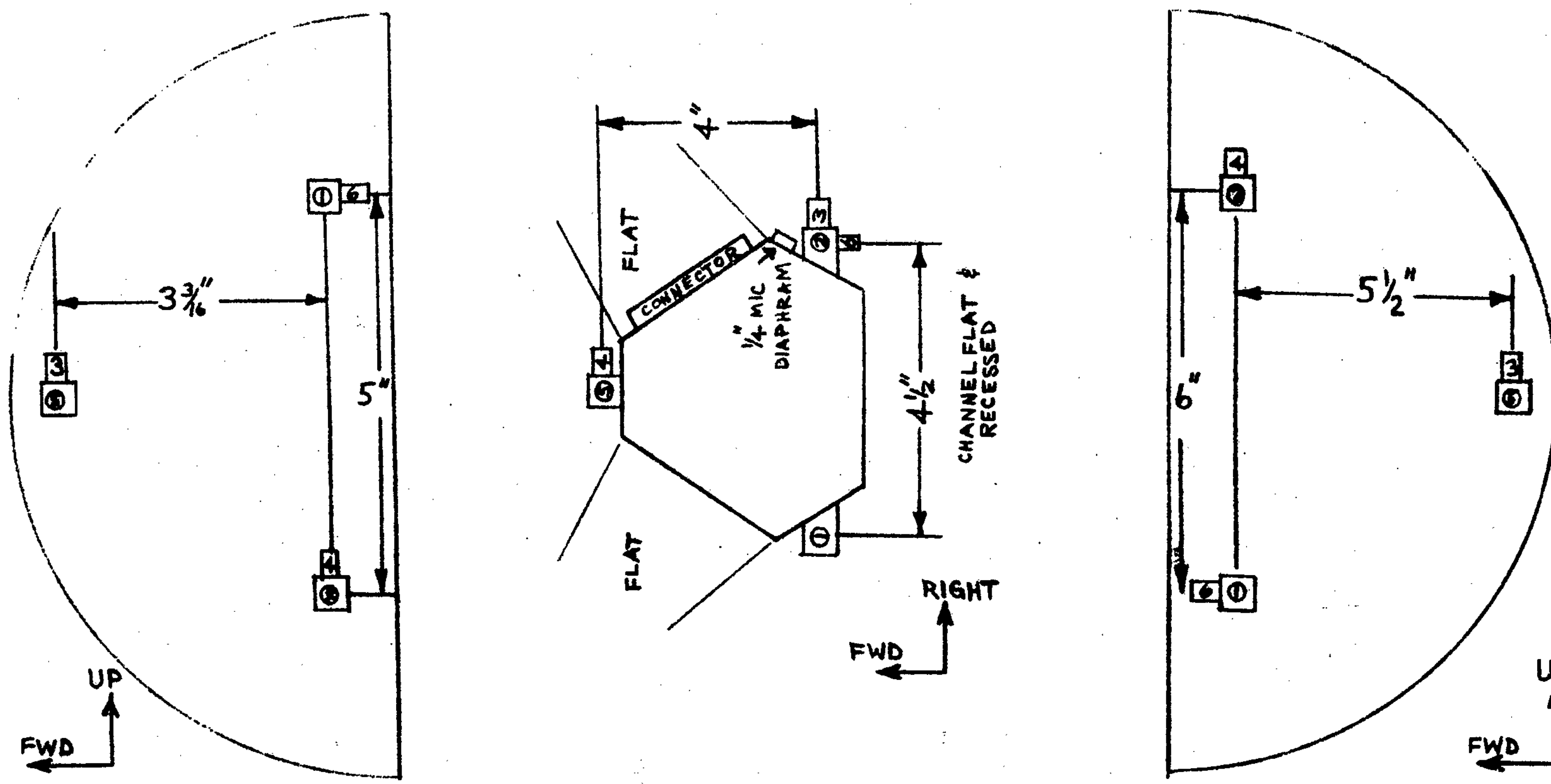


Forward Left AAR-43
Side View

AAR-44
Top View

Aft Right AAR-43
Side View

Figure 4. C-130 Accelerometer Locations



Forward Right AAR-43
Side View

AAR-44
Top View

Aft Left AAR-43
Side View

Figure 5. HH-53 Accelerometer Locations

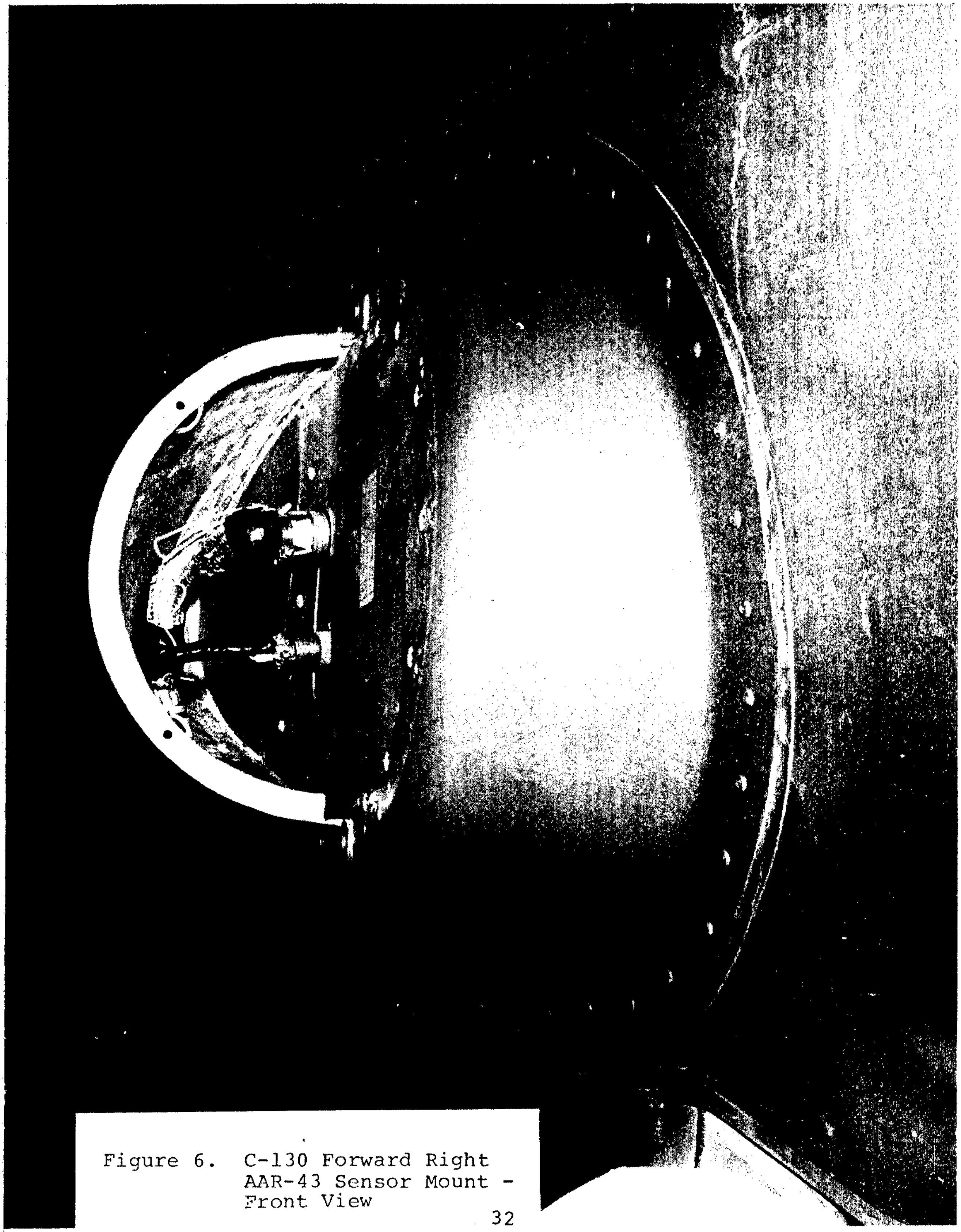


Figure 6. C-130 Forward Right AAR-43 Sensor Mount - Front View

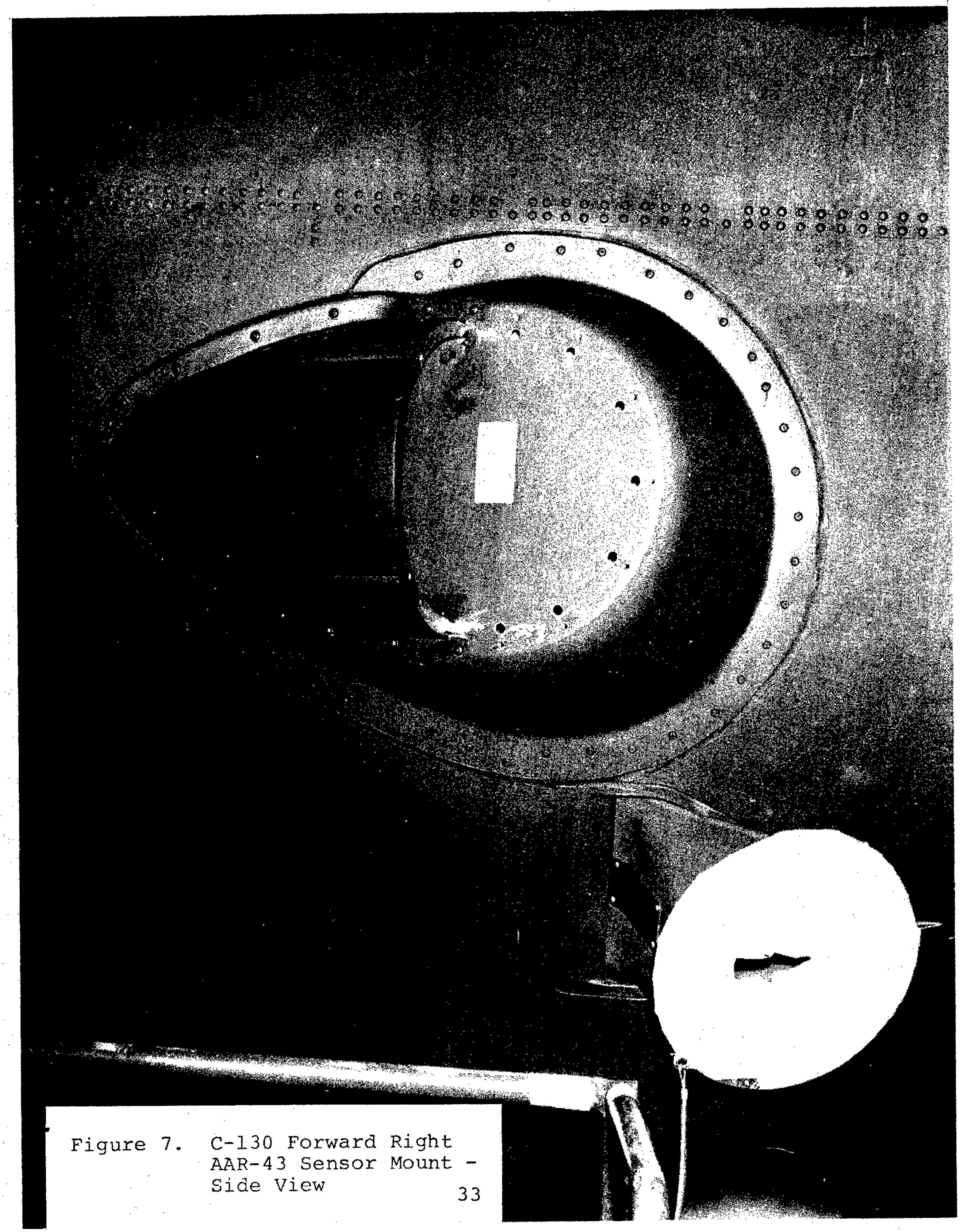


Figure 7. C-130 Forward Right AAR-43 Sensor Mount - Side View

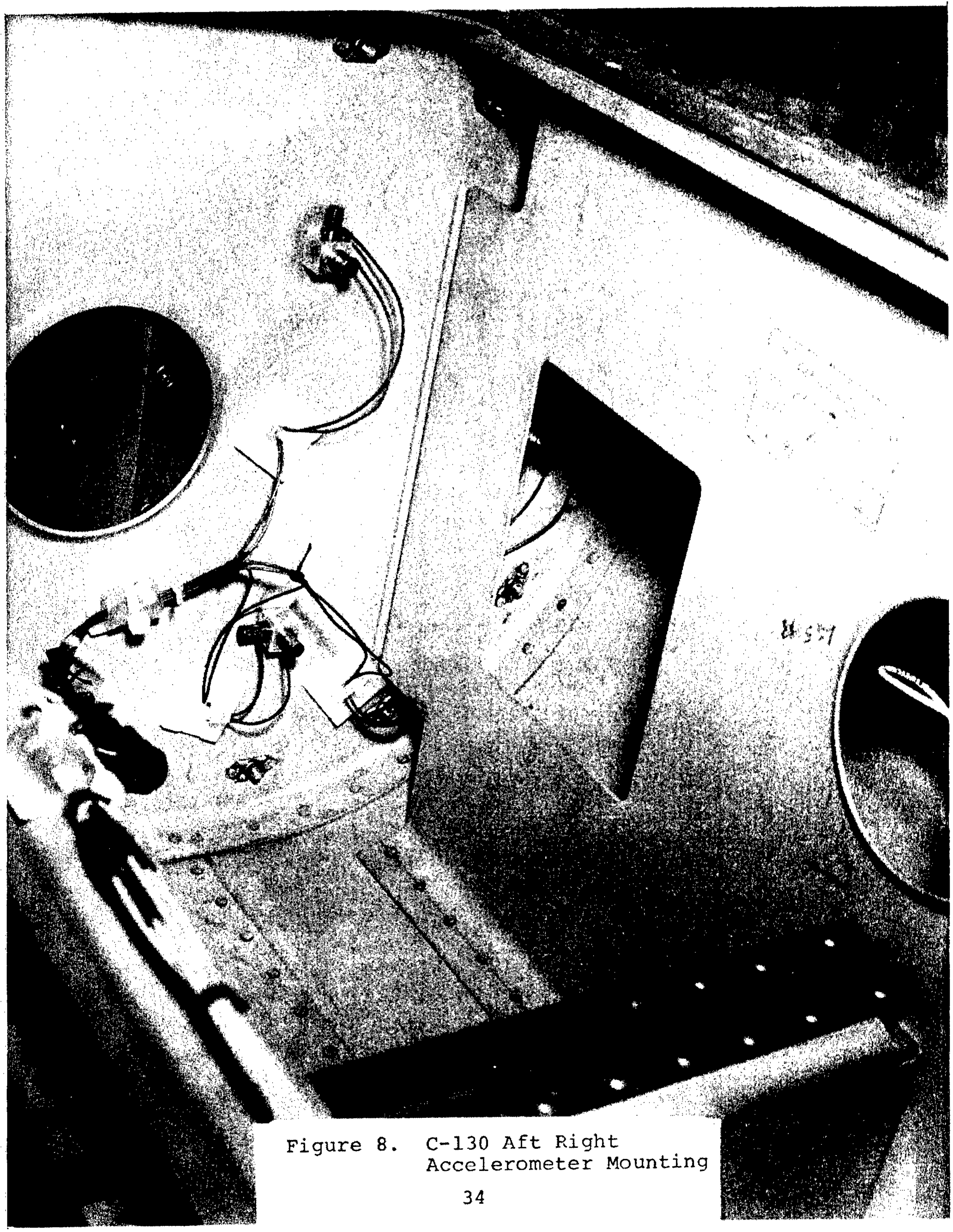


Figure 8. C-130 Aft Right Accelerometer Mounting

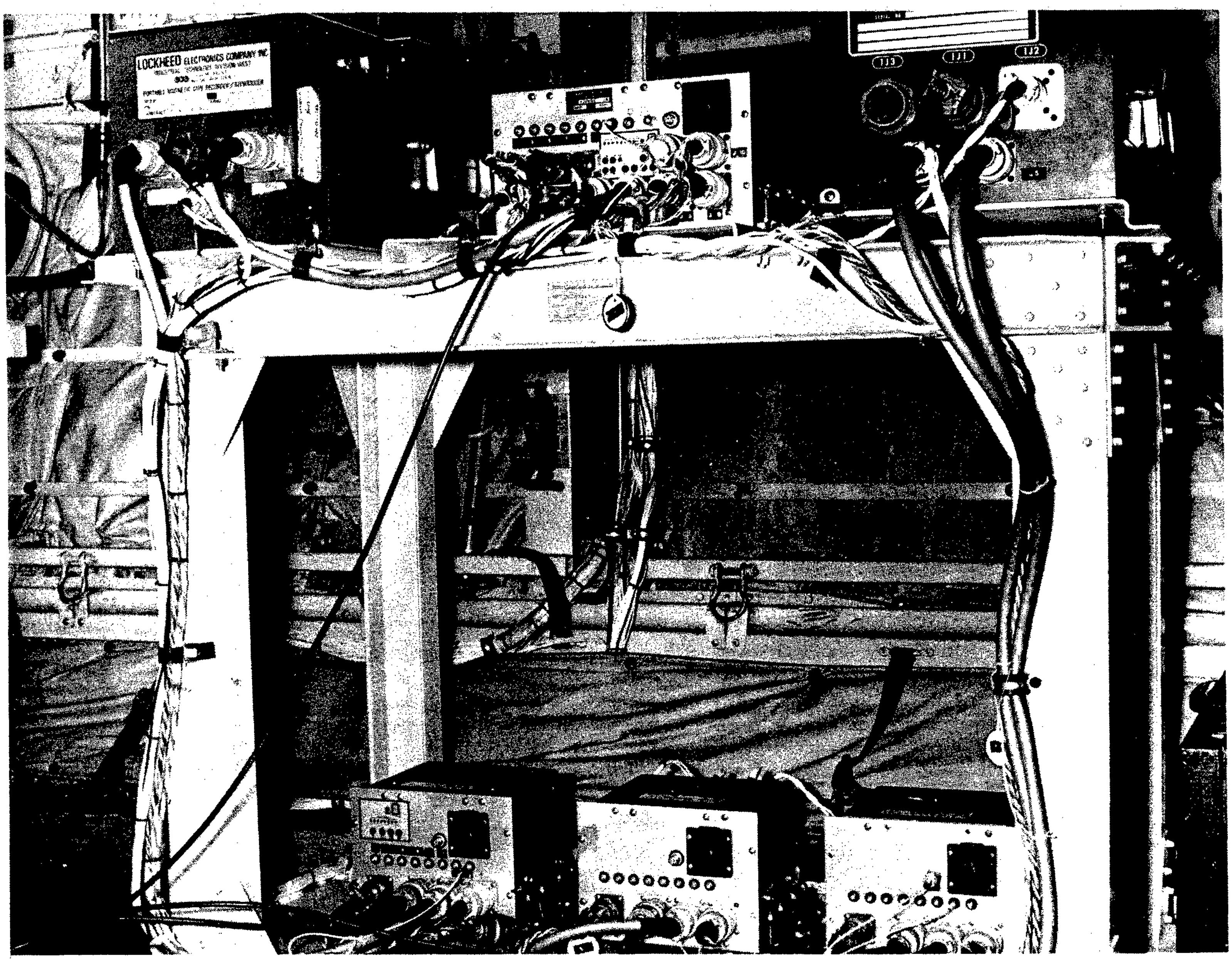


Figure 9. Wheaton Table and Electronics

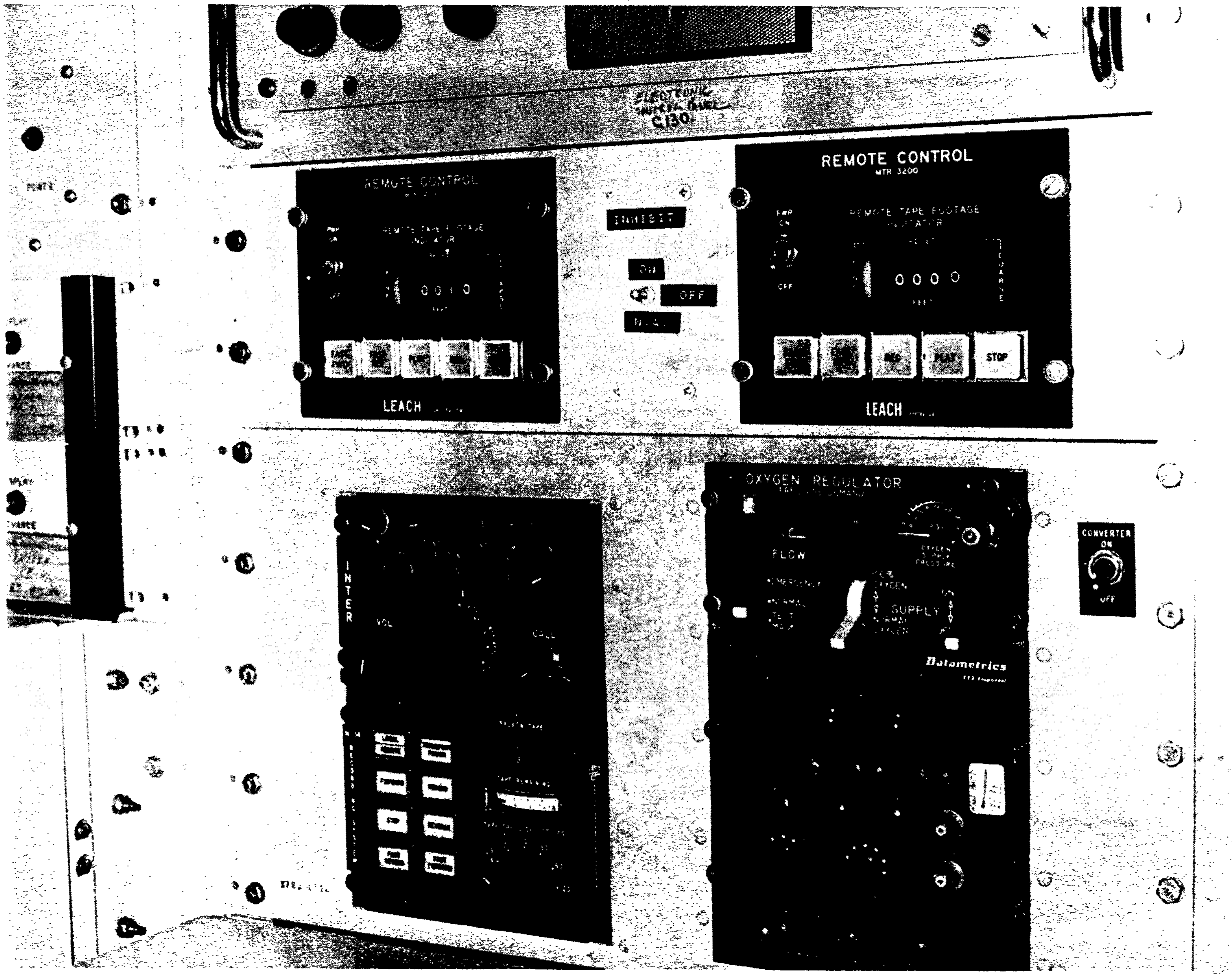


Figure 10. Remote Control Panel for Electronics

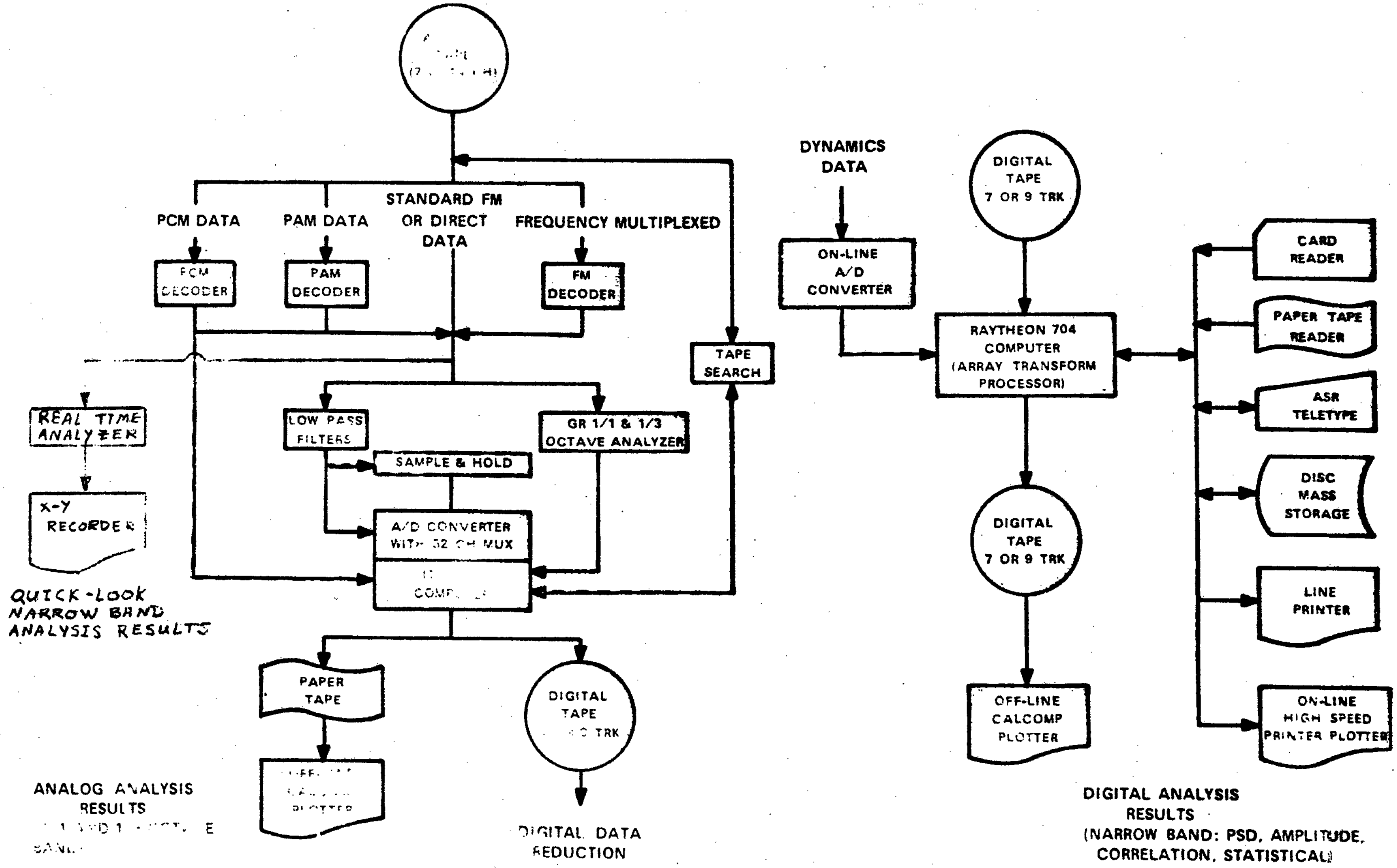
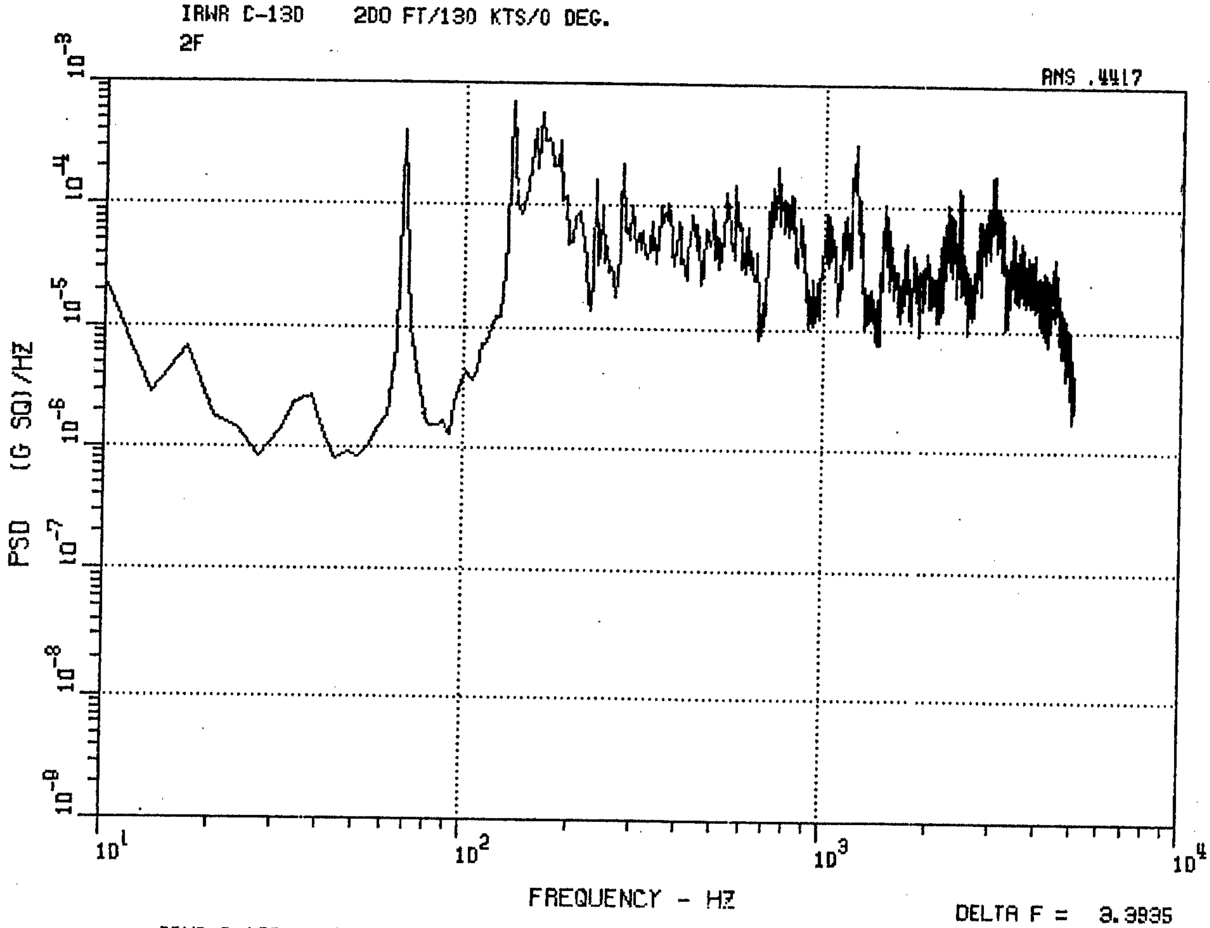


Figure 11. Flow Chart for Data Analysis



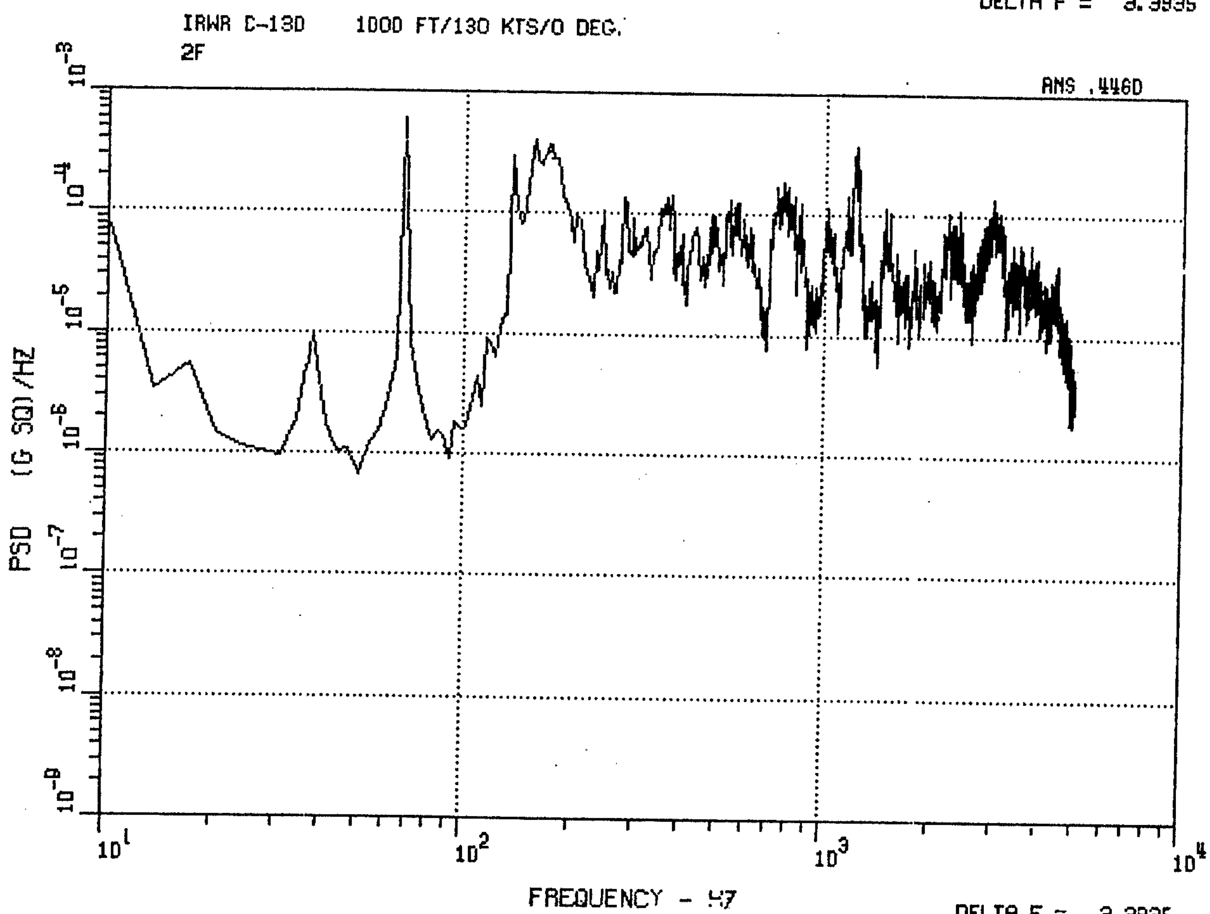


Figure 12. C-130 Fwd Lateral Accelerometer 2F, 200 Ft, 130 Kt, 0 Deg, and 1000 Ft, 130 Kt, 0 Deg.

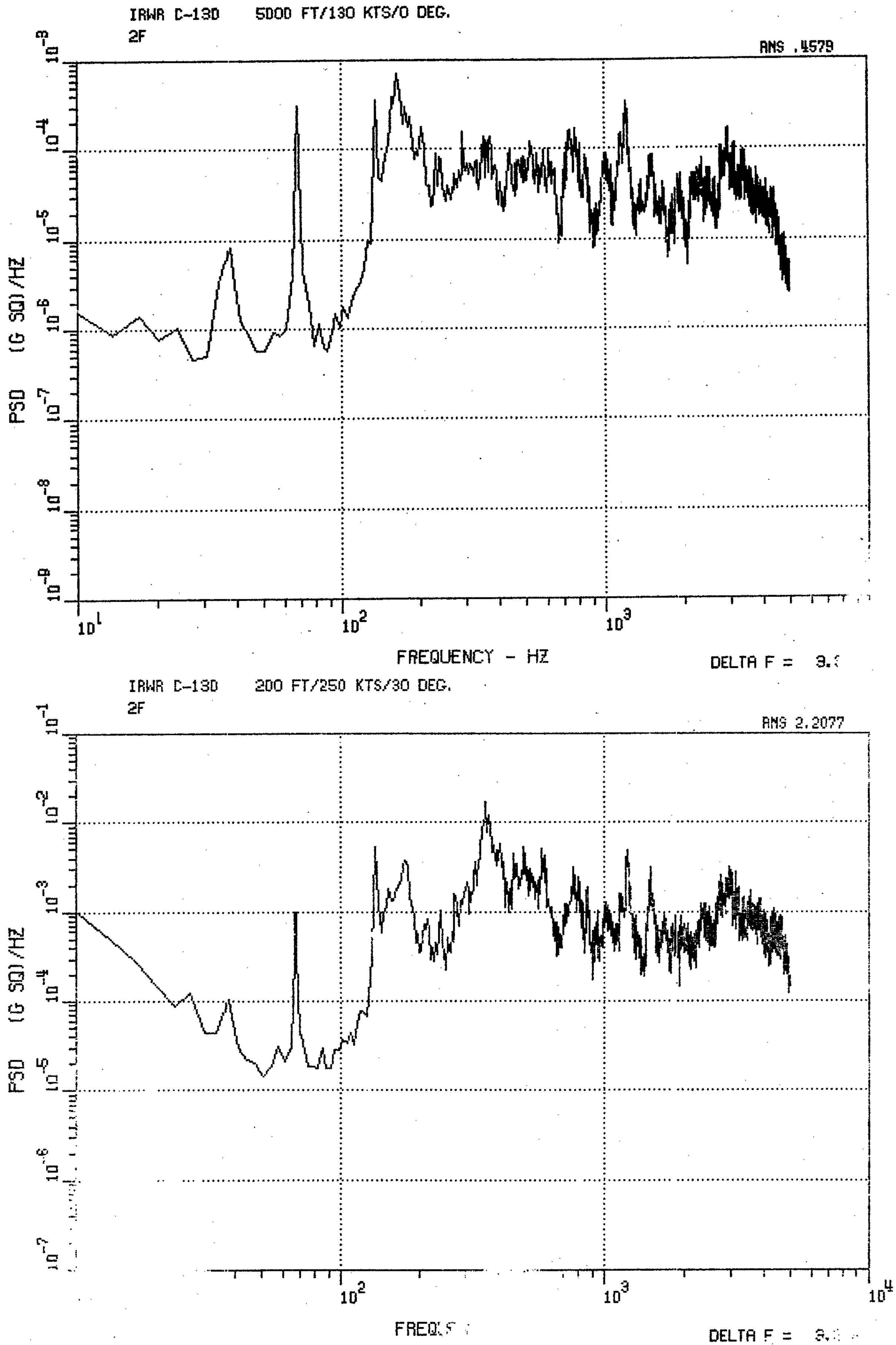


Figure 13. C-130 Fwd Lateral Accelerometer 2F, 5000 Ft, 130 Kt, 0 Deg, and 200 Ft, 250 Kt, 30 Deg.

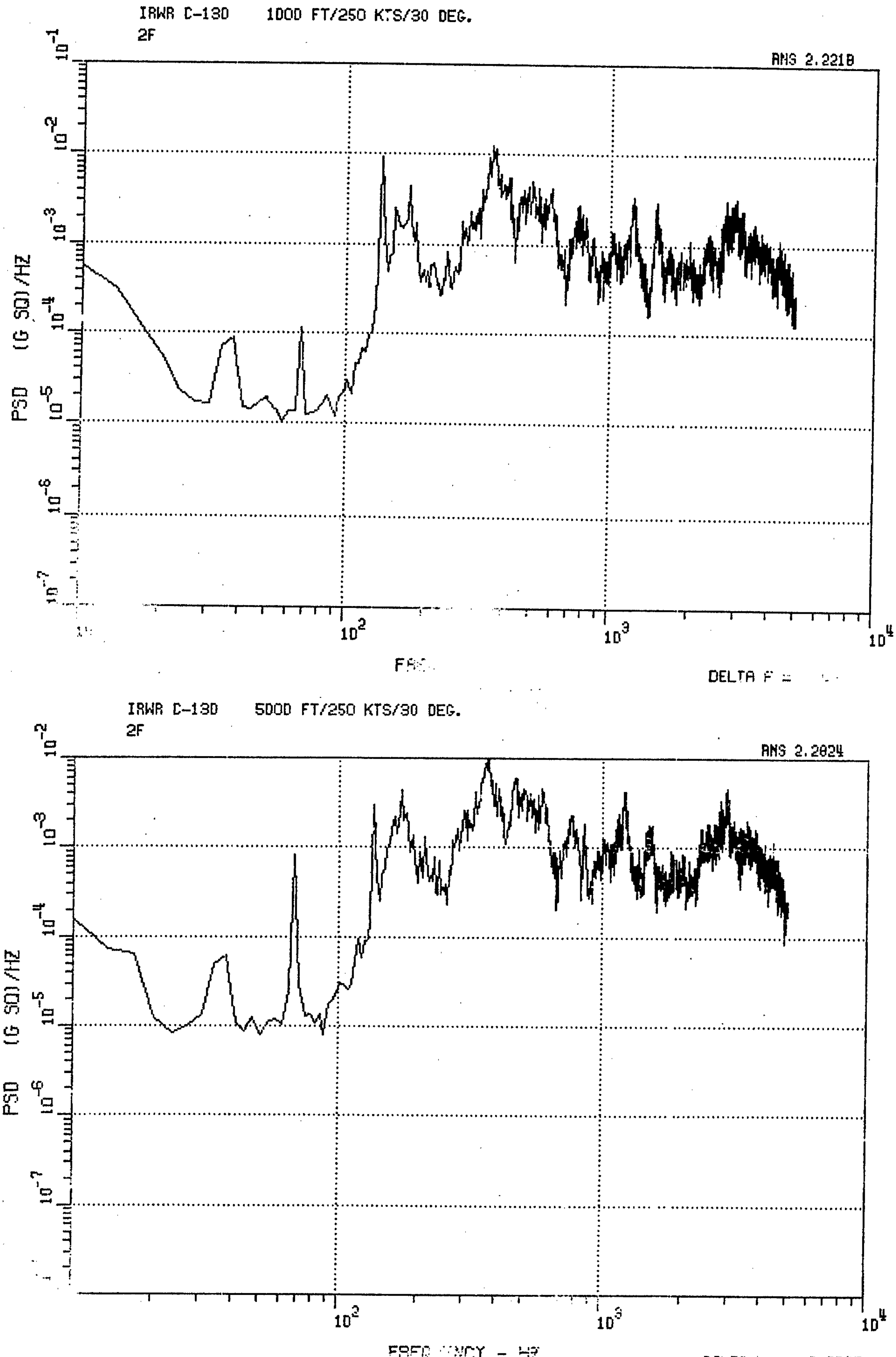


Figure 14. C-130 Fwd Lateral Accelerometer 2F, 1000 Ft, 250 Kt, 30 Deg, and 5000 Ft, 250 Kt, 30 Deg.

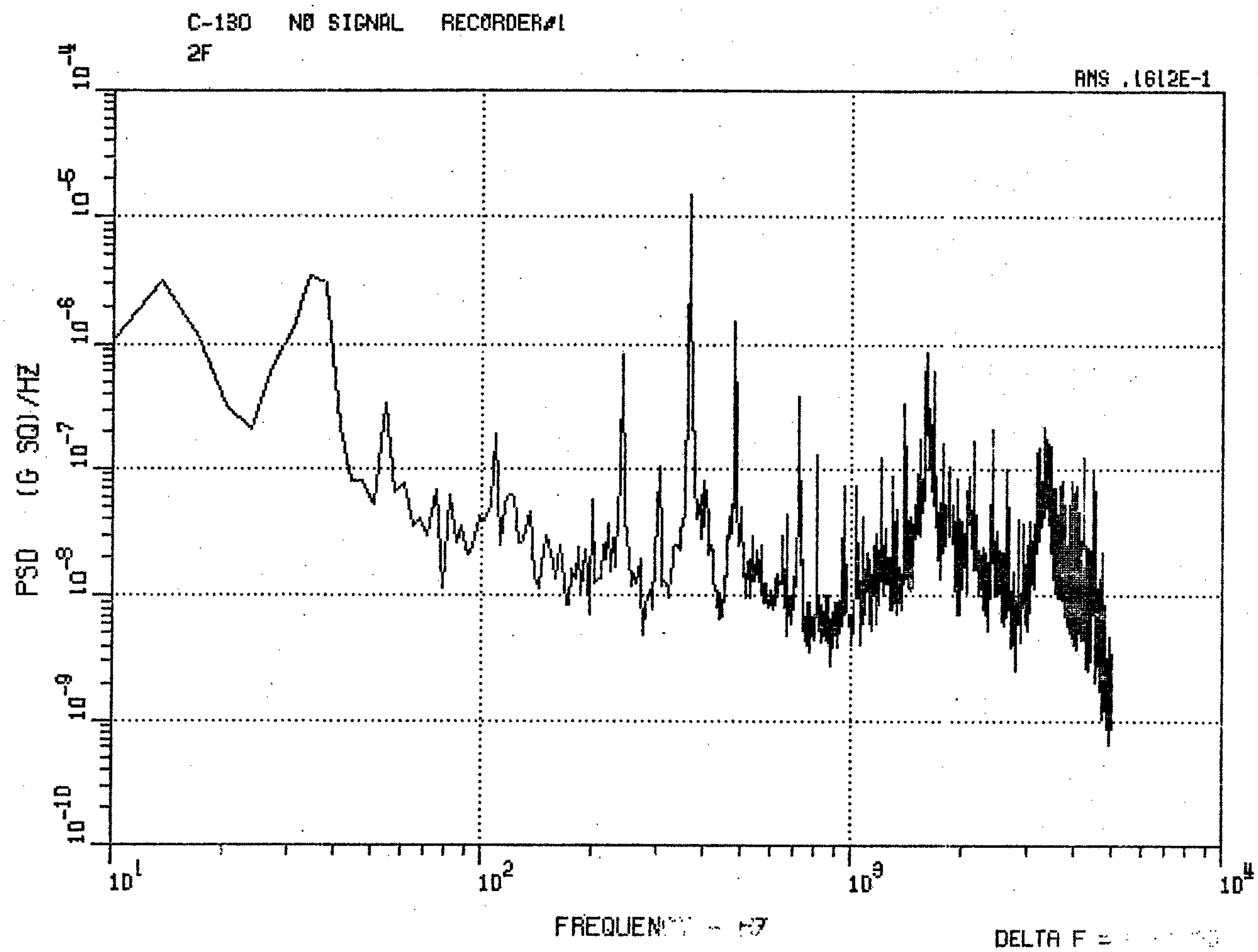
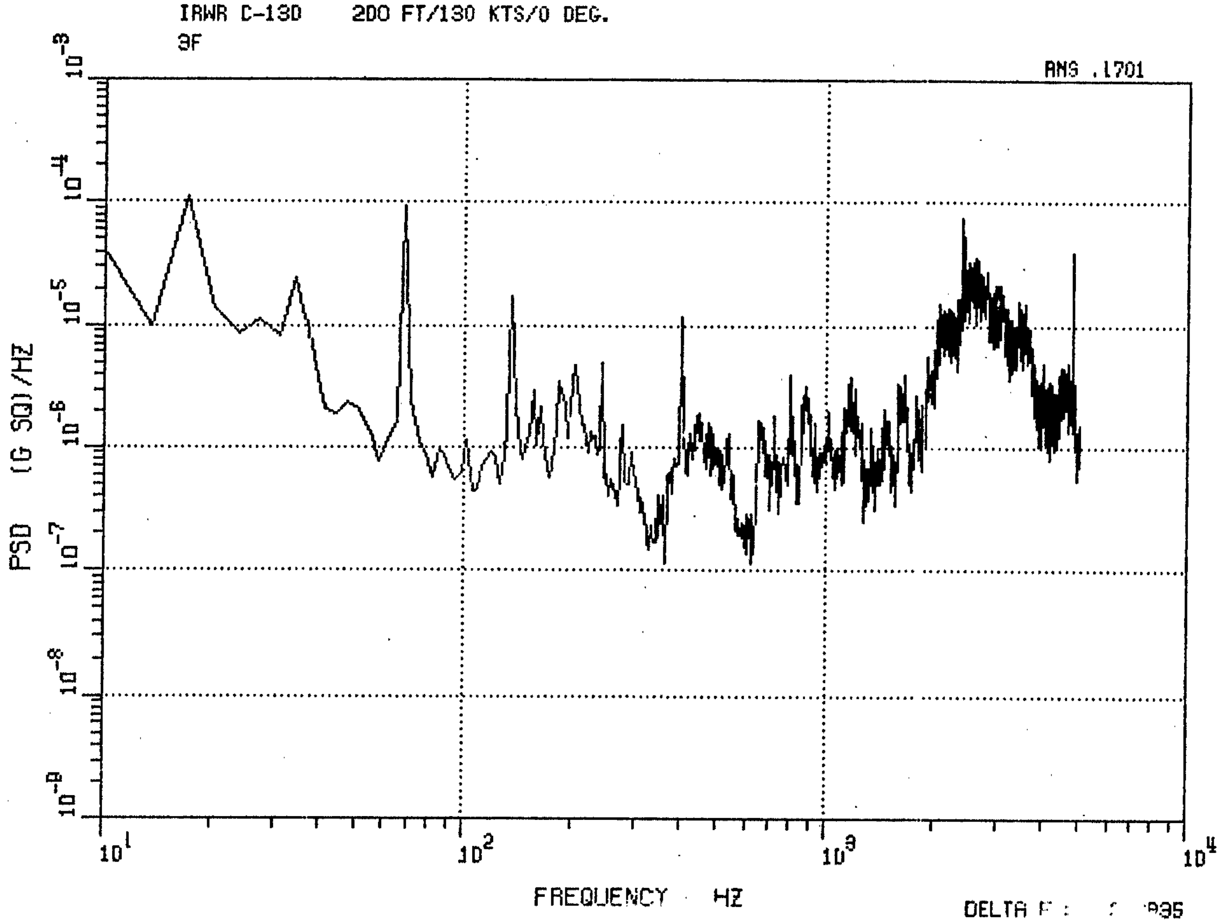


Figure 15. C-130 Fwd Lateral Accelerometer 2F, No-Signal Record.



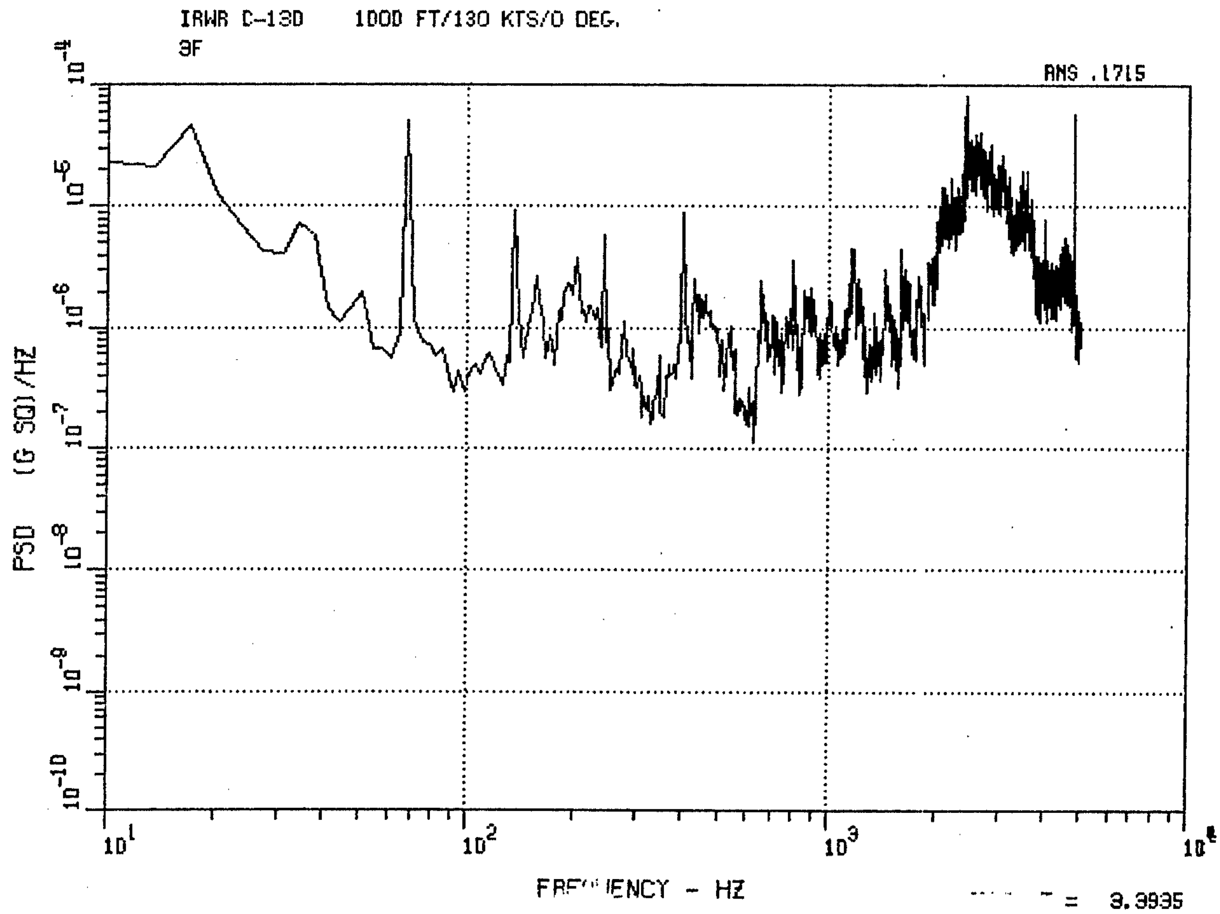


Figure 16. C-130 Fwd Vertical Accelerometer 3F, 200 Ft, 130 Kt, 0 Deg, and 1000 Ft, 130 Kt, 0 Deg.

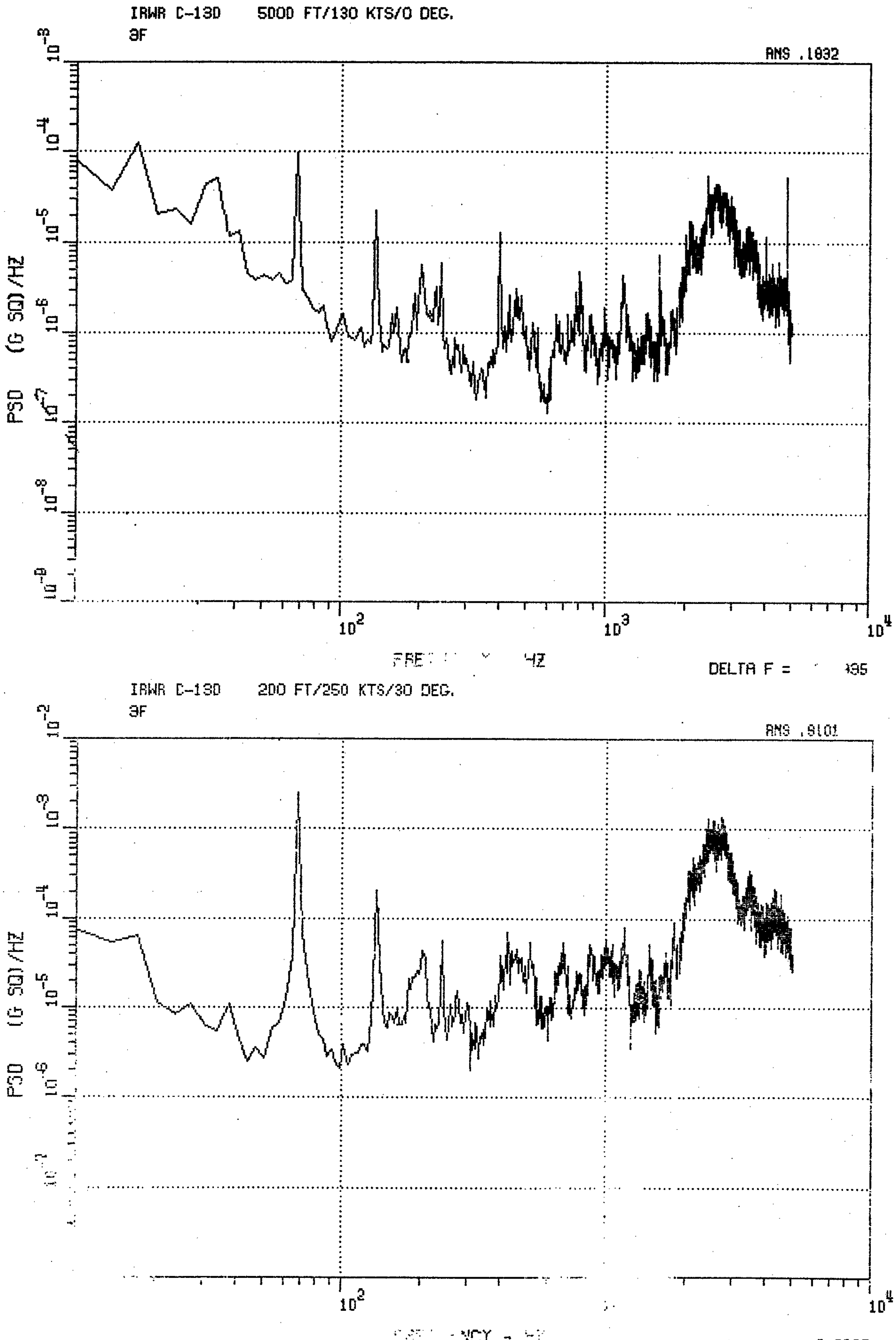
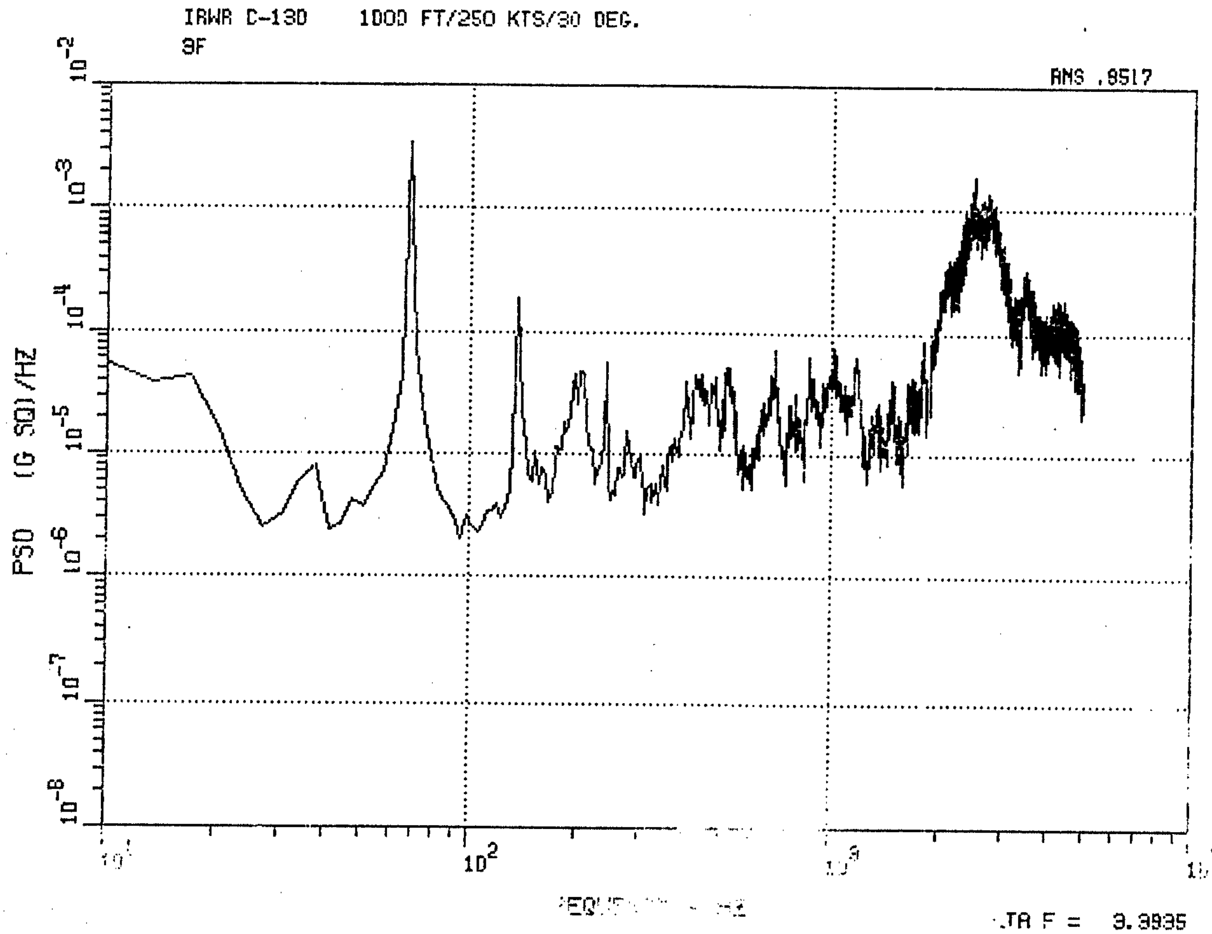


Figure 17. C-130 Fwd Vertical Accelerometer 3F, 5000 Ft, 130 Kt, 0 Deg, and 200 Ft, 250 Kt, 30 Deg.



