KSC-DD-818-TR

SUMMARY OF MEASUREMENTS

OF KSC LAUNCH-INDUCED

ENVIRONMENTAL EFFECTS

(STS-1 THROUGH STS-11)

June 1984

ENGINEERING DEVELOPMENT DIRECTORATE

KSC-DD-818-TR

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ENVIRONMENTAL EFFECTS

(STS-1 THROUGH STS-11)

PREPARED BY
PLANNING RESEARCH CORPORATION
Systems Services
for
ENGINEERING DEVELOPMENT
JOHN F. KENNEDY SPACE CENTER, NASA

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JOHN F. KENNEDY SPACE CENTER, NASA

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ABBREVIATIONS AND ACRONYMS

APS	Aft Propulsion System
APU	Auxiliary Propulsion Unit
Btu	British thermal unit
CCFC	cross-correlation function coefficient
CF	calibration factor
C_L	centerline
cm^2	square centimeter
DAS	Data Acquisition System
dB	decibel
DOF	degree(s) of freedom
ECS	Environmental Control System
EL	elevation
ET	External Tank
F_{max}	maximum analysis frequency
FSS	Fixed Service Structure
ft	foot
g	acceleration due to gravity
G_1	girder (no. 1)
GLOW	Orbiter gross lift-off weight
GO_2	gaseous oxygen
GP	general publication
HDP	holddown post
HIM	hardware interface module
Hz	hertz
in	inch
kHz	kilohertz
kips	thousands of pounds
KSC	John F. Kennedy Space Center
LH_2	liquid hydrogen
LO_2	liquid oxygen
MLP	Mobile Launcher Platform
μin	microinch
μs	microsecond
ms	millisecond
NASA	National Aeronautics and Space Administration
OASPL	overall sound pressure level
OBSPL	octave band sound pressure level
oct	octave
PD	probability density
PIC	Pyro Initiator Controller
PMS	Permanent Measurement System
PRC	Planning Research Corporation
PSD	power spectral density
psia	pounds per square inch, absolute
psig	pounds per square inch, gage
rms	root mean square

ABBREVIATIONS AND ACRONYMS (cont)

RSS	Rotating Service Structure
s	second (of time)
SRB	Solid Rocket Booster
STS	Space Transportation System
T(T-0)	instant of time when the PIC is energized
T_1	truss (no. 1)
TSM	Tail Service Mast
TVM	time variable mean

DECIPHERING THE DESIGNATION

K XX X X

KSC	AC = 60 Hz	D = Vibration	A = Near Field
	AV - Acoustic	G = Force/strain	B = FSS
	CM = LPS	P = Pressure	C = RSS
	FD = Flame deflector	T = Temperature/heat rate	F = MLP-1
	FH = Liquid hydrogen	X = Discrete event	G = MLP-2
	FO = Liquid nitrogen	Y = Acoustics	H = MLP-3
	FT = Floodlight system		I = C/T-1
	EC = ECS Cooling Tower		J = C/T-2
	GH = Gaseous hydrogen		K = VAB/LCC
	IT = Discrete event		7 = Margo
	MS = MLP		8 = Industrial
	MT = Meteorological		Area
	SA = Service and access arms		9 = Far Field
	SM = Tail Service Mast		
	SR = Structural		

Ergo: KSRPG = Plot of the launch-induced reaction of a pressure (P) trans-
ducer installed (see figure 1-1 for location) on the structure
(SR) of MLP-2 (G) at KSC (K).

The time period (holddown or lift-off) or interval within a
time period (SRB ignition or lift-off peak) during which the
reaction was recorded is indicated on each plot.

The numerical suffixes (001A, 002A, . . . 014A, etc.) are se-
quential.

SECTION I

INTRODUCTION

1.1 PURPOSE

The purpose of this document is to present a summary of Shuttle launch-induced environment data acquired at KSC during Space Transportation System (STS) launches.

1.2 SCOPE

The data presented include launch data from STS-1 through STS-11. All Space Shuttles were launched at Pad A from Mobile Launcher Platform (MLP)-1, except STS-6, -8, and -9, which were launched from MLP-2.

1.3 DESCRIPTION

Selection of measurement type, location, range, and sampling frequencies was based primarily on the Shuttle Environment Prediction, GP-1059. Figure 1-1 shows a summary of the measurement type, location, and ranges presented in this document.

Figure 1-2 shows an elevation of LC-39A. Figures 1-3 and 1-4 show the compartment arrangement and main structural members of the MLP. Figures 1-5 and 1-6 show the overpressure sensor locations for both MLP-1 and MLP-2. Figure 1-7 shows the pressure sensors installed on the lightposts for STS-6 launch.

1.4 AUTHORITY

This document was prepared by Planning Research Corporation (PRC) Systems Services Aerospace Division for the NASA/KSC Engineering Development Directorate. Mr. Valentin Sepcenko and Mr. Rocco Sannicandro comprised the PRC technical team for this project. Mr. Frank McInerny and Mr.Bill Tolson of NASA provided direction.

1.5 DATA PROCESSING

The data are initially recorded on magnetic tapes during the launch. These tapes are reduced to raw oscillograms for quick-look analysis and selection of significant time intervals for further processing. Processing was performed in NASA's Wave Analysis Laboratory.

1.5.1 HIGH-FREQUENCY DATA. Launch environment data such as plume pressures, acoustics, strains in structural members, and vibration may be classified as wideband, random, and nonstationary. Data time histories represent long-duration transients where, in a general case, the mean value and the standard deviation calculated within a short time interval are also variable with

Measurement Type	Location	Qty	Range
Pressure	MLP		
	Deck	6	0 to 150 psia
	TSM	12	0 to 25 psia
	Exhaust wells	40	0 to 50 psia
	Flame deflector	8	0 to 300 psia
	FSS	6	0 to 20 psia
	Centaur Porch	8	± 5 psig
Acoustics	MLP (inside)	15	110 dB to 170 dB
	FSS	7	138 dB to 180 dB
	RSS	12	130 dB to 175 dB
	Pad (far field)	18	120 dB to 180 dB
Strain	MLP (inside)	18	$\pm 1,500$ μin/in
	Holddown posts	48	± 500 μin/in
	TSM	8	± 350 to 1,250 μin/in
	RSS	15	± 900 μin/in
Load	MLP holddown posts	12	0 to 2,124 kips
Temperature	MLP		
	Deck	9	32°F to 1,900°F
	Flame deflector	2	32°F to 4,200°F
Heat Rate	MLP deck	6	0 to 820 Btu/ft^2/s
	FSS ET vent arm	1	0 to 300 Btu/ft^2/s
Vibration	MLP (inside)	150	± 5 g to ± 100 g
	FSS	47	± 15 g to ± 100 g
	RSS	41	± 7 g to ± 65 g

Figure 1-1. Shuttle Launch Environment Measurements Summary
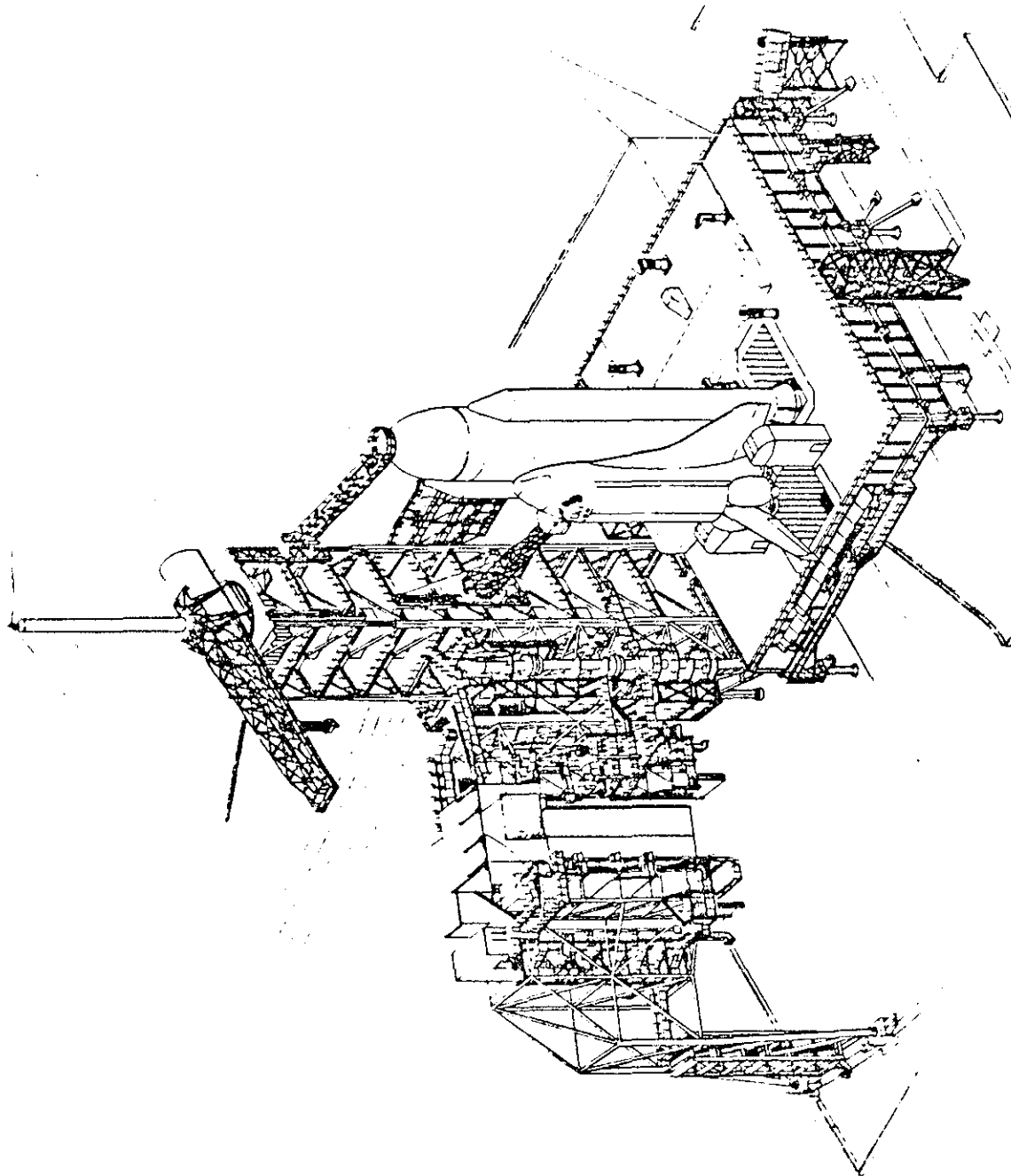
Figure 1-2. Launch Configuration (Sheet 1 of 2)
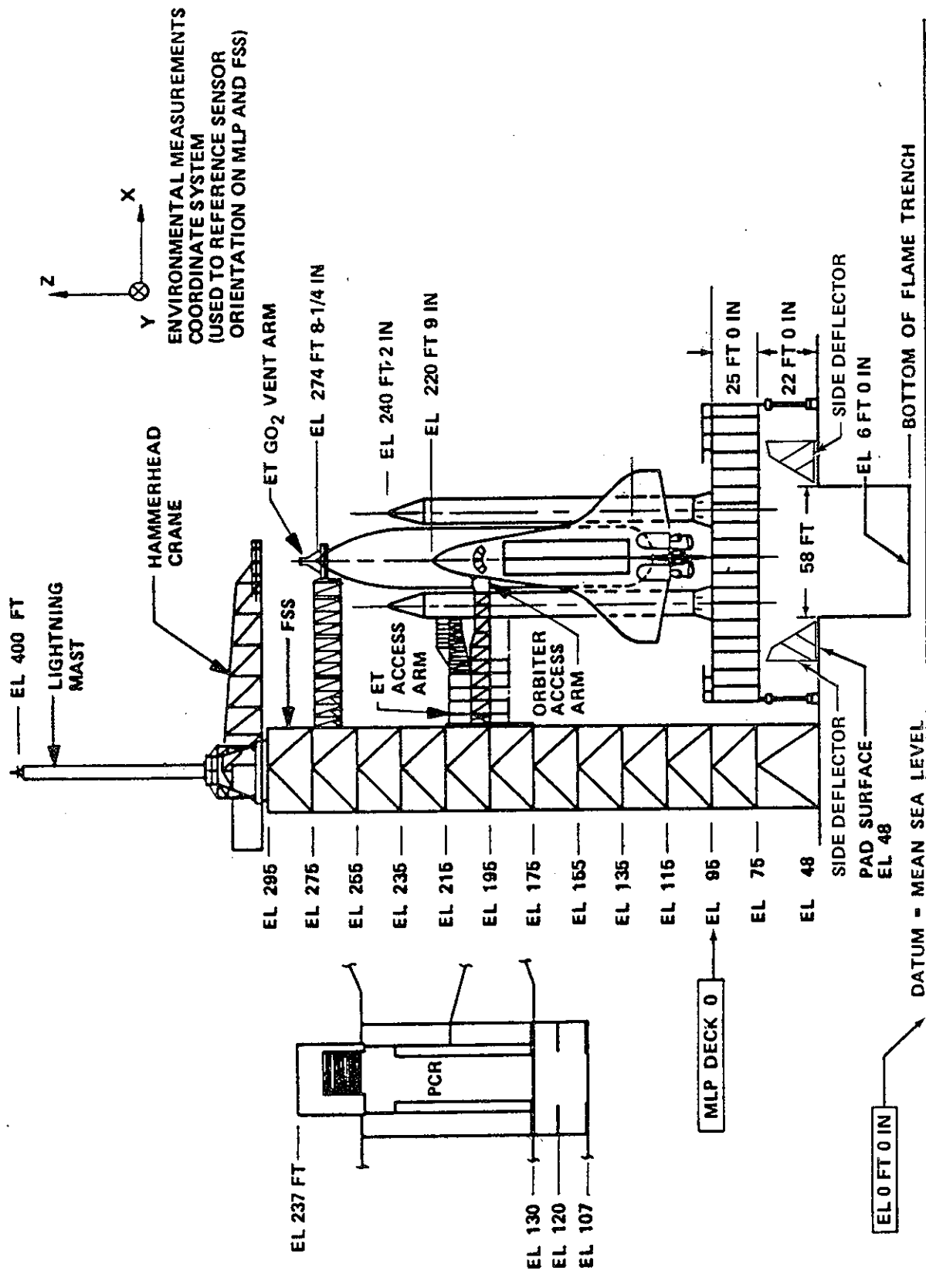
Figure 1-2. Launch Configuration (Sheet 2 of 2)
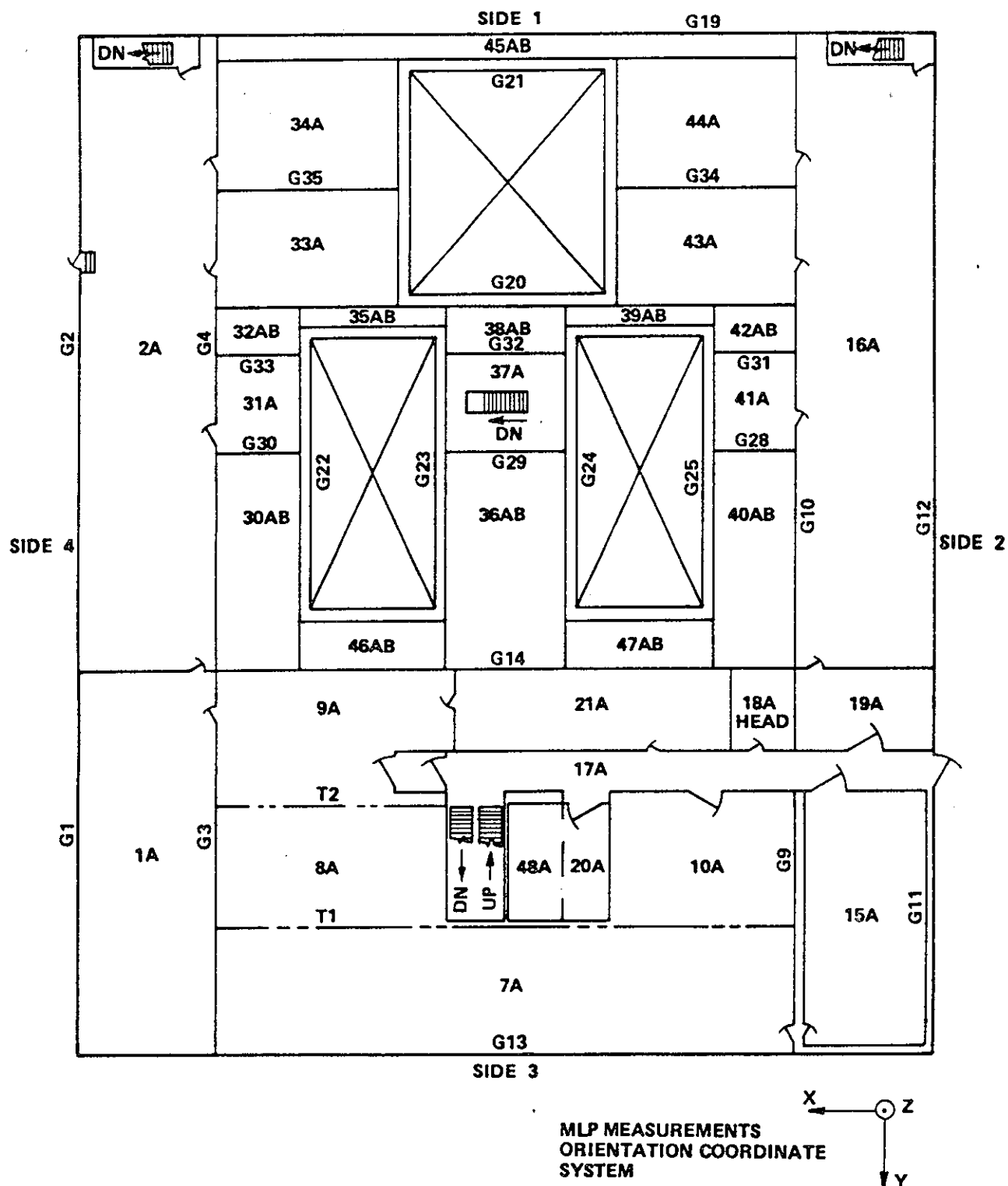
Figure 1-3. MLP Deck A Floor Plan
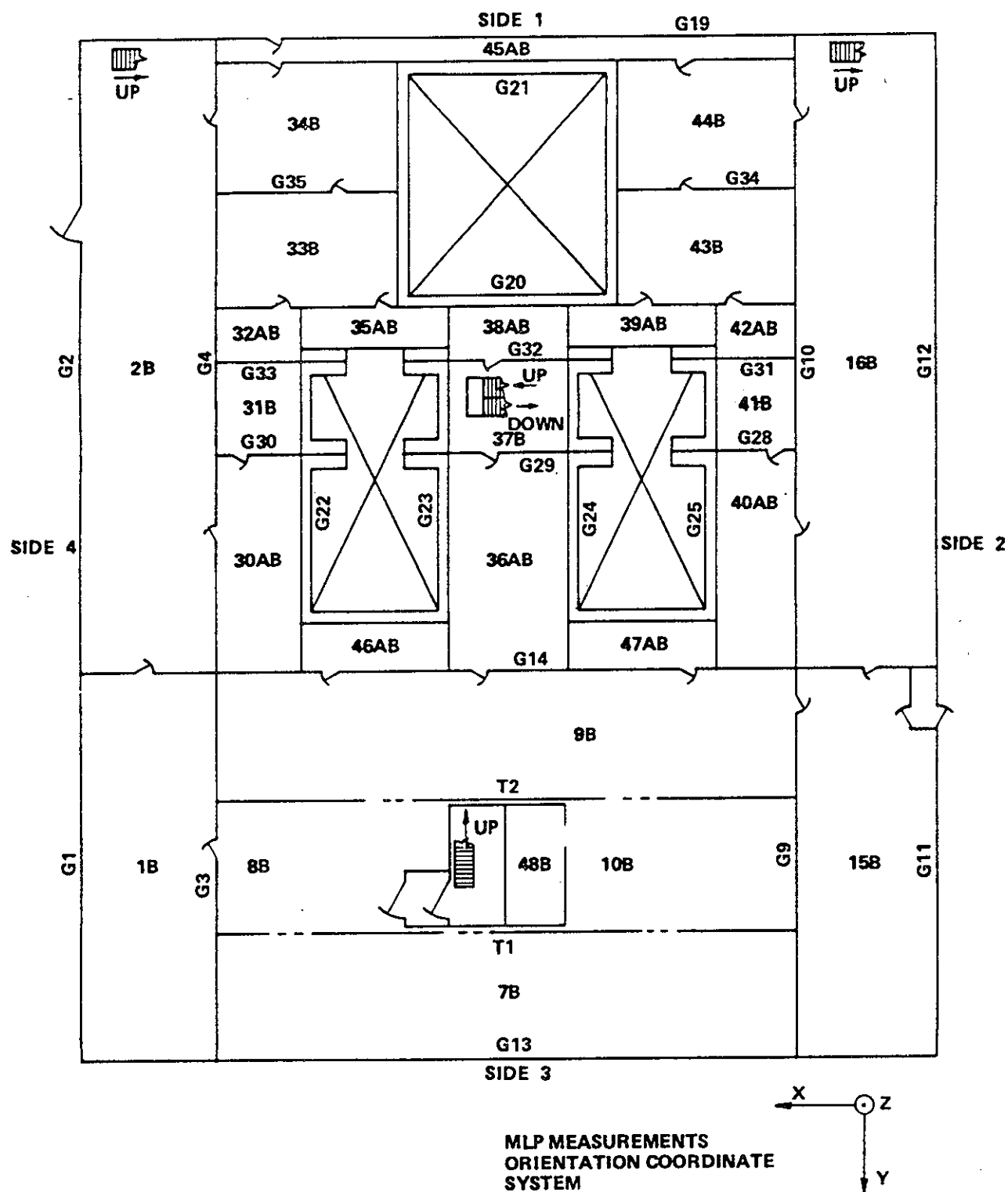
Figure 1-4.   MLP Deck B Floor Plan

Figure 1-5. Overpressure Measurement Locations (MLP-1)
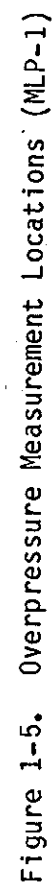
Figure 1-6. Overpressure Measurement Locations (MLP-2)
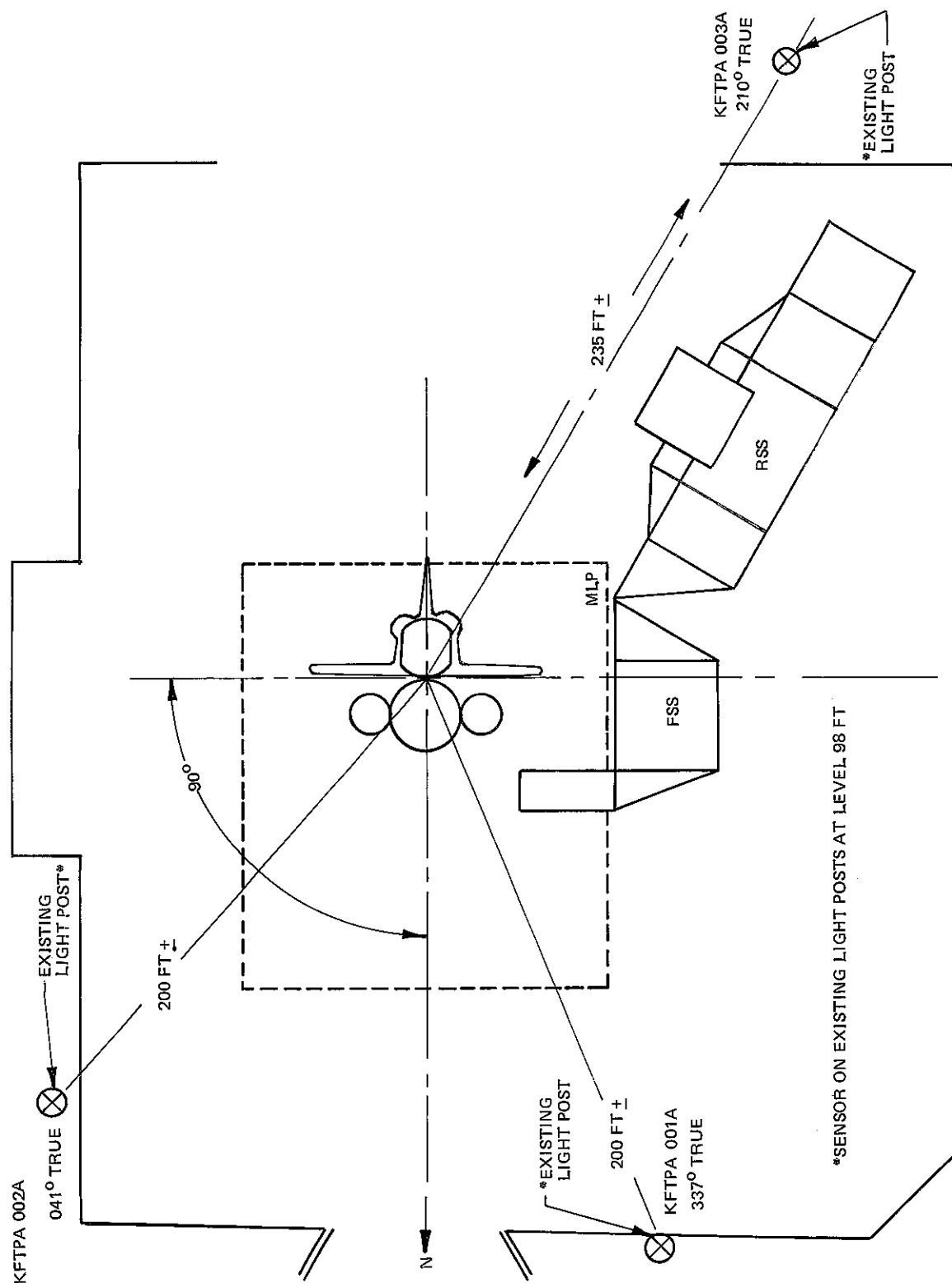
Figure 1-7. STS-6 Sensors Installed at Pad

time. The procedure used to process random nonstationary data in terms of well-developed statistical functions used in stationary data processing is outlined further.

All processing was performed on Hewlett-Packard 5451C Fourier analyzer equipment. The inherent features of the analyzer, such as the choice of a data block size and maximum analysis frequency, have an effect on the processed results because of the nonstationary character of the data. In most cases, statistical accuracy (random error) of processed data was limited by the available duration of the data.

The first step in data processing is the separation of raw data into two components: time variable mean (TVM) and the dynamic component. TVM is calculated from raw data by means of a multiple application of a Hanning smoothing algorithm. The calculated difference between the raw data and the TVM is the dynamic component. The chosen method of digital separation via Hanning algorithm has an advantage over filtering because it does not introduce any phase shift in the data. All further statistical processing involves only the dynamic component.

Certain types of data (vibration, acoustic, and some strains) have an inherent zero mean and did not require the preceding step.

Whenever available memory space permitted, a type of overlap processing was used by generating intermediate data blocks from two adjacent blocks containing a dynamic component. This operation was necessary to reduce random error, a consequence of the short duration of available data and the small number of data blocks. The number of degrees of freedom (DOF) for statistical estimates is almost doubled by overlap processing.

Standard deviation, or the root mean square (rms) of the dynamic component, is calculated on a data block basis. Averaging is performed for the time interval contained within a data block. A plot of standard deviation time history on a data block basis is always presented in this report to depict the nonstationary character of the data during the total time interval of analysis.

Calculation of the dynamic component frequency composition and related cross-functions (power spectra, cross-power spectra, and auto- and cross-correlation function coefficients) via Fourier transformation, followed by conjugate multiplication and averaging of resulting data blocks, required weighting of data blocks prior to averaging. Such a requirement is peculiar only to nonstationary data. A weighting factor, equal to the reciprocal of the data block standard deviation, reduces the time variable standard deviation of the dynamic component to a constant unit value. Normalization was performed on each data block in the time domain to reduce the dynamic component to a stationary data form. From this point on, calculations of power spectra, cross-power spectra, auto- and cross-correlation function coefficients, and coherences follow the standard procedure for stationary data.

Two different windowing functions were applied to the normalized time domain data in order to reduce leakage before taking the Fourier transforms. Both windows use a cosine tapering function applied at each end of a data block to a variable number of points (window taper width). In cases where the overlap processing was used, the window taper width is equal to one-quarter of the data block. In all other cases, the window taper width is equal to one-tenth of the data block. While the data processing program allows specification of any window taper width, the choice of assumed windows was found to be an optimum compromise between the leakage reduction and the alteration of data amplitudes. Preservation of data amplitudes was a governing factor because of the short duration of available data. The correction required to preserve the normalized unit value of standard deviation after windowing is calculated for each window type and applied to the processed data.

Normalized power spectra having a unit area, together with the time history of standard deviation, are a sufficient representation of a class of nonstationary data having a constant frequency composition within the total analysis interval. It should be noted that actual launch data do not perfectly fit such a model. Some frequency variation does occur although relatively slowly and in a continuous manner. In this case, processed power and cross-power spectra represent average rms amplitudes occurring within the total processed time interval.

The final step in calculating power spectra and cross-power spectra was affected by practical considerations of data usage. For the sake of convenience, normalized power spectra were multiplied by the value of variance corresponding to a data block with a maximum value of standard deviation. Similarly, normalized cross-power spectra magnitude was multiplied by the product of maximum values of a pair of standard deviations of data channels entering the cross-power spectrum calculations. Final presentations are in engineering units (squared) per unit bandwidth.

Estimated power spectra and cross-power spectra have a very jagged appearance, caused mainly by the small number of DOF available for these estimates rather than by the actual presence of narrow-band peaks in the data. Plume pressure and acoustic data are inherently wideband. Vibration and strain data contain legitimate peaks at resonance frequencies. It was considered that some frequency domain averaging would improve the legibility and, in the case of plume pressures and acoustics, the quality of the estimates. Therefore, frequency domain averaging using a Hanning algorithm was performed on all data in the frequency domain. However, the presentations always include data before and after performed averaging with an understanding that the user's judgement and experience are necessary to interpret the validity of narrow-band peaks.

The amplitude distribution probability density (PD) function is obtained from the nonstationary dynamic component prior to normalization and by means of histograms on a data block basis. Thus, PD represents a time-averaged estimate for the total duration of an analyzed interval. These estimates deviate from normal (Gaussian) distribution, reflecting the nonstationary character of

the data and, to a lesser degree, the procedure. For presentation, the PD was reduced to a standardized form whereby the abscissas are expressed in units of standard deviations (sigmas) and the ordinates are a product of PD and the standard deviation. The assumed value of the standard deviation is the calculated maximum on a data block basis. Such a presentation facilitates direct comparison with standardized Gaussian distribution.

In practical applications, integrals of PD (i.e., the cumulative probability) are of importance. These integrals were calculated between limits (-1, +1) to (-3, +3) standard deviations in 0.5 intervals.

In addition to the previously described processing, the acoustic and pressure dynamic components were processed in terms of octave band sound pressure levels (OBSPL's). The OBSPL's were calculated from power spectra for standard octave center frequencies and bandwidths. It should be noted that the last point of an OBSPL curve is always affected by the cutoff frequency of an anti-aliasing filter. Also, the accuracy at the lower end of the OBSPL curve is affected by the resolution bandwidth of the calculated power spectral density (PSD) curve. Thus, the accurate range of the OBSPL curve is from about 16 Hz and up to the frequency preceding the last center frequency shown on the OBSPL plots. Below this range (approximately 16 Hz), the dispersion among OBSPL curves from sensors, which should have measured about the same values, is increasing toward the first OBSPL center frequency of 2 Hz. The cause of such a decrease in accuracy is not in the data processing but rather in the fact that within the total available analysis interval there is an insufficient number of cycles at these low frequencies for a reliable statistical estimate. Conversely, at the low frequency end, 4 Hz and below, there is an insufficient number of cycles to produce full resonances in the affected structures.

1.5.2 TIME INTERVALS AND PARAMETERS FOR DATA PROCESSING.

1.5.2.1 Time Intervals. Time intervals (as shown in figure 1-8) selected for high-frequency data processing are referenced to an instant of time, T (often called T-zero), which is the time of a signal sent to the Pyrotechnic Initiator Controller (PIC).

Figure 1-8 depicts a typical data-time history where T divides a total data duration into two periods: Orbiter holddown and lift-off.

1.5.2.1.1 Orbiter Holddown Period. The Orbiter holddown period begins with Space Shuttle Main Engine (SSME) ignition and the occurrence of measurable data; it ends at T. It is characterized by a rapid rise of the standard deviation to a peak followed by a small decay and transition into a steady state. The total duration of this period is about 5.5 s.

1.5.2.1.2 Lift-off Period. By definition, the lift-off period begins at time T. The extent and the end of this period are vaguely defined by a decay of data amplitudes beyond significant values. Usually this decay is accompanied by a visible shift in the data frequency composition toward the lower end of the spectrum.
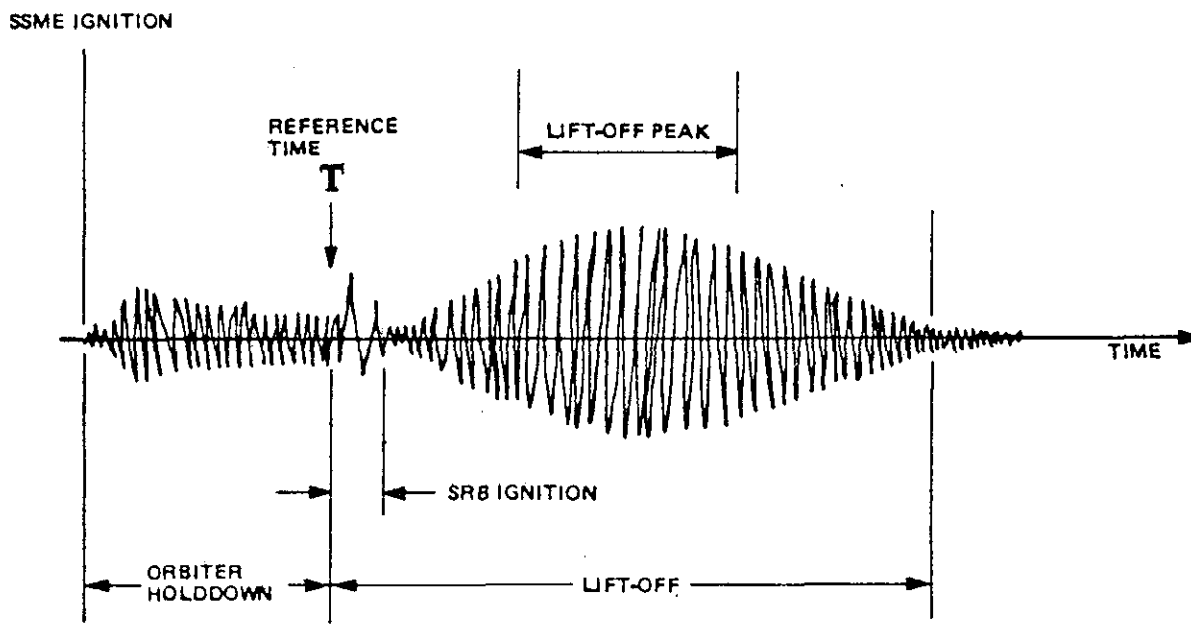
Figure 1-8. Time Periods and Intervals of the Launch Environment

1.5.2.1.3 Lift-off Period Intervals. Within the lift-off period, there are two intervals containing different types of data. The first interval is designated SRB ignition. This interval contains a distinct pulse caused by the SRB ignition overpressure that is superimposed over a steady-state environment generated by the SSME exhaust plumes. The second interval, designated lift-off peak, is centered on the lift-off period to contain the peak data amplitudes recorded during lift-off.

In a general case, processing was performed on data from the period of Orbiter holddown and from the two lift-off intervals: SRB ignition and lift-off peak.

Since sensor calibration was performed to accommodate the anticipated peak amplitudes at lift-off, there are cases where holddown data are either near or below the usable sensor range; i.e., the data are in the noise domain. In such cases, holddown data were not processed. Similarly, there are cases where the SRB ignition did not induce significant response and, consequently, processing was omitted. In each case, a judgement was involved in the selection within the general classification of outlined launch-time intervals.

1.5.2.2 Parameters for Data Processing. The choice of parameters governing data processing [block size, maximum analysis frequency (F_{max}), total analysis time (TAT), etc.] was made after examination of launch data oscillograms. The appearance of raw data within the time interval selected for processing and the frequency-response range of the sensor imposed the upper limit on the selection of F_{max}.

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The choice of a data block size is usually a compromise among a desired resolution bandwidth, the available length of data for a desired large number of DOF affecting the random error, and a requirement to have essentially stationary data within the selected block size. The last requirement could not always be met because of the nonstationary character of the data. In order to improve the resolution in the lower frequency range, a few processing runs were necessary using the lower values of F_{max} rather than the upper limit governed by the total frequency content in the data. Thus, most of the processed data are presented for two and sometimes three values of F_{max} and other parameters. All pertinent parameters appear on the plots of processed data.

1.5.2.3 <u>Definitions of Parameters</u>. Following are definitions of some parameters appearing in the data plots of this publication.

a. Sample rate is always set to be twice F_{max}. Anti-aliasing filter setting is always one-half F_{max}.

b. Start time defines the beginning of the total interval used in processing. It is always referenced with respect to time, T.

c. Time domain filter taper width defines the number of data points at each end of a data block in the time domain window smoothed by the cosine function.

d. Standard deviation and rms are used interchangeably and pertain to the dynamic component only.

e. Filter bandwidth represents the resolution bandwidth of a frequency domain plot; i.e., the spacing of plotted data points.

f. Raw data, TVM, or dynamic component. Whenever these terms are presented, the plots correspond to a data block having a maximum value of standard deviation. The location of this data block within the total processing interval may be found from the plot of standard deviation time history on a data block basis.

g. Number of Hanning smoothings represents the number of passes of the smoothing algorithm applied to separate the TVM from the raw data (in the time domain) or to provide averaging in the frequency domain (PSD plots).

The remaining parameters and plot titles appearing in this document are self-explanatory.

1.6 SPACE SHUTTLE LAUNCH ENVIRONMENT REFERENCE MATERIAL

Document No.	Title
KSC-DD-457-TR	Space Shuttle STS-1 Launch Processed Ground Measurements; Volumes 1 and 2, September 1981
KSC-DD-593-TR	Space Shuttle STS-2 Launch Processed Ground Measurements; Volumes 1 and 2, May 1982
KSC-DD-651-TR	Space Shuttle STS-3 Launch Processed Ground Measurements; Volumes 1 and 2, October 1982 Appendix A STS-3 MLP Vibration Data Appendix B STS-3 RSS Vibration Data Appendix C STS-3 FSS Vibration Data
KSC-DD-655-TR	Space Shuttle STS-4 Launch Processed Ground Measurements; February 1982 Appendix A FSS Acoustic Summary
KSC-DD-677-TR	Space Shuttle STS-3 Launch Vibration Displacements and Acceleration Spectral Densities of the MLP, RSS, and FSS; February 1983
KSC-DD-684-TR	Vibration Environment Effect on Payload Ground Handling Mechanism During STS-6 Flight Readiness Firing; March 1983
KSC-DD-688-TR	Space Shuttle STS-5 Launch Processed Ground Measurements; April 1982 Appendix A FSS Acoustics Summary Appendix B SRB Holddown Post Strains and Loads During the Holddown Period
KSC-DD-712-TR	Space Shuttle STS-6 Launch Processed Ground Measurements; July 1983 Appendix A FSS Acoustics Summary Appendix B TSM Acoustics Summary Appendix C STS-6 Near-Field Pressure on Light Posts Appendix D Acoustics Inside MLP-1 and MLP-2 Appendix E Vibration Inside MLP-1 and MLP-2

SECTION II

PRESSURE AND ACOUSTICS

2.1   FSS ACOUSTICS SUMMARY

The FSS acoustics summary includes data from five pressure sensors, KSAPB001A through KSAPB005A, recorded during STS-1 through STS-9 launches. All sensors were oriented horizontally and located on the corner column of sides 1 and 4 of the FSS. Figures 2-1 through 2-5 show mean and limit (limit = mean + 2 sigma) PSD's for each sensor, processed using two different sets of processing parameters and different time intervals during peak environment at lift-off. The left frame of each figure (2-1 through 2-5) presents peak PSD's of pressure components above approximately 50 Hz, up to the plot limit of 750 Hz. The right frame of each figure (2-1 through 2-5) presents peak PSD's of pressure components below approximately 50 Hz. This dual presentation accounts for observed variation in the pressure waveform frequency composition, which occurs in a continuous manner during a launch.

PSD statistics (mean and limit) obtained by lumping all FSS sensor data are shown on figures 2-6 through 2-13. Heading text that accompanies each figure (plot) provides information pertinent to data processing and rms (standard deviation) values of pressures within presented frequency range. Statistics on figures 2-6, -8, -10, and -12 present separate mean and limit PSD's obtained from measurements shown on figures 2-7, -9, -11, and -13, which serve mainly as illustrations of data dispersion on the FSS. For applications such as a test specification or a design criterion, or both, limit curves on figures 2-6 and 2-10 (or 2-12) are recommended. Limit curve on figure 2-6 will govern for frequencies above approximately 50 Hz, while limit curve on figure 2-10 will govern for frequencies below approximately 50 Hz. It is necessary to mention that below about 10 or 12 Hz, the number of pressure cycles occurring during the peak is insufficient to induce full resonance. The peak environment is usually contained within a single data block of about 0.5 s duration. Within a longer interval of about 1.5 s, the peak environment decays to about 85 percent of its peak value. The user is advised to examine individual measurement rms time histories published for launches STS-1 through STS-6, and, whenever responses were calculated assuming steady-state theory, to introduce a correction for a limited number of excitation cycles. Without such correction, responses below 12 Hz will be overestimated.

Figures 2-14 and 2-15 present enlarged PSD plots obtained from the output of sensor KSAPB005A located on the 245-ft level for STS-1 through STS-8. Both mean and limit curves are nearly identical to those on figure 2-5 (right frame) showing that the addition of one series of launch data (STS-9) does not introduce any significant change to presented statistics. The limit curve on figure 2-14 was used to check ET GO_2 vent arm for dynamic loads.

Figure 2-16 presents comparative plots between predicted and measured (STS-1 through STS-6) OBSPL's. For applications, we recommend the use of presented PSD's rather than OBSPL's because these PSD's have a substantially better resolution than that obtainable from conversion of OBSPL's into an average octave band PSD.

No distinct "static" type pressures were measured on the FSS during STS-1 through STS-9 launches. Measured pressures are clearly dynamic transients. Same low baseline drifts were noticed in the outputs of all pressure sensors on the FSS. These drifts were becoming progressively worse as the number of launches increased, and during STS-11 two FSS sensors failed. Baseline drifts, both positive and negative, which may be mistaken for pseudostatic pressures, are caused mainly by radiating heat and a very high rate of heat input resulting in nonuniform temperature distribution and consequent thermal deformations within sensor bodies.

Figure 2-17 presents a summary of PSD's obtained from the output of sensor KSAPB006A. This sensor is located on the ET vent arm at the top of haunch pivot and is oriented upward. Because of its proximity to the exhaust plume, the output of this sensor was significantly affected by heat; therefore, the data were processed using a high-pass filter to eliminate high baseline drift, and so it is not known whether there were any "static" pressure components (below 2 Hz) present in the sensor output.