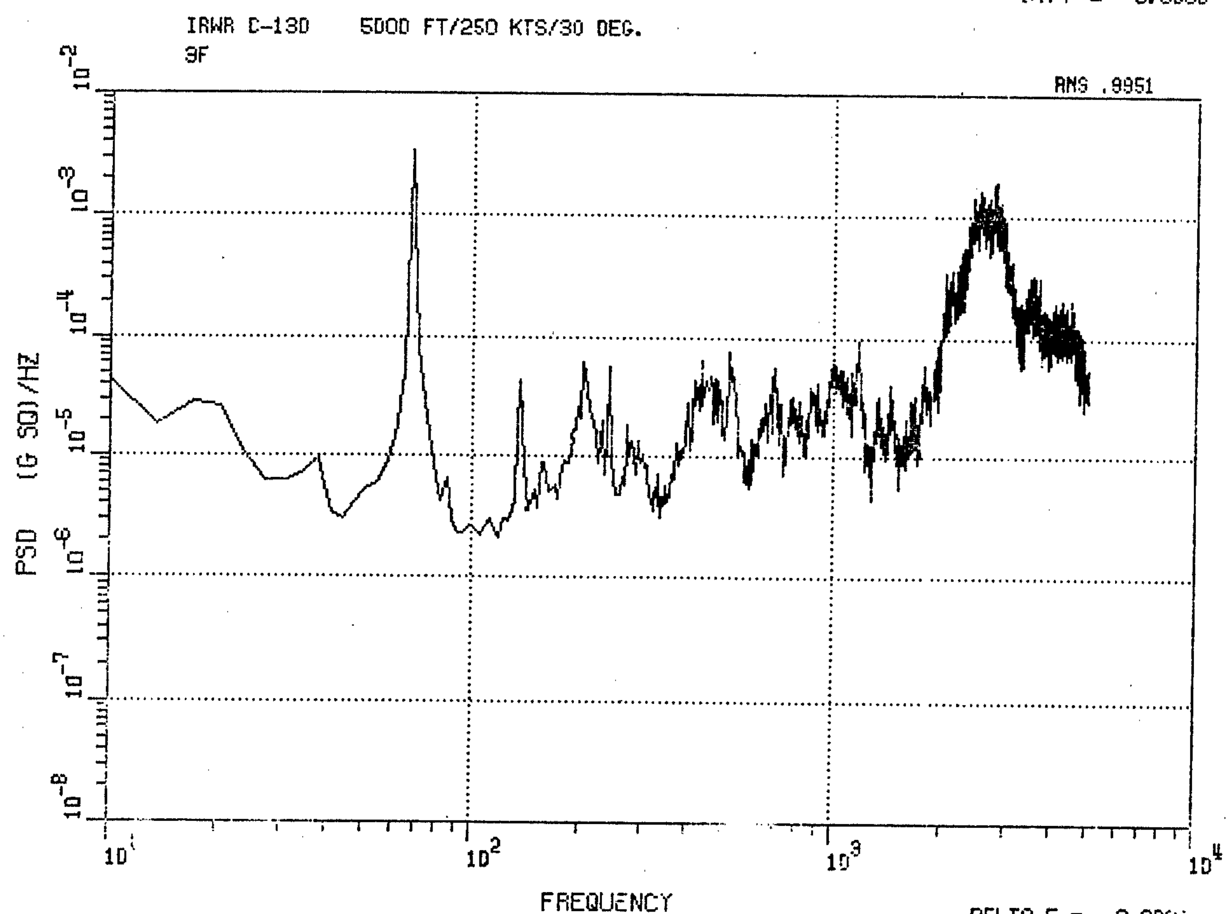


Figure 18. C-130 Fwd Vertical Accelerometer 3F, 1000 Ft, 250 Kt, 30 Deg, and 5000 Ft, 250 Kt, 30 Deg.

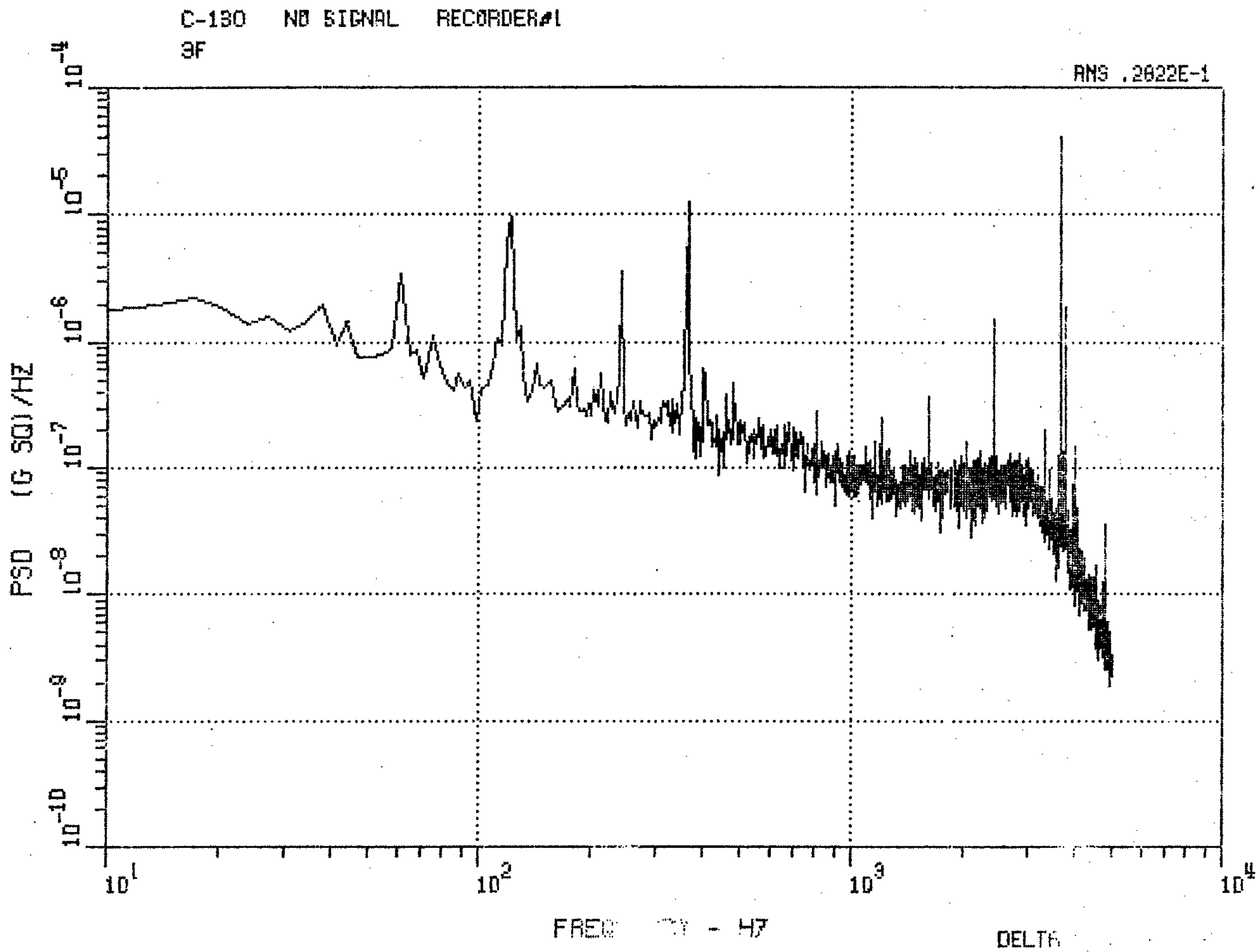
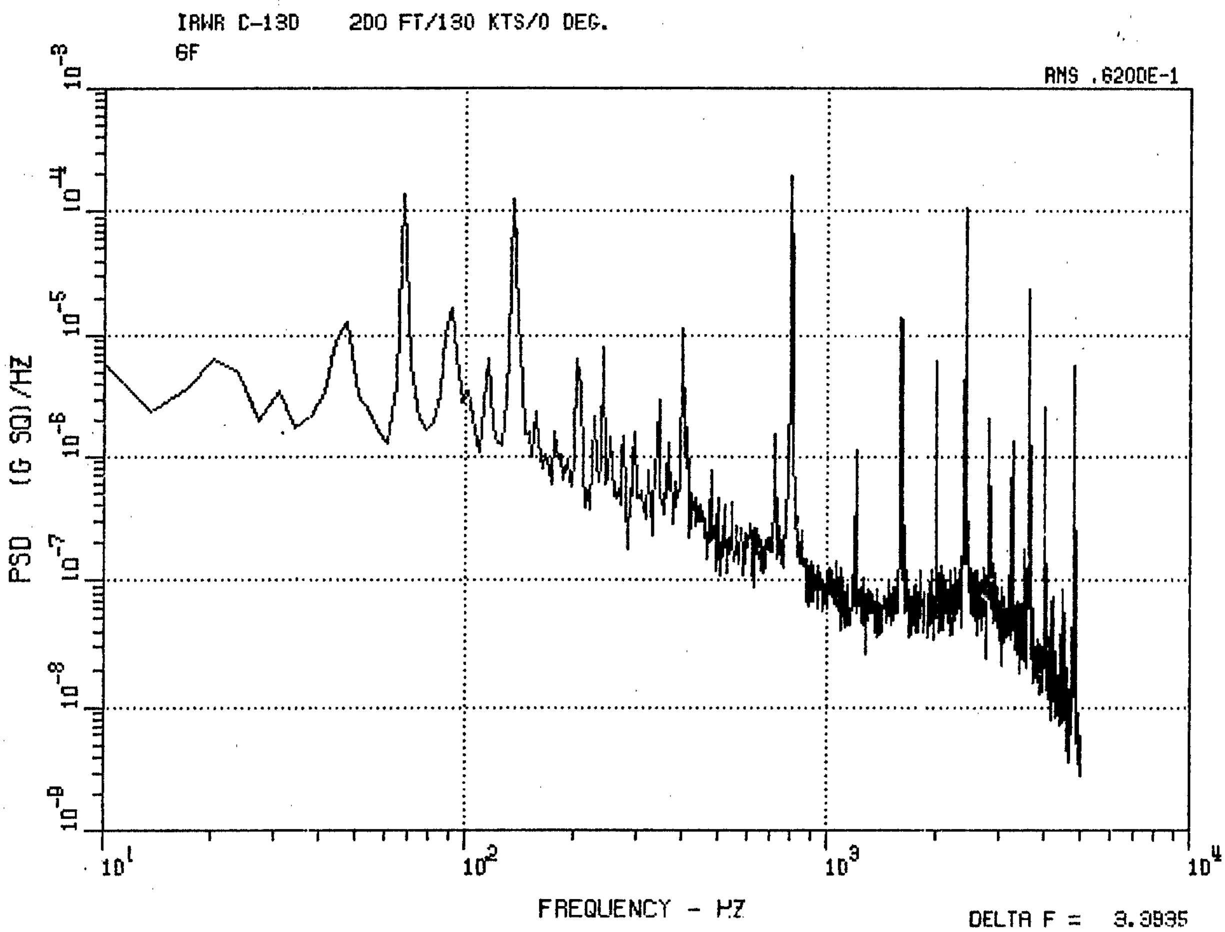


Figure 19. C-130 Fwd Vertical Accelerometer 3F, No-Signal Record.



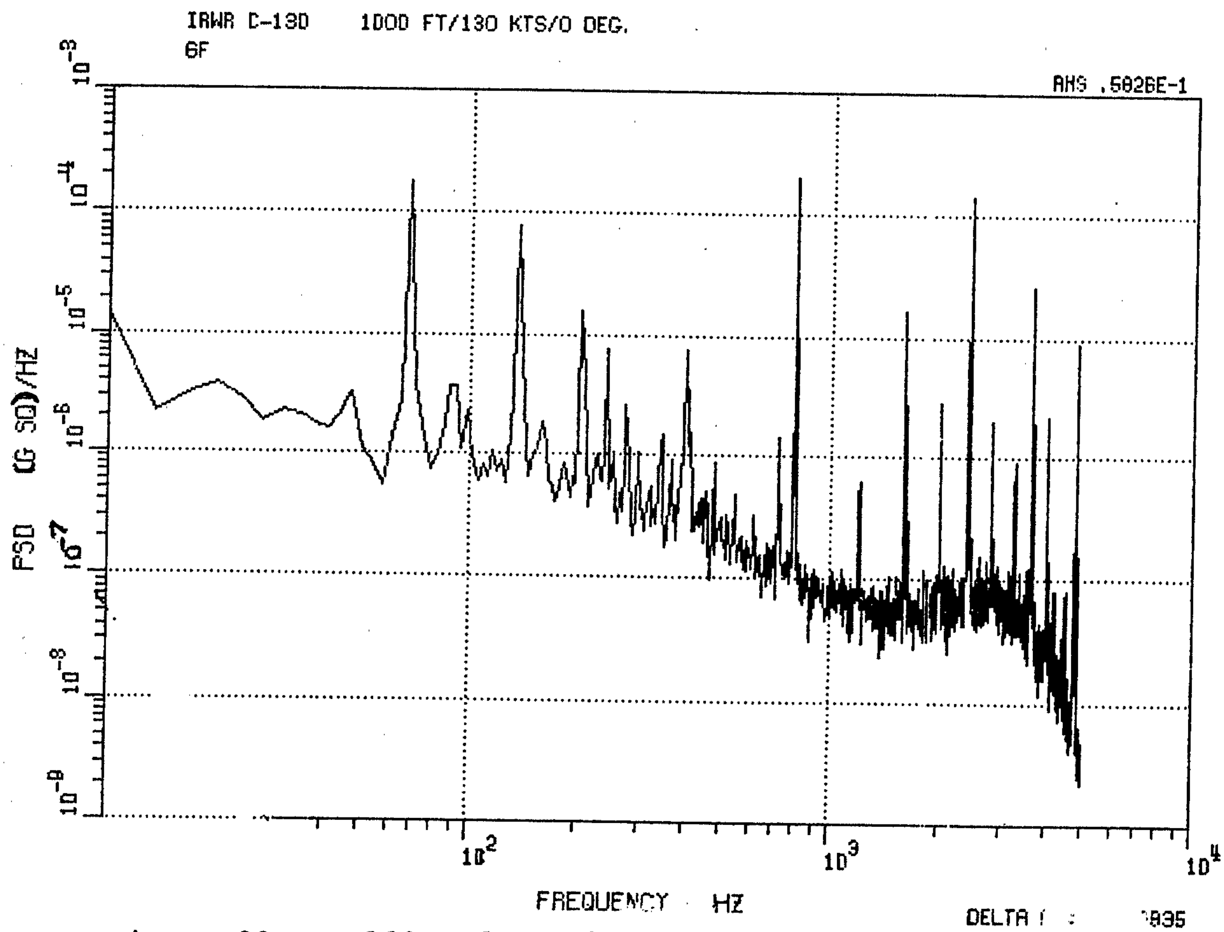
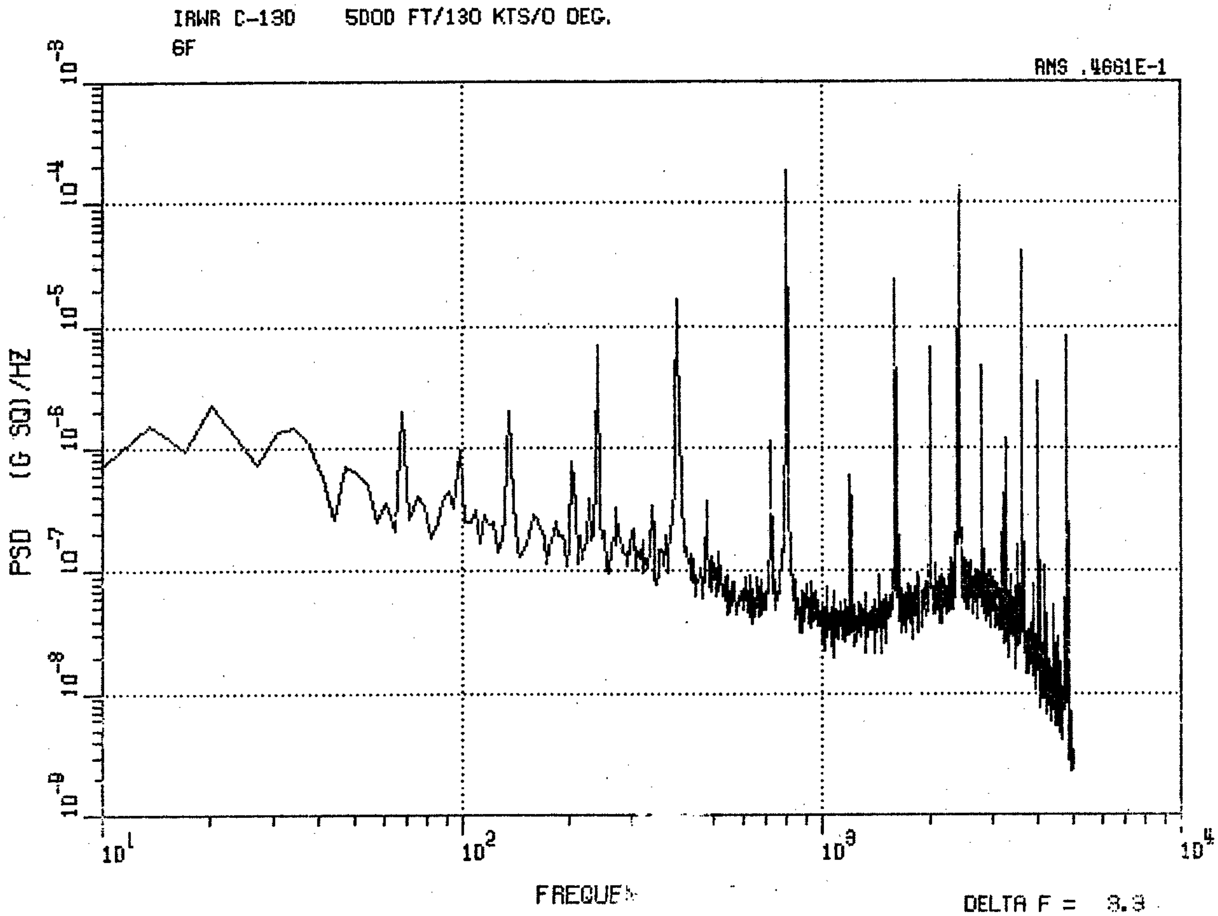


Figure 20. C-130 Fwd Longitudinal Accelerometer 6F, 200 Ft, 130 Kt, 0 Deg, and 1000 Ft, 130 Kt, 0 Deg.



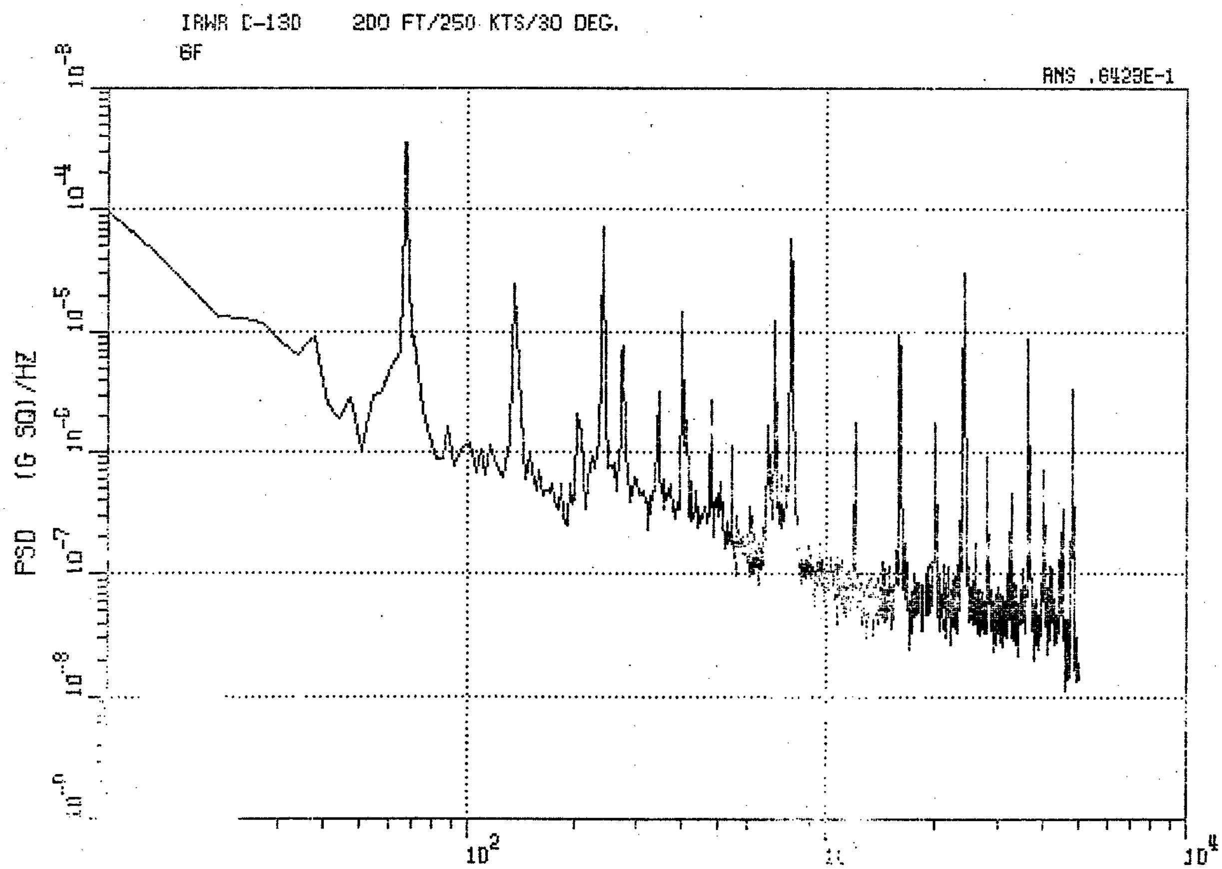
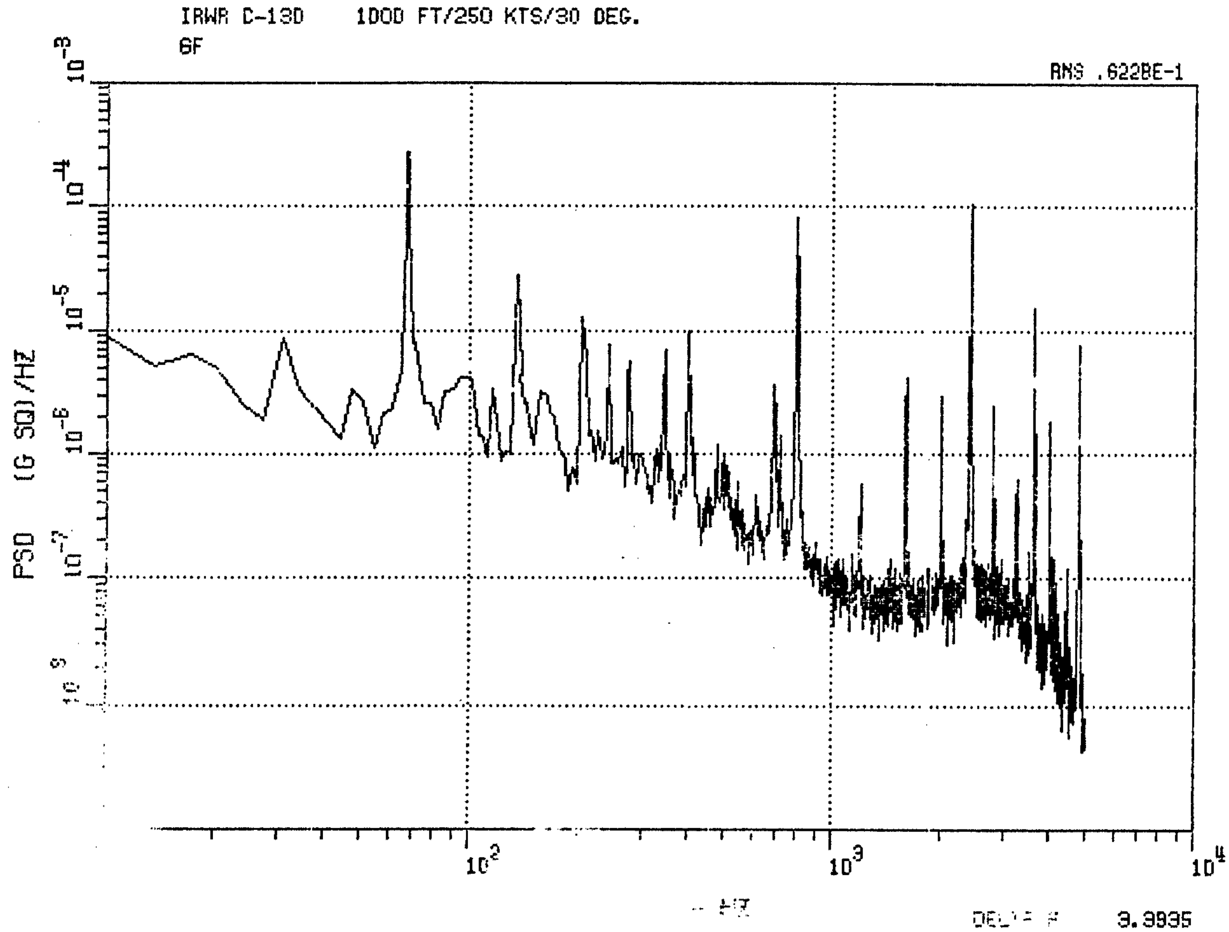


Figure 21. C-130 Fwd Longitudinal Accelerometer 6F, 5000 Ft, 130 Kt, 0 Deg, and 200 Ft, 250 Kt, 30 Deg.



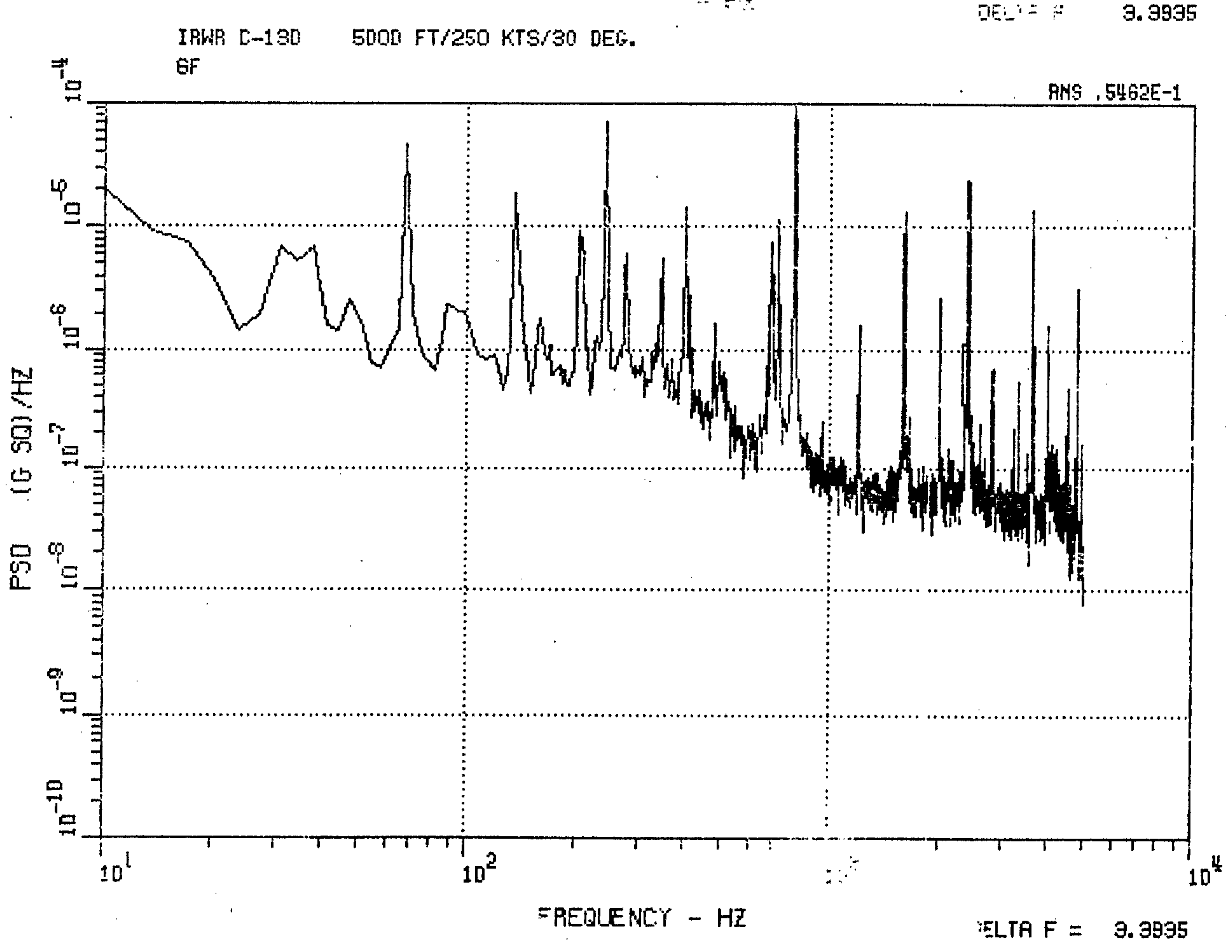


Figure 22. C-130 Fwd Longitudinal Accelerometer 6F, 1000 Ft, 250 Kt, 30 Deg, and 5000 Ft, 250 Kt, 30 Deg.

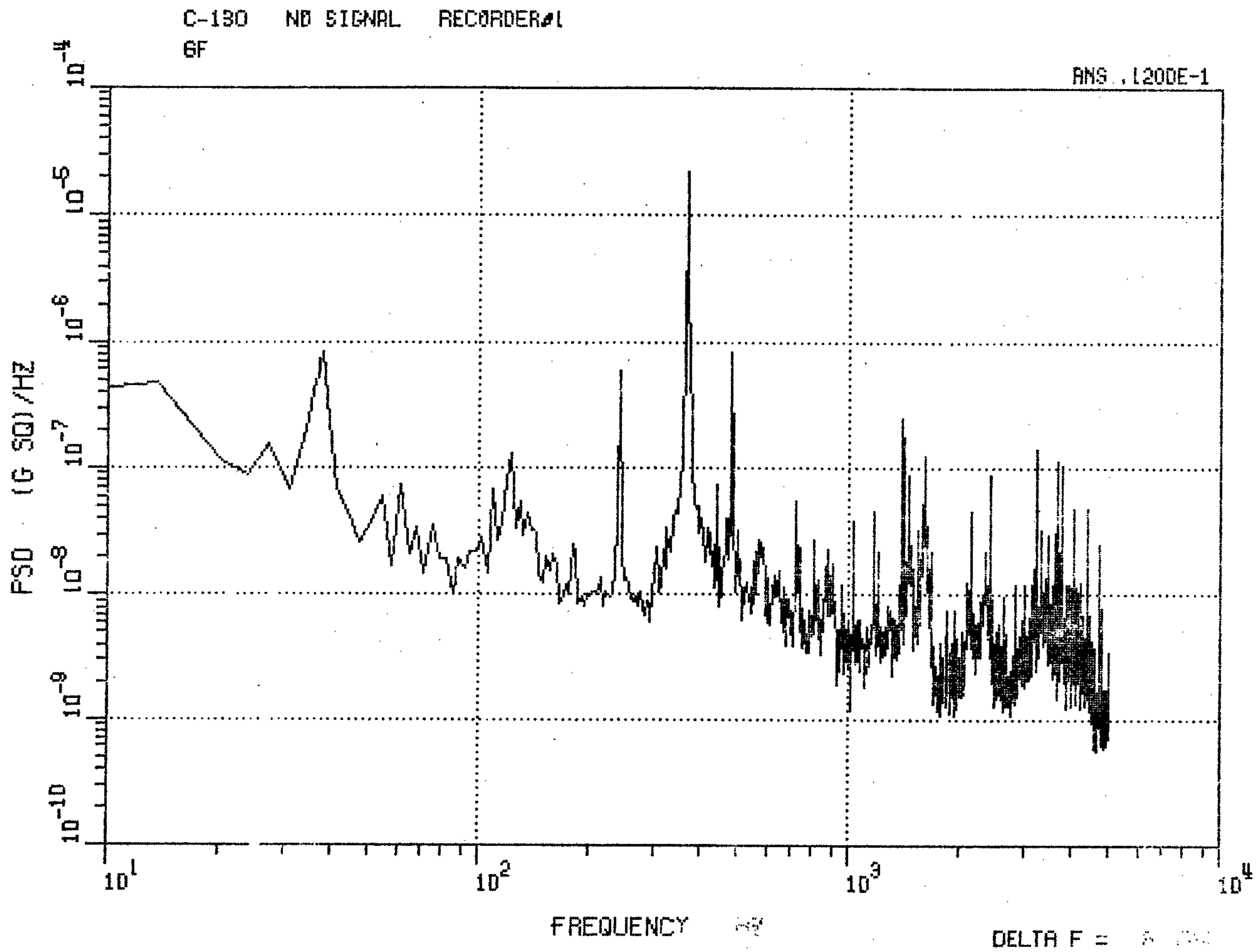
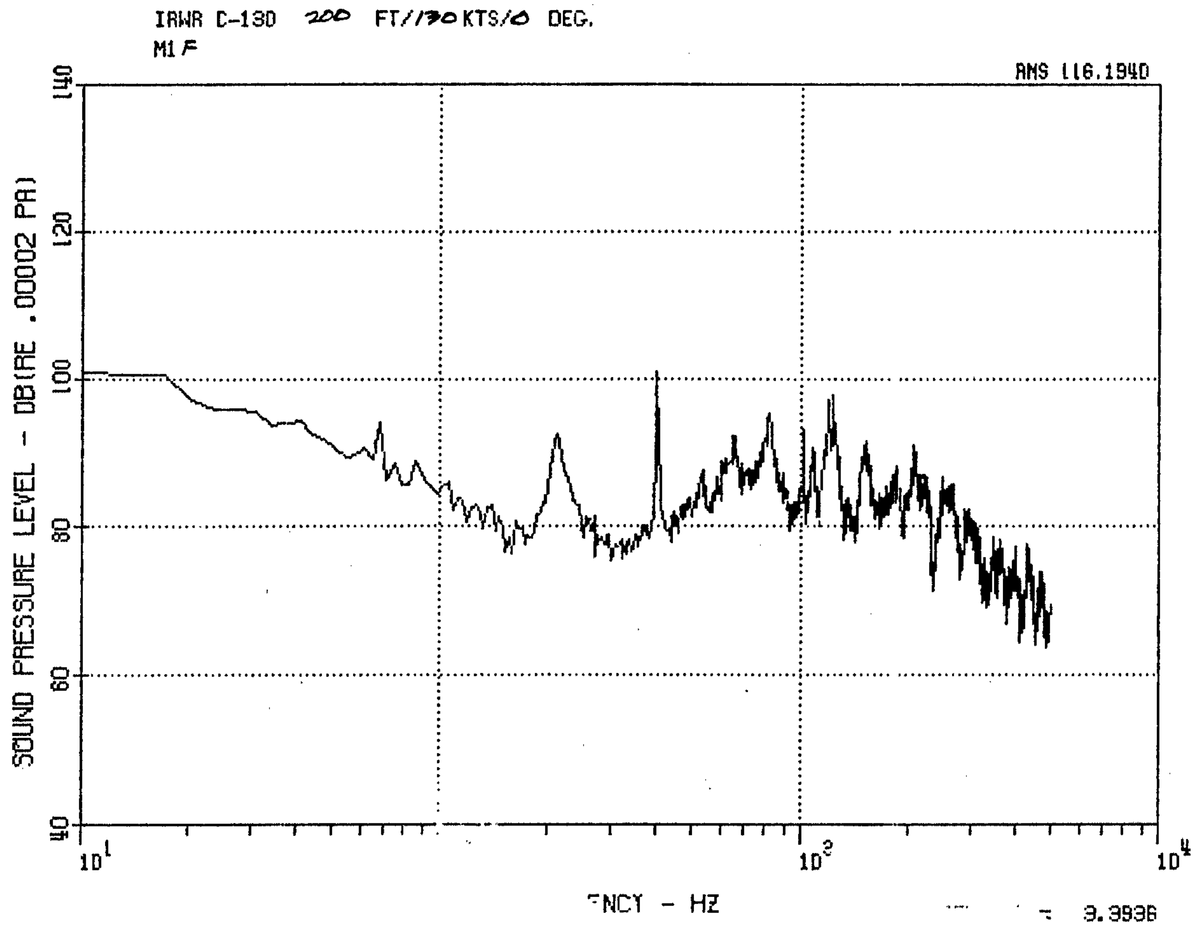


Figure 23. C-130 Fwd Longitudinal Accelerometer 6F, No-Signal Record.



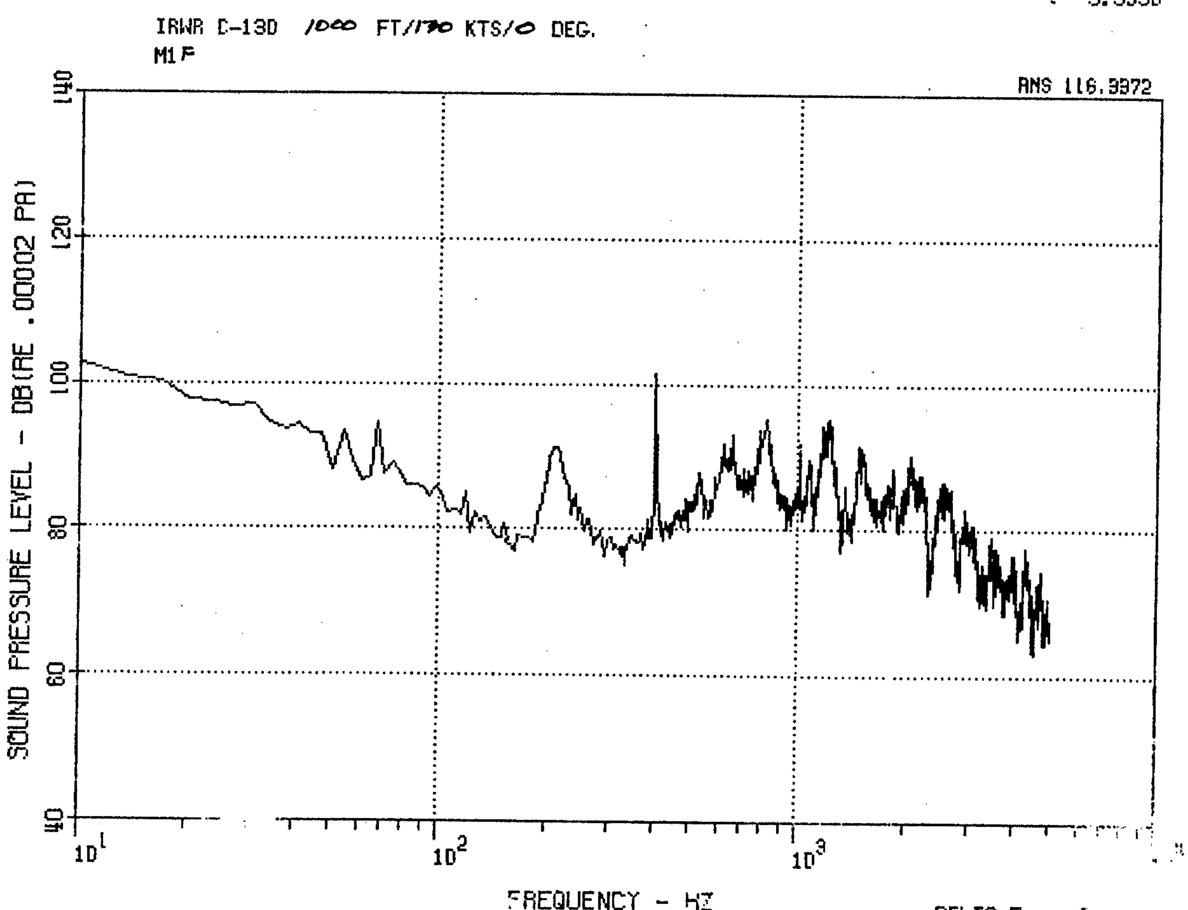


Figure 24. C-130 Fwd Microphone MF, 200 Ft, 130 Kt, 0 Deg, and 1000 Ft, 130 Kt, 0 Deg.

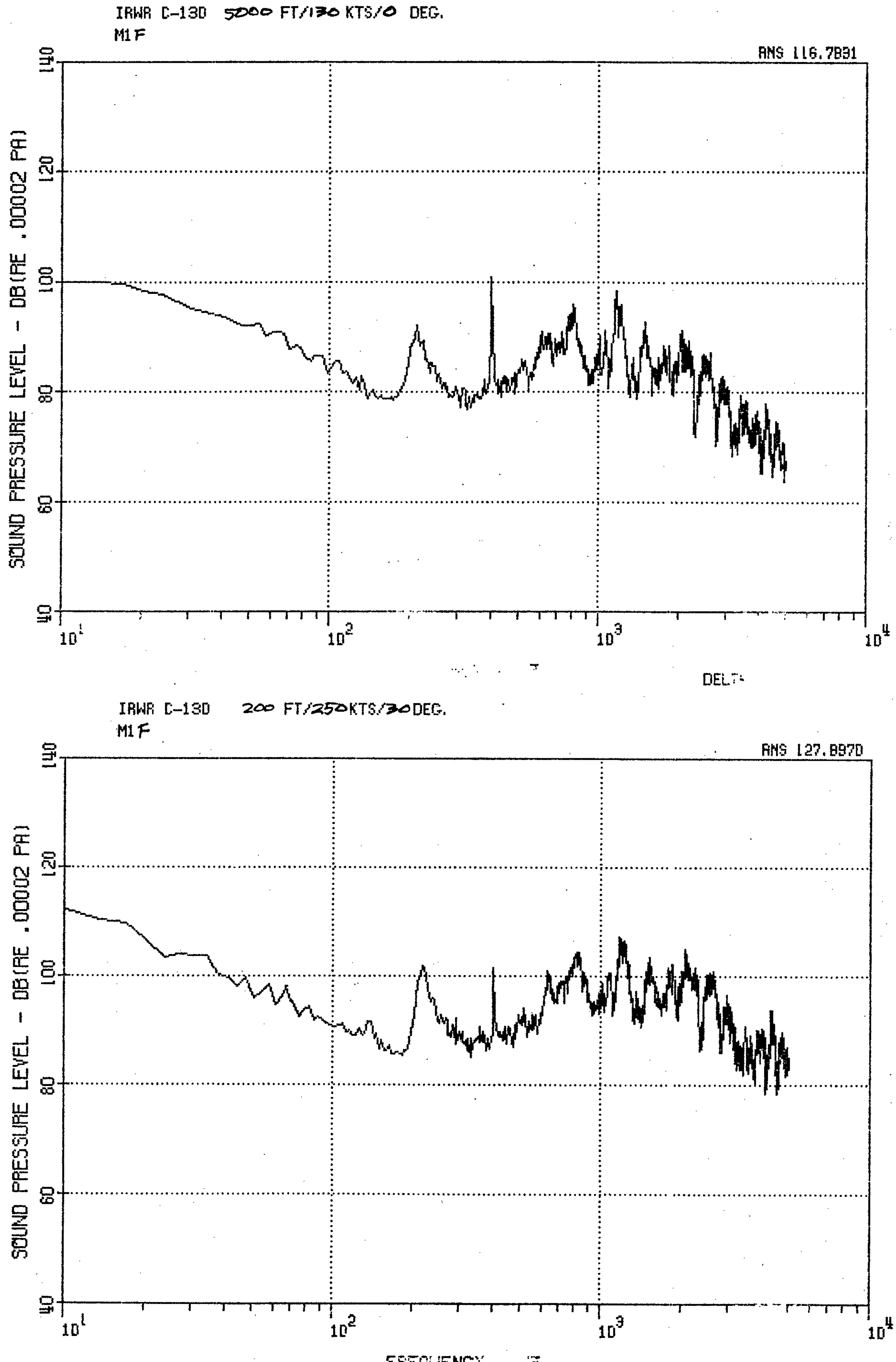


Figure 25. C-130 Fwd Microphone MF, 5000 Ft, 130 Kt, 0 Deg, and 200 Ft, 250 Kt, 30 Deg.

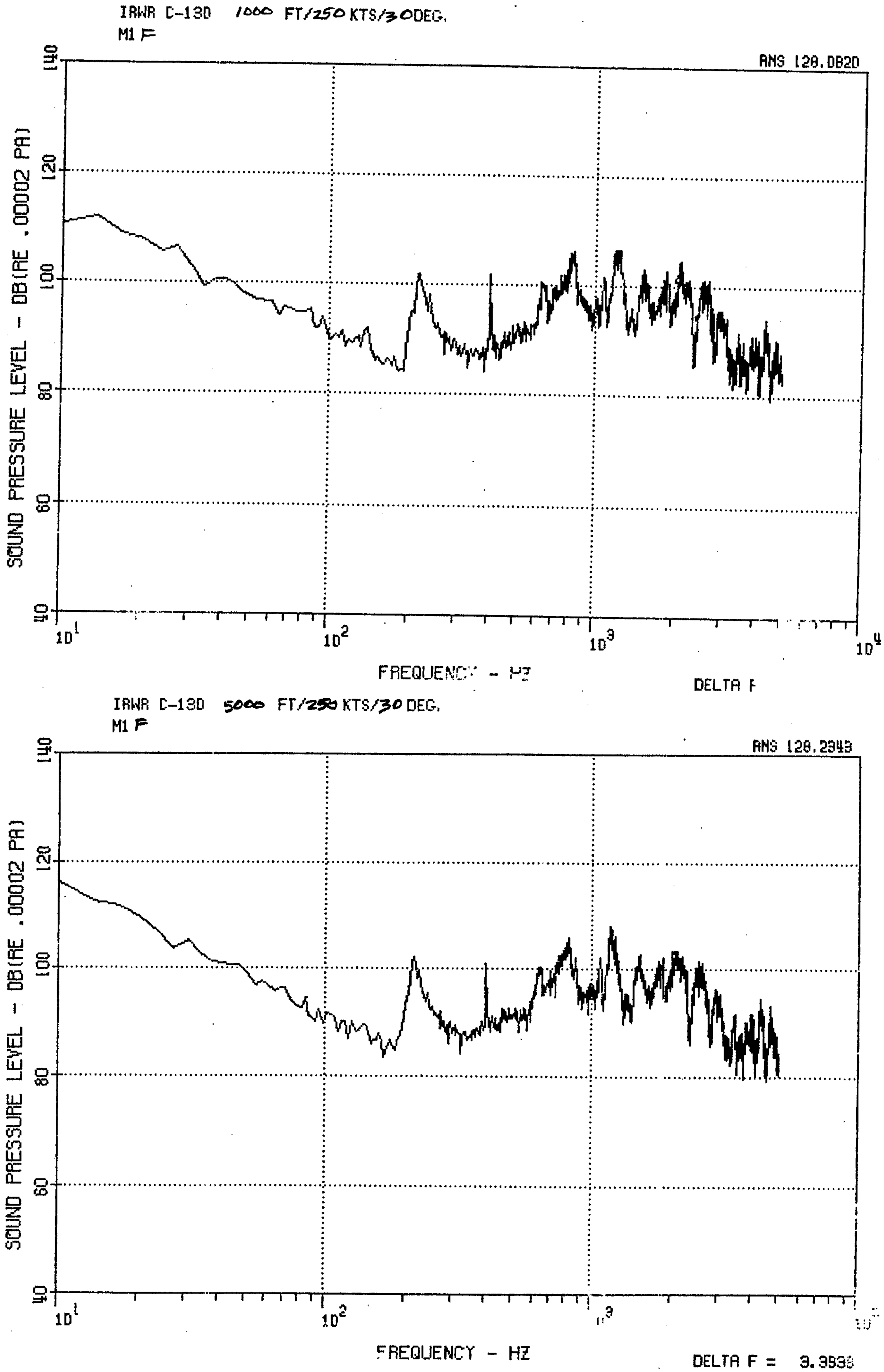


Figure 26. C-130 Fwd Microphone MF, 1000 Ft, 250 Kt, 30 Deg, and 5000 Ft, 250 Kt, 30 Deg.

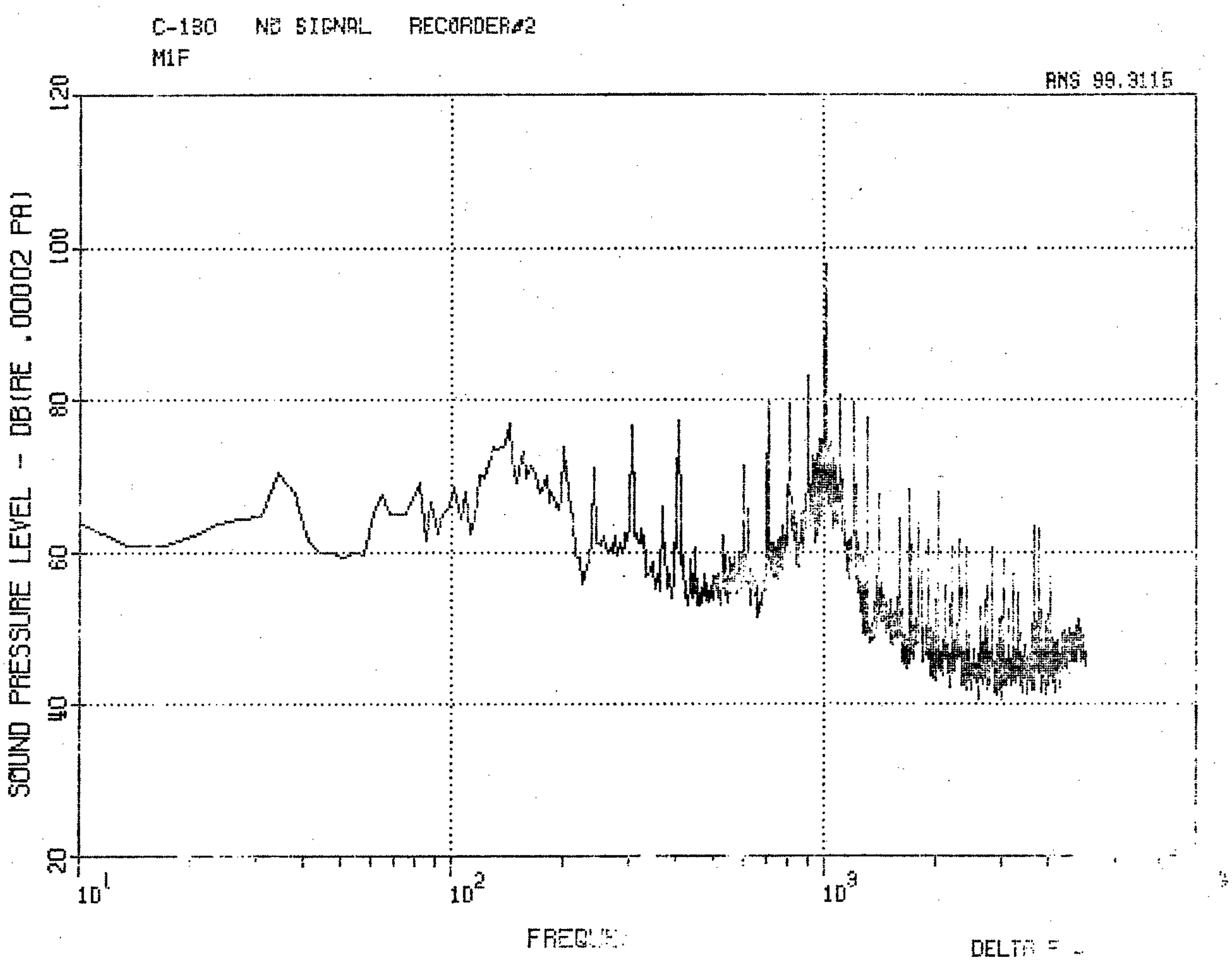


Figure 27. C-130 Fwd Microphone MF, No-Signal Record.

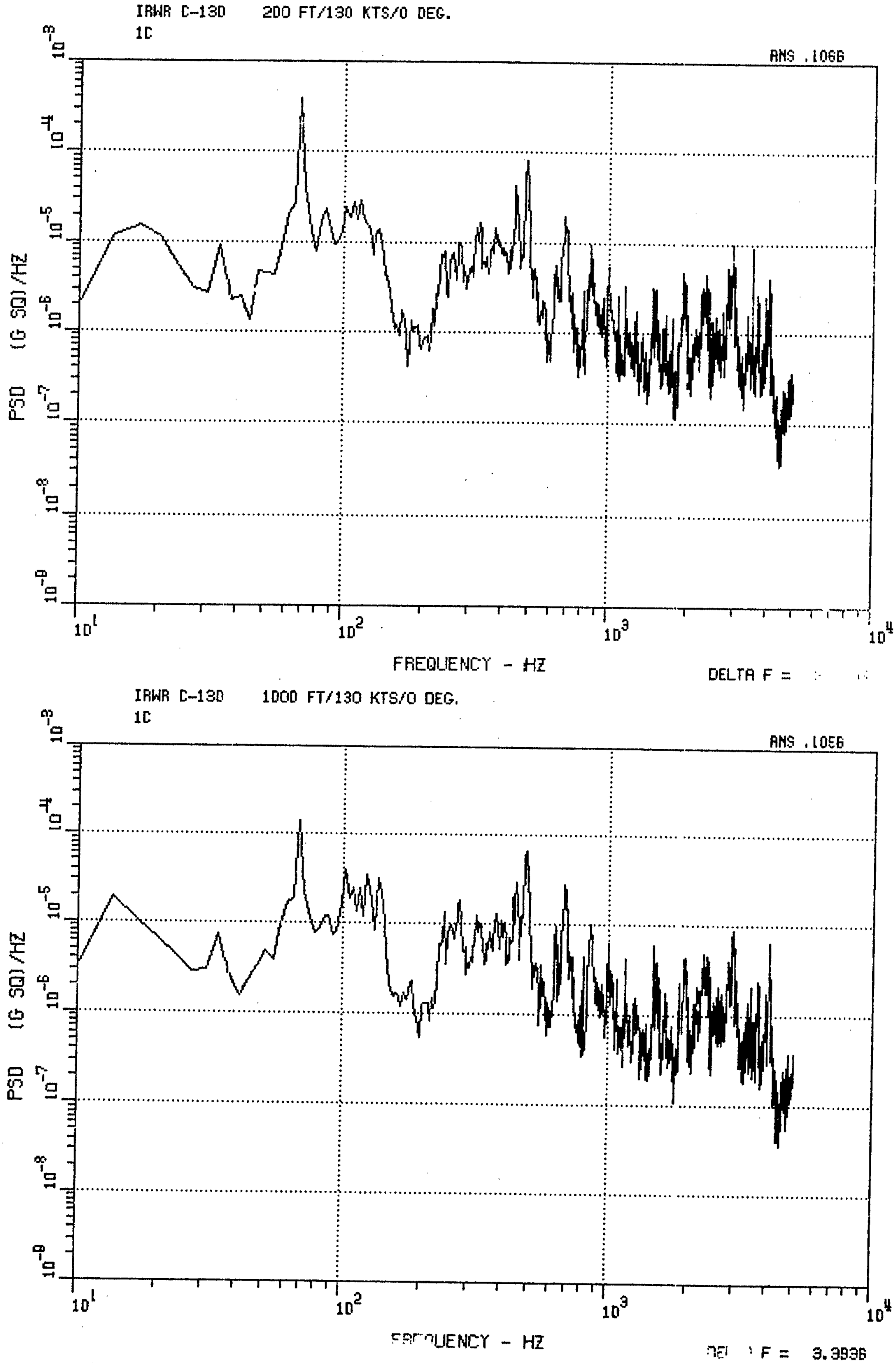
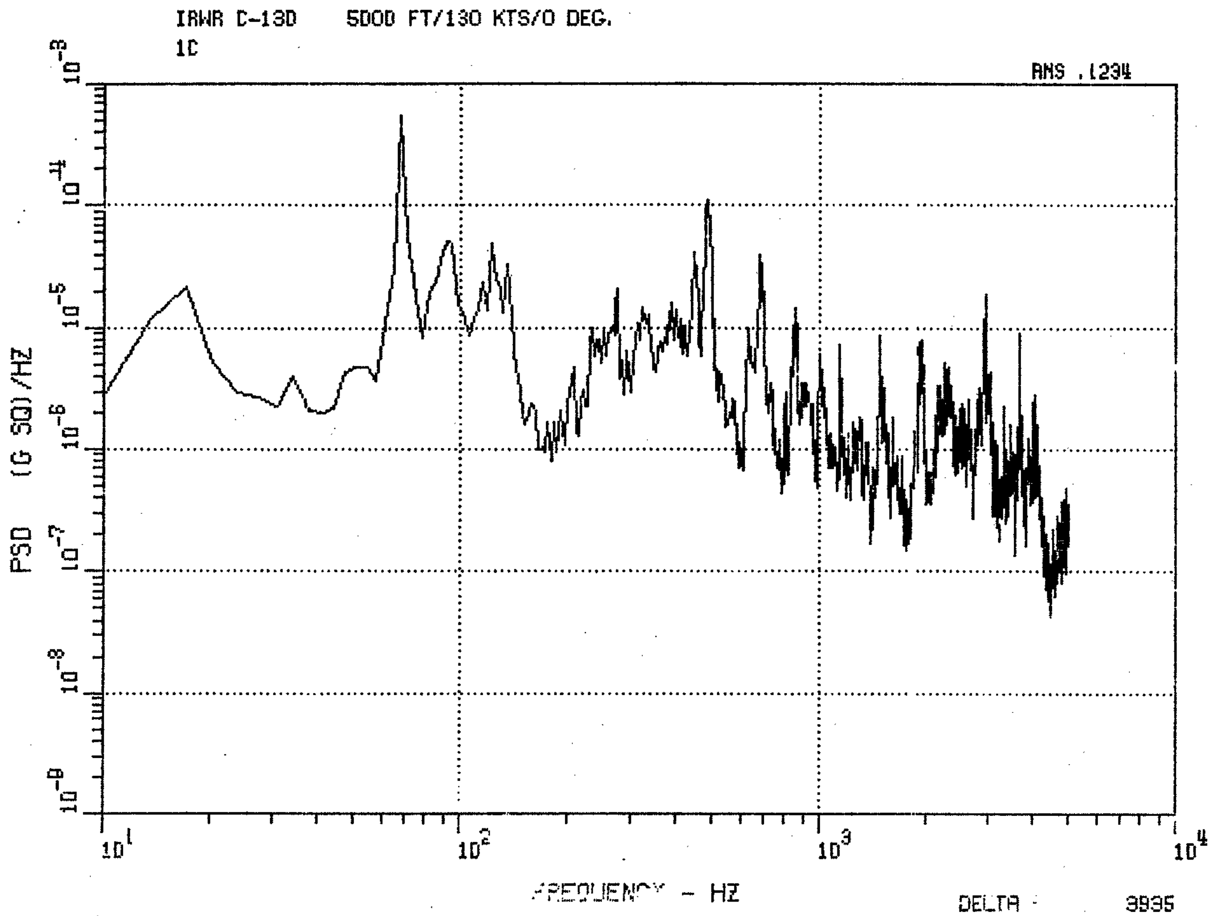


Figure 28. C-130 Center Vertical Accelerometer 1C, 200 Ft, 130 Kt, 0 Deg, and 1000 Ft, 130 Kt, 0 Deg.



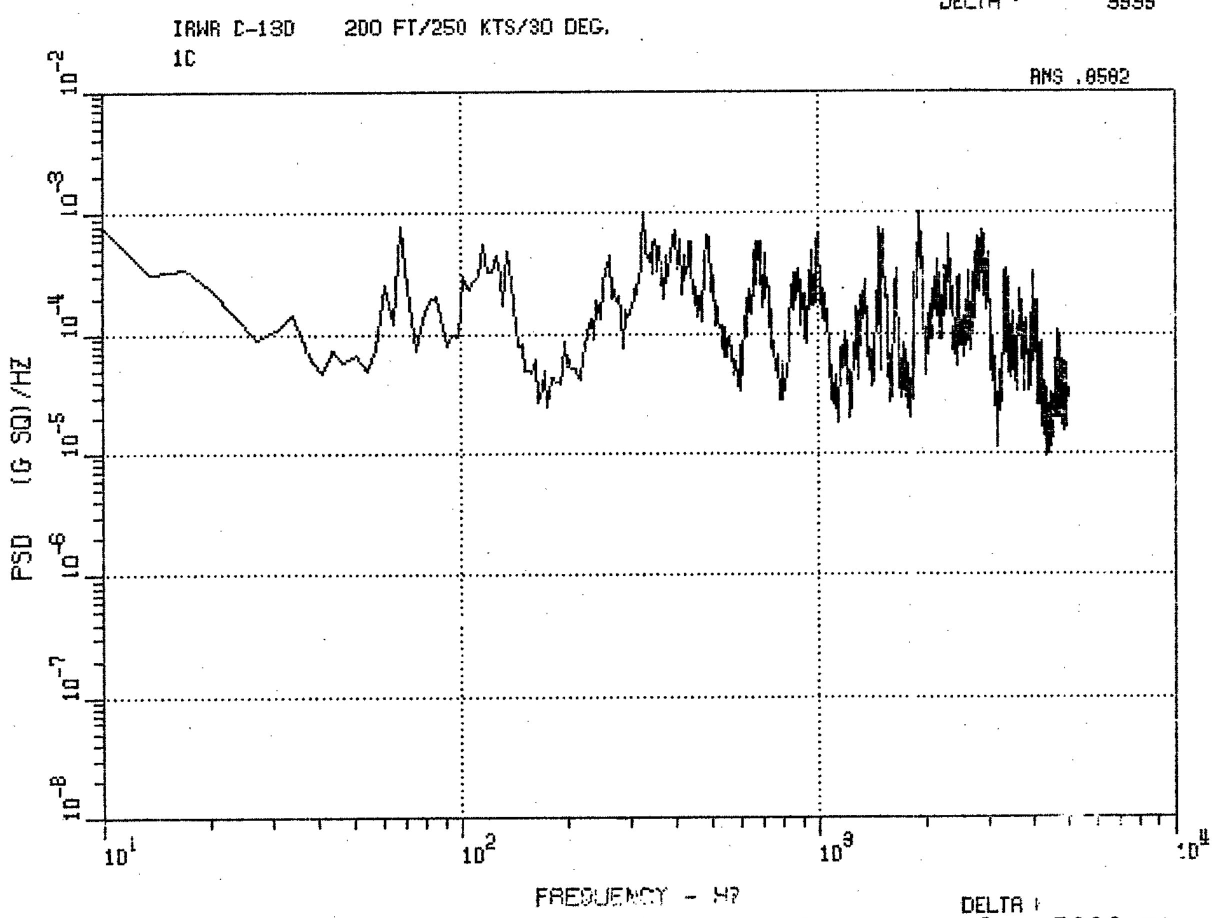


Figure 29. C-130 Center Vertical Accelerometer 1C, 5000 Ft, 130 Kt, 0 Deg, and 200 Ft, 250 Kt, 30 Deg.

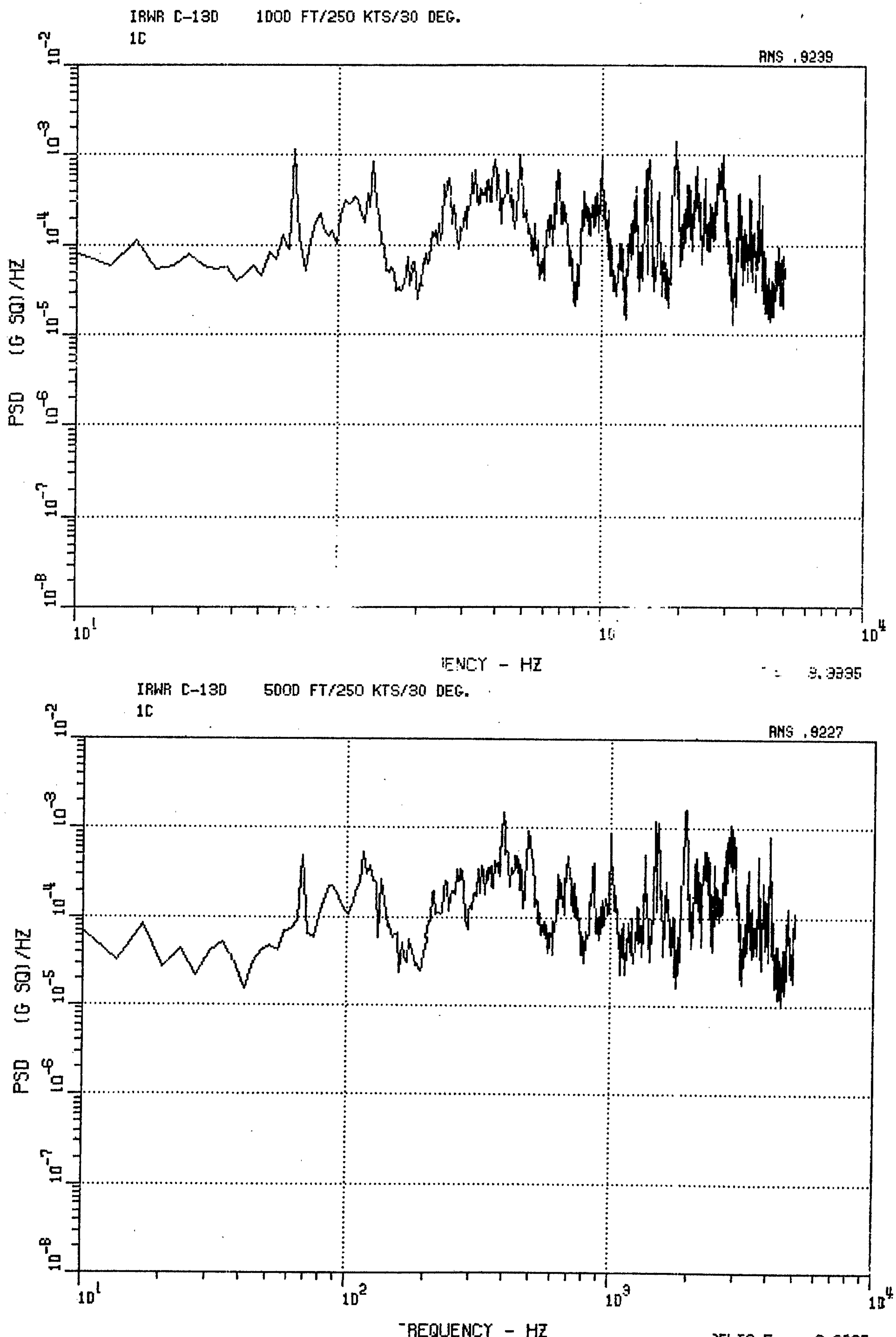


Figure 30. C-130 Center Vertical Accelerometer 1C, 1000 Ft, 250 Kt, 30 Deg, and 5000 Ft, 250 Kt, 30 Deg.

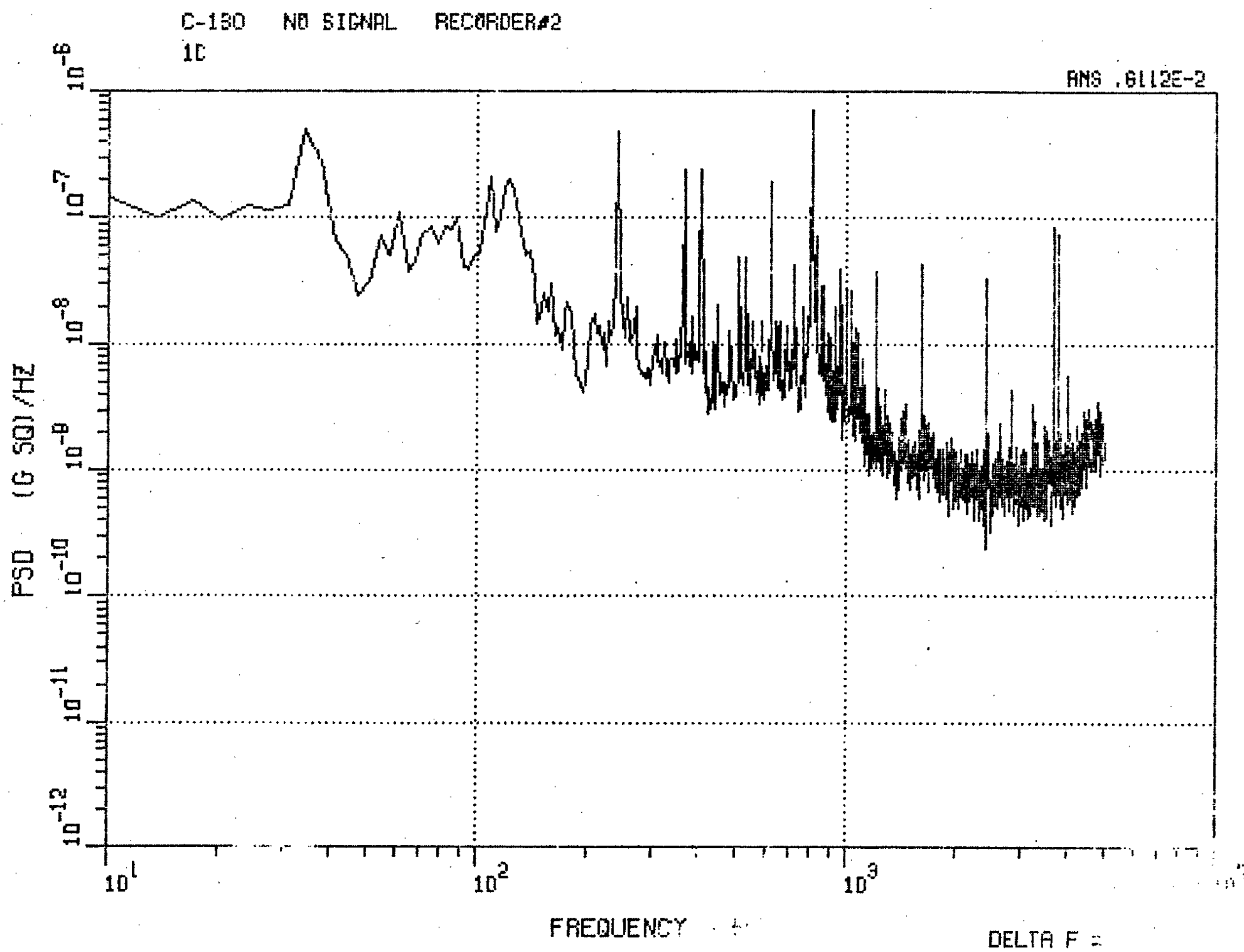
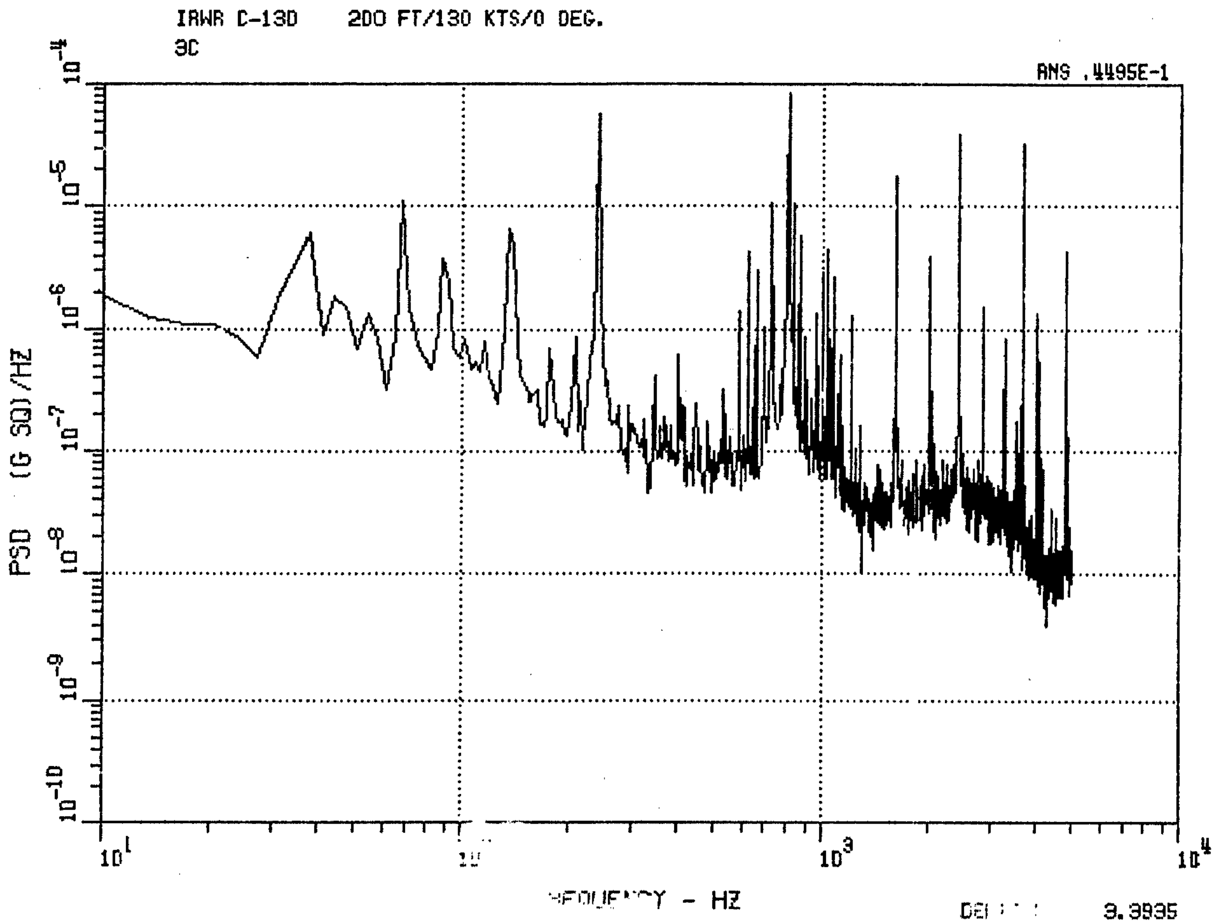


Figure 31. C-130 Center Vertical Accelerometer 1C, No-Signal Record.



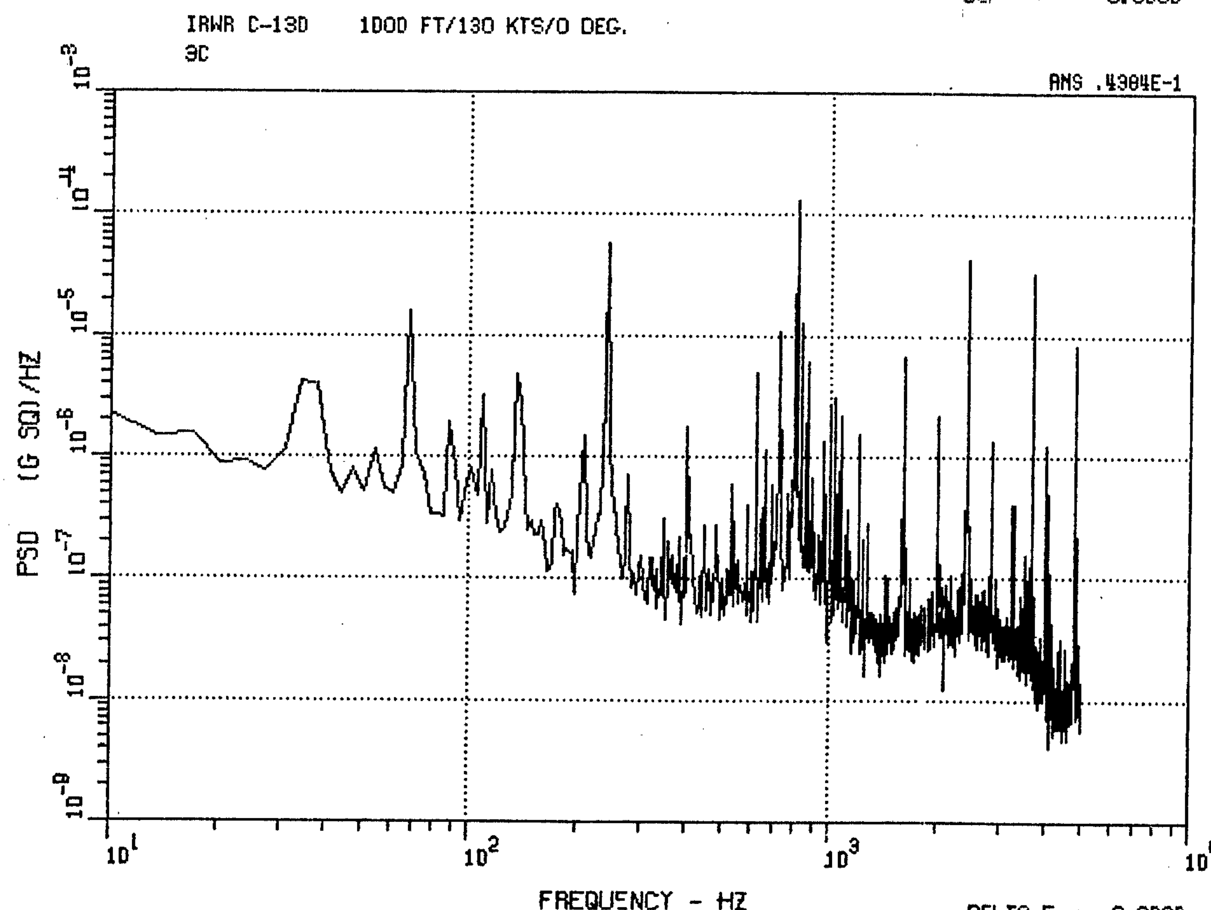


Figure 32. C-130 Center Lateral Accelerometer 3C, 200 Ft, 130 Kt, 0 Deg, and 1000 Ft, 130 Kt, 0 Deg.

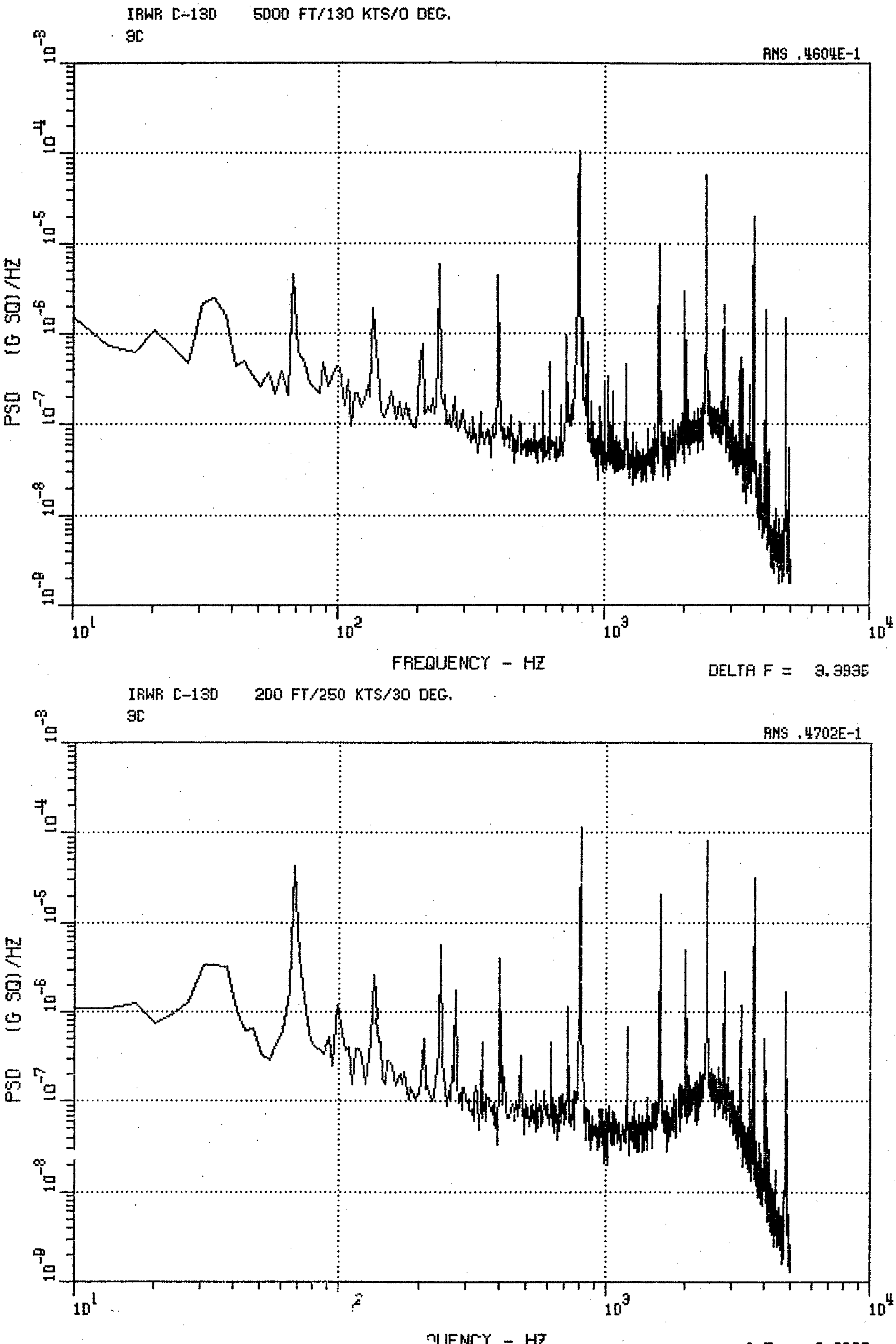
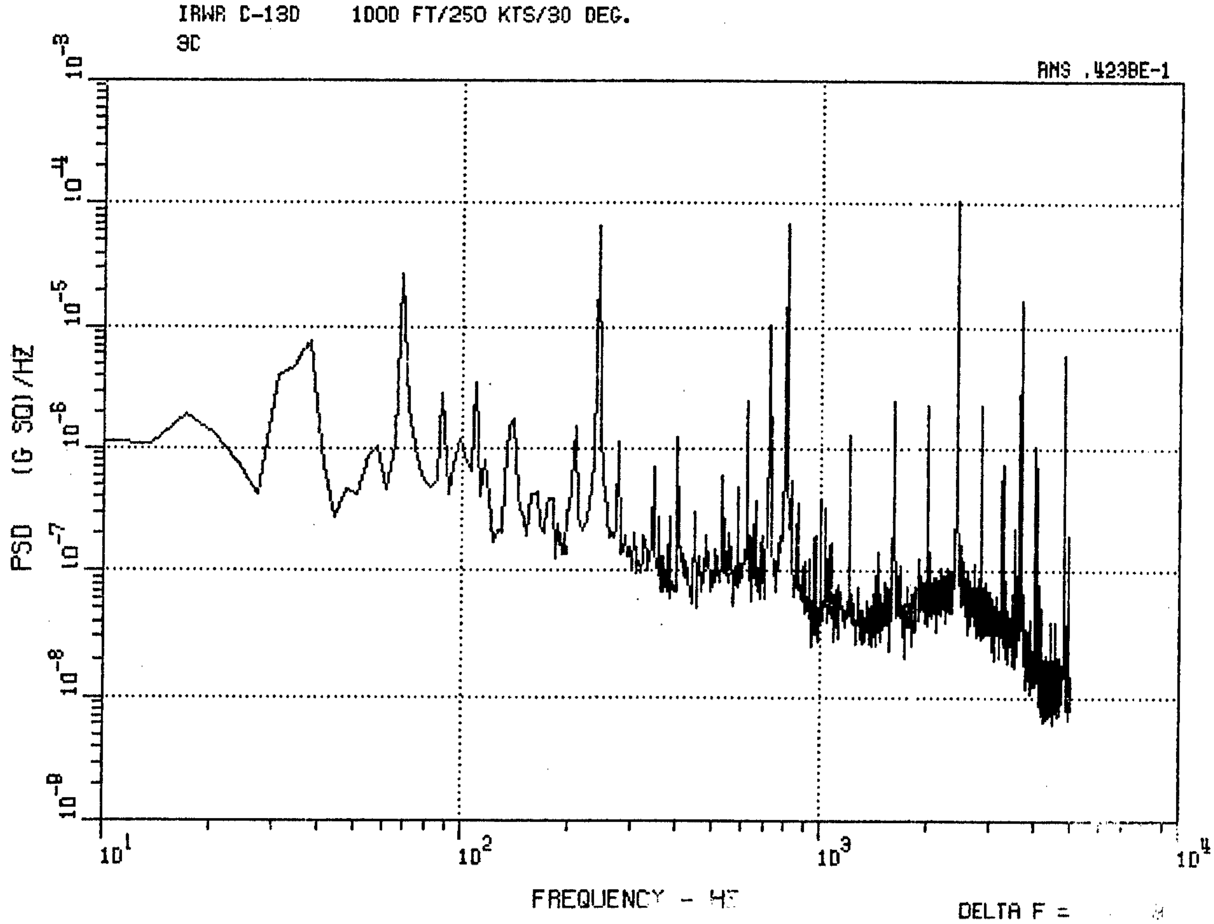


Figure 33. C-130 Center Lateral Accelerometer 3C, 5000 Ft, 130 Kt, 0 Deg, and 200 Ft, 250 Kt, 30 Deg.



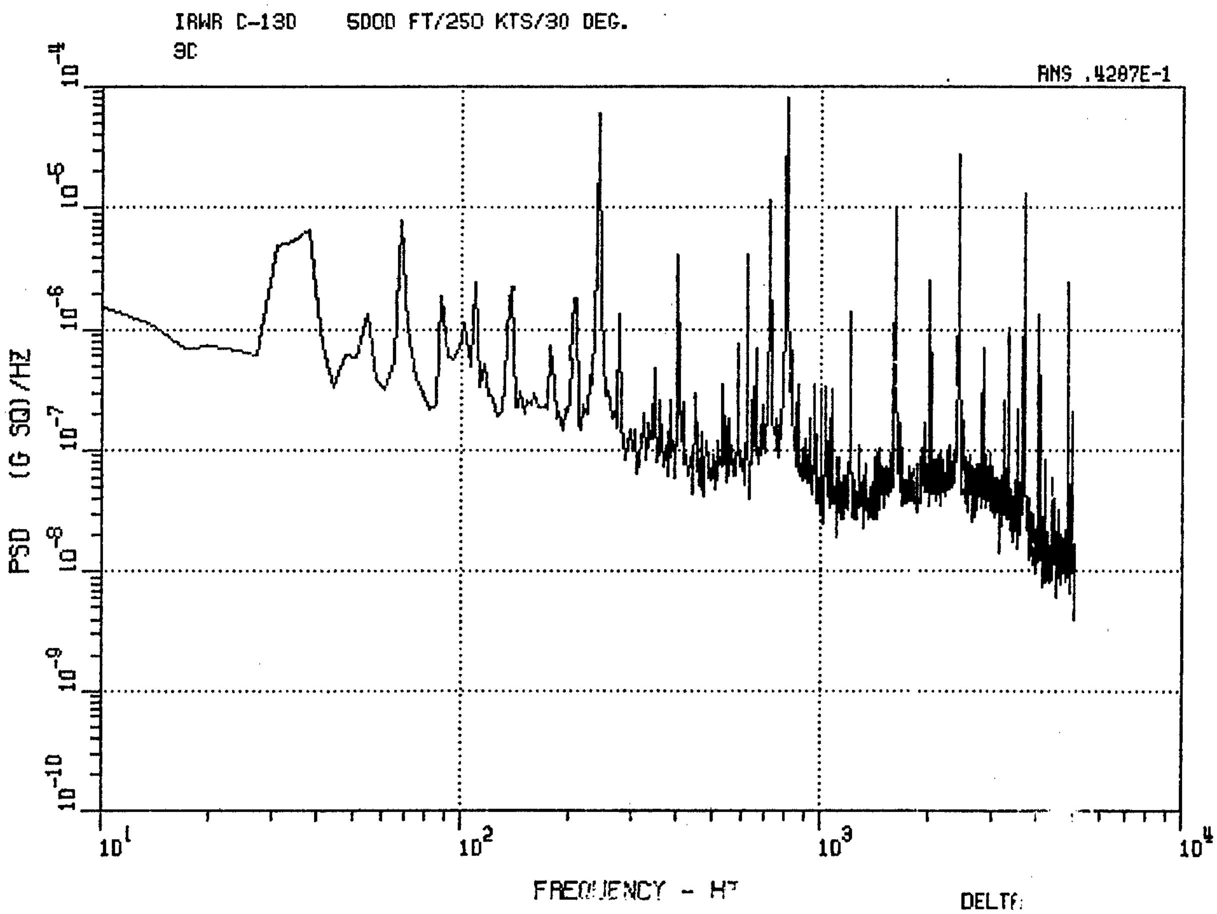


Figure 34. C-130 Center Lateral Accelerometer 3C, 1000 Ft, 250 Kt, 30 Deg, and 5000 Ft, 250 Kt, 30 Deg.

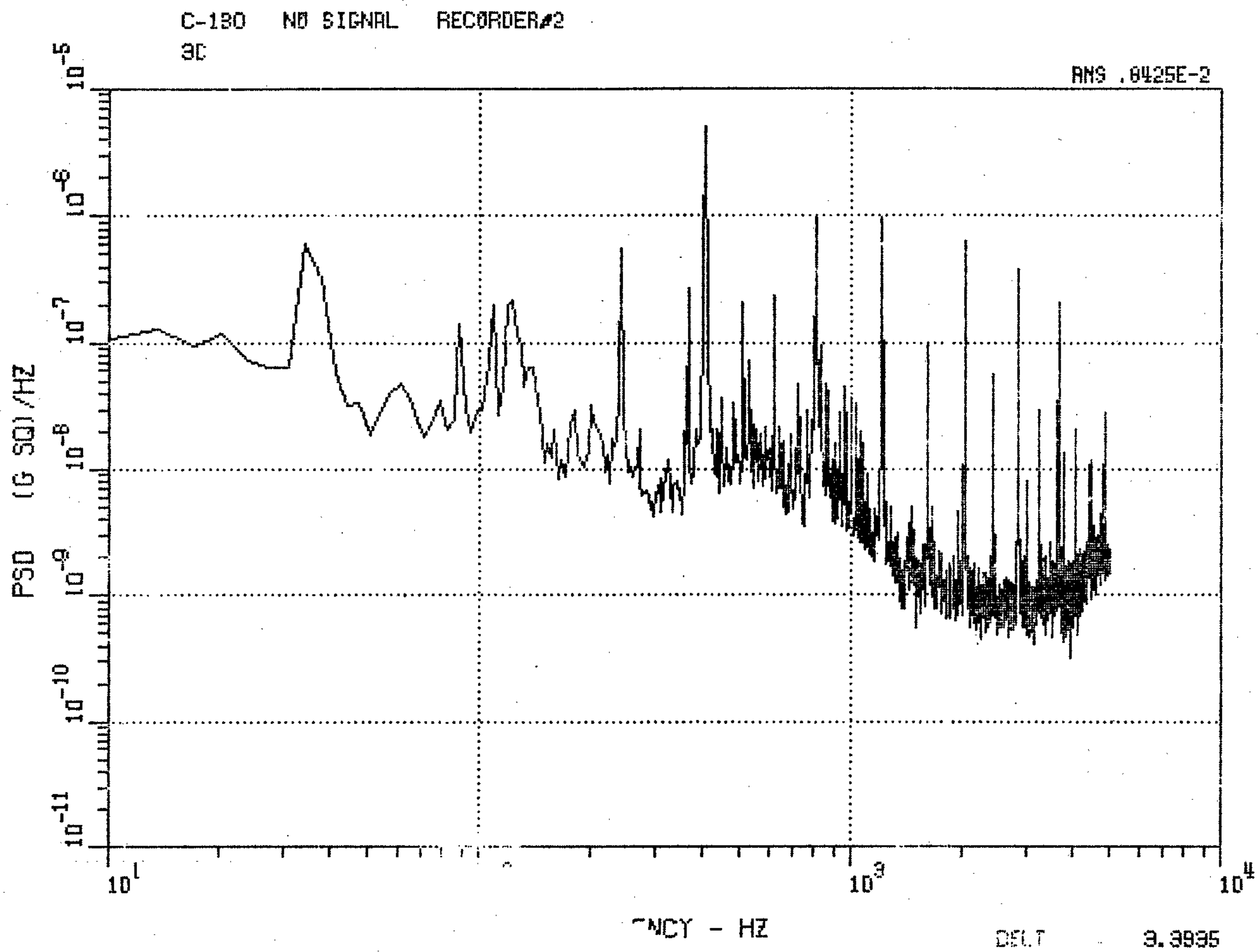


Figure 35. C-130 Center Lateral Accelerometer 3C, No-Signal Record.

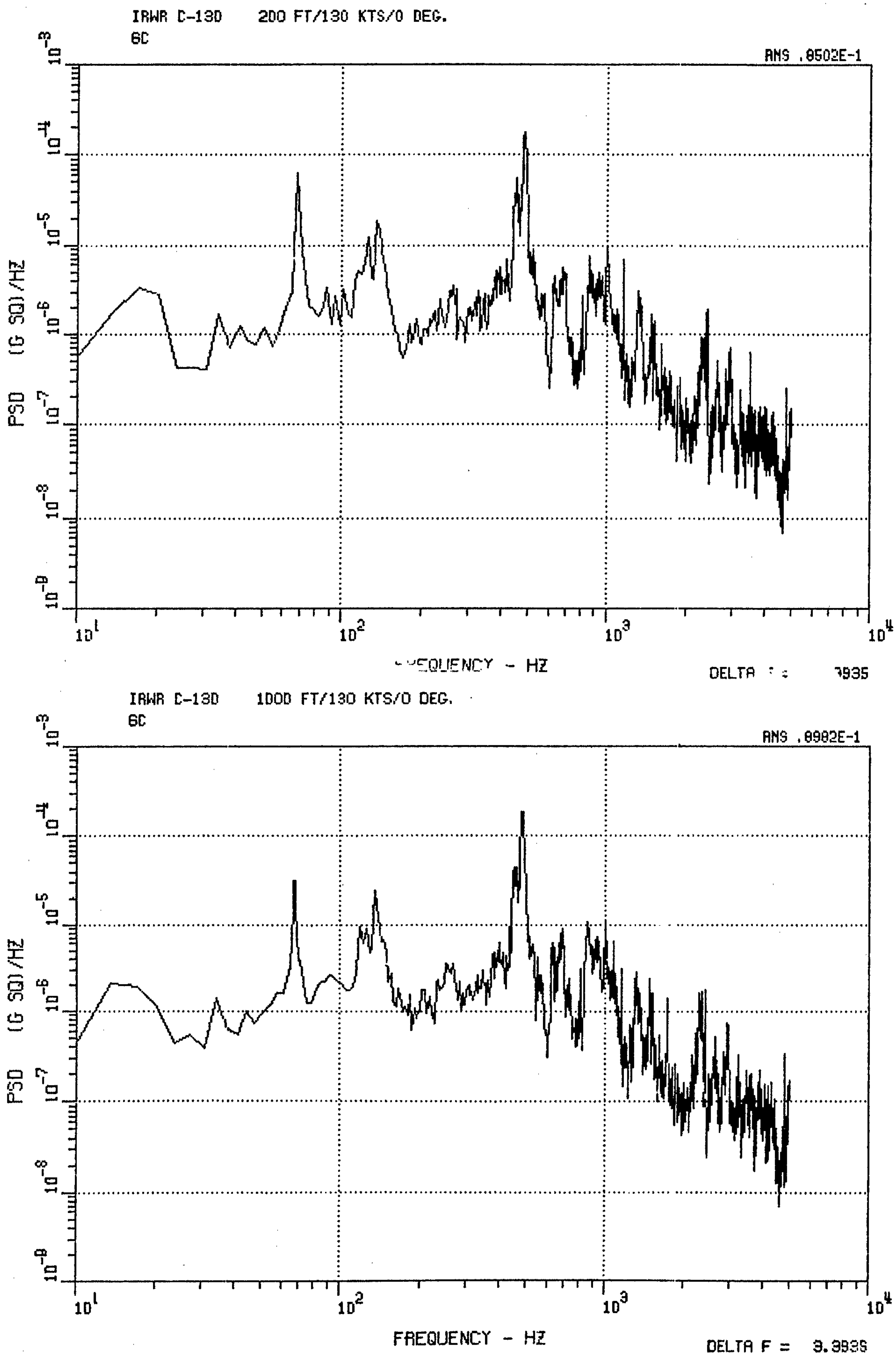


Figure 36. C-130 Center Longitudinal Accelerometer 6C, 200 Ft, 130 Kt, 0 Deg, and 1000 Ft, 130 Kt, 0 Deg.

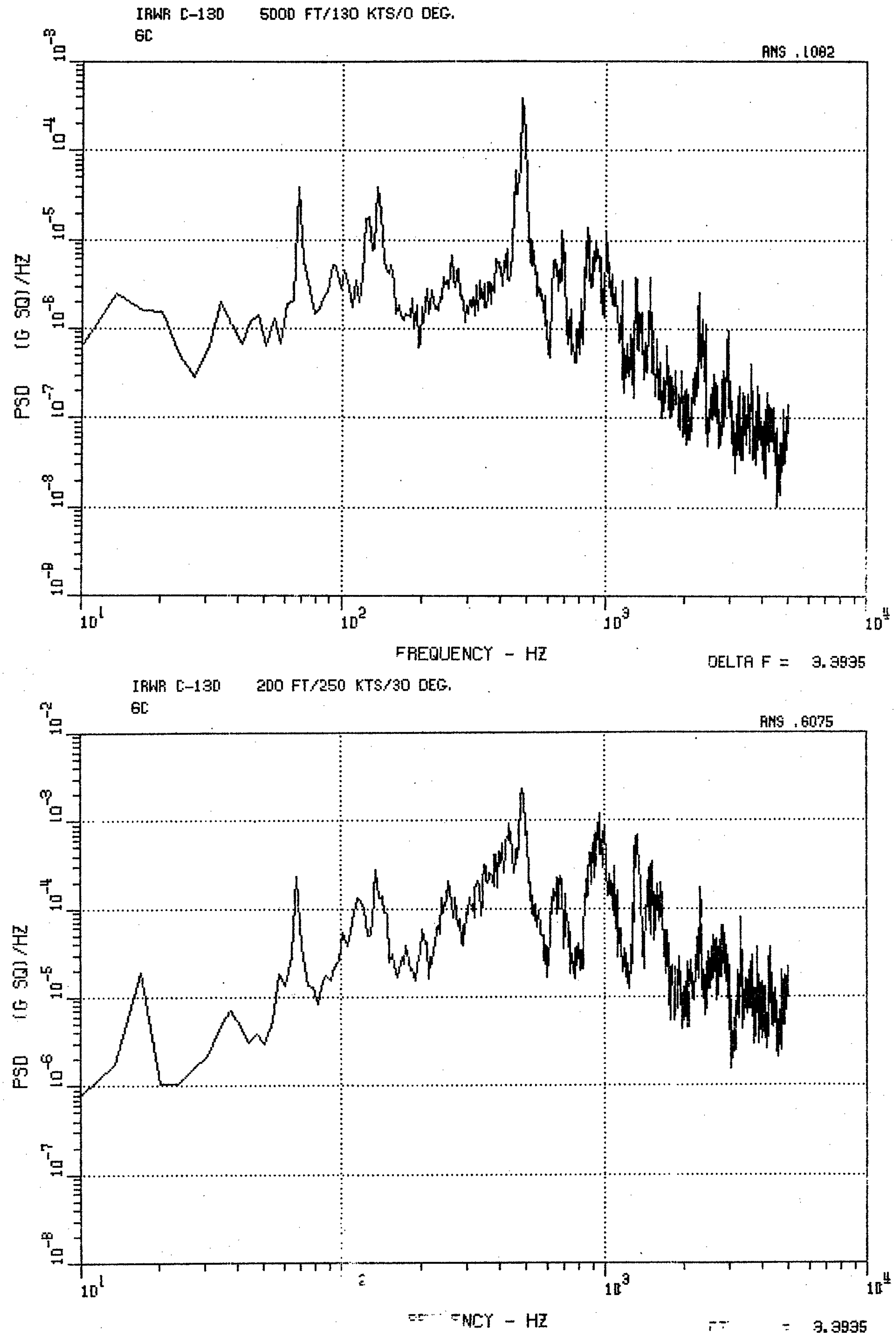
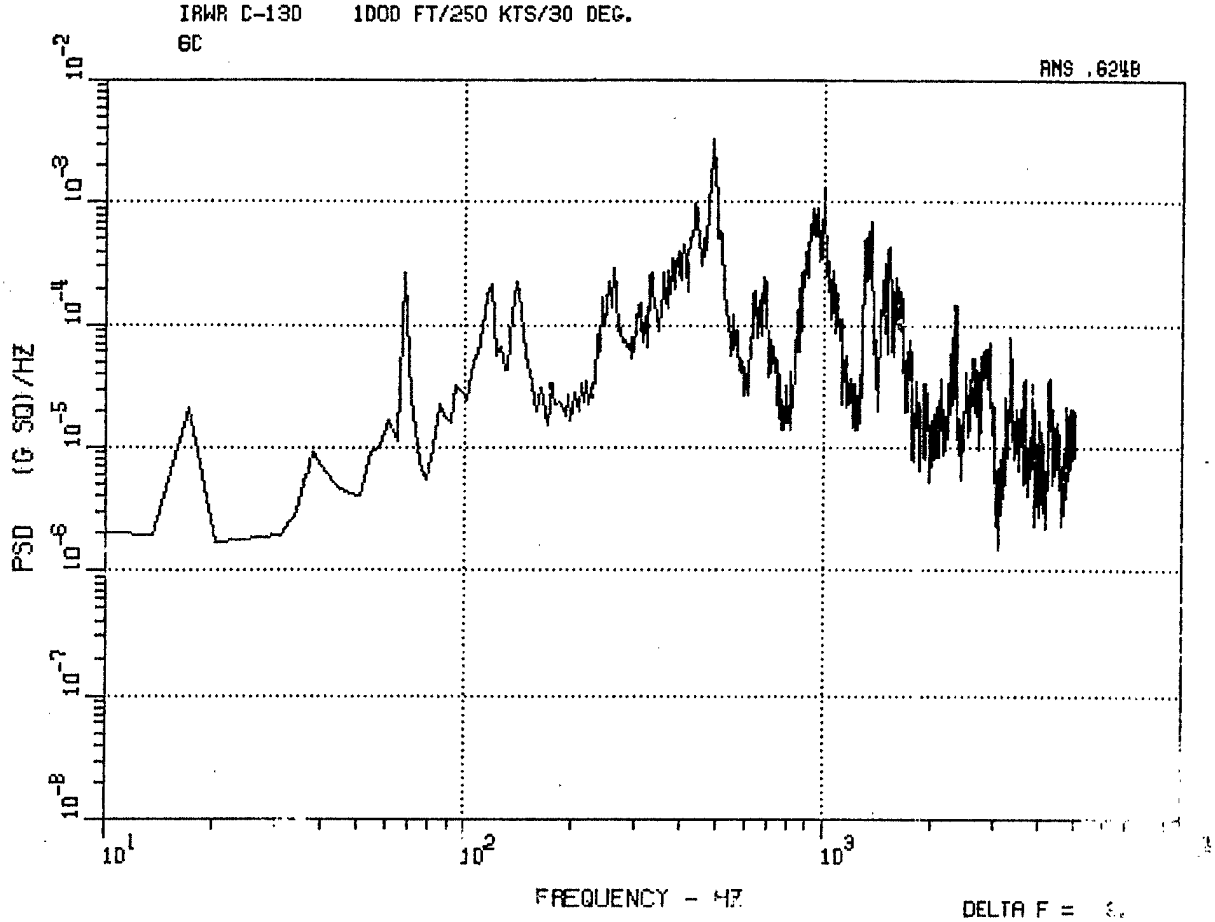


Figure 37. C-130 Center Longitudinal Accelerometer 6C, 5000 Ft, 130 Kt, 0 Deg, and 200 Ft, 250 Kt, 30 Deg.



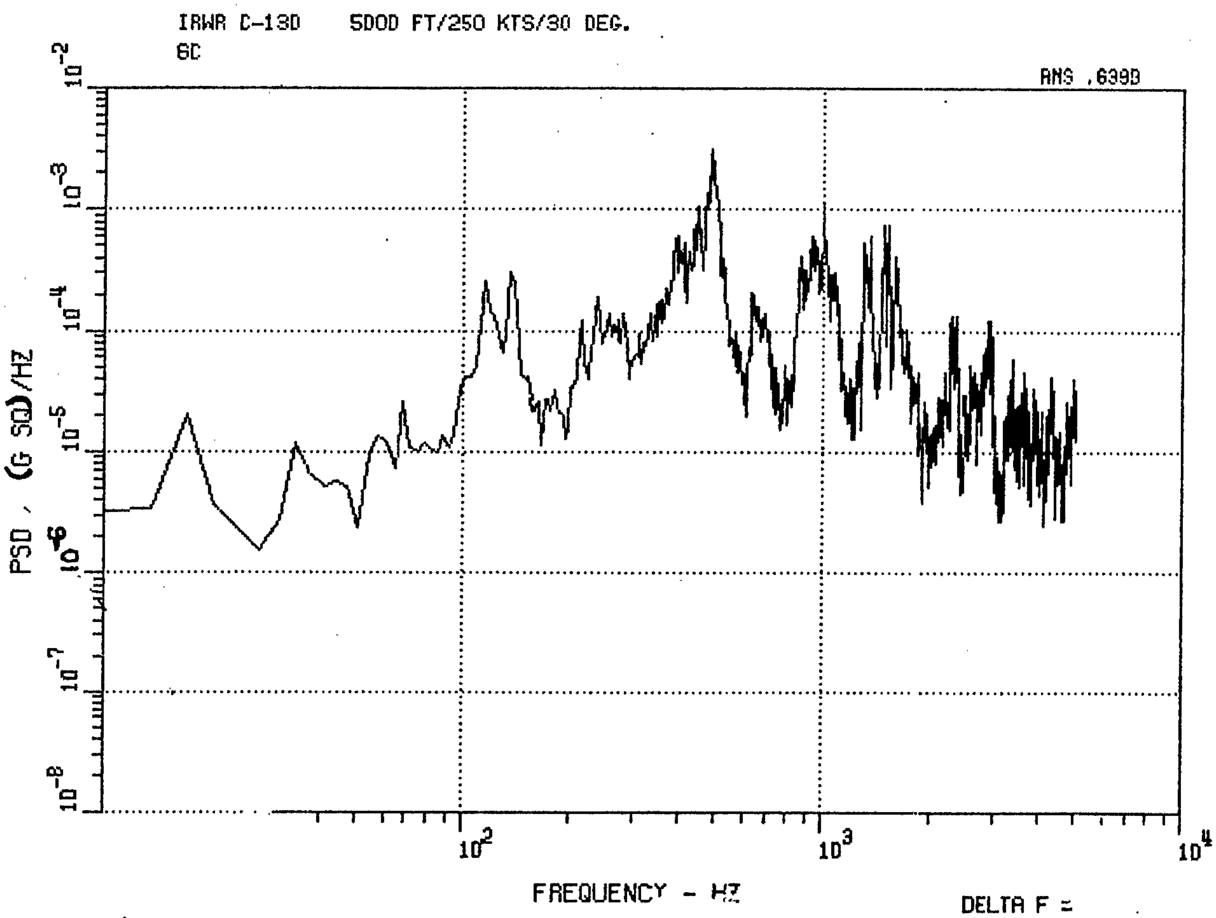


Figure 38. C-130 Center Longitudinal Accelerometer 6C, 1000 Ft, 250 Kt, 30 Deg, and 5000 Ft, 250 Kt, 30 Deg.

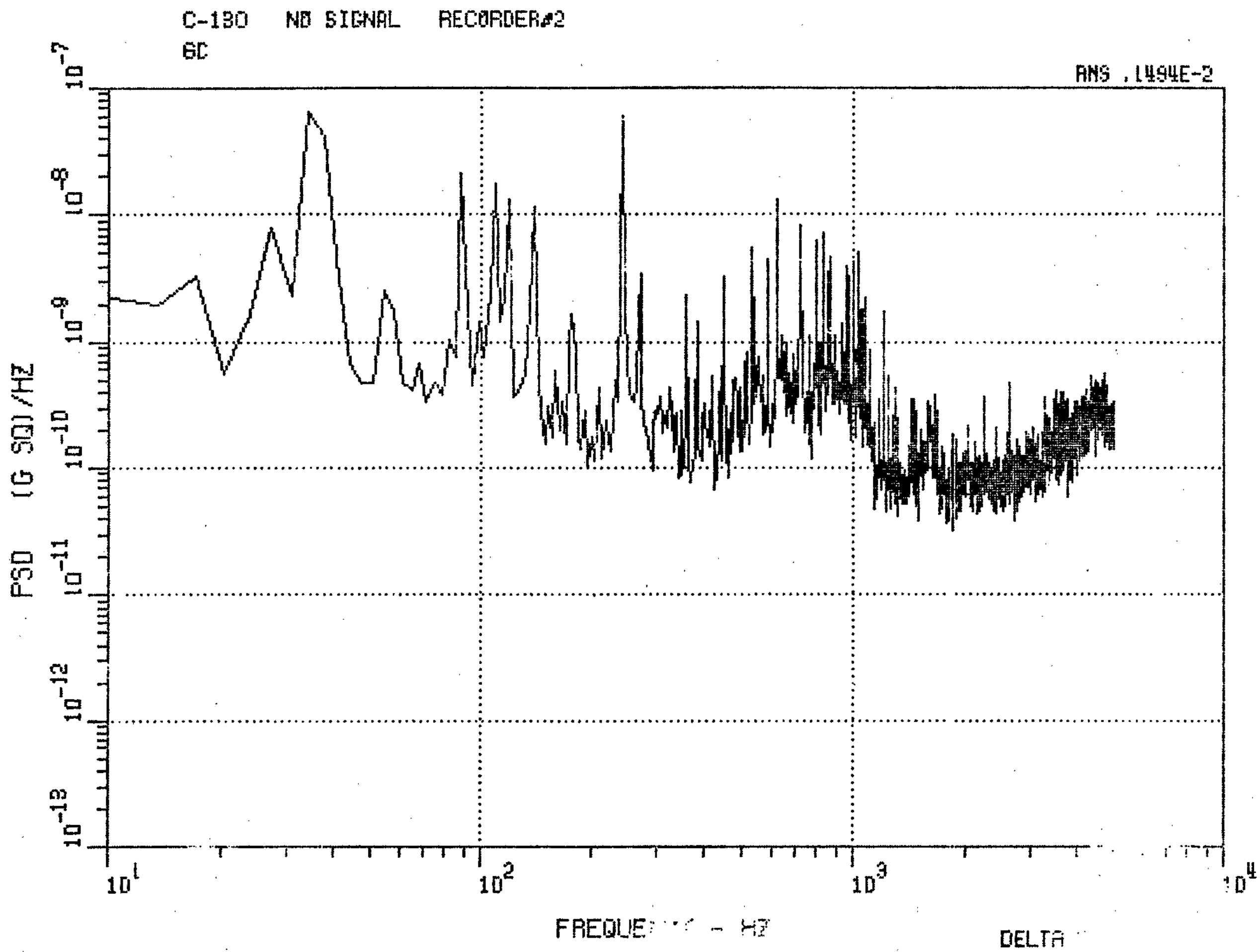
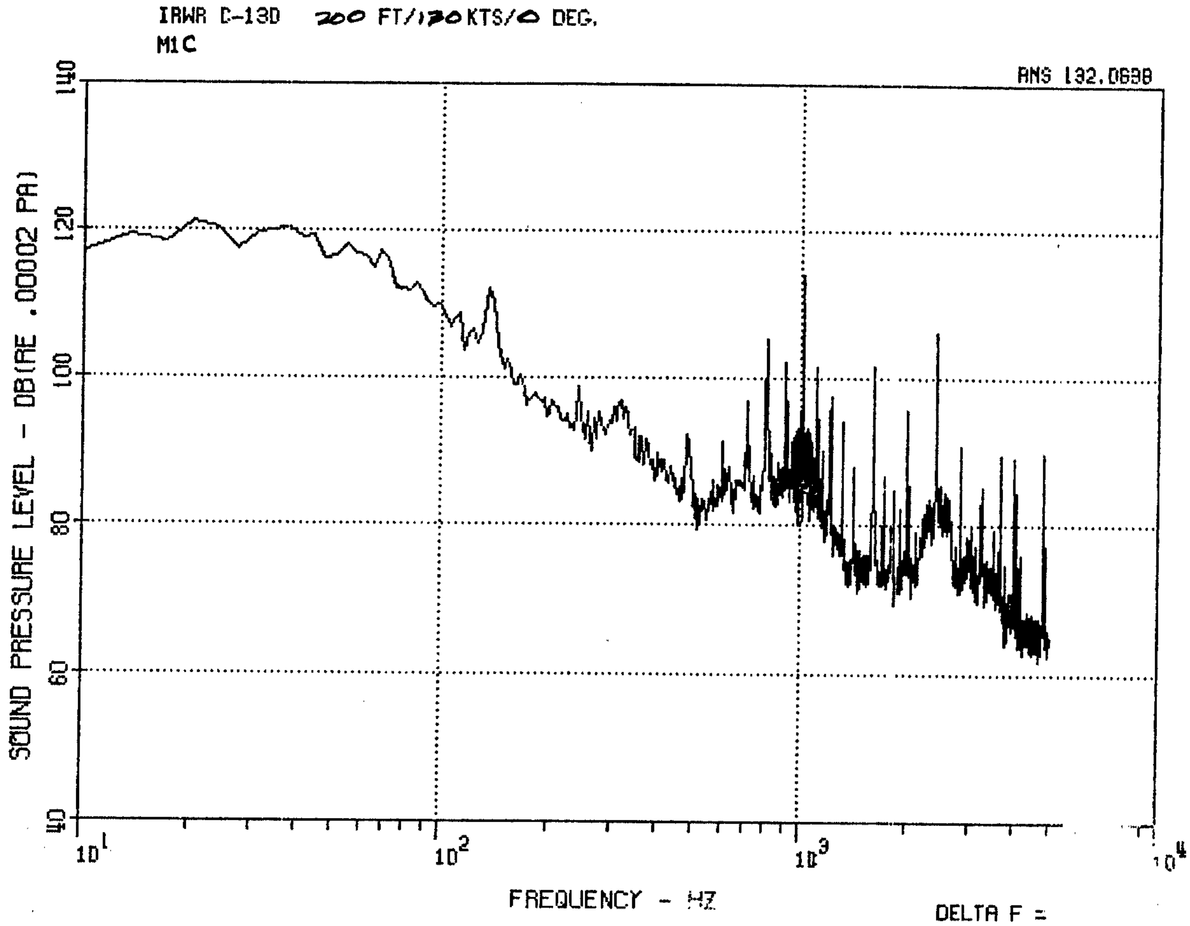


Figure 39. C-130 Center Longitudinal Accelerometer 6C, No-Signal Record.



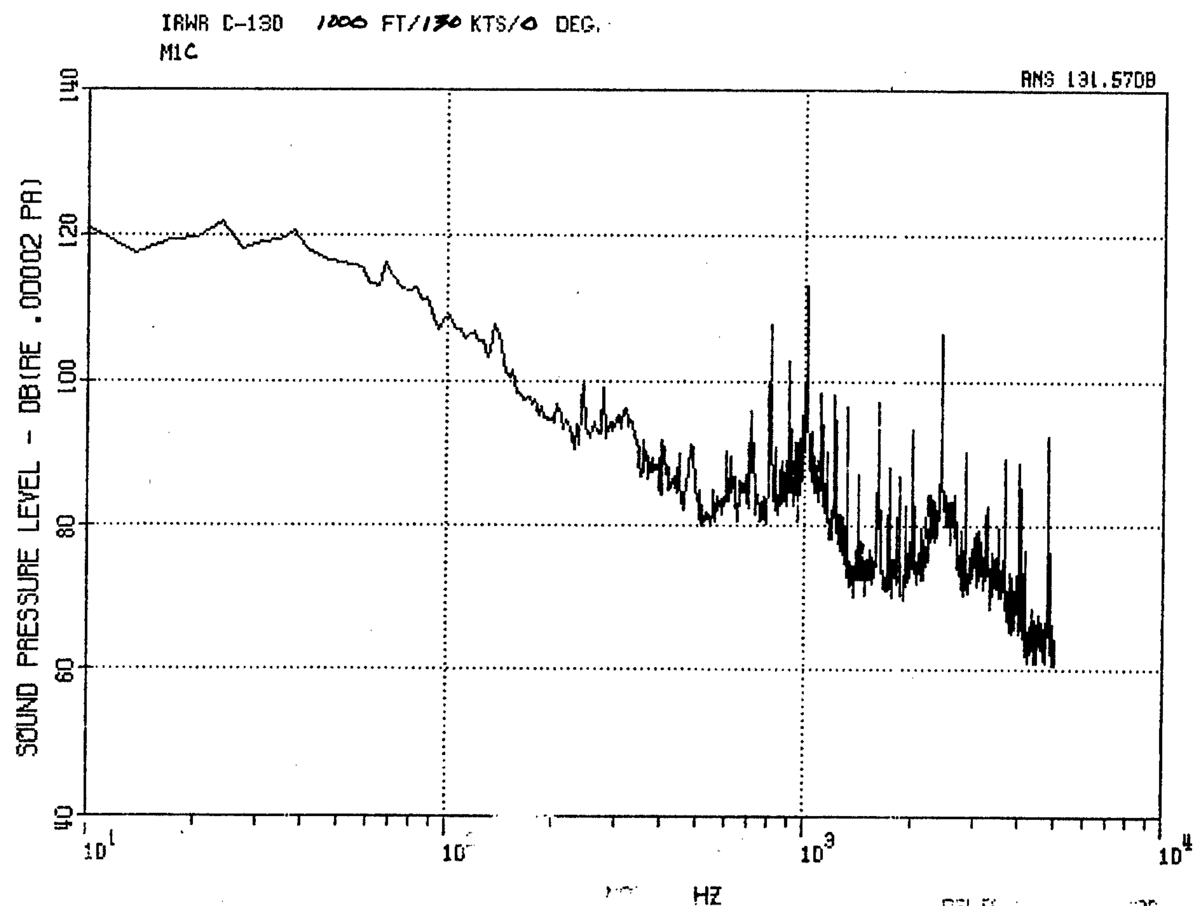


Figure 40. C-130 Center Microphone MC, 200 Ft, 130 Kt, 0 Deg, and 1000 Ft, 130 Kt, 0 Deg.

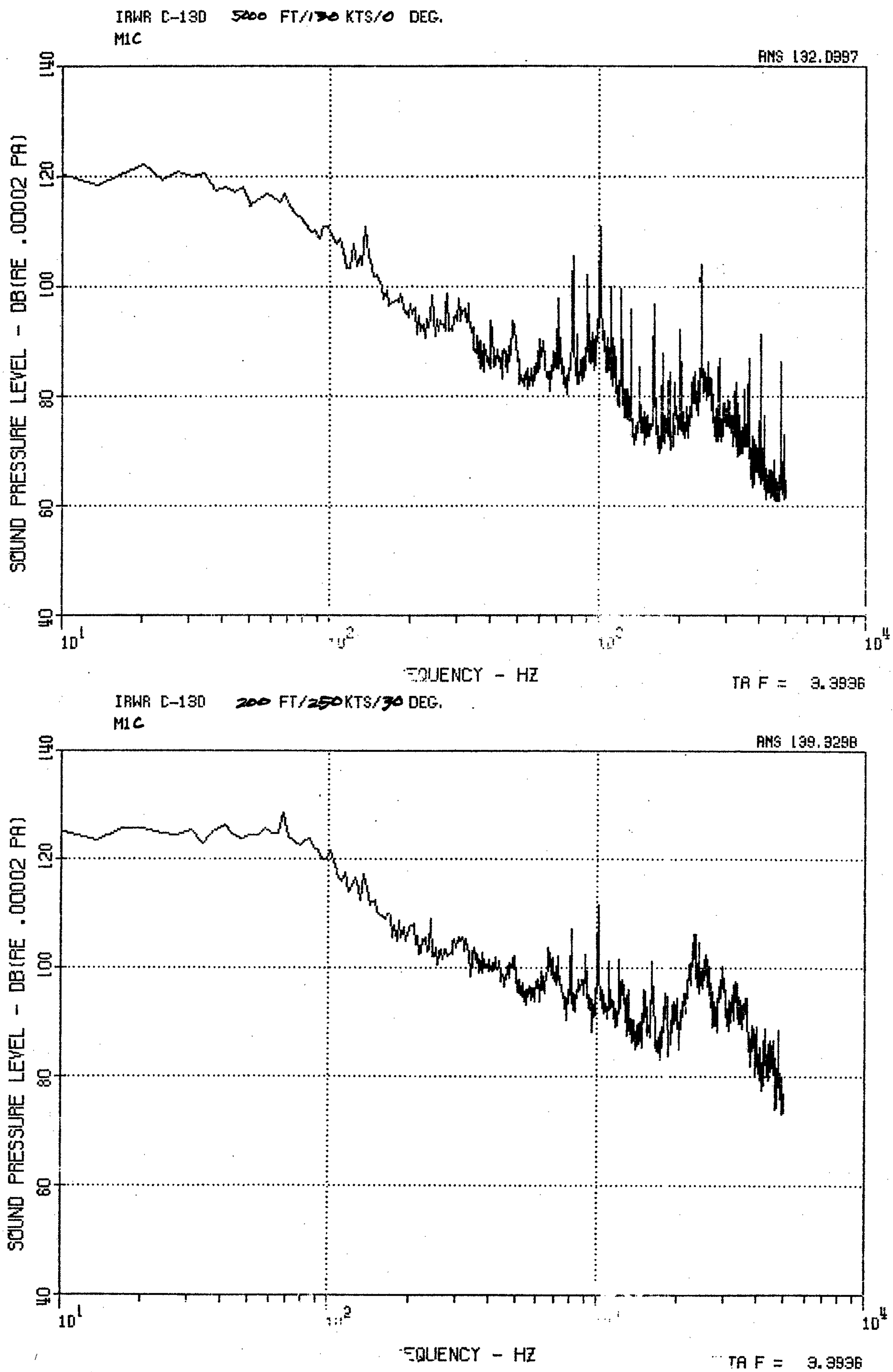


Figure 41. C-130 Center Microphone MC, 5000 Ft, 130 Kt, 0 Deg, and 200 Ft, 250 Kt, 30 Deg.