Vehicle trajectory and engine gimbaling have a significant effect on this measurement. Two lowest PSD curves on figures 2-17 (STS-5 and STS-6) have a magnitude similar to data recorded on the FSS proper (sensors KSAPB001A through KSAPB005A). STS-7 and especially STS-8 data are significantly higher.
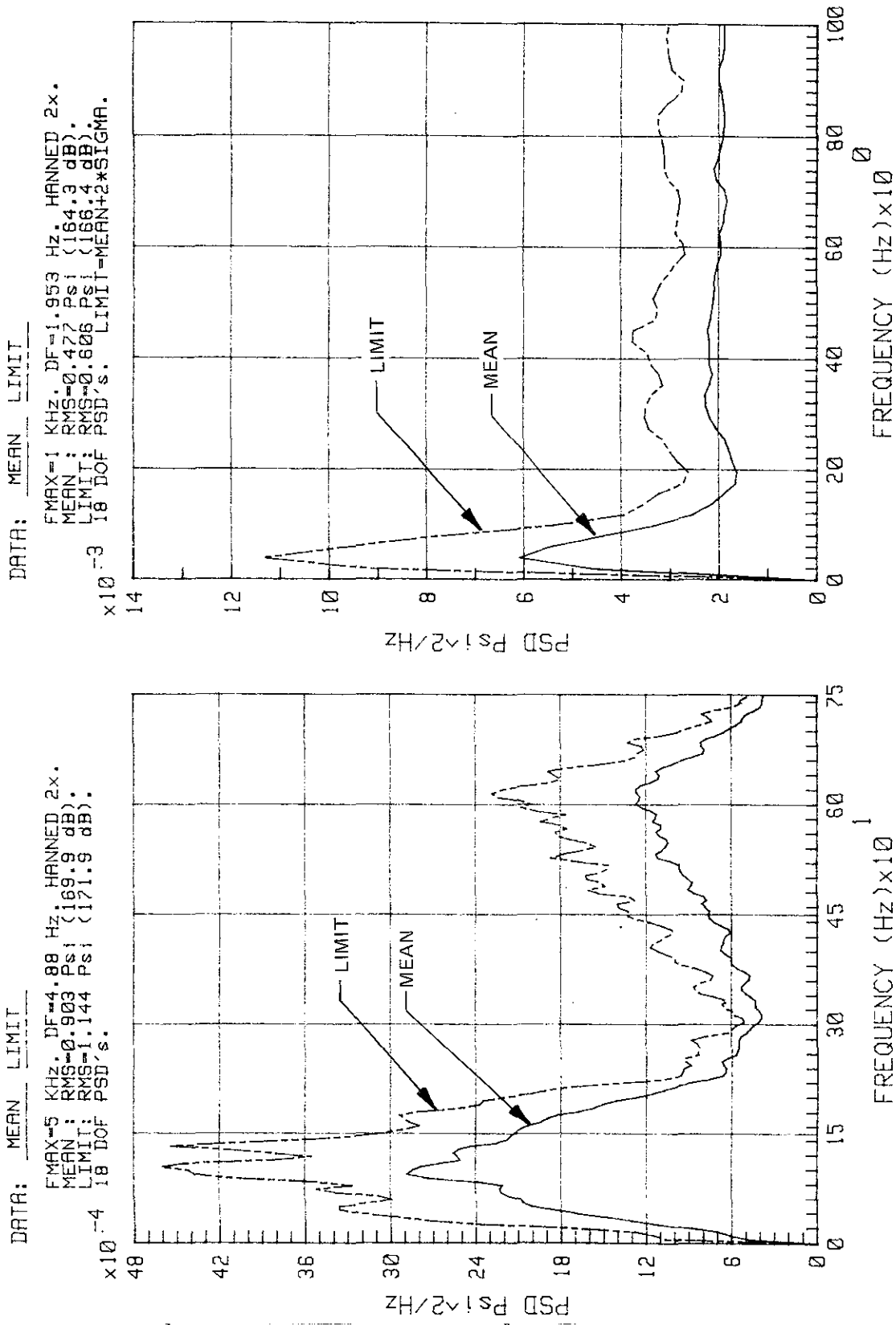
Figure 2-1. STS-1 Through -9 FSS Acoustics at Lift-Off Peak - Sensor KSAPB001A at 125-ft Elevation
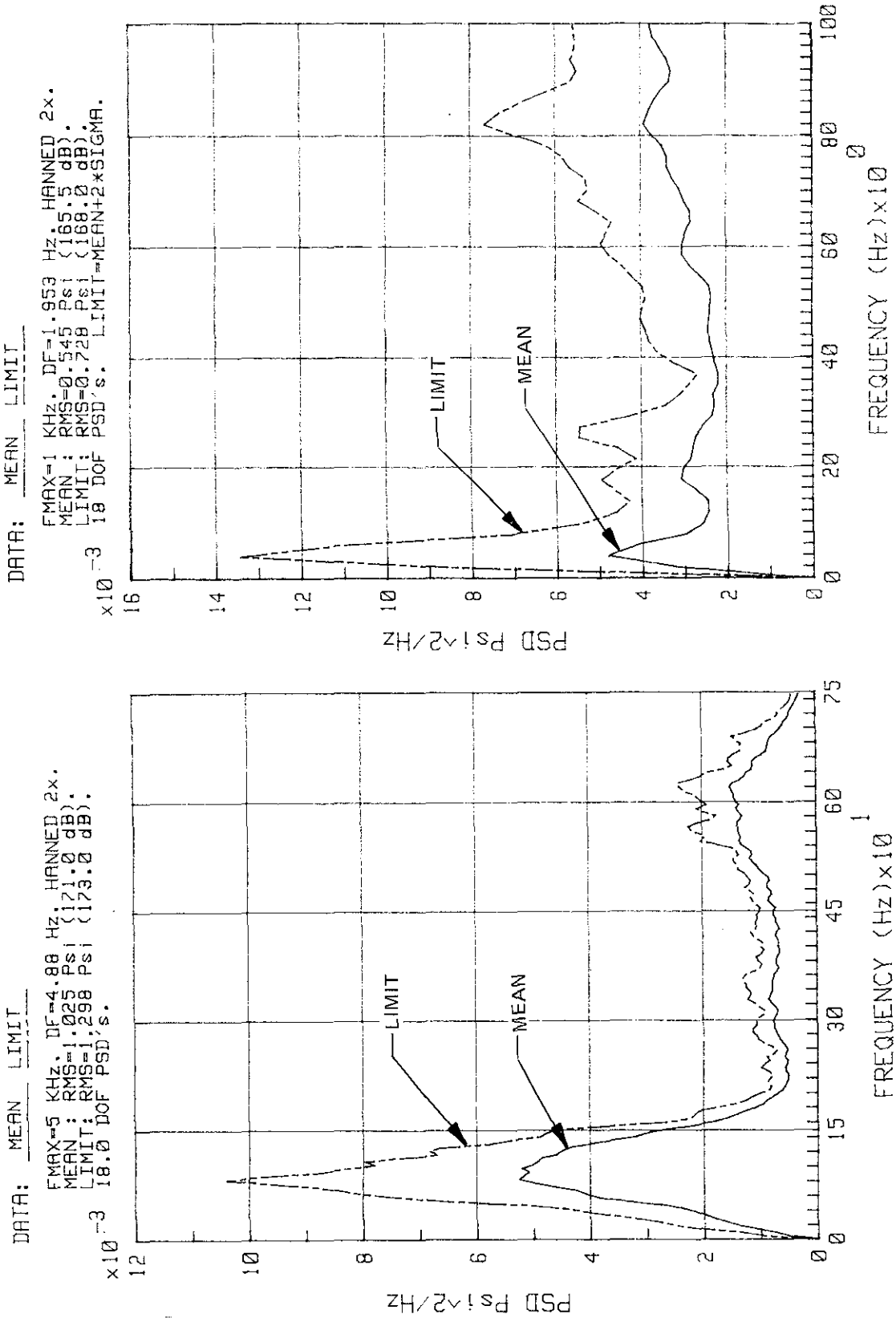
Figure 2-2. STS-1 Through -9 FSS Acoustics at Lift-Off Peak - Sensor KSAPB002A at 155-ft Elevation
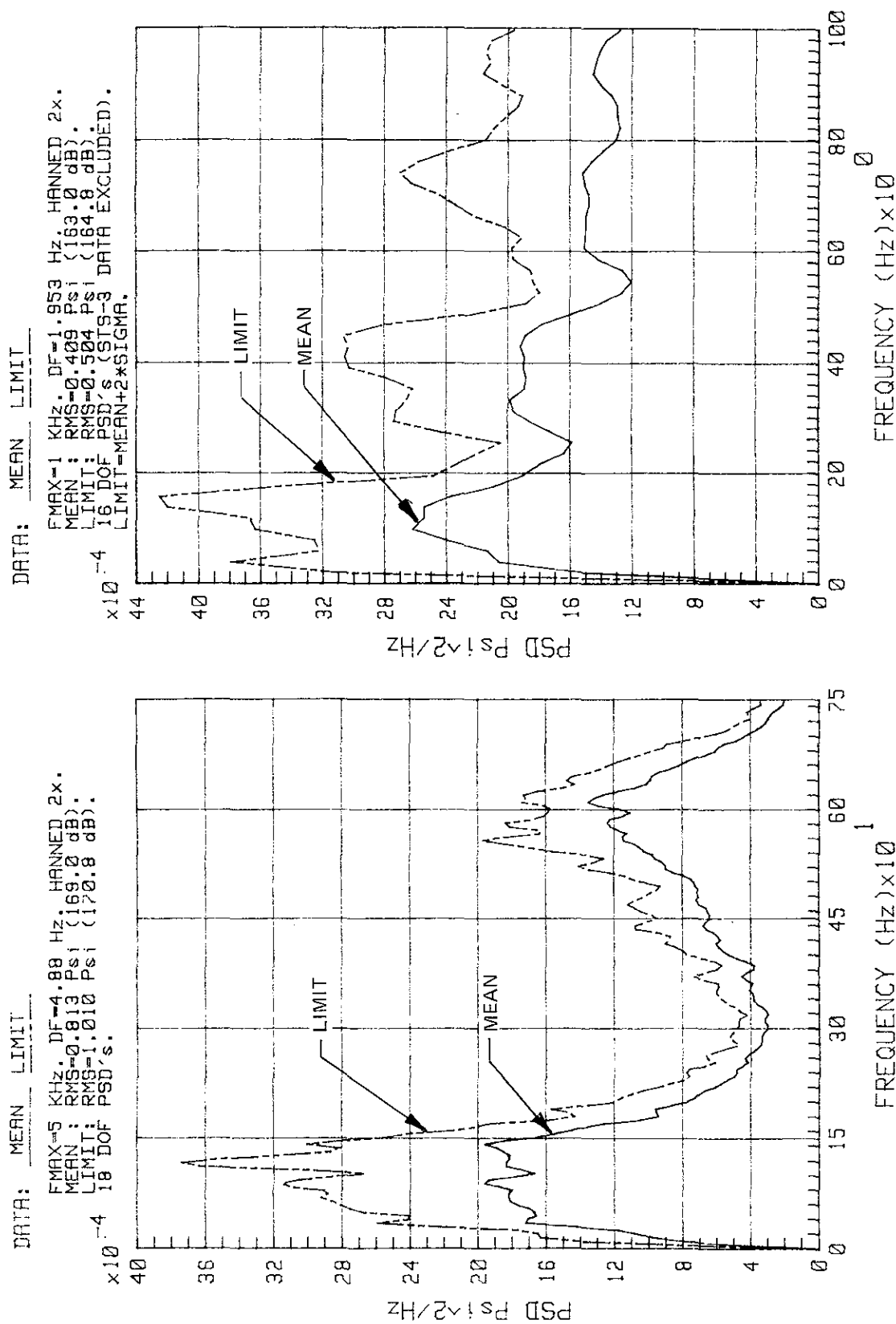
Figure 2-3. STS-1 Through -9 FSS Acoustics at Lift-Off Peak - Sensor KSAPB003A at 185-ft Elevation
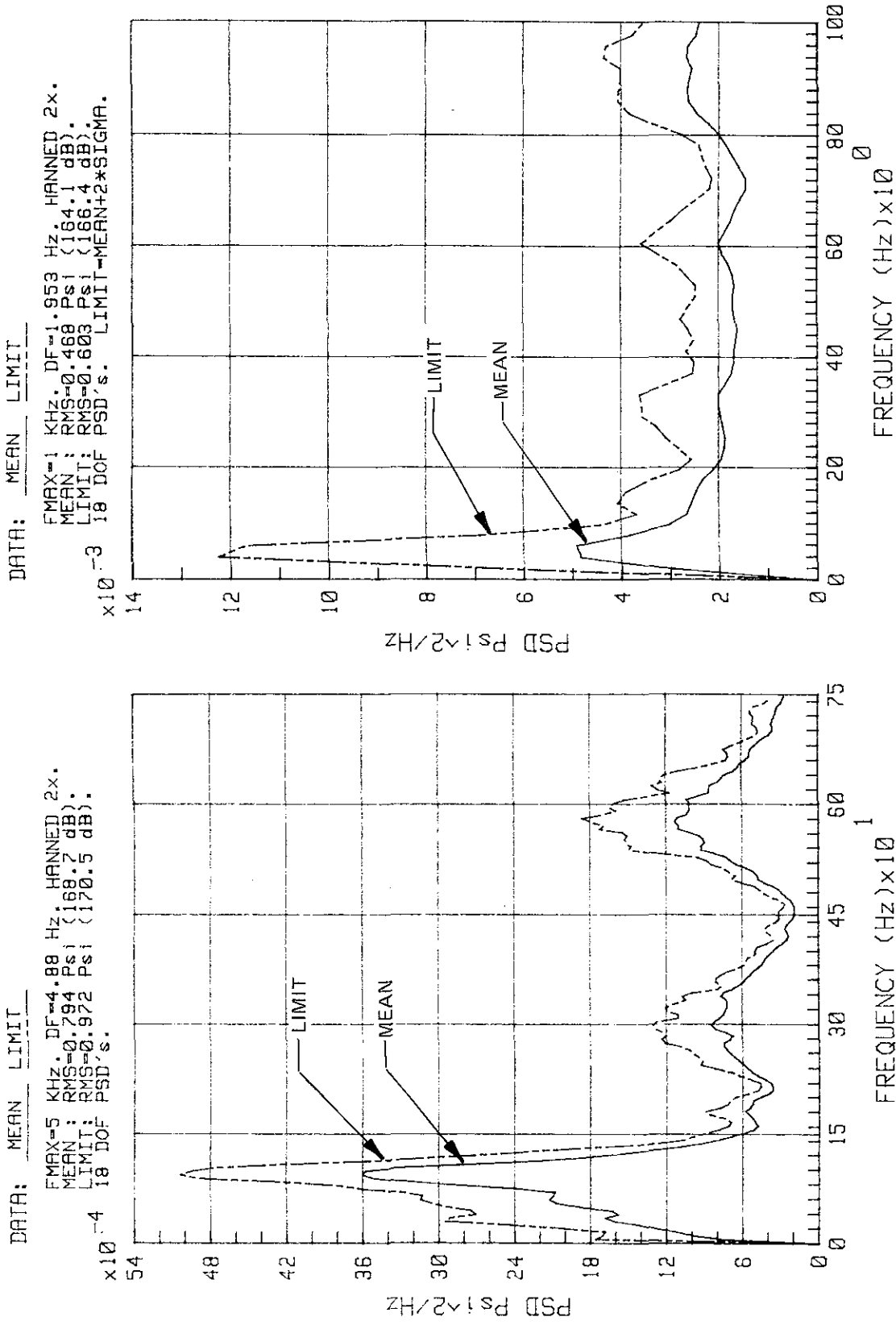
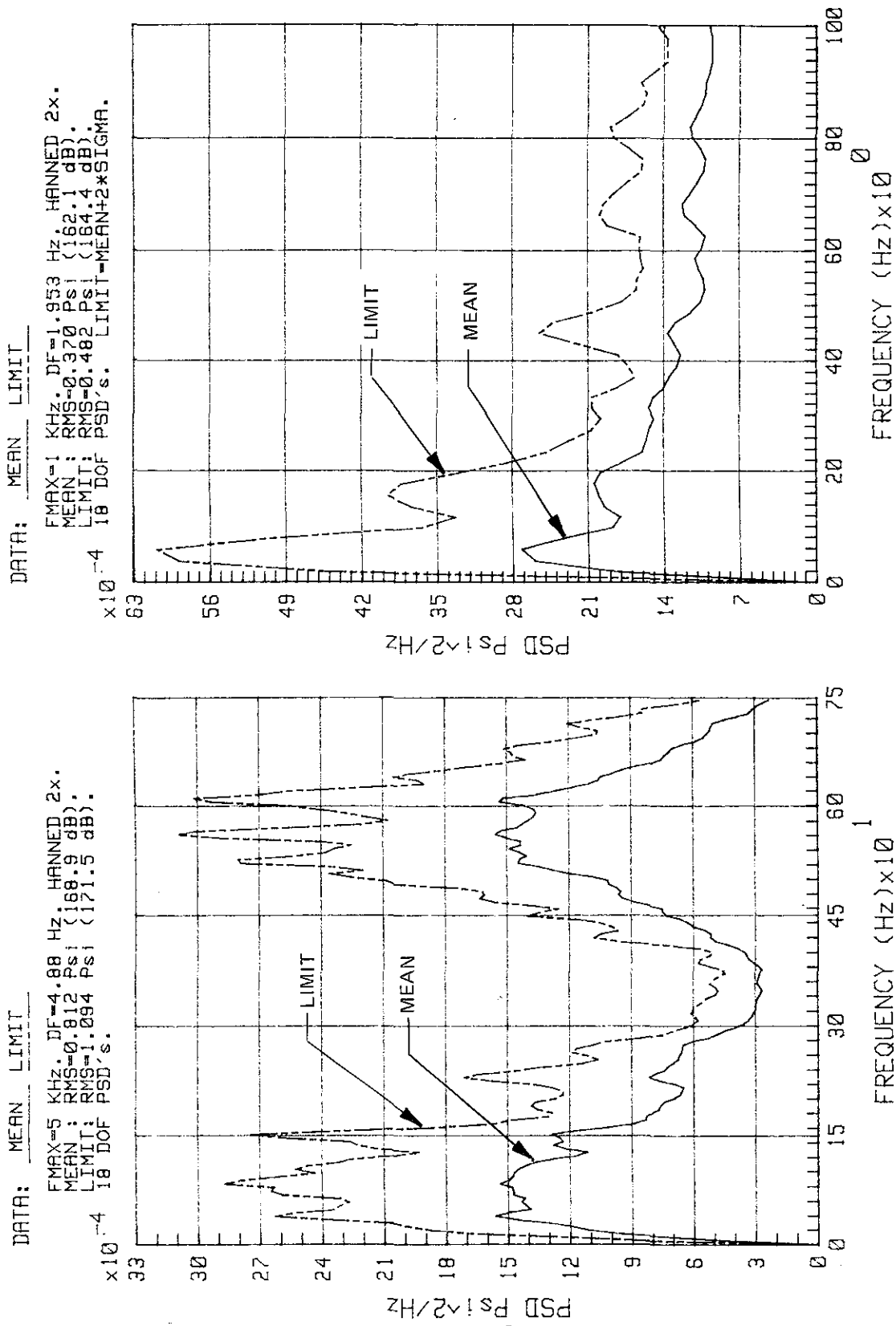Figure 2-4. STS-1 Through -9 FSS Acoustics at Lift-Off Peak - Sensor KSAPB004A at 215-ft Elevation

Figure 2-5. STS-1 Through -9 FSS Acoustics at Lift-Off Peak - Sensor KSAPB005A at 245-ft Elevation
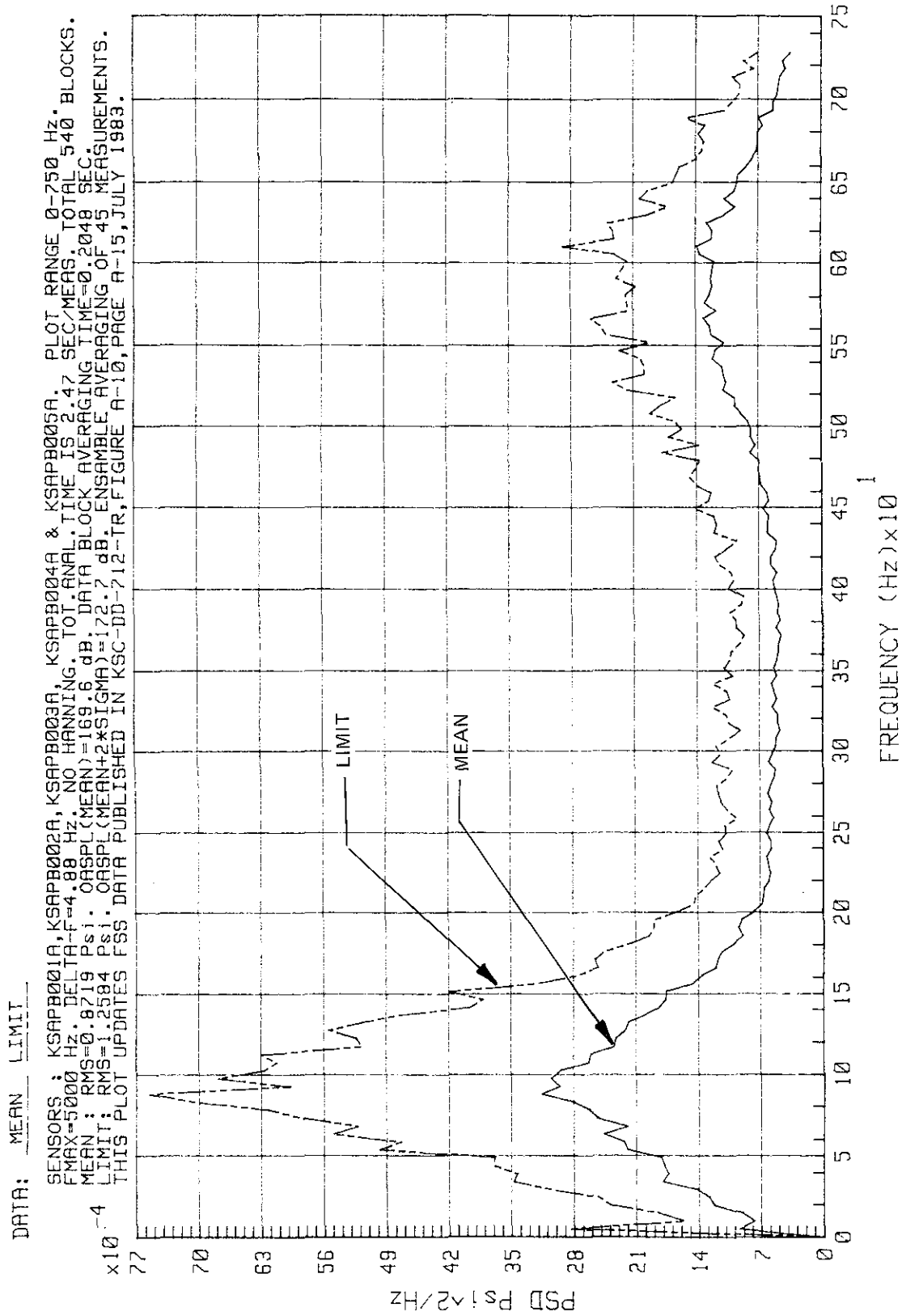
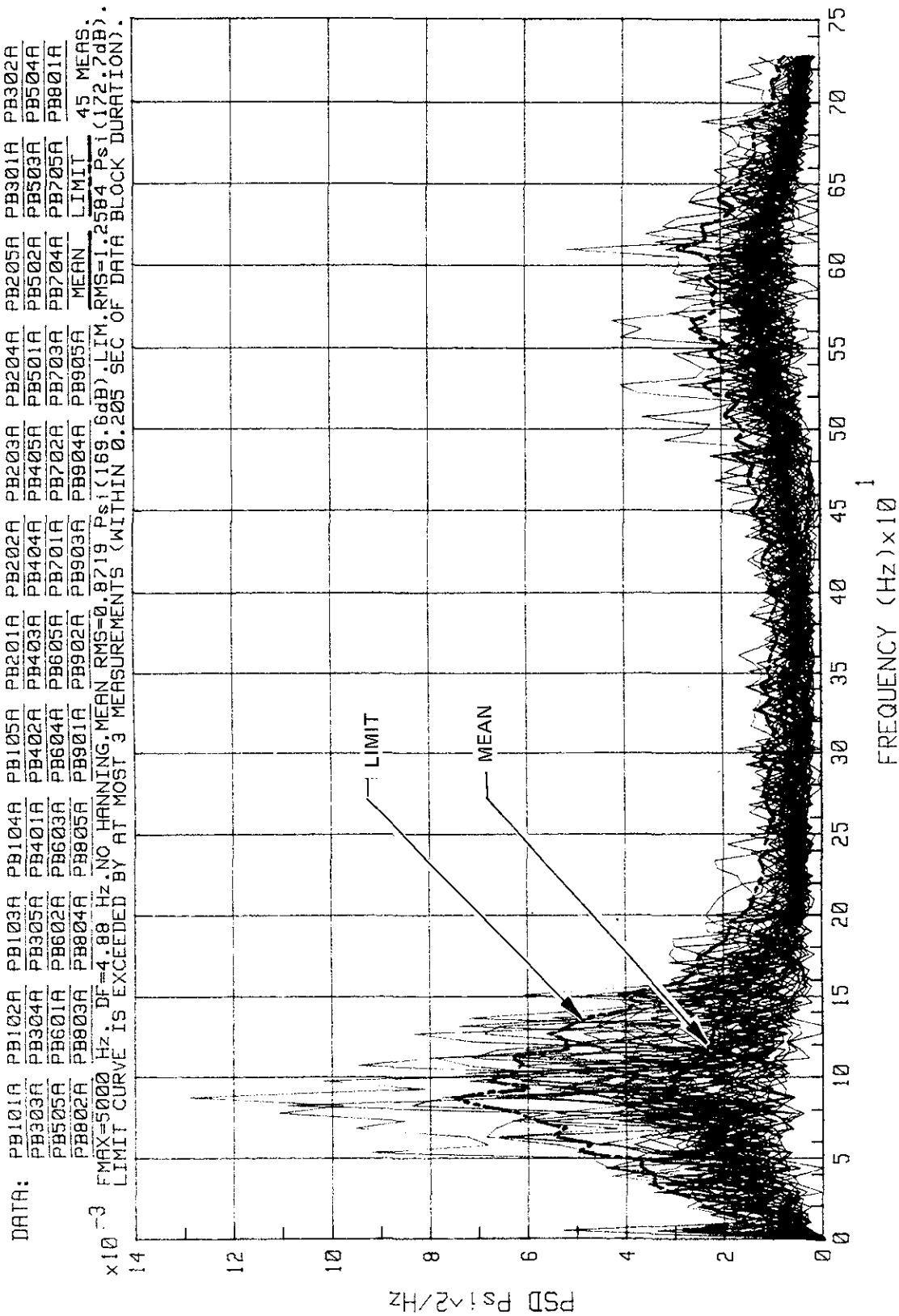Figure 2-6. STS-1 Through -9 Summary of FSS Acoustics at Lift-Off Peak - 90 DOF PSD's (Mean and Limit Only)

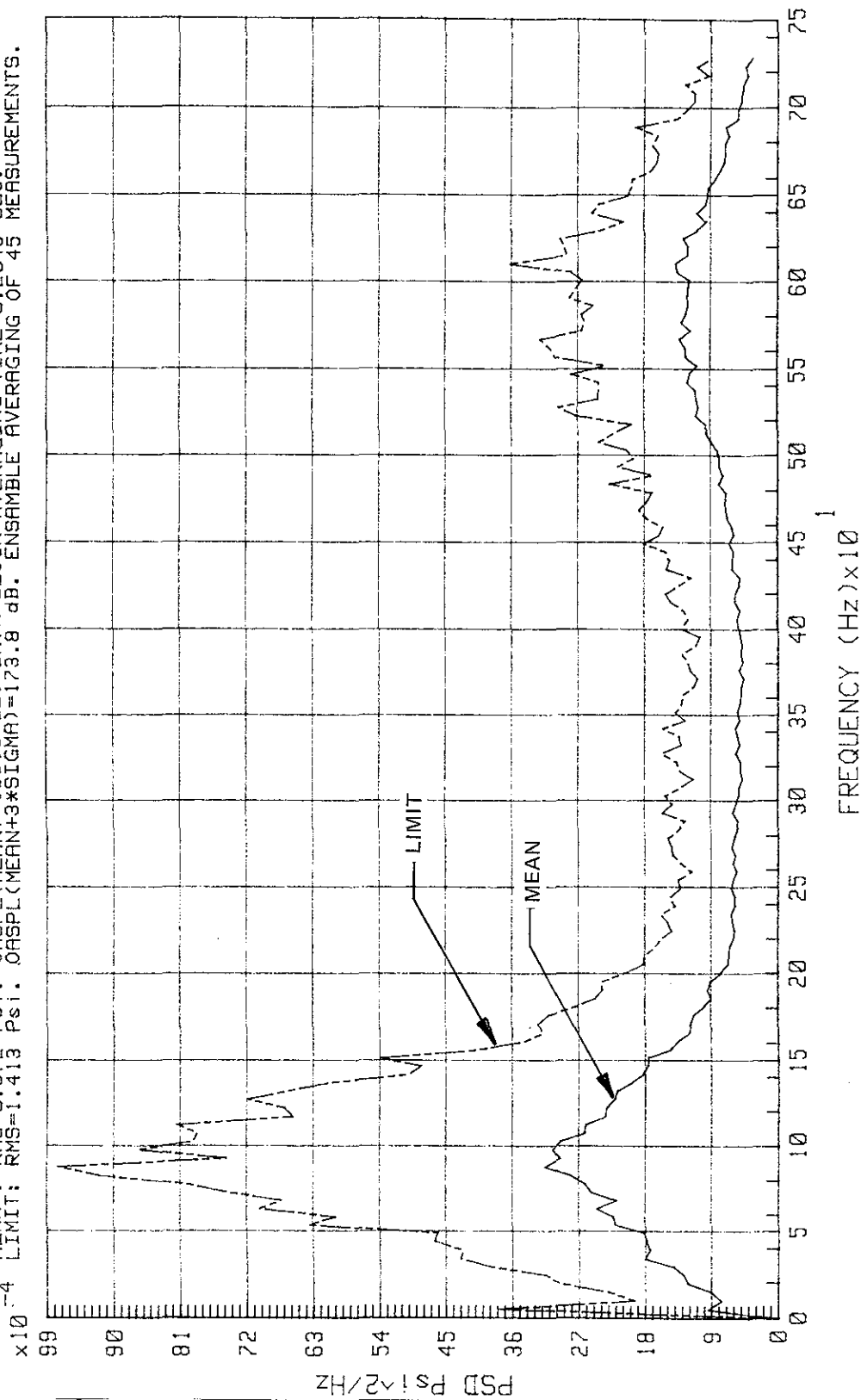Figure 2-7. STS-1 Through -9 Summary of FSS Acoustics at Lift-Off Peak - 90 DOF PSD's

Figure 2-8. STS-1 Through -9 Summary of FSS Acoustics at Lift-Off
Peak - 3-Sigma Limit (Mean and Limit Only)

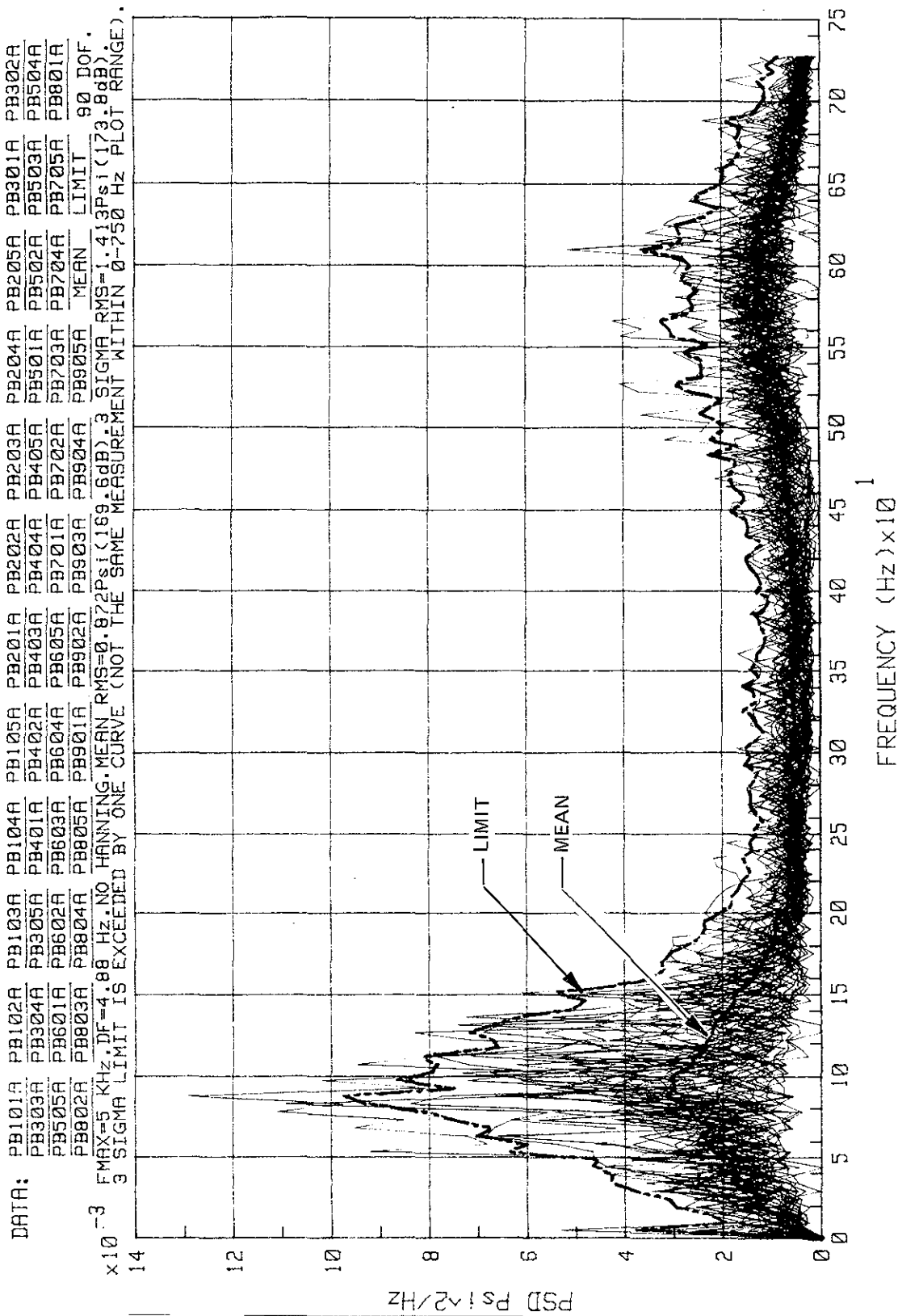Figure 2-9. STS-1 Through -9 Summary of FSS Acoustics at Lift-Off Peak - 3-Sigma Limit

Figure 2-10. STS-1 Through -9 Summary of FSS Acoustics at Lift-Off Peak -
88 DOF PSD's (Mean and Limit Only)
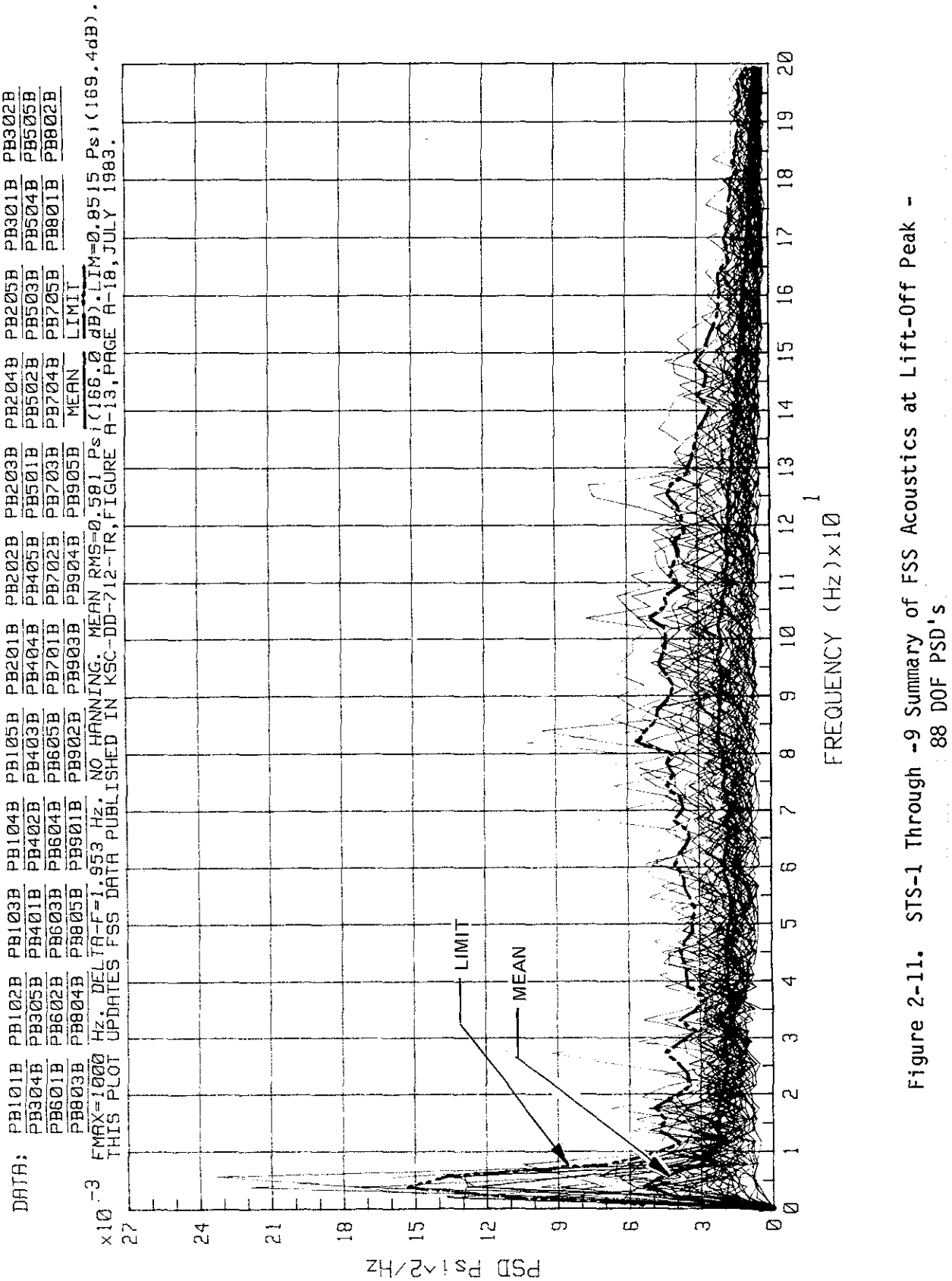
Figure 2-11. STS-1 Through -9 Summary of FSS Acoustics at Lift-Off Peak - 88 DOF PSD's
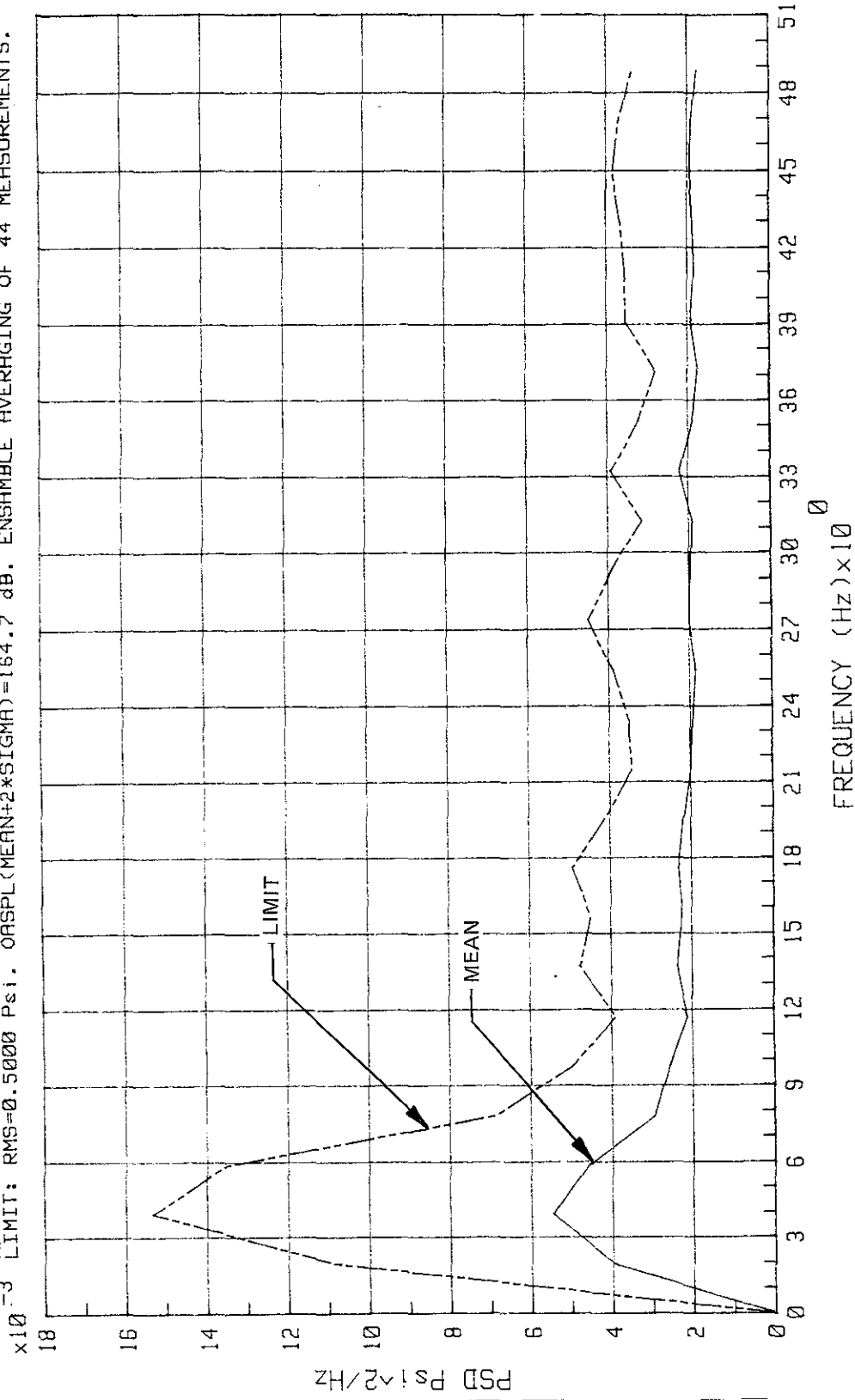
Figure 2.-12. STS-1 Through -9 Summary of FSS Acoustics at Lift-Off Peak - Data for 0 Hz to 50 Hz
(Mean and Limit Only)
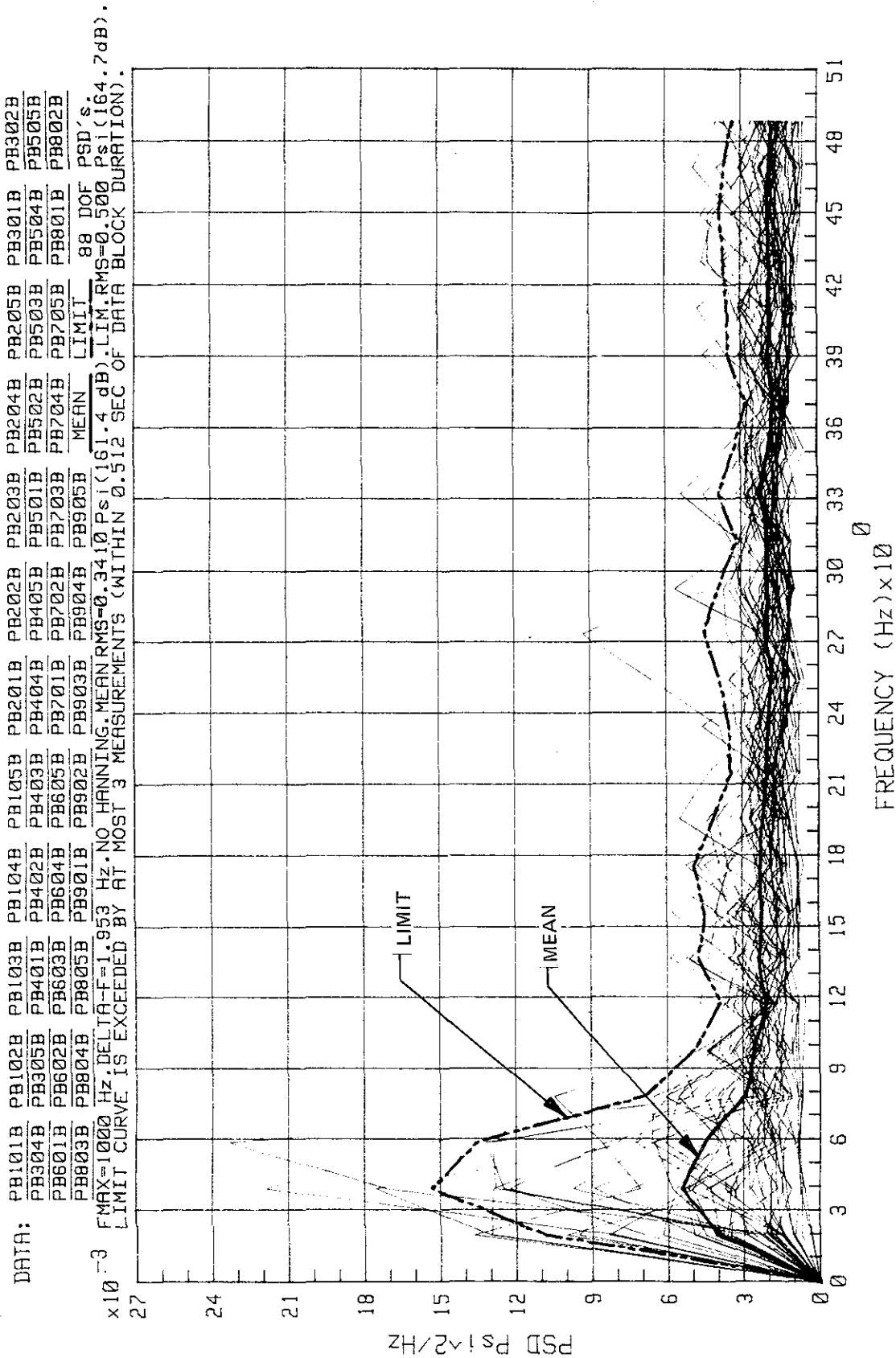
Figure 2-13. STS-1 Through -9 Summary of FSS Acoustics at Lift-Off Peak - Data for 0 Hz to 50 Hz
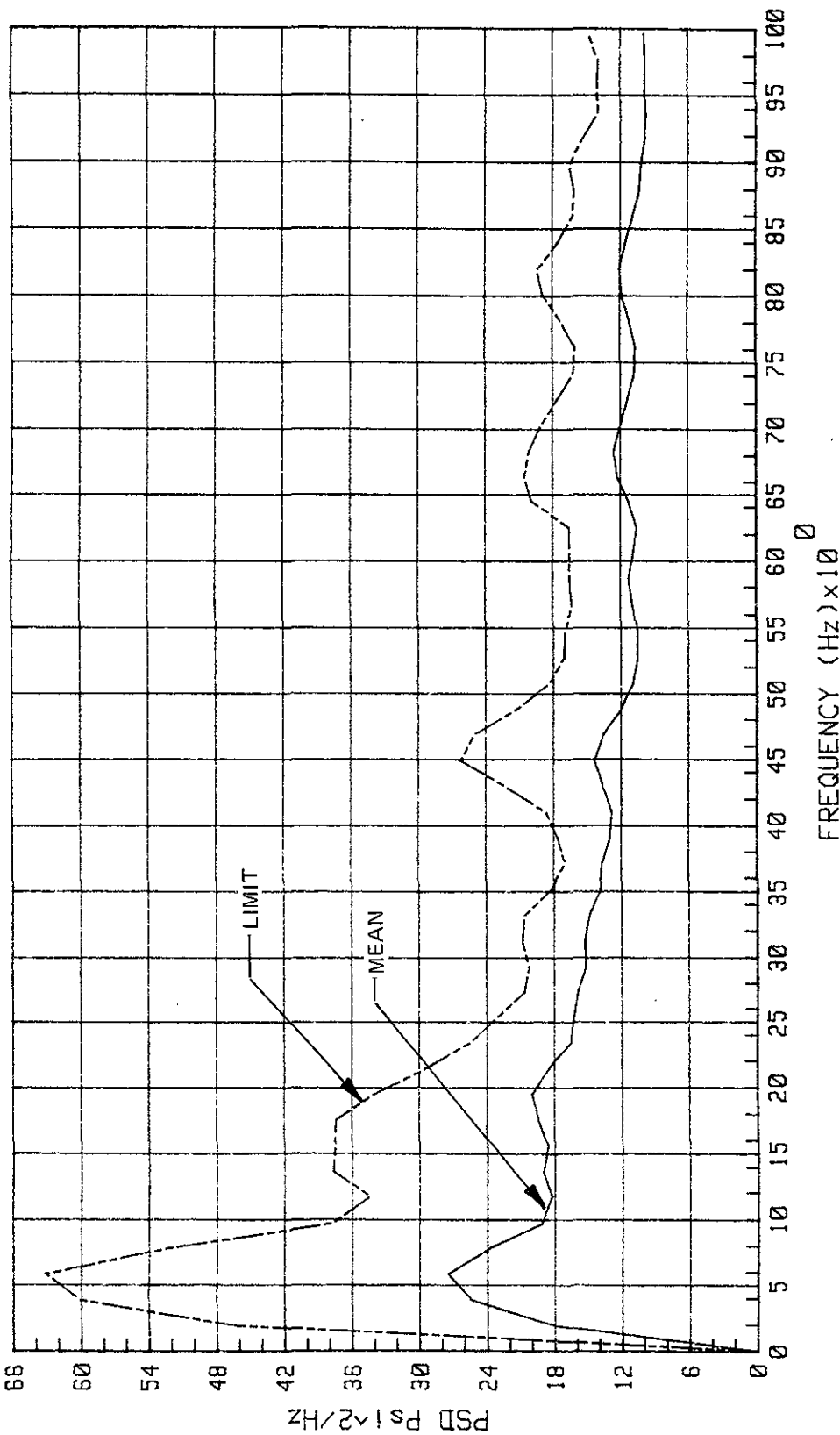
Figure 2-14. STS-1 Through -8 Lift-Off Peak - FSS Acoustics at
245-ft Level, 16 DOF PSD's (Mean and Limit Only)

Figure 2-15. STS-1 Through -8 Lift-Off Peak - FSS Acoustics at 245-ft Level, 16 DOF PSD's

Figure 2-16. Plots of Predicted and Measured OBSPL's for STS-1 Through -6, FSS, All Tower Levels

Figure 2-17. STS-5, -6, -7, -8 Lift-Off Peak - Acoustics on ET Vent Arm, Top of Haunch Pivot

2.2 RSS ACOUSTICS SUMMARY

The summary of RSS acoustics was obtained from data collected in two separate
measurement efforts. The first effort was conducted for STS-1 through STS-3
launches, using sensors used during the Saturn V program. Data are presented
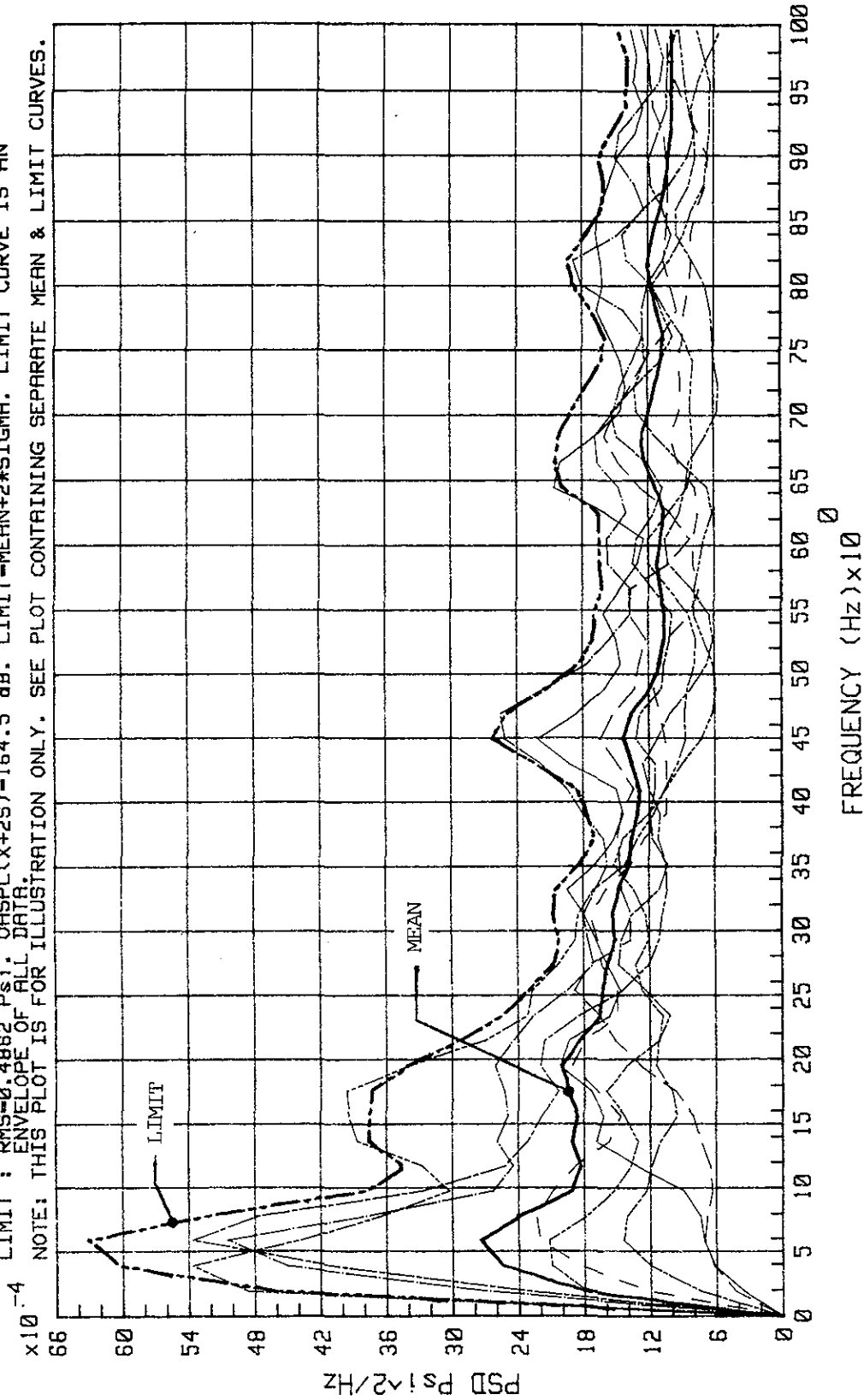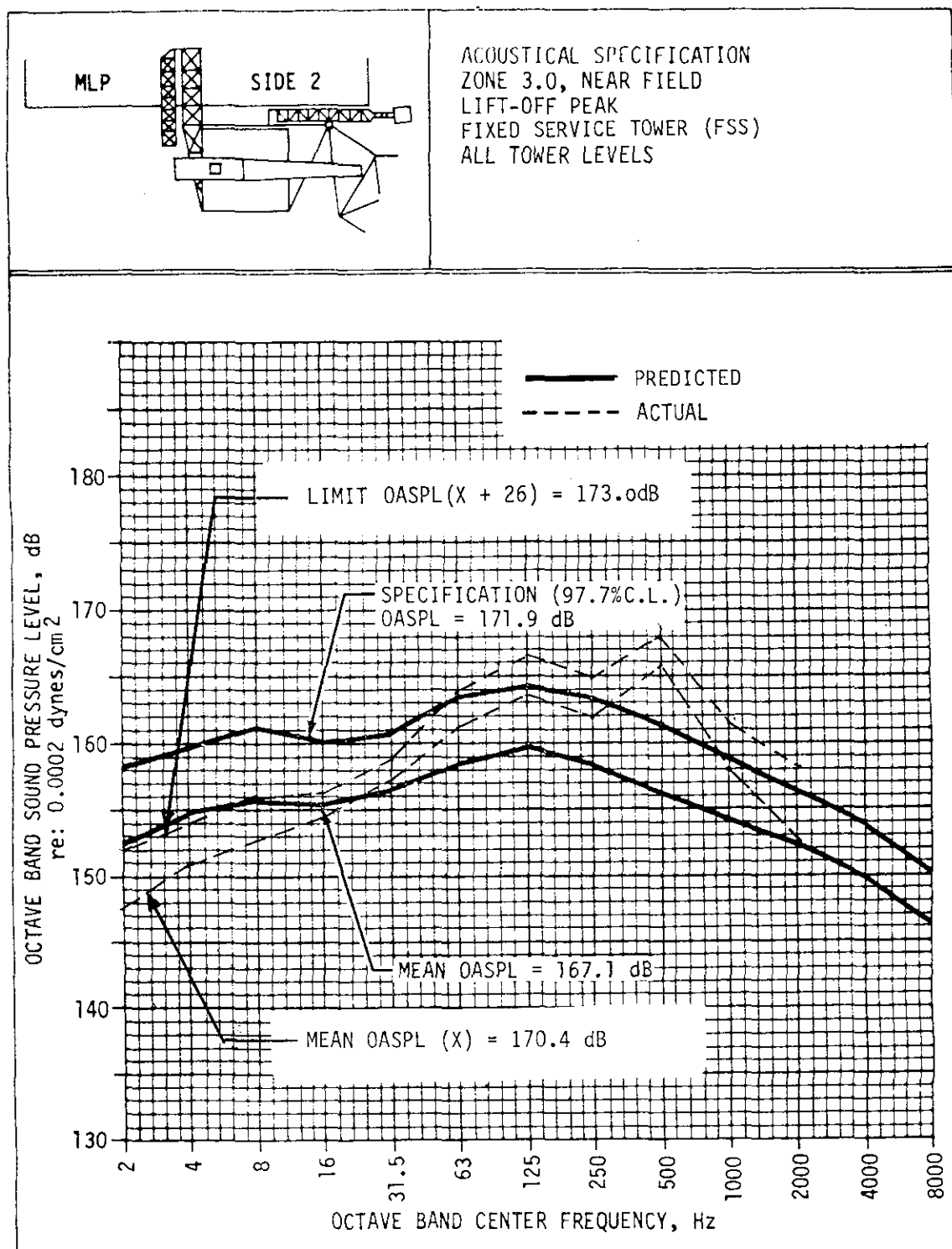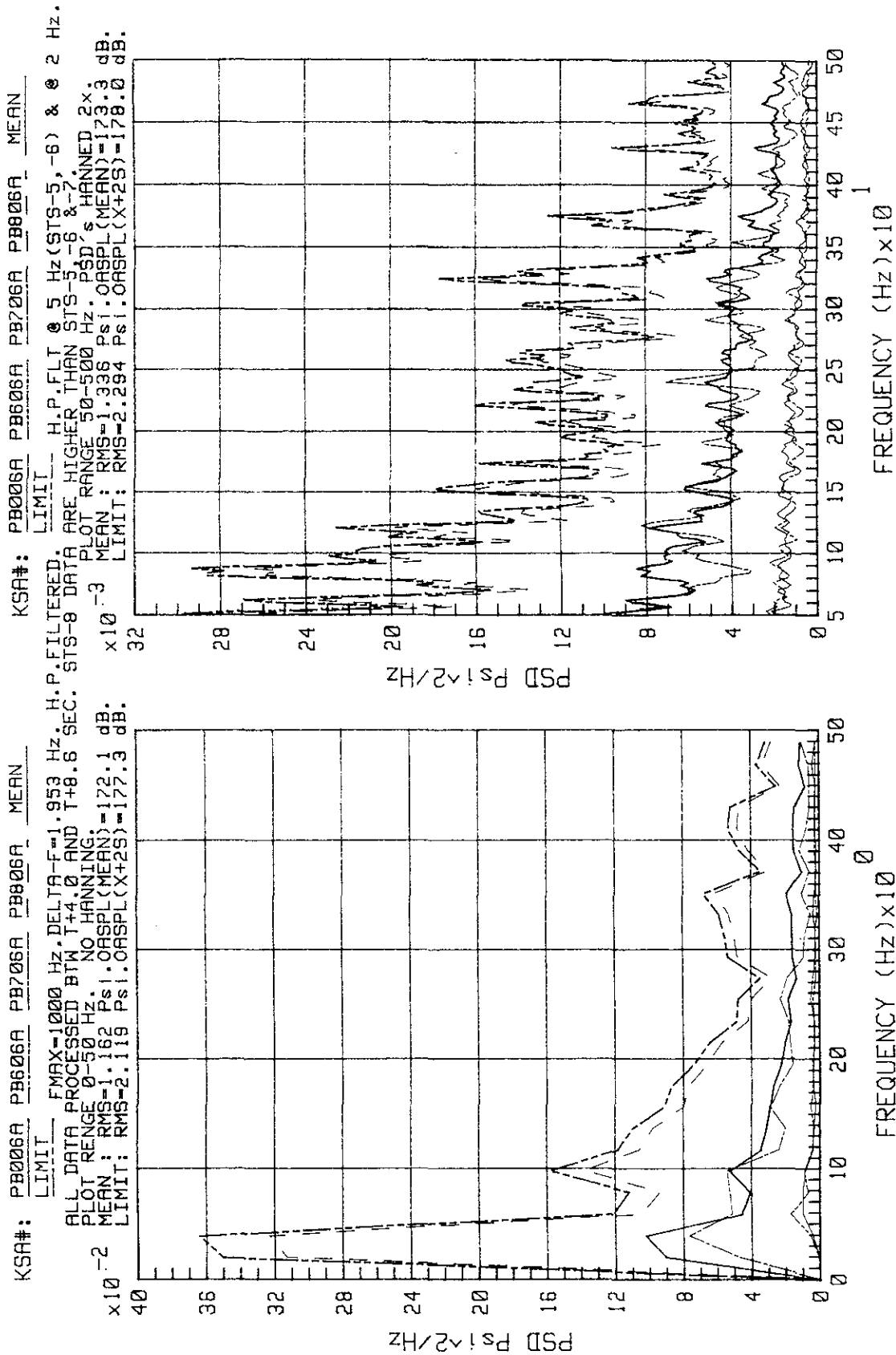in the form of OBSPL's on figures 2-18 through 2-25 and compared to predic-
tions. Because the STS-1 through STS-3 measured data did not compare well
with predictions, a second effort was initiated for STS-7 and STS-8, using new
acoustic sensors. Resulting data are presented in the form of PSD's on fig-
ures 2-26 through 2-35. In either case, measured data were similar, as can be
seen from the comparison of overall sound pressure level (OASPL) values calcu-
lated from PSD's and shown on the plot headings. Acoustic pressures at a
given sensor location are comparable between launches; however, because of
diffraction, shielding, and ground reflections, the output of different sen-
sors, although located on the same side, are not always comparable. Sensor
locations and orientations are shown on plot headings on figures 2-26 through
2-35 to alert the user to these differences.
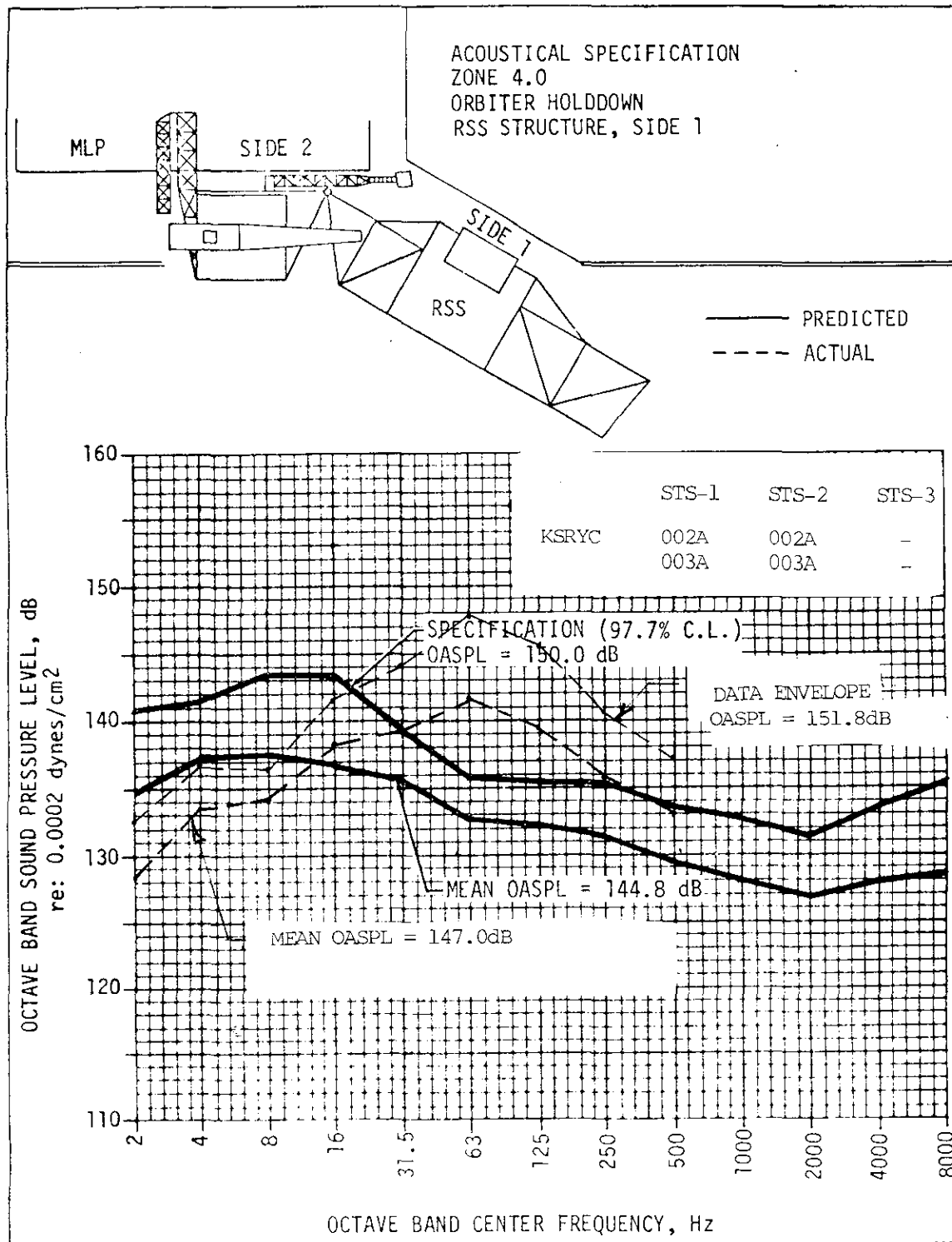
Figure 2-18. Comparison of Predicted and Actual OBSPL's,
Orbiter Holddown, RSS Side 1