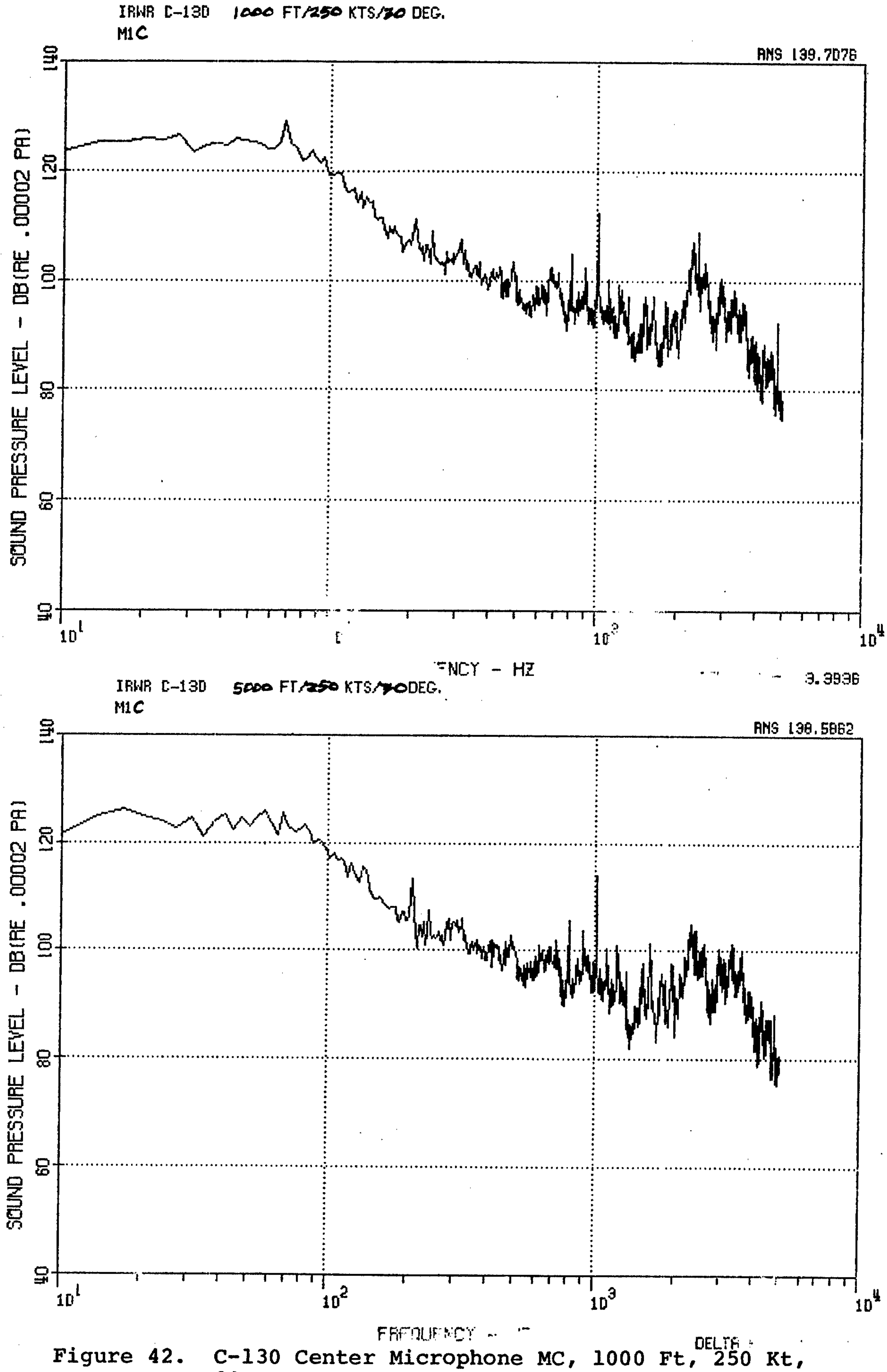


Figure 42. C-130 Center Microphone MC, 1000 Ft, 250 Kt, 30 Deg, and 5000 Ft, 250 Kt, 30 Deg.

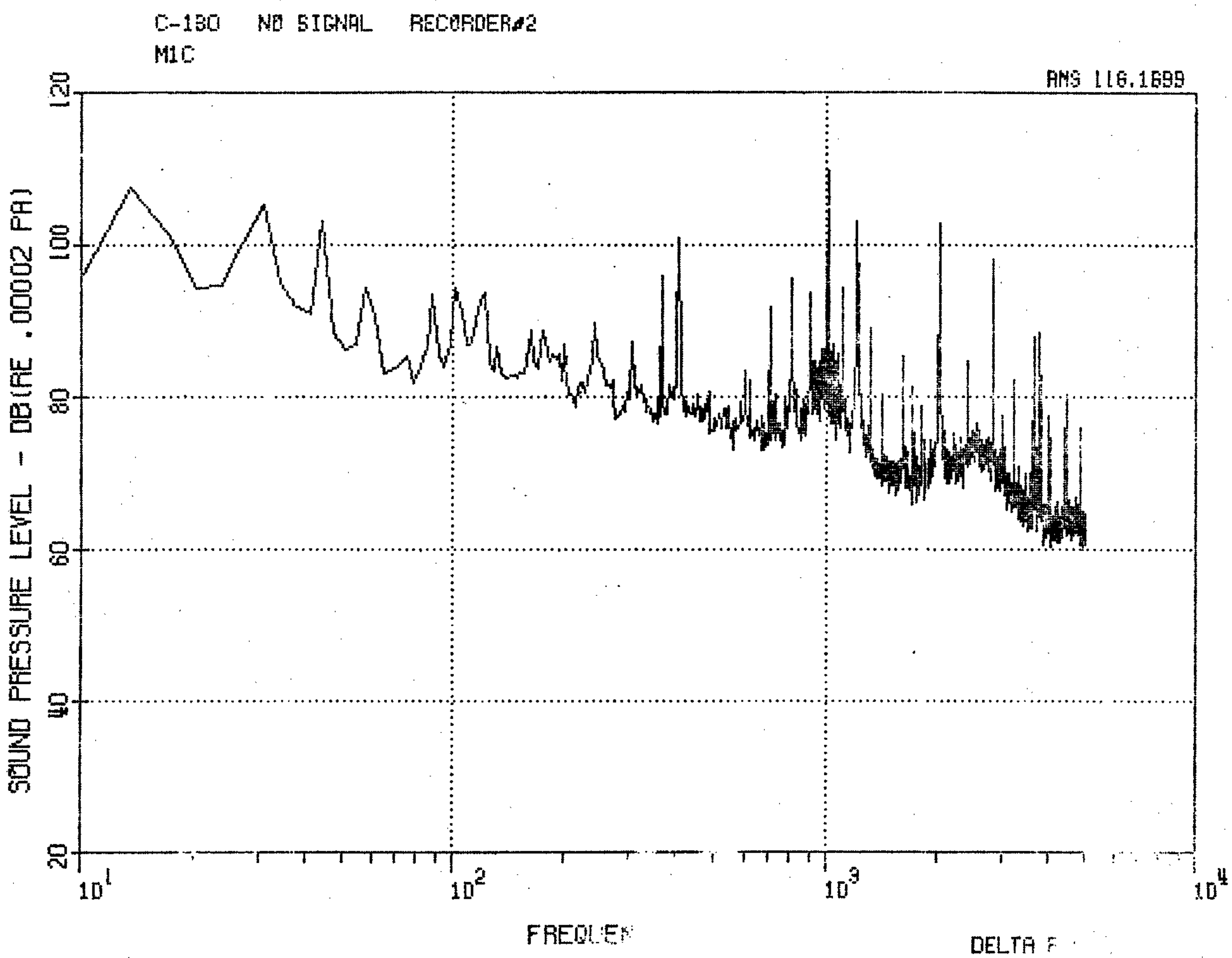


Figure 43. C-130 Center Microphone MC, No-Signal Record.

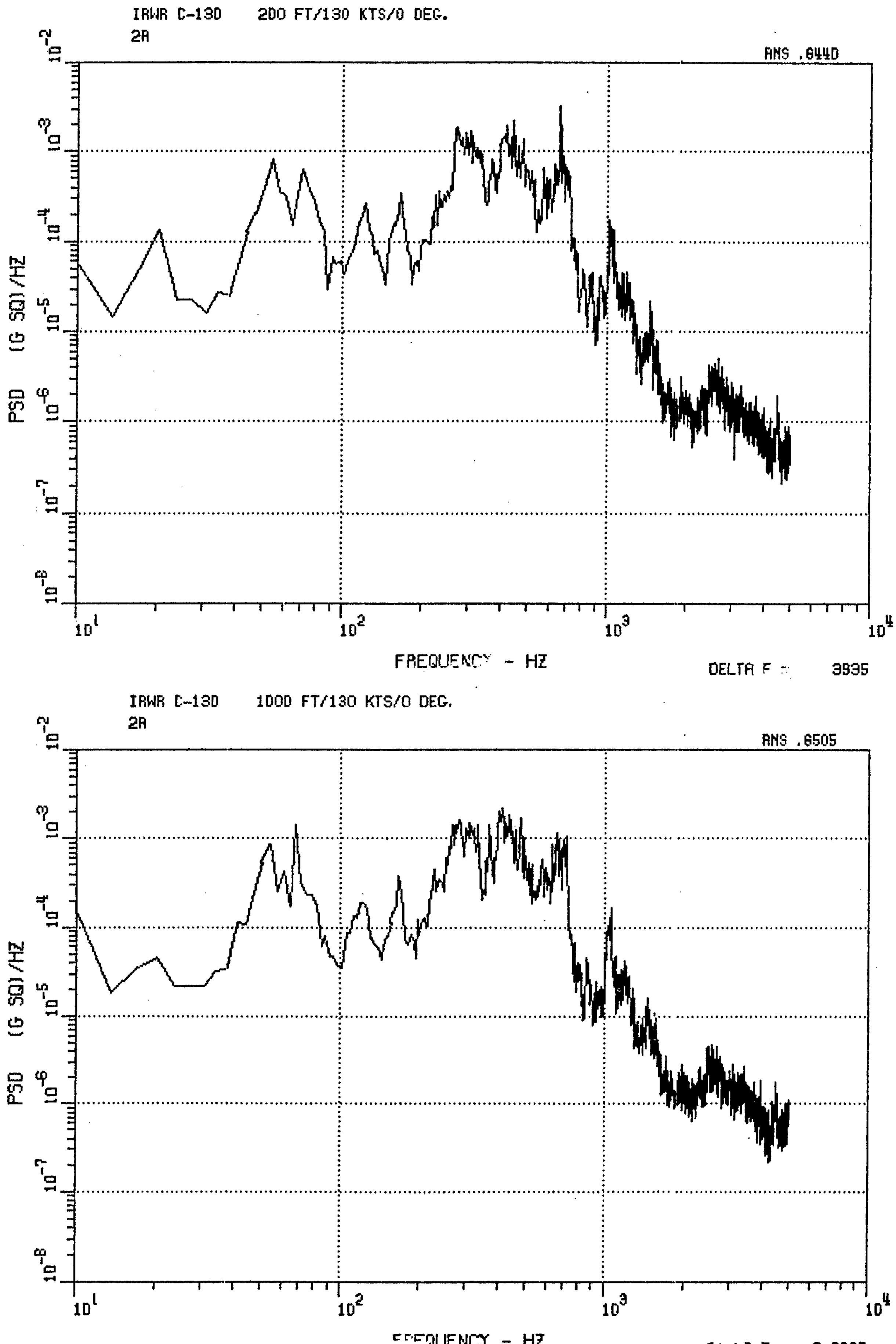


Figure 44. C-130 Aft Lateral Accelerometer 2A, 200 Ft, 130 Kt, 0 Deg, and 1000 Ft, 130 Kt, 0 Deg.

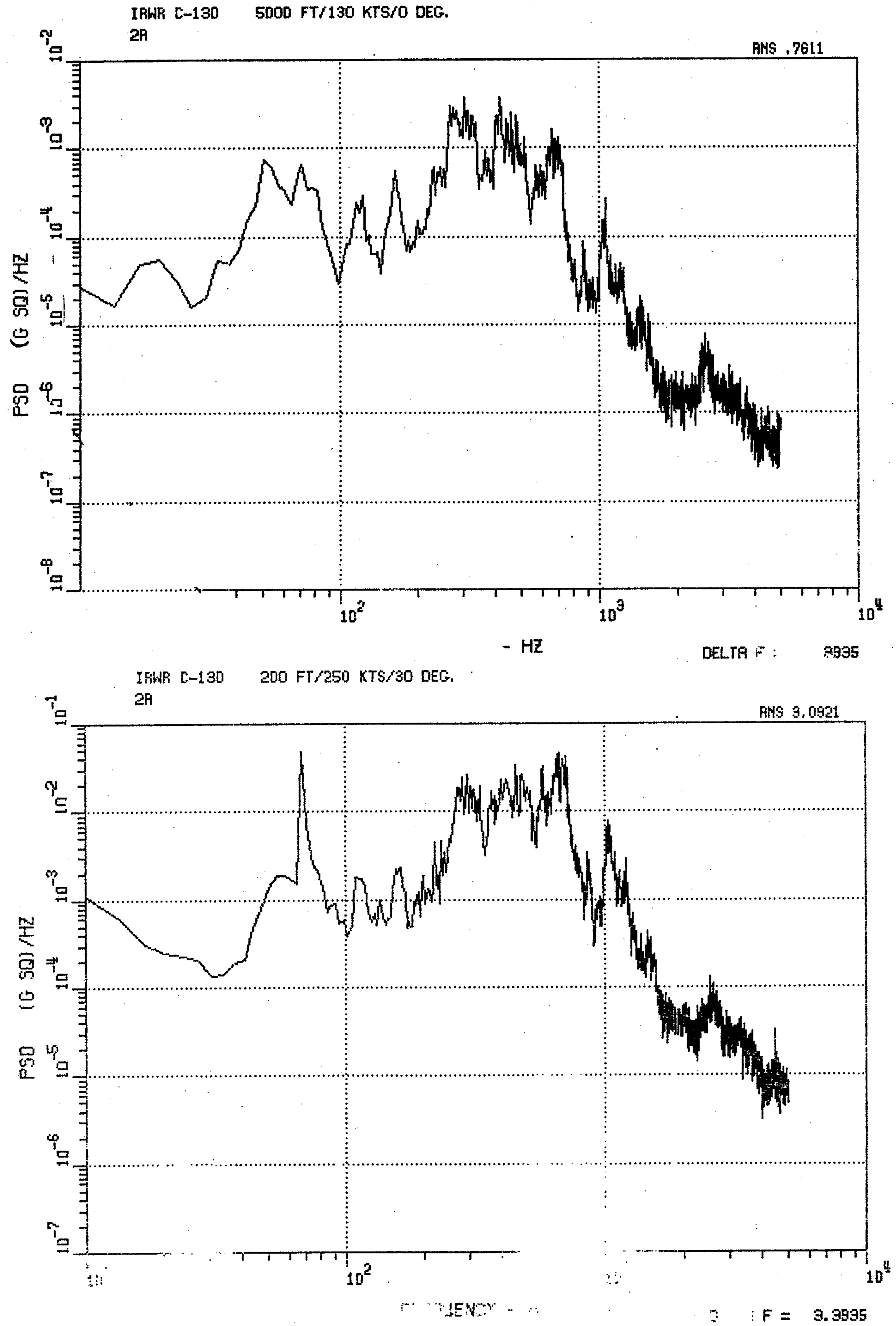
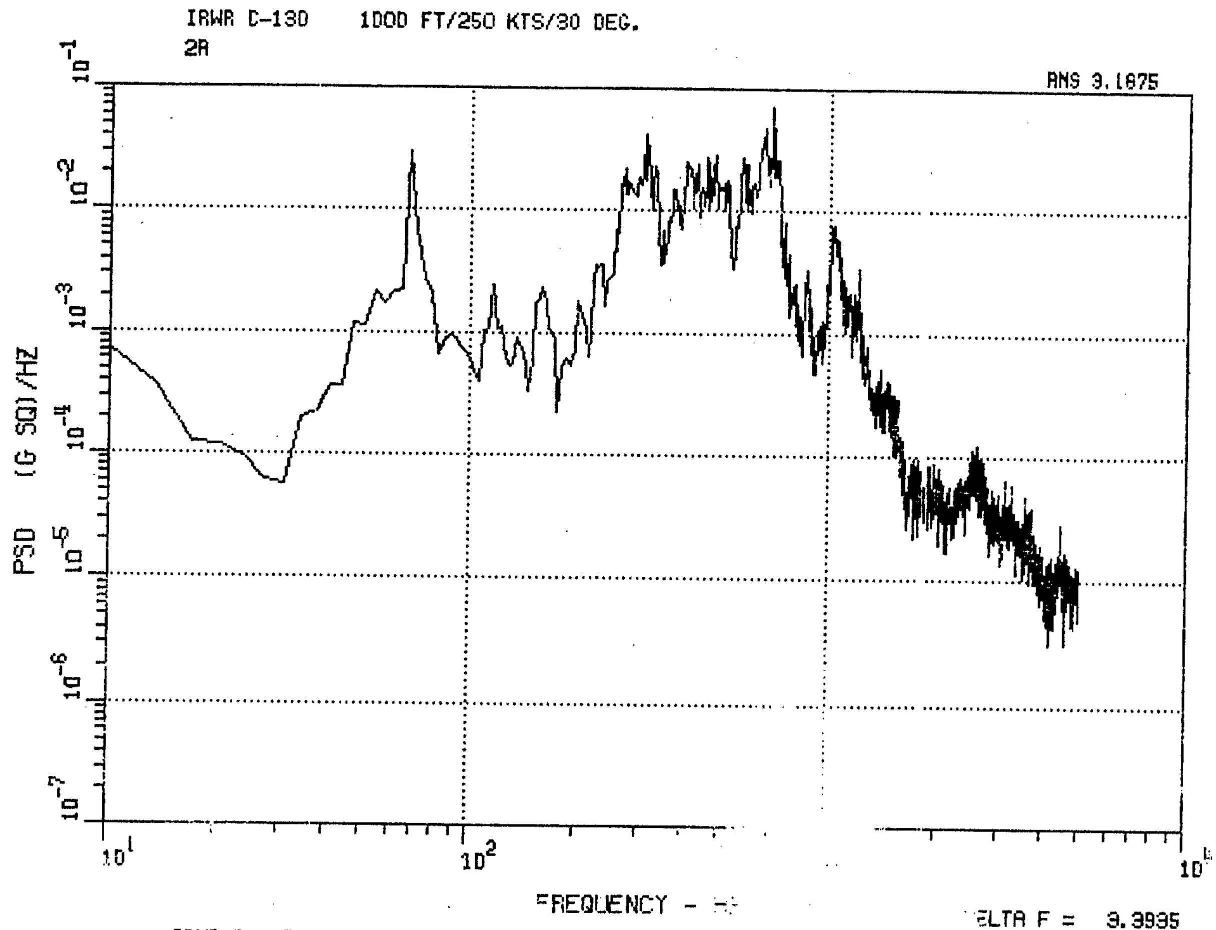


Figure 45. C-130 Aft Lateral Accelerometer 2A, 5000 Ft, 130 Kt, 0 Deg, and 200 Ft, 250 Kt, 30 Deg.



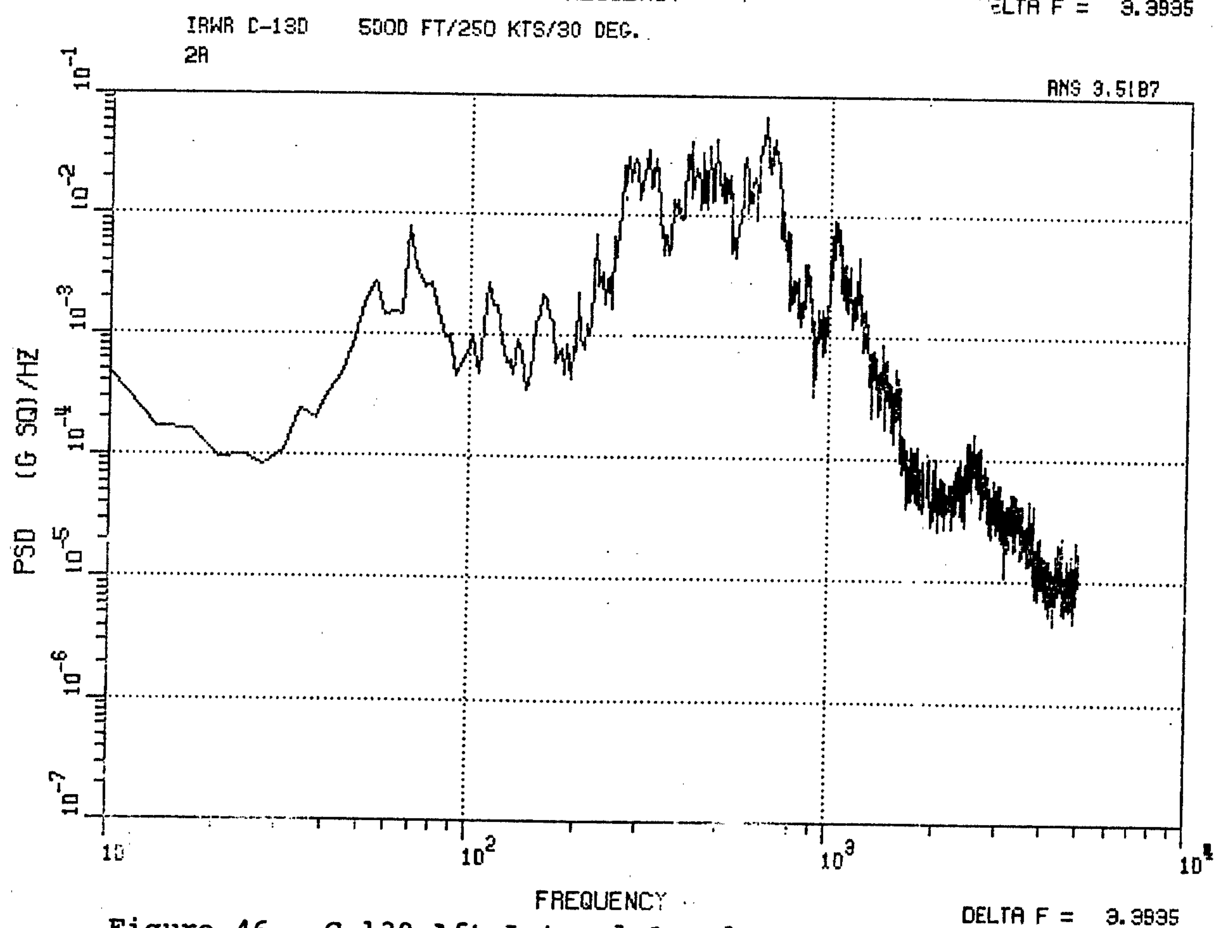


Figure 46. C-130 Aft Lateral Accelerometer 2A, 1000 Ft, 250 Kt, 30 Deg, and 5000 Ft, 250 Kt, 30 Deg.

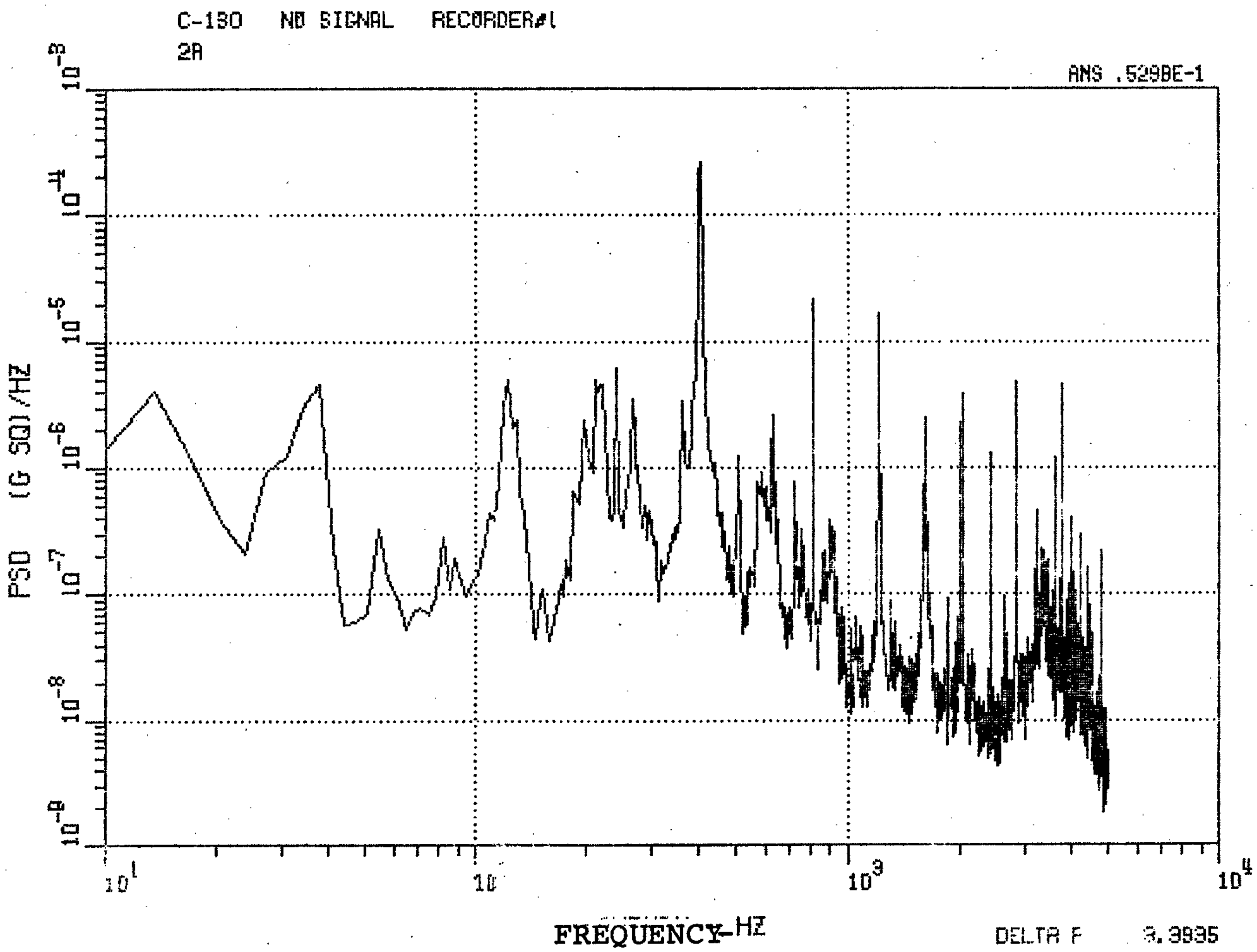


Figure 47. C-130 Aft Lateral Accelerometer 2A, No-Signal Record.

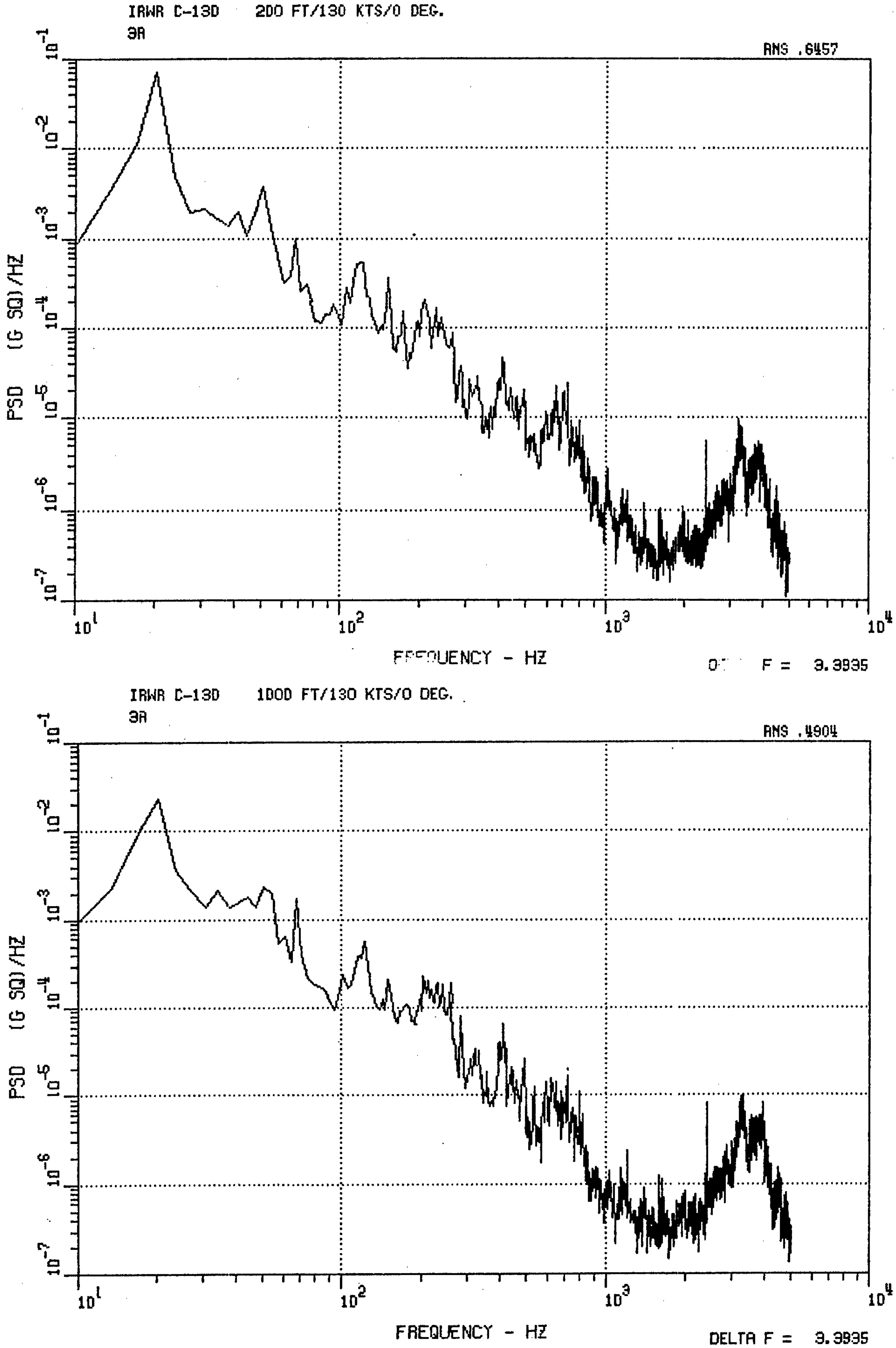
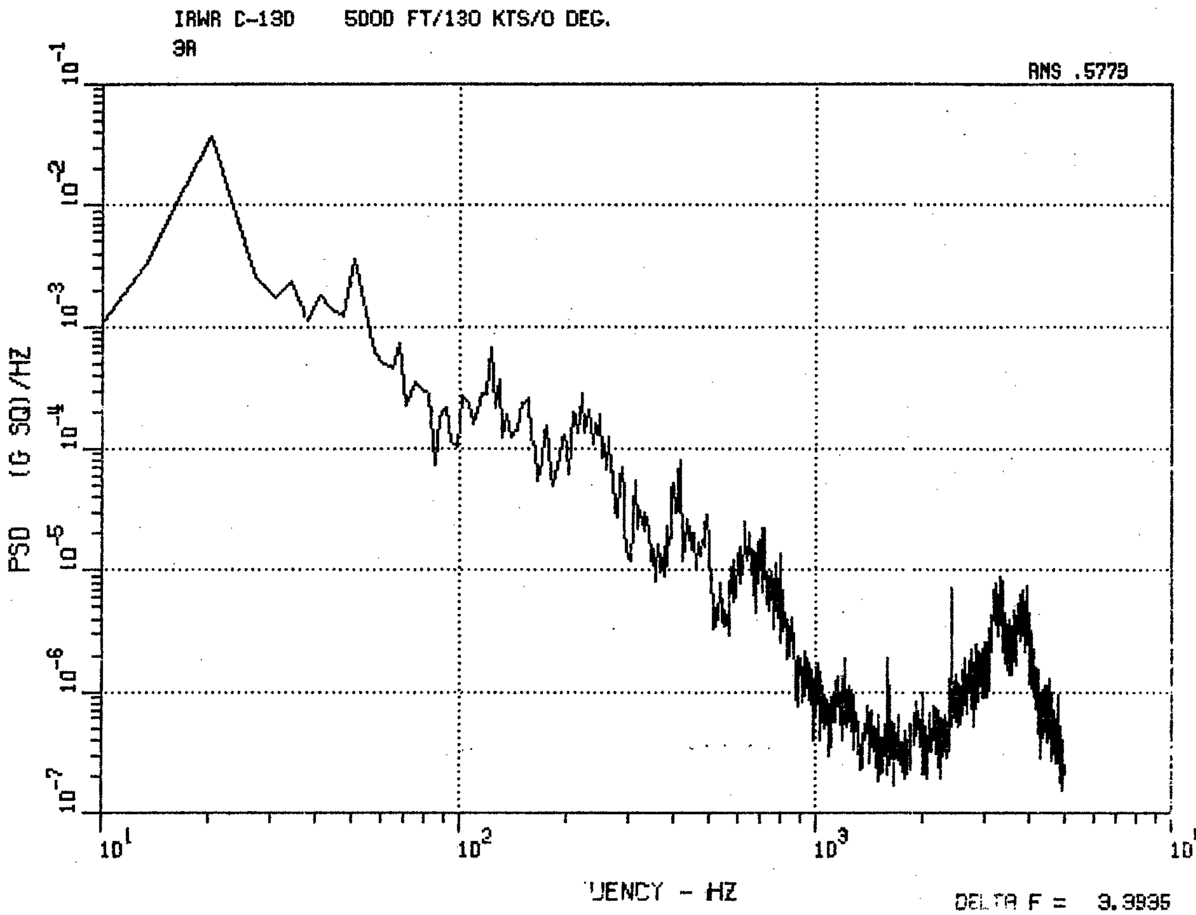


Figure 48. C-130 Aft Vertical Accelerometer 3A, 200 Ft, 130 Kt, 0 Deg, and 1000 Ft, 130 Kt, 0 Deg.



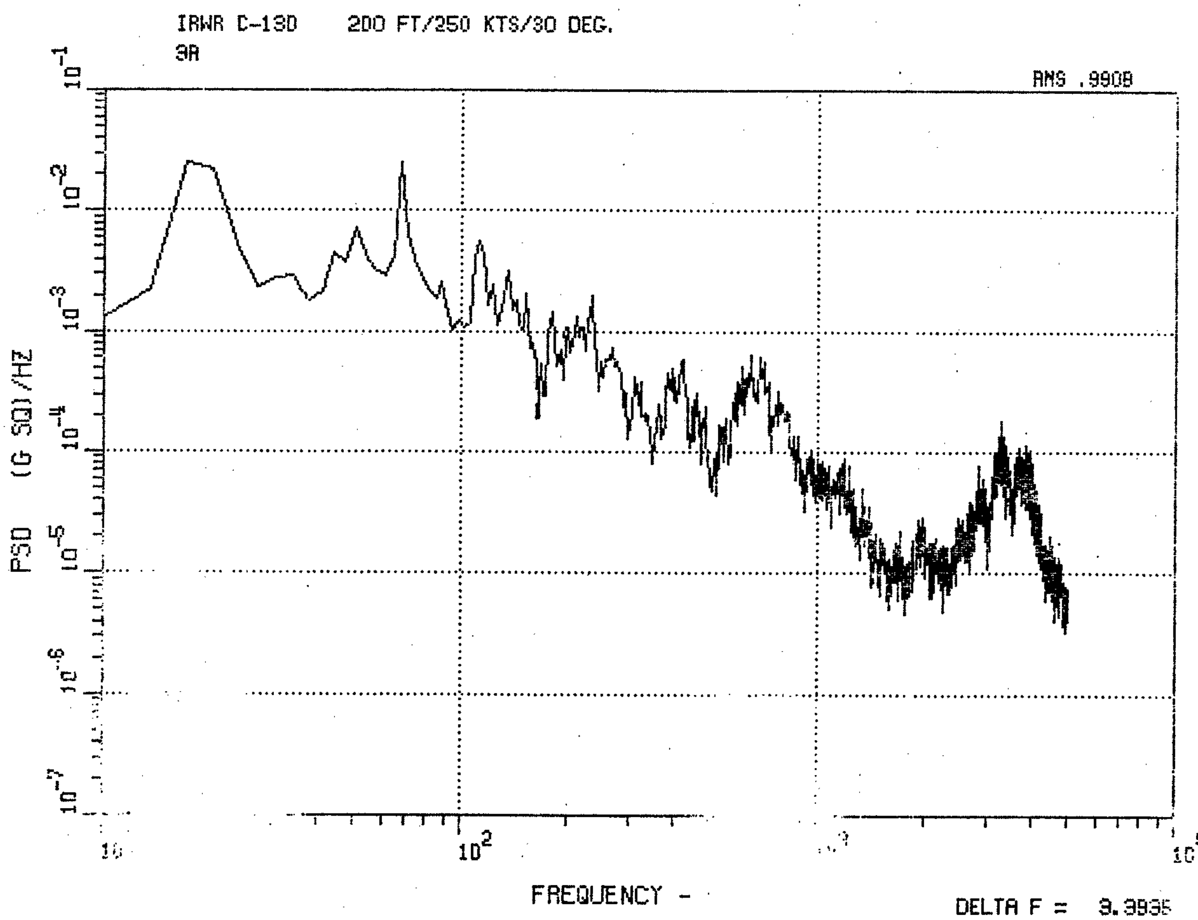


Figure 49. C-130 Aft Vertical Accelerometer 3A, 5000 Ft, 130 Kt, 0 Deg, and 200 Ft, 250 Kt, 30 Deg.

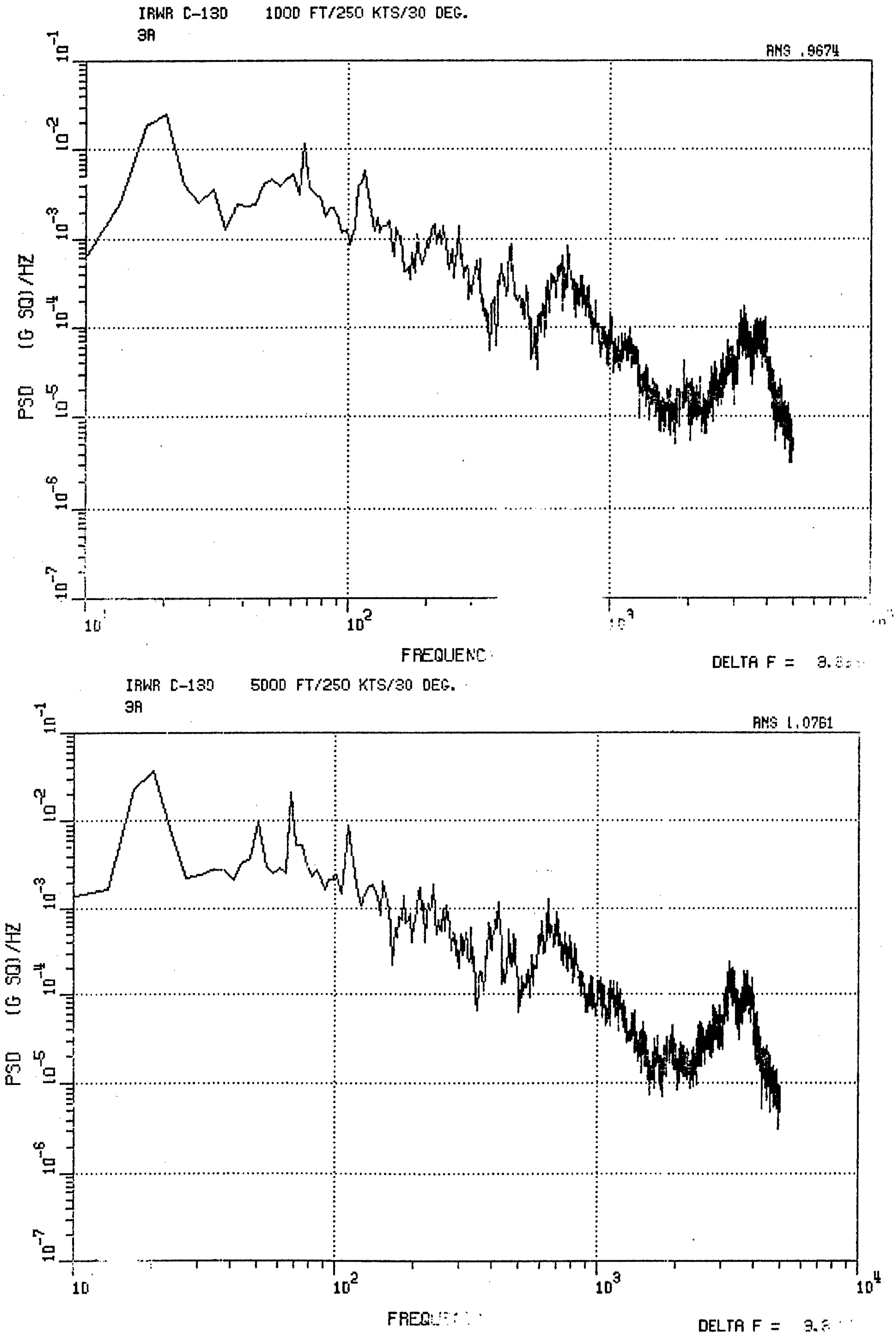


Figure 50. C-130 Aft Vertical Accelerometer 3A, 1000 Ft, 250 Kt, 30 Deg, and 5000 Ft, 250 Kt, 30 Deg.

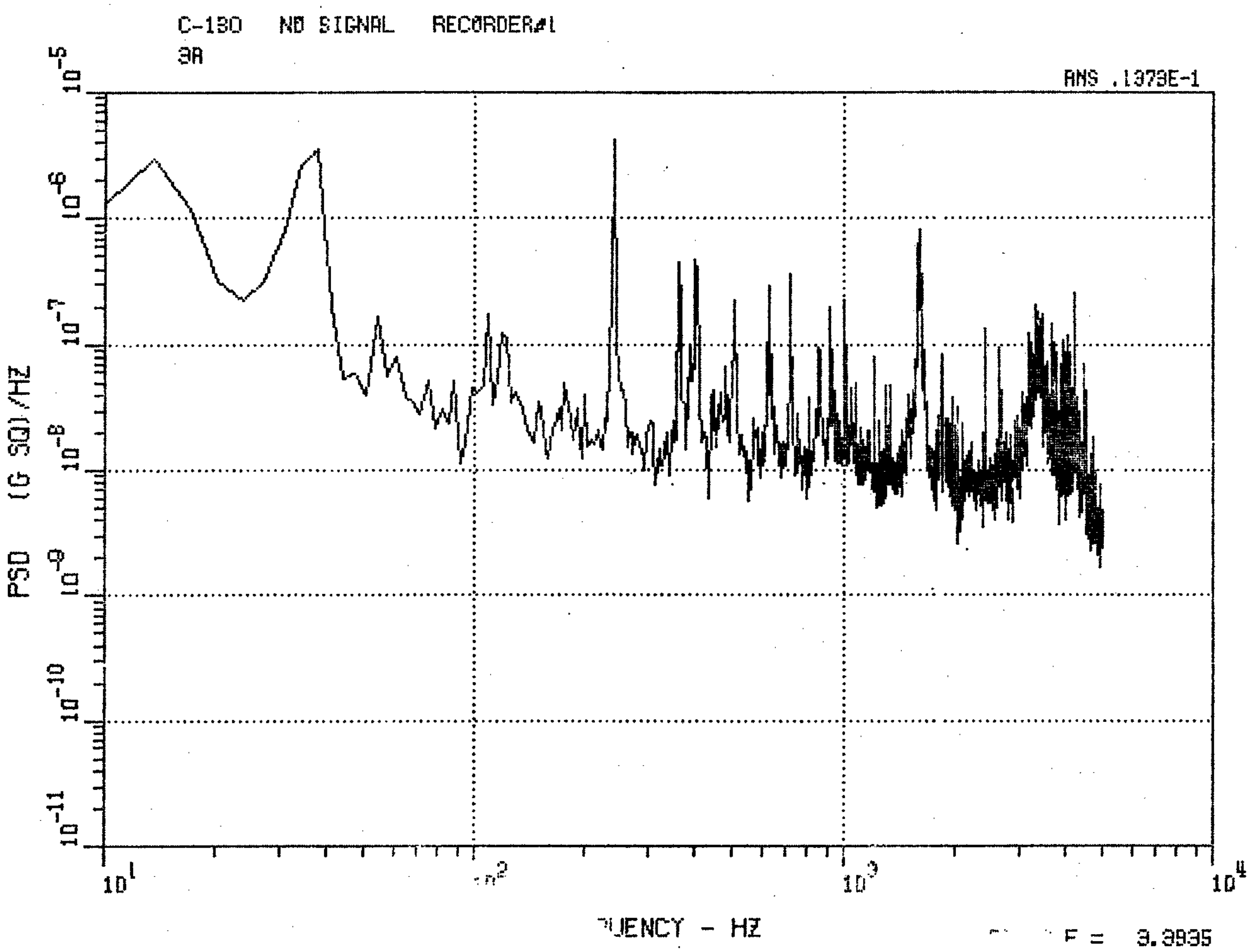


Figure 51. C-130 Aft Vertical Accelerometer 3A, No-Signal Record.

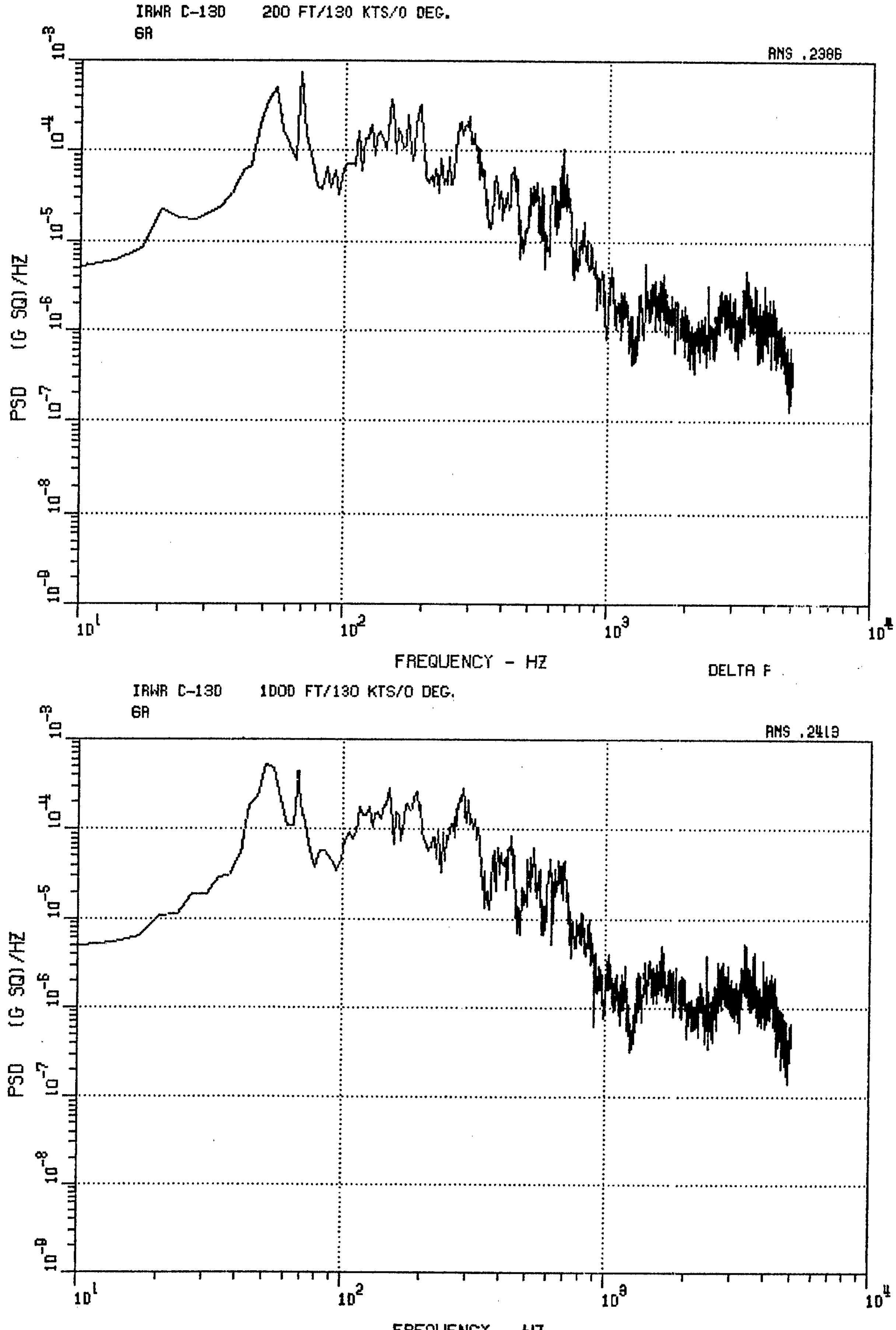
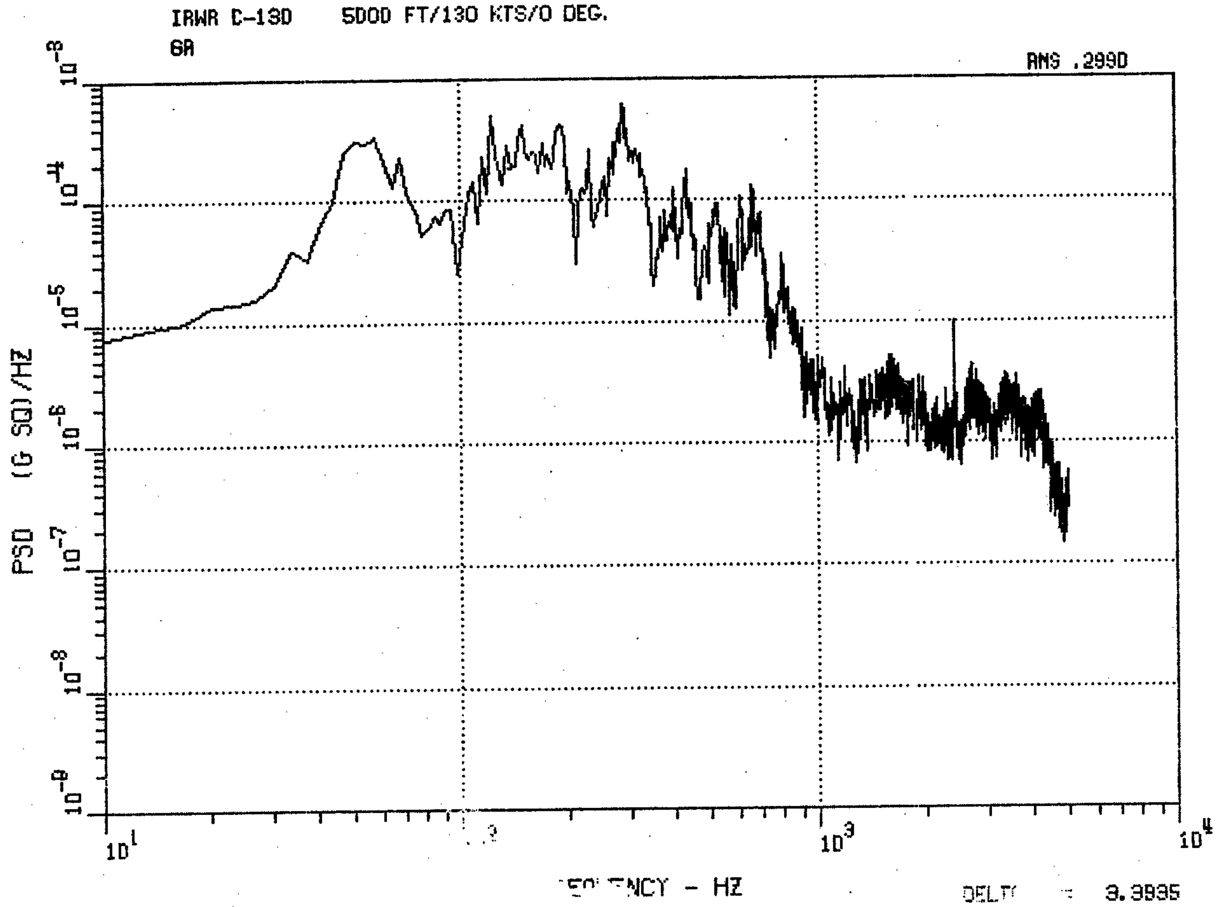


Figure 52. C-130 Aft Longitudinal Accelerometer 6A, 200 Ft, 130 Kt, 0 Deg, and 1000 Ft, 130 Kt, 0 Deg.



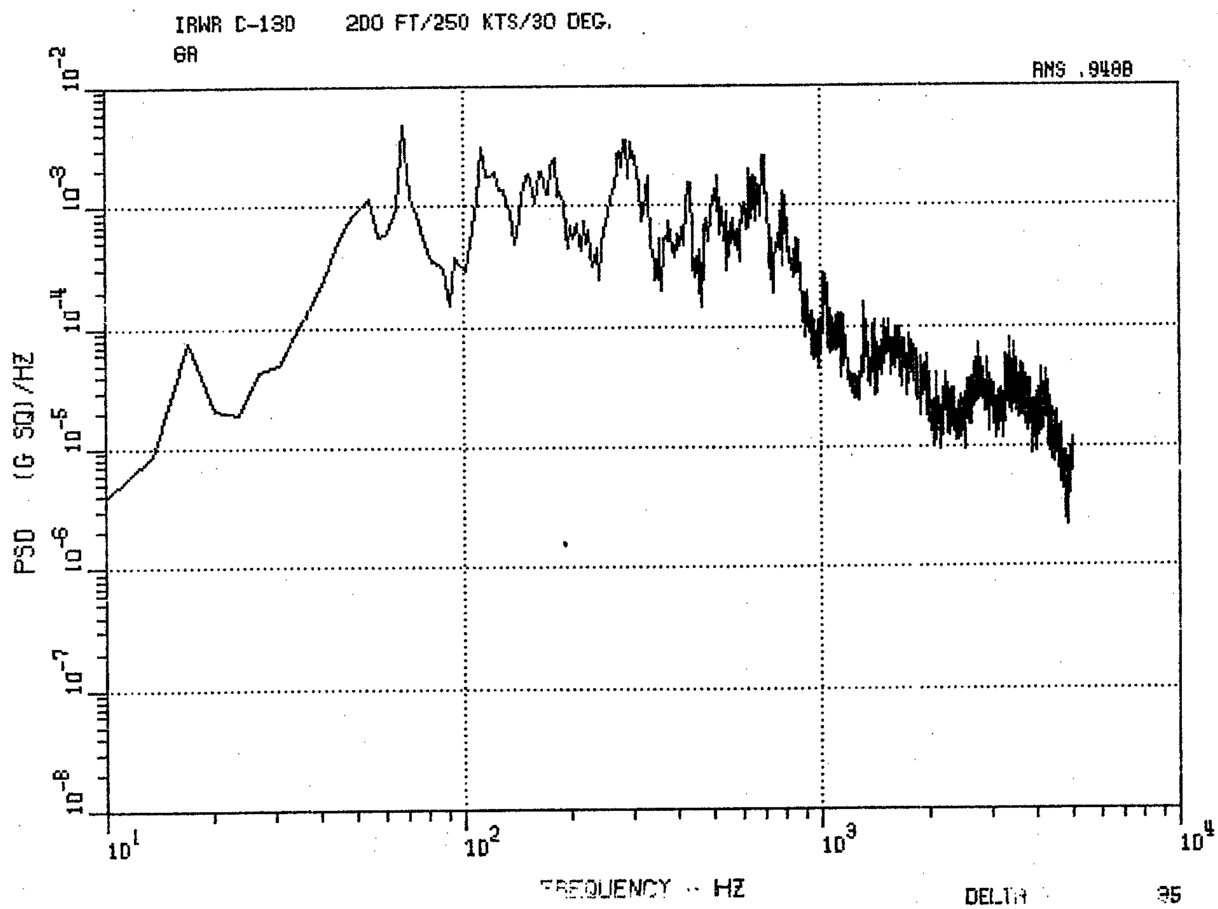


Figure 53. C-130 Aft Longitudinal Accelerometer 6A, 5000 Ft, 130 Kt, 0 Deg, and 200 Ft, 250 Kt, 30 Deg.

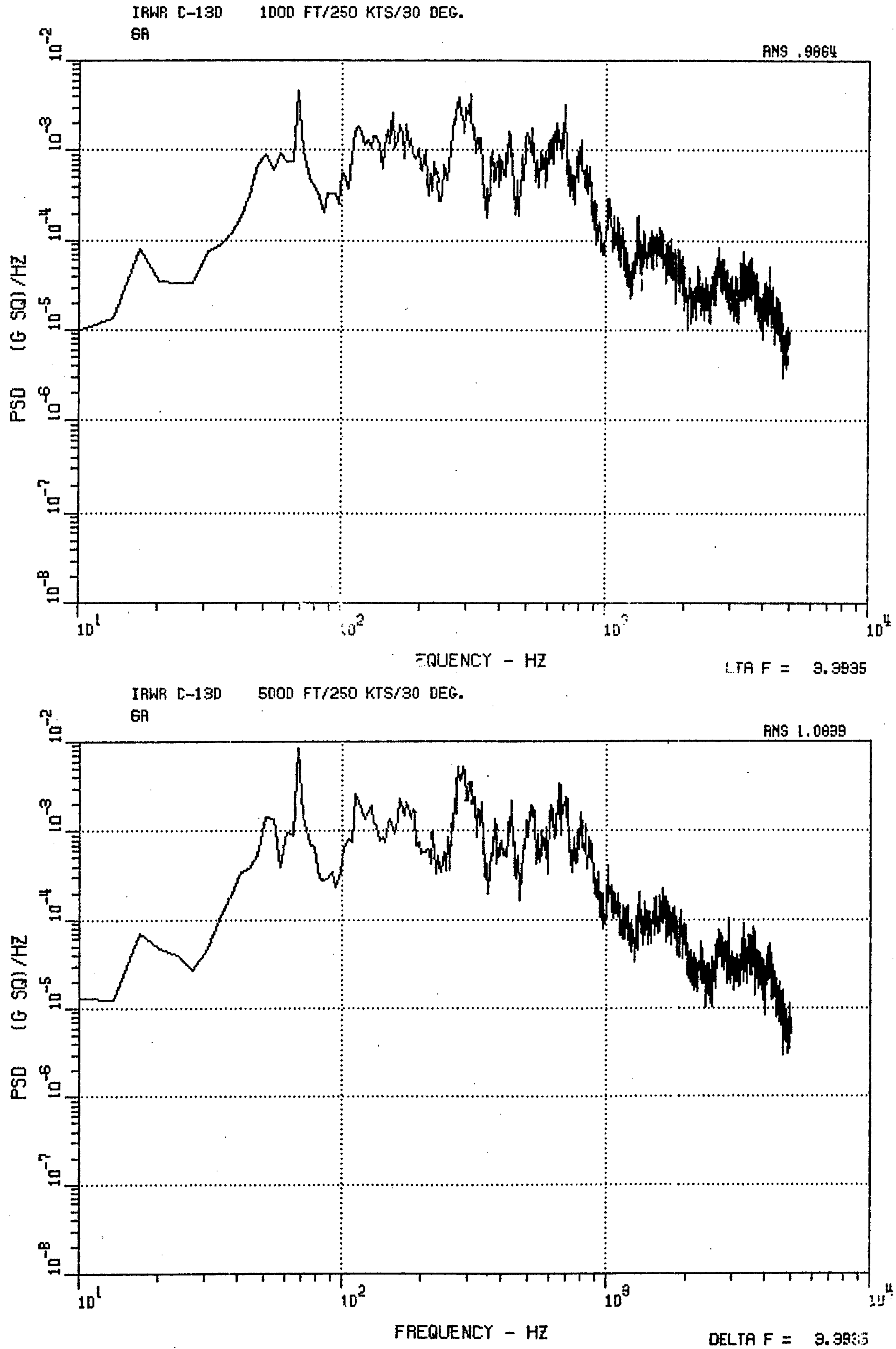


Figure 54. C-130 Aft Longitudinal Accelerometer 6A, 1000 Ft, 250 Kt, 30 Deg, and 5000 Ft, 250 Kt, 30 Deg.

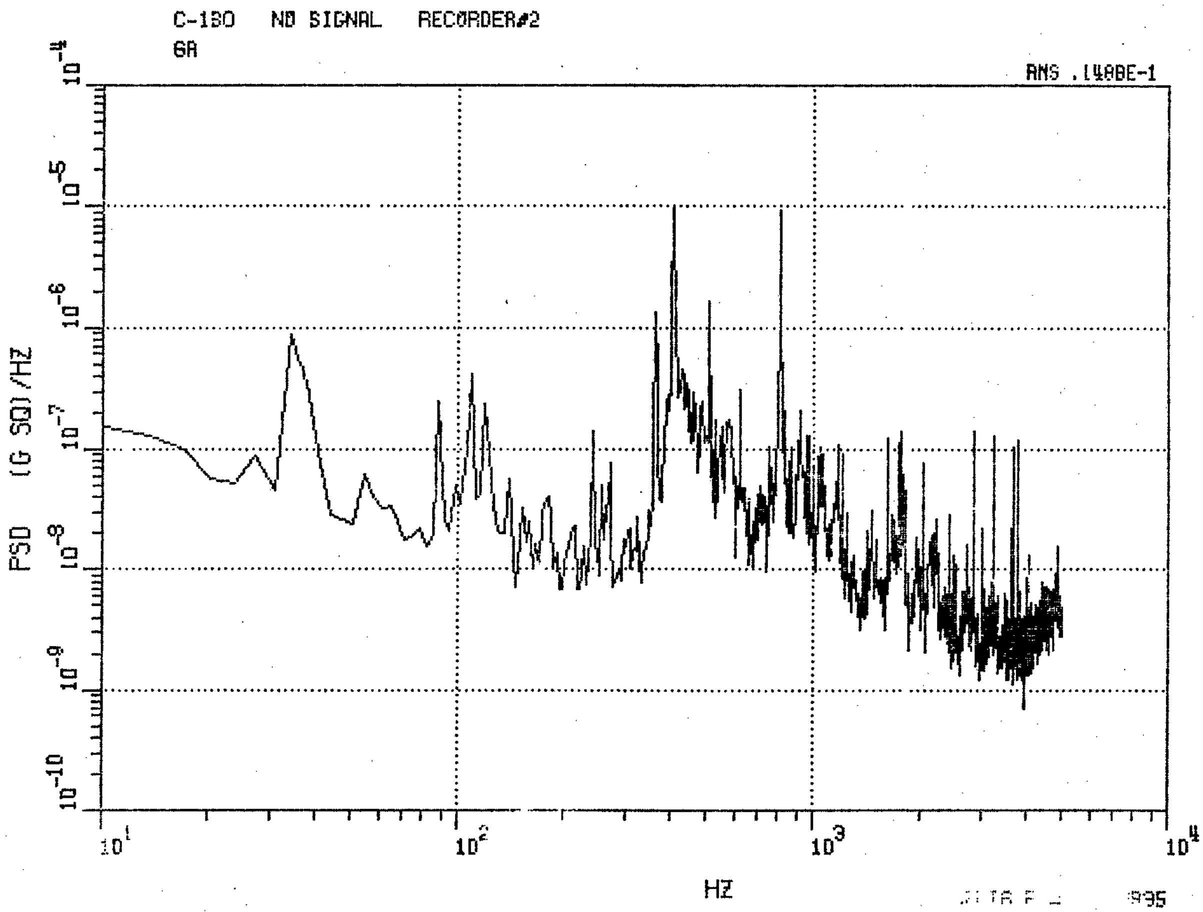
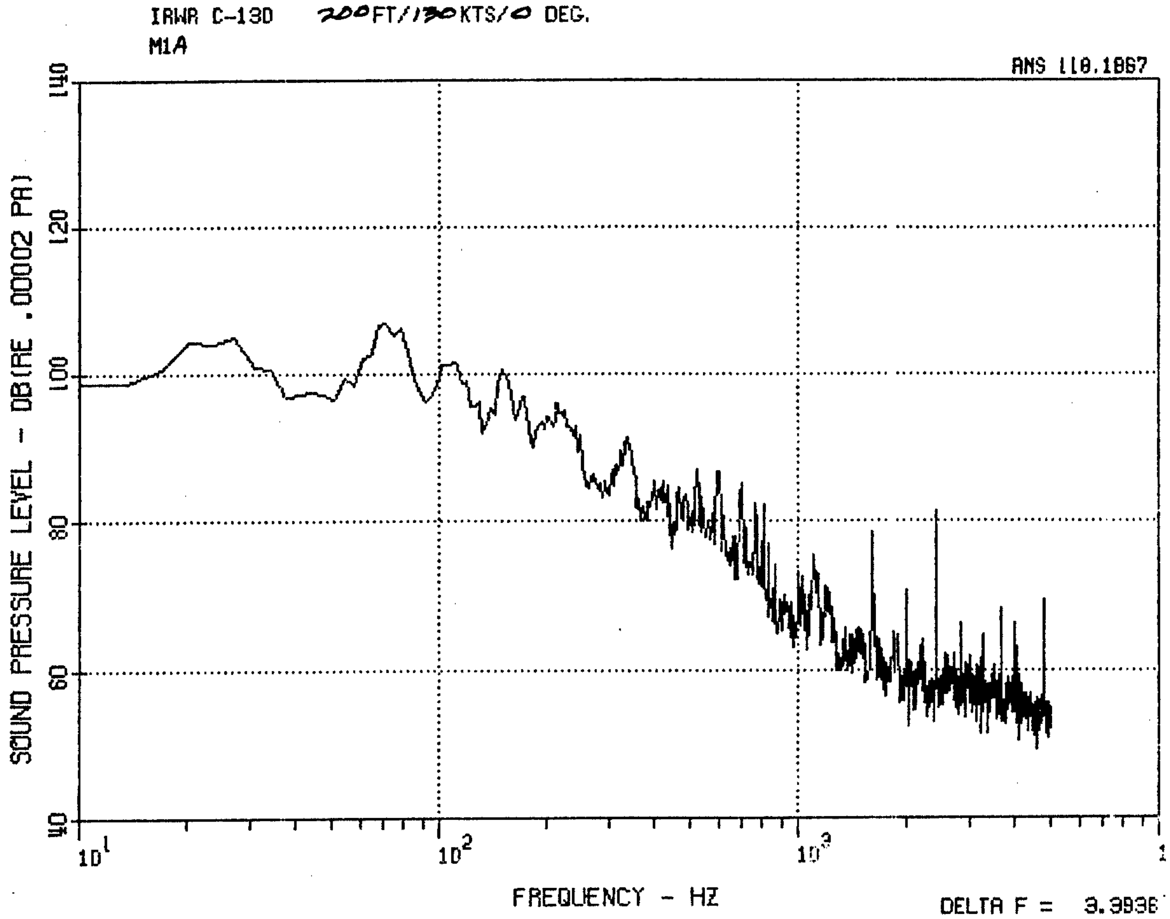


Figure 55. C-130 Aft Longitudinal Accelerometer 6A, No-Signal Record.



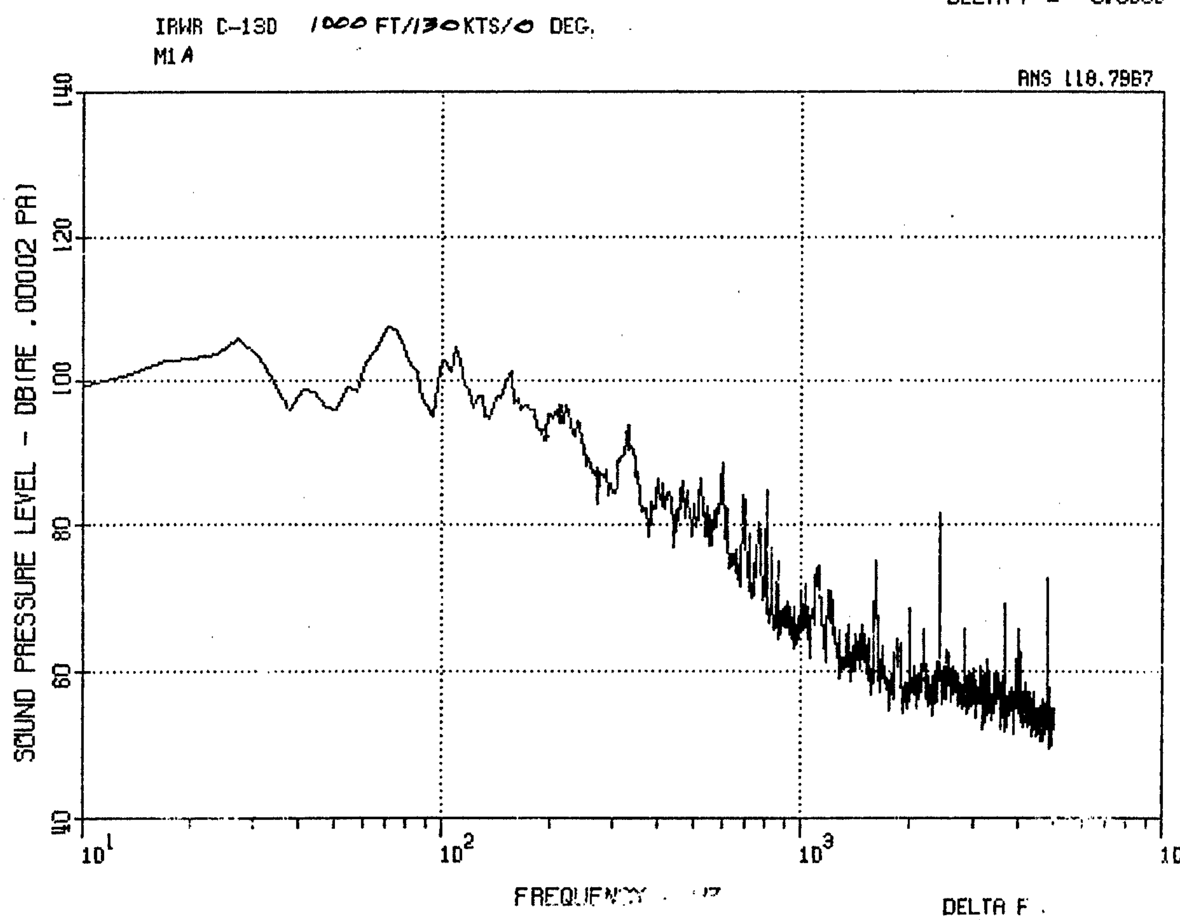
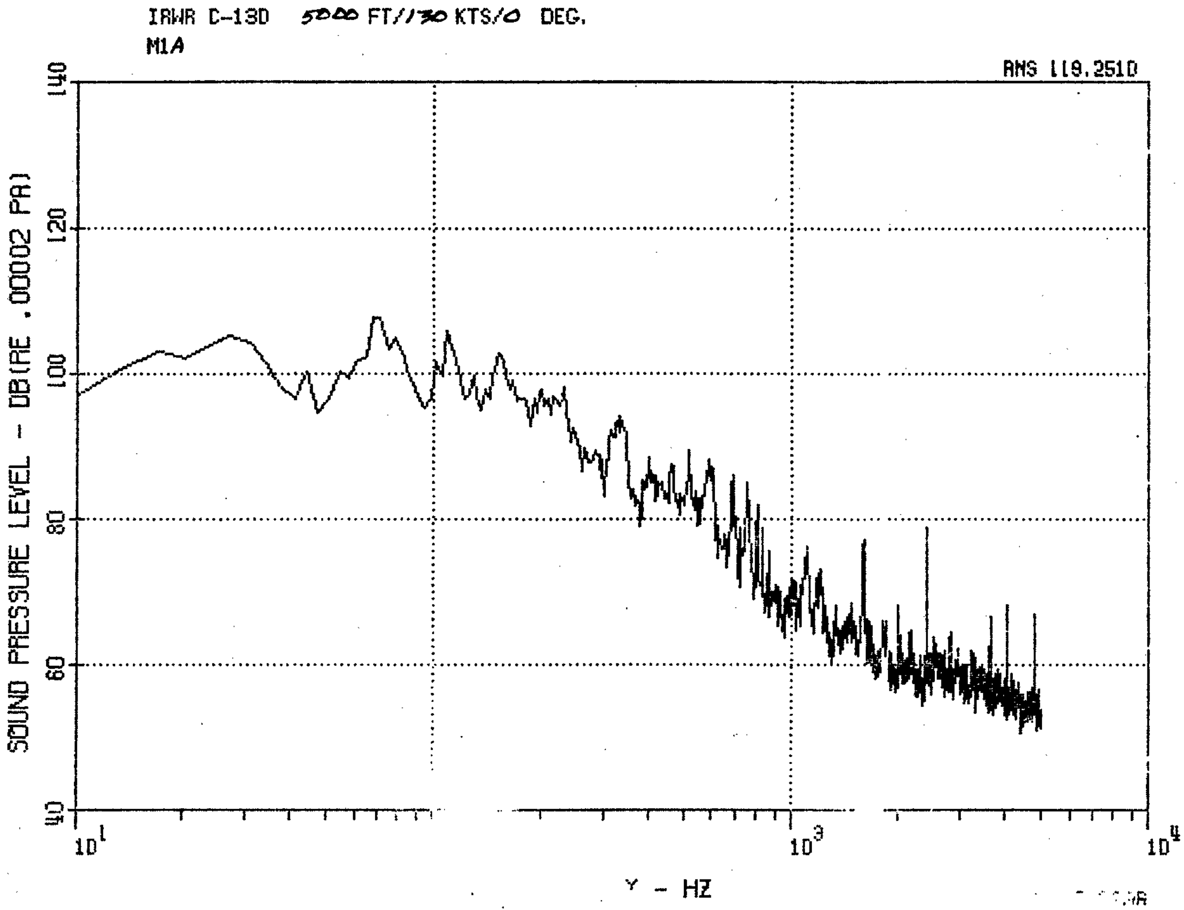


Figure 56. C-130 Aft Microphone MA, 200 Ft, 130 Kt, 0 Deg, and 1000 Ft, 130 Kt, 0 Deg.



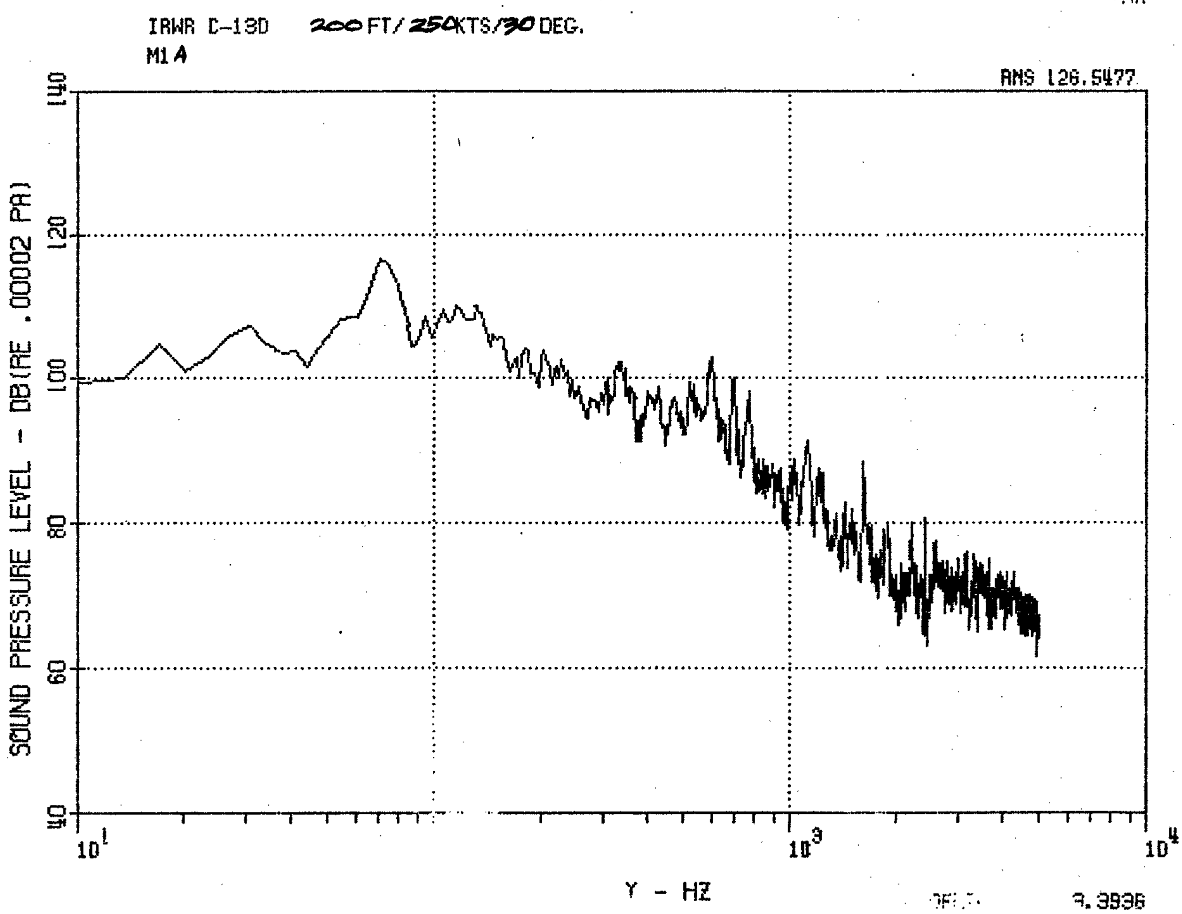
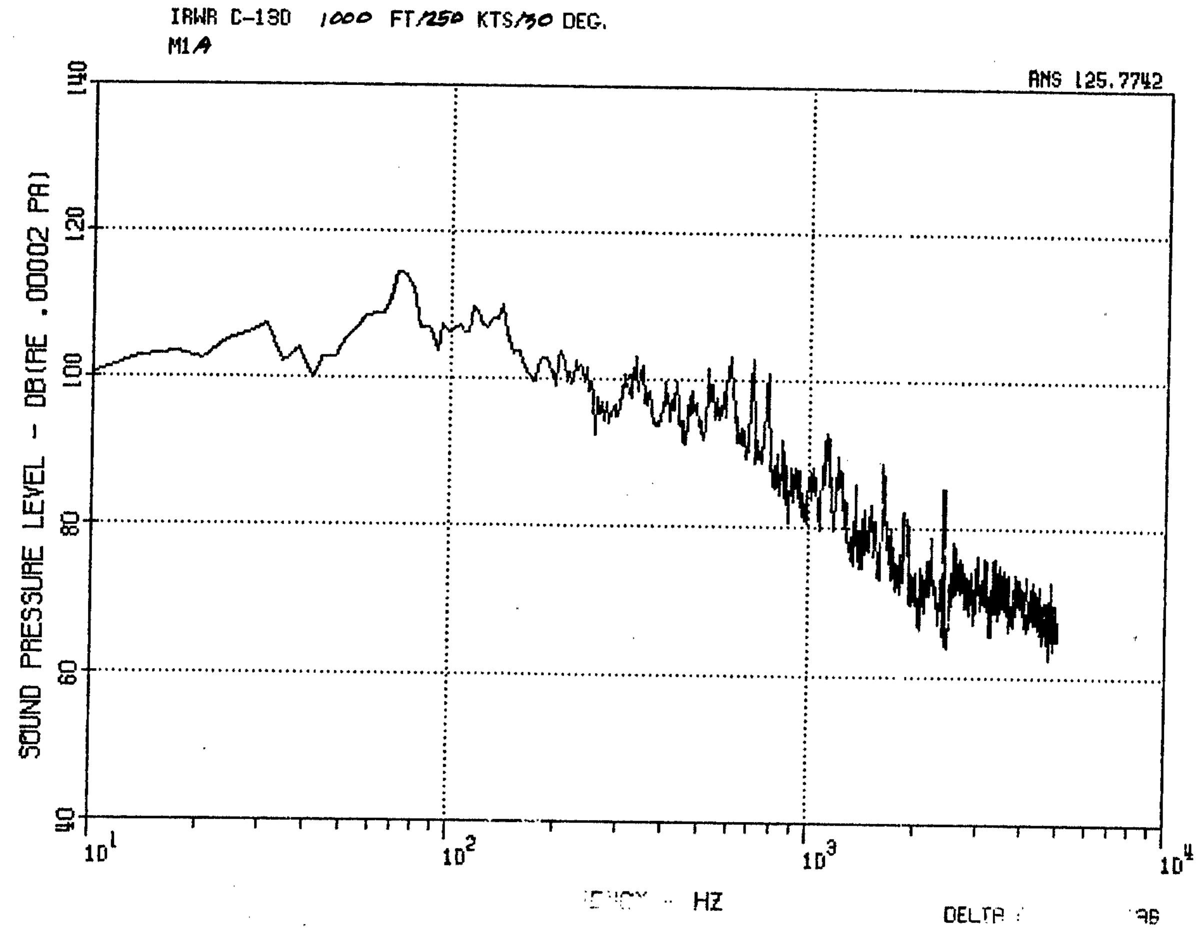


Figure 57. C-130 Aft Microphone MA, 5000 Ft, 130 Kt, 0 Deg, and 200 Ft, 250 Kt, 30 Deg.



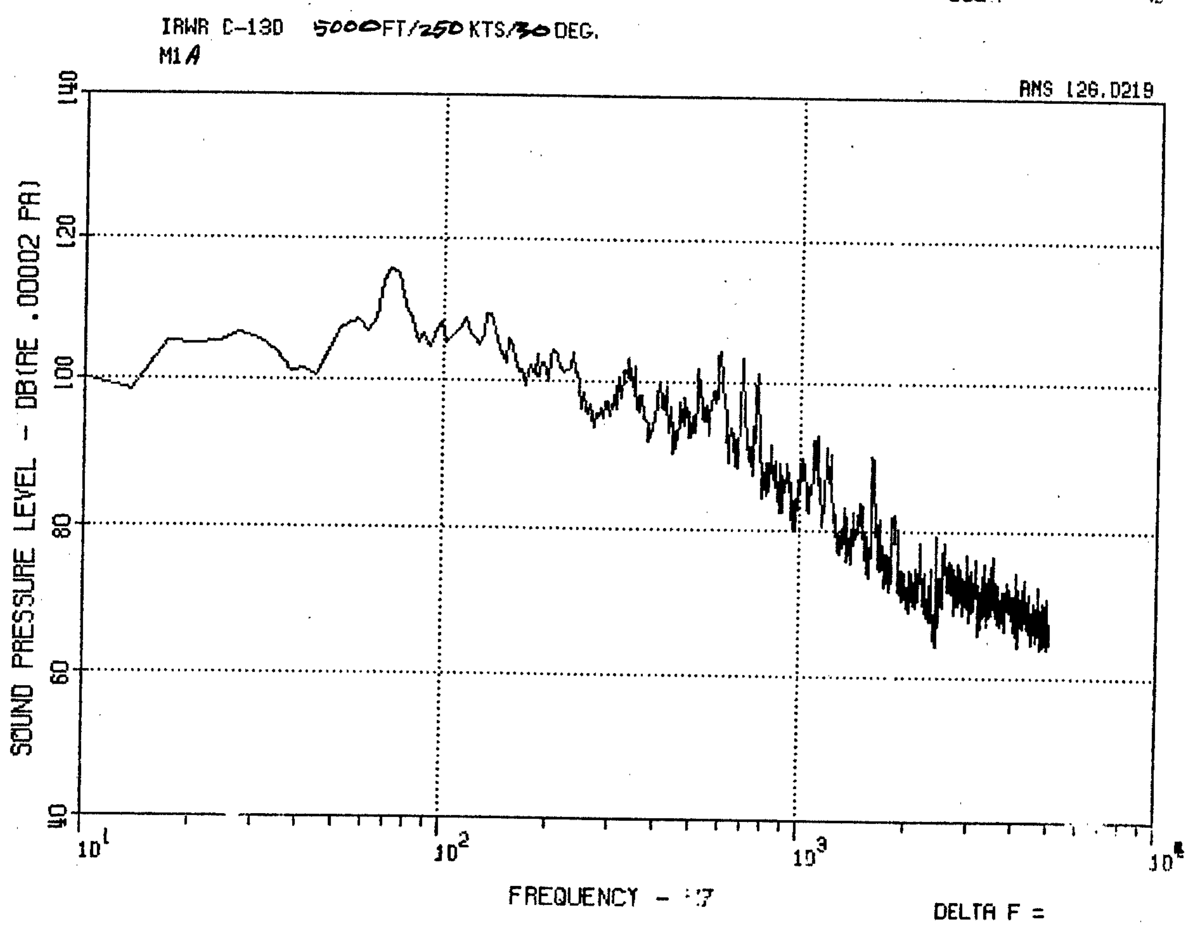


Figure 58. C-130 Aft Microphone MA, 1000 Ft, 250 Kt, 30 Deg, and 5000 Ft, 250 Kt, 30 Deg.

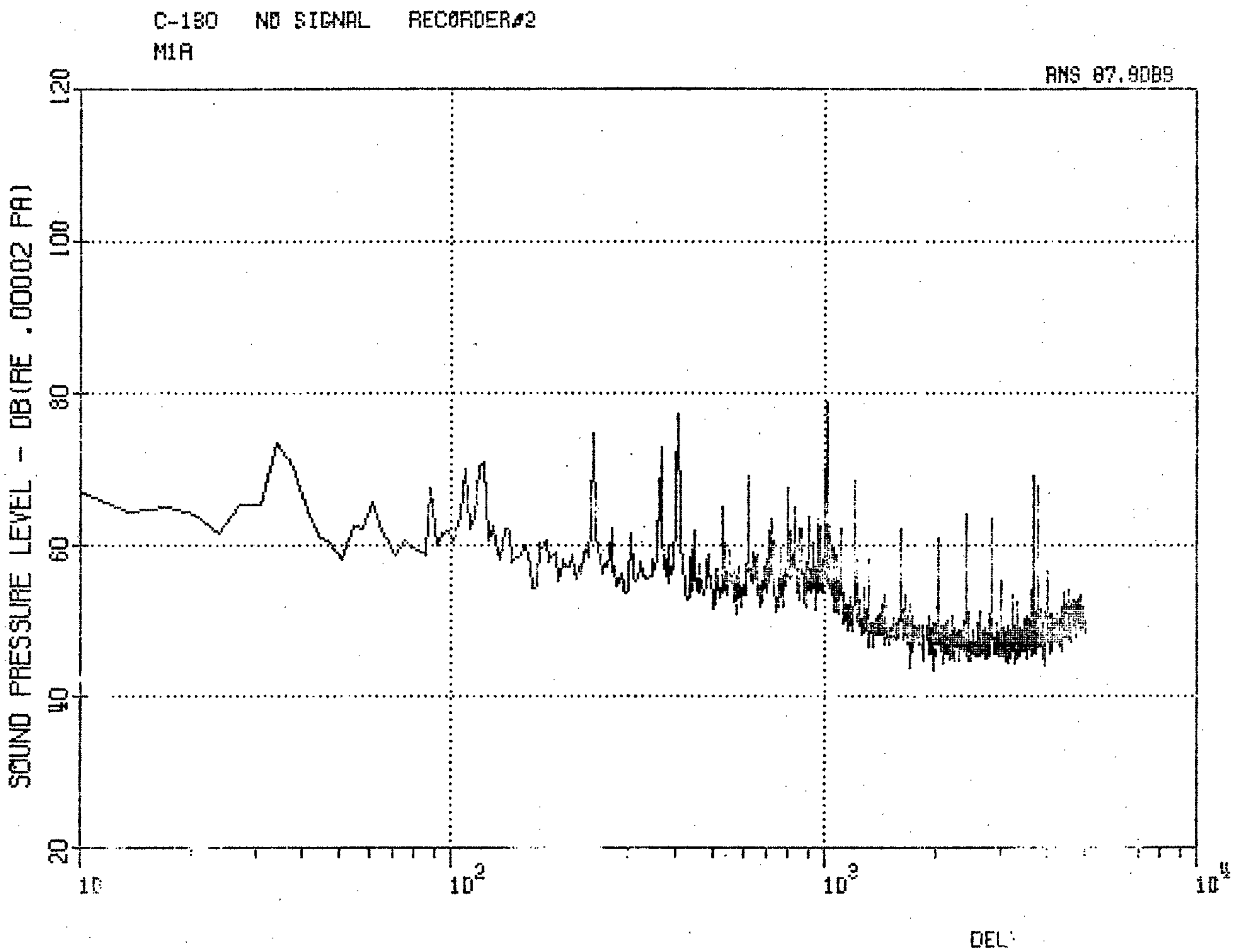
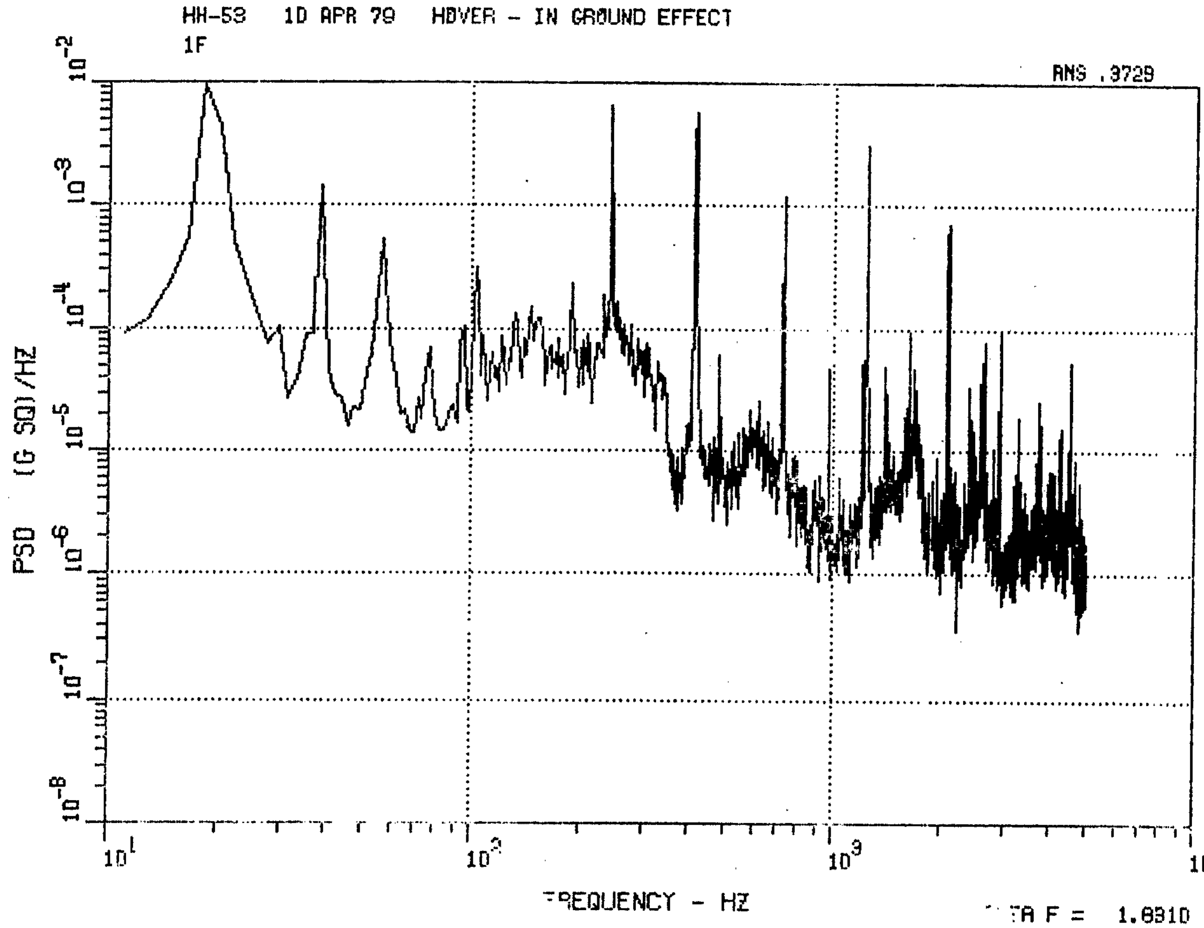


Figure 59. C-130 Aft Microphone MA, No-Signal Record.



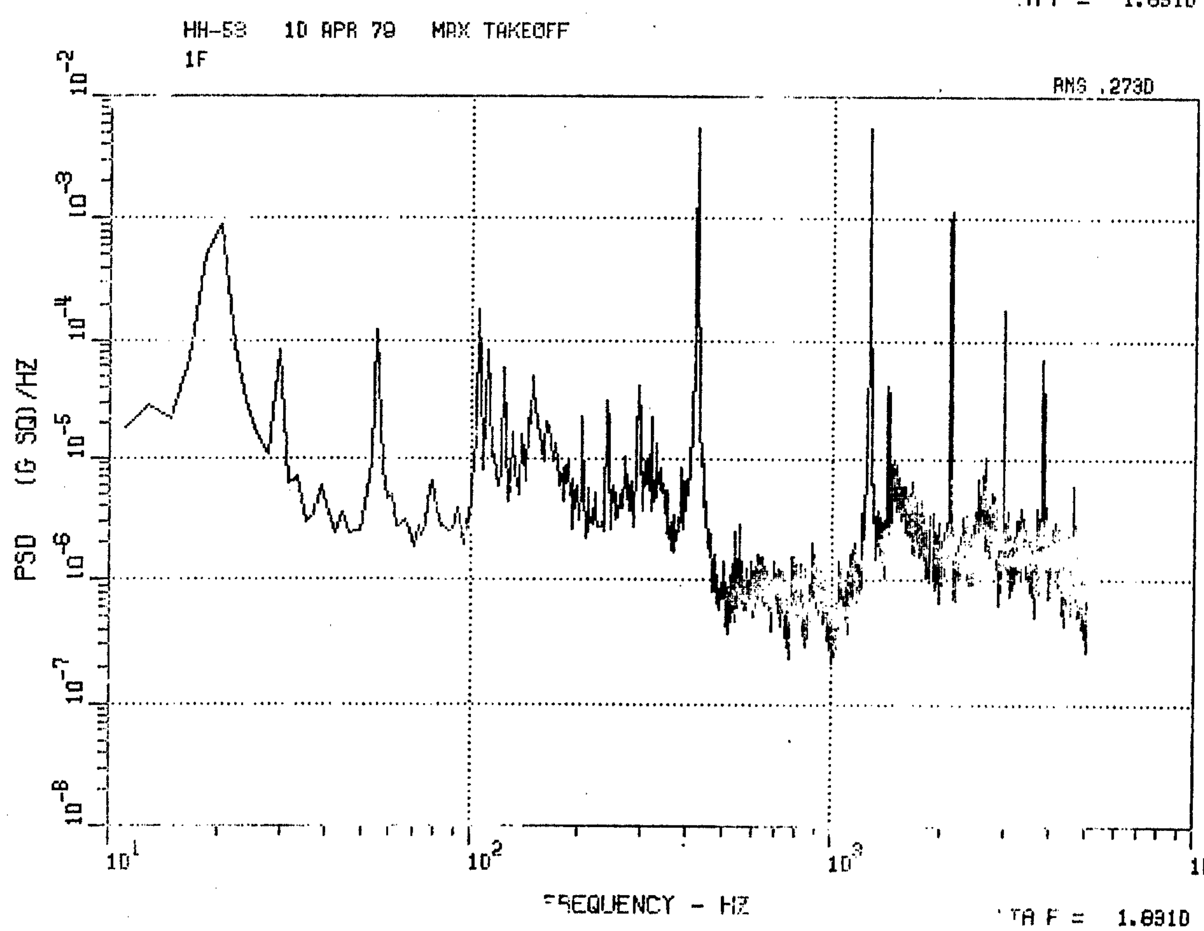
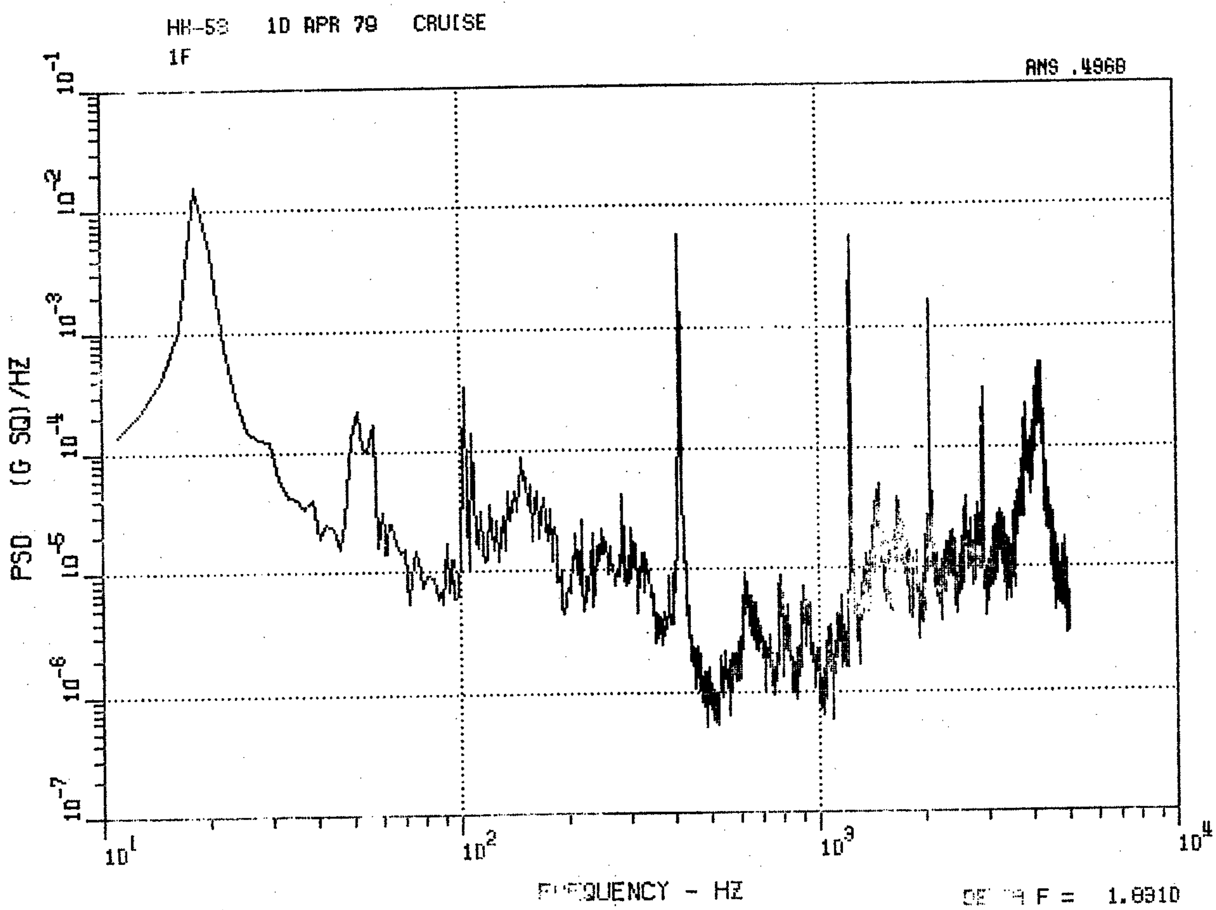


Figure 60. HH-53 Fwd Lateral Accelerometer 1F, Hover IGE and Max Takeoff.



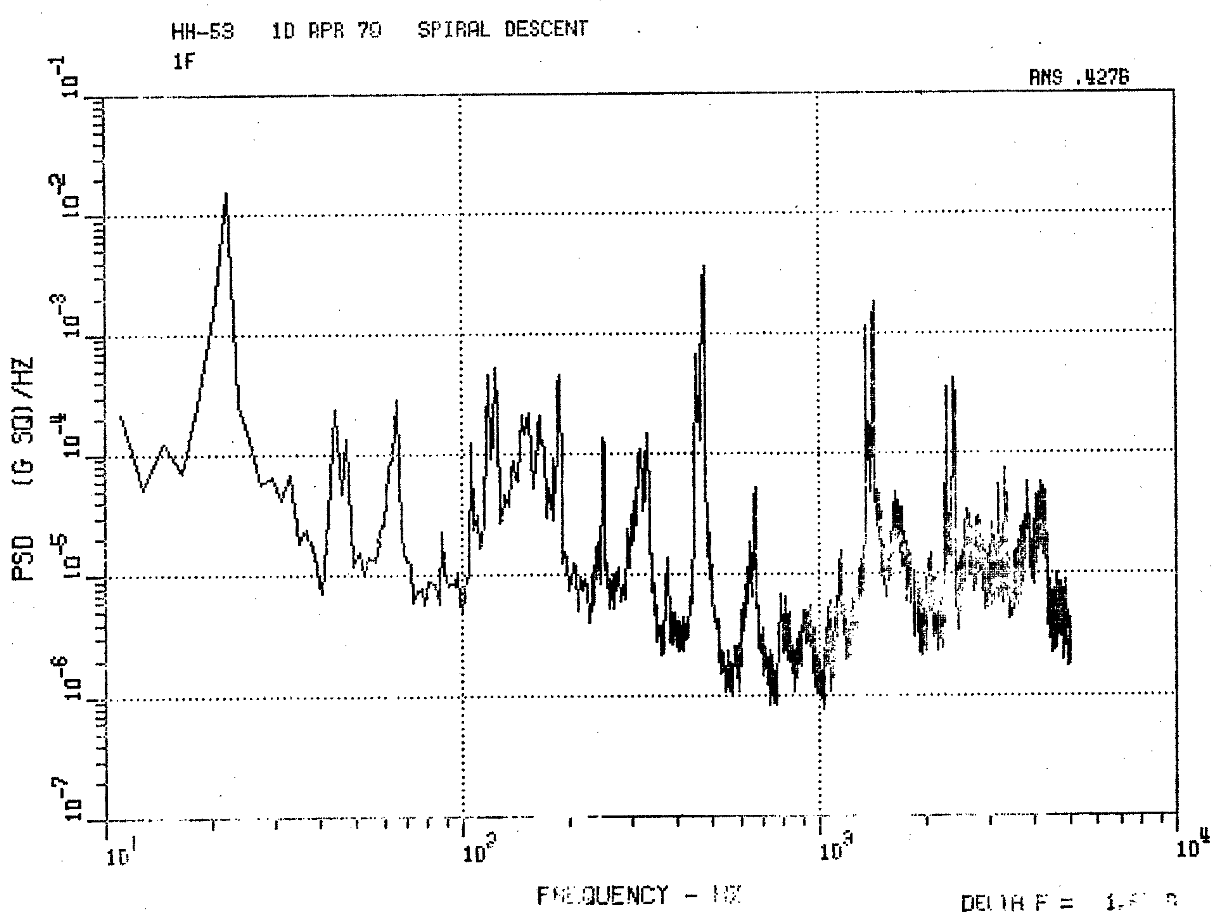
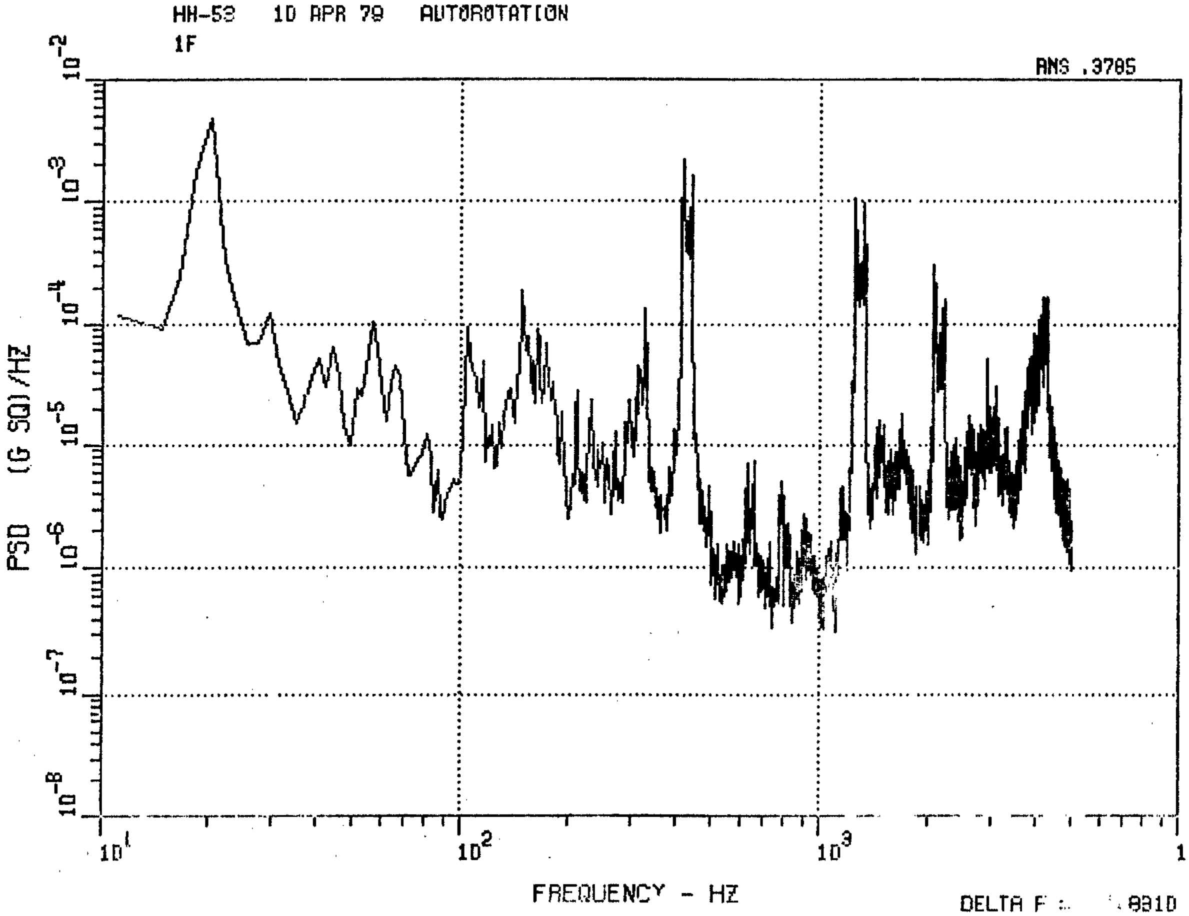


Figure 61. HH-53 Fwd Lateral Accelerometer 1F, Cruise and Spiral Descent.



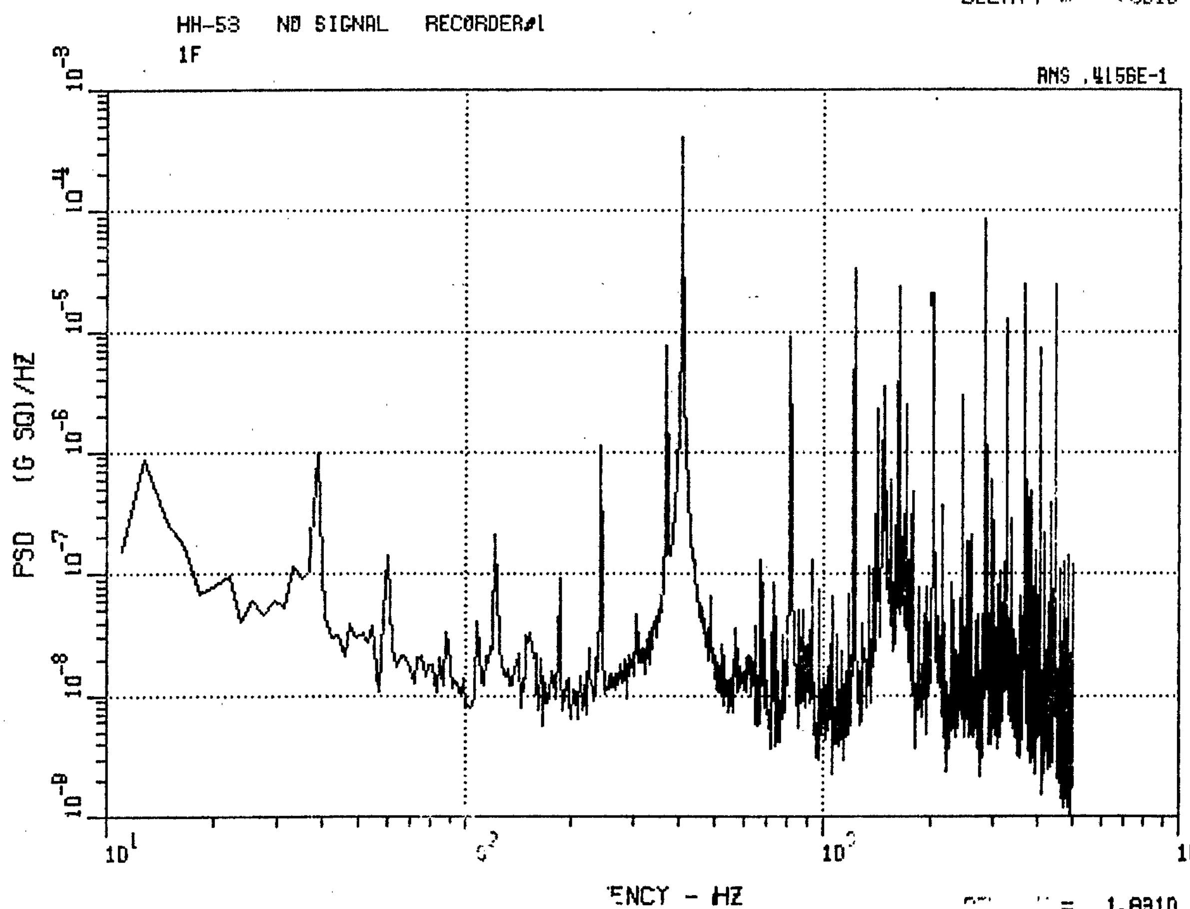


Figure 62. HH-53 Fwd Lateral Accelerometer 1F, Autorotation and No-Signal Record.

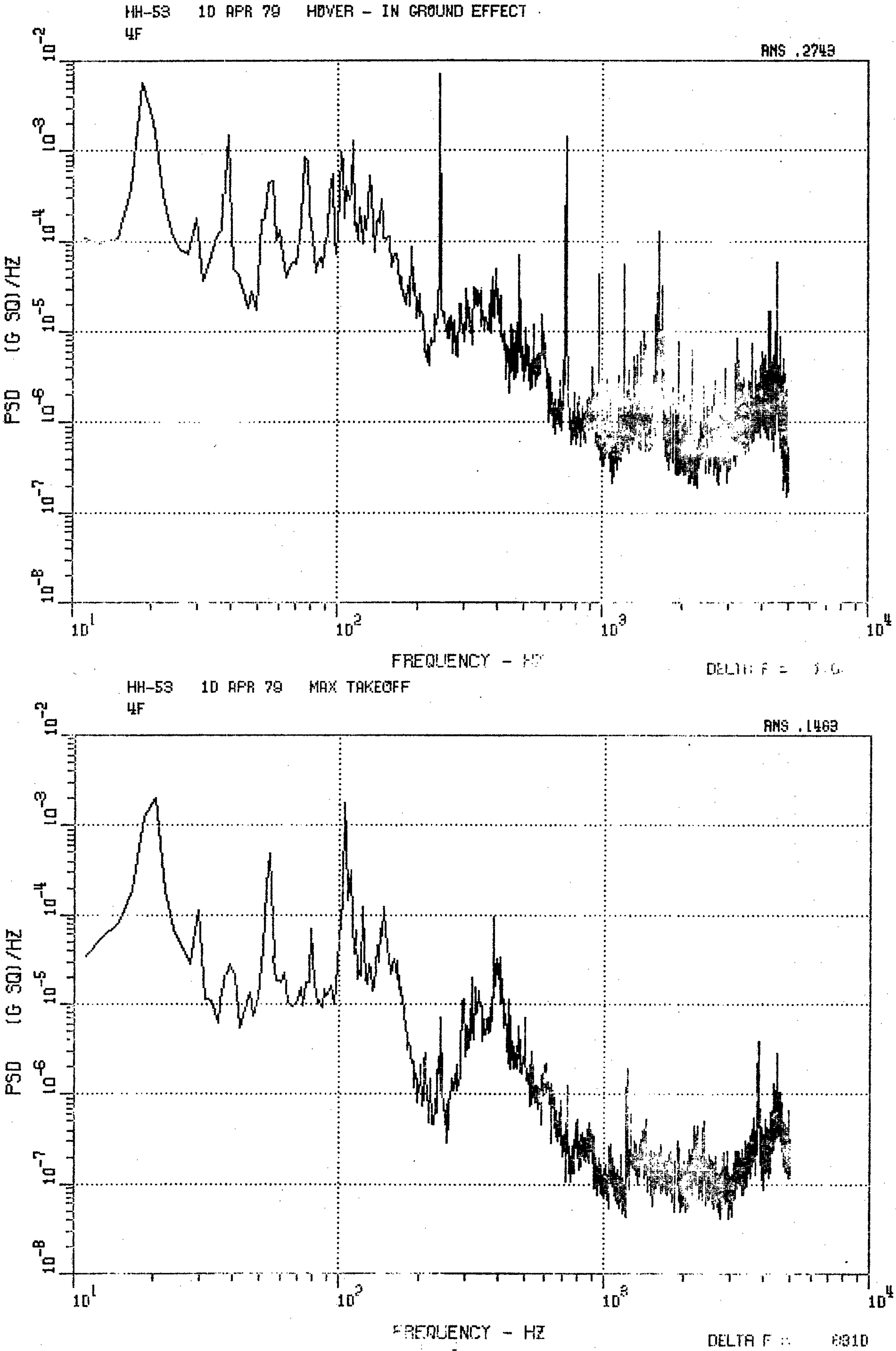
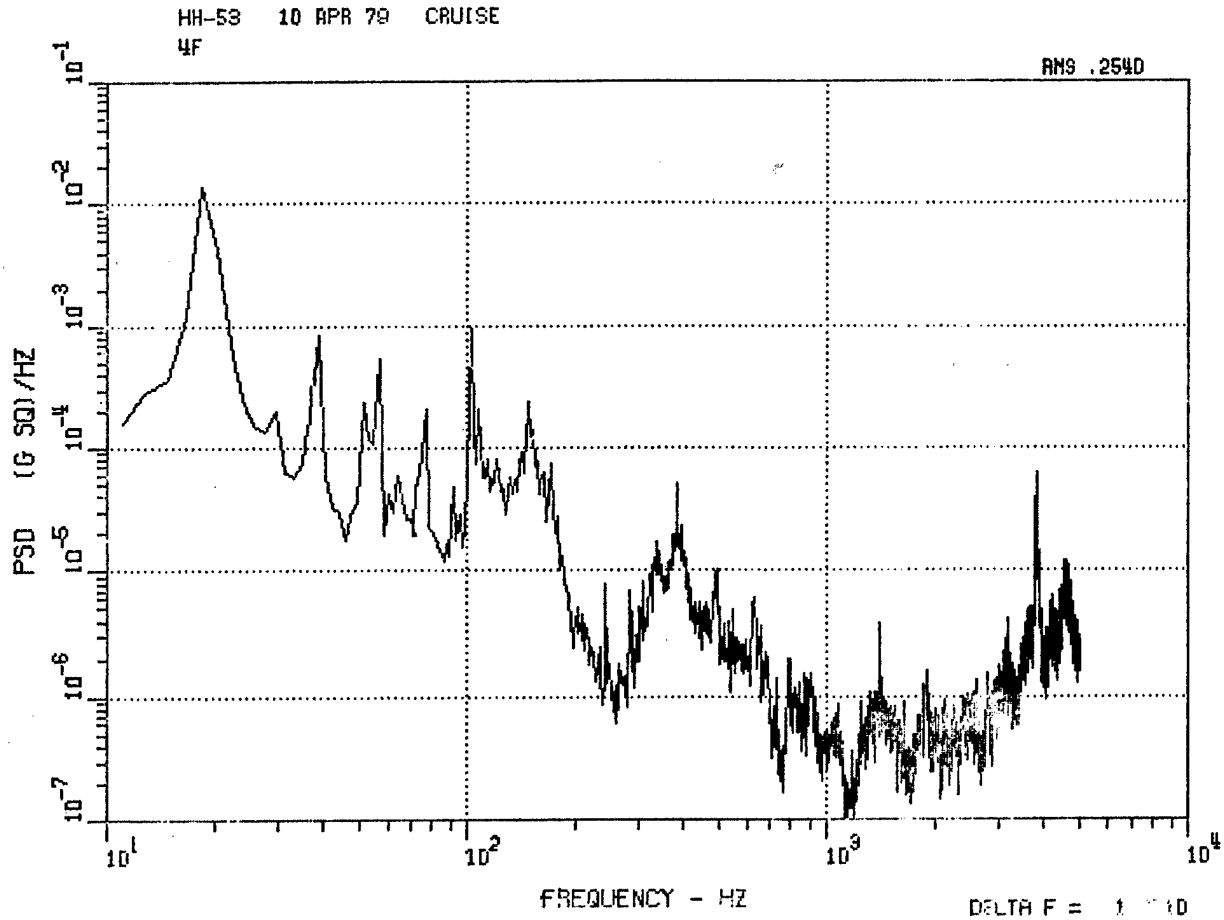


Figure 63. HH-53 Fwd Vertical Accelerometer 4F, Hover IGE and Max Takeoff.



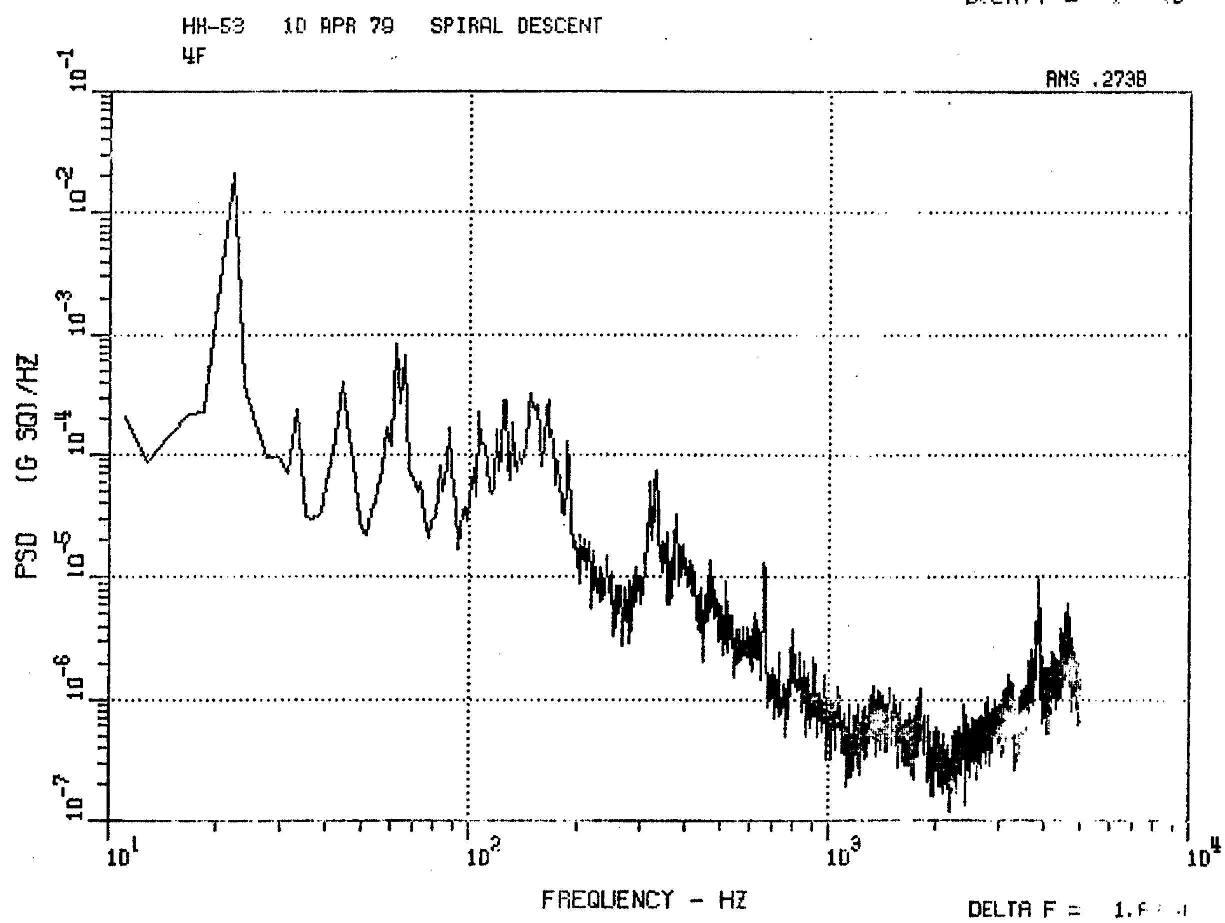


Figure 64. HH-53 Fwd Vertical Accelerometer 4F, Cruise and Spiral Descent.