Figure 2-19. Comparison of Predicted and Actual OBSPL's,
Lift-Off Peak, RSS Side 1
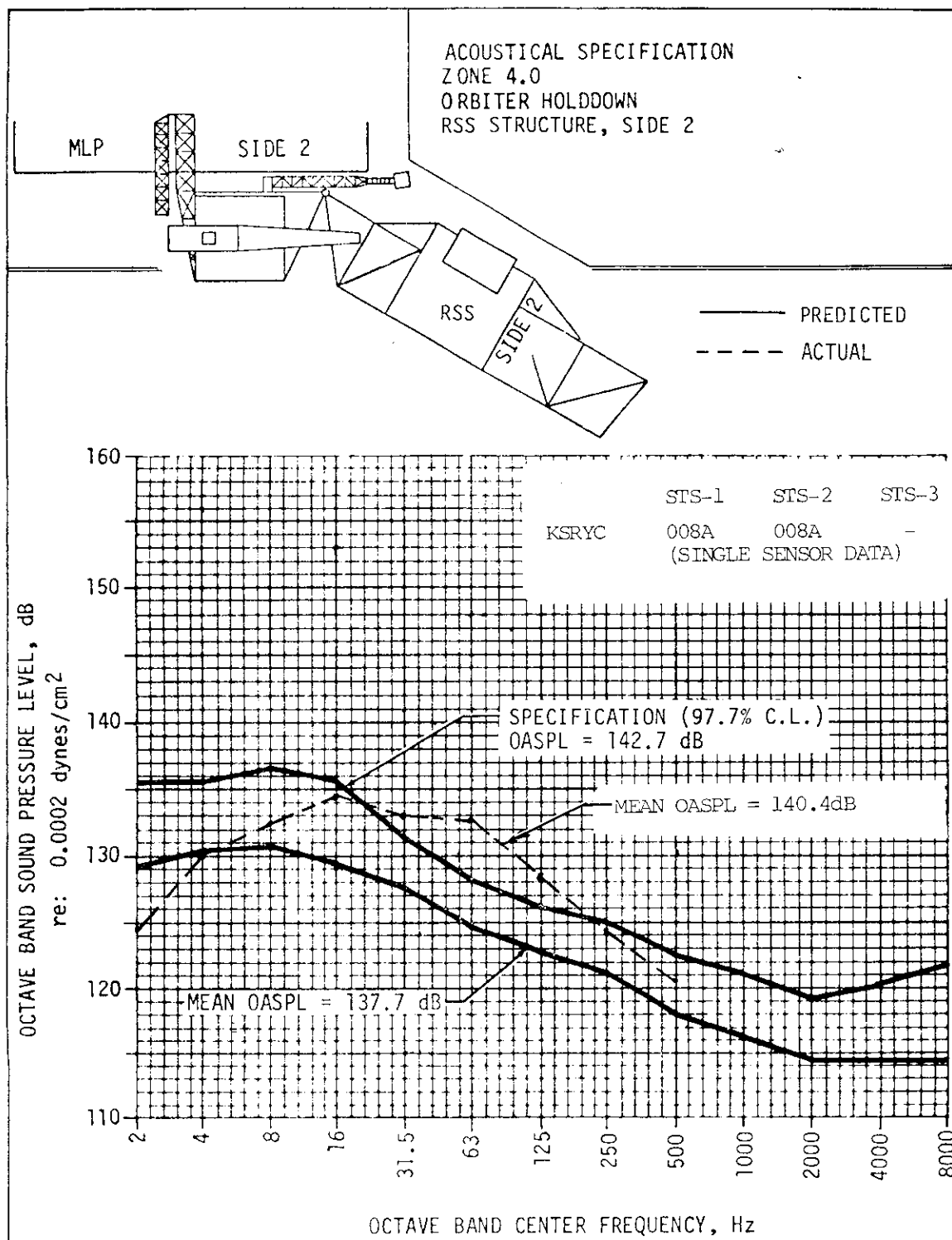
Figure 2-2C. Comparison of Predicted and Actual OBSPL's,
Orbiter Holddown, RSS Side 2
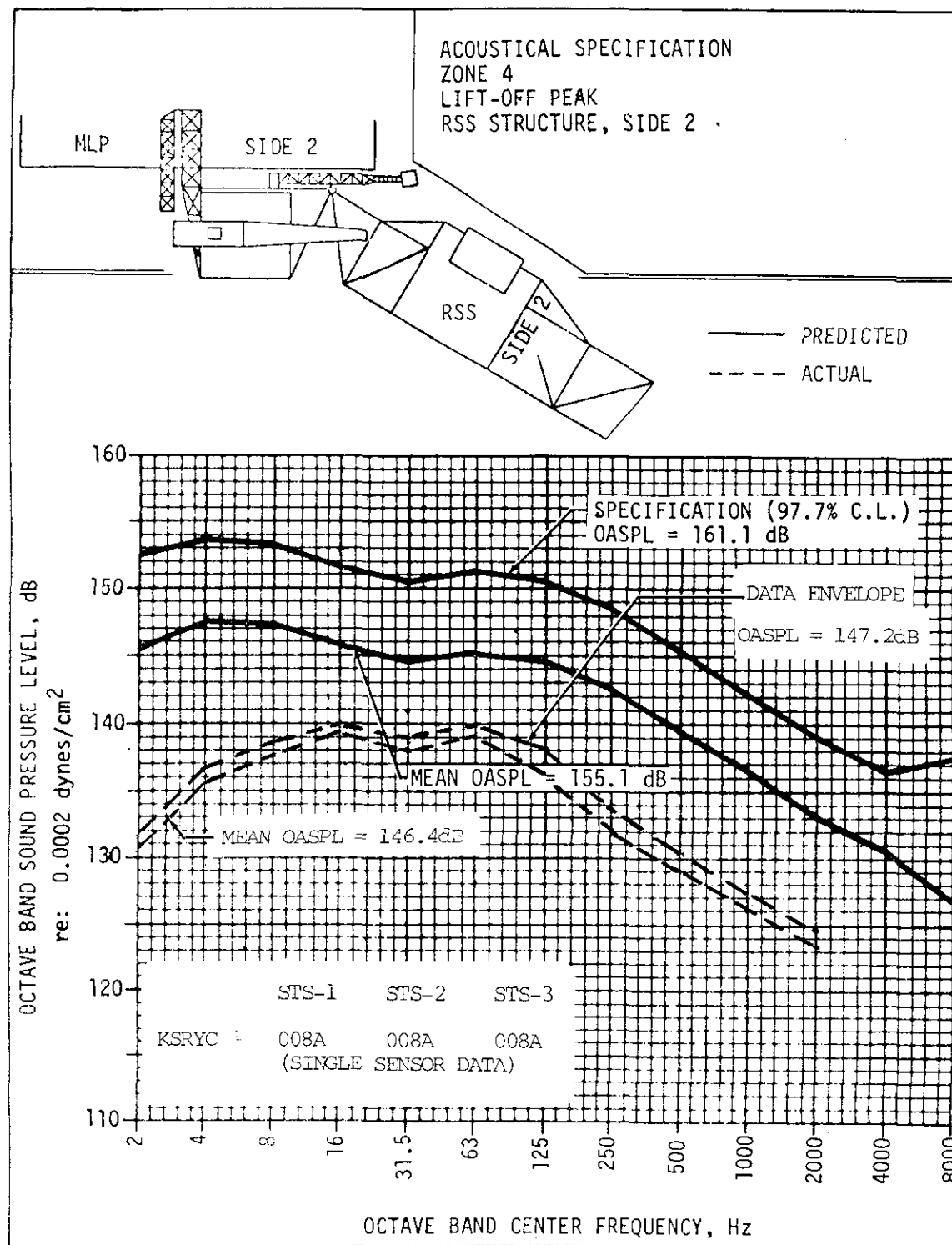
Figure 2-21. Comparison of Predicted and Actual OBSPL's,
Lift-Off Peak, RSS Side 2
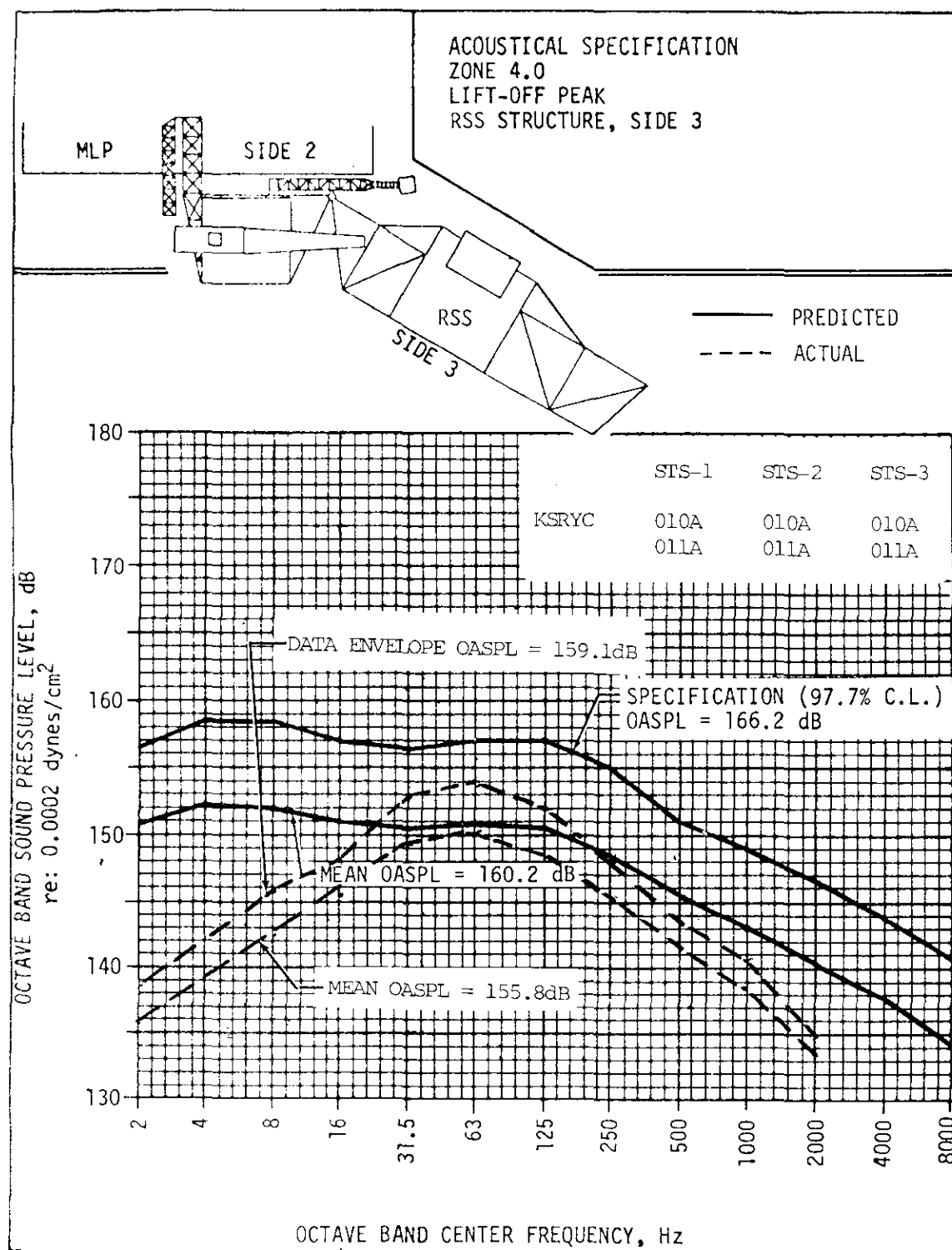
Figure 2-22. Comparison of Predicted and Actual OBSPL's,
Lift-Off Peak, PCR Side 3
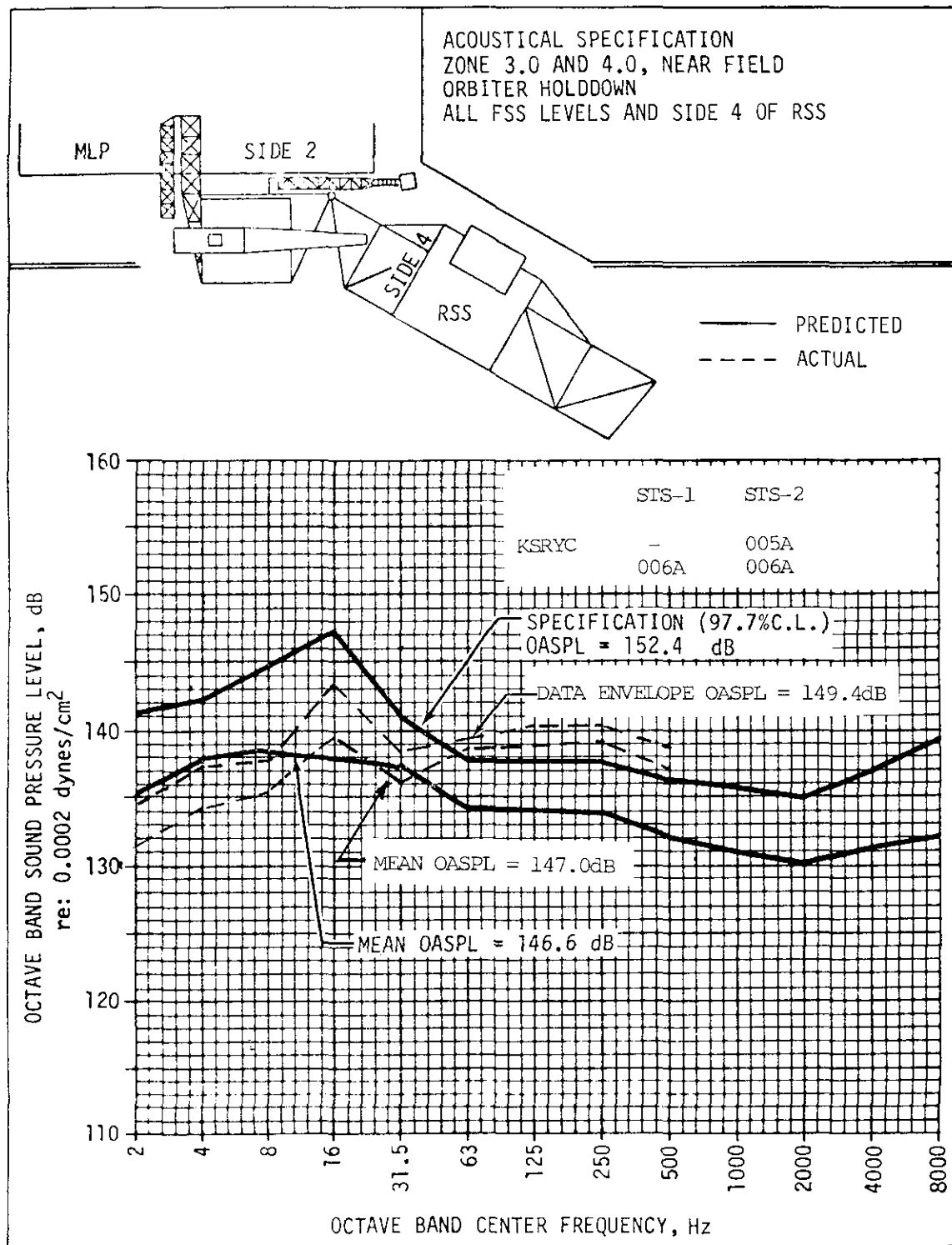
Figure 2-23. Comparison of Predicted and Actual OBSPL's, Orbiter Holddown,
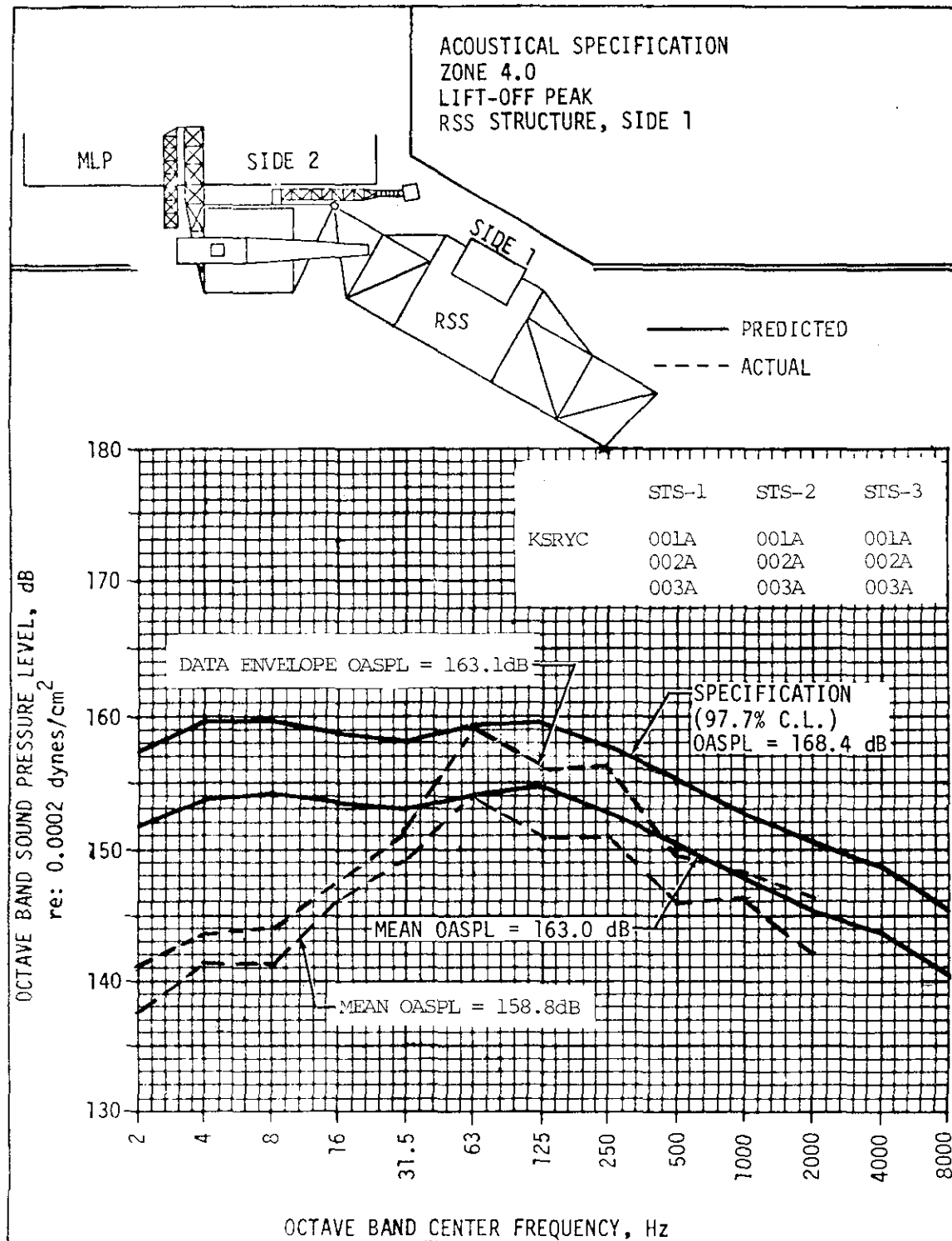All FSS Levels and Side 4 of RSS
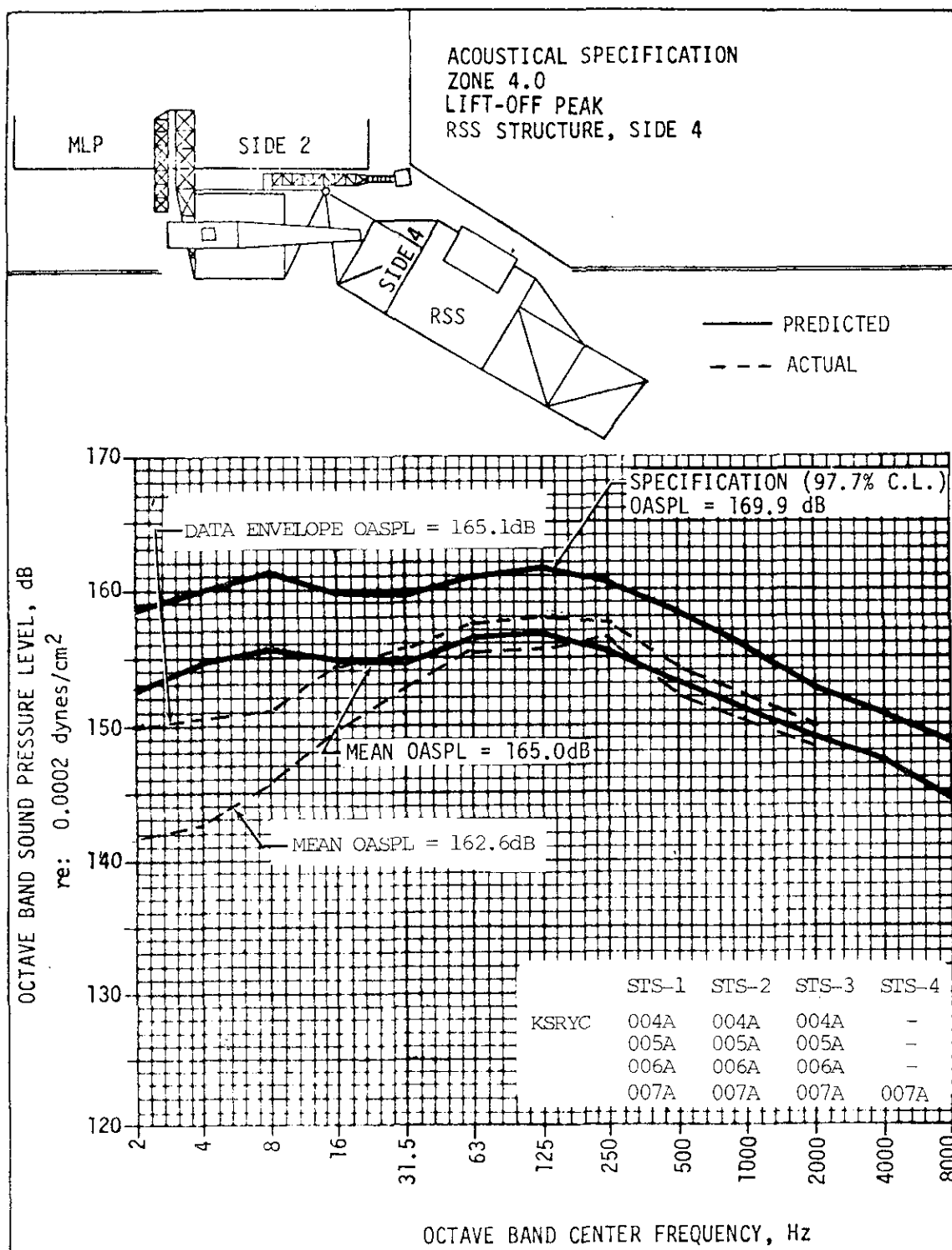
Figure 2-24.   Comparison of Predicted and Actual OBSPL's,
Lift-Off Peak, RSS Side 4
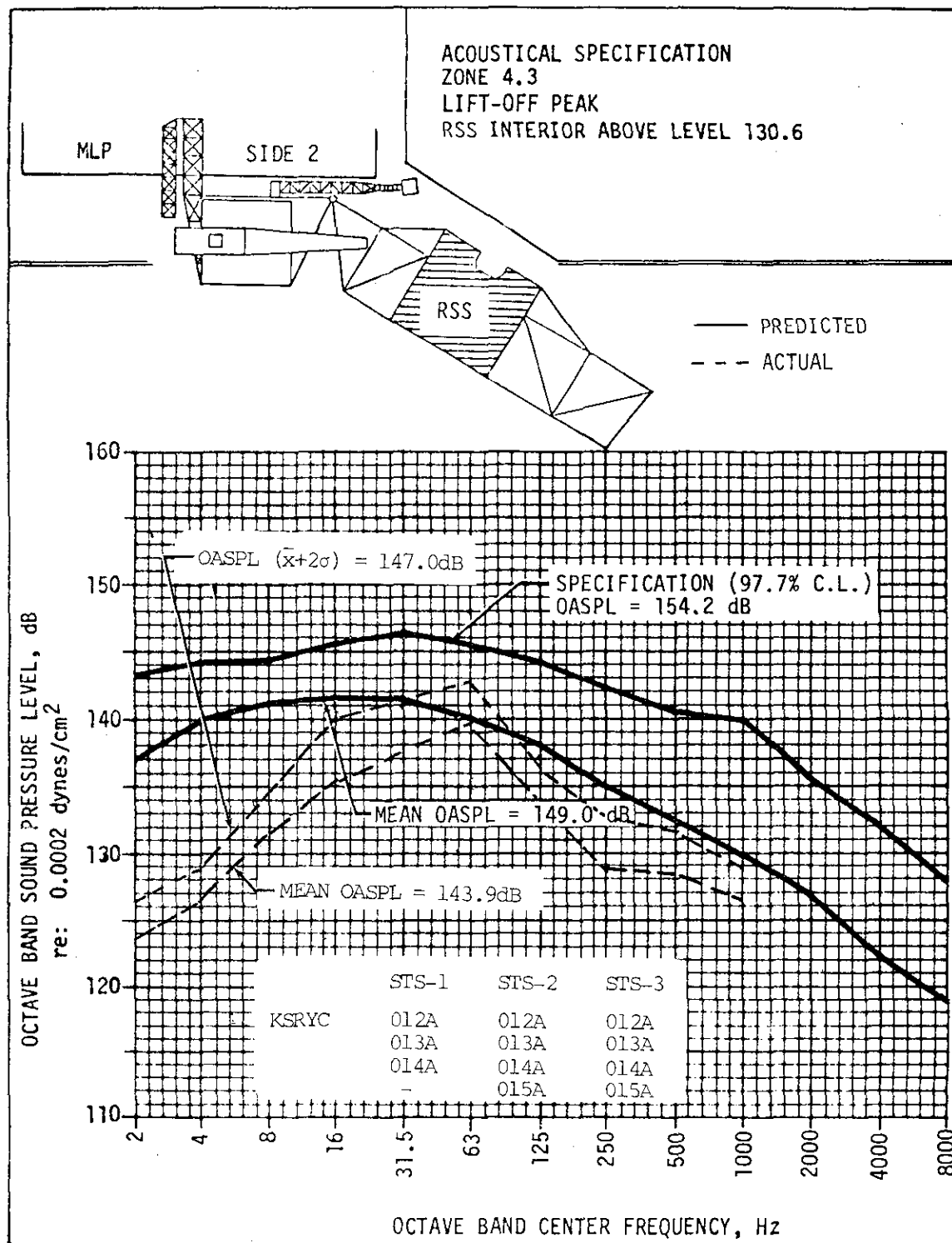
Figure 2-25. Comparison of Predicted and Actual OBSPL's, Lift-Off Peak, RSS Interior Above 130.6-ft Level
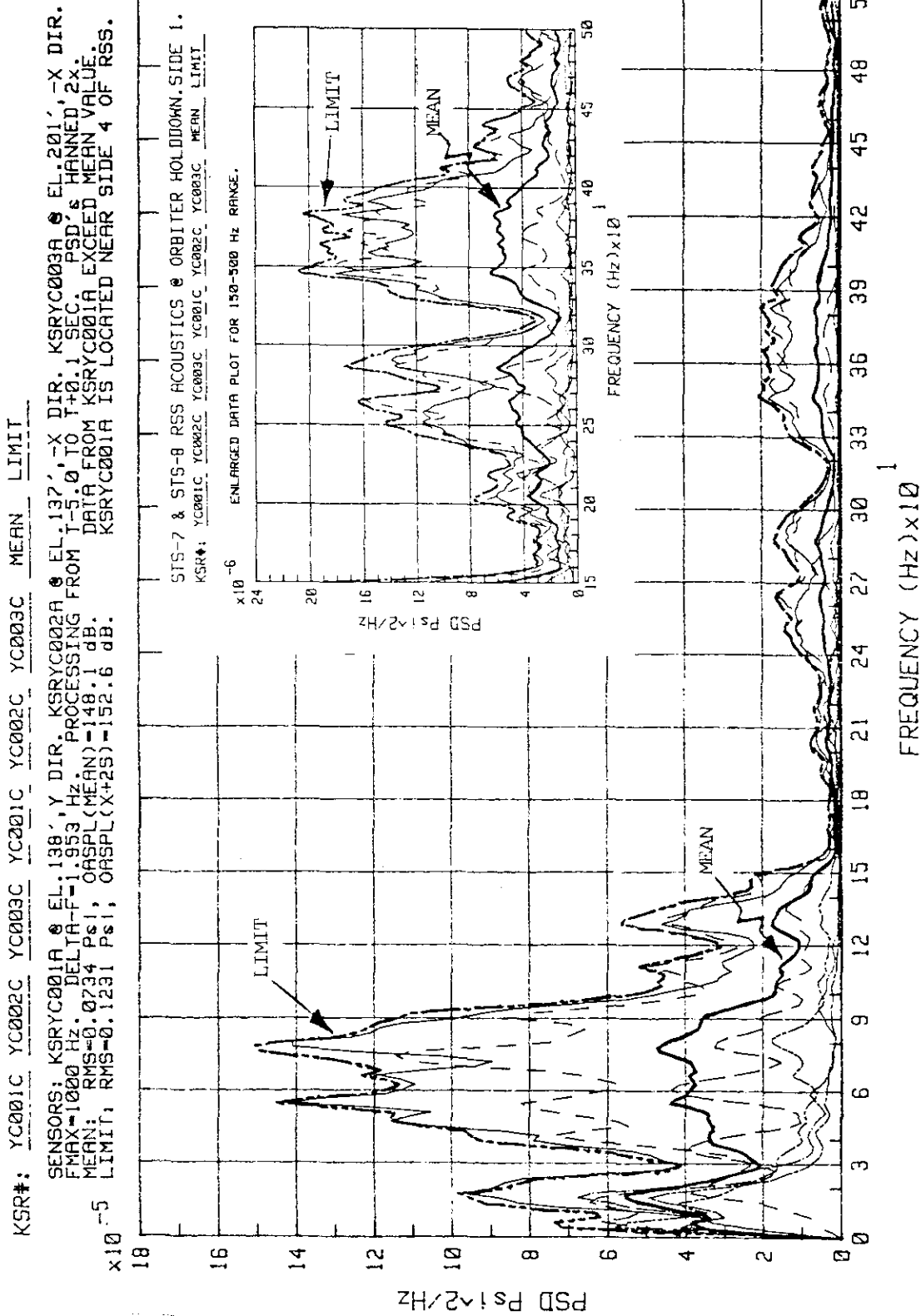
Figure 2-26. STS-7 and -8 RSS Acoustics at Orbiter Holddown - Sensors on Side 1
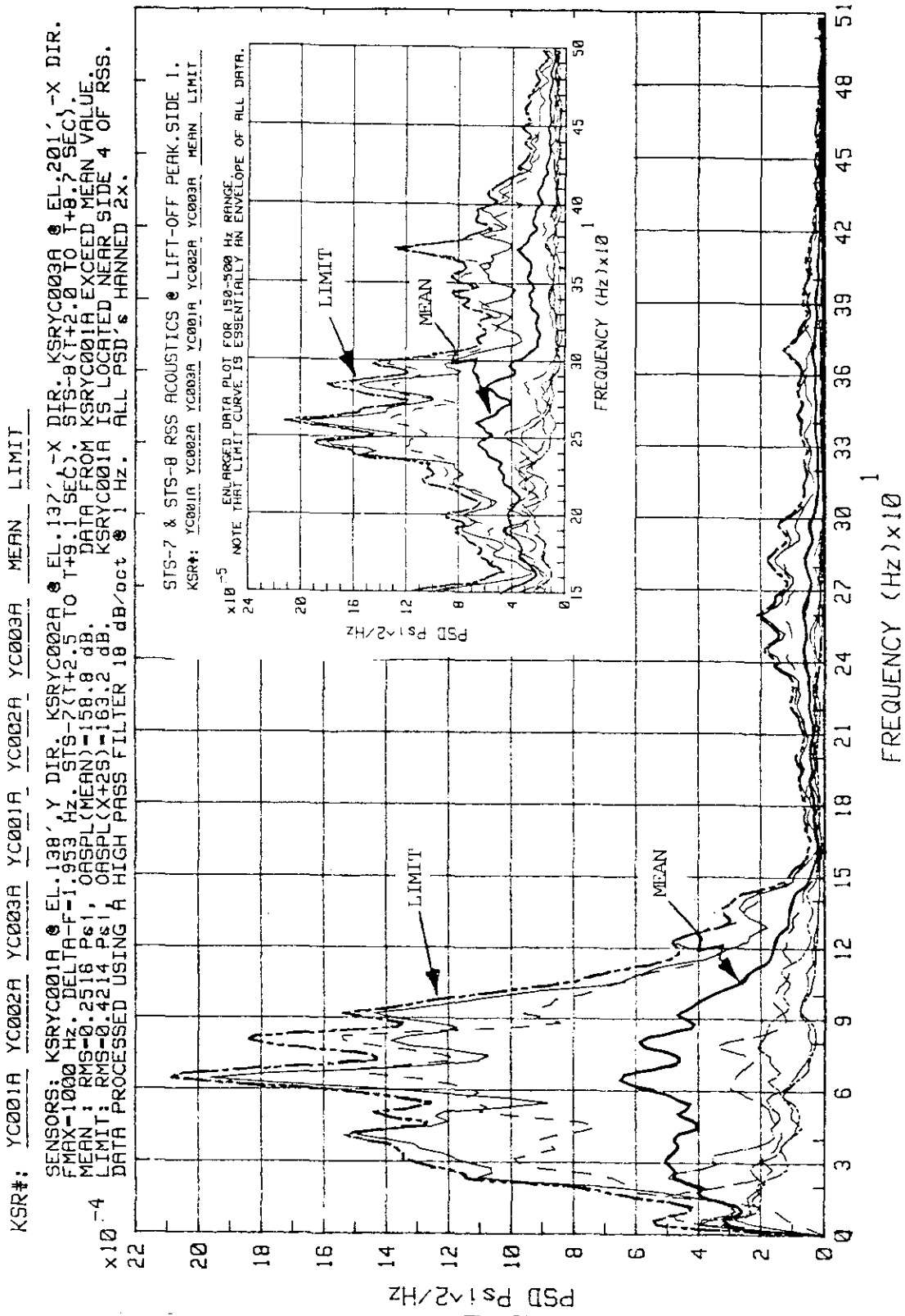
Figure 2-27. STS-7 and -8 RSS Acoustics at Lift-Off Peak - Sensors on Side 1
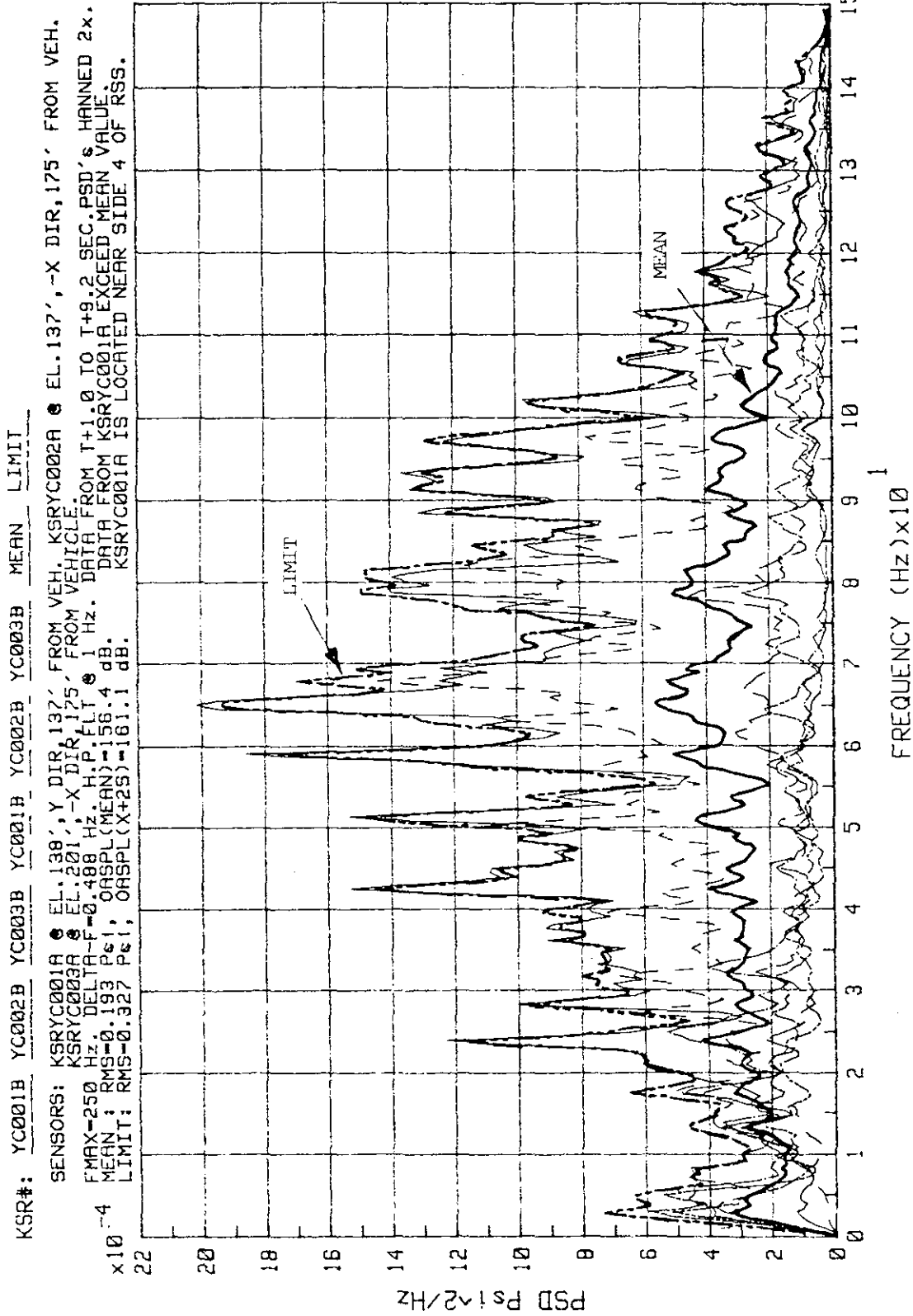
Figure 2-28. STS-7 and -8 RSS Acoustics at Lift-Off Peak - Sensors on Side 1 (Zoom Plot)
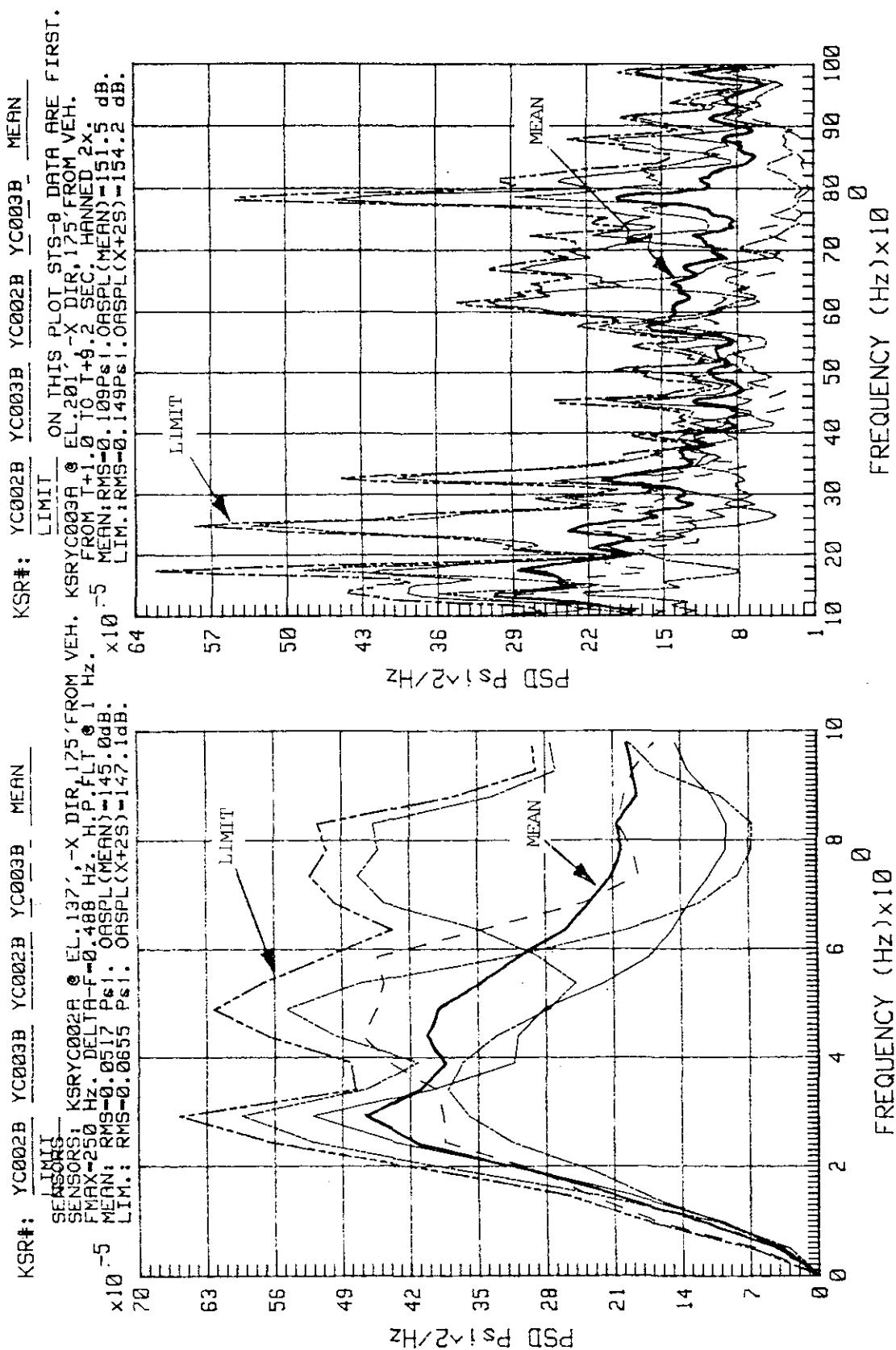
Figure 2-29. STS-7 and -8 RSS Acoustics at Lift-Off Peak - Sensors at Grazing Incidence, Side 1
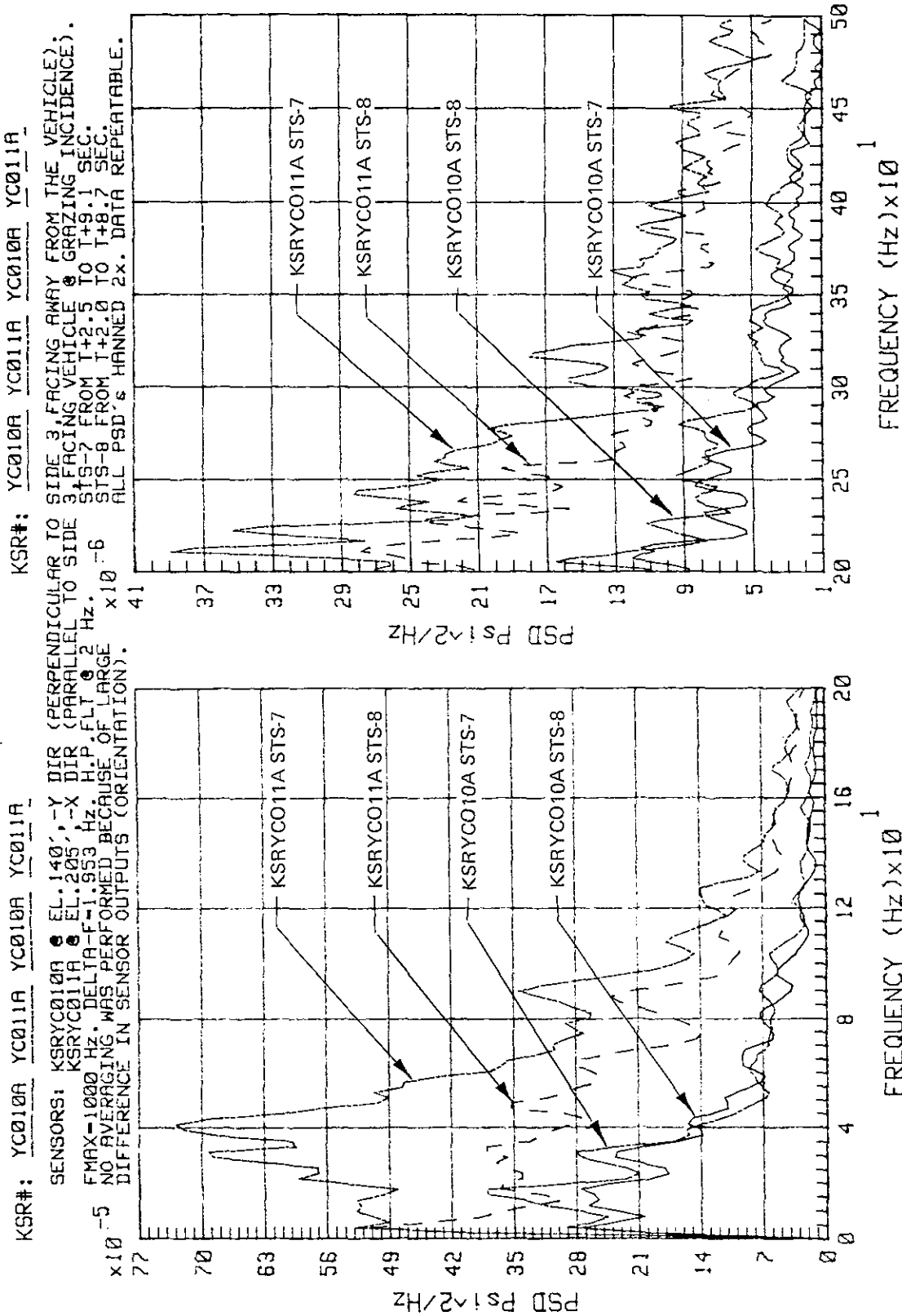
Figure 2-30. STS-7 and -8 RSS Acoustics at Lift-Off Peak - Sensors on Side 3
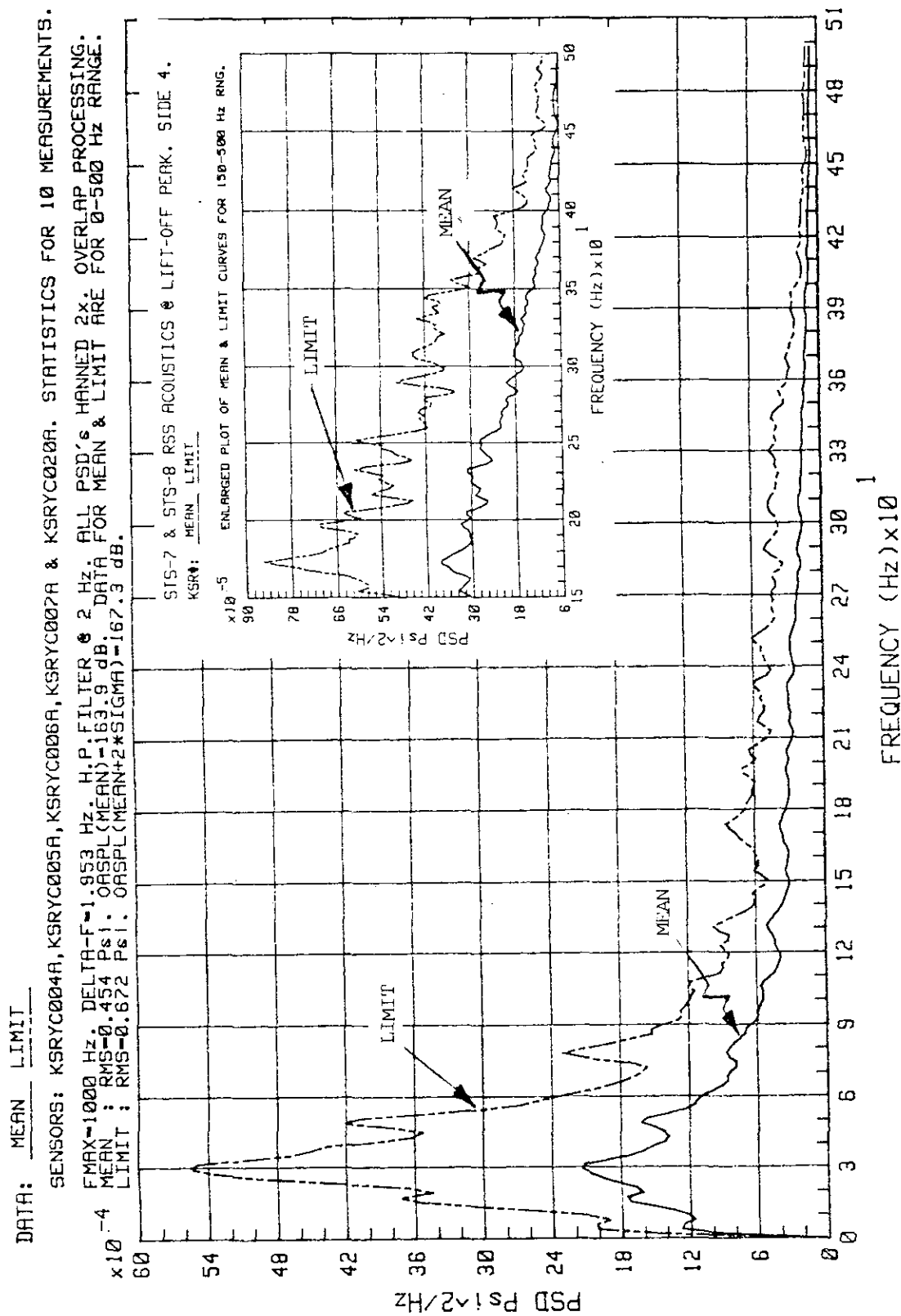
Figure 2-31. STS-7 and -8 RSS Acoustics at Lift-Off Peak - Sensors on Side 4 (Mean and Limit Only)