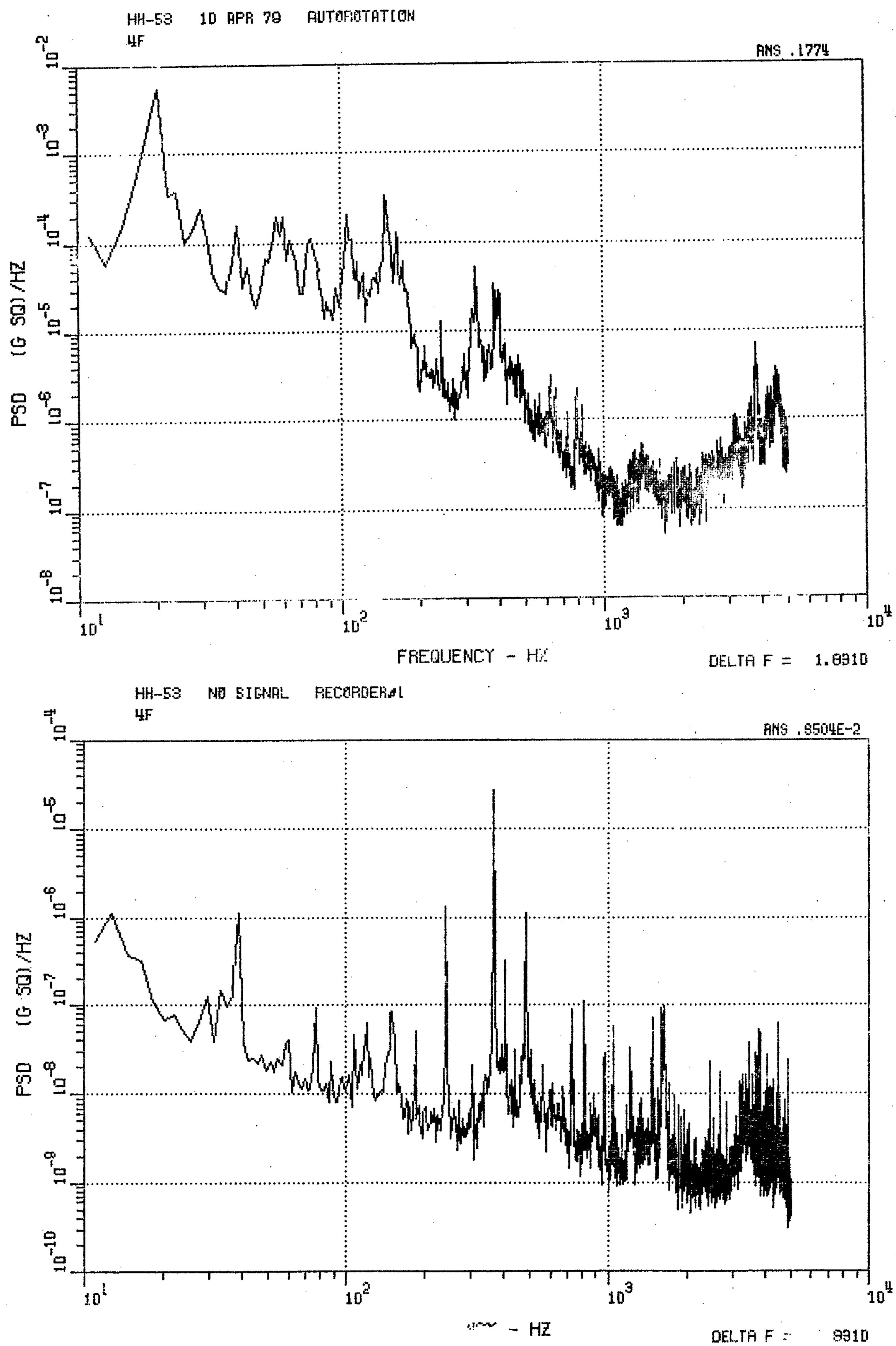


Figure 65. HH-53 Fwd Vertical Accelerometer 4F, Autorotation and No-Signal Record.

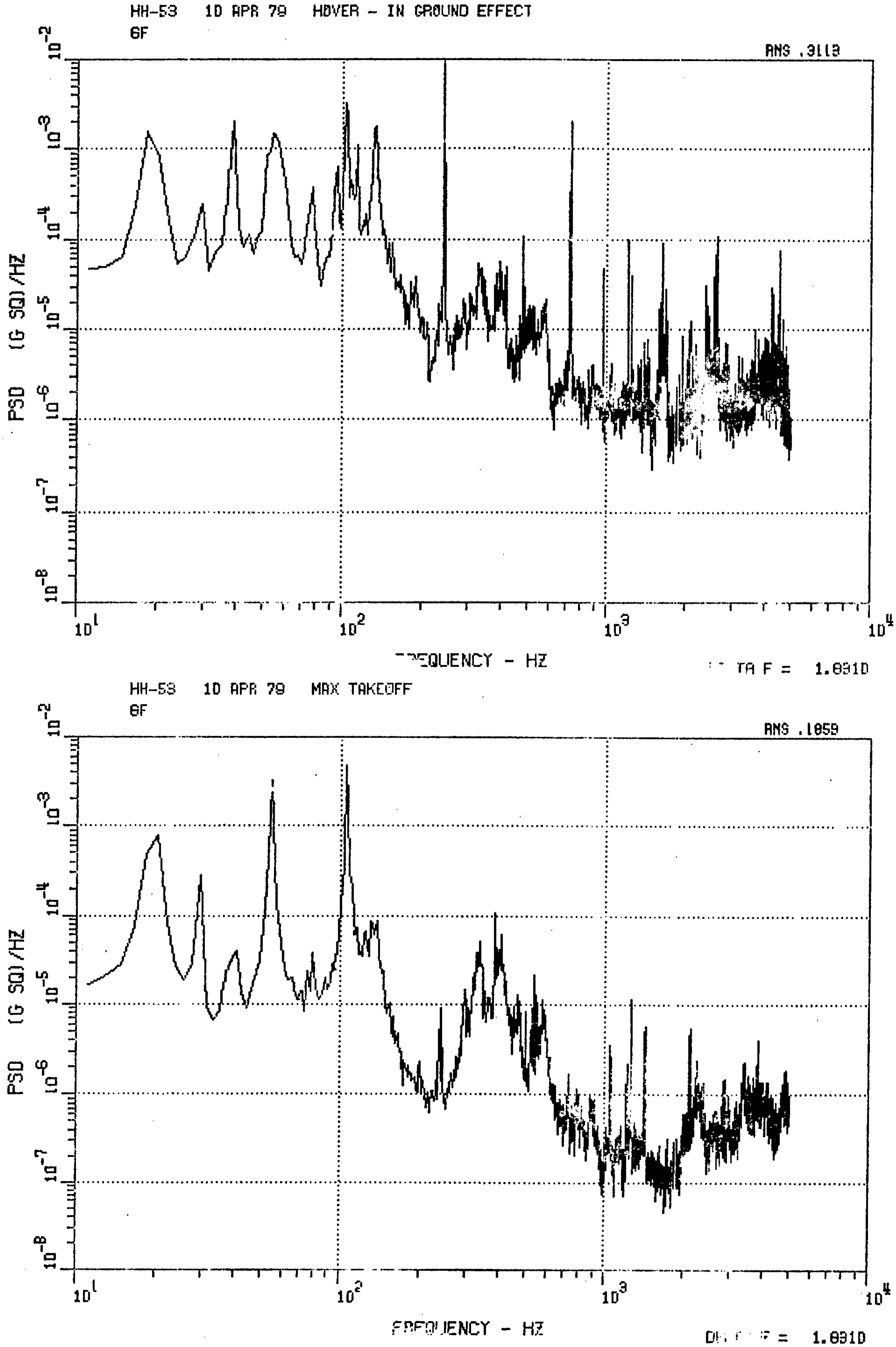


Figure 66. HH-53 Fwd Longitudinal Accelerometer 6F, Hover IGE and Max Takeoff.

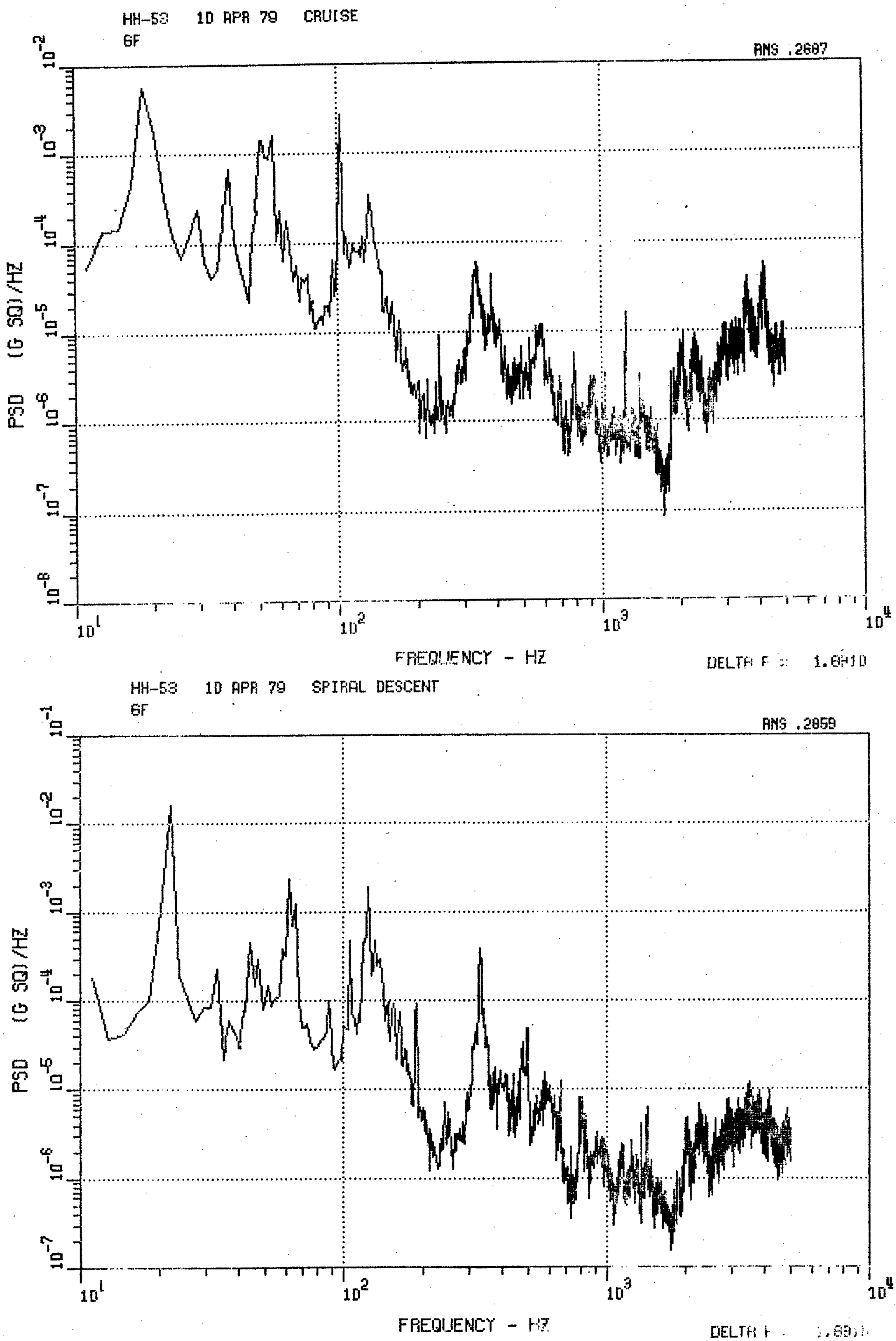


Figure 67. HH-53 Fwd Longitudinal Accelerometer 6F, Cruise and Spiral Descent.

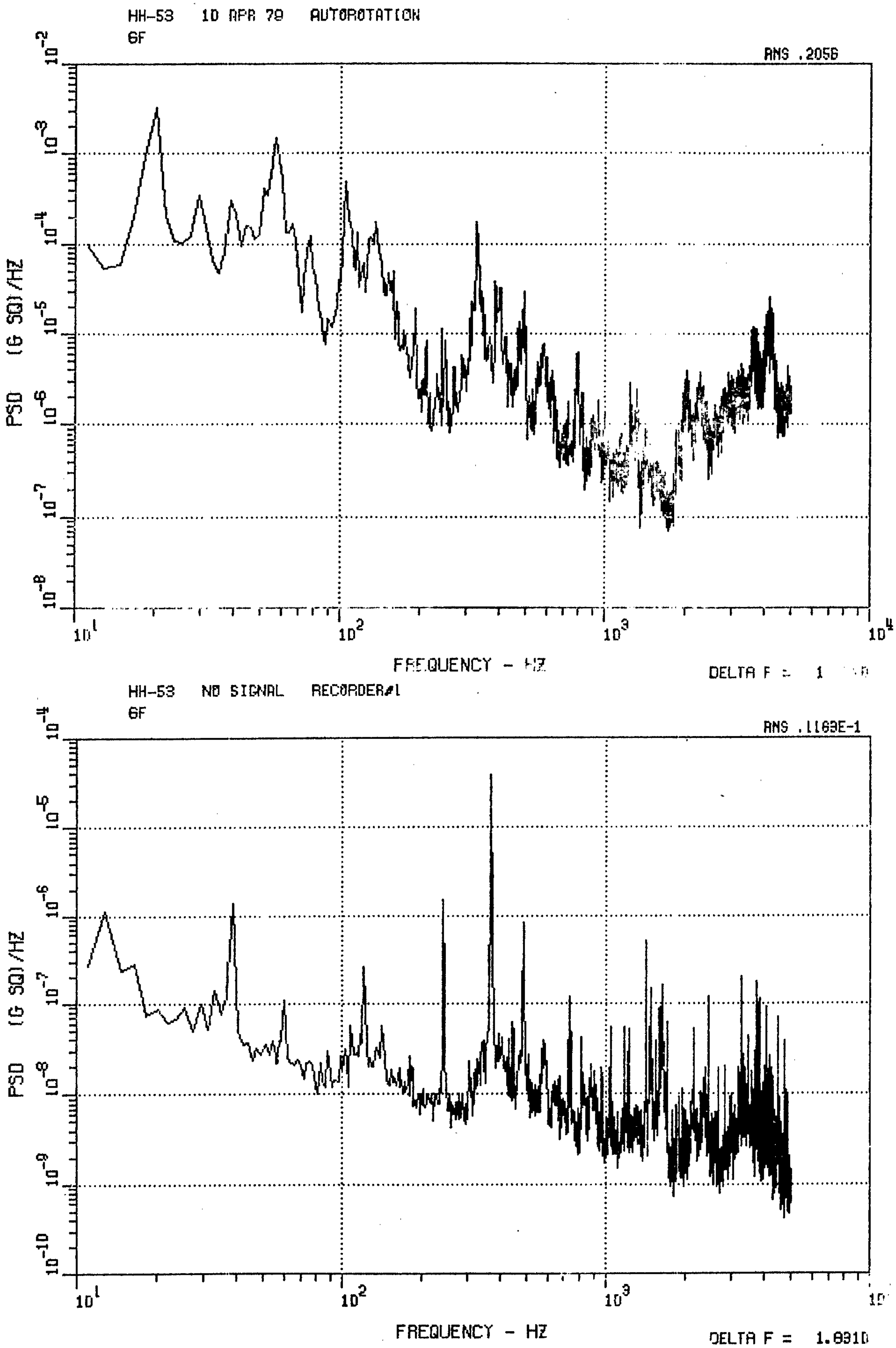
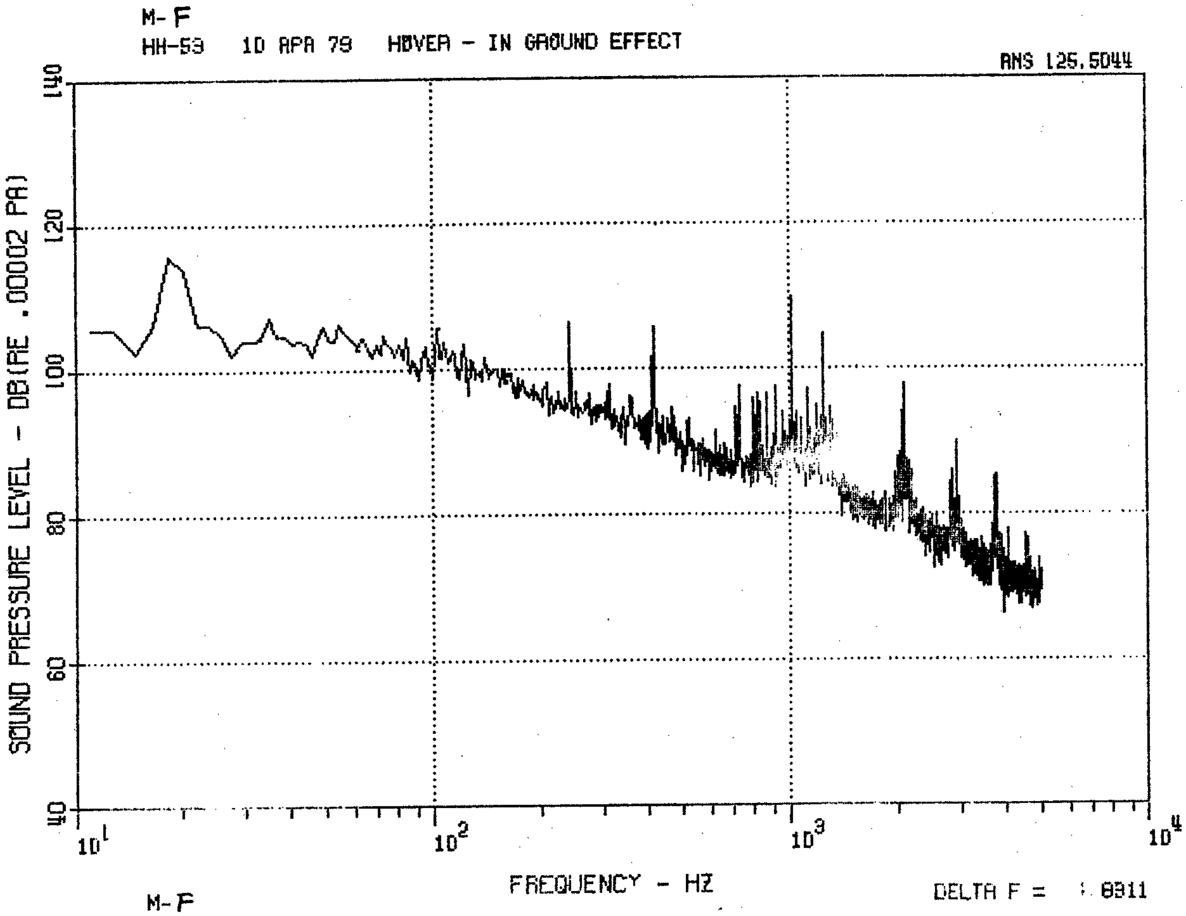


Figure 68. HH-53 Fwd Longitudinal Accelerometer 6F, Autorotation and No-Signal Record.



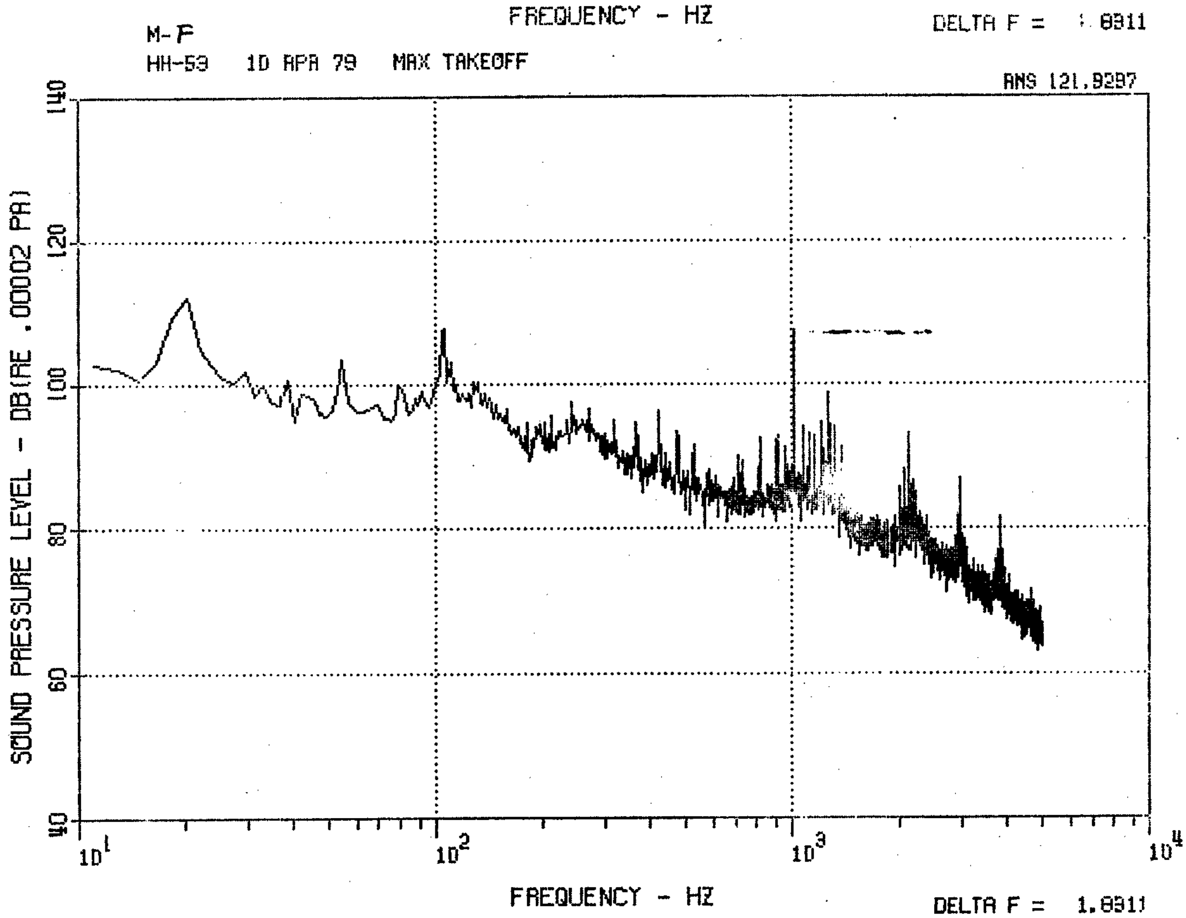
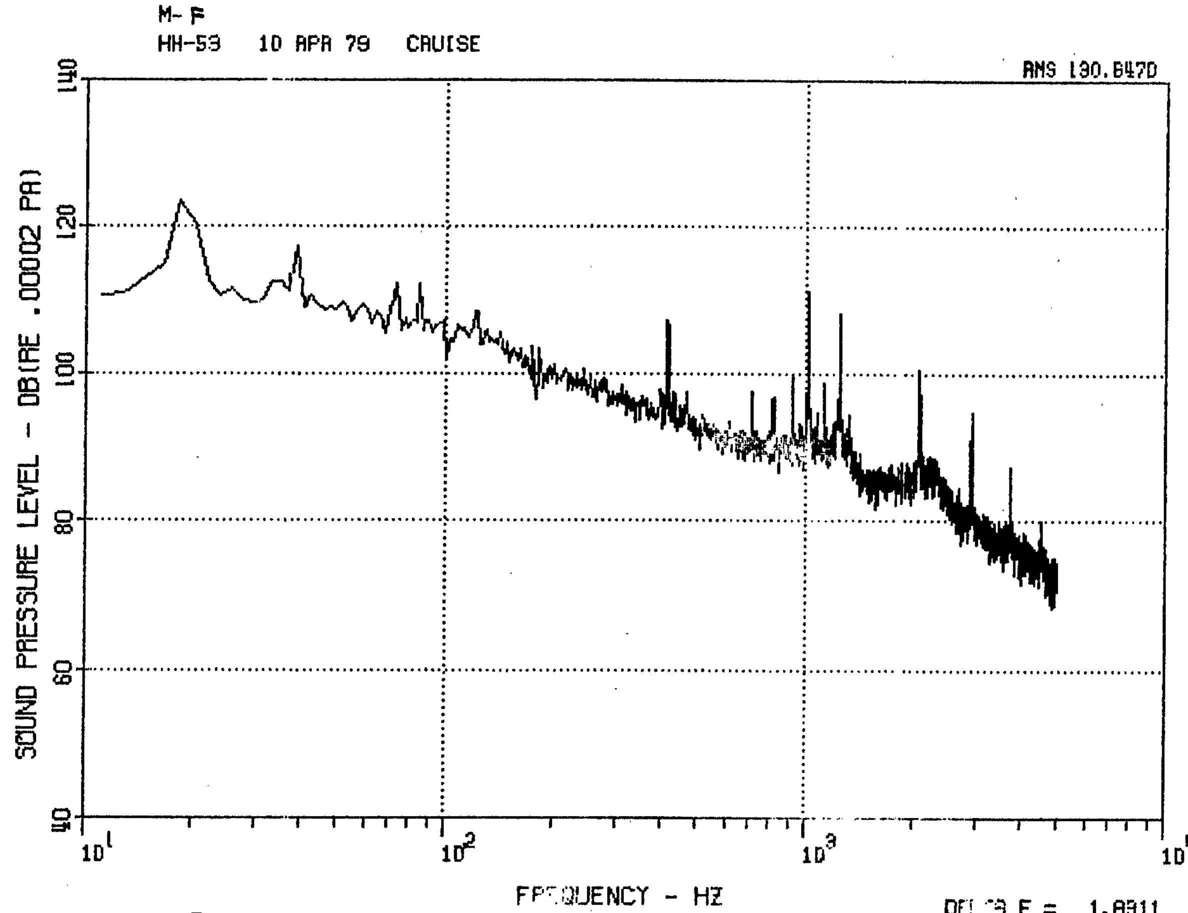


Figure 69. HH-53 Fwd Microphone MF, Hover IGE and Max Takeoff.



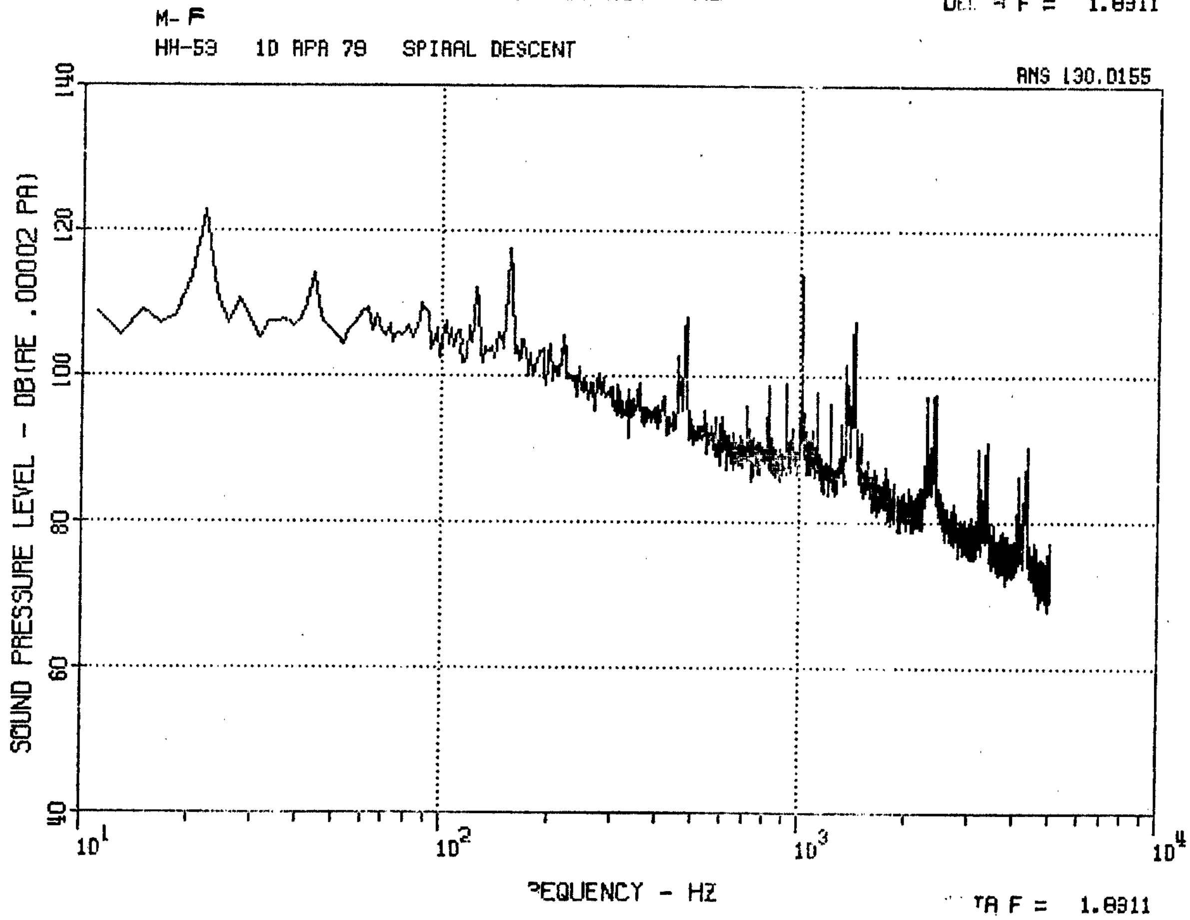
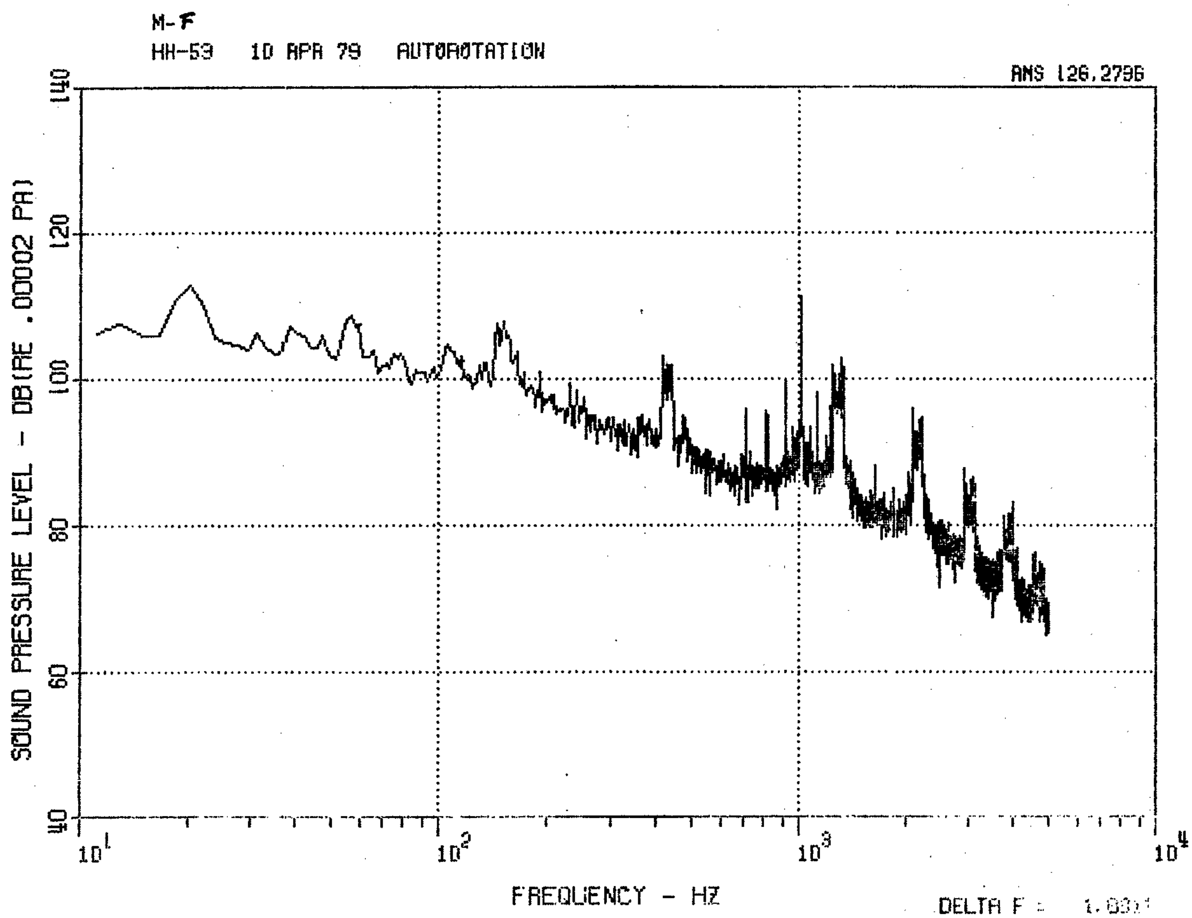


Figure 70. HH-53 Fwd Microphone MF, Cruise and Spiral Descent.



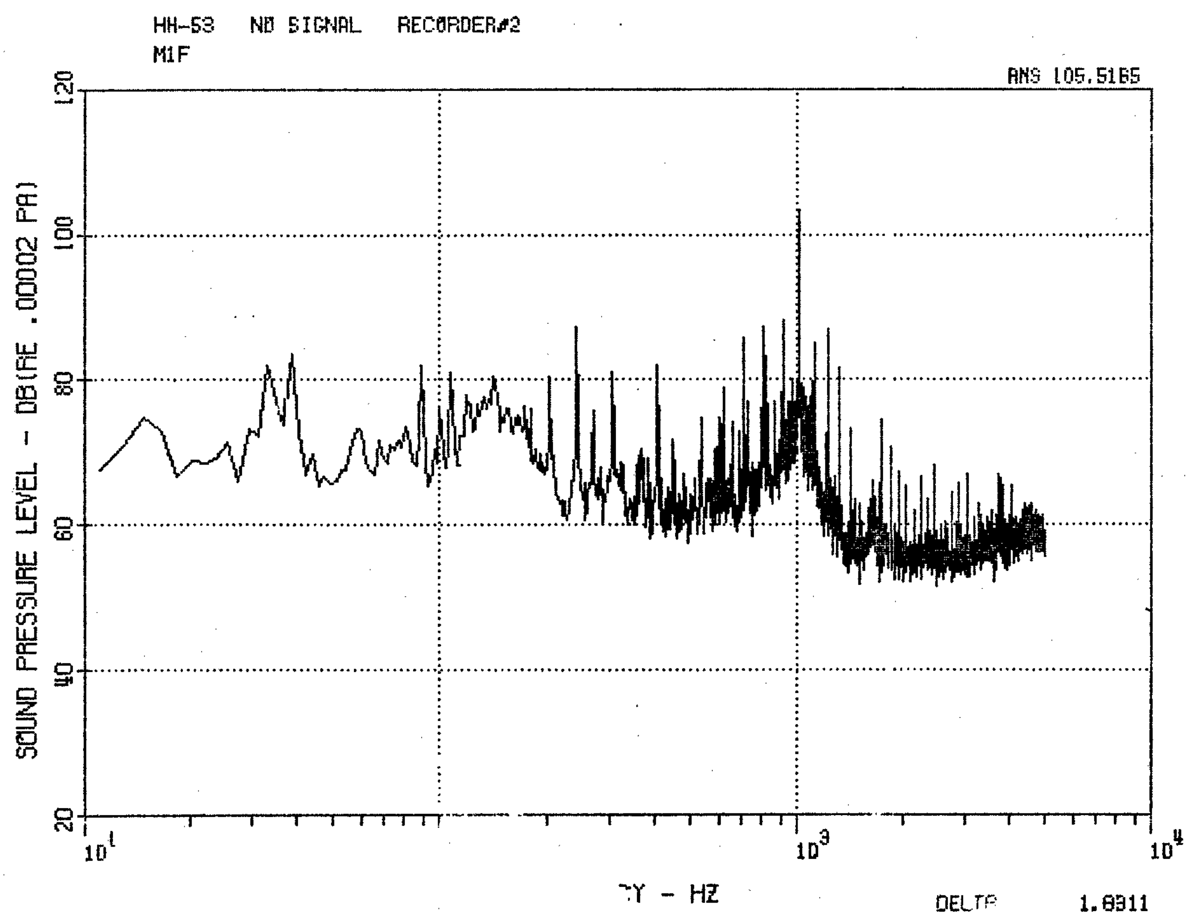
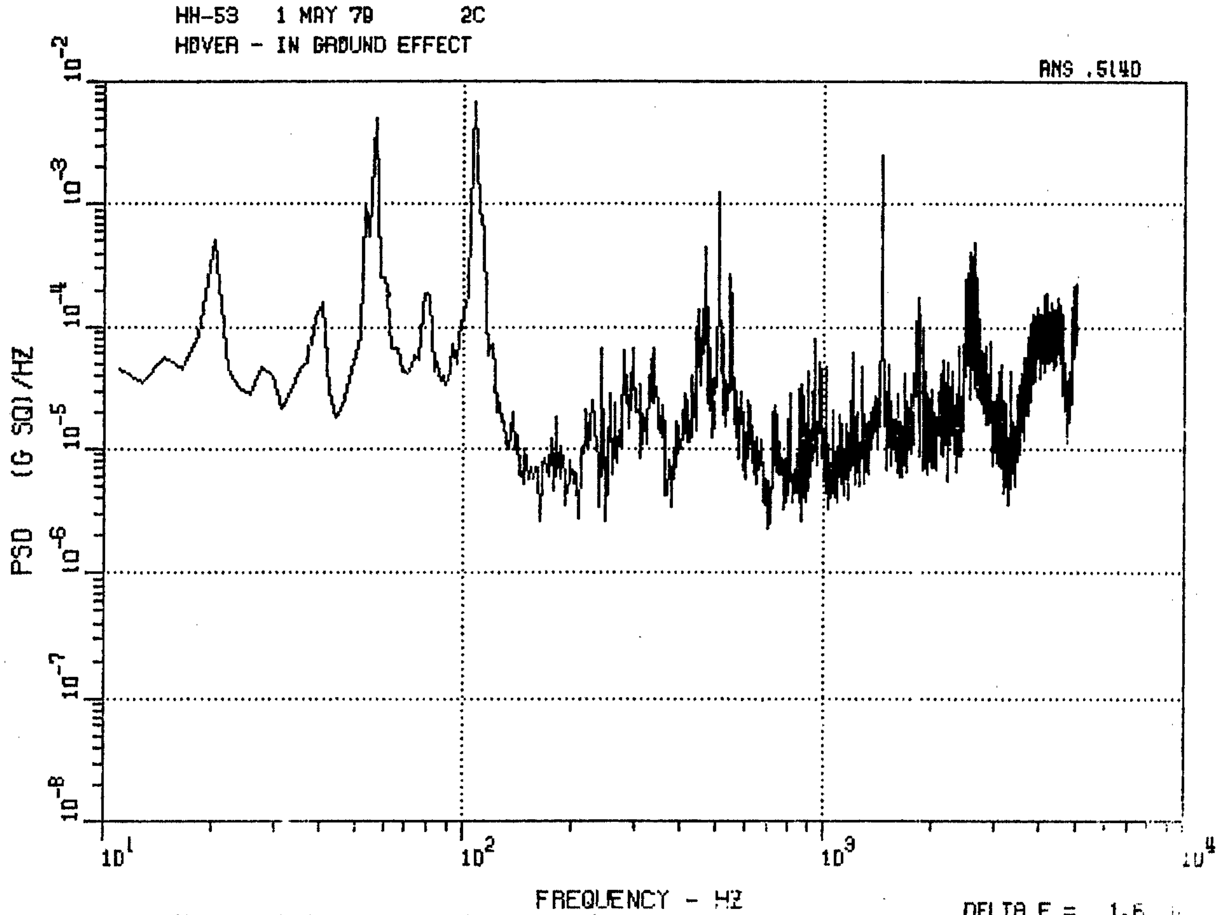


Figure 71. HH-53 Fwd Microphone MF, Autorotation and No-Signal Record.



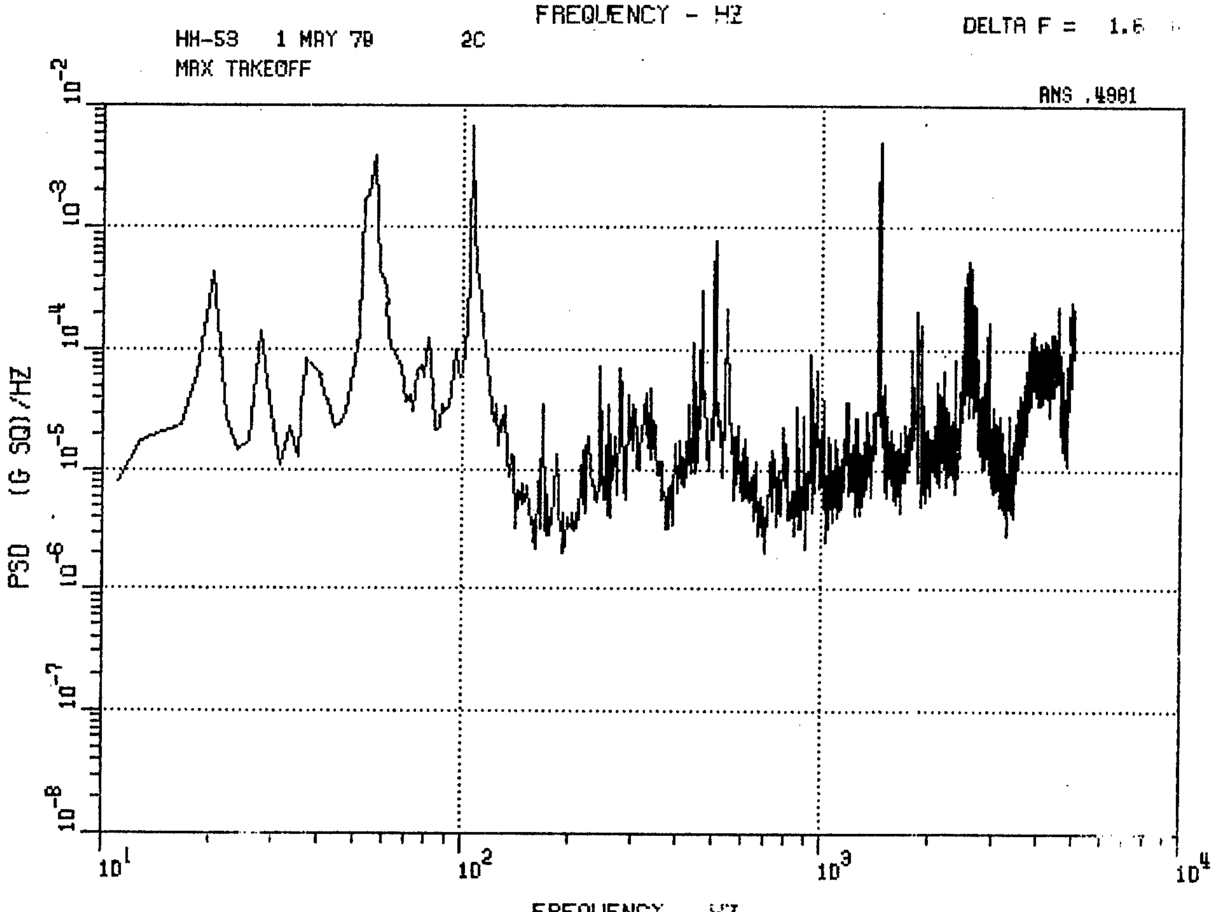


Figure 72. HH-53 Center Vertical Accelerometer 2C, Hover IGE and Max Takeoff.

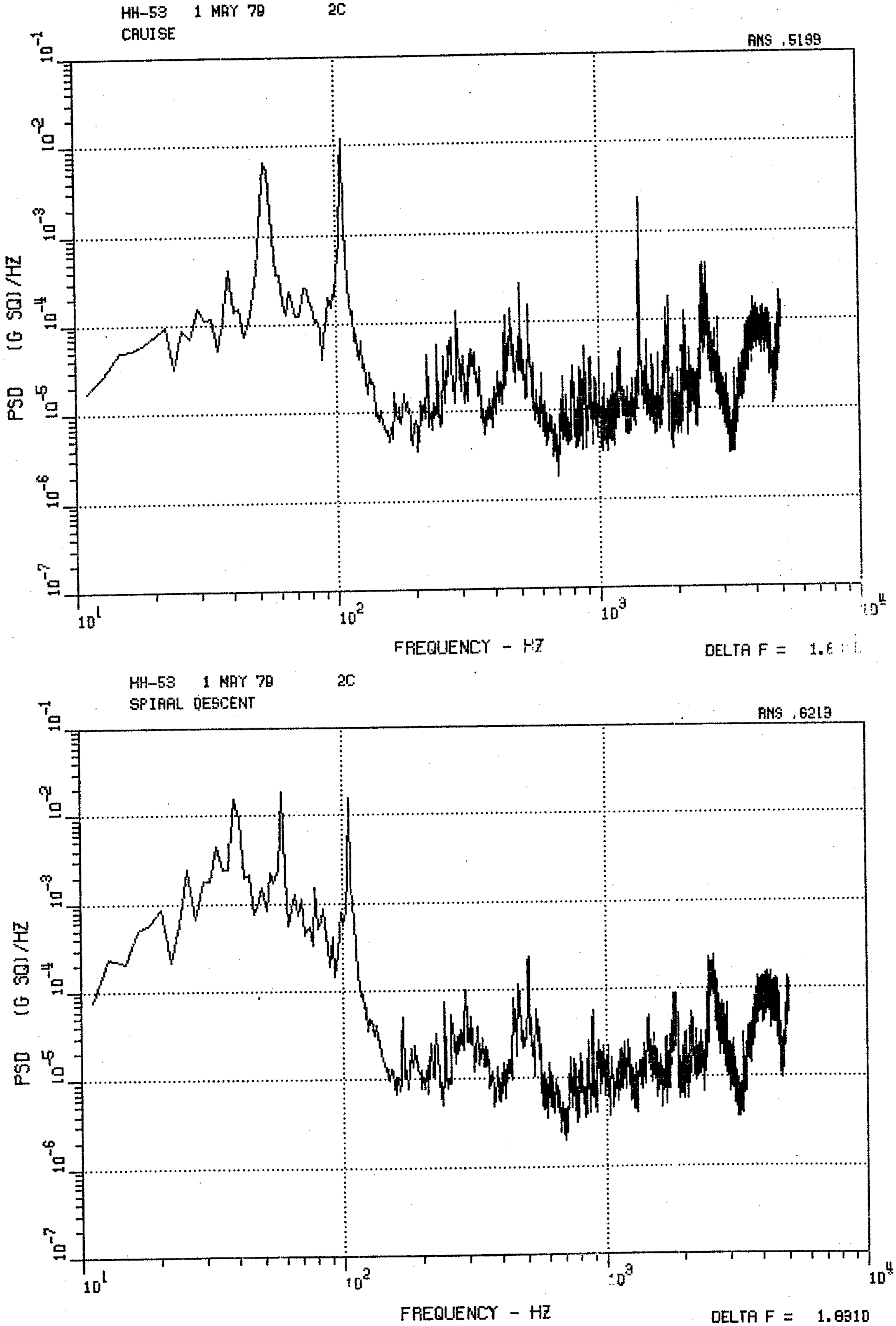
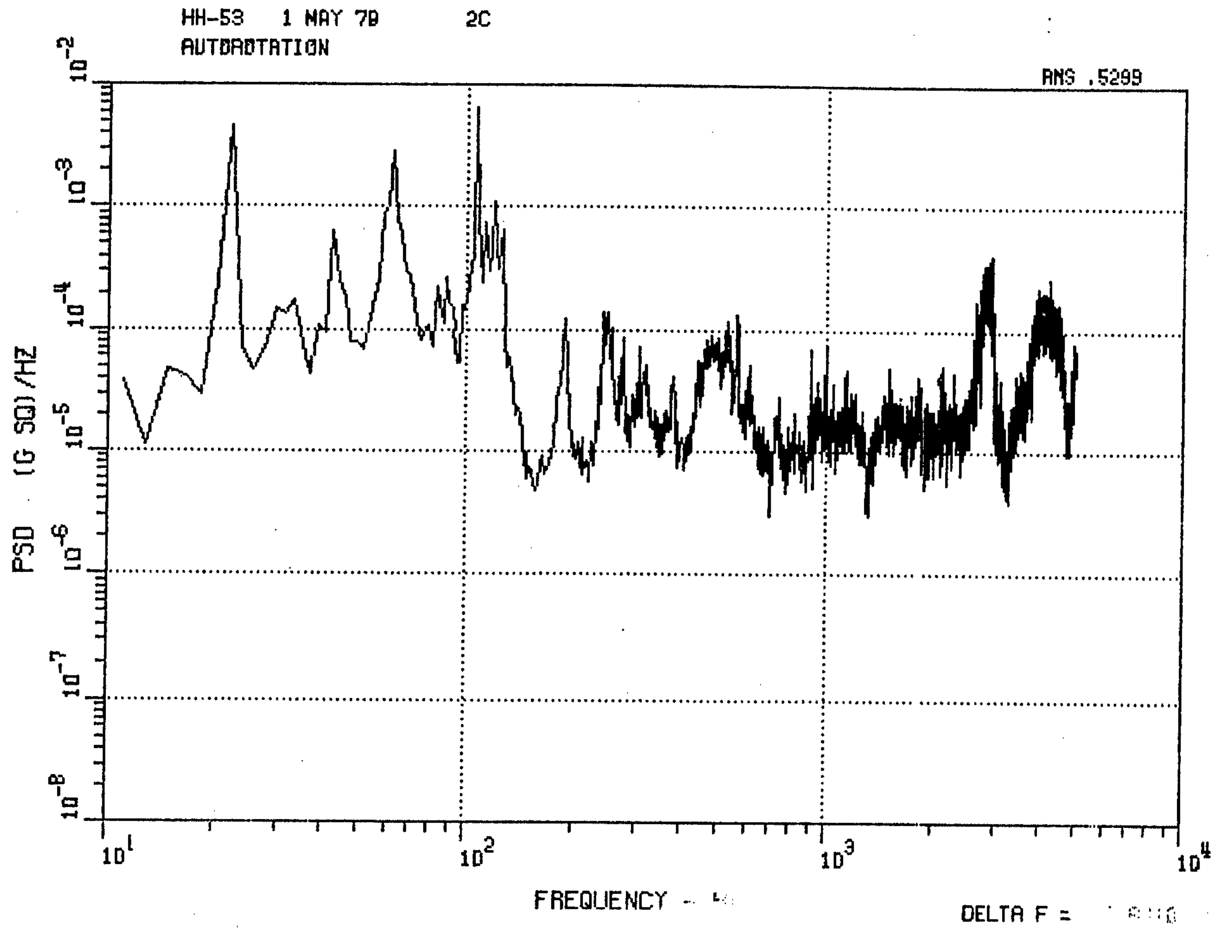


Figure 73. HH-53 Center Vertical Accelerometer 2C, Cruise and Spiral Descent.



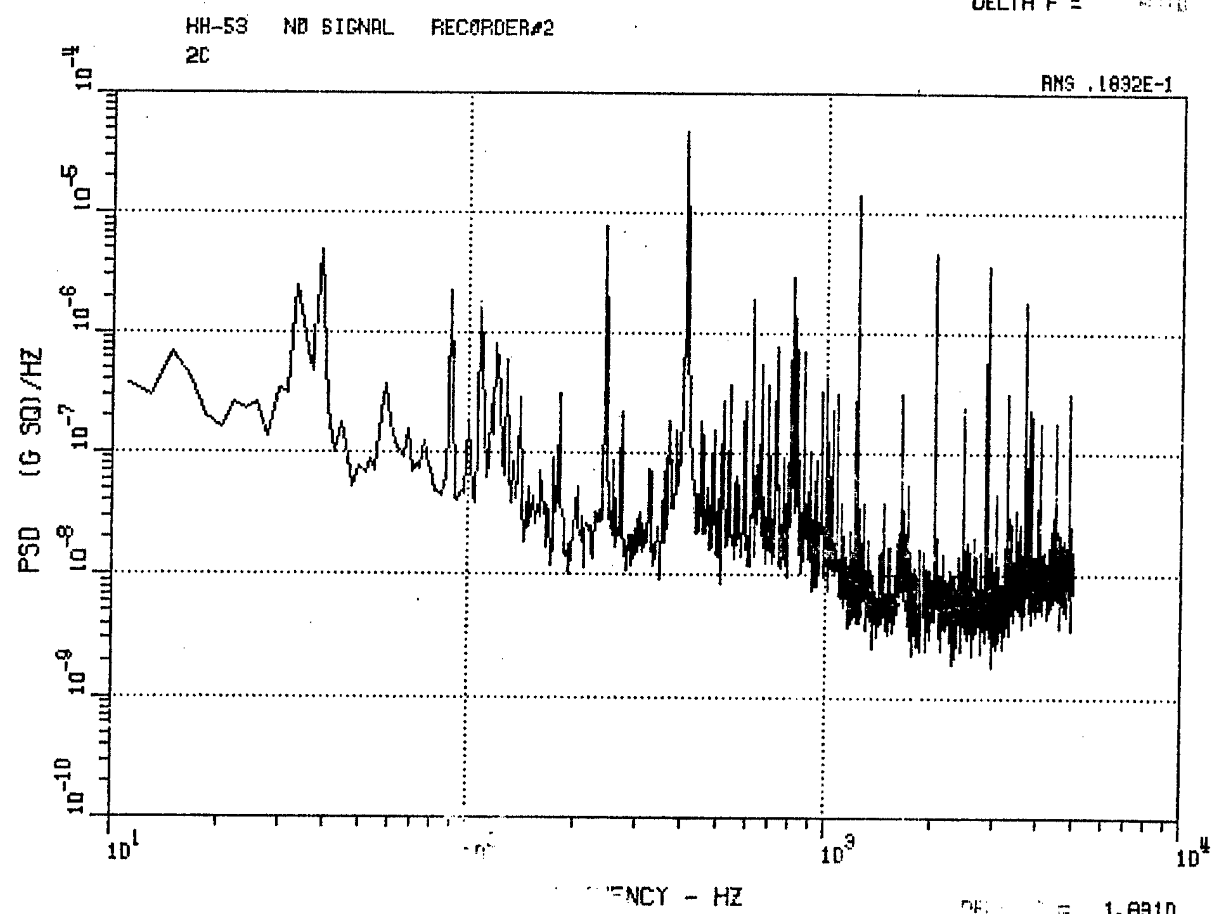


Figure 74. HH-53 Center Vertical Accelerometer 2C, Autorotation and No-Signal Record.

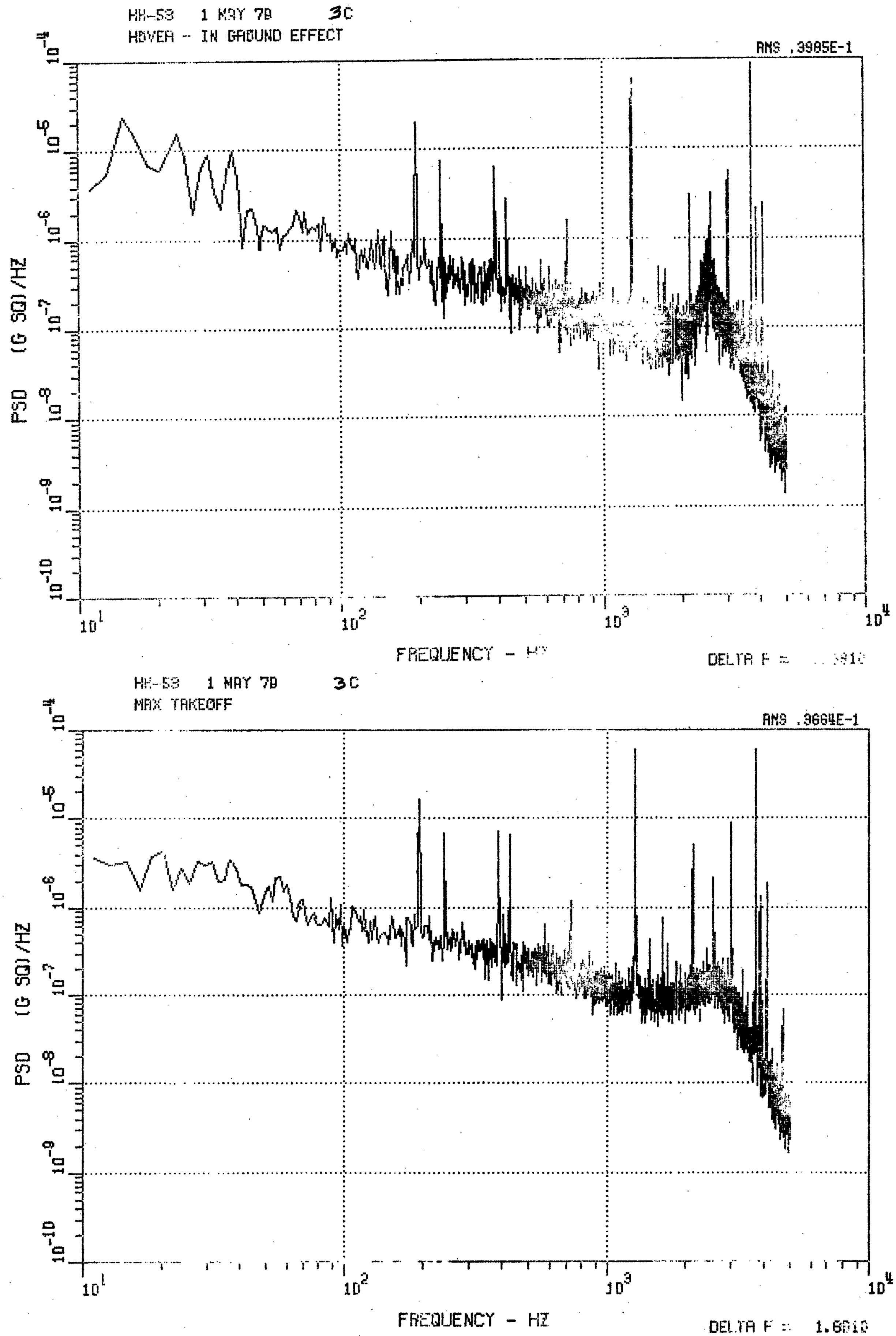


Figure 75. HH-53 Center Lateral Accelerometer 3C, Hover IGE and Max Takeoff.

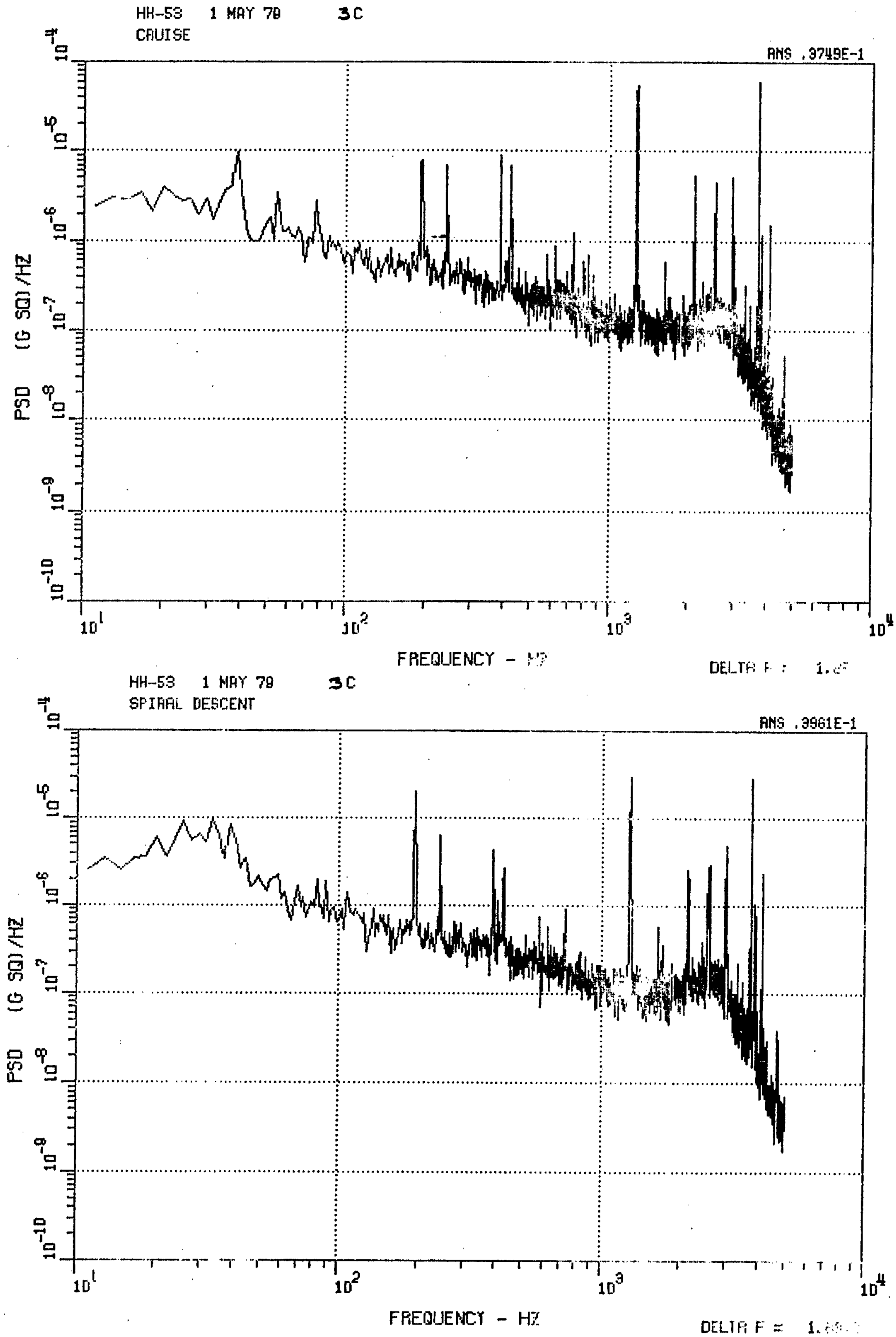


Figure 76. HH-53 Center Lateral Accelerometer 3C, Cruise and Spiral Descent.

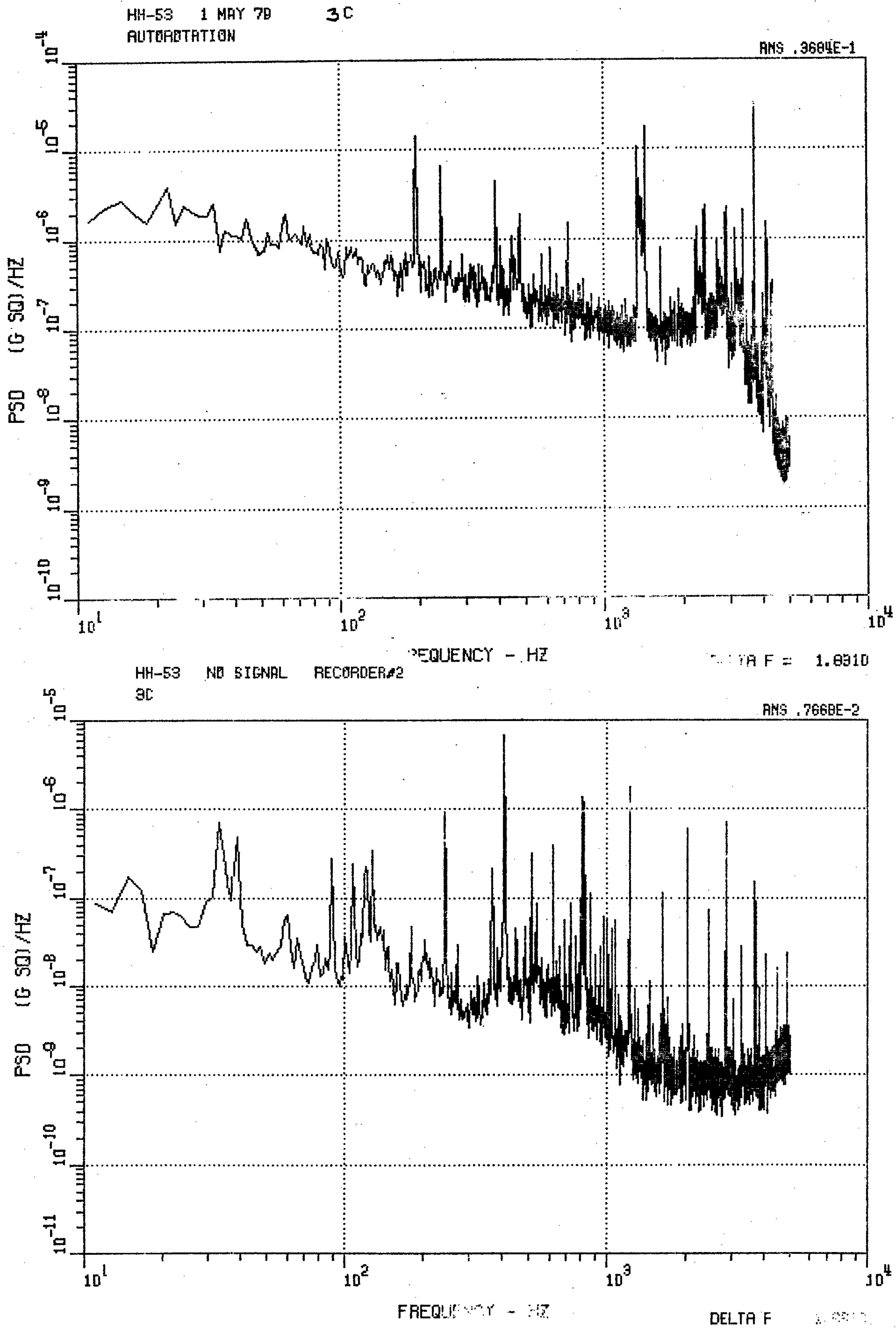
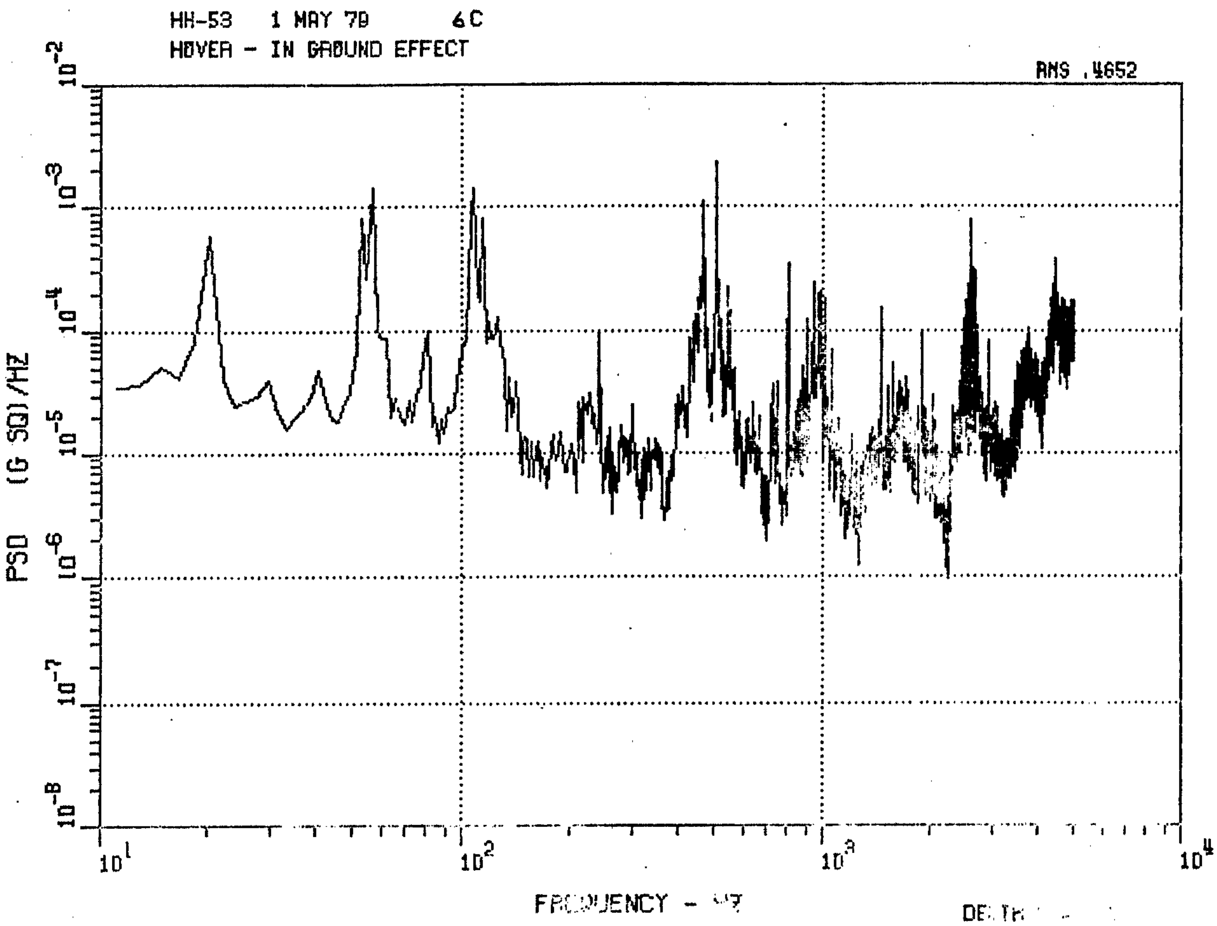


Figure 77. HH-53 Center Lateral Accelerometer 3C, Autorotation and No-Signal Record.



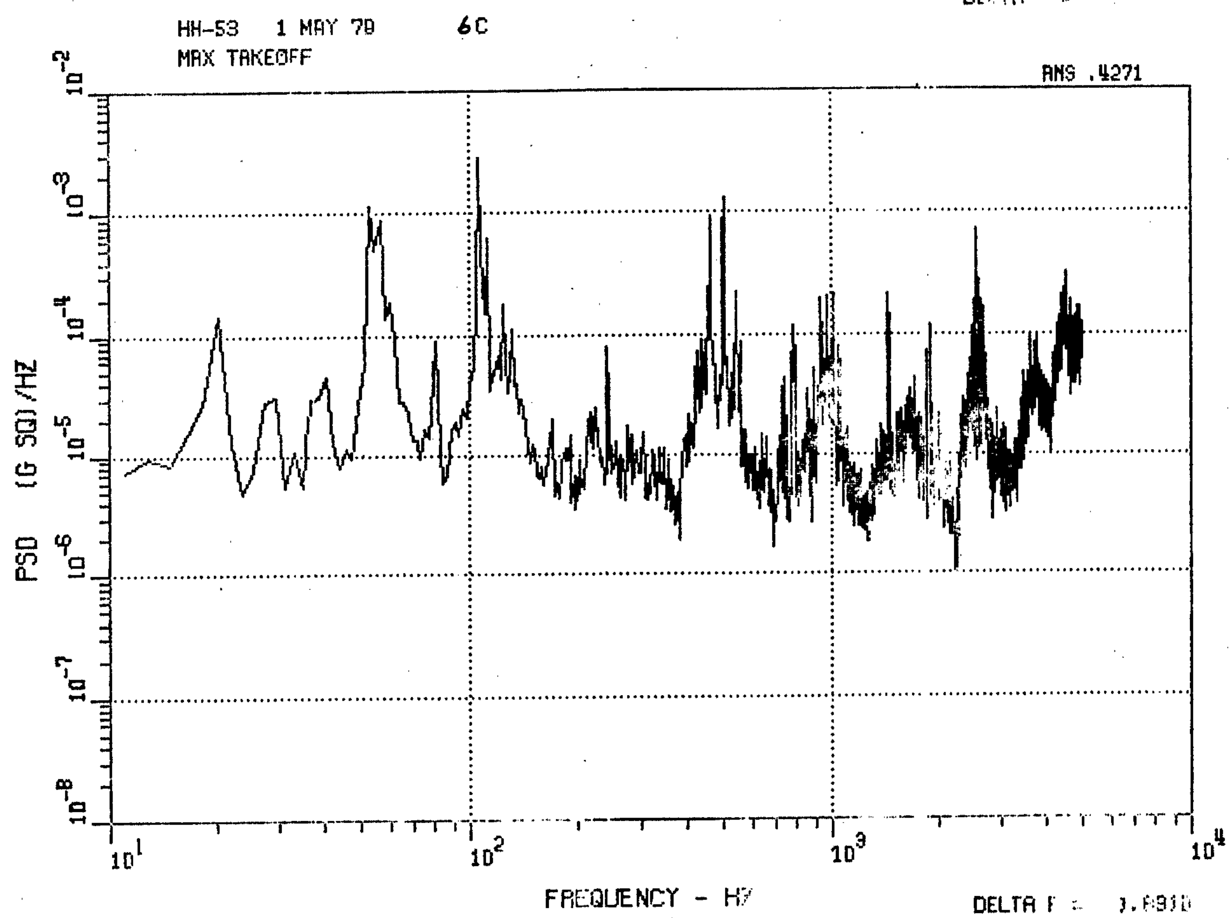


Figure 78. HH-53 Center Longitudinal Accelerometer 6C, Hover IGE and Max Takeoff.

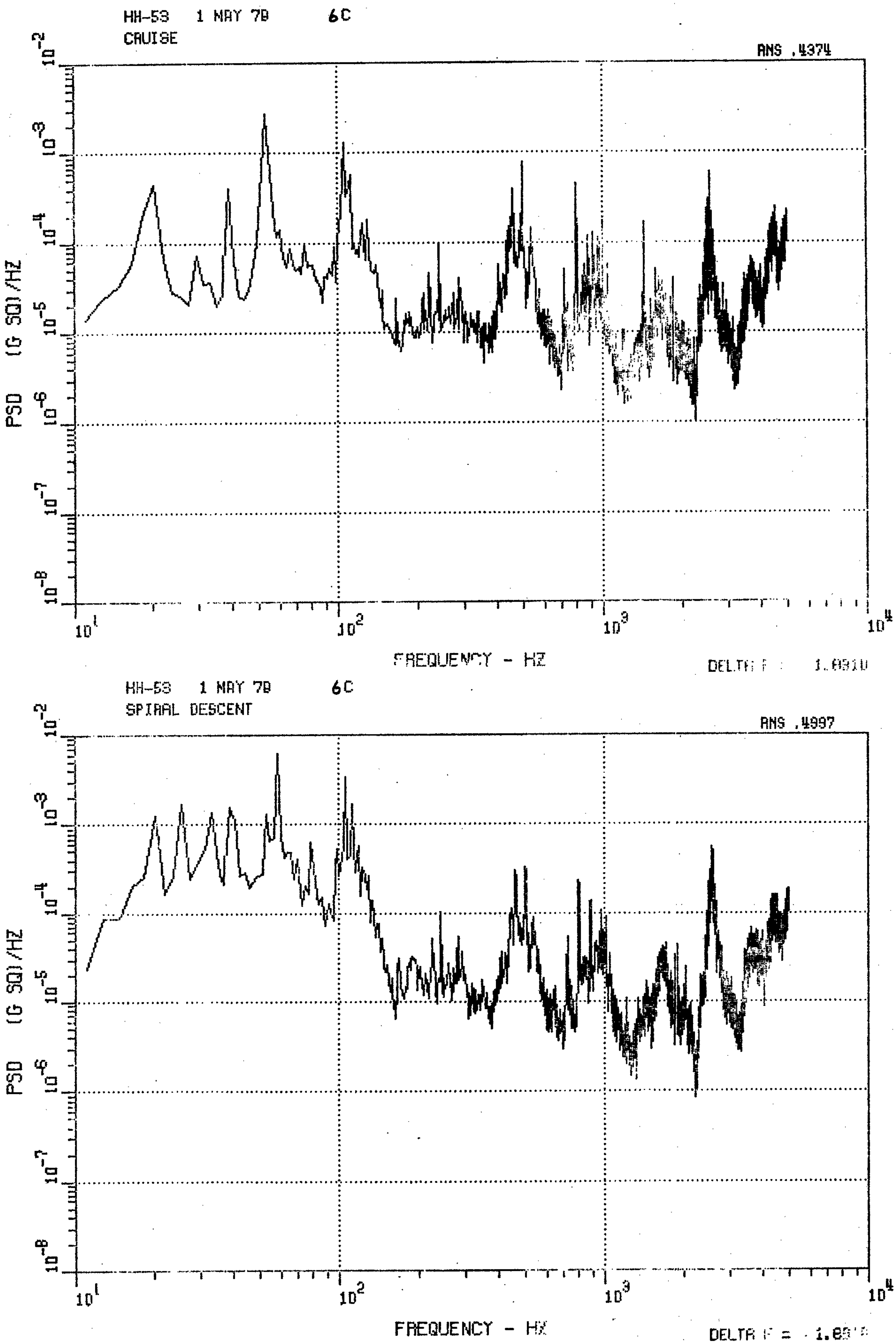
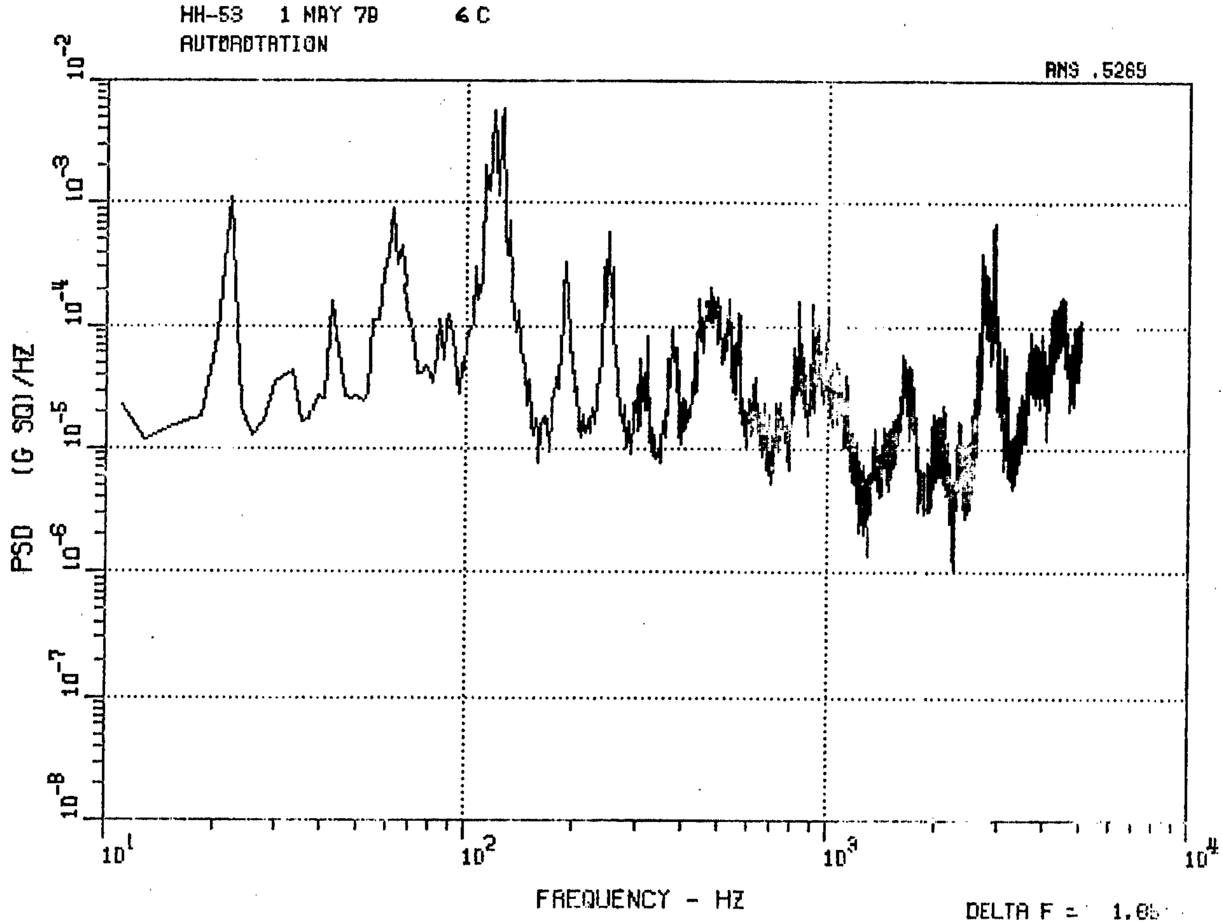


Figure 79. HH-53 Center Longitudinal Accelerometer 6C, Cruise and Spiral Descent.



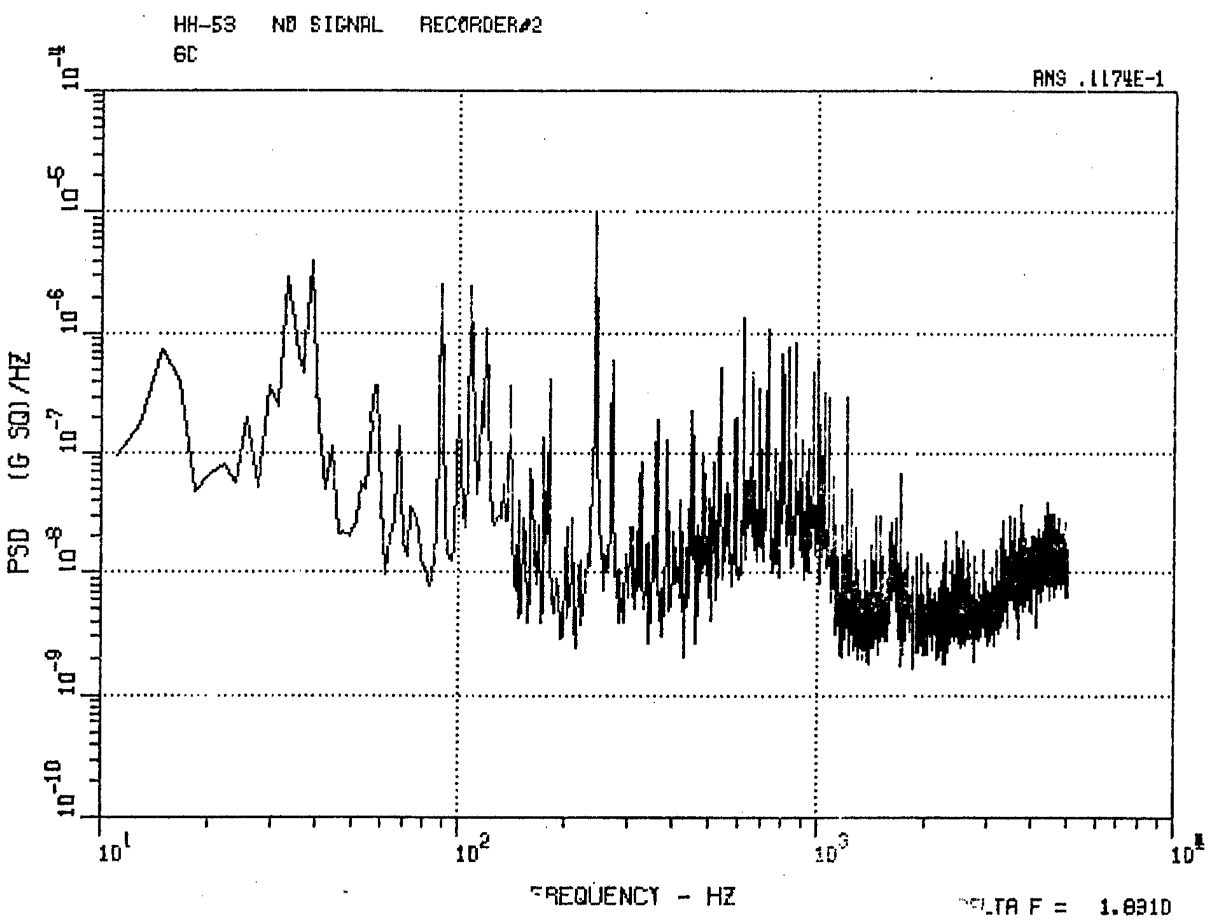
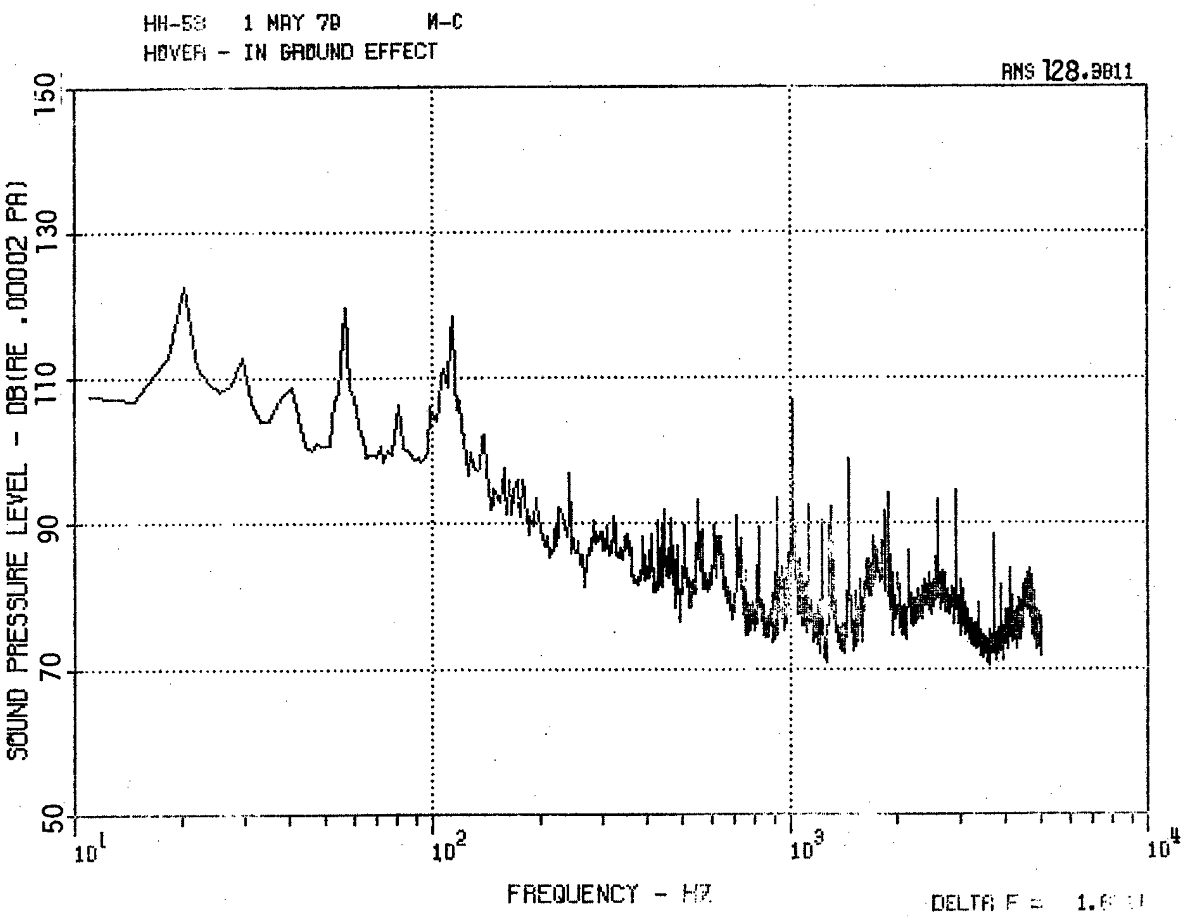


Figure 80. HH-53 Center Longitudinal Accelerometer 6C, Autorotation and No-Signal Record.



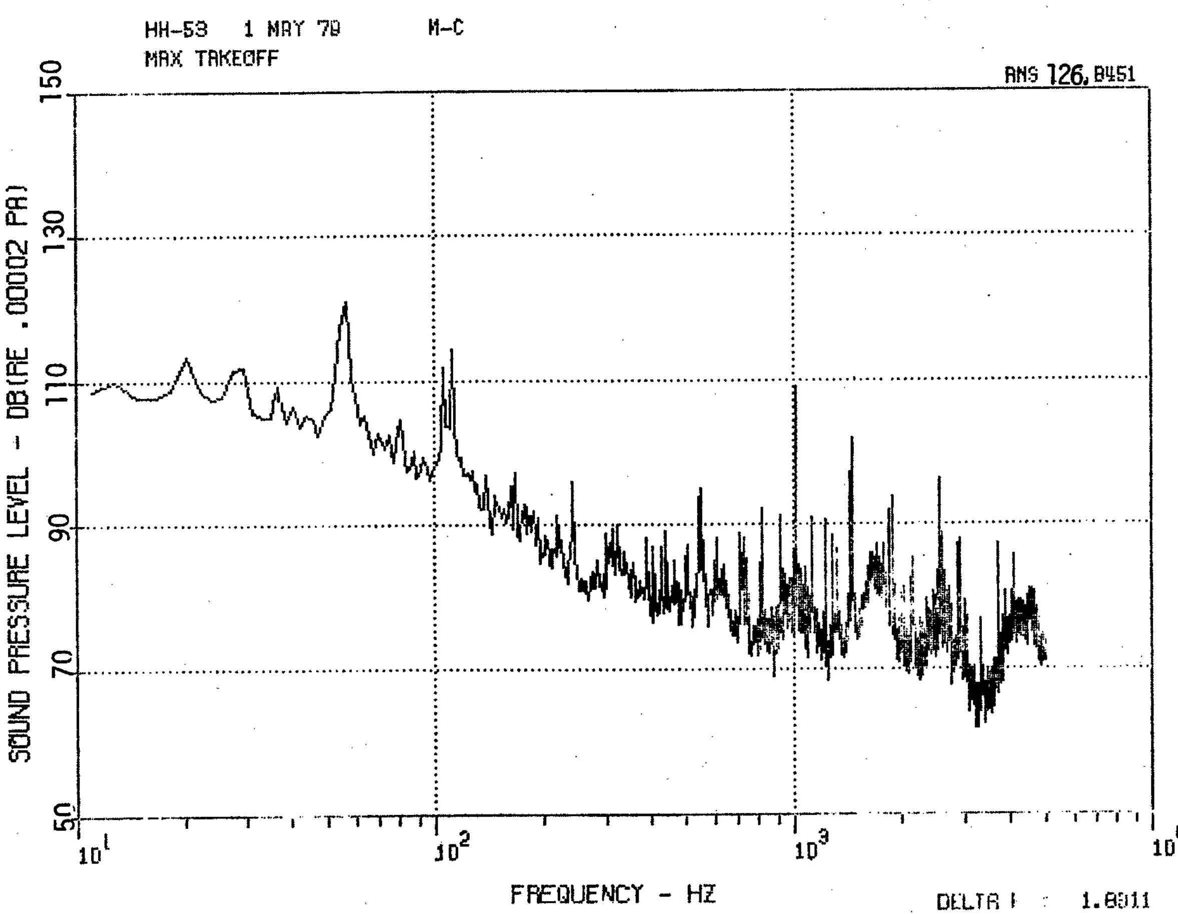
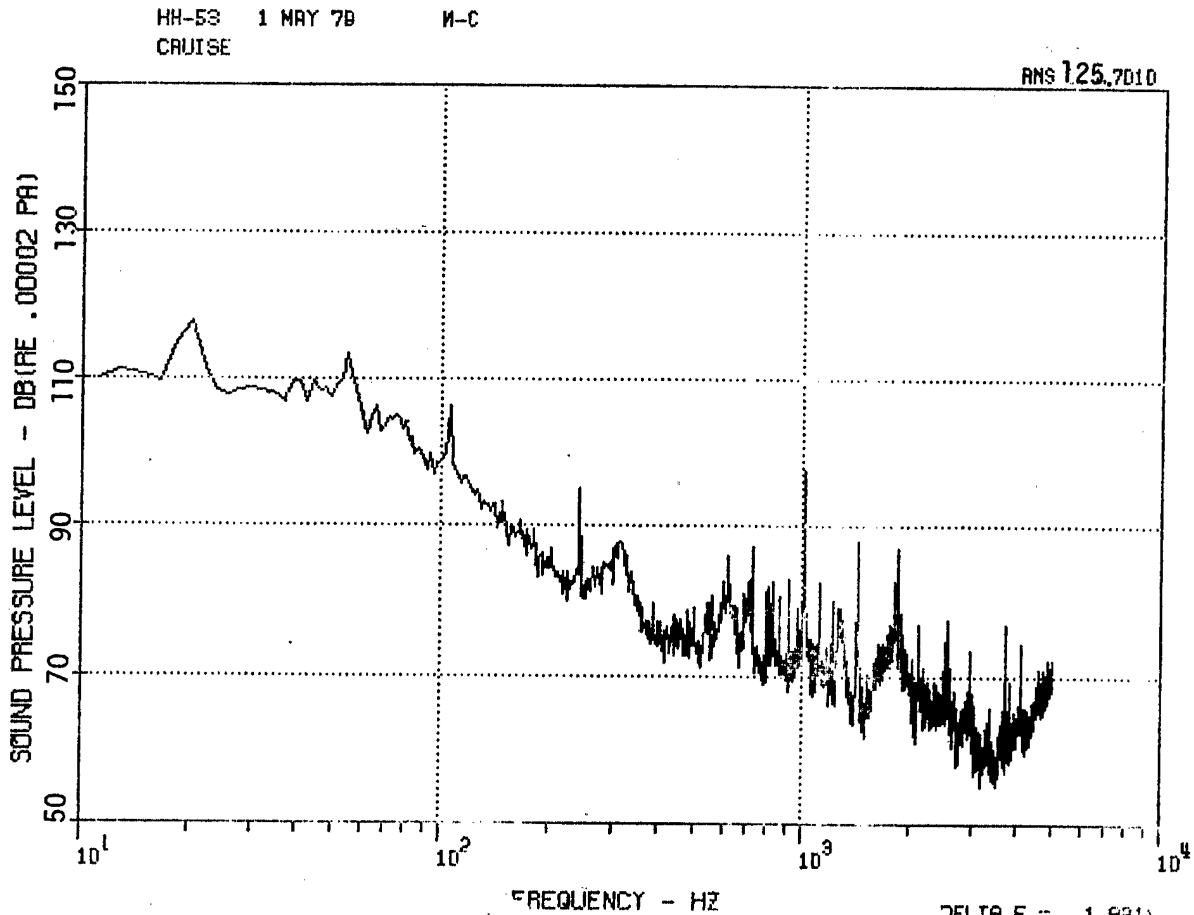


Figure 81. HH-53 Center Microphone MC, Hover IGE and Max Takeoff.



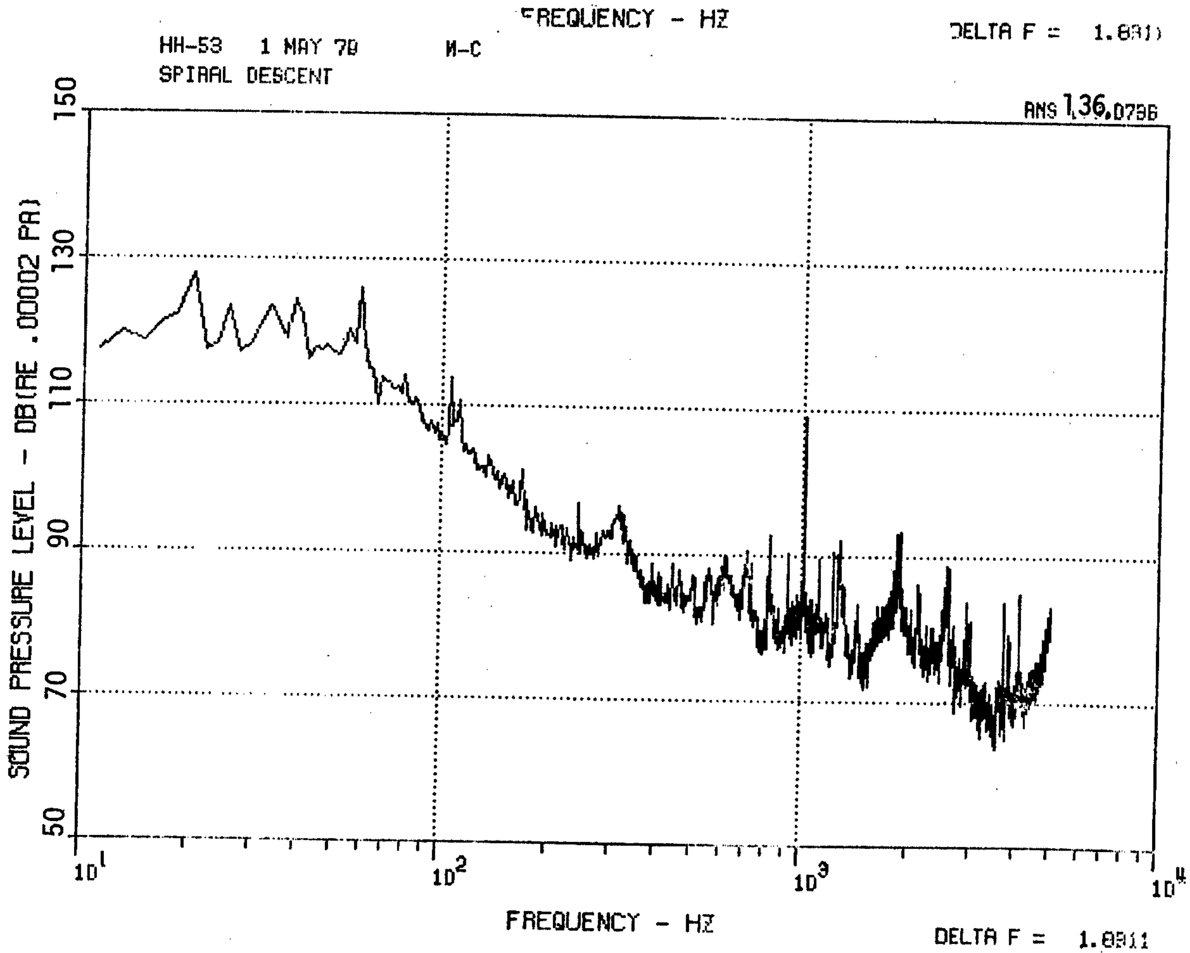
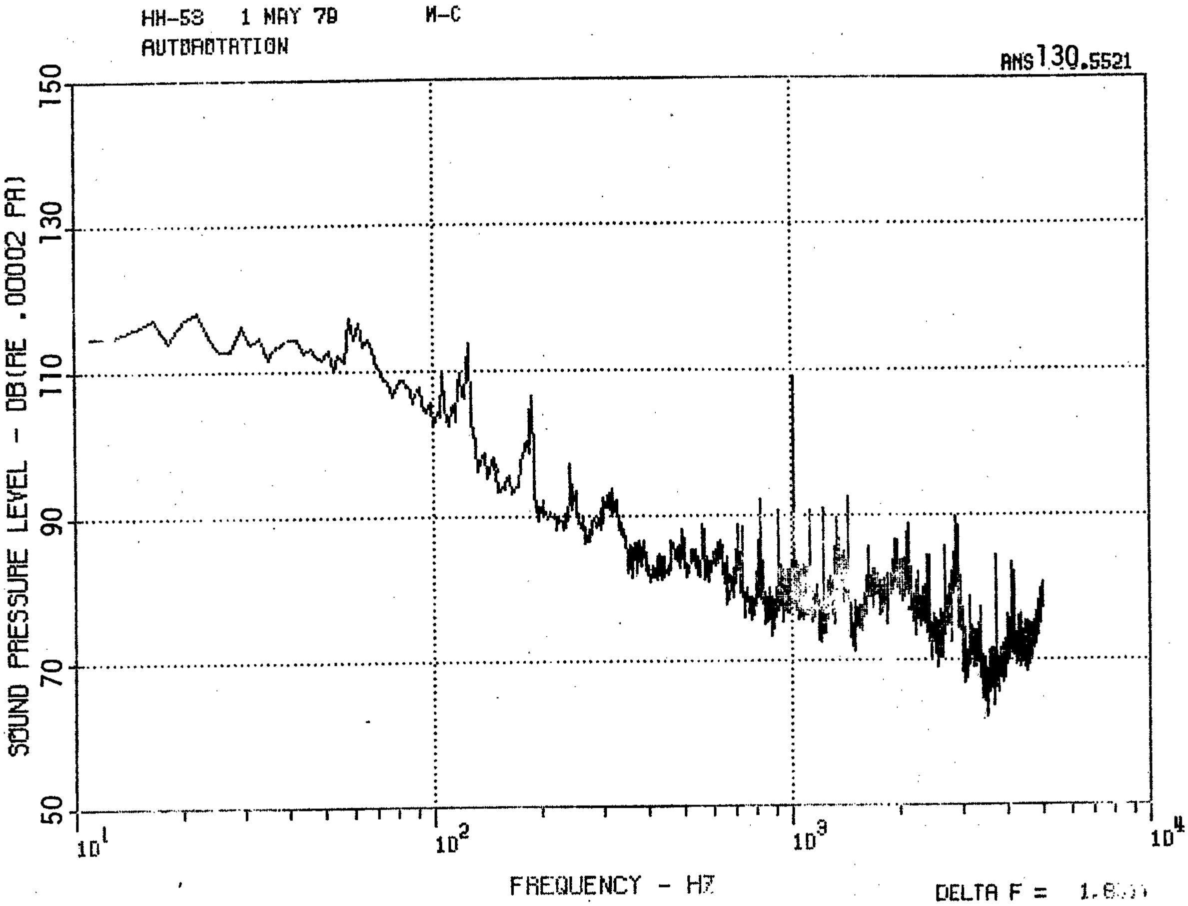


Figure 82. HH-53 Center Microphone MC, Cruise and Spiral Descent.



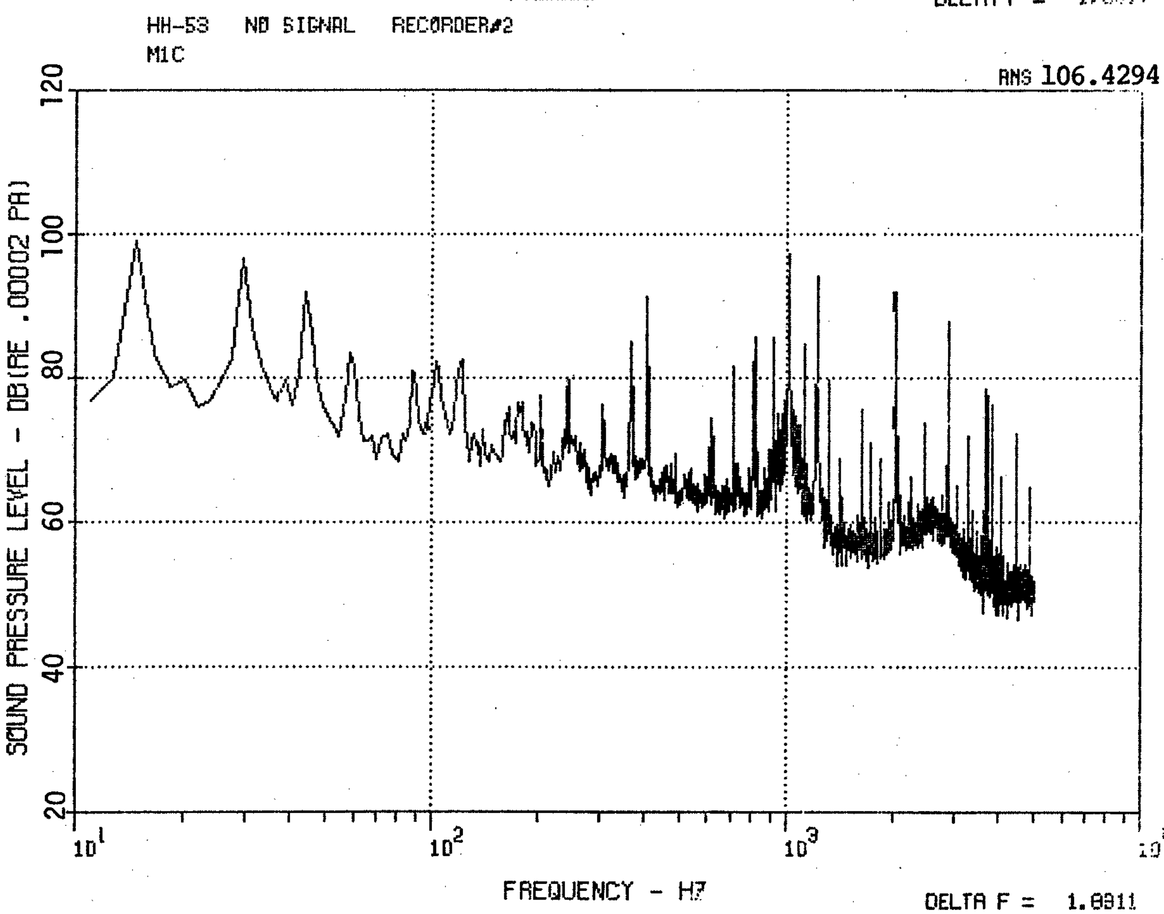


Figure 83. HH-53 Center Microphone MC, Autorotation and No-Signal Record.

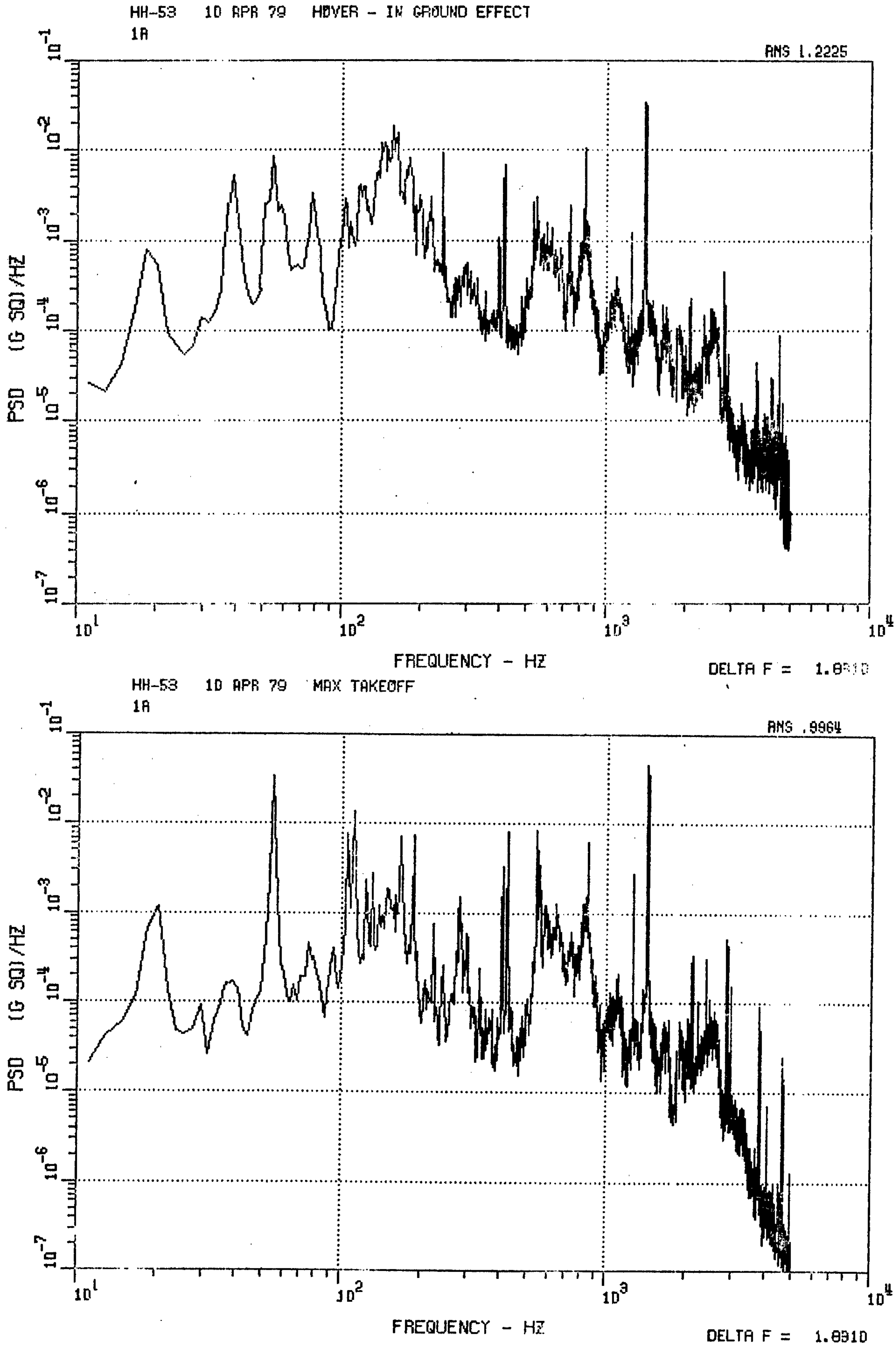


Figure 84. HH-53 Aft Lateral Accelerometer 1A, Hover IGE and Max Takeoff.

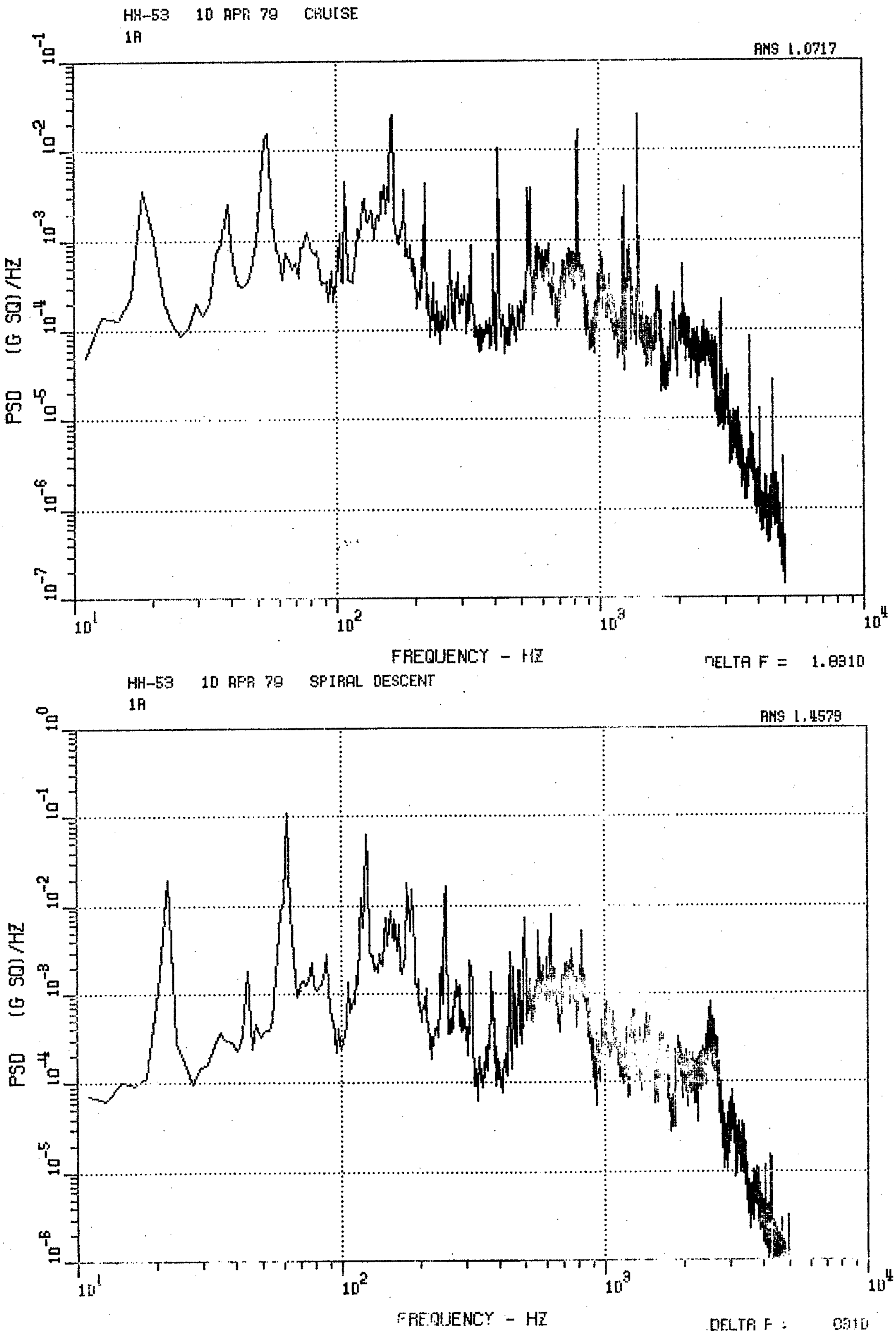


Figure 85. HH-53 Aft Lateral Accelerometer 1A,
Cruise and Spiral Descent.

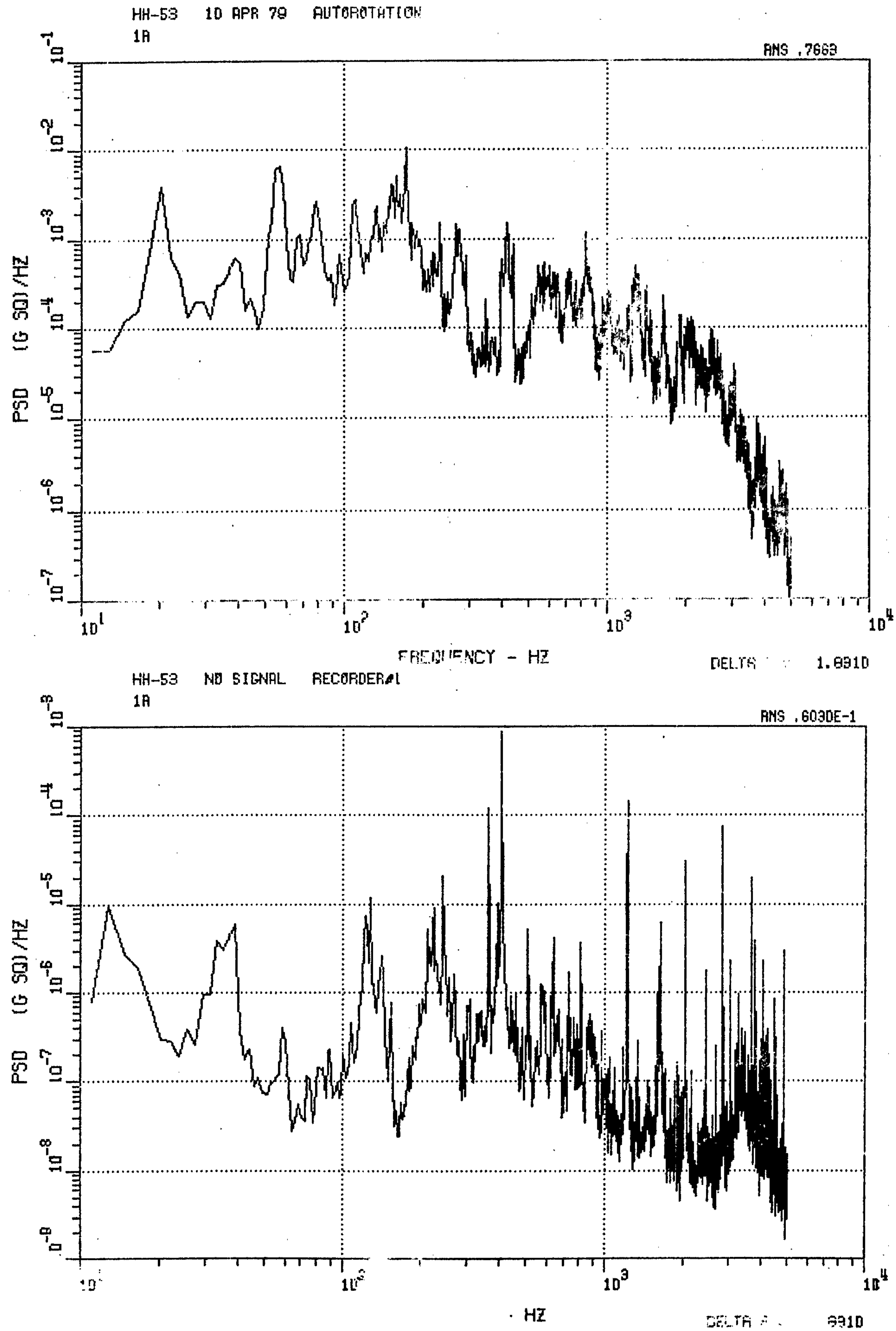


Figure 86. HH-53 Aft Lateral Accelerometer 1A, Autorotation and No-Signal Record.

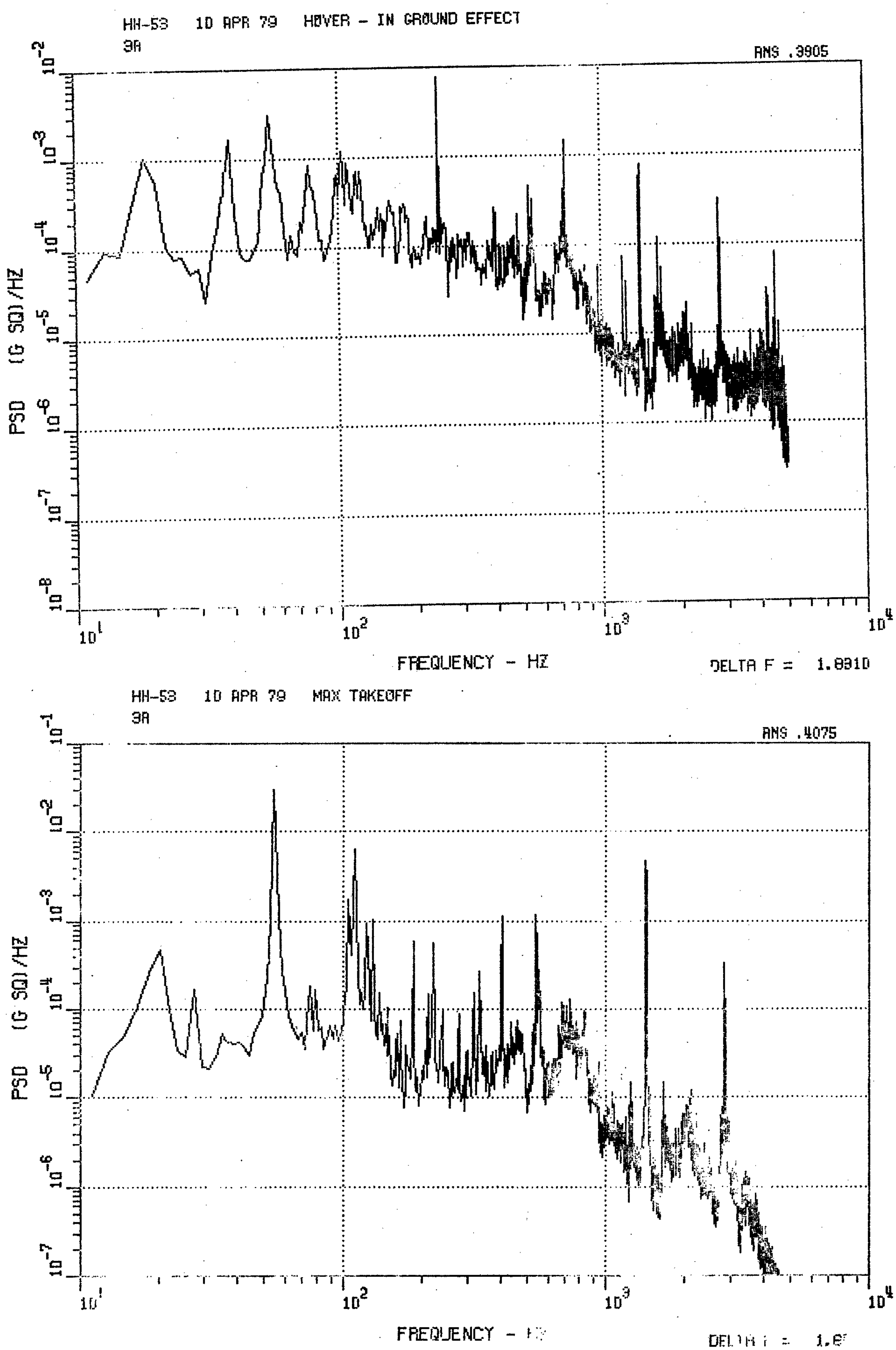
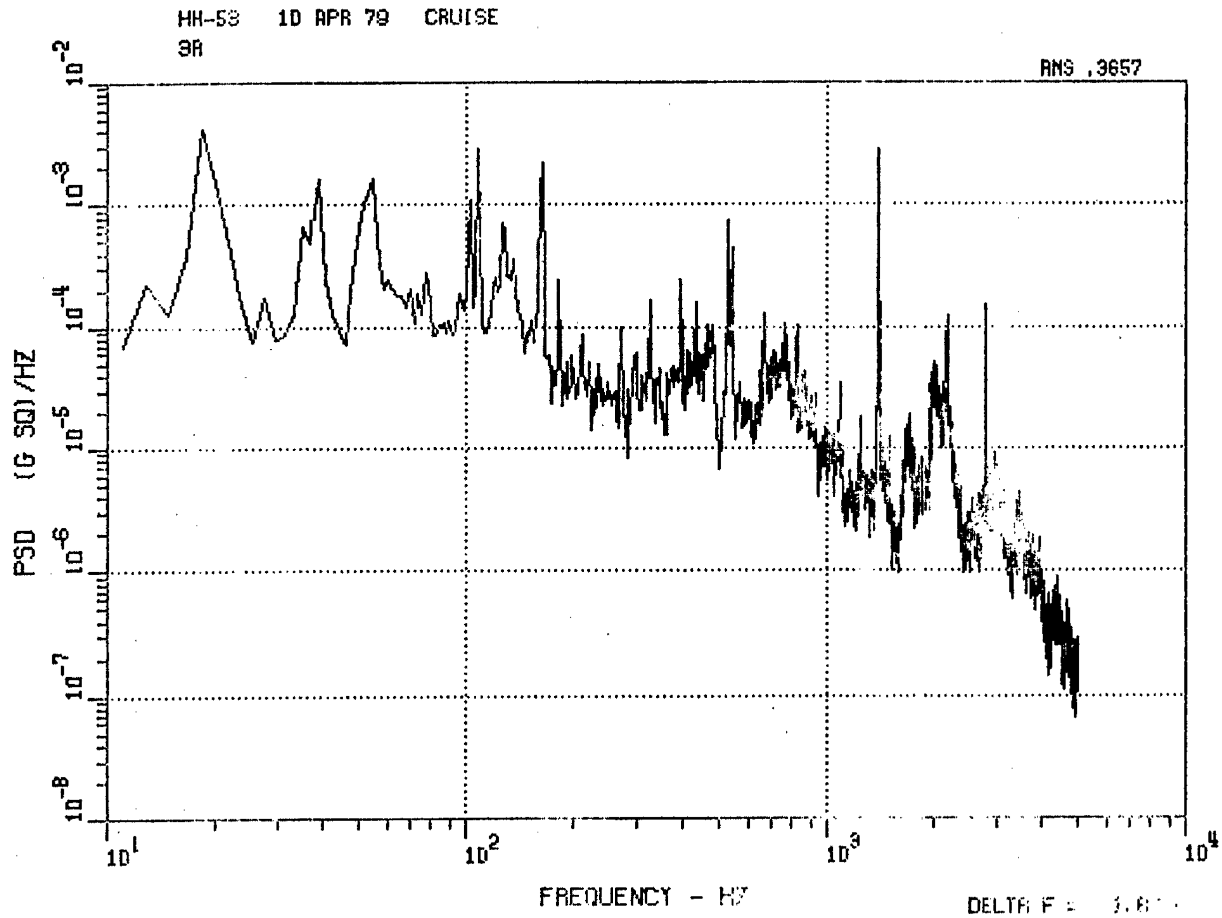


Figure 87. HH-53 Aft Vertical Accelerometer 3A, Hover IGE and Max Takeoff.