Figure 2-32.   STS-7 and ~8 RSS Acoustics at Lift-Off Peak – Sensors on Side 4

Figure 2-33. STS-7 and -8 RSS Acoustics at Lift-Off Peak - Sensors on Side 4 (Mean and Limit Only)

Figure 2-34. STS-7 and -8 RSS Acoustics at Lift-Off Peak - Sensors on Side 4

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Figure 2-35. STS-7 and -8 RSS Free Field Acoustics at Lift-Off Peak - Sensors on Side 4
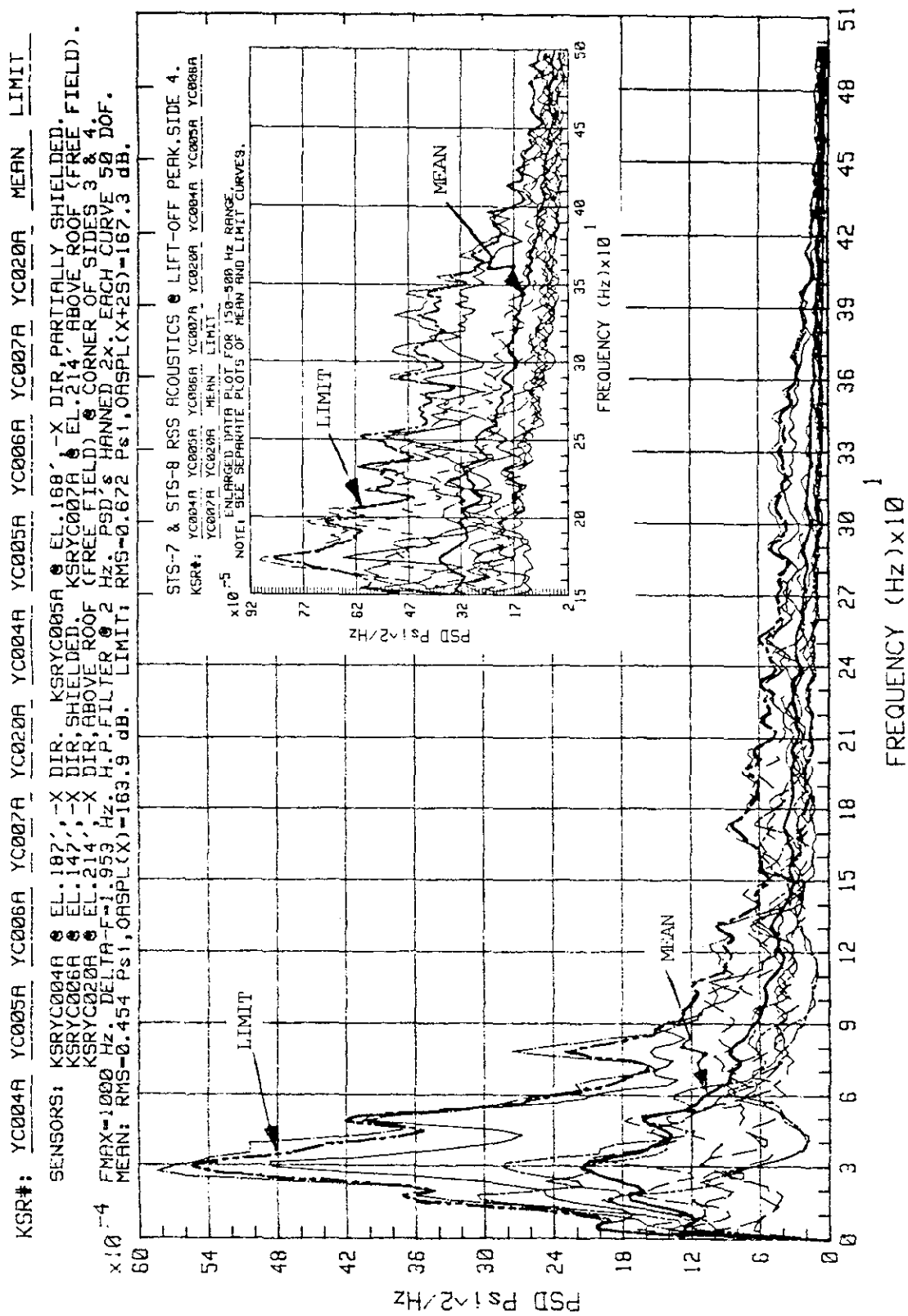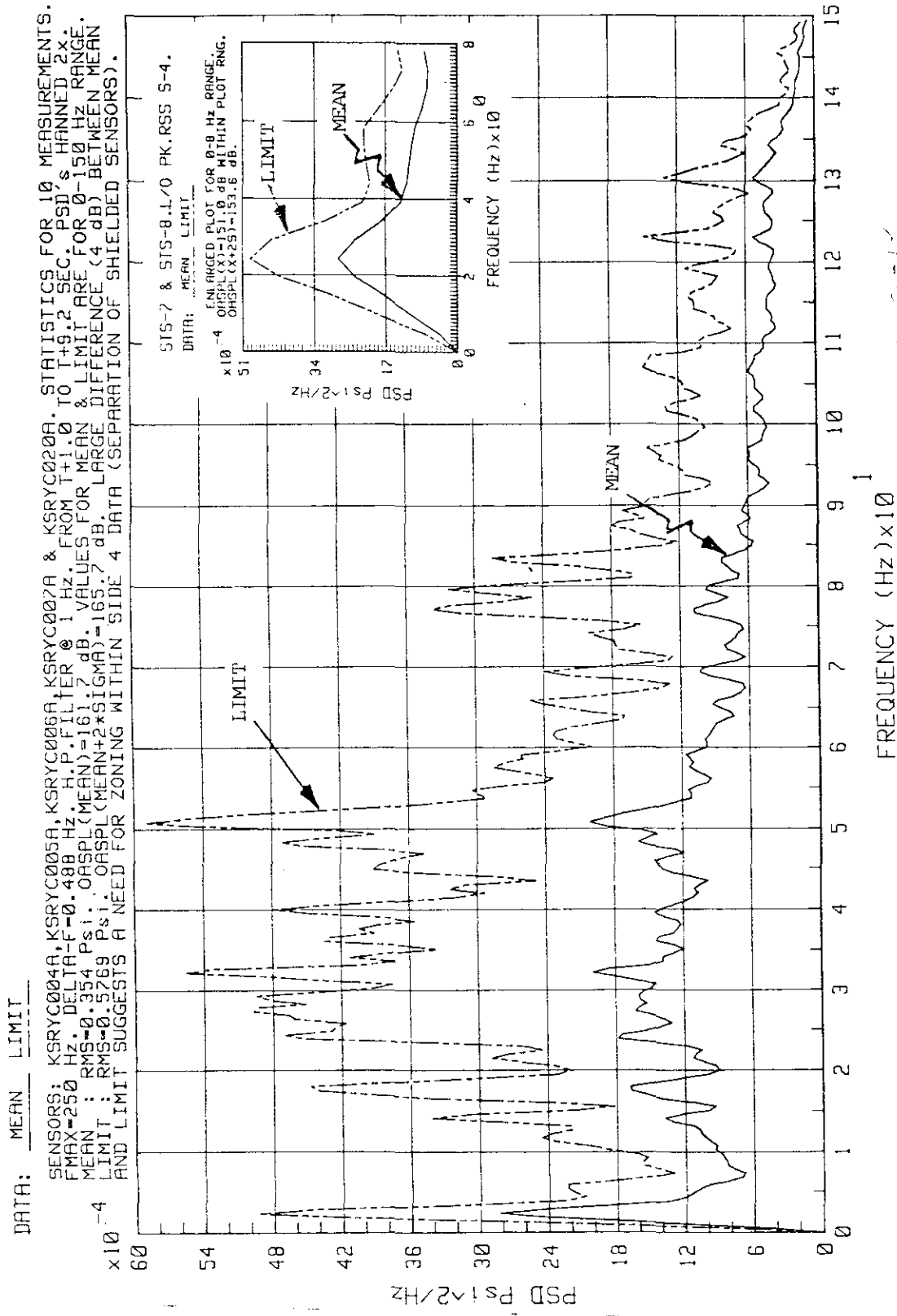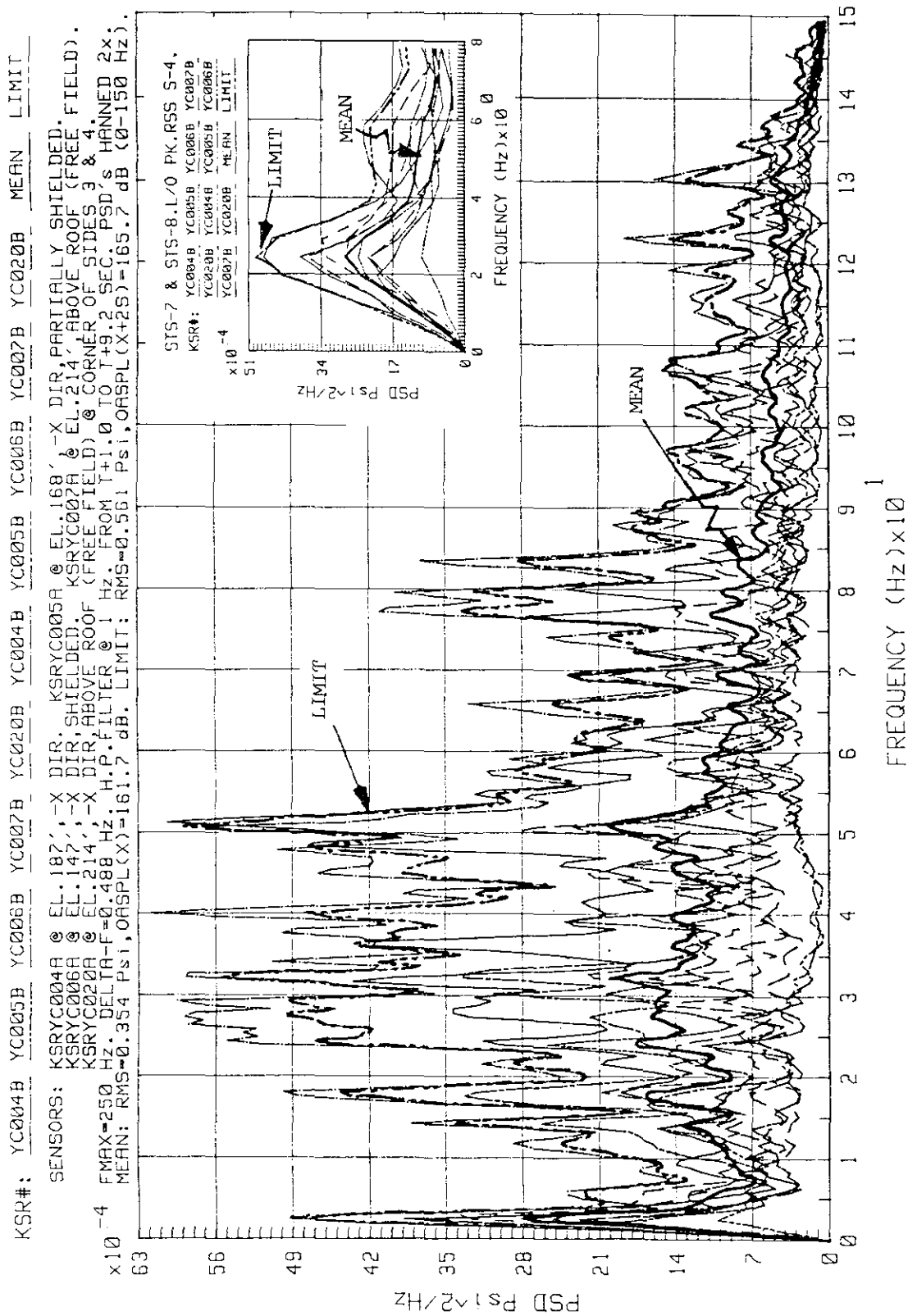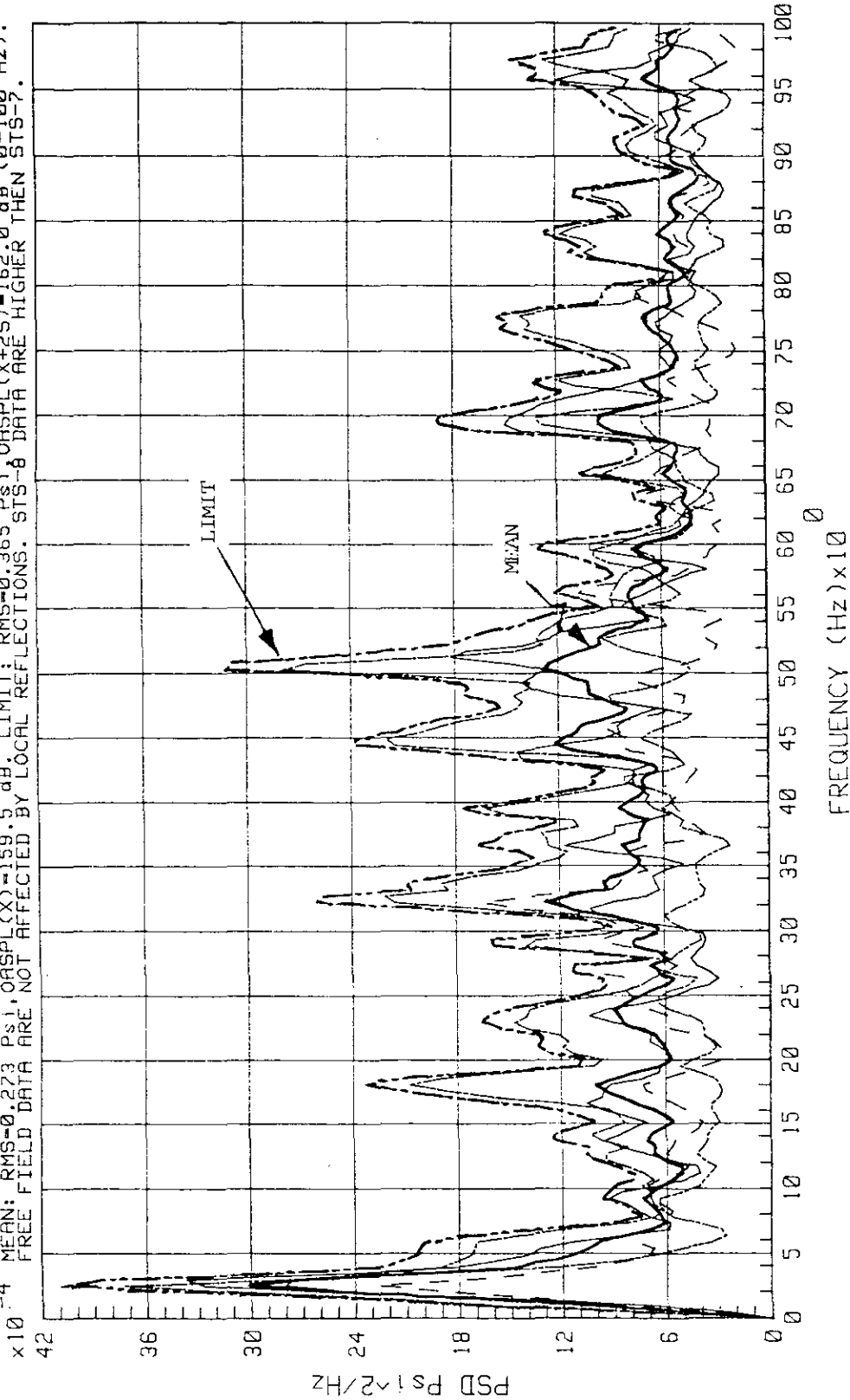
2.3 CENTAUR ROLLING BEAM PORCH ASSEMBLY

This summary of acoustic pressures on the Centaur porch assembly is based on data from pressure sensors KSRPB001A through KSRPB008A, recorded during STS-9 and STS-11 launches. Eight pressure sensors were installed in pairs at four locations on the porch, two pairs at the east cantilevered end and two pairs at FSS support. Within each sensor pair, one was oriented vertically (Z-direction) and another horizontally (X-direction). Sensors were installed at the end of bent (45°) tubes in order to protect diaphragms from direct exposure to radiating heat. Additional protection from heat in the form of ablative coating was applied to all sensor housings for STS-11. In spite of these precautions, all sensor outputs contained some baseline drift. Because of the baseline drift, data were processed using a high-pass filter.

No distinct "static" type pressures were measured on the porch during STS-9 and STS-11. This conclusion is based on the following observations, disregarding the possibility that baseline drift could have masked "static" pressures:

    a. The amount of baseline drift was the same in each sensor pair during STS-9. STS-11 data show a substantial reduction in the baseline drift as a consequence of additional thermal protection, while the sign of drift in the majority of sensors reversed to negative.

    b. If there were any static pressures, they would be recorded by sensors oriented vertically, in the opposite direction to the exhaust flow. Examination of low-frequency end of spectra shows that horizontally oriented sensors always have higher PSD ordinates at these frequencies than their vertically oriented pairs. This indicates dominant direction of pressure waves to be closer to horizontal than to vertical direction, and an absence of continuous exhaust flow at sensor locations.

The summary of acoustic environment on the porch assembly is presented on figures 2-36 through 2-49 in terms of PSD's. Figures 2-36 through 2-38 depict environment during Orbiter holddown period caused by the burn of SSME's. All pertinent data processing parameters are shown in the plot headings. There are no substantial differences between acoustic environments recorded by sensors at the cantilever end and at FSS support during this period.

Figures 2-39 through 2-49 present summary of acoustic environment recorded during the lift-off peak period. Data processing was performed using three different values of F_{max} (Nyquist frequency) with corresponding different analysis time intervals. Such processing was necessary in order to account for the continuous variation in the data frequency composition. In processing cases corresponding to F_{max} = 5 kHz and 1 kHz, all PSD's were lumped together regardless of sensor locations. The case corresponding to F_{max} = 5 kHz, where PSD's are dominated by a wideband peak between 500 and 800 kHz, shows no significant difference between environments at porch end and FSS support. The

case corresponding to F_{max} = 1 kHz shows that below approximately 25 Hz, higher values of PSD's (near factor of 2) were derived from sensors located closer to the vehicle (on the porch end). Figure 2-45, which shows all PSD mean and limit curve calculations, illustrates this difference.

The case corresponding to F_{max} = 100 Hz required separate mean and limit curve plots for sensors at cantilever end and FSS support because of 6.2-dB difference in the mean values within the 0- to 20-Hz range. Figures 2-48 and 2-49 present summaries for the case F_{max} = 100 Hz. The user should keep in mind that data are nonstationary and the number of cycles of waveform components below approximately 10 Hz at peak amplitudes is limited and cannot induce full response resonances.

Figures 2-50 and 2-51 present STS-11 cross-correlation function coefficients (CCFC's) between adjacent sensor pairs calculated at sampling rate 10 kHz (F_{max} = 5 kHz) and at sampling rate 2 kHz (F_{max} = 1 kHz). The timelag of the peak is about 0.5 ms. The sign of the lag at peak is positive whenever the first sensor entering cross-correlation calculations is oriented in the X direction. The sign becomes negative when the first sensor is oriented in the Z direction. This indicates that the prevailing direction of pressures wave propagation is close to horizontal, since a sensor oriented in the horizontal (X) direction records a wave before (by 0.5 ms) it reaches a sensor oriented in the vertical (Z) direction. The base of the first CCFC peak (theoretically this is the time between zero crossings, but in practical computations it may be taken as a crossing of ±0.1 CCFC noise line), which defines correlation length as a function of analysis bandwidth and thus, of F_{max}. For the case of F_{max} = 1 kHz, the base of CCFC peak (figure 2-51) is about 3 ms. Thus, the average correlation length (essentially an average of all waveform components within the range 0 to 500 kHz) is less than 3.5 ft. The value of CCFC peak (less than 1) is a consequence of multiple sources within the exhaust plumes where pressure waves are generated.

Figures 2-52 through 2-54 present coherences between adjacent sensors calculated for processing cases of F_{max} = 5 kHz, 1 kHz, and 100 Hz. There is a trend toward higher coherences between sensor pairs located farther away from the exhaust plumes.

Figures 2-55 through 2-61 show narrow band, 1 to 10 Hz, pressure time histories for STS-11. For adjacent sensors, both time histories are shown on the same plot.

Figures 2-62 through 2-64 show typical rms time histories for two sensors (KSRPB002A and KSRPB003A) corresponding to each of the processing cases of F_{max}.

Figure 2-65 shows probability density plots of KSRPB002A for two cases of F_{max}.
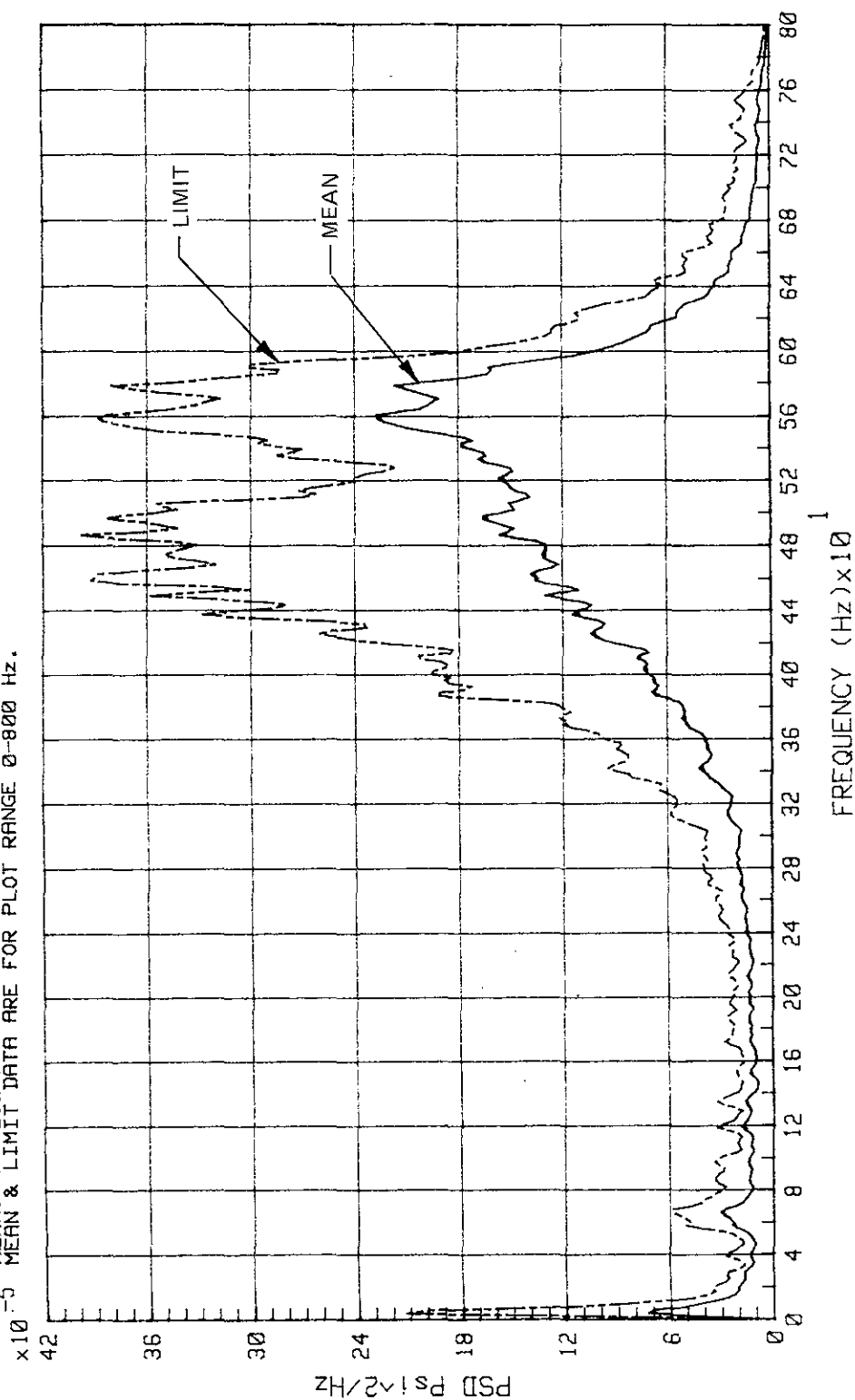
Figure 2-36. STS-9 and -11 Orbiter Holddown - Centaur Porch Assembly Pressures, All Sensor Data (Mean and Limit Only)
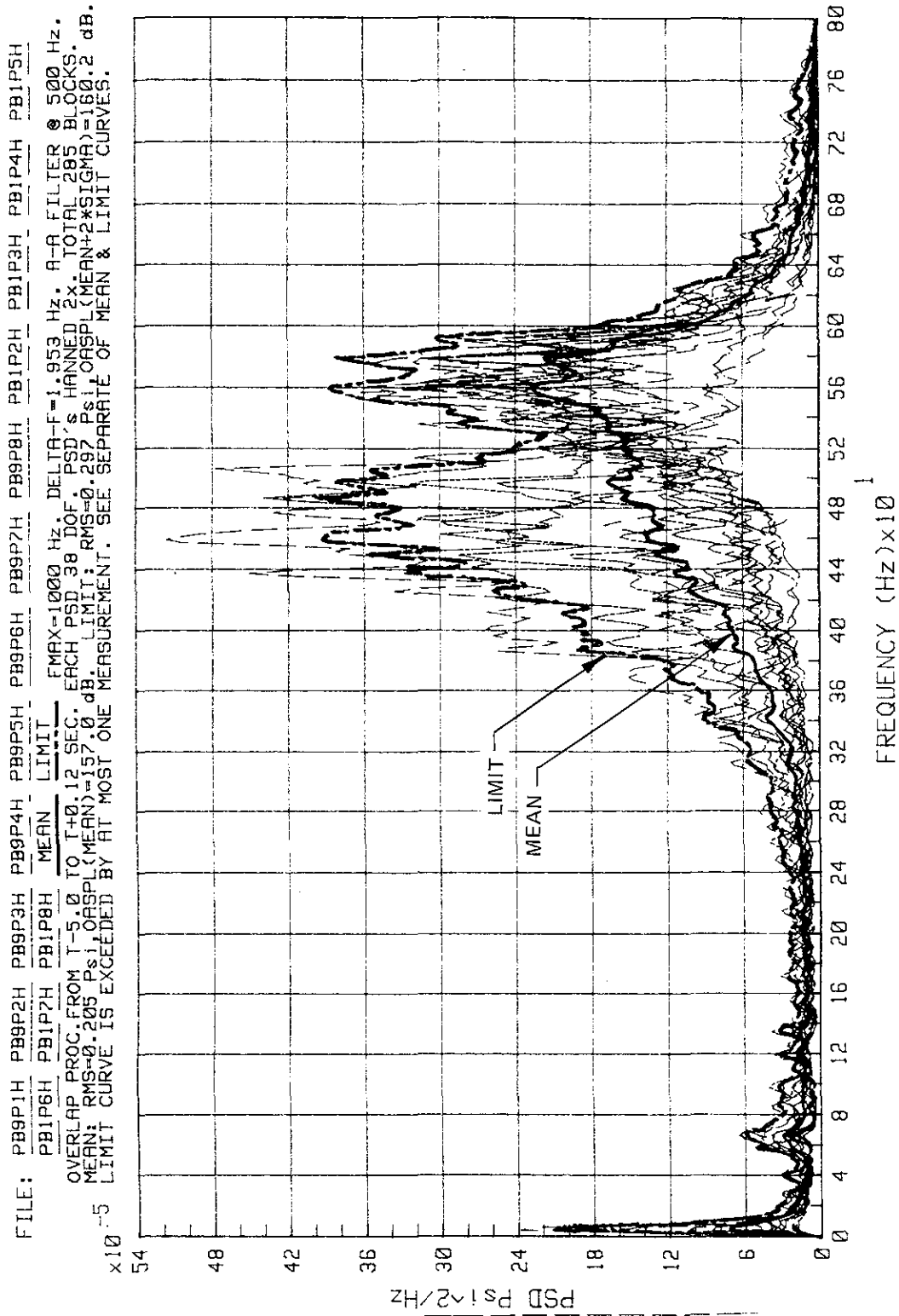
Figure 2-37. STS-9 and -11 Orbiter Holddown - Centaur Porch Assembly Pressures, All Sensor Data
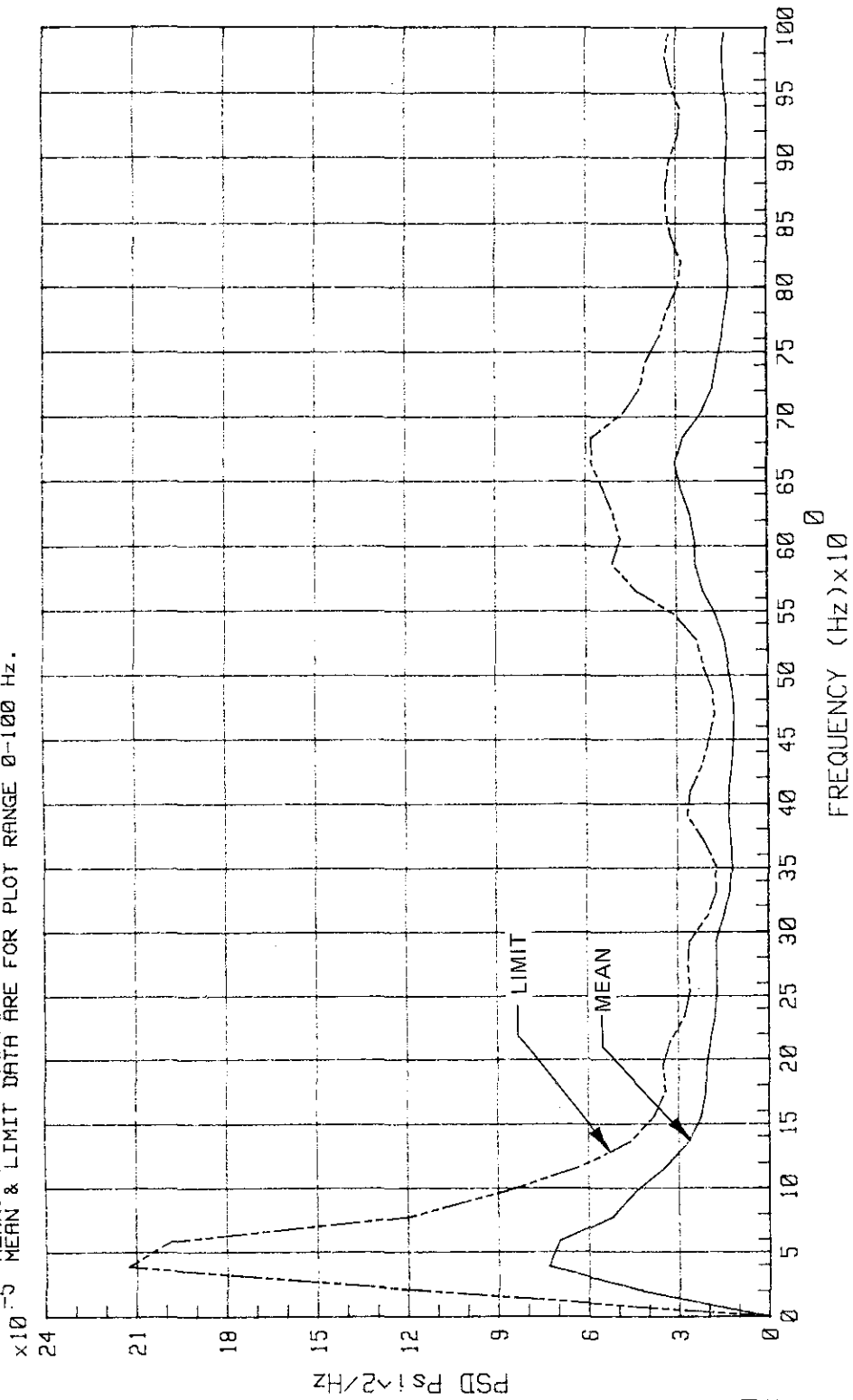
Figure 2-38. STS-9 and -11 Orbiter Holddown - Centaur Porch Assembly Pressures, All Sensor Data (Zoom Plot)

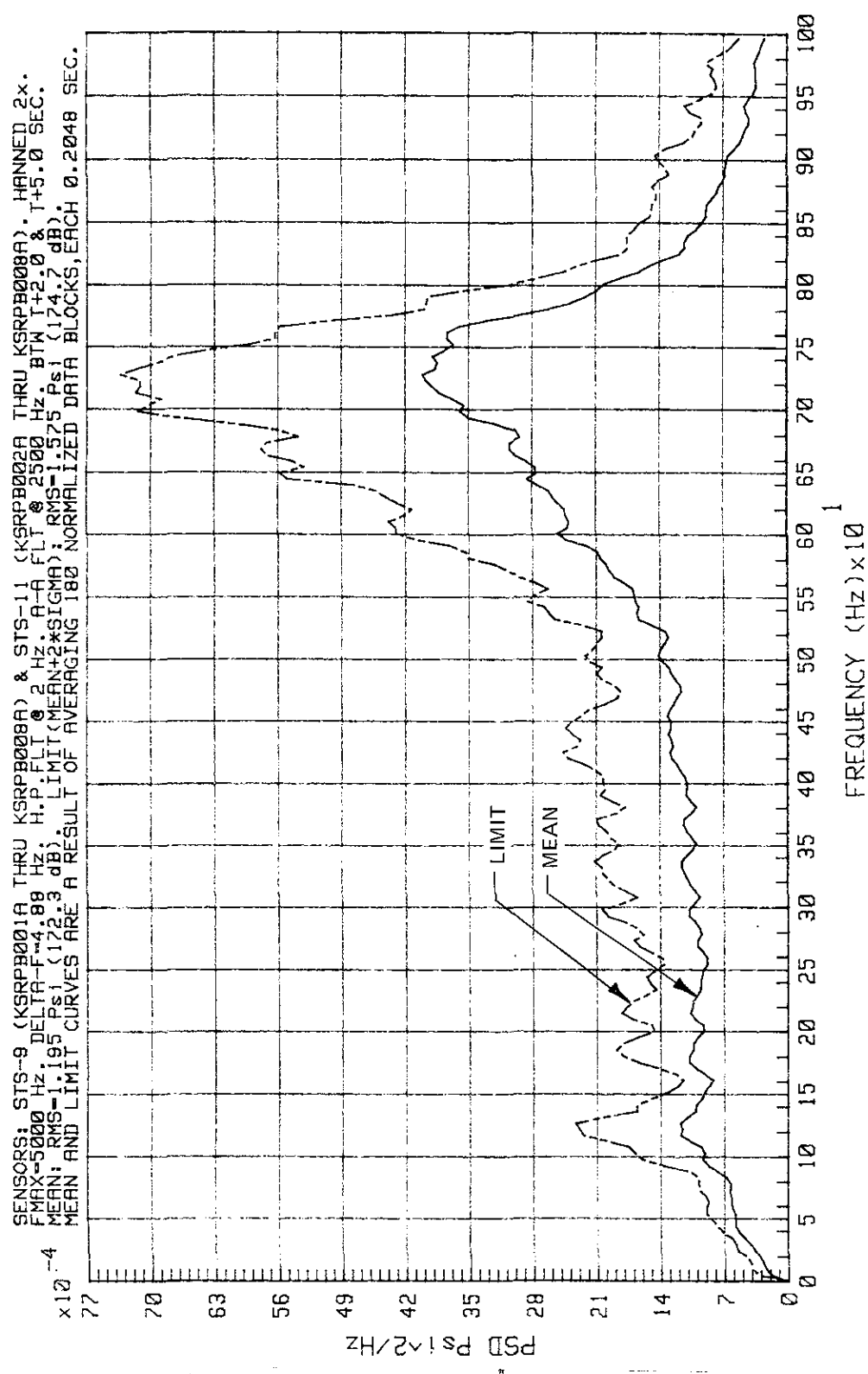Figure 2-39. STS-9 and -11 Lift-Off Peak – Centaur Porch Assembly Pressures (Mean and Limit; F_{max} = 5 kHz)
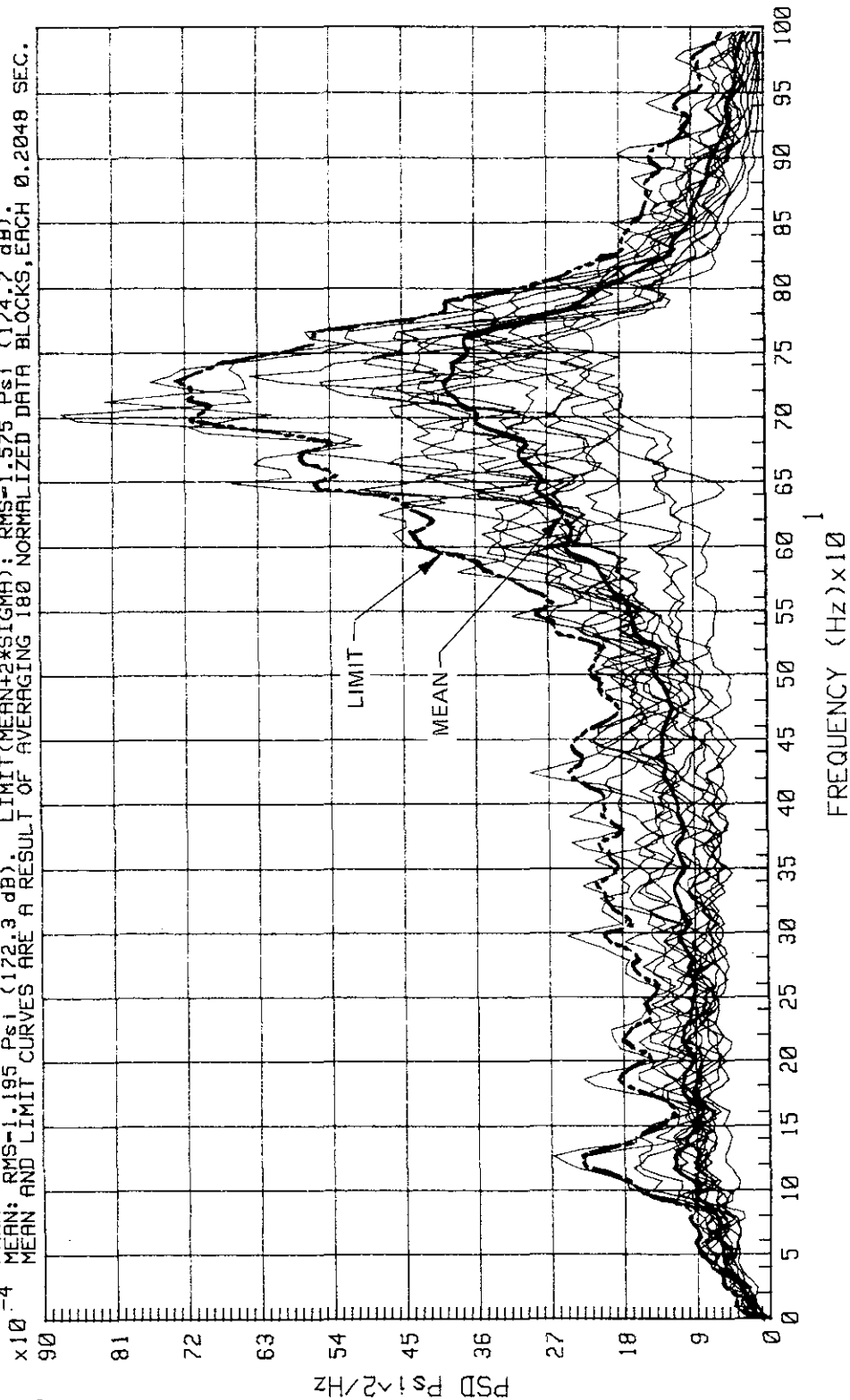
Figure 2-40. STS-9 and -11 Lift-Off Peak - Centaur Porch Assembly Pressures (F_{max} = 5 kHz)
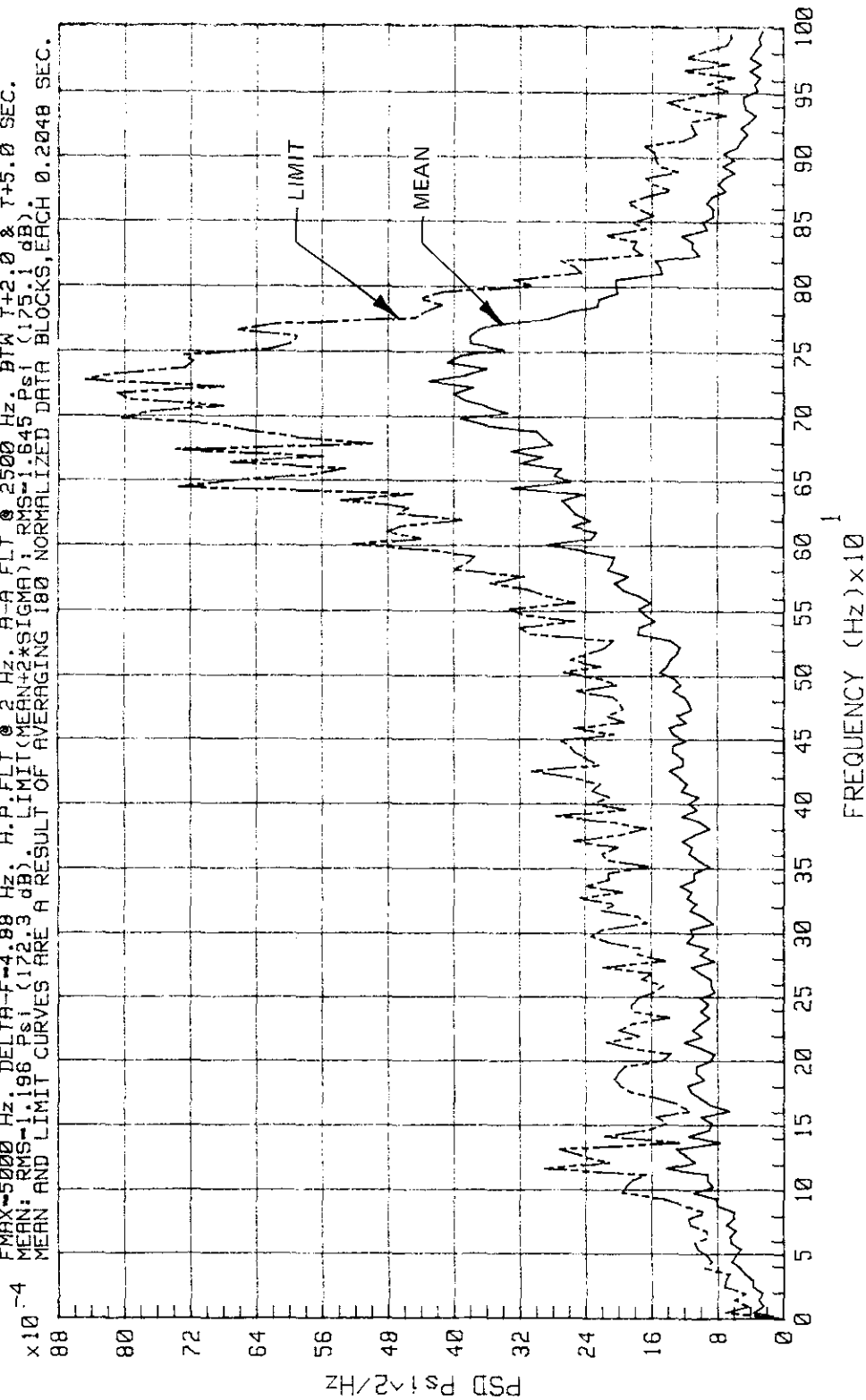
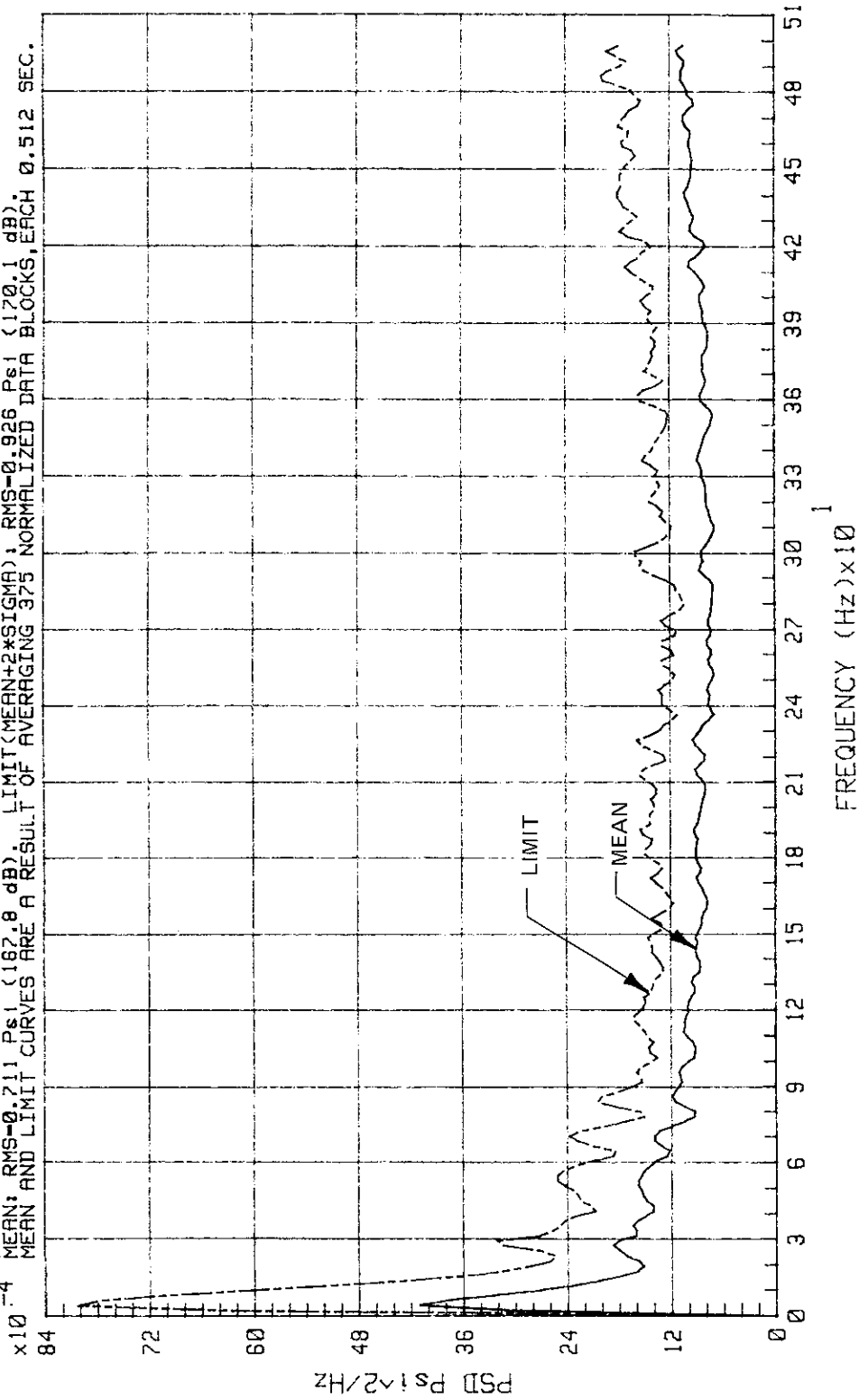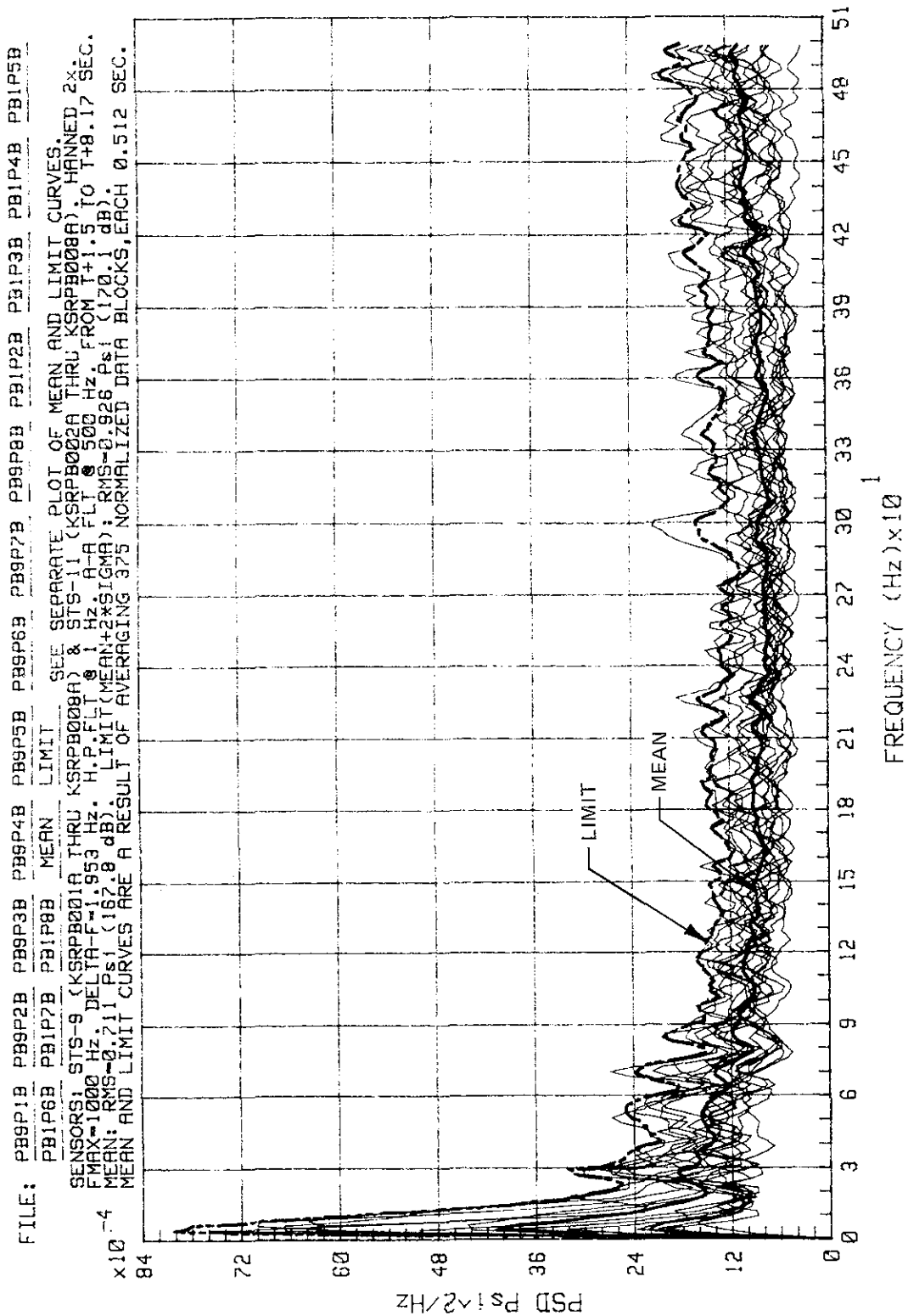Figure 2-41. STS-9 and -11 Lift-Off Peak - Centaur Porch Assembly Pressures (No Hanning)