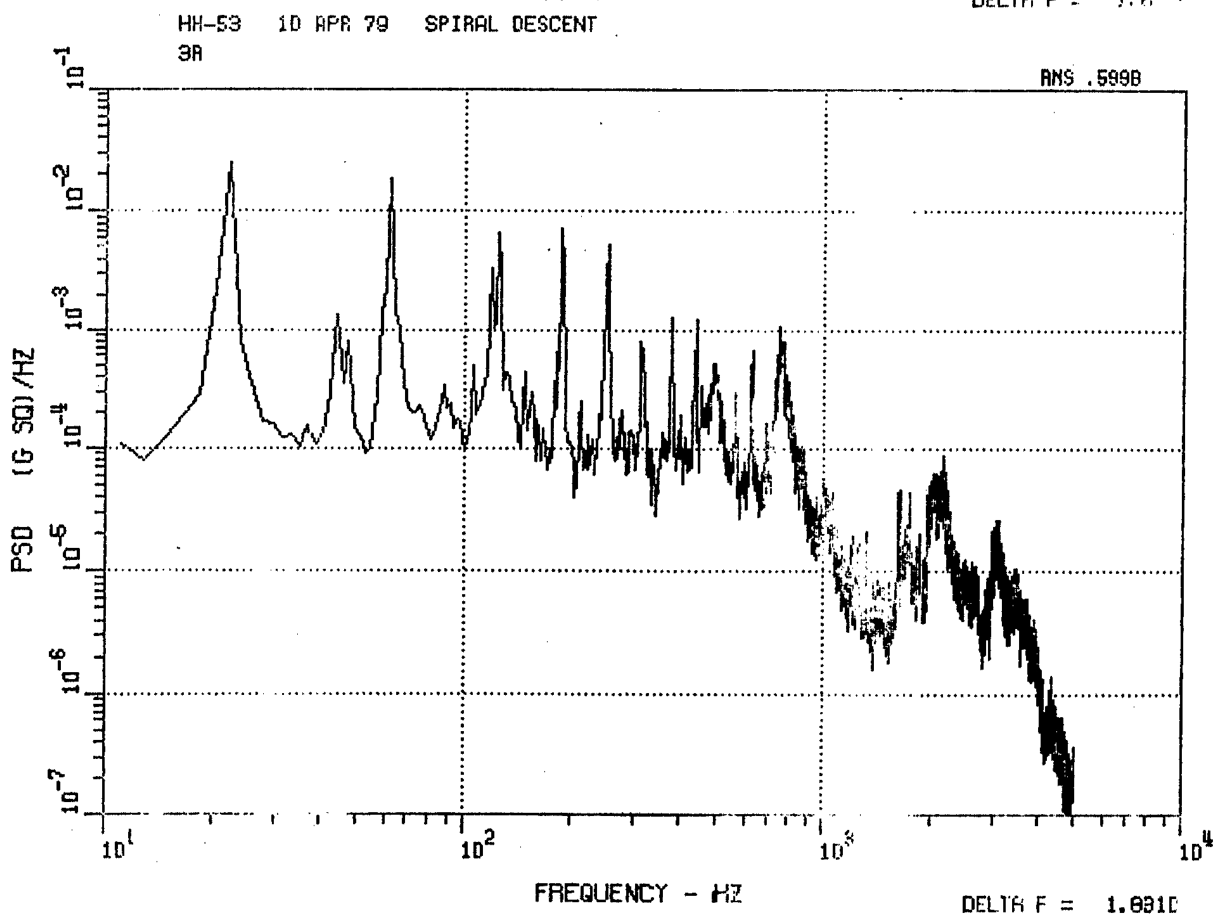


Figure 88. HH-53 Aft Vertical Accelerometer 3A, Cruise and Spiral Descent.

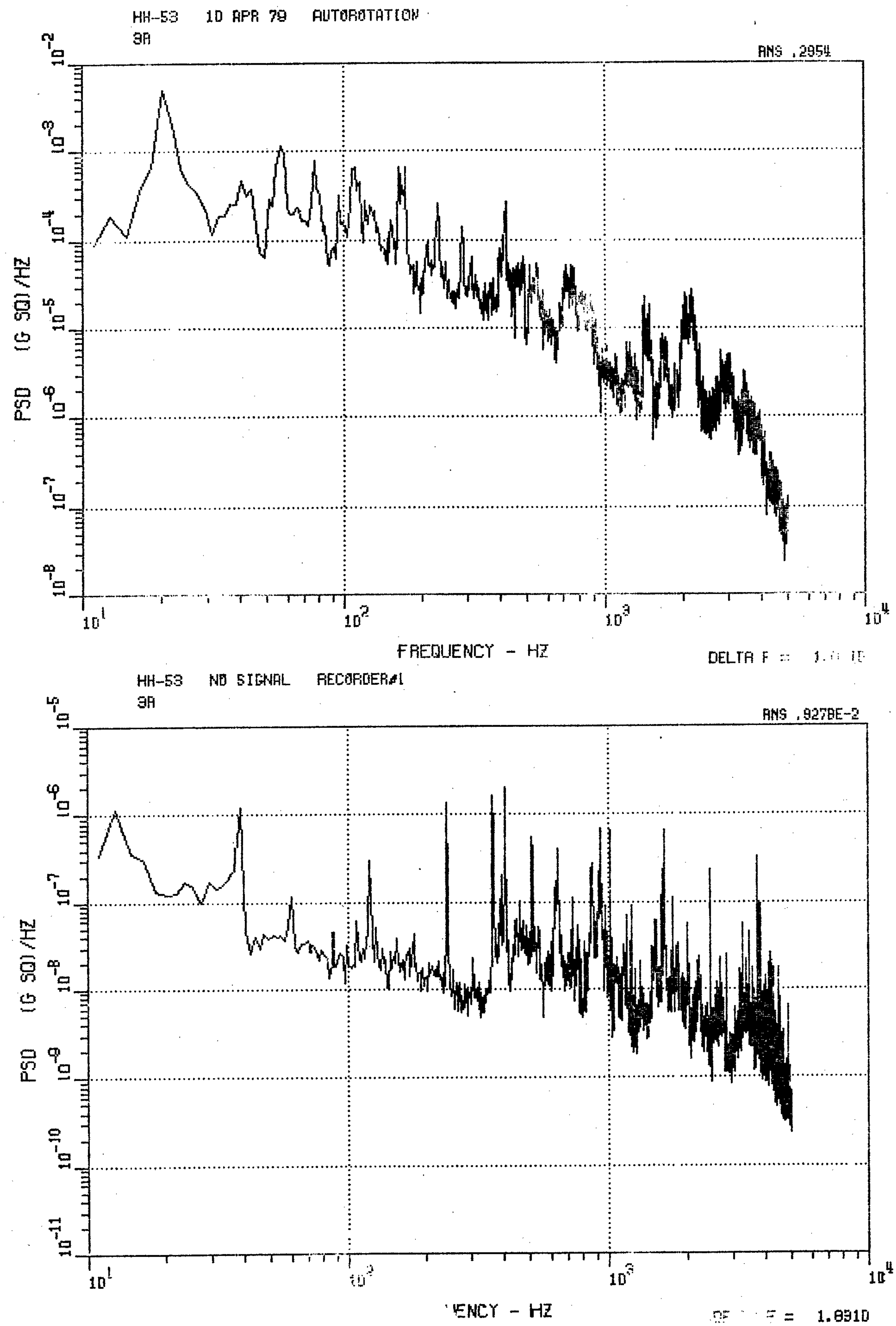


Figure 89. HH-53 Aft Vertical Accelerometer 3A, Autorotation and No-Signal Record.

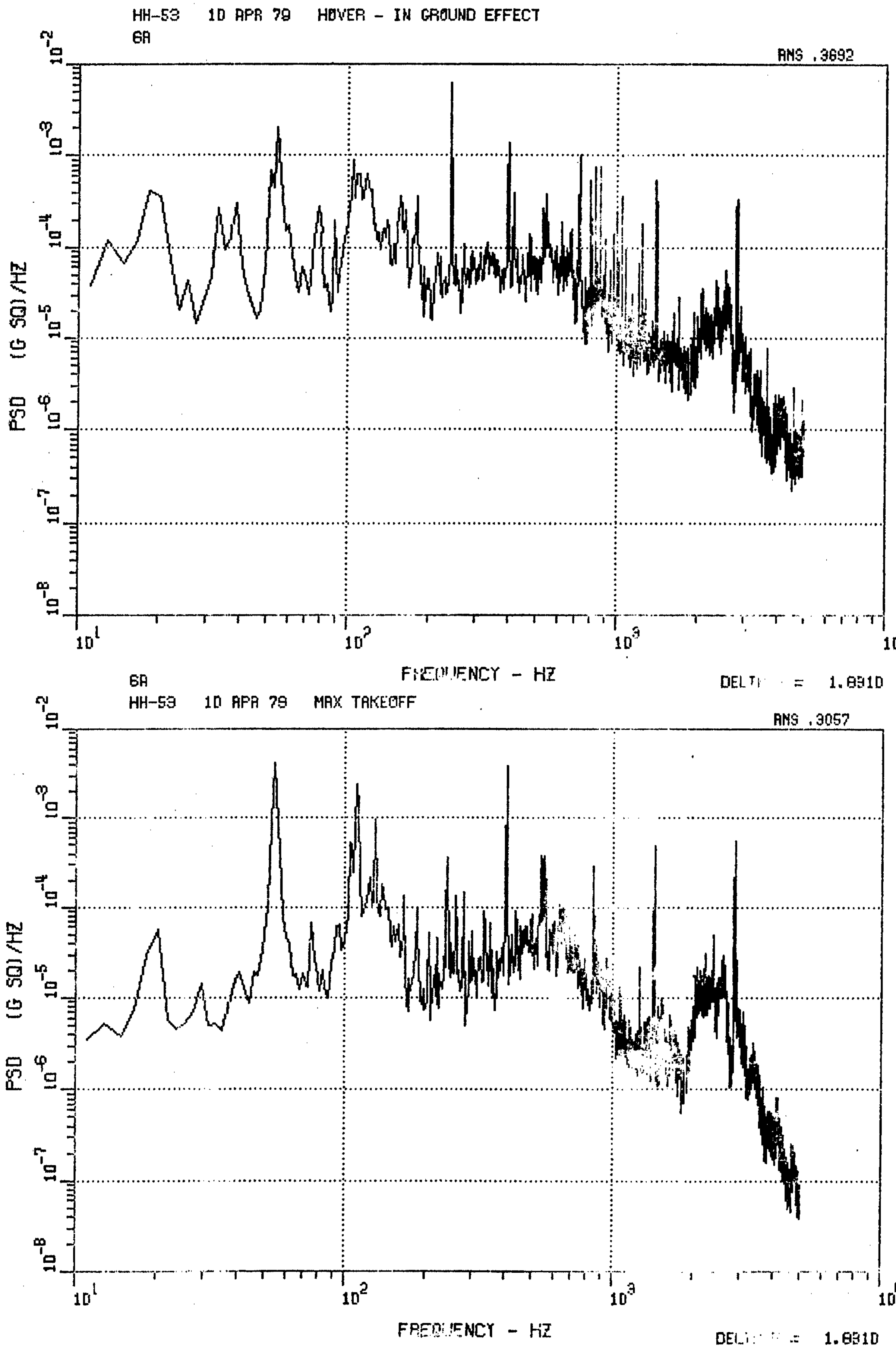


Figure 90. HH-53 Aft Longitudinal Accelerometer 6A, Hover IGE and Max Takeoff.

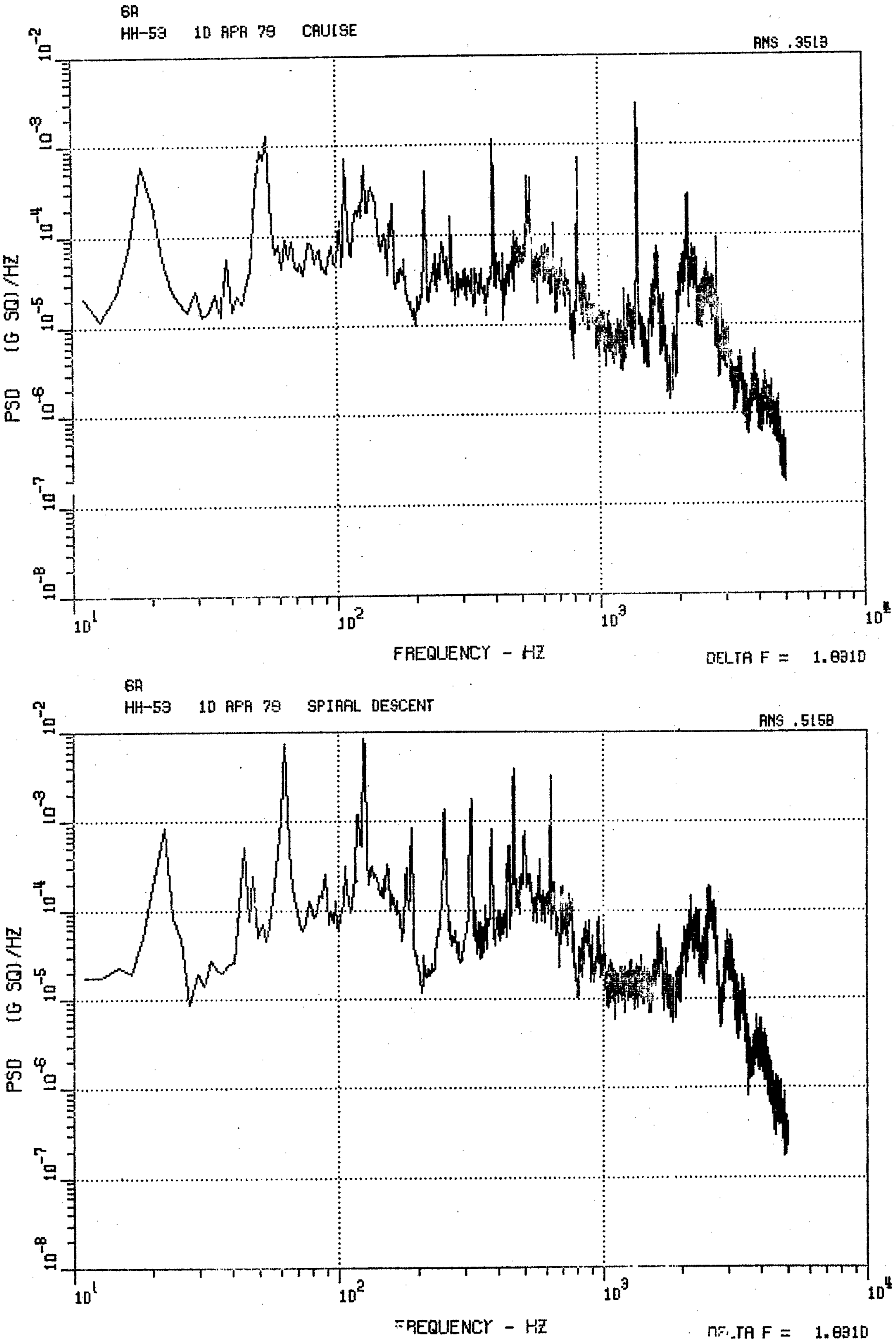
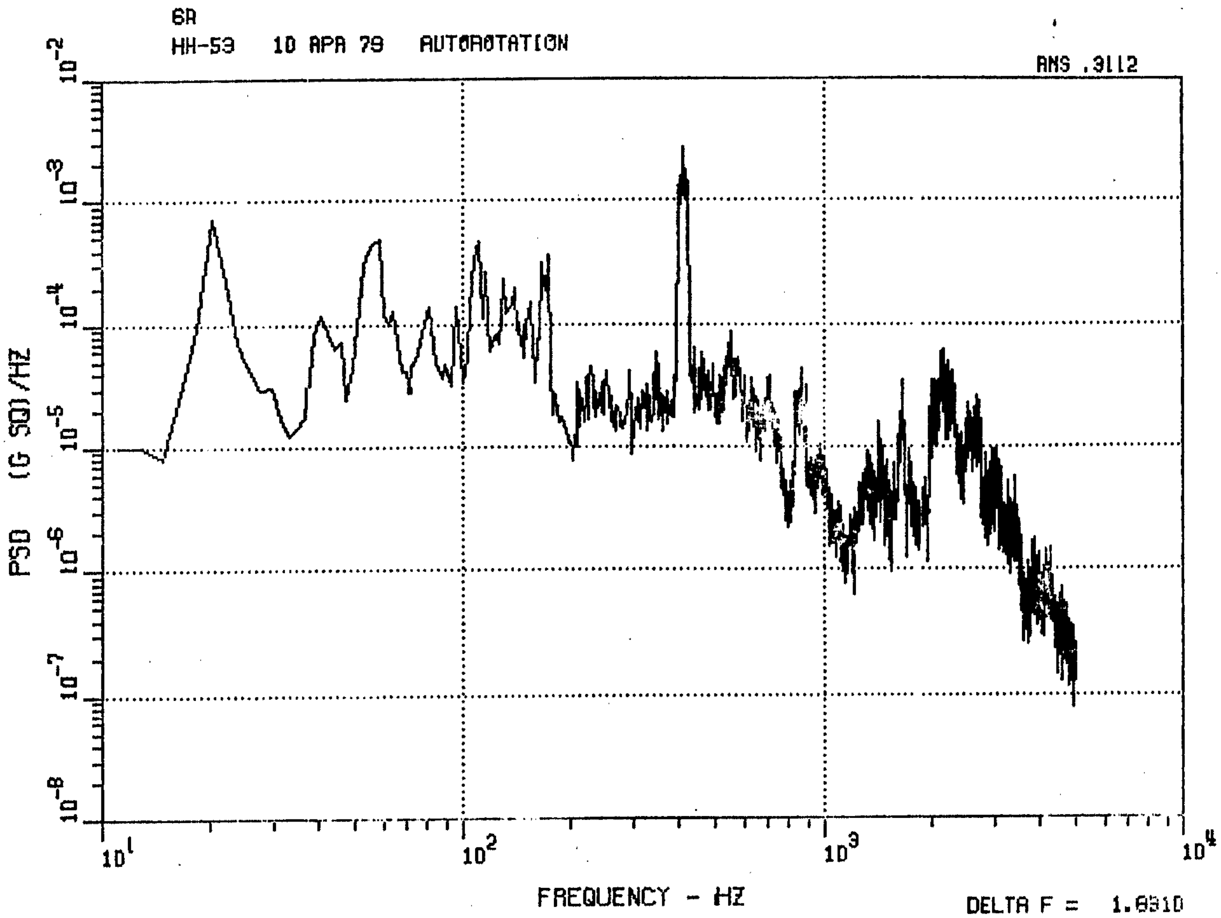


Figure 91. HH-53 Aft Longitudinal Accelerometer 6A, Cruise and Spiral Descent.



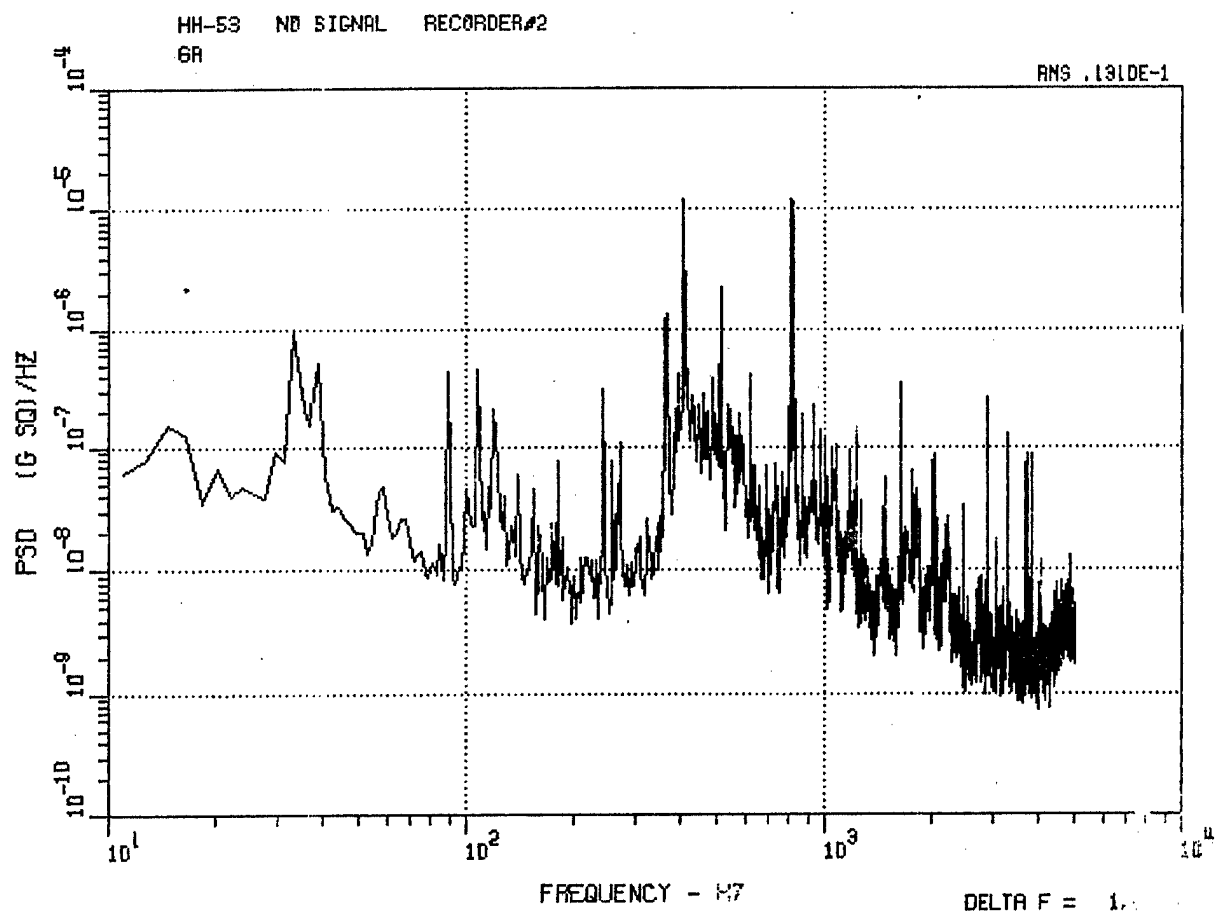
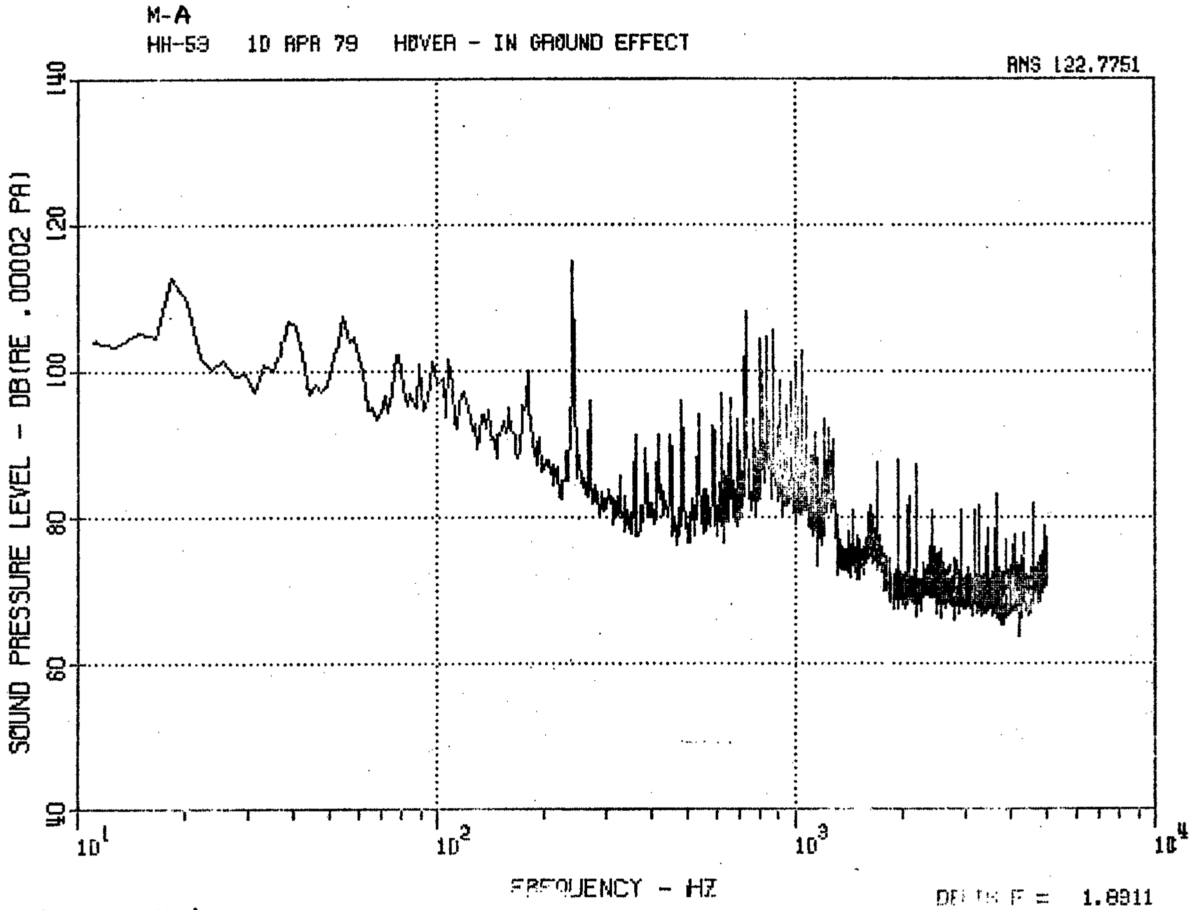


Figure 92. HH-53 Aft Longitudinal Accelerometer 6A, Autorotation and No-Signal Record.



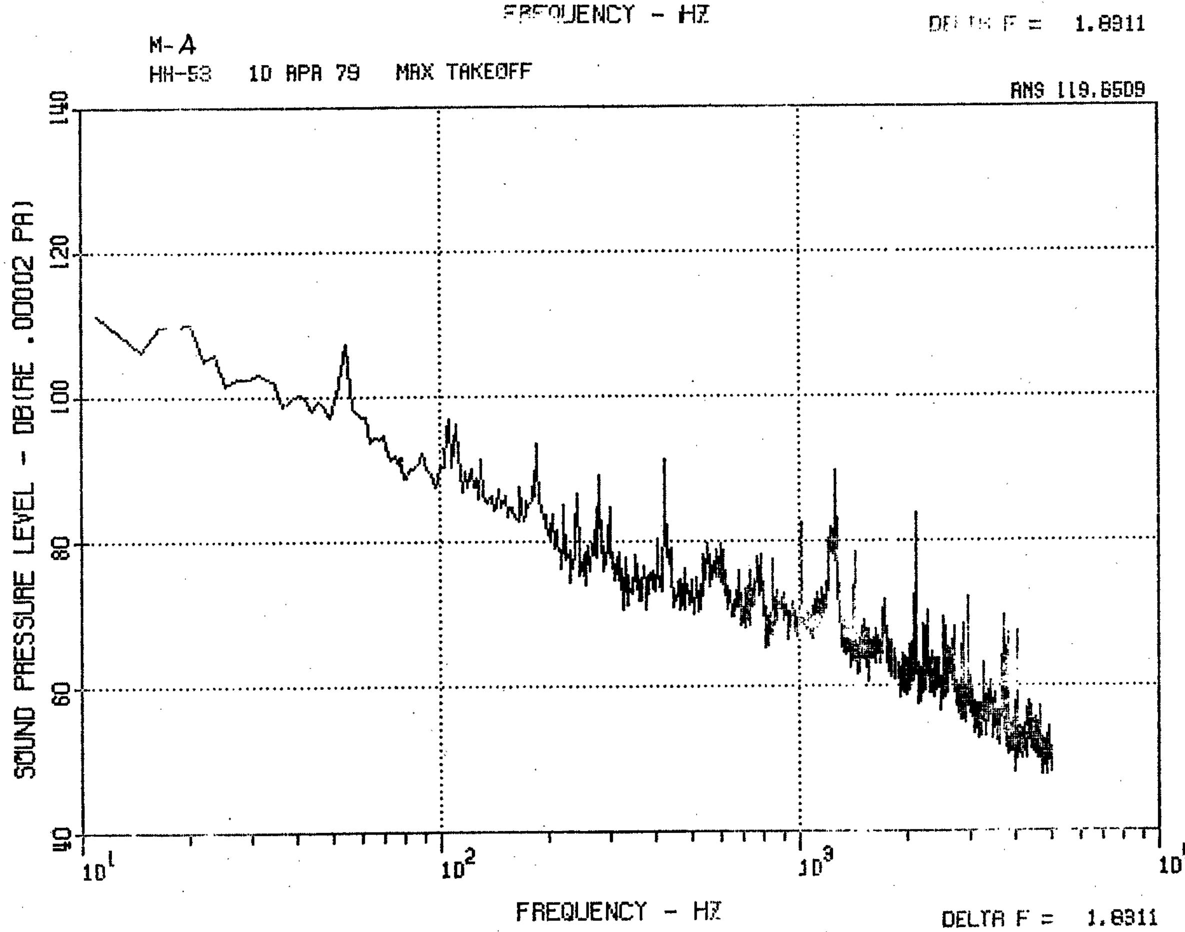
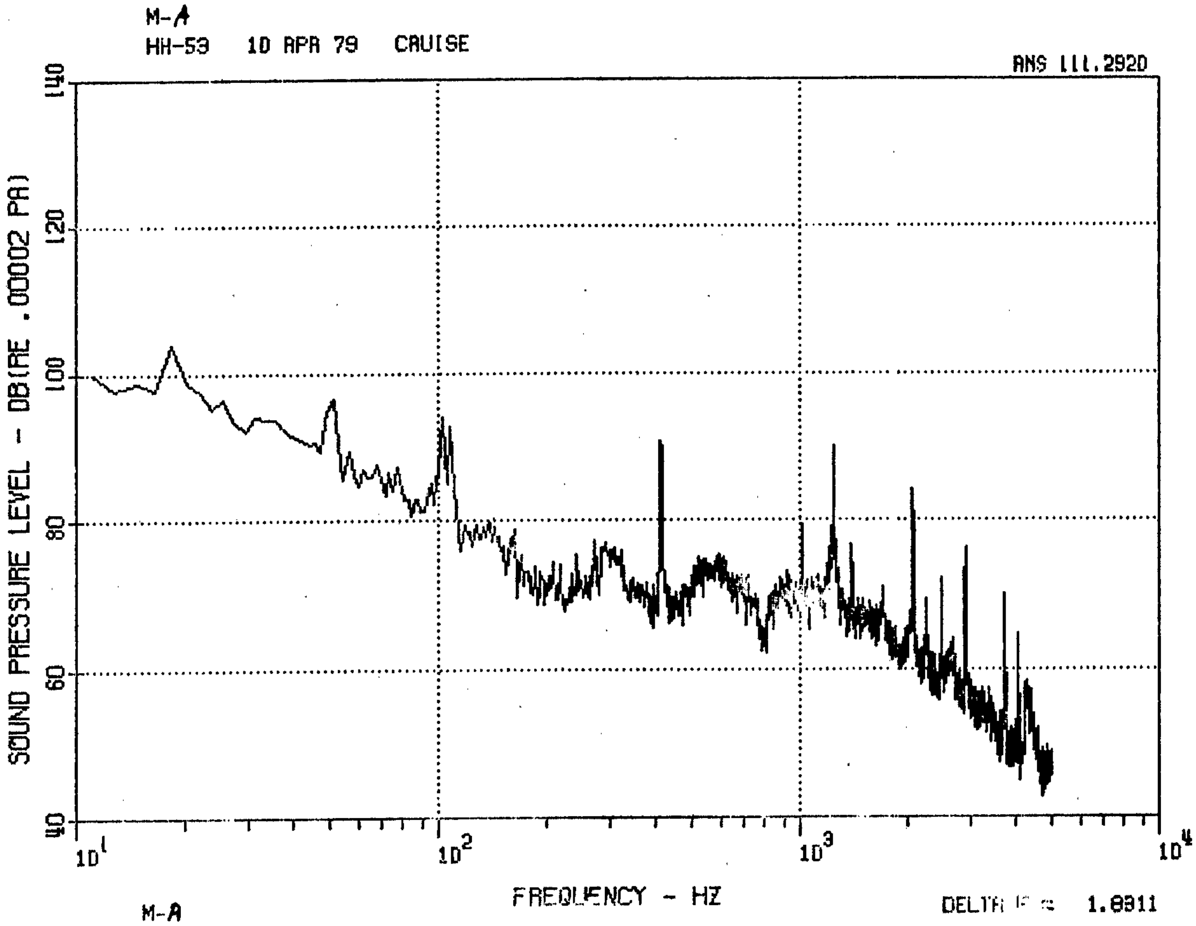


Figure 93. HH-53 Aft Microphone MA, Hover IGE and Max Takeoff.



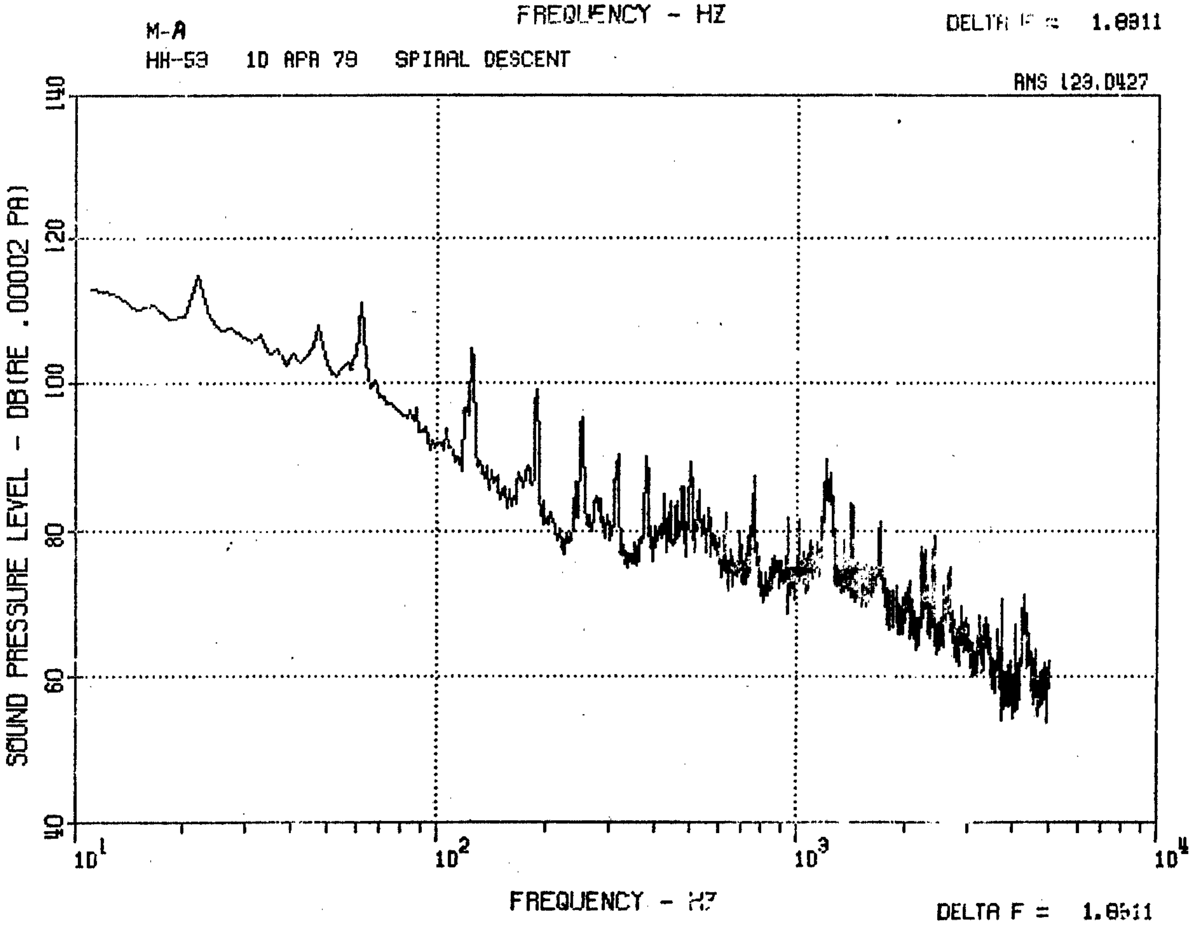


Figure 94. HH-53 Aft Microphone MA, Cruise and Spiral Descent.

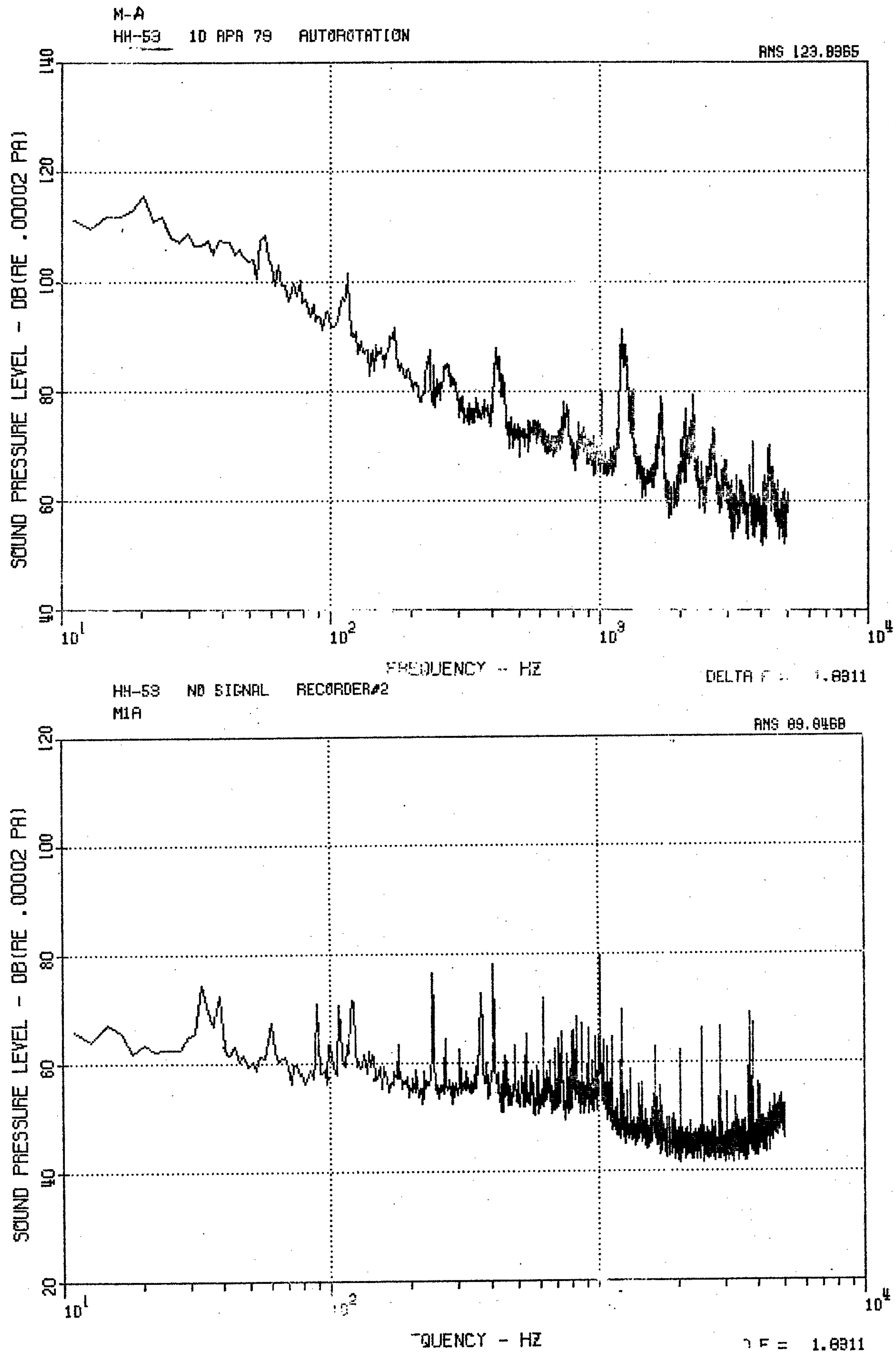


Figure 95. HH-53 Aft Microphone MA, Autorotation and No-Signal Record.

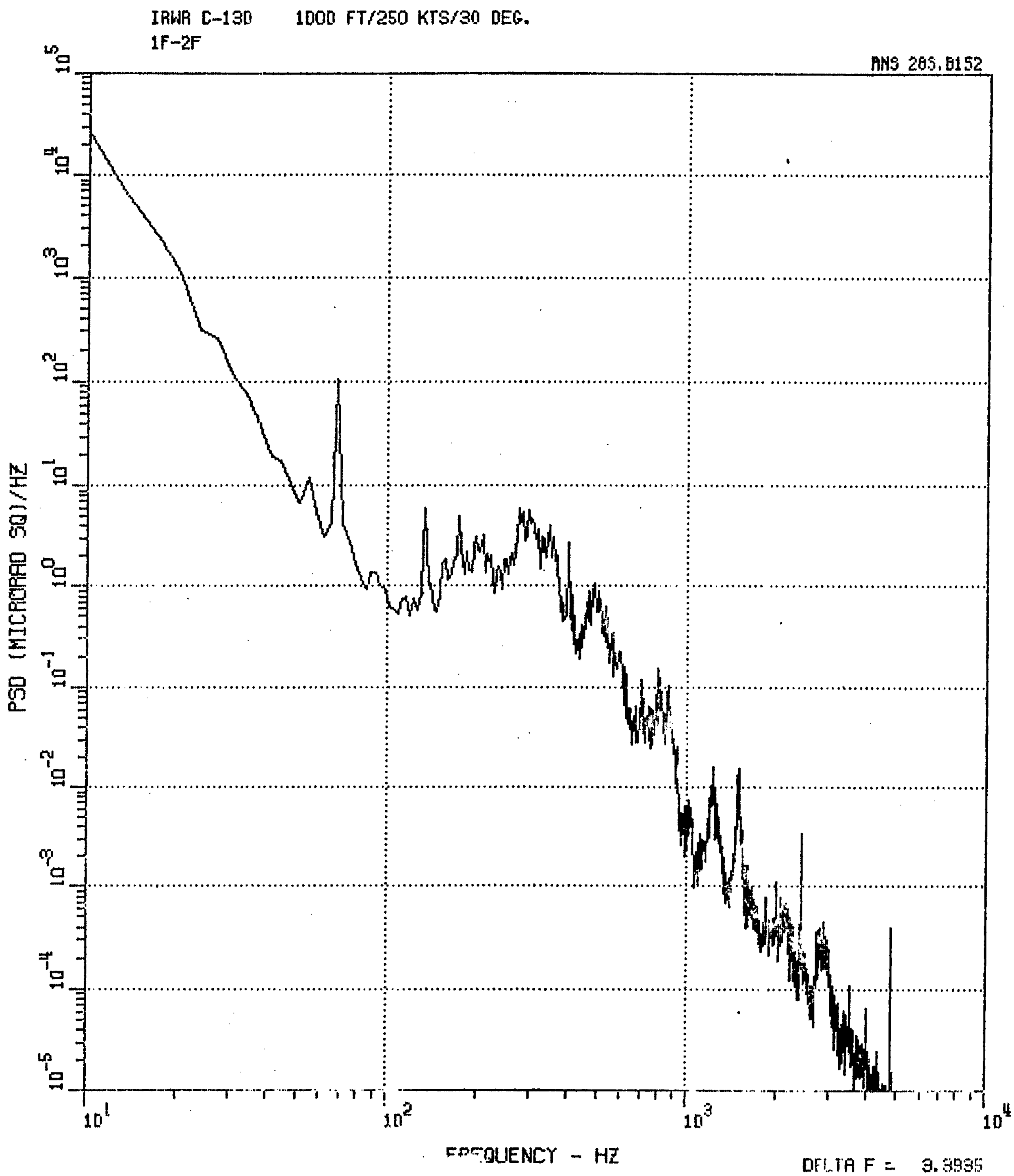


Figure 96. C-130 Fwd Roll PSD, 1F-2F, 1000 Ft, 250 Kt, 30 Deg.

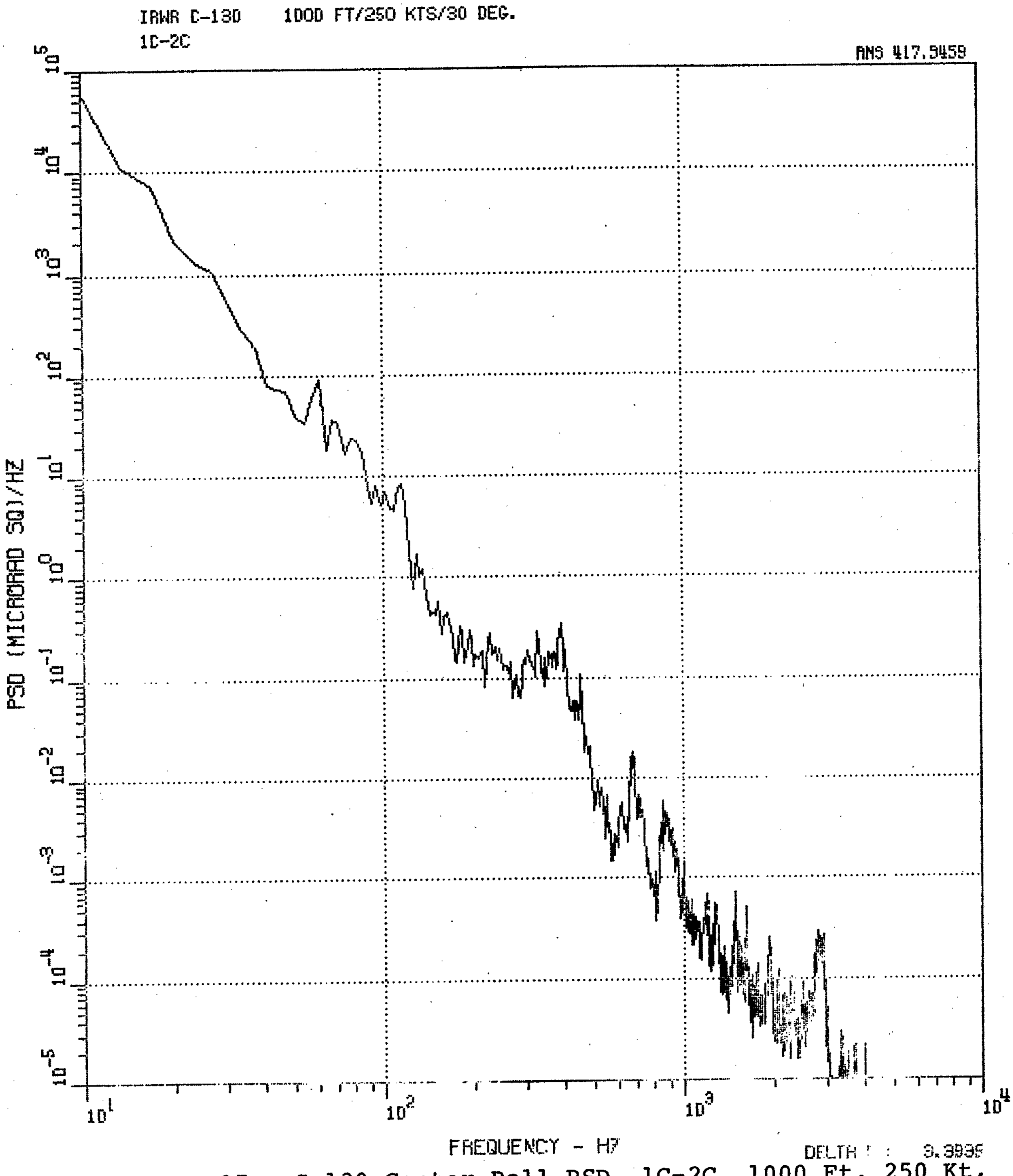


Figure 97. C-130 Center Roll PSD, 1C-2C, 1000 Ft, 250 Kt, 30 Deg.

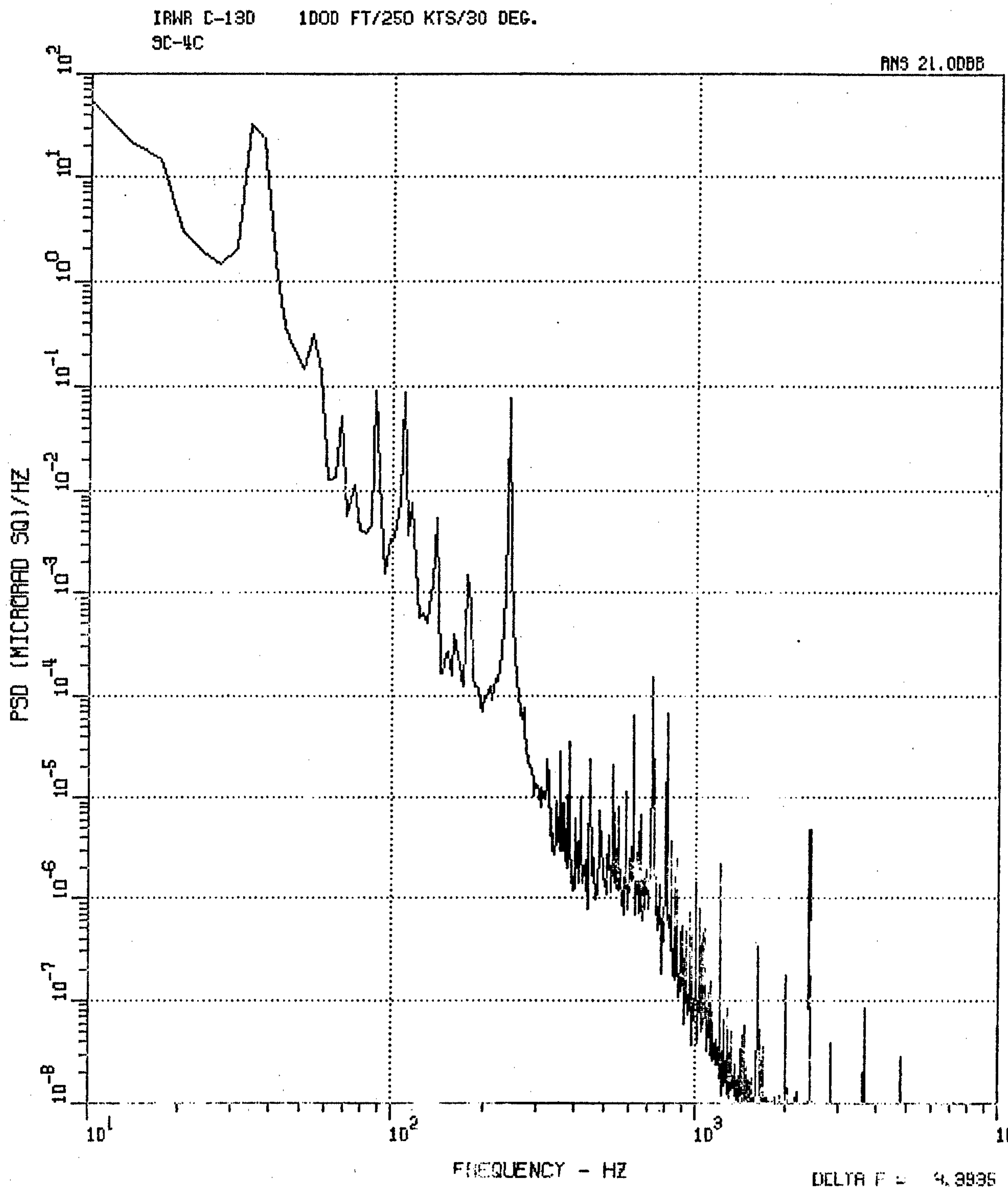


Figure 98. C-130 Center Yaw PSD, 3C-4C, 1000 Ft, 250 Kt, 30 Deg.

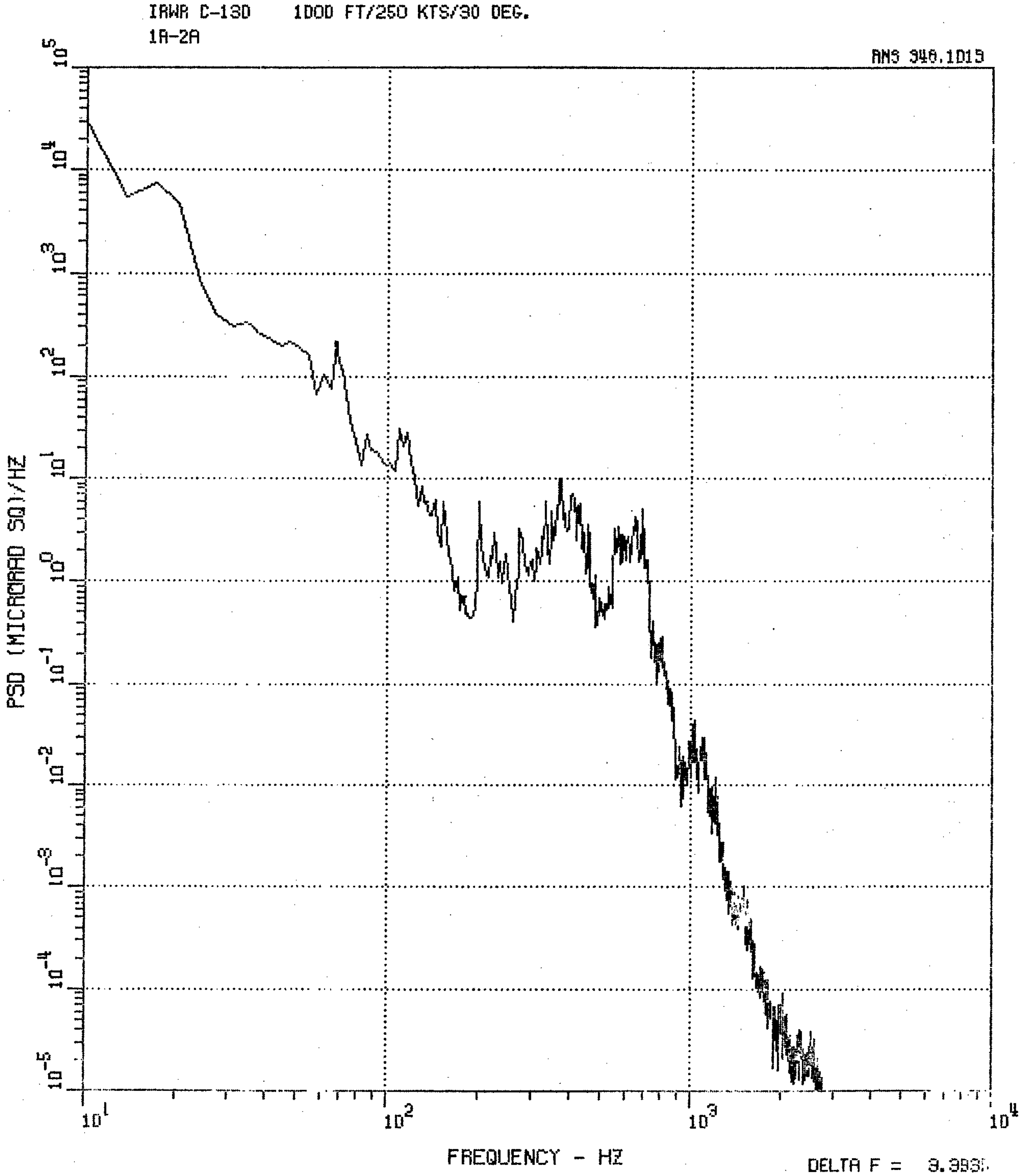


Figure 99. C-130 Aft Roll PSD, 1A-2A, 1000 Ft, 250 Kt, 30 Deg.

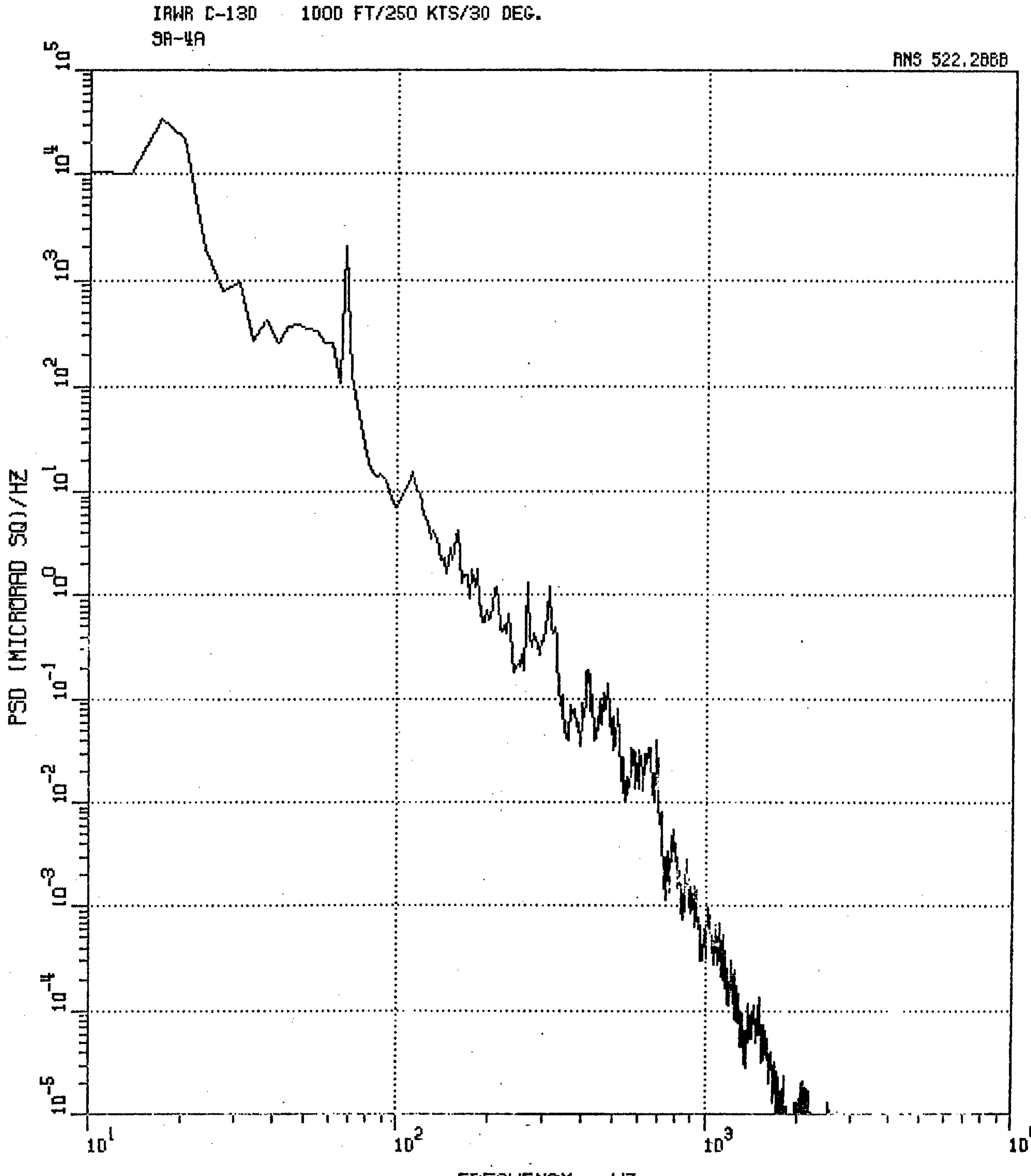


Figure 100. C-130 Aft Picth PSD, 3A-4A, 1000 Ft, 250 Kt, 30 Deg.