Figure 2-42. STS-9 and -11 Lift-Off Peak - Centaur Porch Assembly Pressures (Mean and Limit; F_{max} = 1 kHz)

Figure 2-43. STS-9 and -11 Lift-Off Peak - Centaur Porch Assembly Pressures ($F_{max} = 1$ kHz)

Figure 2-44. STS-9 and -11 Lift-Off Peak - Centaur Porch Assembly Pressures (Mean and Limit; F_{max} = 1,000 Hz; High-Pass Filter at 1 Hz)

Figure 2-45. STS-9 and -11 Lift-Off Peak - Centaur Porch Assembly Pressures
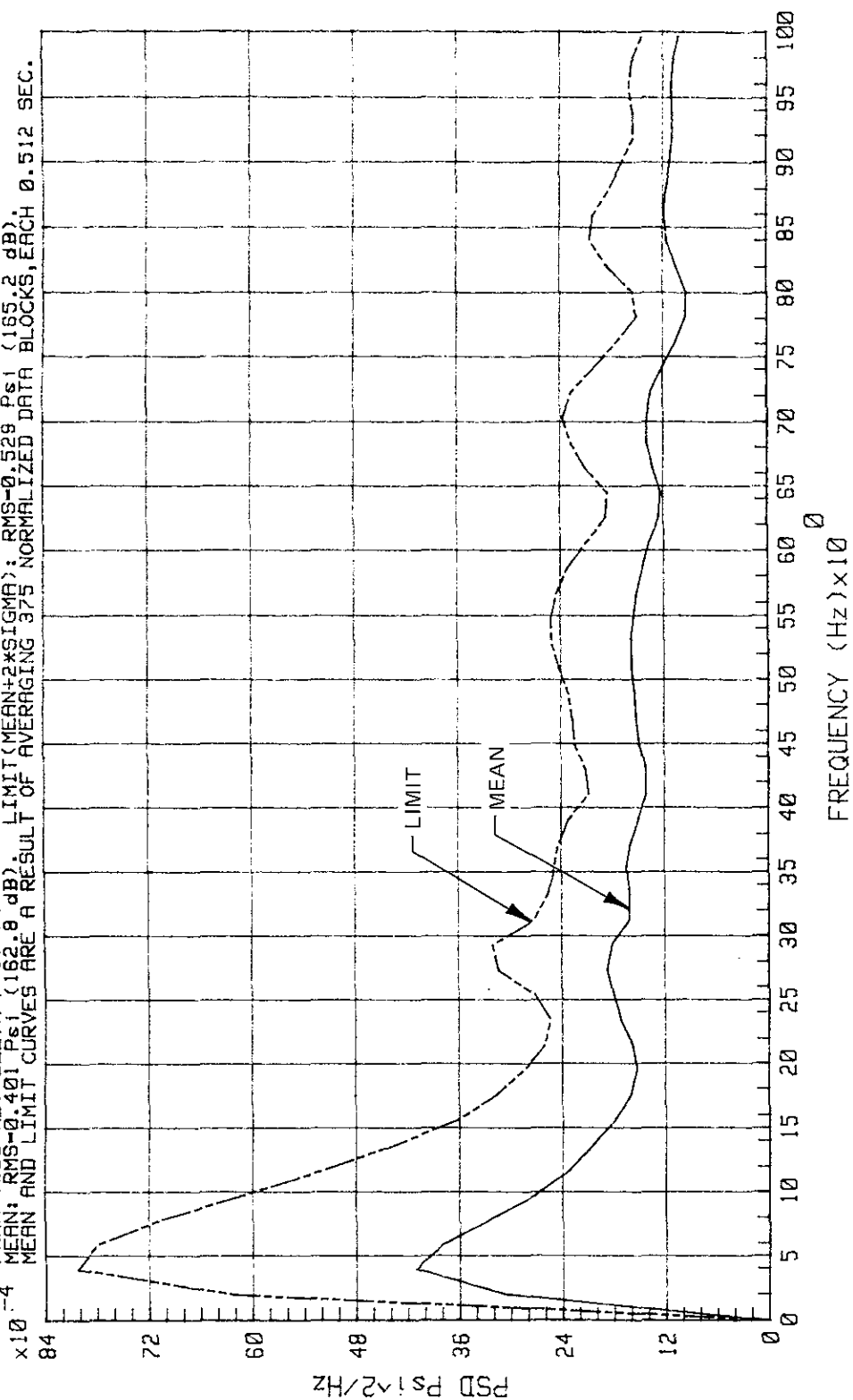(F_{max} = 1,000 Hz; High-Pass Filter at 1 Hz)

Figure 2-46. STS-9 and -11 Lift-Off Peak - Centaur Porch Assembly Pressures (Mean and Limit; F$_{max}$ = 1,000 Hz; High-Pass Filter at 1 Hz; No Hanning)
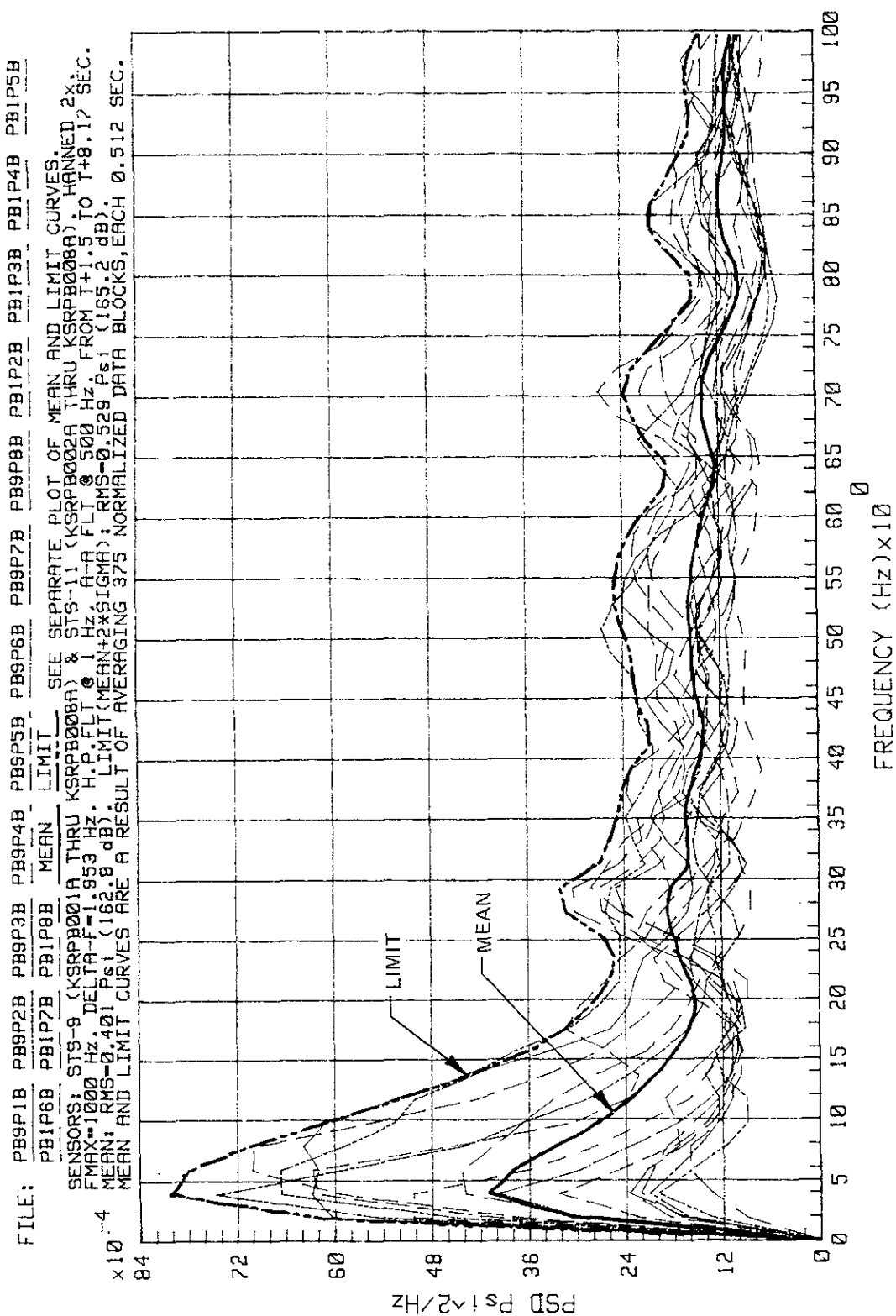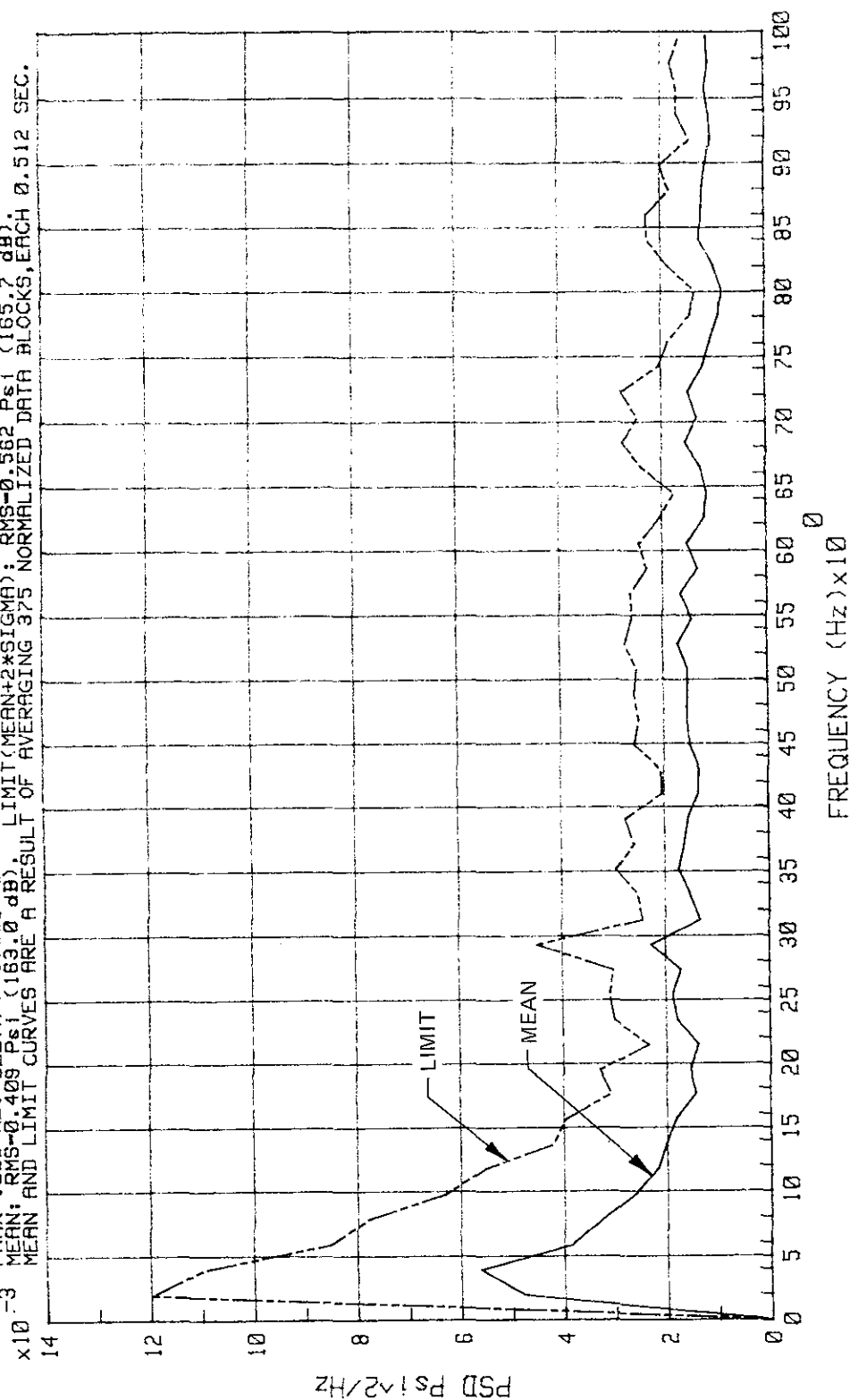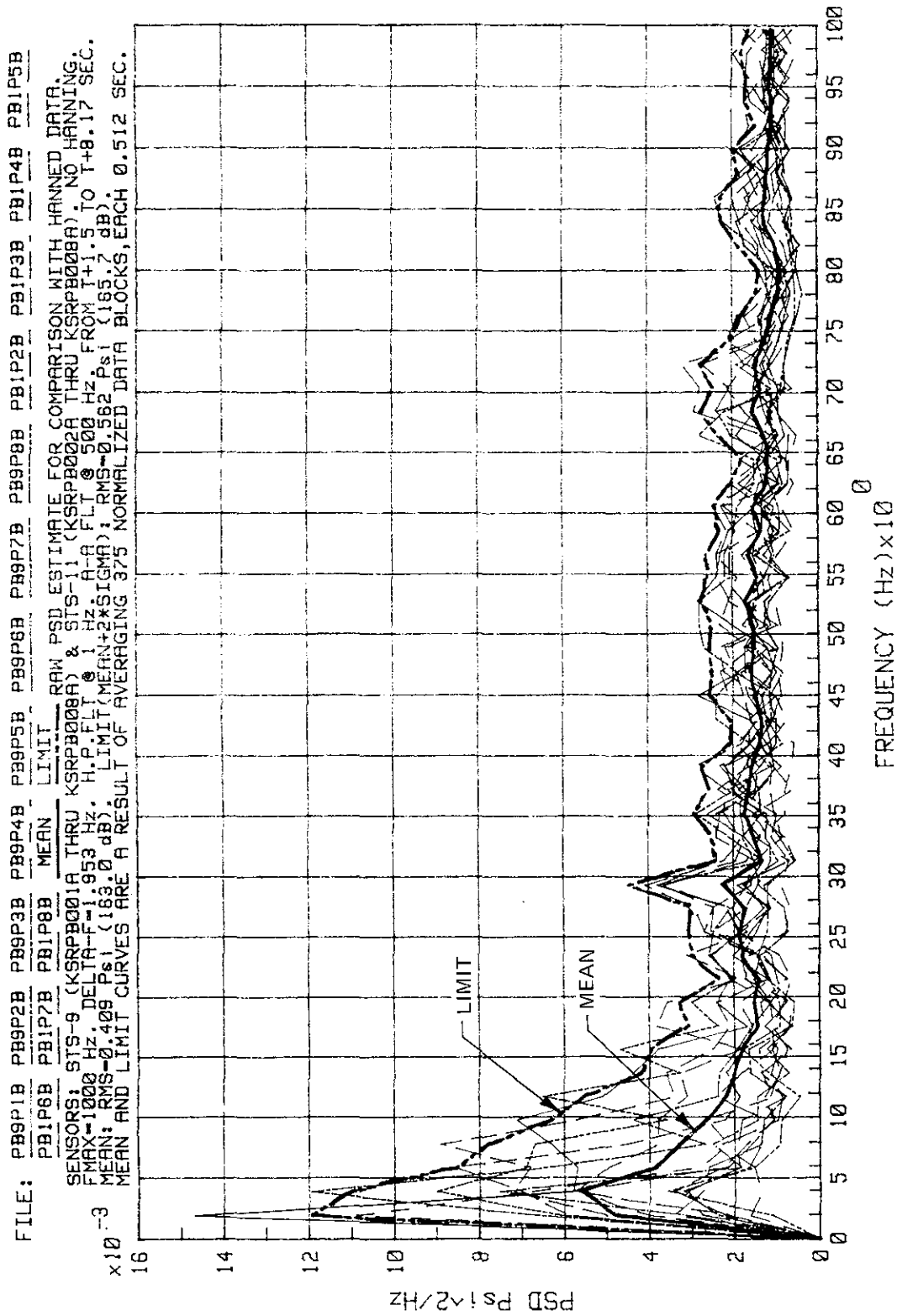
Figure 2-47. STS-9 and -11 Lift-Off Peak - Centaur Porch Assembly Pressures (F_{max} = 1 kHz), Comparison of Hanned Data to Data Without Hanning
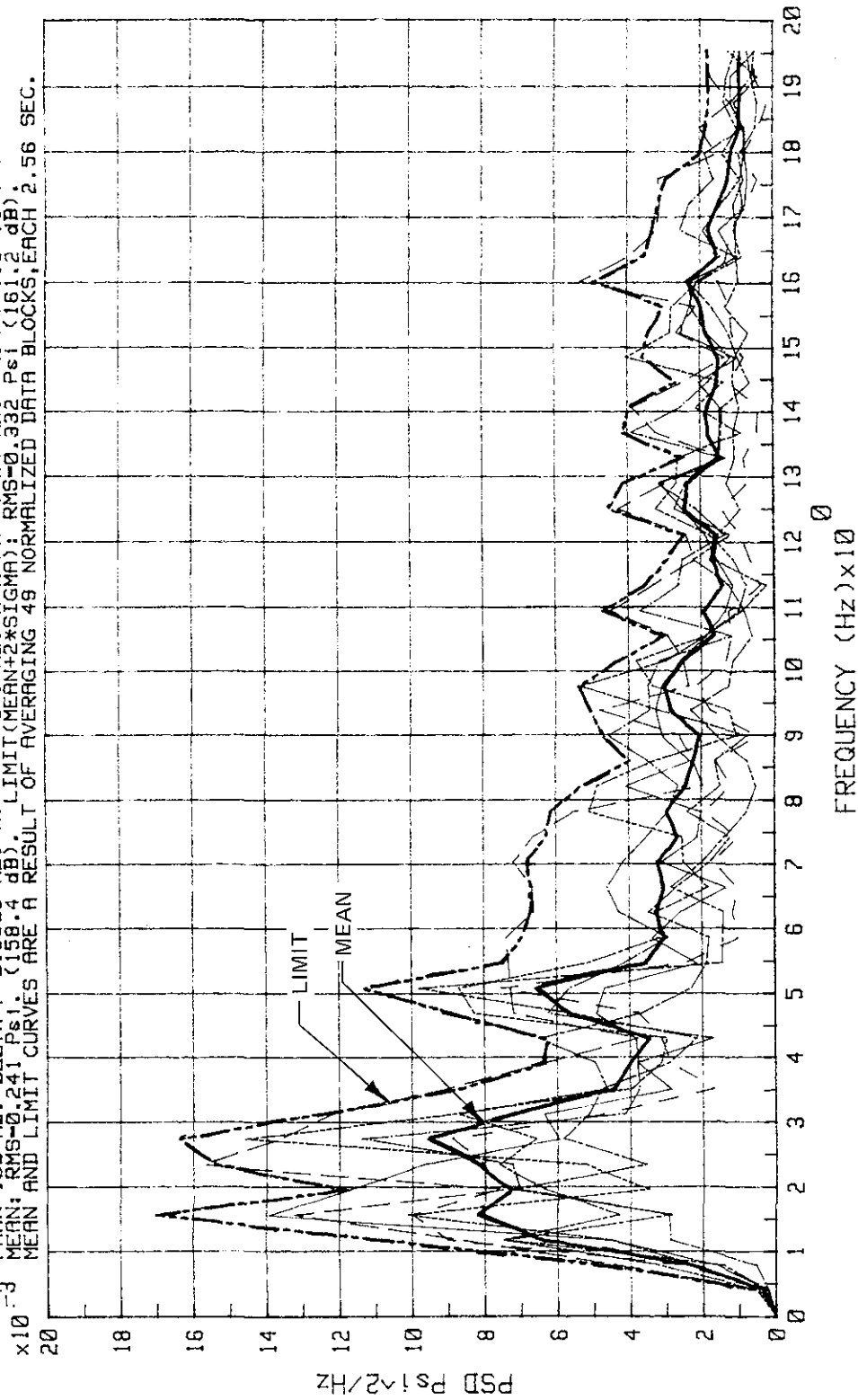
Figure 2-48.   STS-9 and -11 Lift-Off Peak - Centaur Porch Assembly Pressures
(F_{max} = 100 Hz), Sensors Closest to Vehicle

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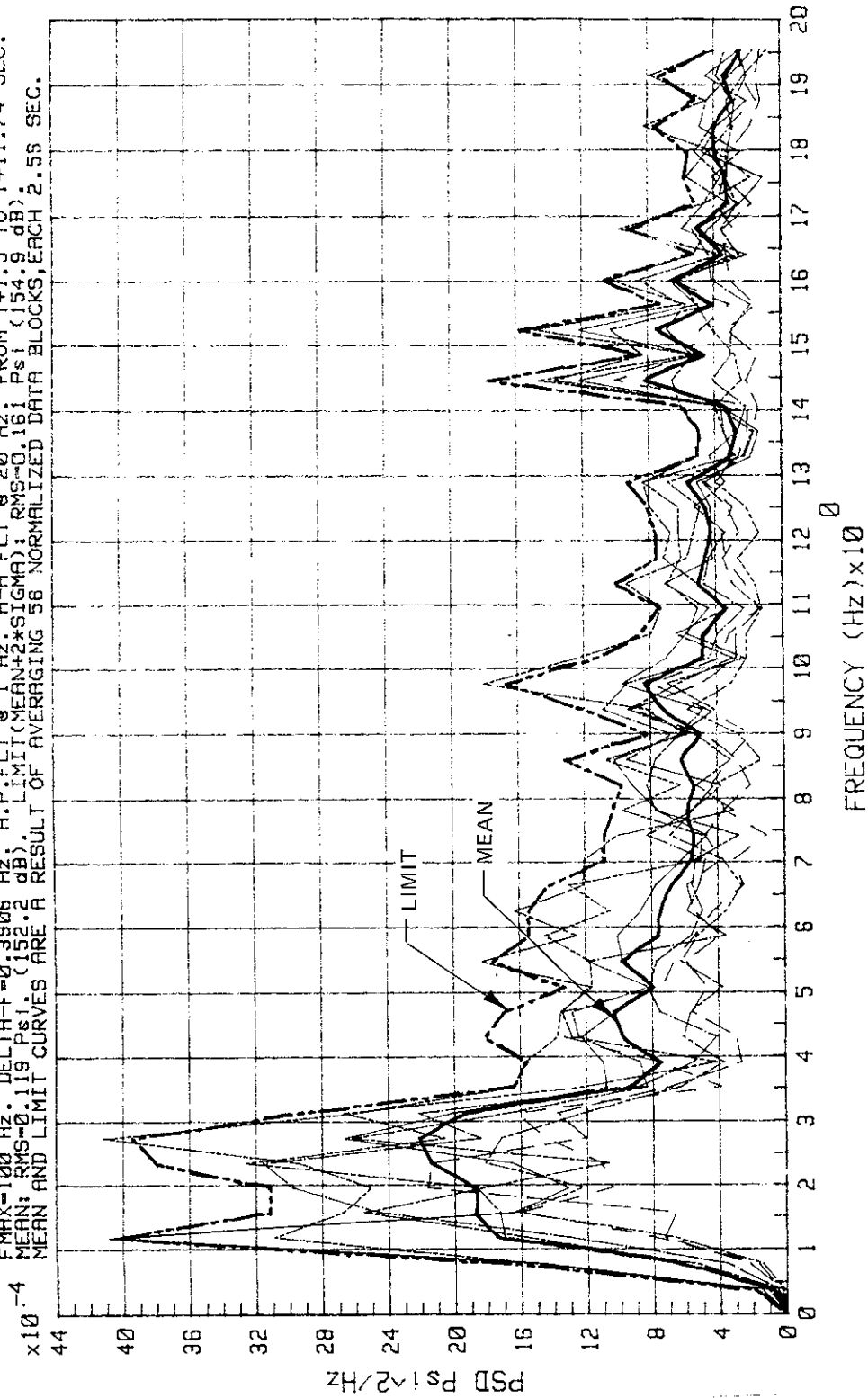
Figure 2-49. STS-9 and -11 Lift-Off Peak - Centaur Porch Assembly Pressures (F_{max} = 100 Hz), Sensors Farthest From Vehicle
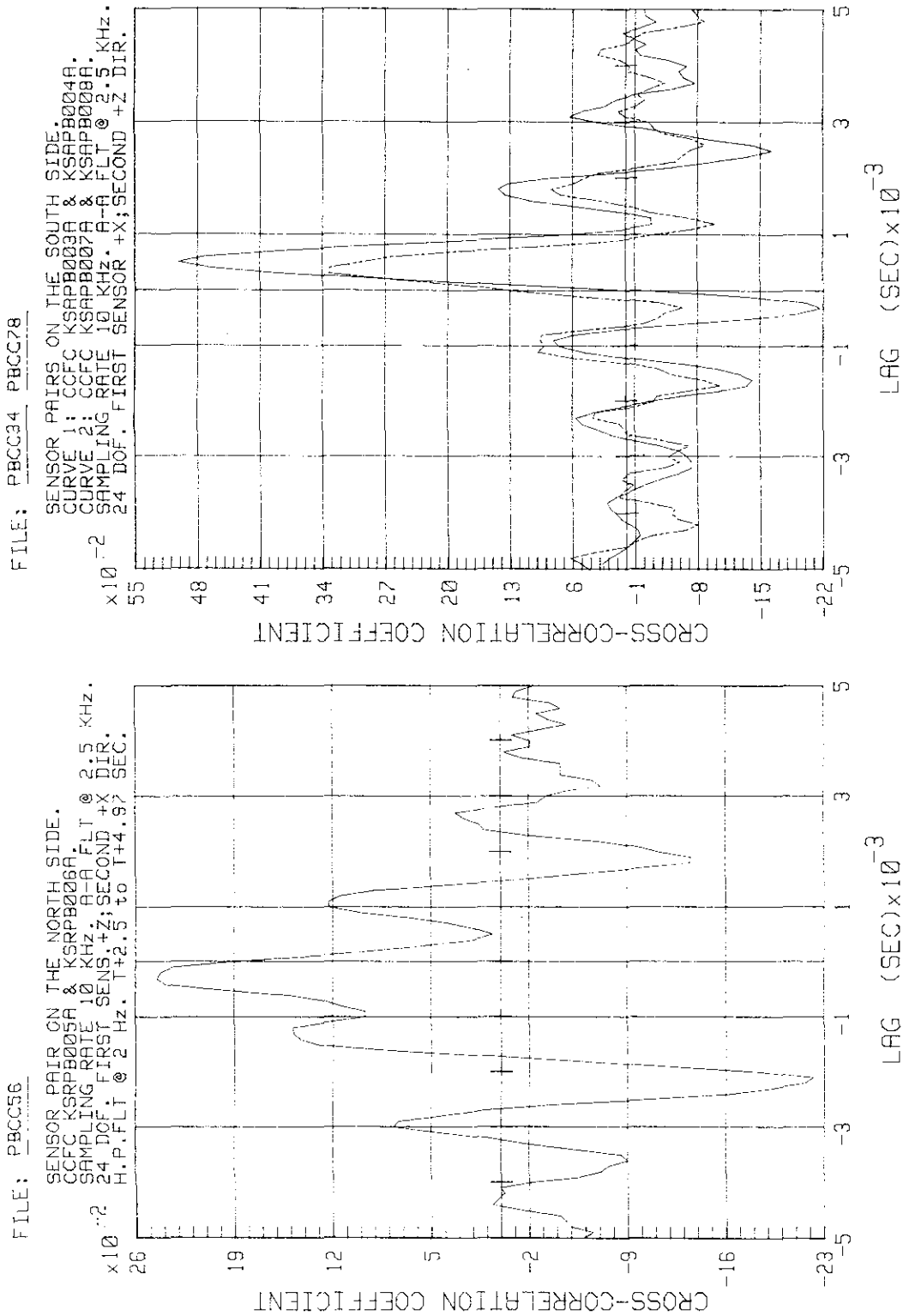
Figure 2-50. STS-11 Lift-Off Peak - Centaur Porch Pressure Cross-Correlation
(Adjacent Sensors; Sampling Rate = 10 kHz)
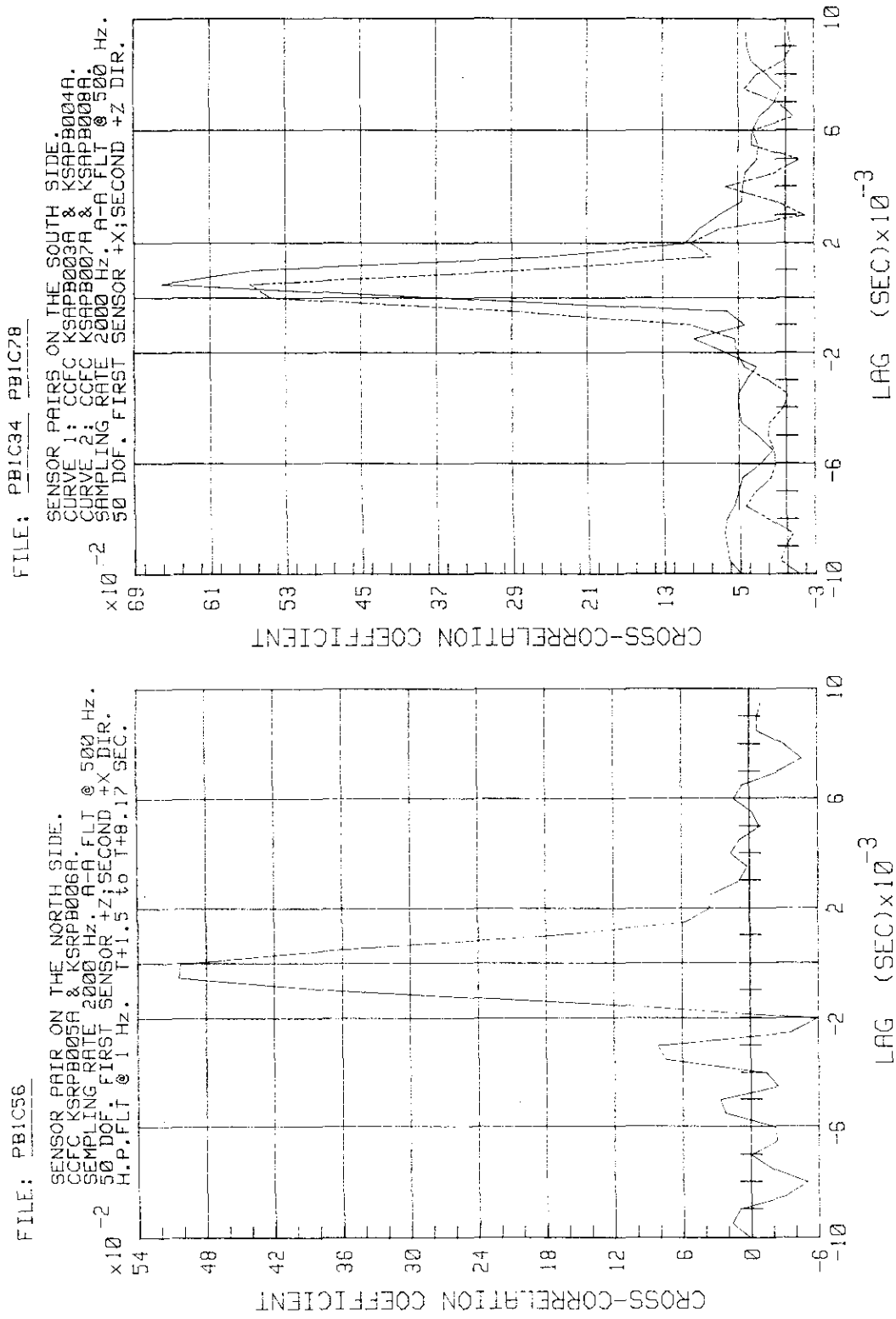
Figure 2-51. STS-11 Lift-Off Peak - Centaur Porch Pressure Cross-Correlation (Adjacent Sensors; Sampling Rate = 2 kHz)
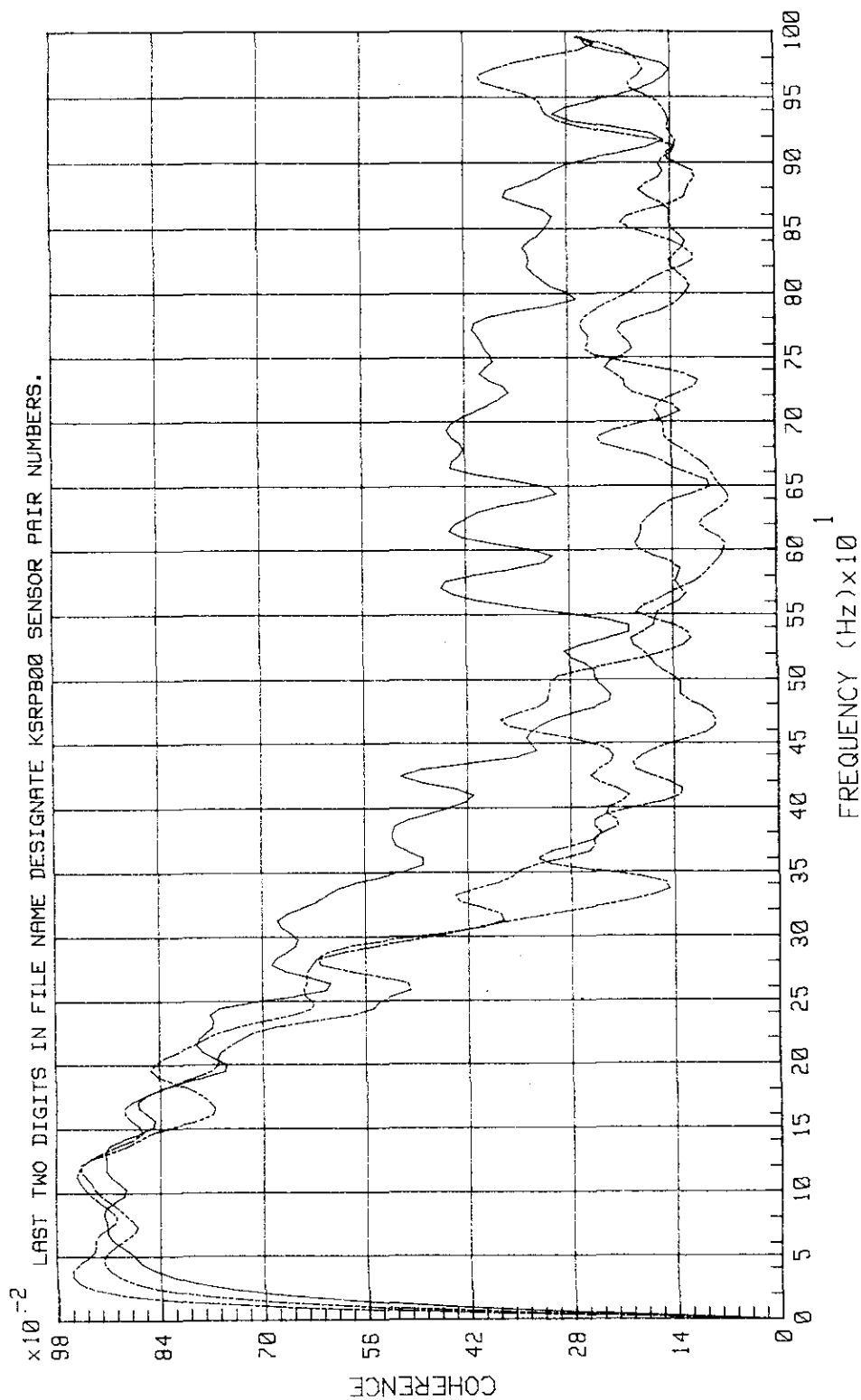
Figure 2-52. STS-11 Lift-Off Peak - Centaur Porch Pressure Coherences
(Adjacent Sensors; F_{max} = 5 kHz)

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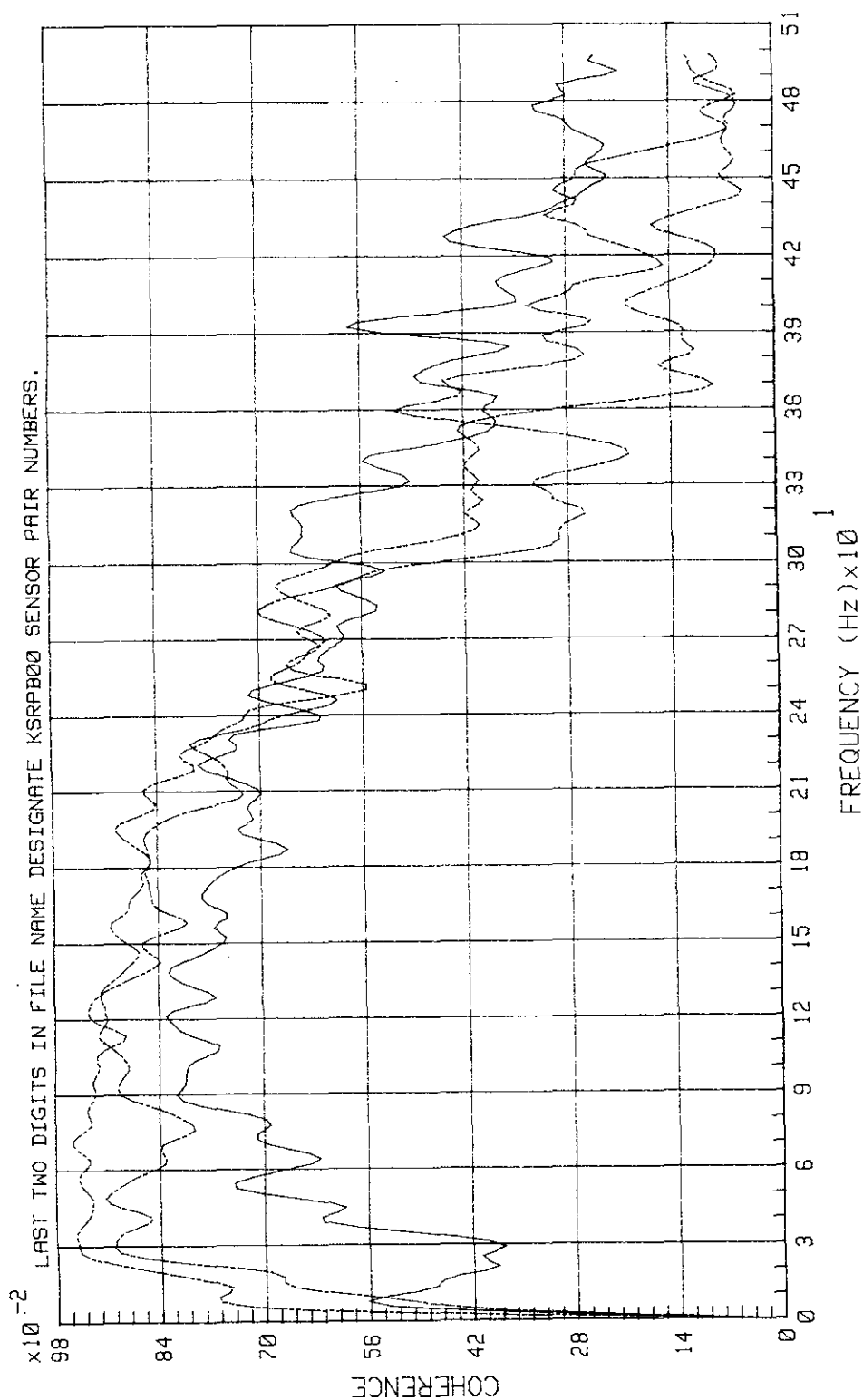
Figure 2-53. STS-11 Lift-Off Peak - Centaur Porch Pressure Coherences (Adjacent Sensors; F_{max} = 1 kHz)

2-58
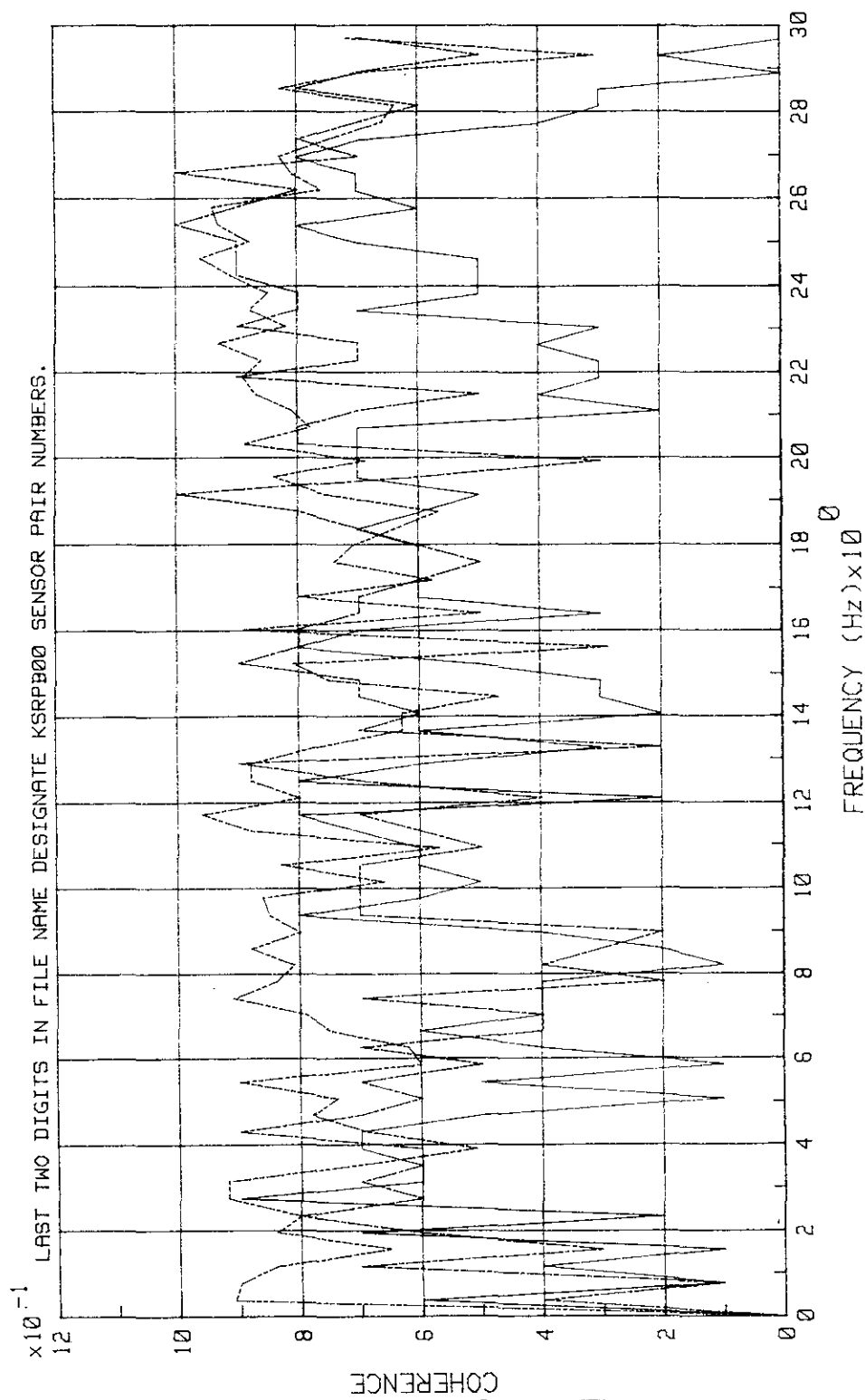
Figure 2-54. STS-11 Lift-Off Peak – Centaur Porch Pressure Coherences (Adjacent Sensors; F_{max} = 100 Hz)
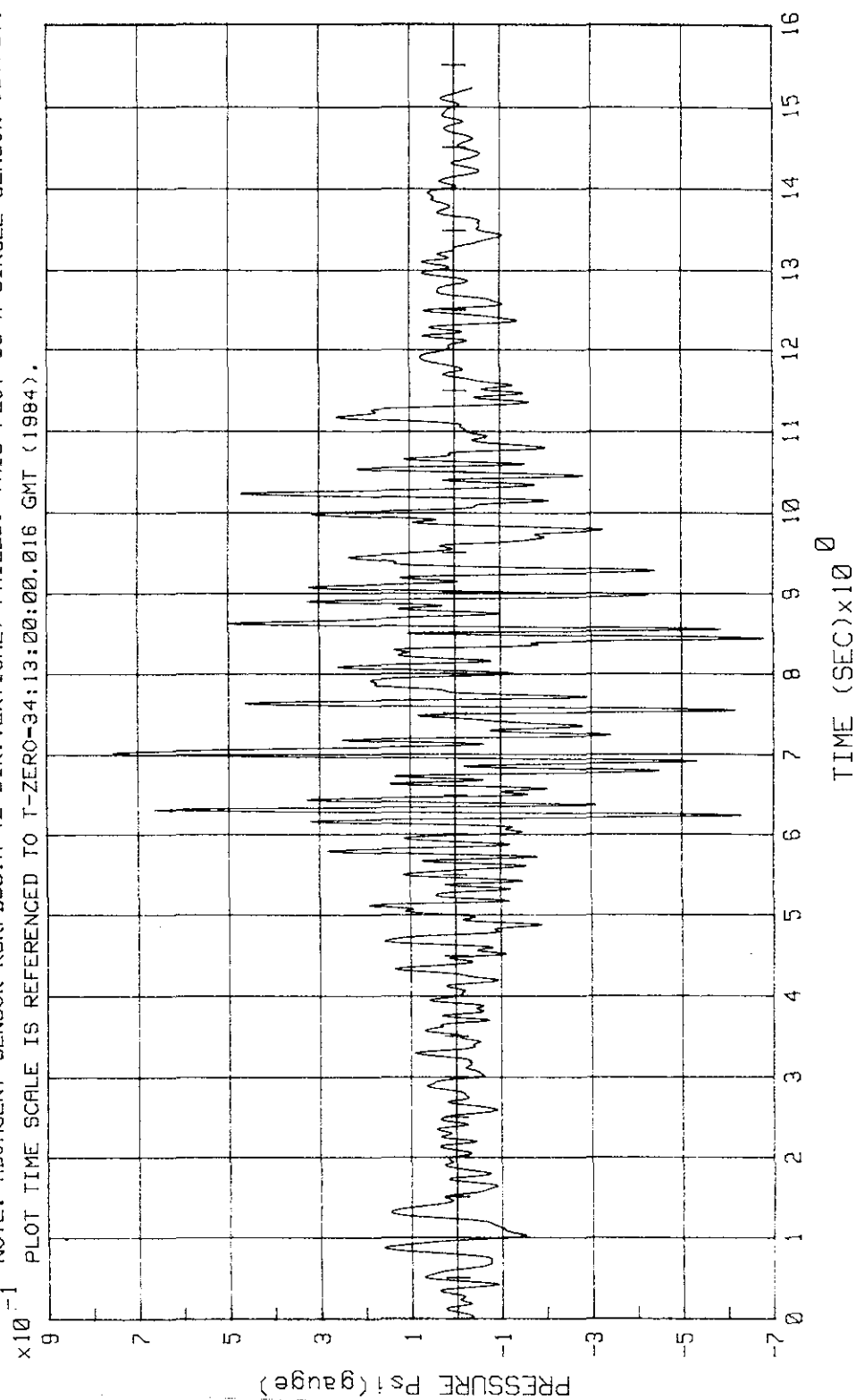
Figure 2-55. STS-11 Lift-Off – Centaur Porch Assembly Pressures at East End, Sensor KSRPB002A (1 Hz to 10 Hz)
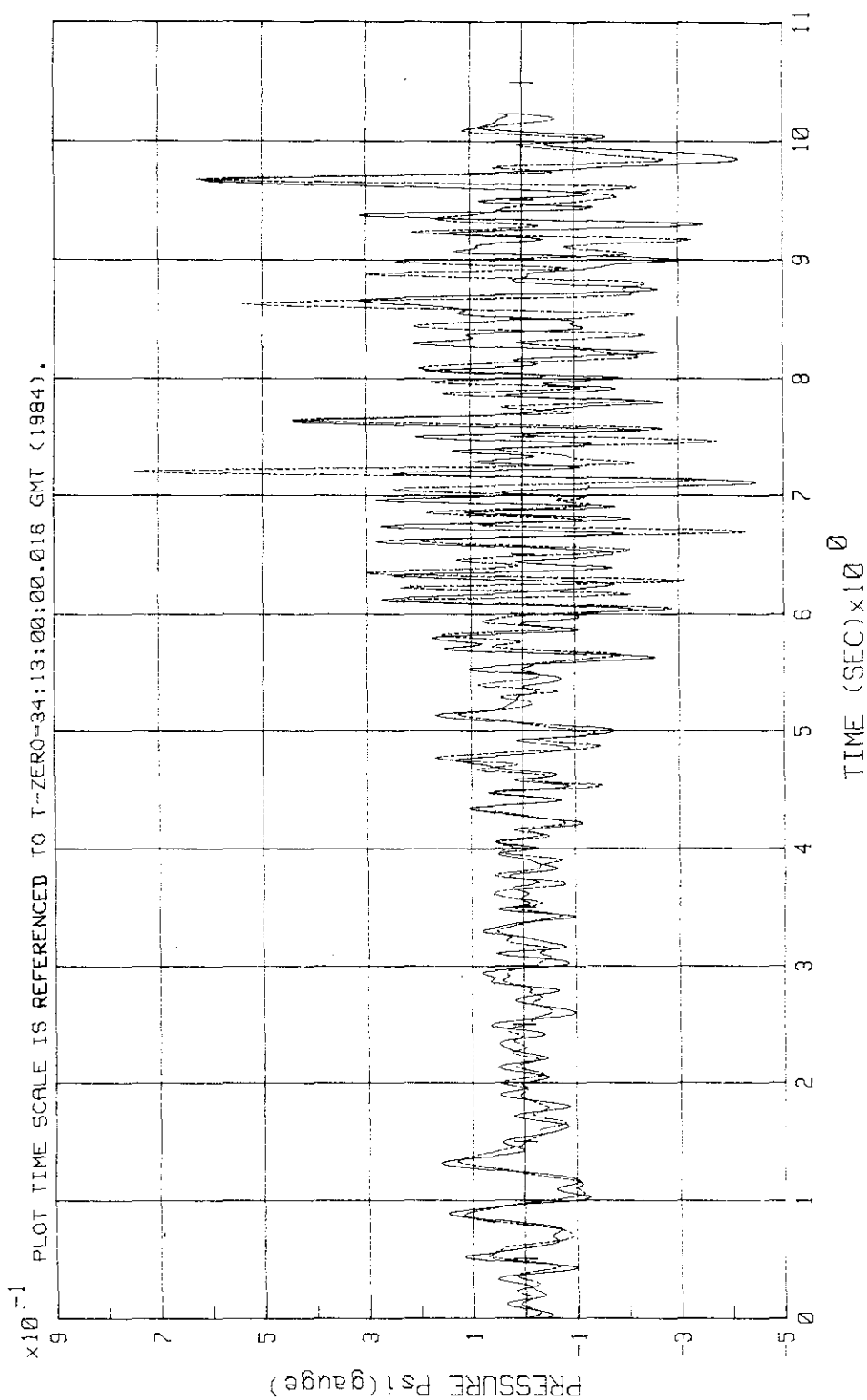
Figure 2-56. STS-11 Lift-Off – Centaur Porch Assembly Pressures at East End, Sensors KSRPB003A and -004A, 1 Hz to 10 Hz (From T to T + 10.24 s)
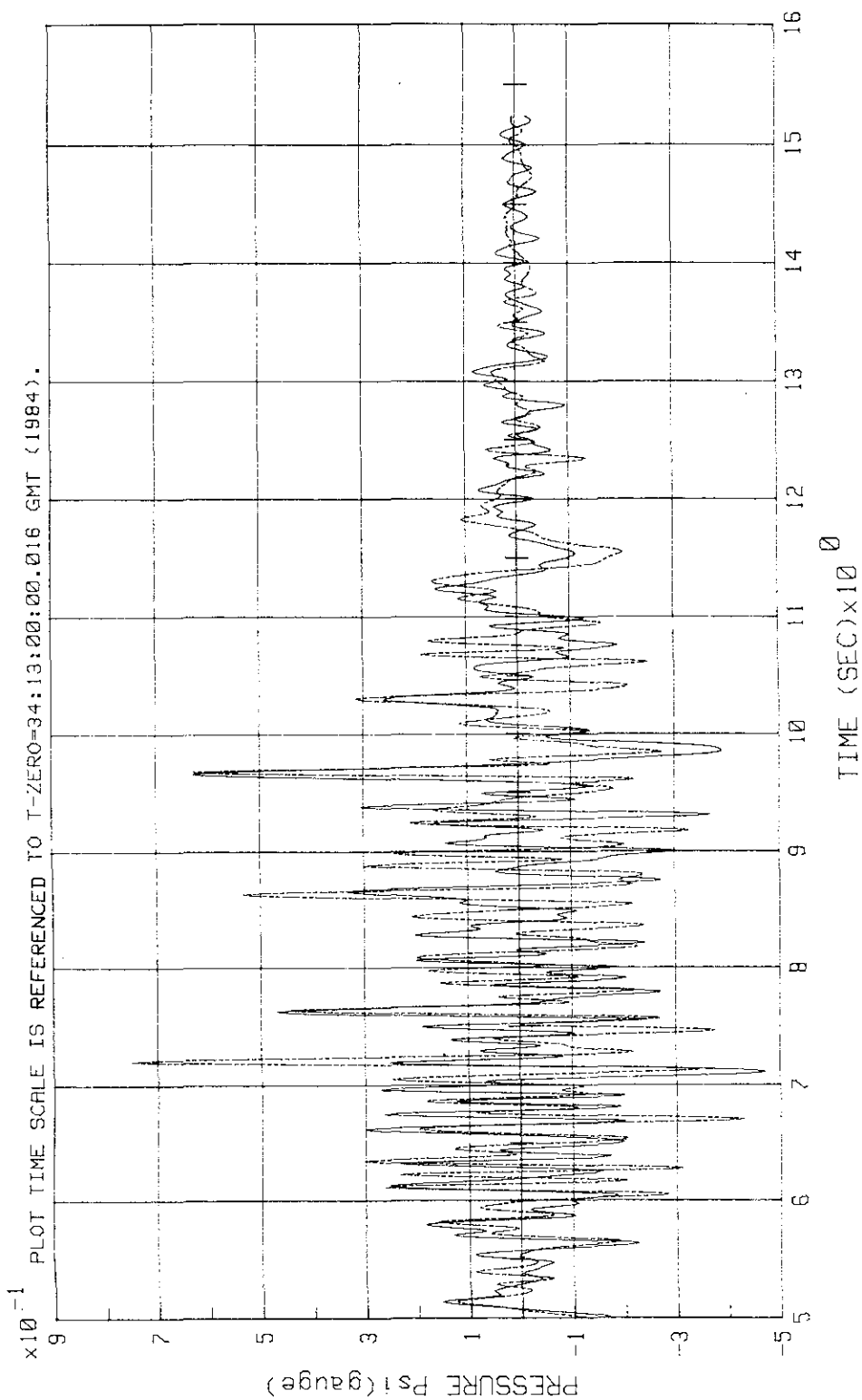
Figure 2-57. STS-11 Lift-Off - Centaur Porch Assembly Pressures at East End, Sensors KSRPB003A and -004A, 1 Hz to 10 Hz (From T + 5 to T + 15.24 s)
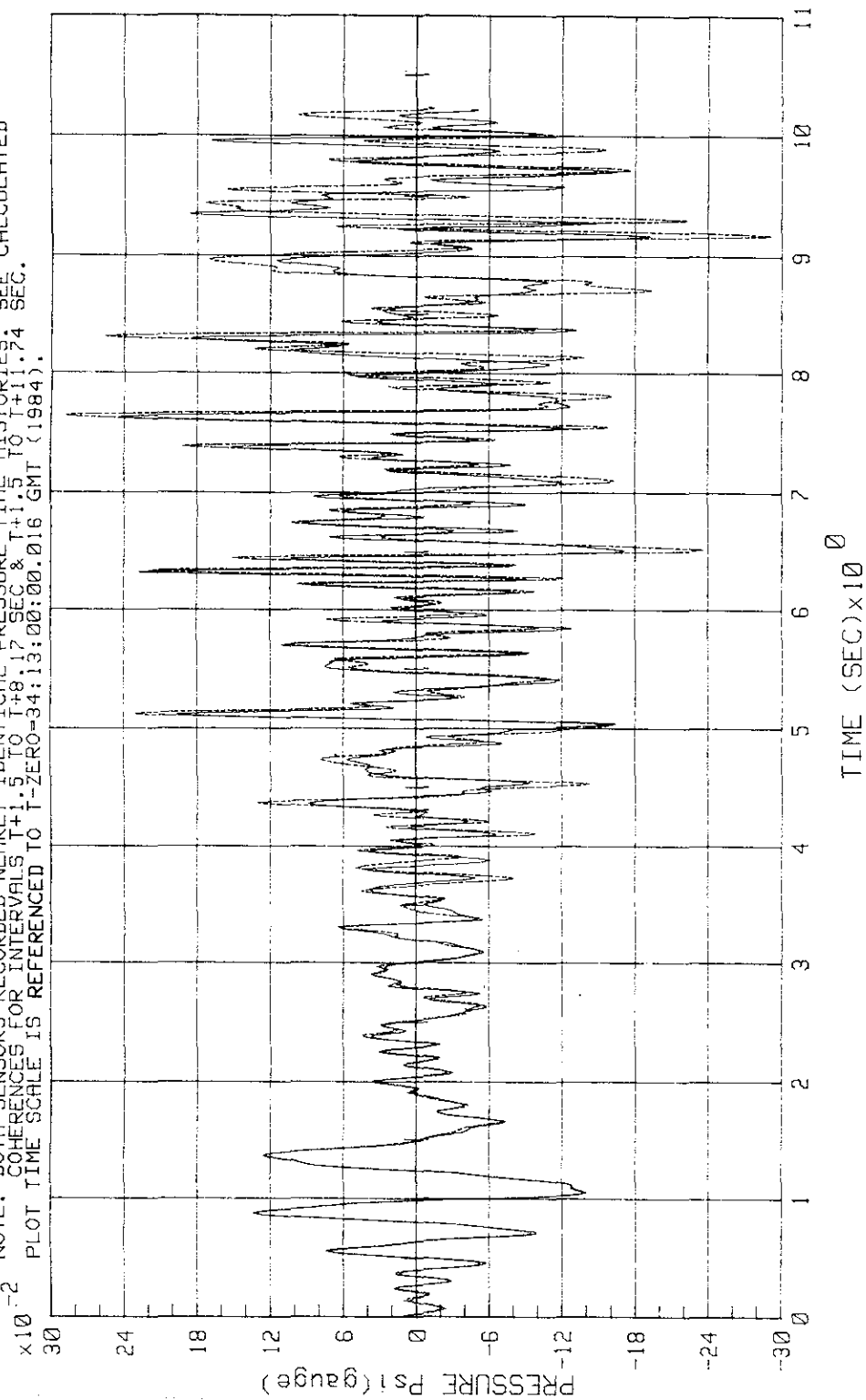
Figure 2-58. STS-11 Lift-Off - Centaur Porch Assembly Pressures at FSS Support,
Sensors KSRPB005A and -006A, 1 Hz to 10 Hz (From T to T + 10.24 s)
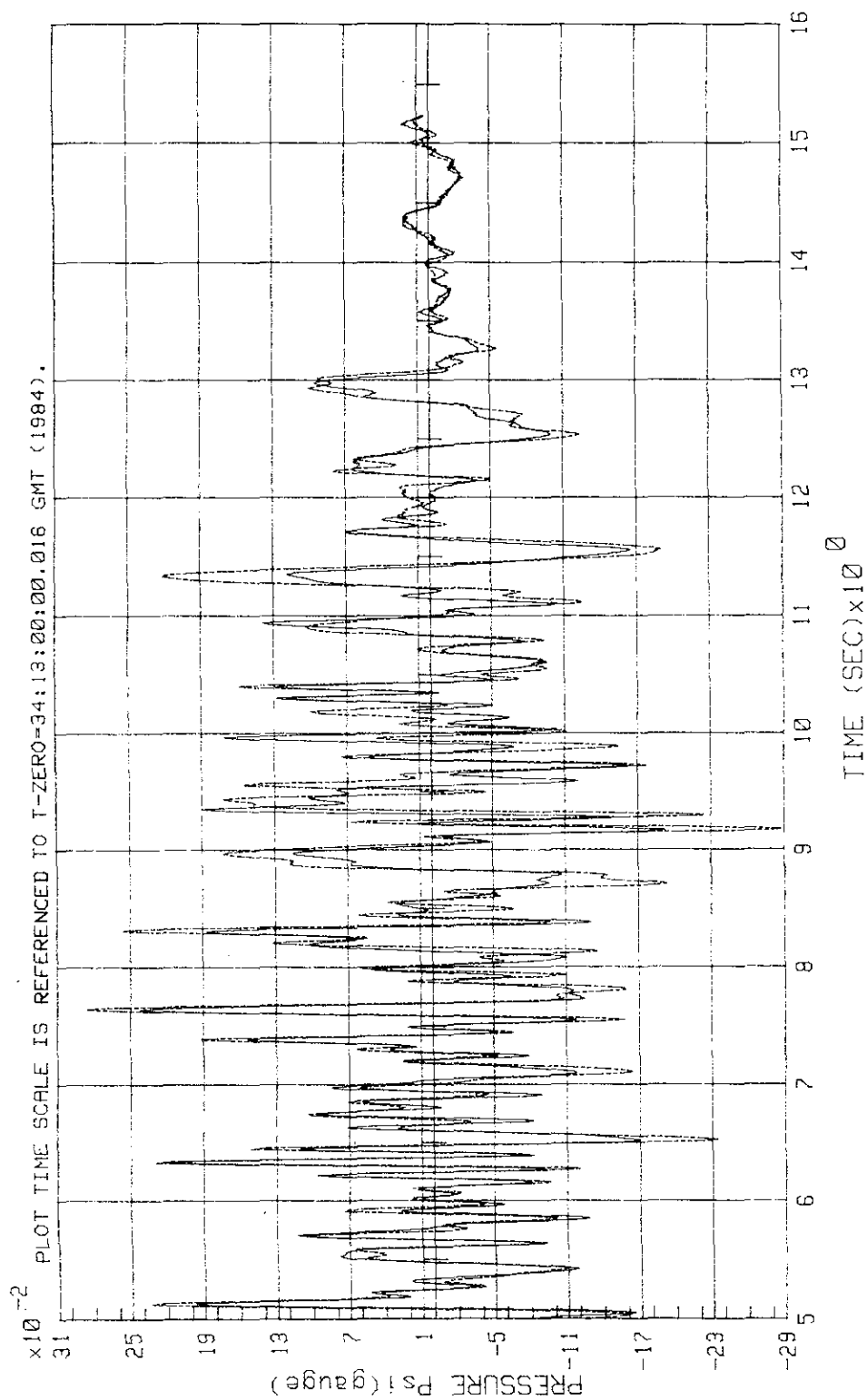
Figure 2-59. STS-11 Lift-Off - Centaur Porch Assembly Pressures at FSS Support, Sensors KSRPB005A and -006A, 1 Hz to 10 Hz (From T + 5 to T + 15.24 s)
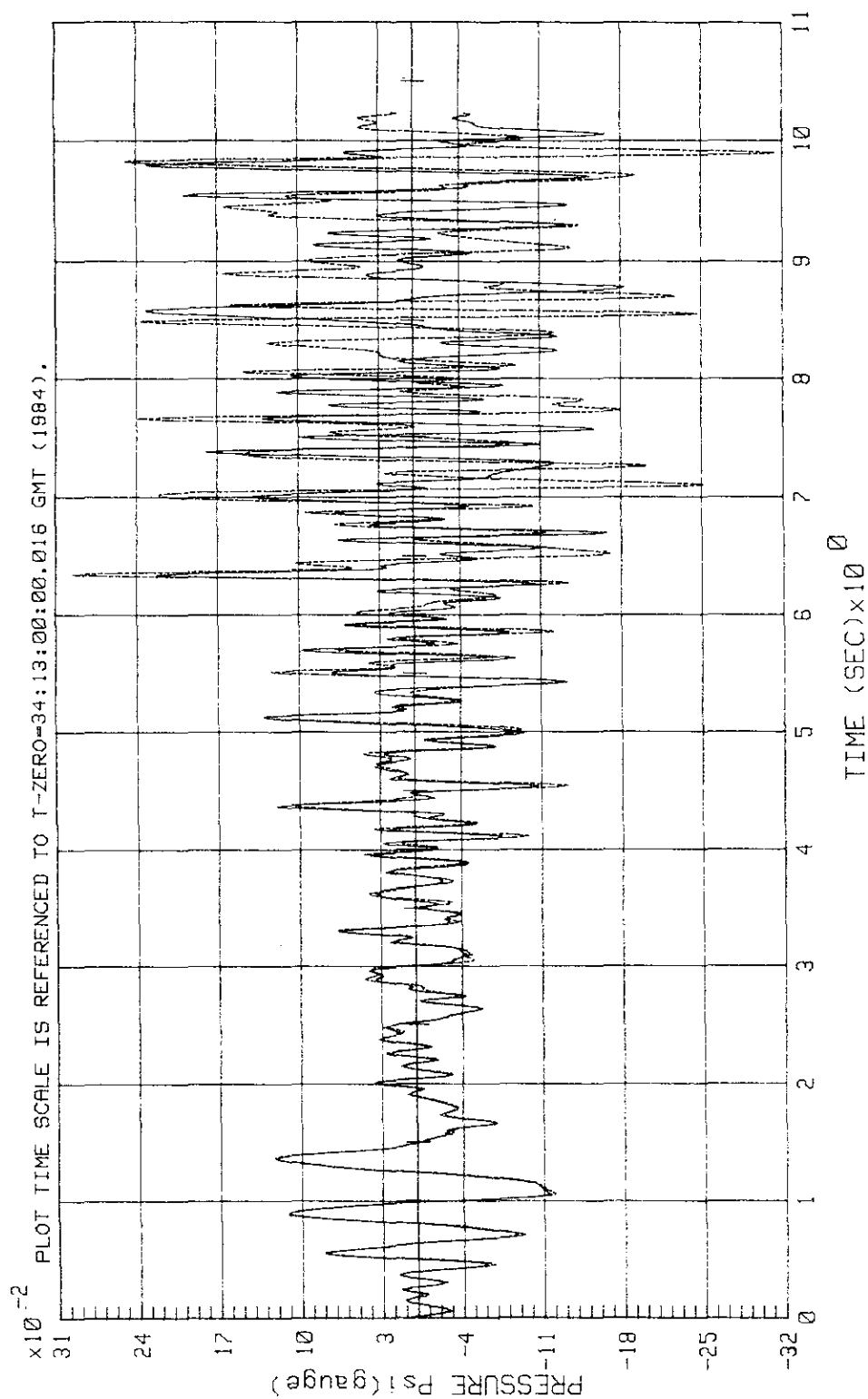
Figure 2-60. STS-11 Lift-Off - Centaur Porch Assembly Pressures at FSS Support, Sensors KSRPB007A and -C08A, 1 Hz to 10 Hz (From T to T + 10.24 s)
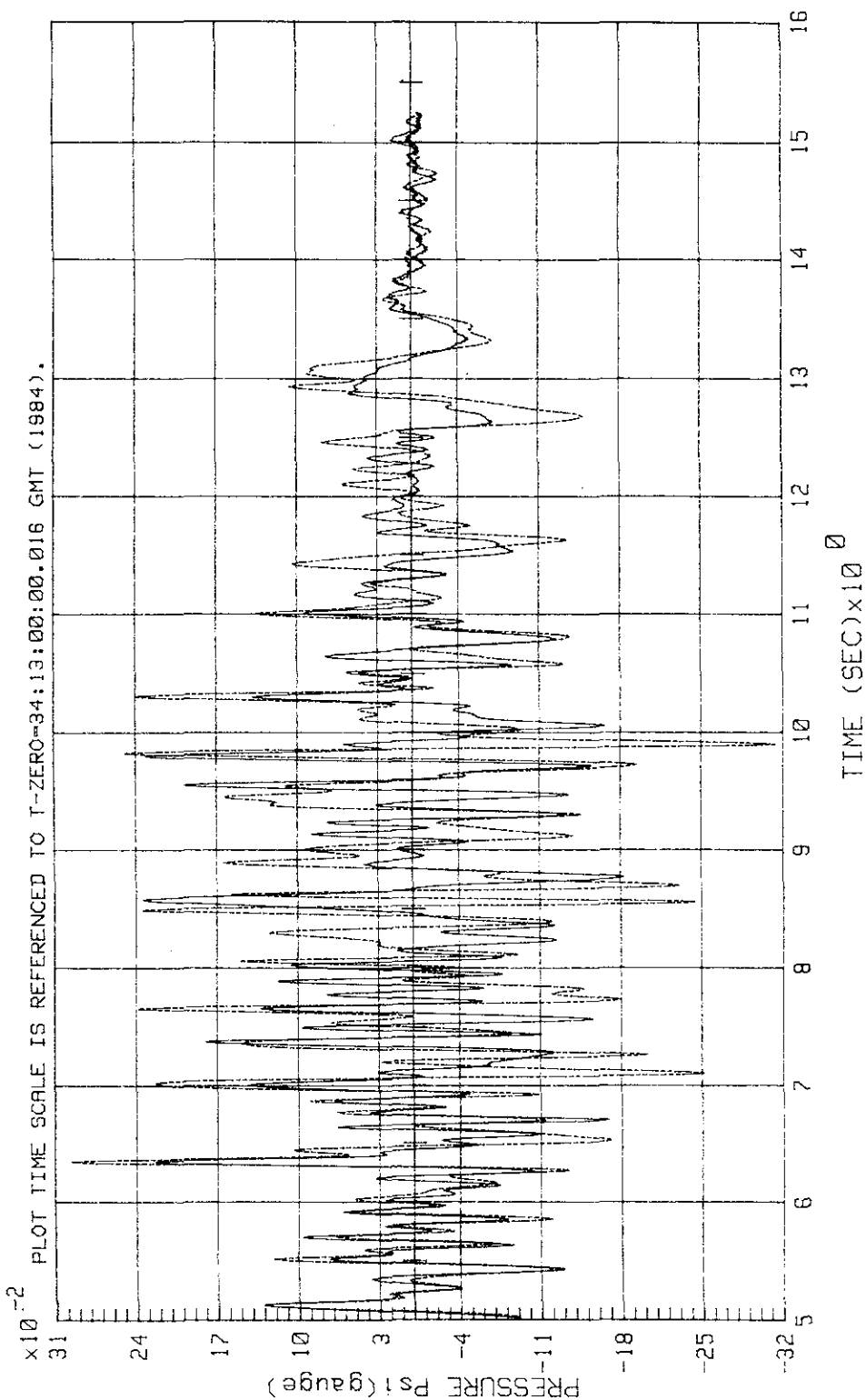
Figure 2-61. STS-11 Lift-Off – Centaur Porch Assembly Pressures at FSS Support, Sensors KSRPB007A and -008A, 1 Hz to 10 Hz (From T + 5 s to T + 16 s)
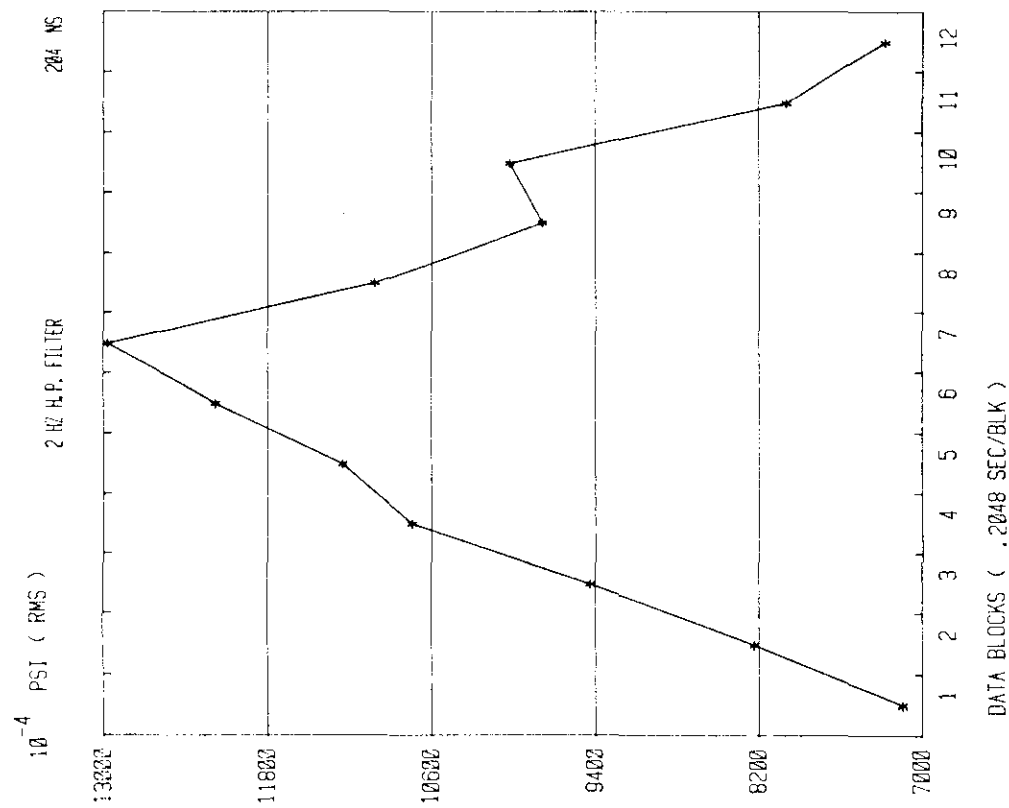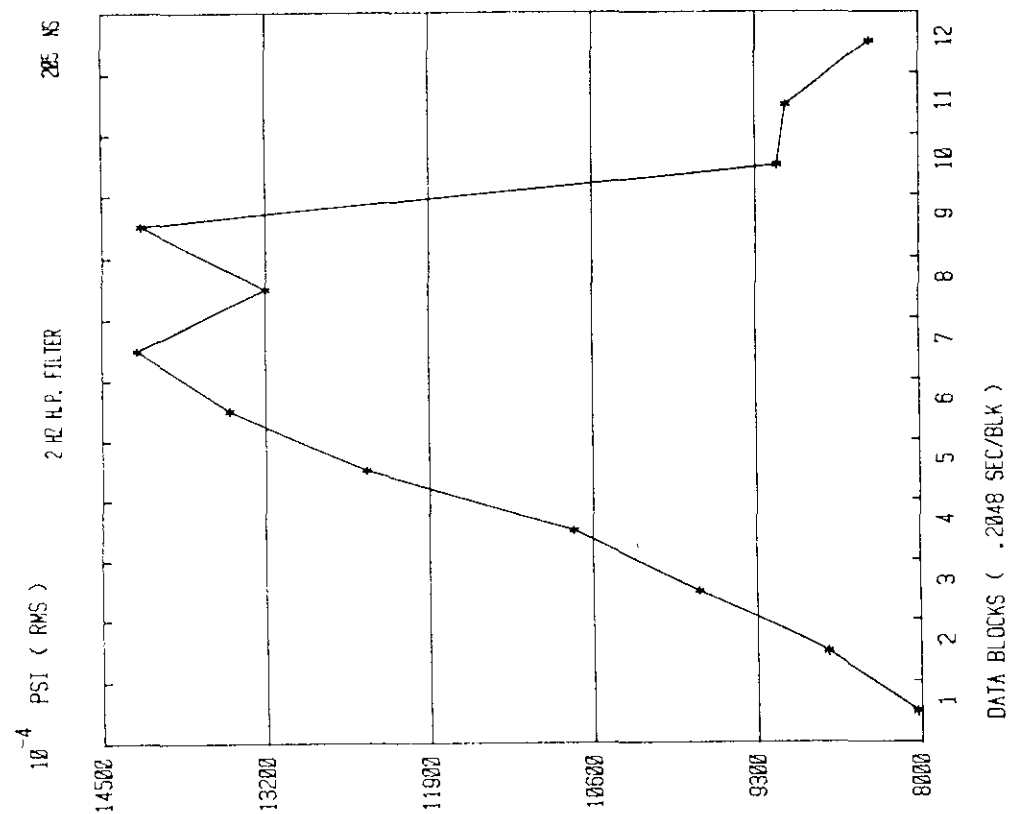
Figure 2.-62.   Typical RMS Plot of Centaur Porch Pressures Using a 2-Hz High-Pass Filter

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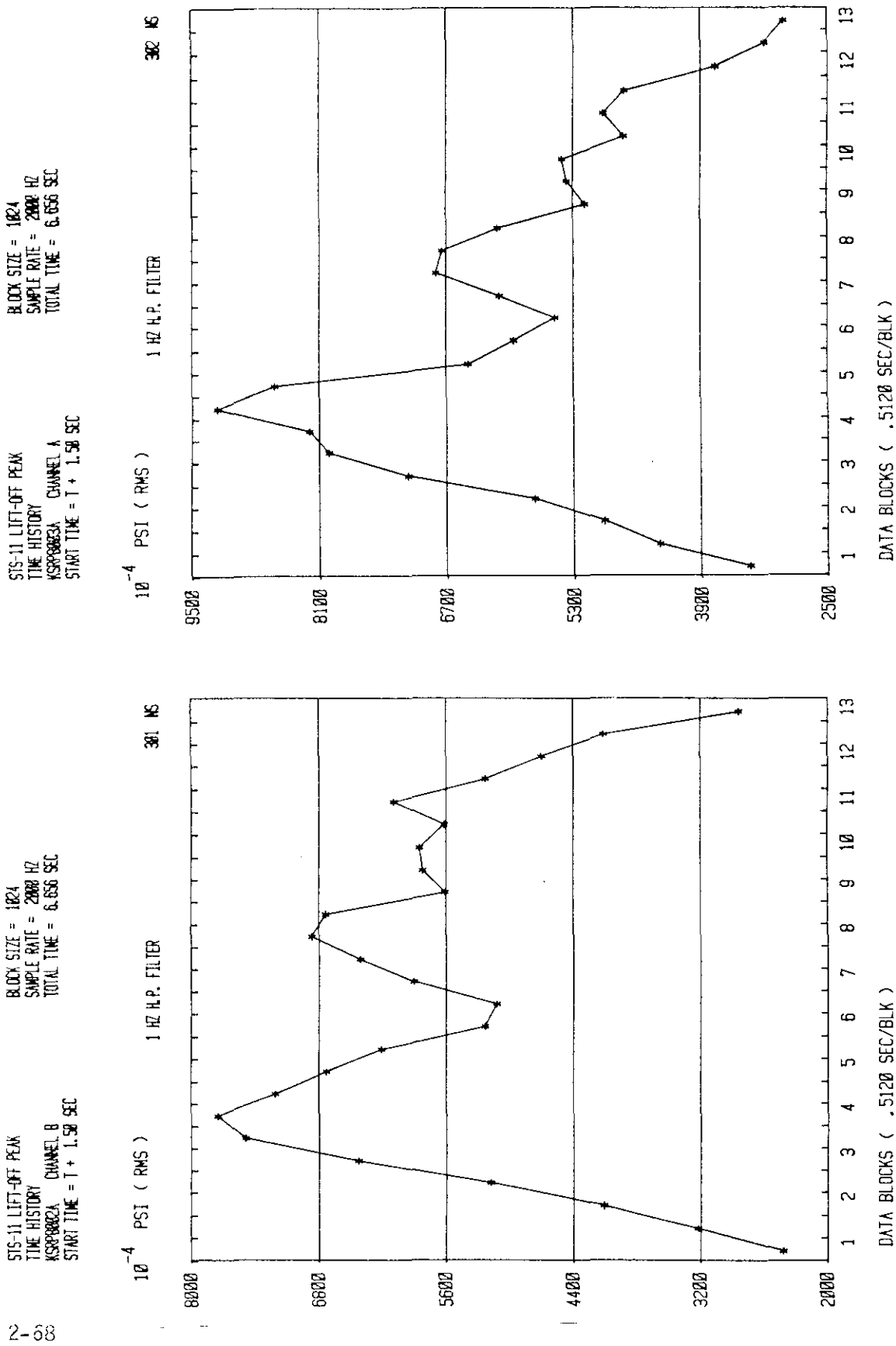
Figure 2-63. Typical RMS Plot of Centaur Porch Pressures Using a 1-Hz High-Pass Filter

2-68
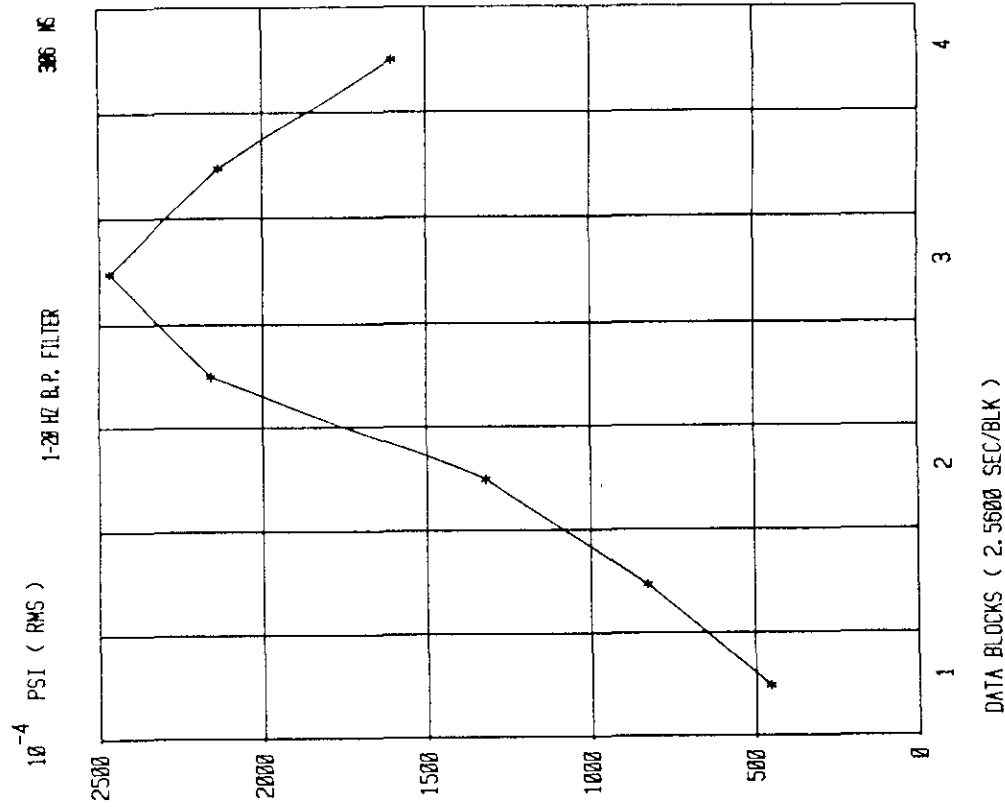
Figure 2-64. Typical RMS Plot of Centaur Porch Pressures Using a 1-Hz to 20-Hz Bandpass Filter
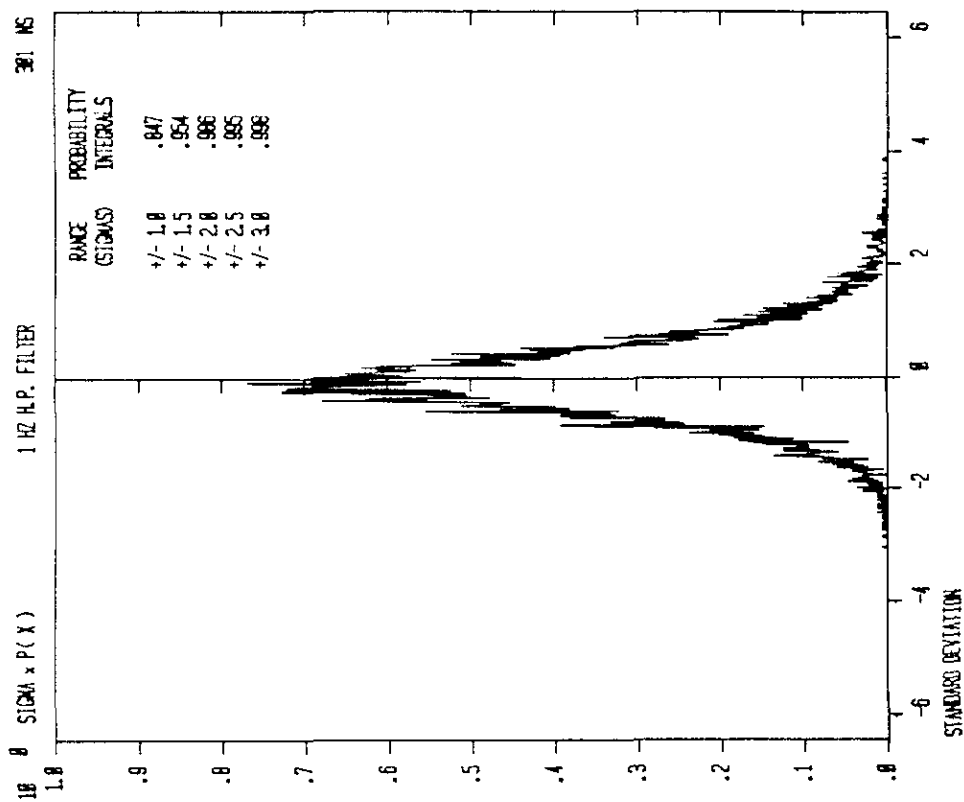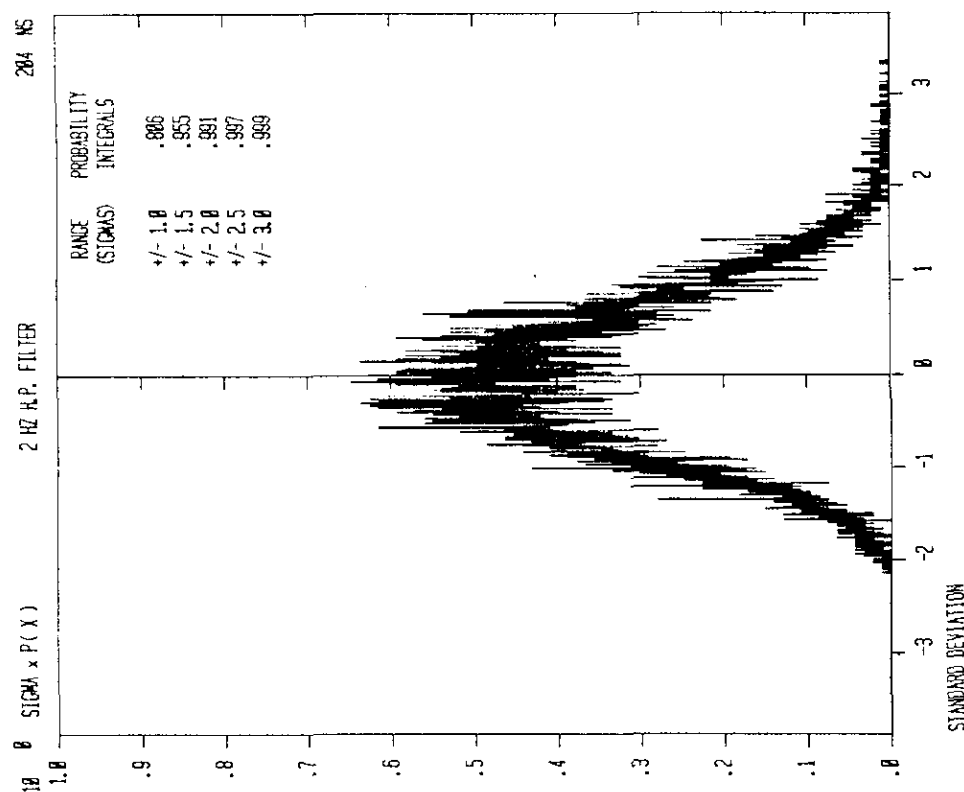
Figure 2-65. Typical Standard Deviation Plot of Centaur Porch Pressures Using 1- and 2-Hz High-Pass Filters

2.4 FAR FIELD ACOUSTICS

This section includes a summary of measured far field acoustic pressures at various distances and azimuths from the center of Pad A.

2.4.1 FAR FIELD ACOUSTIC PRESSURES, BEARING 322° TRUE. The following sensors recorded the acoustics along the line from Pad A to Pad B.

Measurement No.	Distance From Pad A Center (ft)
KAVYA001A	257
KAVYA003A	610
KAVYA004A, 13A, and 15A	1,200
KAVYA005A	2,754

During STS-1, -2, and -3 launches, KAVYA005A was reported to be 2,500 ft from Pad A center. Cross-correlation data obtained during STS-9 and STS-11 showed that the actual distance of this sensor from Pad A was 2,754 ft. A cross-country survey confirmed this distance.

Figures 2-66 through 2-73 show far field raw data and smoothed (Hanned) time histories for the STS-11 launch. Since all measurements contained baseline drift caused by radiating heat, data processing required the use of high-pass filter at 1 Hz in order to eliminate the drift.

Figures 2-74 and 2-75 present CCFC's obtained from STS-9 and STS-11 measurements for a time period involving transients generated at SRB ignition. Close examination of these data and enlarged summaries presented on figures 2-76 through 2-78 show the effect of atmospheric conditions on the trace velocity of sound propagation. Time delay (lag) of the CCFC's first peaks varies between launches. The average velocity of pressure wave propagation calculated from the peak lags for STS-9, -10, and -11 launches (figure 2-76) is 1,153 ft/s.

Figures 2-79 through 2-82 present coherences calculated between adjacent (about 4 in apart) sensors at 1,200 ft. Such high coherences exist only between closely spaced sensors. These coherences confirm validity of sensor outputs at 1,200 ft.

Figures 2-83 through 2-85 present STS-11 PSD's. Headings on each figure show selected processing time intervals and other pertinent processing parameters. Output of KAVYA003A (see figure 2-83) was processed using four different total analysis time intervals because of variations observed in its time history (see figures 2-66 and 2-67). This sensor appeared to have been hit by the reflected SRB plume splashing over the sloping pad apron at approximately T + 12.0 s. The output was lost at T + 13.8 s. Plume splash was observed during

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STS-11 only and did not occur during STS-8 or STS-9 launches. Outputs of all other sensors, figures 2-84 and 2-85, were processed twice, using intervals that included and excluded SRB ignition transient.

Figure 2-86 presents typical probability densities calculated from the outputs of KAVYA003A and KAVYA004A sensors. It should be noted that because of inadvertent reversal of sensor polarity and consequent use of negative values for calibration constants, signs of probability integrals are reversed. It should be noted also, that the values of probability integrals below the range ±2.5 sigma are substantially different from a normal (Gaussian) distribution as a consequence of nonstationary data. Presented probability densities in standardized form are referenced to maximum rms (maximum sigma) values. The 99% confidence limit, often used in design considerations, occurs within ±2.2-sigma range, while in a Gaussian distribution, the same confidence limit is within ±2.58-sigma range, about 17% higher.

Summaries of derived PSD's at each sensor location are presented on figures 2-87 through 2-90. In each case, a mean and limit (limit = mean + 2 sigma) curve are calculated. Because of the small number of collected measurements, the limit curve is essentially an envelope of all measurements. The use of limit curve is recommended for design applications.

Launch-to-launch dispersion is obtained from the difference between OASPL's, calculated by integrating limit and mean PSD curves within presented range 0 to 50 Hz, and converting these into dB. Calculated dispersions are 2 dB, 1.7 dB, and 1.3 dB at respective distances 610, 1,200, and 2,754 ft. It is of interest to note that within the same 0- to 50-Hz range, dispersion on the FSS calculated from 45 measurements (STS-1 through STS-9) is 3.3 dB.

2.4.2 NEAR FIELD ACOUSTIC PRESSURES ON THREE LIGHT POSTS. The following measurements recorded acoustic pressures on three existing light posts during the STS-6 launch at elevation 98 ft (3 ft above MLP deck 0) shown on figure 1-7:

Measurement No.	Distance from Pad A Center	Azimuth From Pad A Center
KFTPA001A	200	337° true
KFTPA002A	200	41° true
KFTPA003A	235	210° true

The purpose of these measurements was to establish pressure on structures surrounding the MLP when SRB plumes splash over the deck 0 and, after being deflected, impinge on surrounding structures that are elevated above the MLP.

Pressure time histories from all three measurements were affected by heat input and contain baseline drift corresponding to unreal negative pressures. This malfunction begins at T + 6.0 s in the output of KFTPA001A and KFTPA002A, and at T + 7.7 s in the output of KFTPA003, which is located on the south side

of Pad A and was least exposed to plume impingement. A high-pass filter (at 1 Hz, 18 dB/oct) was required to eliminate baseline drift in the output of all sensors. The remaining data above 1 Hz are considered to be valid.

Figure 2-91 shows overplots of data processed using two different sets of parameters. The left frame presents data essentially before the SRB plumes splash over the MLP. The splash begins at about T + 6.0 s.

The right frame is a relatively long-duration (up to T + 13.9 s) processing of a fairly narrow (0 to 50 Hz) band of data that include effects of the splash. Notice a substantial increase in all amplitudes (0 to 50 Hz) on the right frame compared to those on the left frame.

Figure 2-92 presents an enlarged zoom plot of the same data as the left frame on figure 2-91. Data on both figures were Hanned two times in order to reduce jogged appearance of PSD's resulting from a low number of DOF's available for these estimates.

Figure 2-93 presents an enlarged zoom plot of the same data as the right frame on figure 2-91, except that no Hanning was applied in order to obtain the highest value of PSD peak at 1.24 Hz, which indicates that sensor KFTPA002A was exposed to impingement by the east SRB plume deflected from the MLP deck. The peak at 1.24 Hz exceeds data obtained on the FSS by narrow band analysis. Examination of raw data time history confirms that this peak is real and not a consequence of the baseline drift. The peak amplitude of 1.24 Hz raw data component is about 0.25 psi and only about 5 cycles were recorded. Thus, presented PSD on figure 2-93 below approximately 5 Hz, should not be considered as a steady-state input.

2.4.3 FAR FIELD ACOUSTIC PRESSURES ON THE ECS COOLING TOWER. Measurements KECYA001 and KECYA002 were installed on the ECS cooling tower located approximately 450 ft and 270° true from Pad A center during STS-7 and -8 launches. Damage to the tower walls was occurring. Hardening of the structure solved the problem. PSD plots are presented for both launches, including the mean and limit (mean plus 2-sigma) curves in figures 2-94 and 2-95.

2.4.4 COMPARISON OF ACTUAL FAR FIELD ACOUSTIC DATA TO PREDICTIONS. Figure 2-96 shows a comparison between predicted far field acoustic levels at various distances from Pad A center to the average of actual data recorded at the distances shown.

Figure 2-66. STS-11 Lift-Off - Sensor KAVYA003A at 610 ft From the Pad, Raw Data Time History

Figure 2-67. STS-11 Lift-Off – Sensor KAVYA003A at 610 ft From the Pad, Hanned Time History

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Figure 2-68. STS-11 Lift-Off – Sensor KAVYA004A at 1,200 ft From the Pad, Raw Data Time History

2-76

Figure 2-69. STS-11 Lift-Off - Sensor KAVYA004A at 1,200 ft From the Pad, Hanned Time History

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Figure 2-70. STS-11 Lift-Off – Sensor KAVYA015A at 1,200 ft From the Pad, Raw Data Time History

2-78

FILE: YAR15B YAR15C

SAMPLING RATE 200 Hz. HIGH-PASS FILTER @ 1 Hz. ANTI-ALIASING FILTER @ 50 Hz.
RAW DATA WERE HANNED 50x IN ORDER TO EMPHASIZE LOW FREQUENCY COMPONENTS.
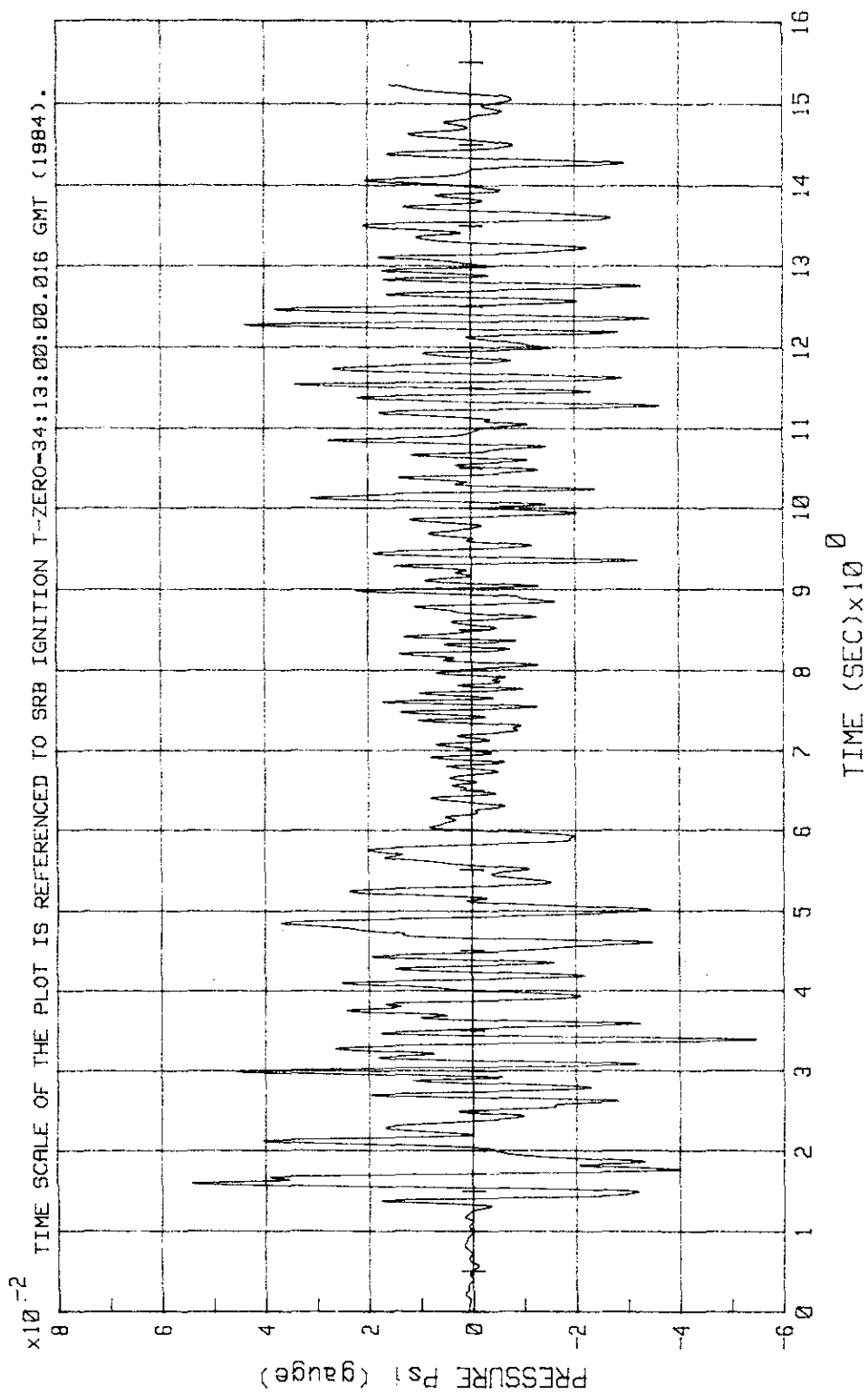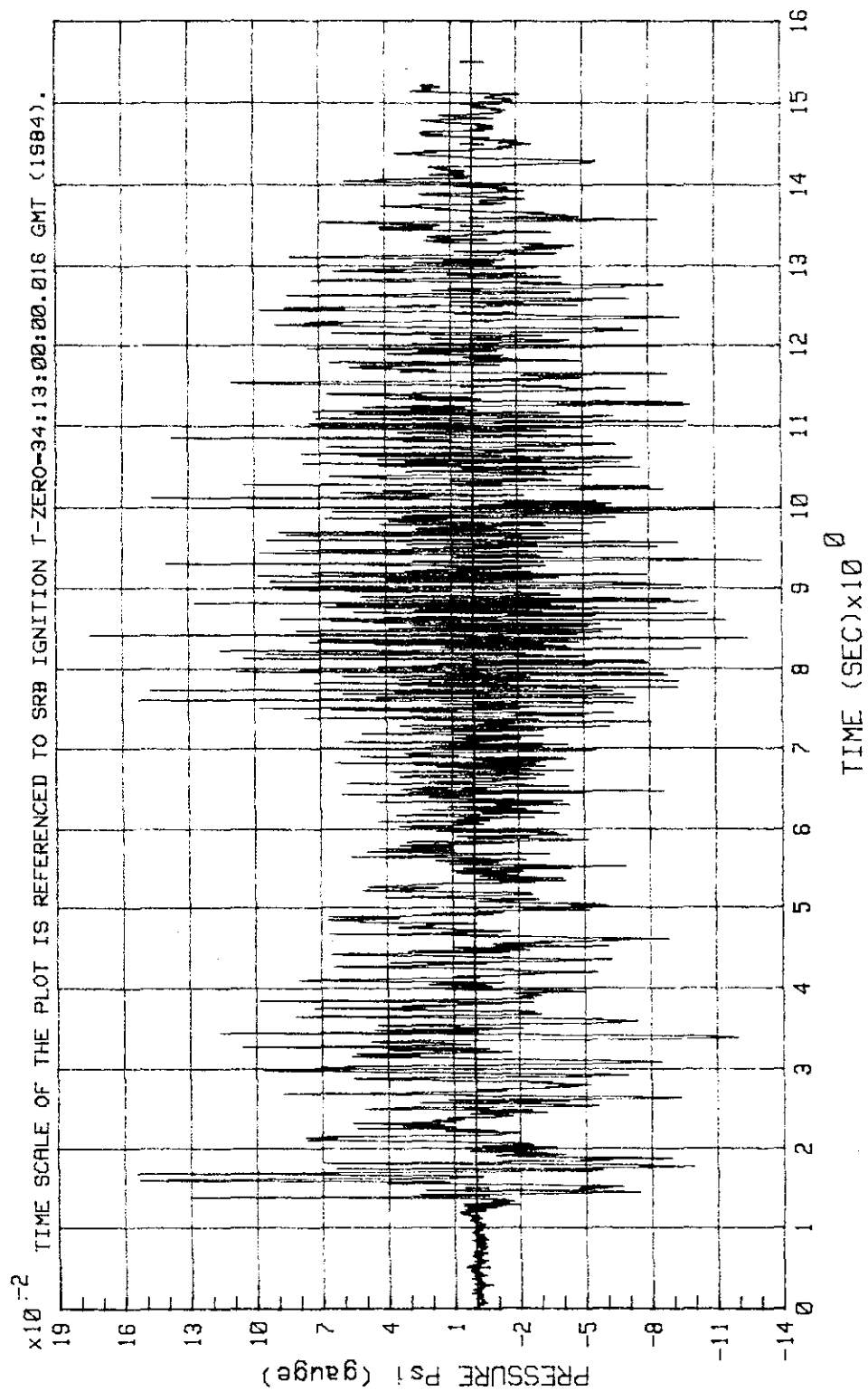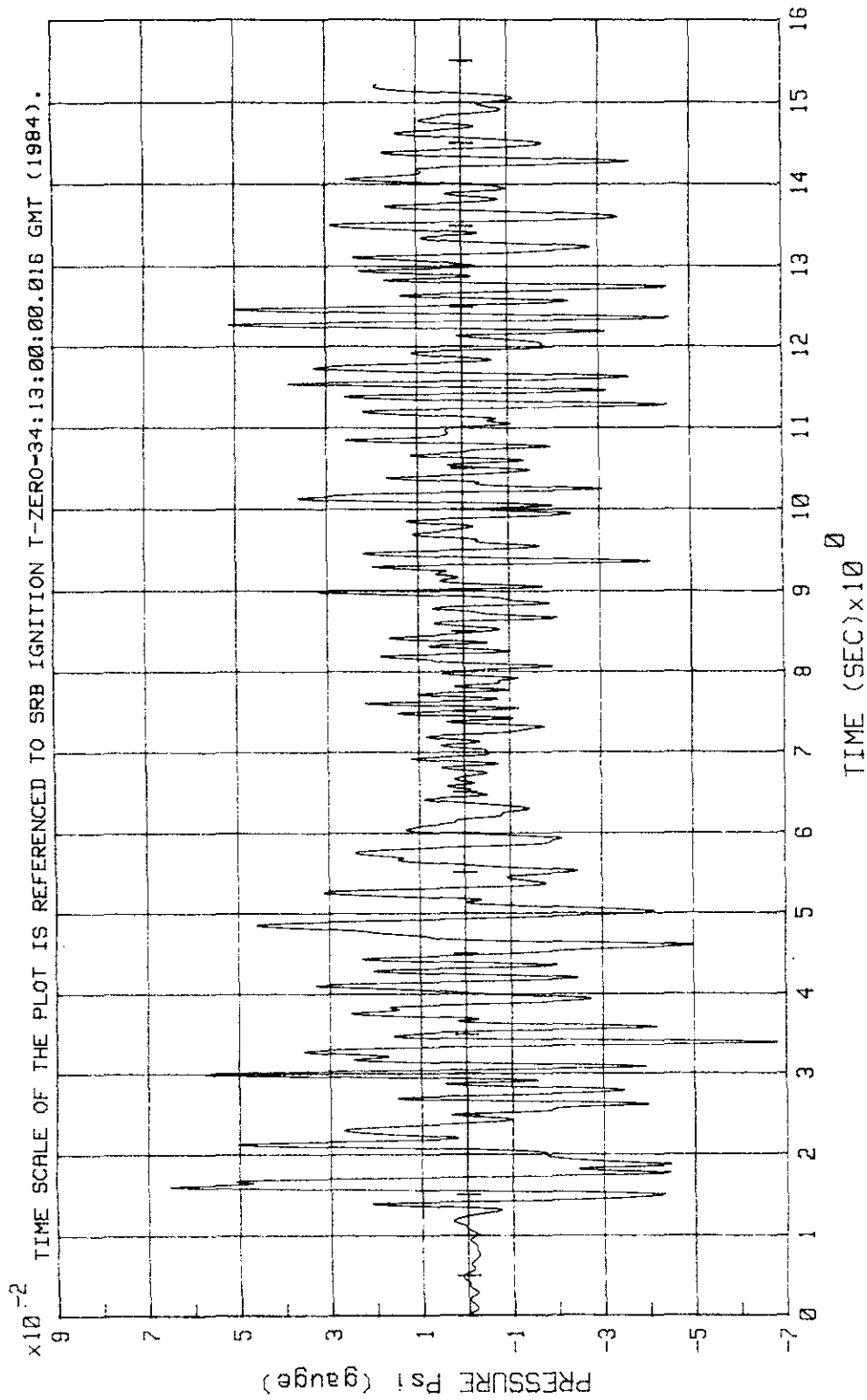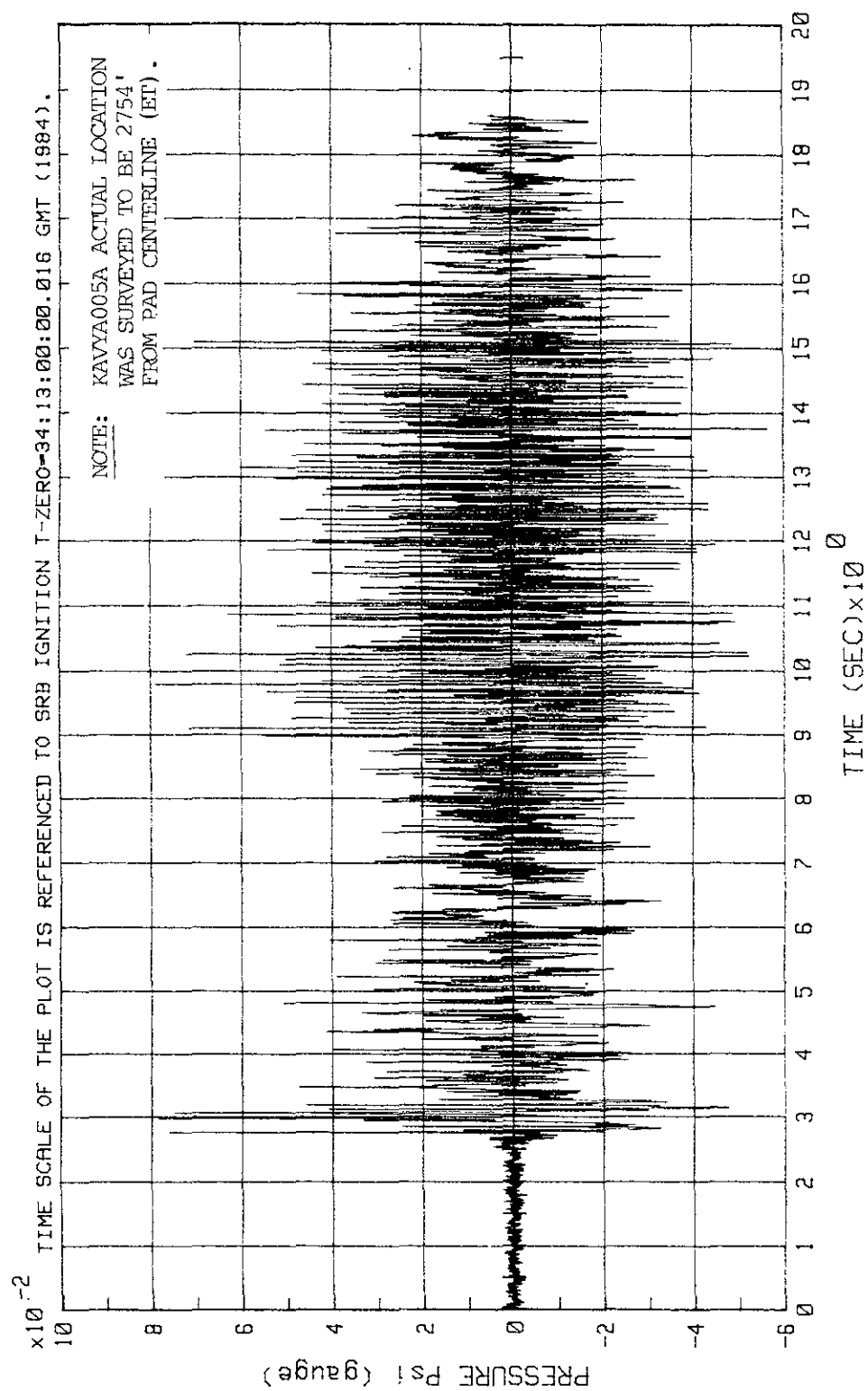
TIME SCALE OF THE PLOT IS REFERENCED TO SRB IGNITION T-ZERO-34:13:00:00.016 GMT (1984).

PRESSURE Psi (gauge)

TIME (SEC)×10

Figure 2-71. STS-11 Lift-Off - Sensor KAVYA015A at 1,200 ft From the Pad, Hanned Time History

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Figure 2-72. STS-11 Lift-Off - Sensor KAVYA005A at 2,500 ft From the Pad, Raw Data Time History
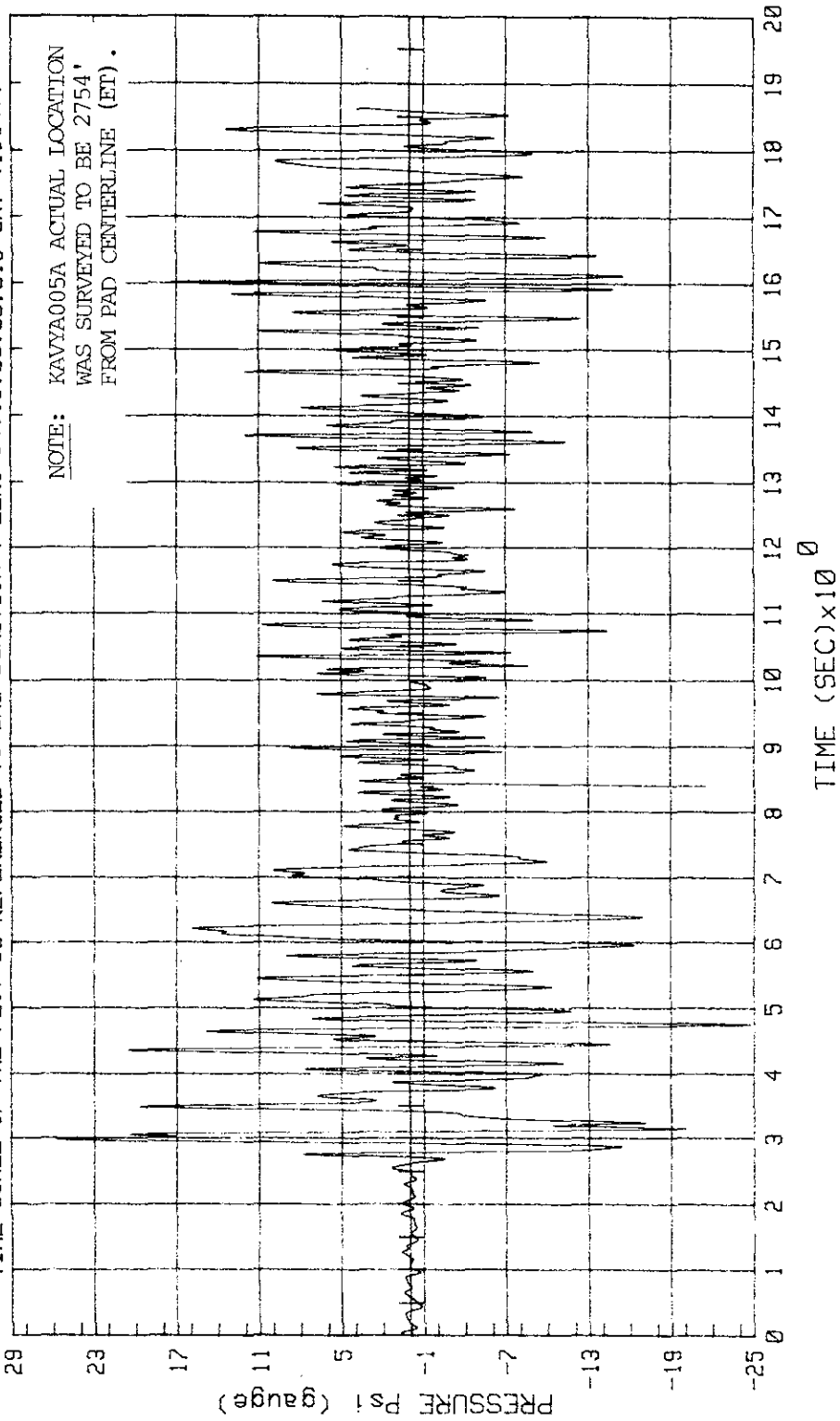
Figure 2-73. STS-11 Lift-Off – Sensor KAVYA005A at 2,500 ft From the Pad, Hanned Time History
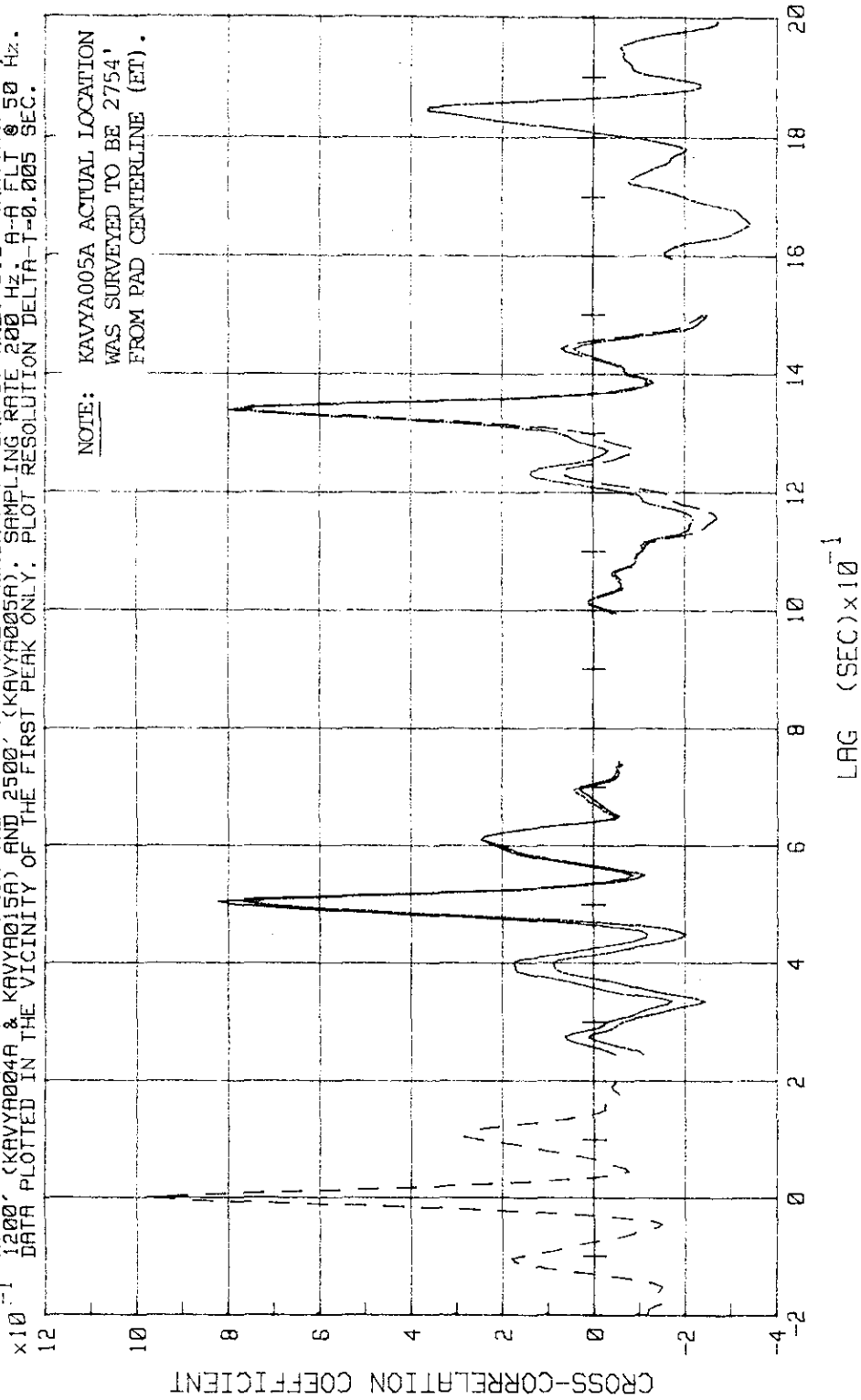
Figure 2-74. STS-9 SRB Ignition - Cross-Correlation Between KAVYA003A, -004A, -015A, and -005A
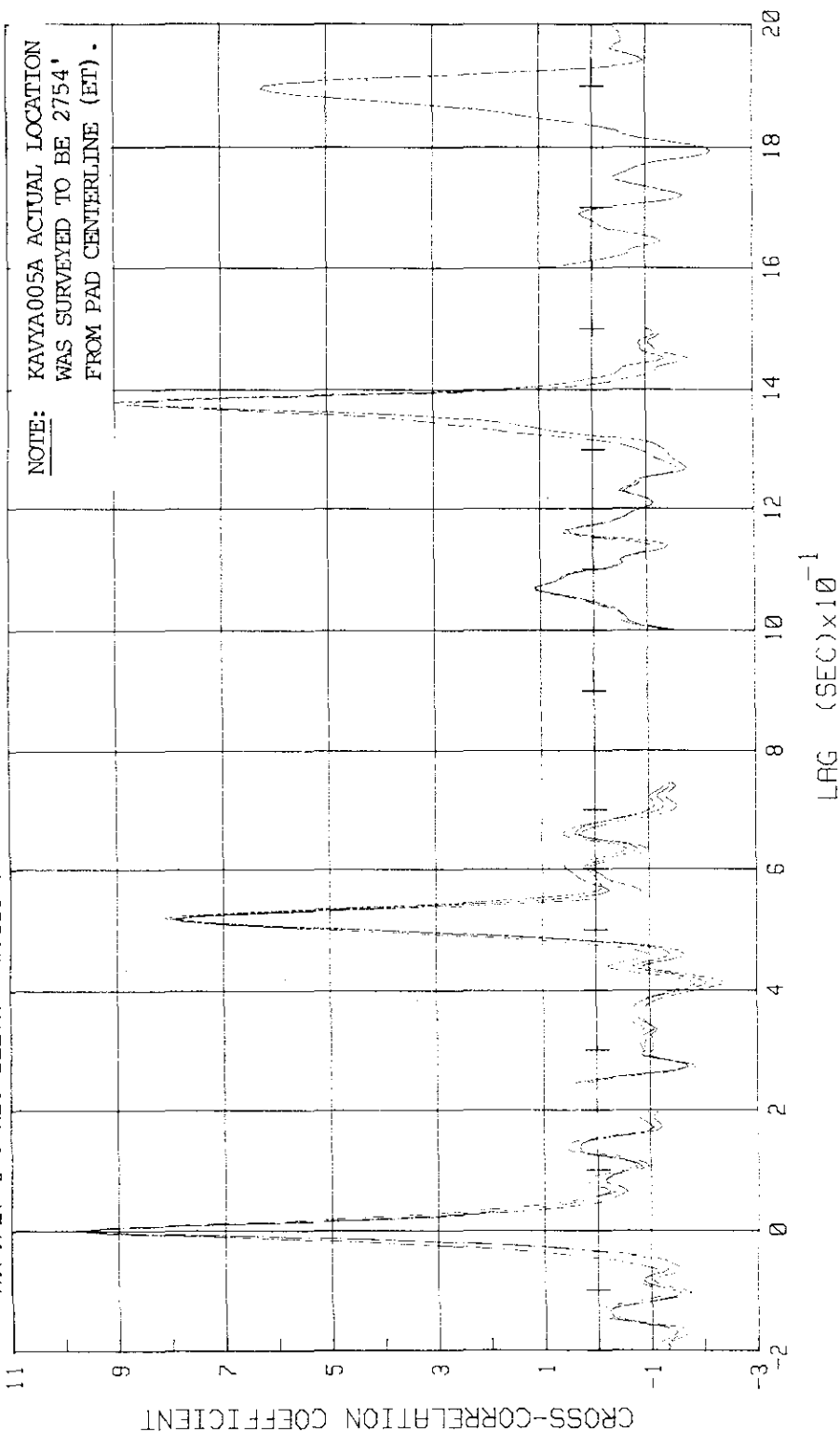
Figure 2-75. STS-11 SRB Ignition -- Cross-Correlation Between KAVYA003A, -004A, -012A, and -015A, and -005A
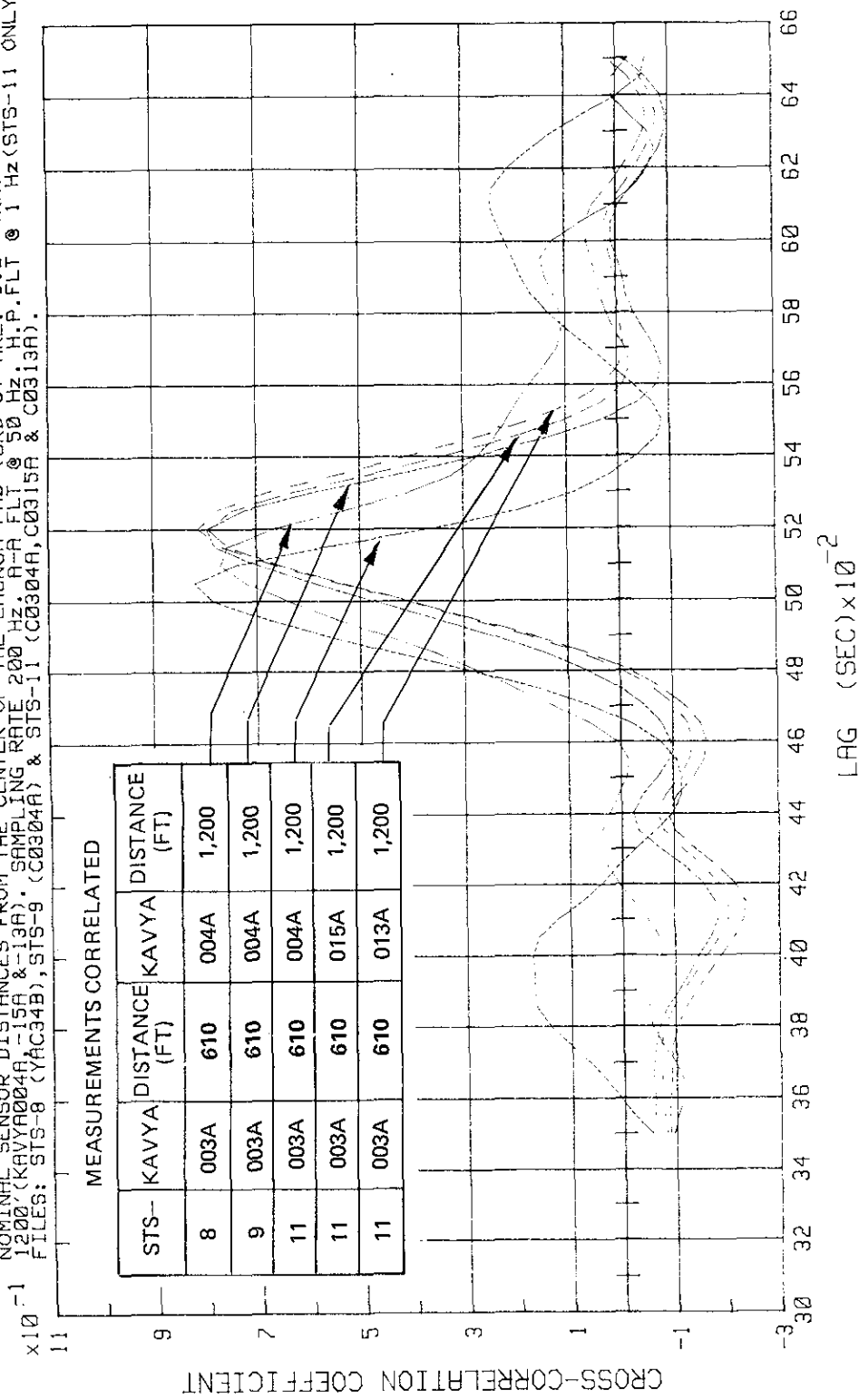
Figure 2-76. STS-8, -9, and -11 SRB Ignition - Cross-Correlation Between KAVYA003A, -004A, -015A, and -005A
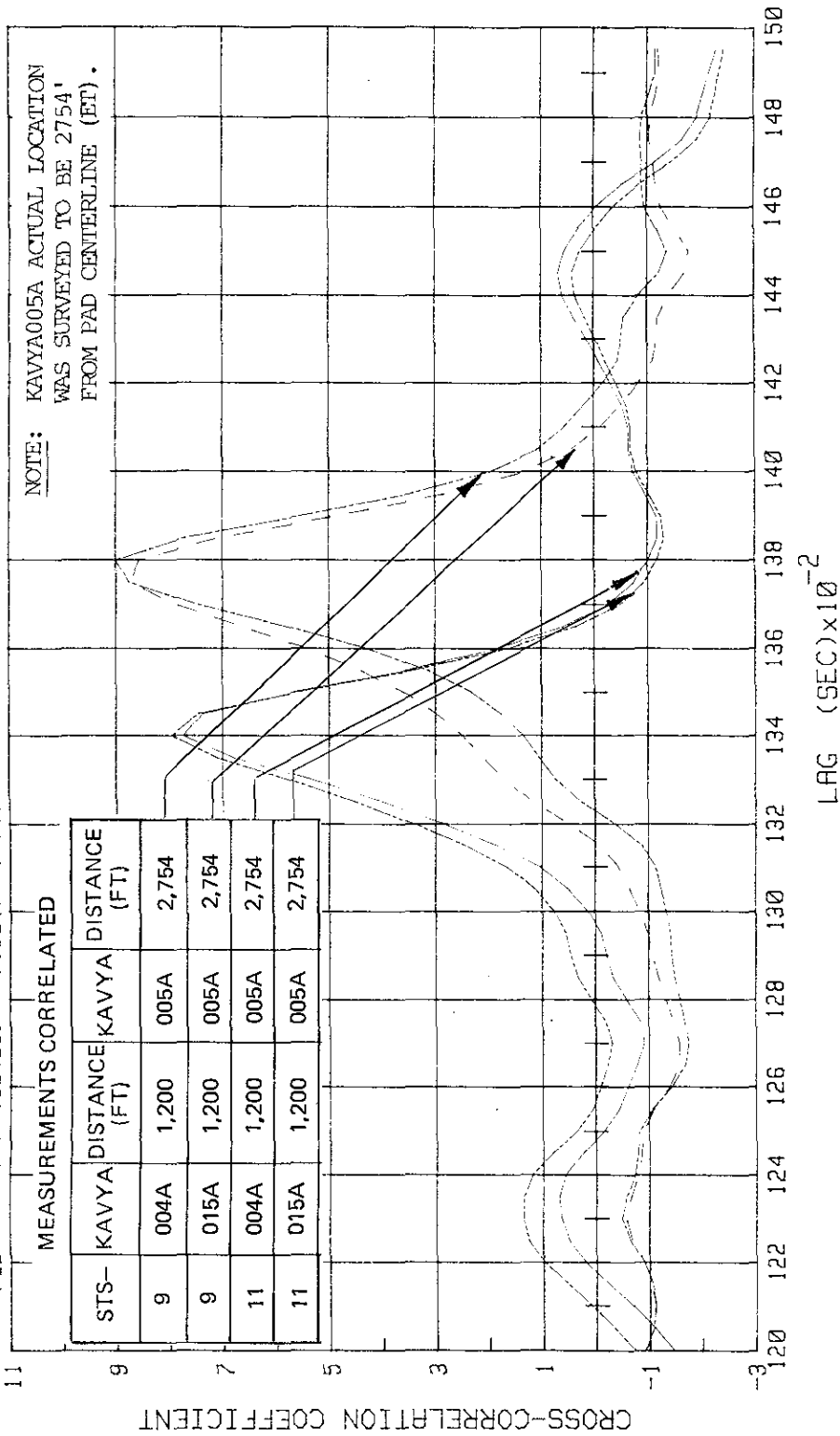
Figure 2-77. STS-9 and -11 SRB Ignition - Cross-Correlation Between KAVYA004A, -015A, and -005A
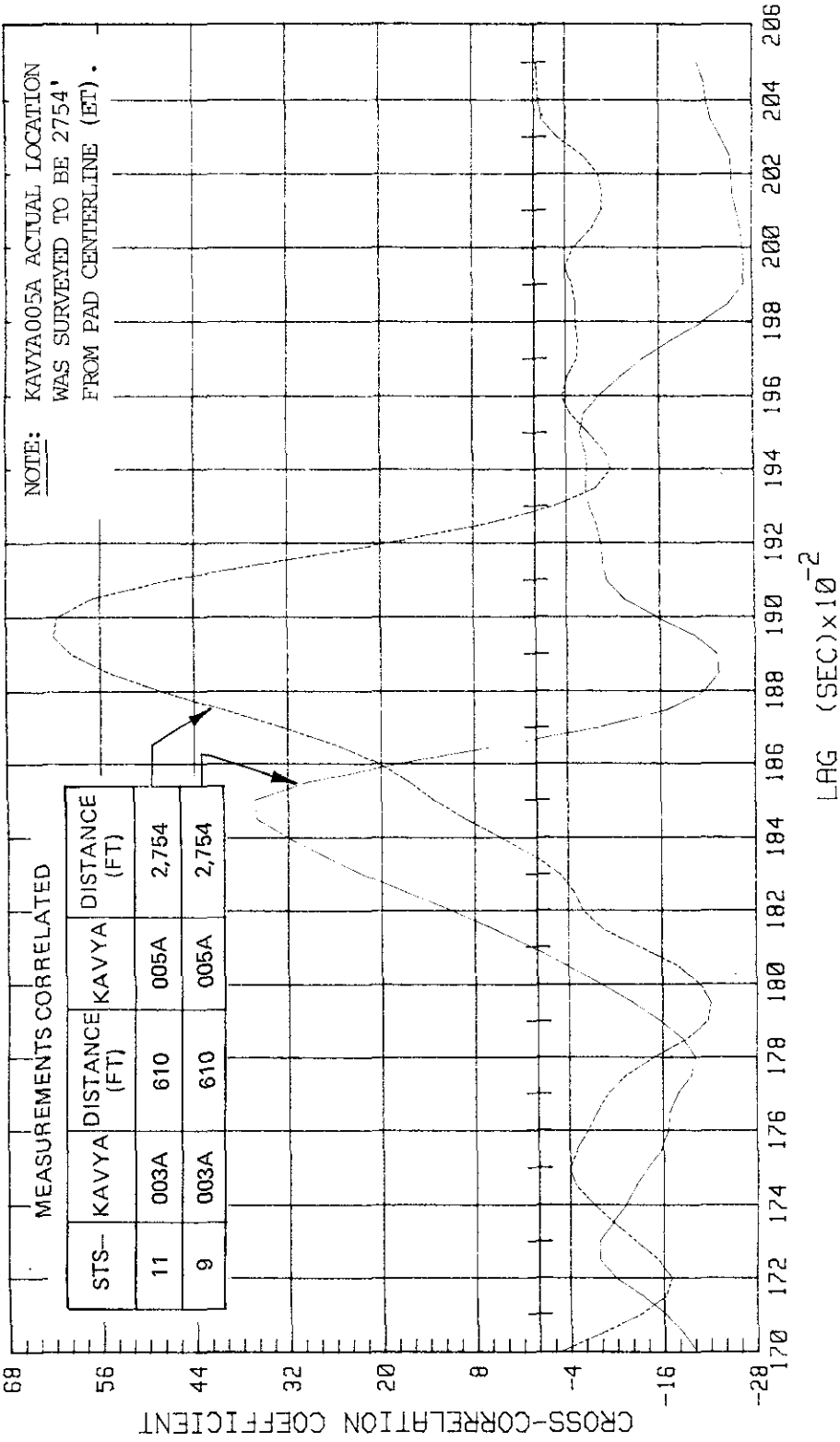
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Figure 2-78. STS-9 and -11 SRB Ignition - Cross-Correlation Between KAVYA003A, and -005A.
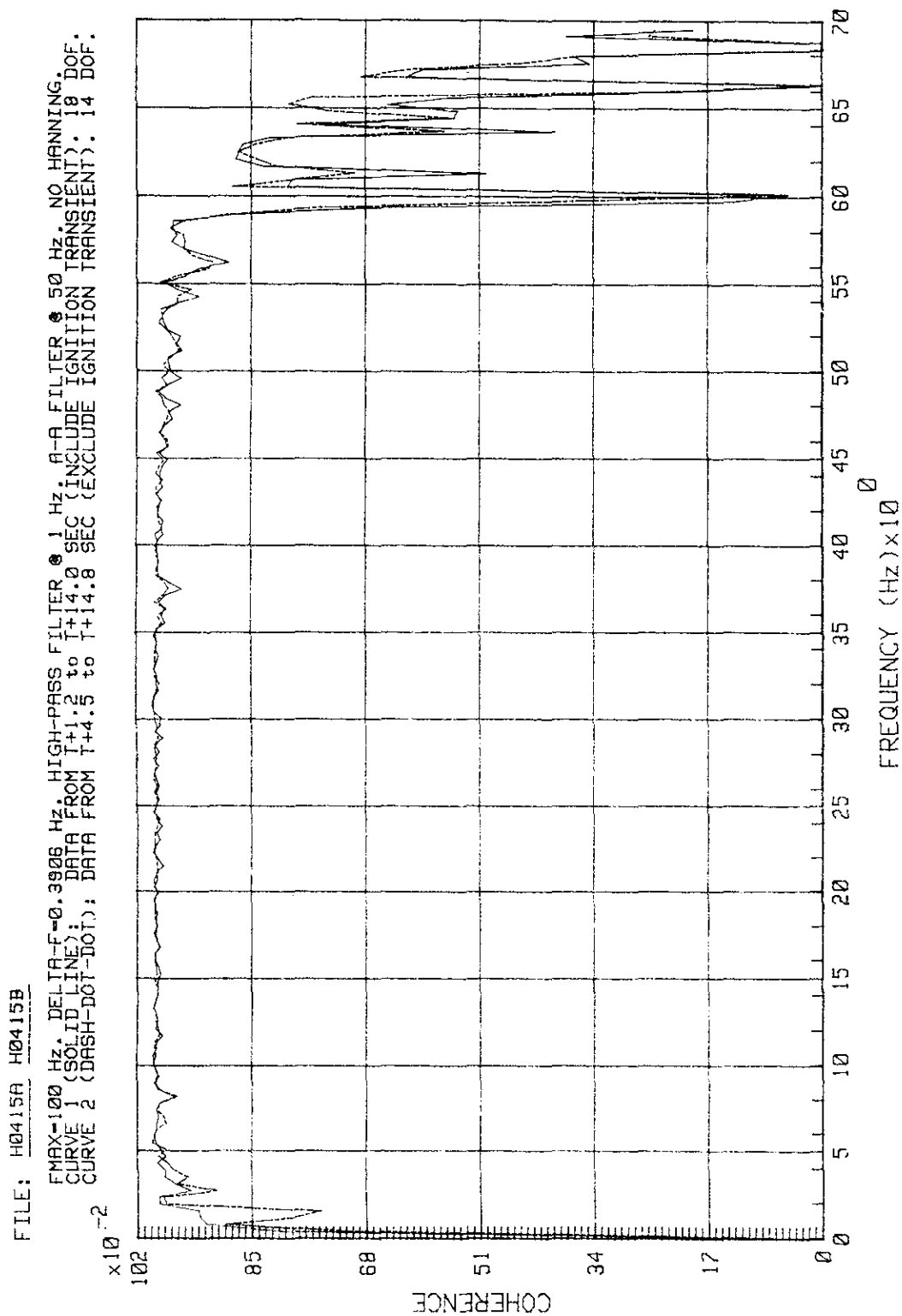
Figure 2-79. STS-11 Lift-Off Peak - Coherence Between Adjacent KAVYA004A and -015A Sensor Data

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Figure 2-80. STS-11 Lift-Off Peak –
Coherence Between Adjacent KAVYA004A and -015A Sensor Data (Mean)

2-88

FILE: H0413A H0413B

FMAX=100 Hz. DELTA-F=0.3906 Hz. HIGH-PASS FILTER @ 1 Hz. A-A FILTER @ 50 Hz. NO HANNING.
CURVE 1 (SOLID LINE): DATA FROM T+1.2 to T+14.0 SEC (INCLUDE IGNITION TRANSIENT). 18 DOF.
CURVE 2 (DASH-DOT-DOT): DATA FROM T+4.5 to T+14.8 SEC (EXCLUDE IGNITION TRANSIENT). 14 DOF.
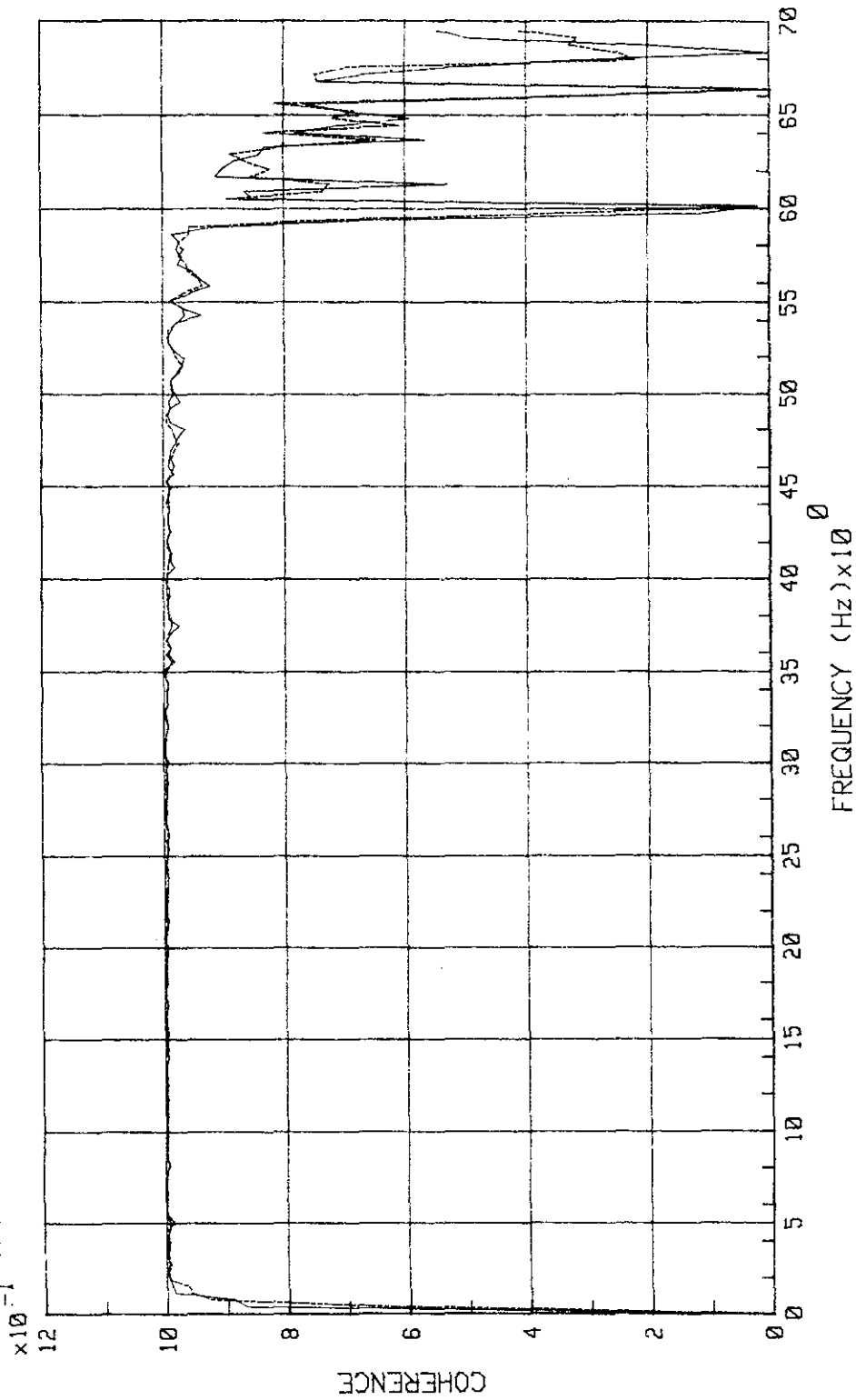
Figure 2-81. STS-11 Lift-Off Peak - Coherence Between Adjacent KAVYA004A and -013A Sensor Data
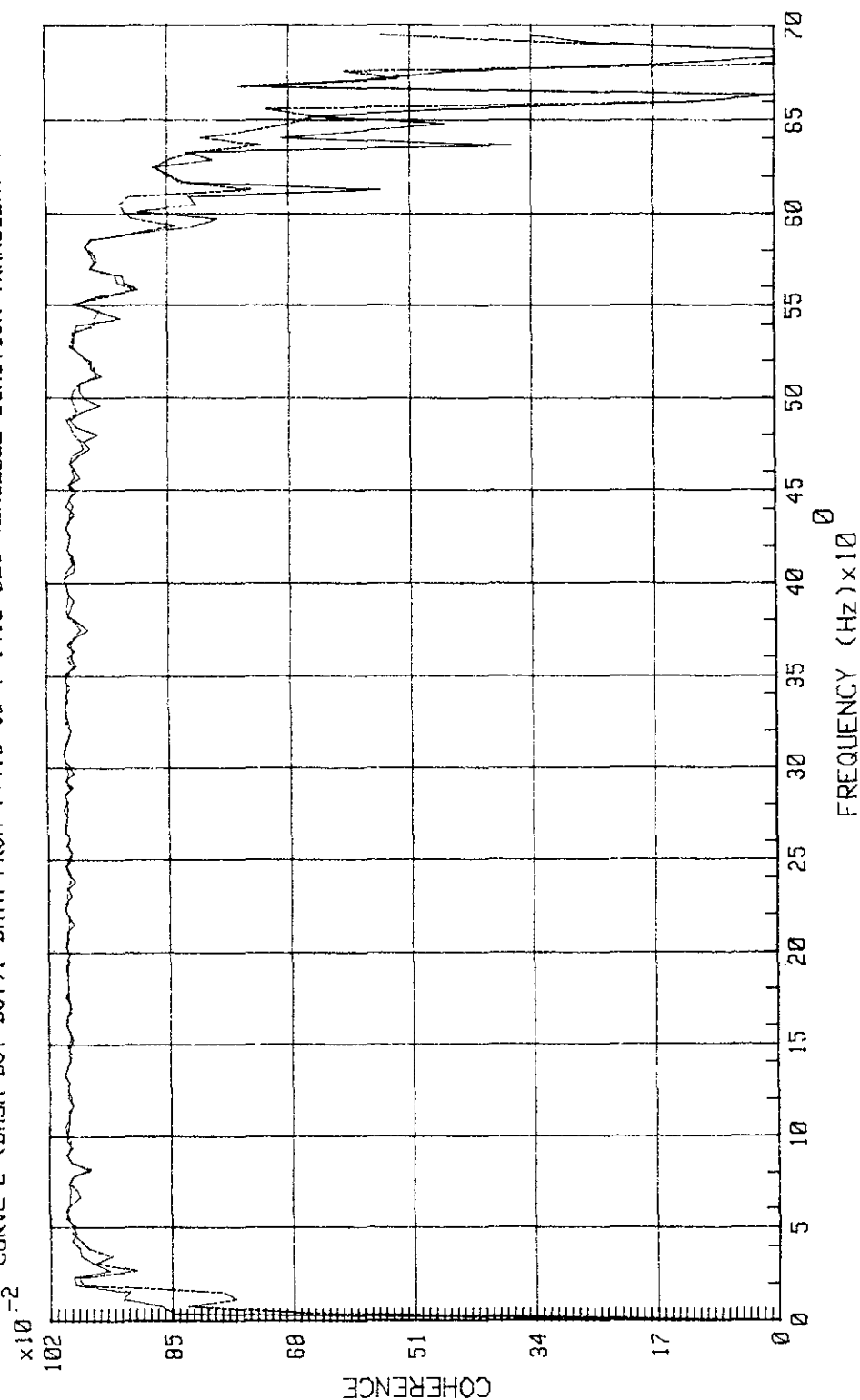
Figure 2-82. STS-11 Lift-Off Peak - Coherence Between Adjacent KAVYA015A and -013A Sensor Data
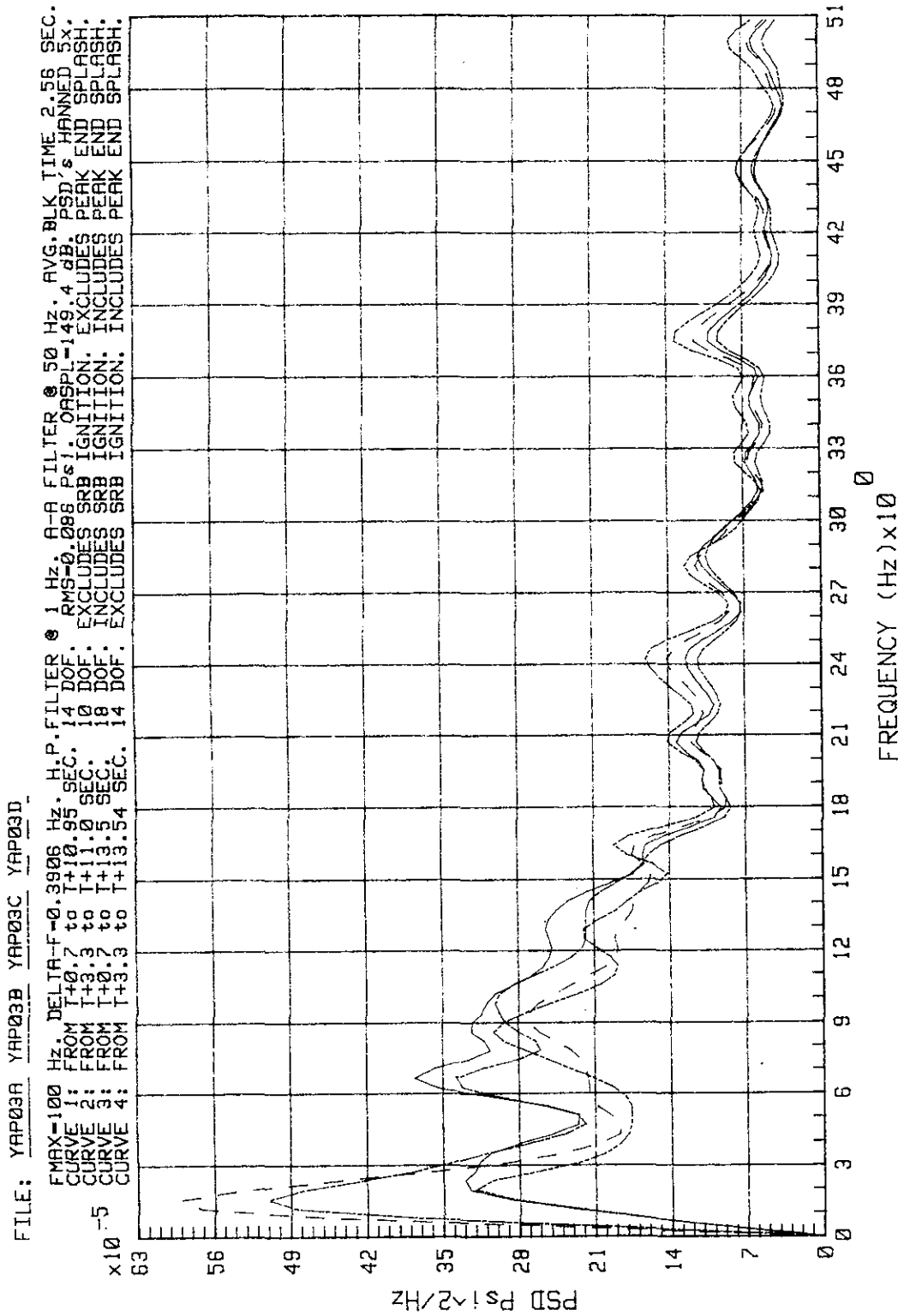
Figure 2-83.   STS-11 Lift-Off Peak and Peak End - PSD, Sensor KAVYA003A at 610 ft From the Pad
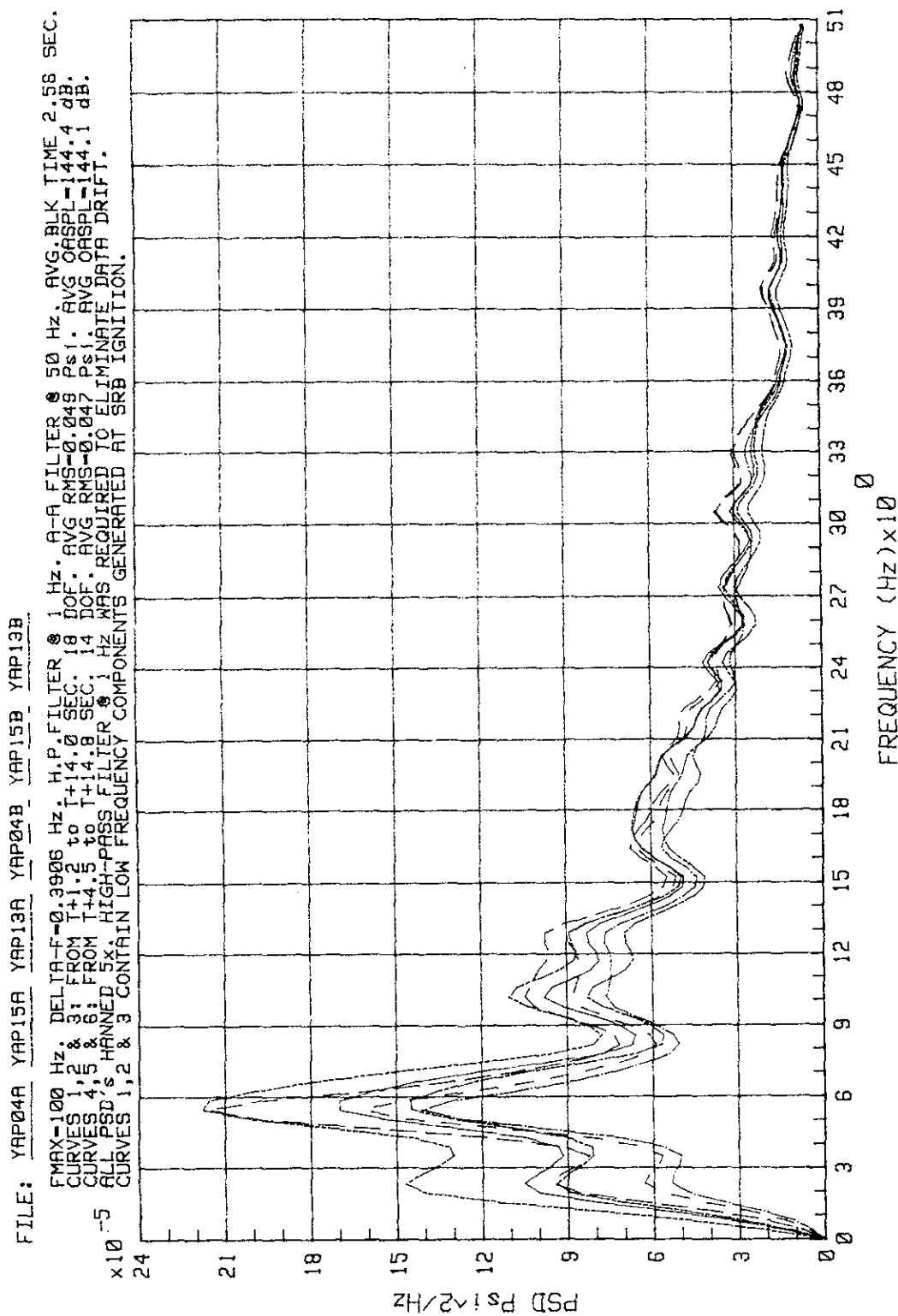
Figure 2-84. STS-11 Lift-Off Peak - PSD, Adjacent Sensors
KAVYA004A, -015A, and -013A at 1,200 ft From the Pad
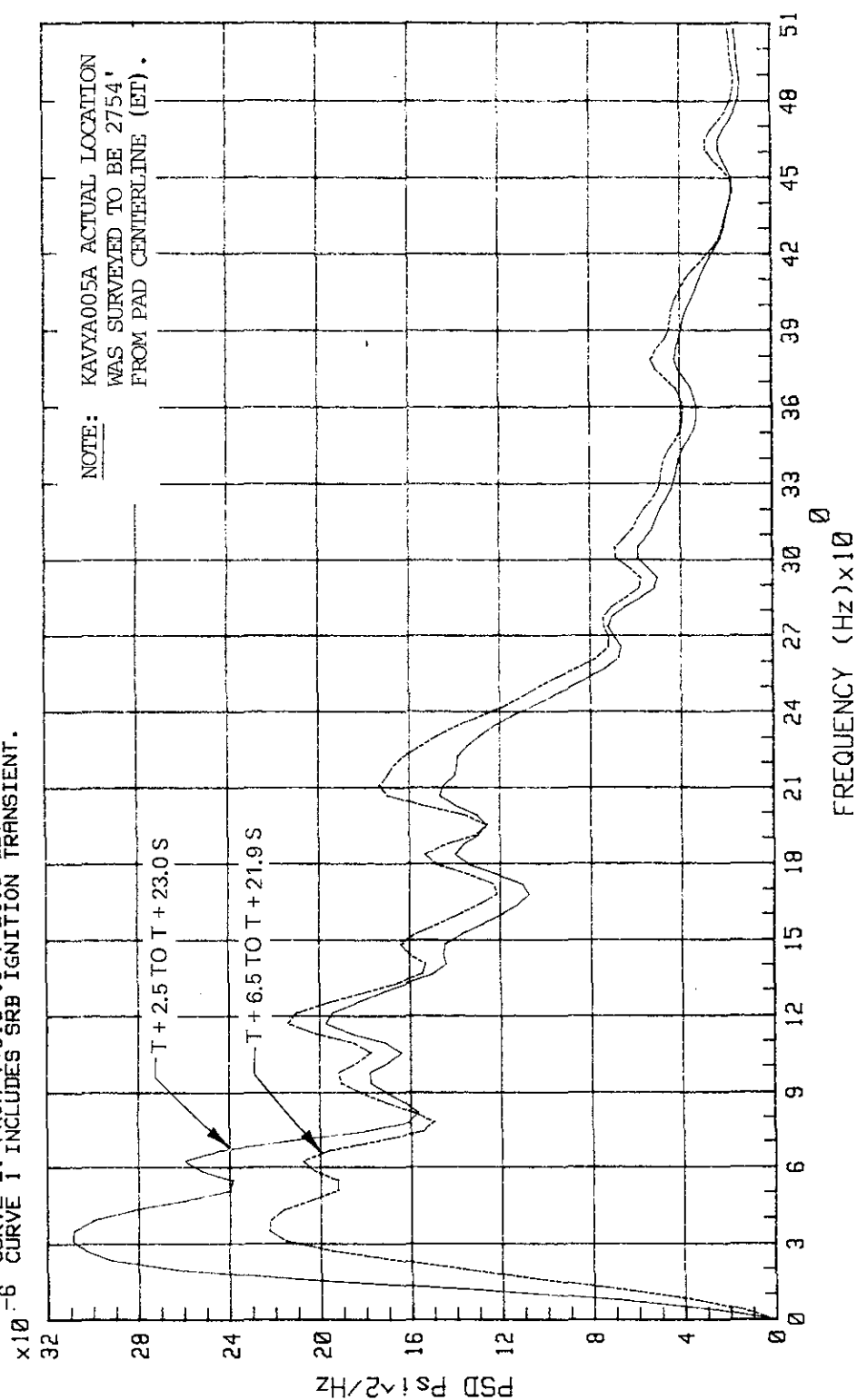
Figure 2-85. STS-11 Lift-Off Peak - PSD, Sensor KAVYA005A at 2,500 ft From the Pad

Figure 2-86.   STS-11 SRB Ignition/Lift-Off — Probability Density, Sensors KAVYA003A and -CC4A.
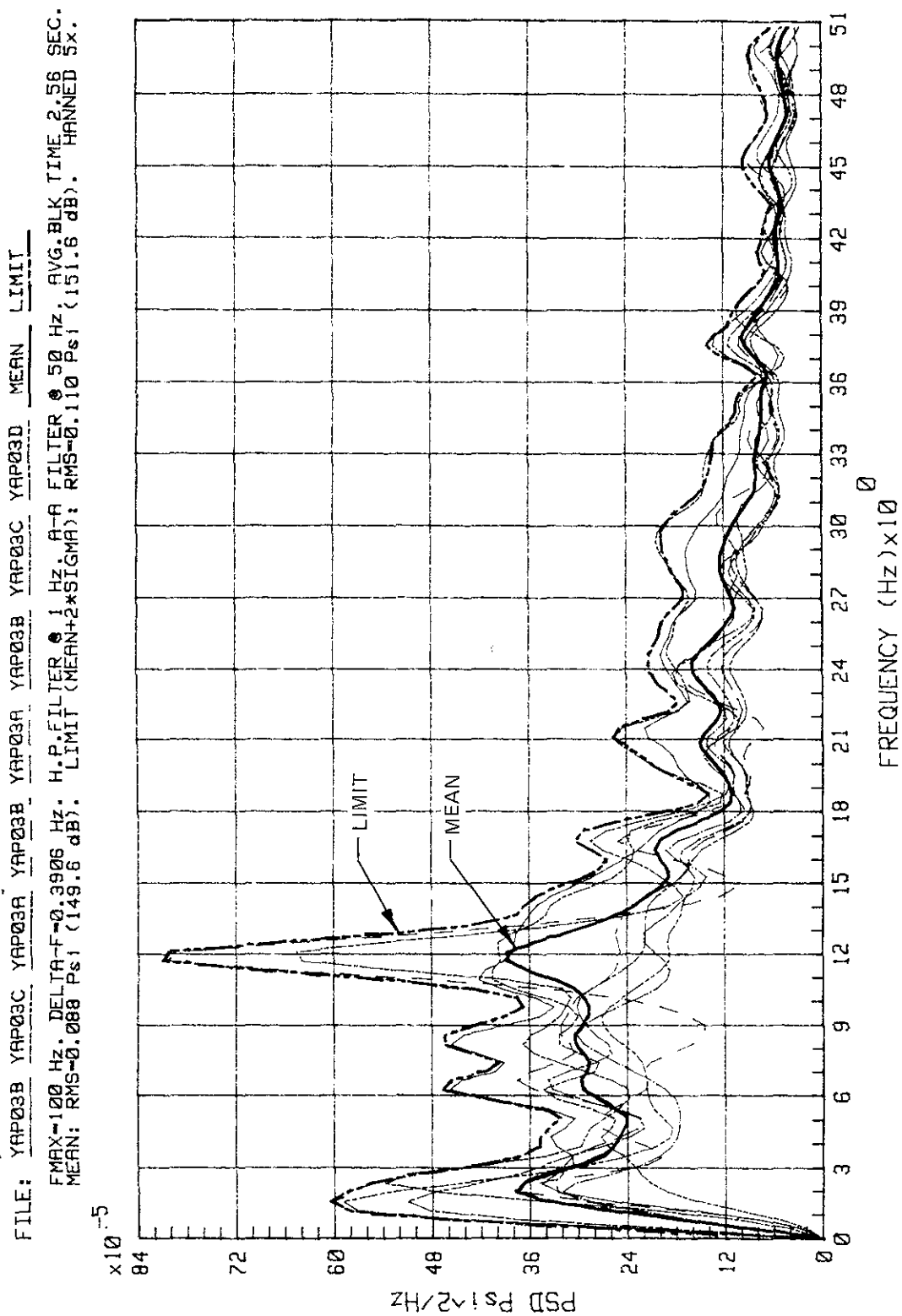
Figure 2-87. STS-8, -9, and -11 Summary at Lift-Off - PSD, Sensor KAVYA003A at 610 ft From the Pad
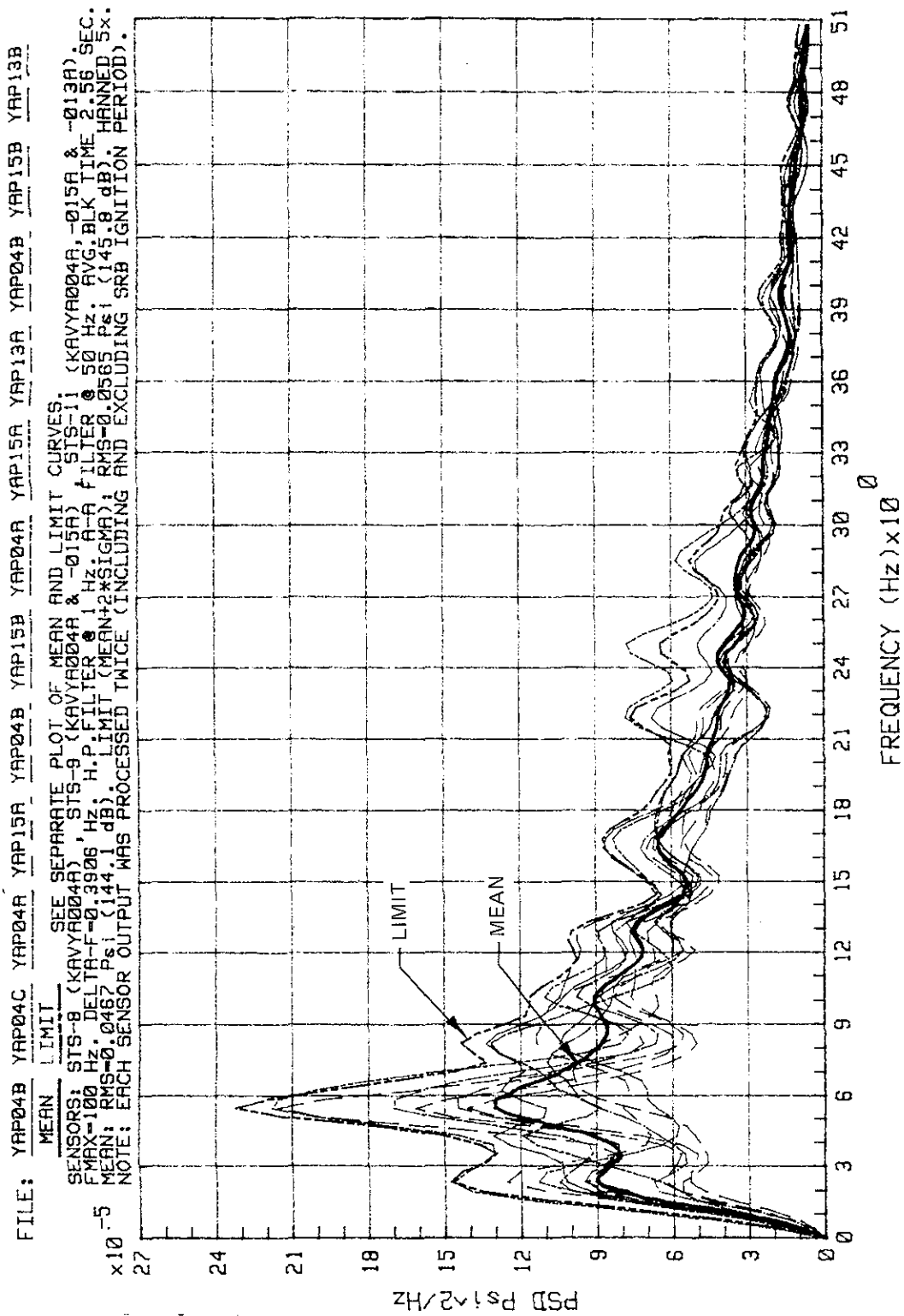
Figure 2-88. STS-8, -9, and -11 Summary at Lift-Off - PSD, Sensors at 1,200 ft From the Pad

Figure 2-89. STS-8, -9, and -11 Summary at Lift-Off - PSD, Sensors at 1,200 ft From the Pad
(Mean and Limit Only)
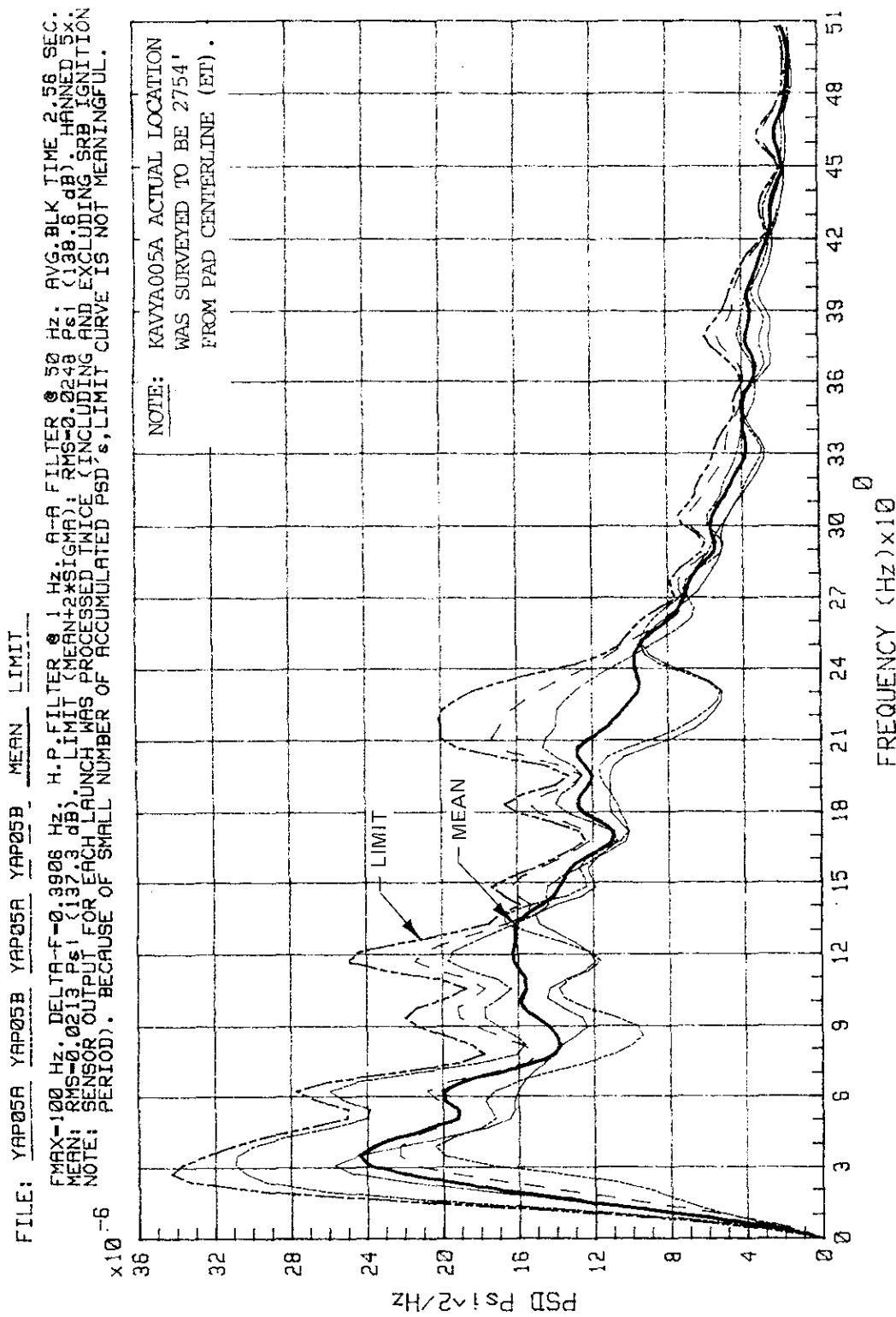
Figure 2-90. STS-9 and -11 Summary at Lift-Off - PSD, Sensor KAVYA005A at 2,500 ft From the Pad
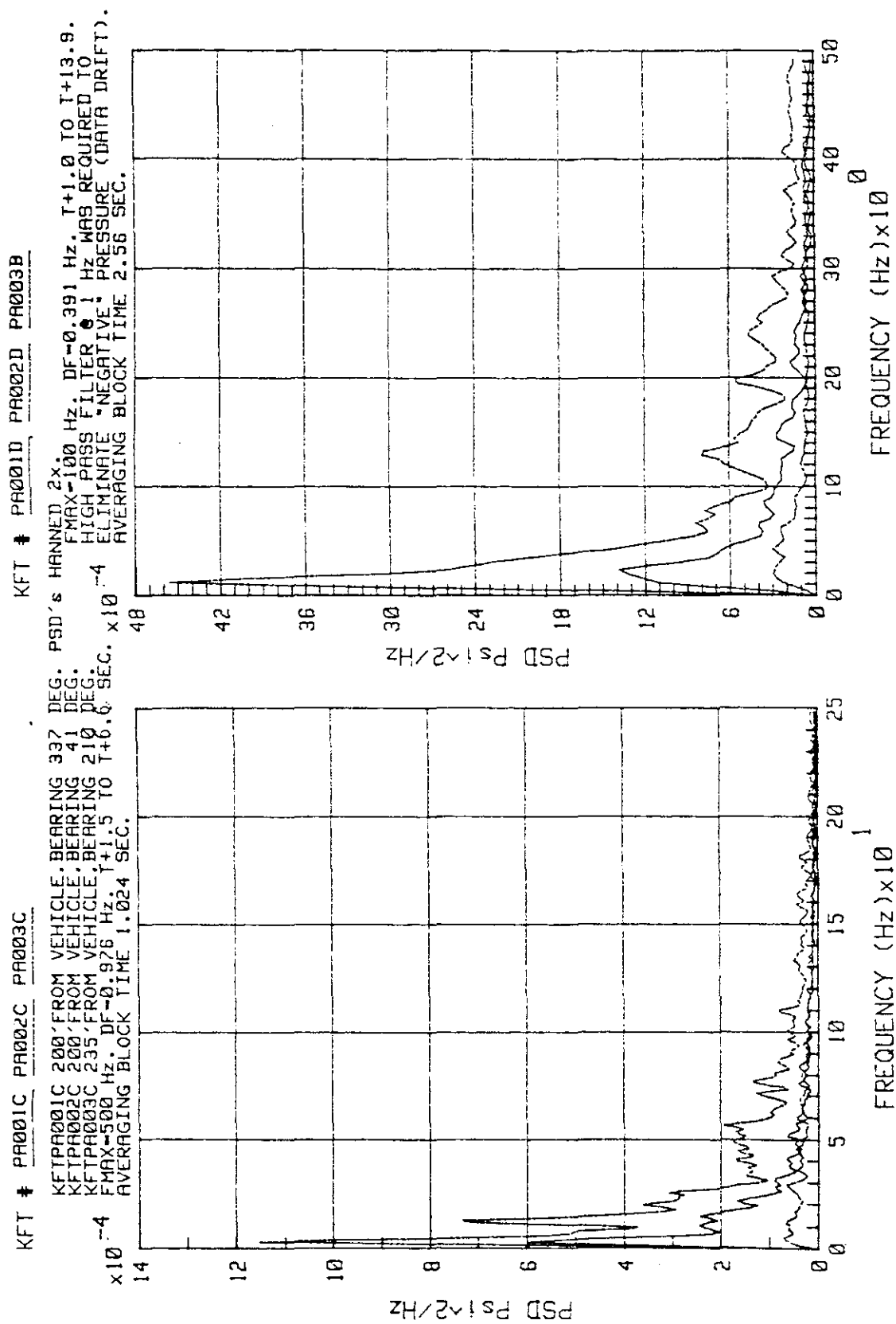
Figure 2-91. STS-6 Acoustic Pressure on Light Posts at the 98-ft Elevation With Sensors Facing the Vehicle (Averaging Block Time 1.024 s and 2.56 s)
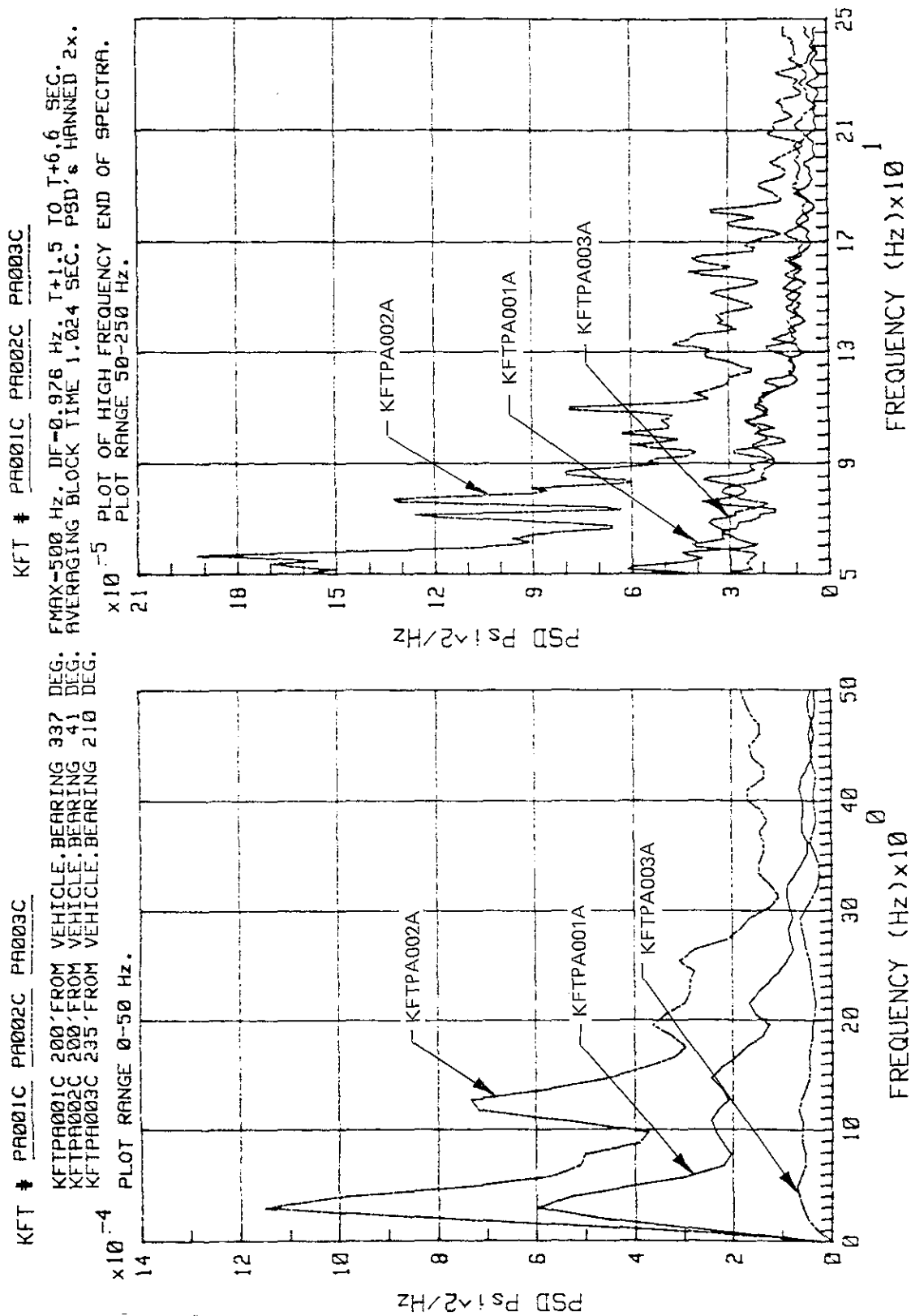
Figure 2-92. STS-6 Acoustic Pressure on Light Posts at the 98-ft Elevation With Sensors Facing the Vehicle (0- to 50-Hz and 50- to 250-Hz Plot Range)
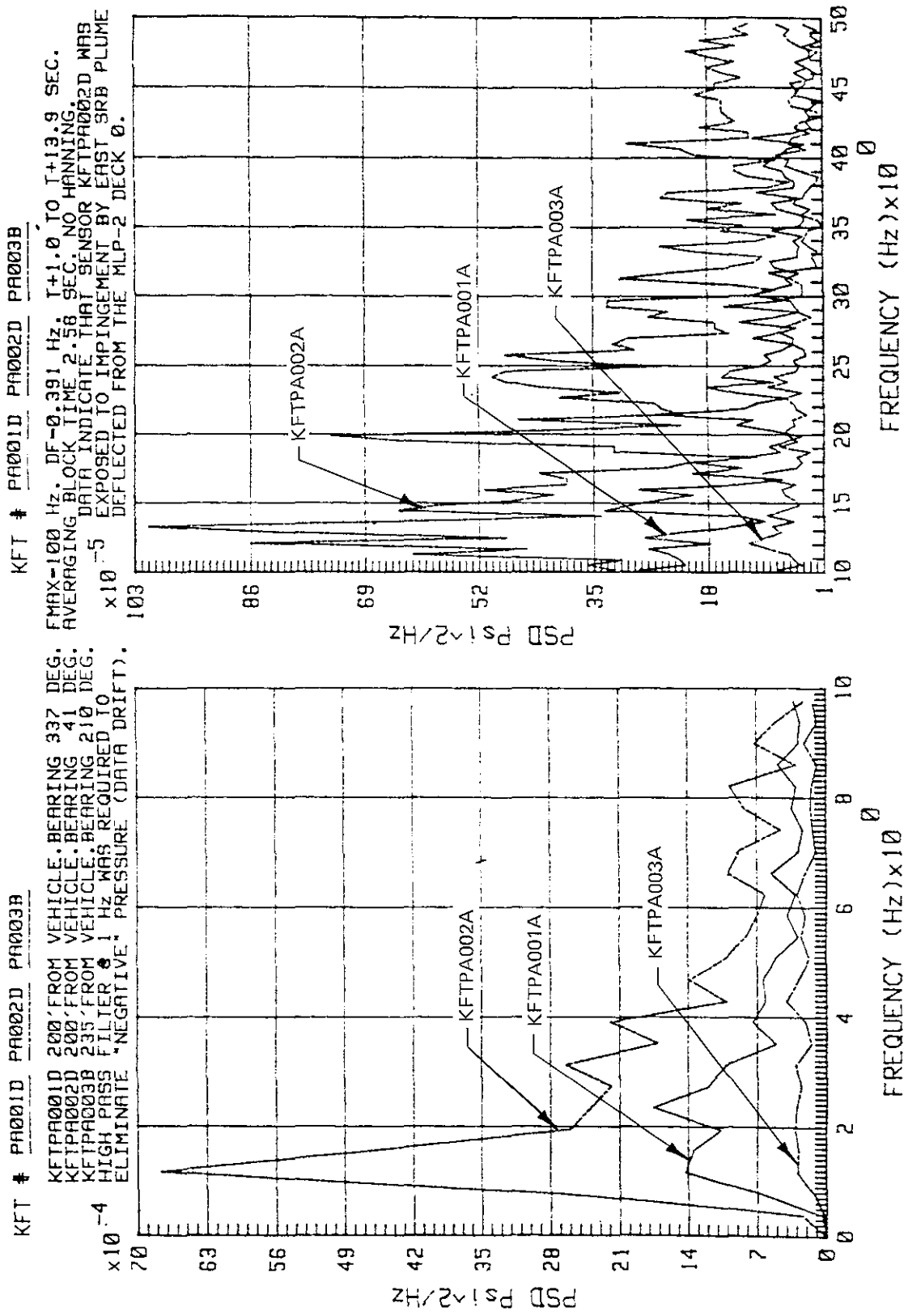
Figure 2-93. STS-6 Acoustic Pressure on Light Posts at the 98-ft Elevation With Sensors Facing the Vehicle (0- to 10-Hz and 10- to 50-Hz Plot Range)
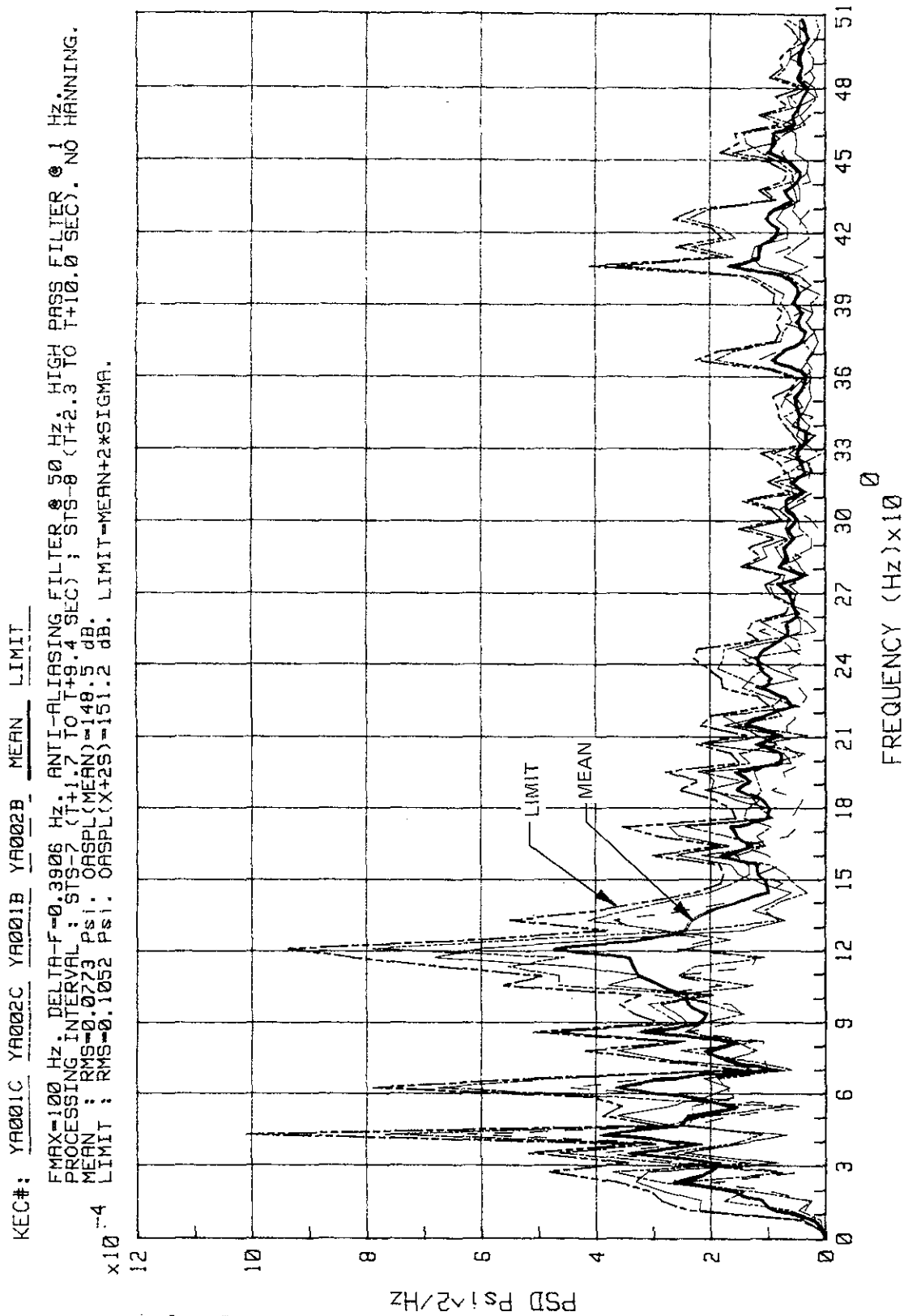
Figure 2-94. STS-7 and -8 Lift-Off Peak - ECS Cooling Tower Acoustics (No Hanning)

Figure 2-95. STS-7 and -8 Lift-Off Peak - ECS Cooling Tower Acoustics (All PSD's Hanned)

FAR FIELD
PREDICTED AVERAGE SOUND PRESSURE LEVELS
(50 PERCENT CONFIDENCE LEVELS)

Direction:
322° T from Pad Centerline
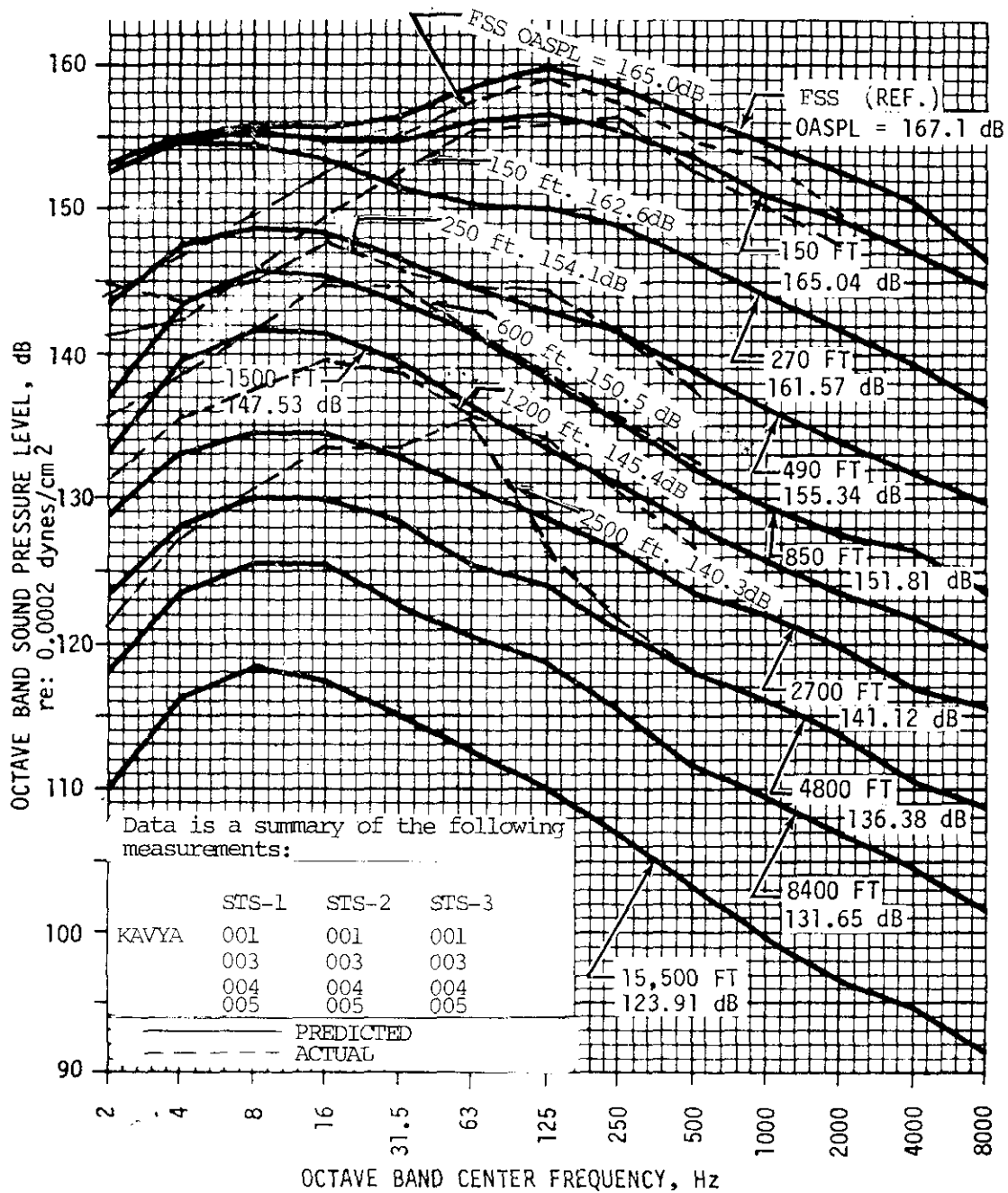
Figure 2-96.   Predicted and Actual Sound Pressure Levels Data Summary

2.5 MLP DECK 0 PRESSURES

This section presents a summary of plume impingement pressures recorded by six
pressure sensors during STS-1, -2, -3, and -9 launches. The thermally pro-
tected sensors were located only on MLP-1 as shown in figure 2-97. Not all
sensors provided valid data for each launch. Data losses, mainly dropouts,
were caused by the severe vibration environment affecting the data acquisition
system (DAS). Remaining valid data were processed to provide slow varying
pressure components designated as TVM and rapidly varying dynamic components,
further processed to yield PSD's. Extraction of TVM used multiple application
of time domain averaging by means of Hanning algorithm, a symmetric coeffi-
cient digital filter that acts as a low-pass filter but without introducing
time delay (phase shift) in filtered data.

Extracted TVM's, often identified as "static" pressures, for each launch are
shown on figures 2-98 through 2-101. Sensors that provided data and other
pertinent information are shown in plot headings.

A summary of static pressures recorded by each pair of sensors equidistant
from the SRB's in prelaunch position is shown on figures 2-102 through 2-104.

Typical PSD's obtained from dynamic pressure components (dynamic component is
the difference between raw data and TVM) for STS-9 are shown on figure 2-105.
The user is referred to previously published STS-1 through STS-3 data docu-
ments for additional information (PSD's, rms time histories, probability den-
sities, etc.) on processed dynamic components. The highest values of dynamic
components were recorded during STS-1 by sensor KSRPF011A (14.7 psi rms aver-
age within 0.512 s data block). Pertinent plots are shown on figures 2-106
and 2-107. The right plot on figure 2-106 shows probability density with
asymmetric distribution of dynamic pressure components.

As an illustration of response to both static and dynamic pressure components,
figure 2-108 presents STS-1 strain time histories (raw data, TVM, and dynamic
components) recorded by a strain gage on the bottom flange of T-2 truss top
chord. These time histories are similar to those of pressures. Note that
after the peak, a slow decay of TVM to ambient is delayed (by a few minutes)
by induced thermal strains in the deck 0. Peak amplitudes of dynamic strain
components slightly exceed peak values of TVM strains.
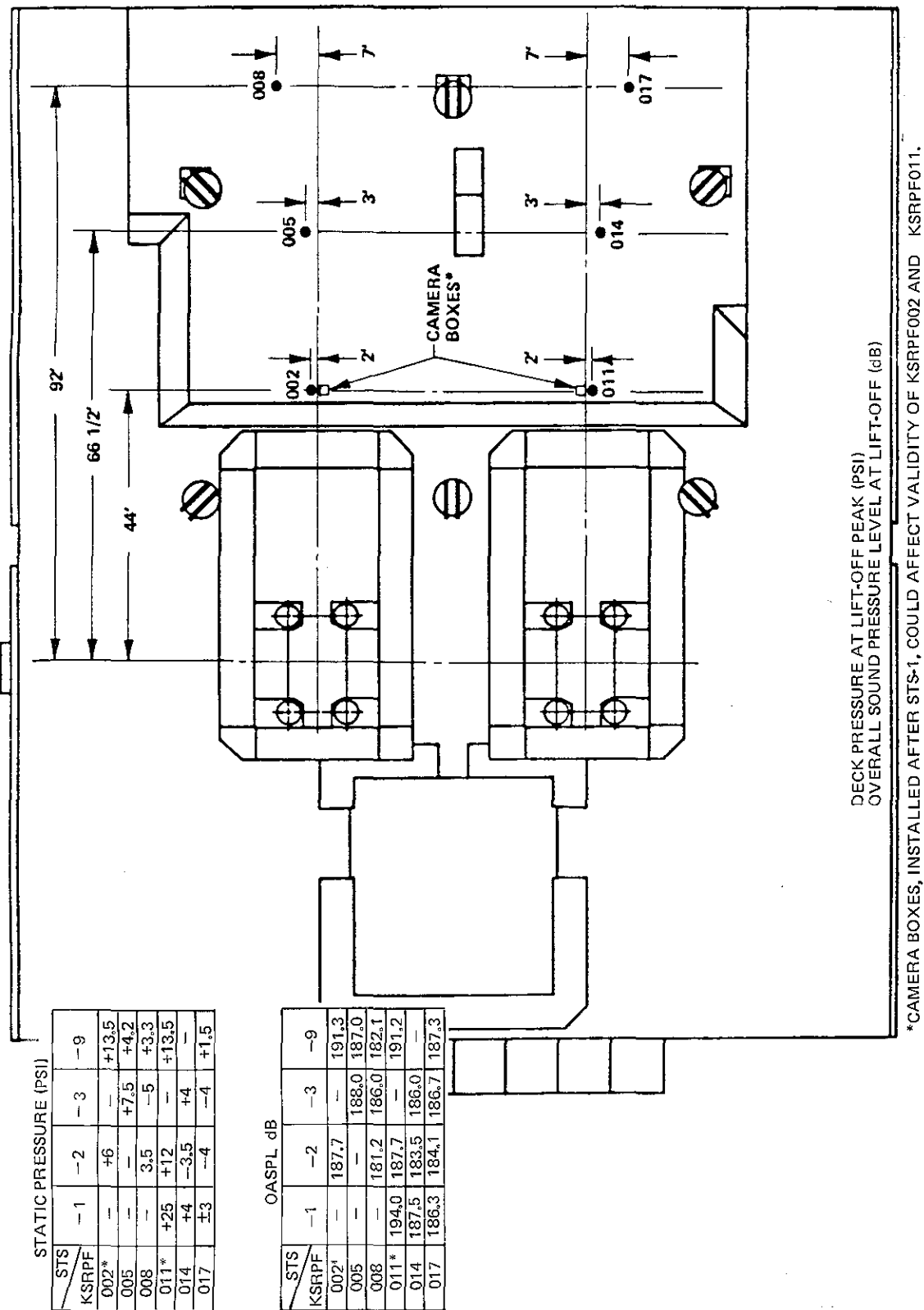
Figure 2-97. MLP-1 Static Pressures and OASPL's

DECK PRESSURE AT LIFT-OFF PEAK (PSI)
OVERALL SOUND PRESSURE LEVEL AT LIFT-OFF (dB)

*CAMERA BOXES, INSTALLED AFTER STS-1, COULD AFFECT VALIDITY OF KSRPF002 AND KSRPF011.

STATIC PRESSURE (PSI)

STS KSRPF	-1	-2	-3	-9
002*	—	+6	—	+13.5
005	—	—	+7.5	+4.2
008	—	3.5	-5	+3.3
011*	+25	+12	—	+13.5
014	+4	-3.5	+4	—
017	±3	-4	-4	+1.5

OASPL dB

STS KSRPF	-1	-2	-3	-9
002†	—	187.7	—	191.3
005	—	—	188.0	187.0
008	—	181.2	186.0	182.1
011*	194.0	187.7	—	191.2
014	187.5	183.5	186.0	—
017	186.3	184.1	186.7	187.3
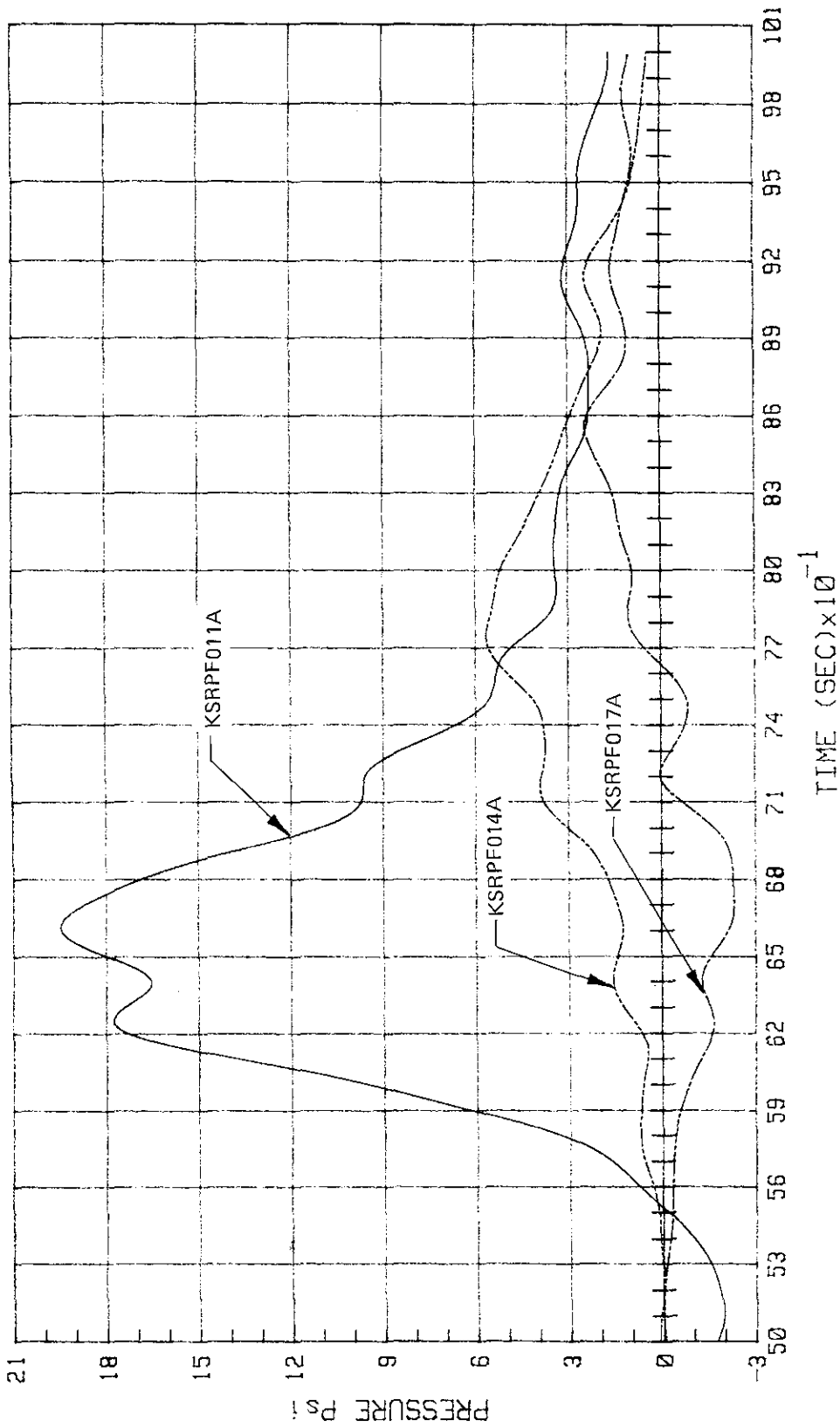
Figure 2-98. STS-1 MLP-1 Deck 0 Impinging Plume Pressure (TVM)
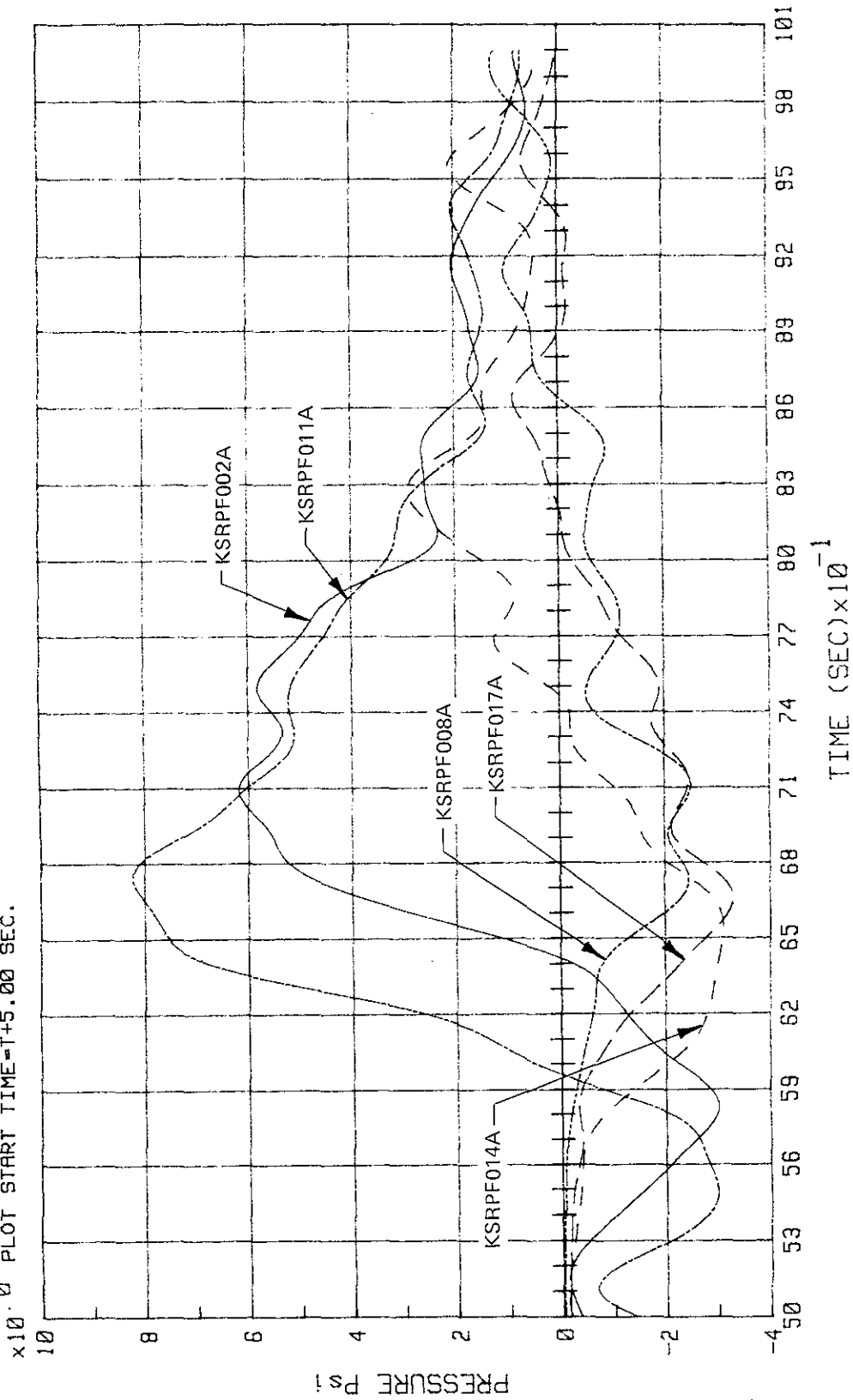
Figure 2-99. STS-2 MLP-1 Deck 0 Impinging Plume Pressure (TVM)
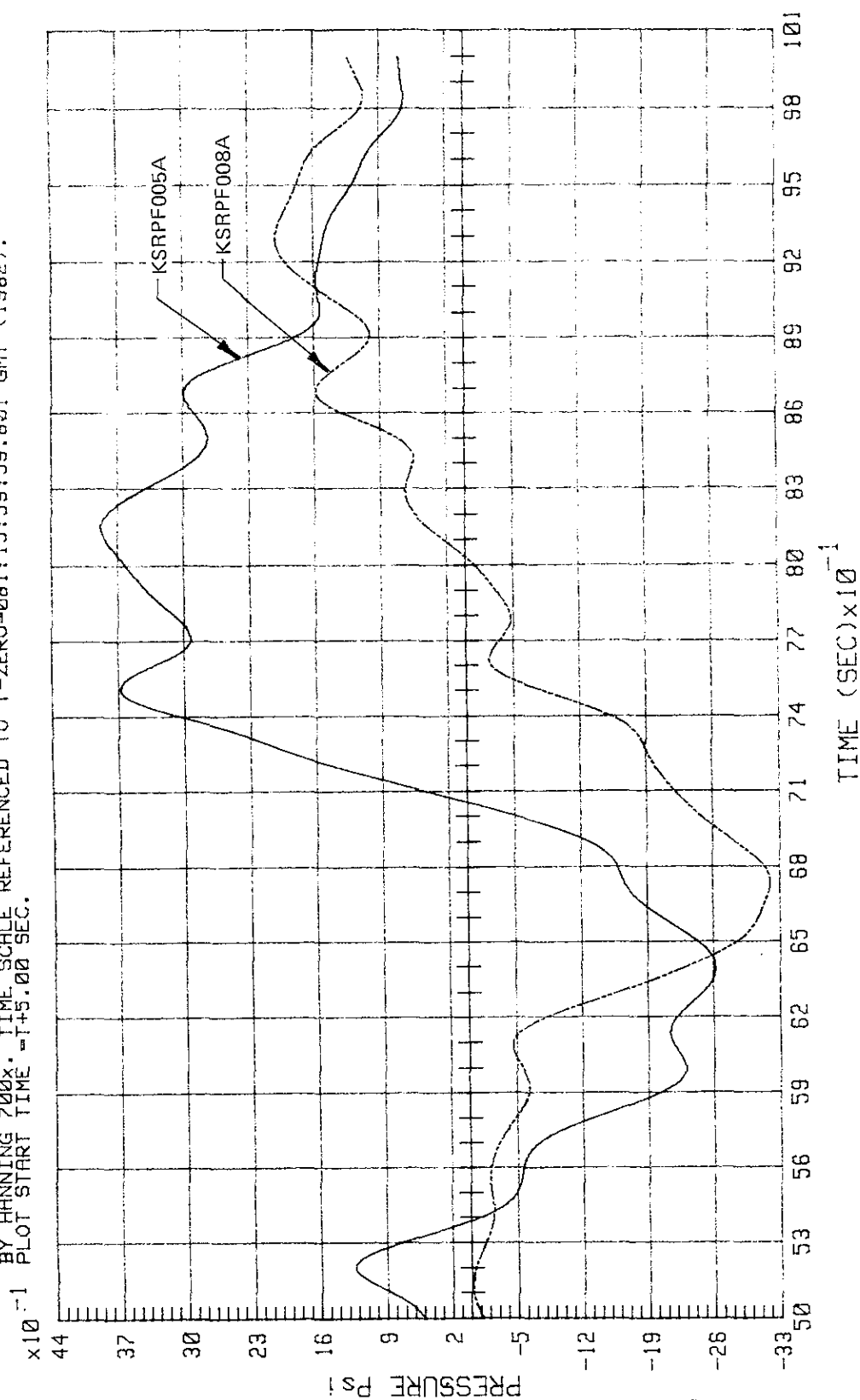
Figure 2-100. STS-3 MLP-1 Deck 0 Impinging Plume Pressure (TVM)
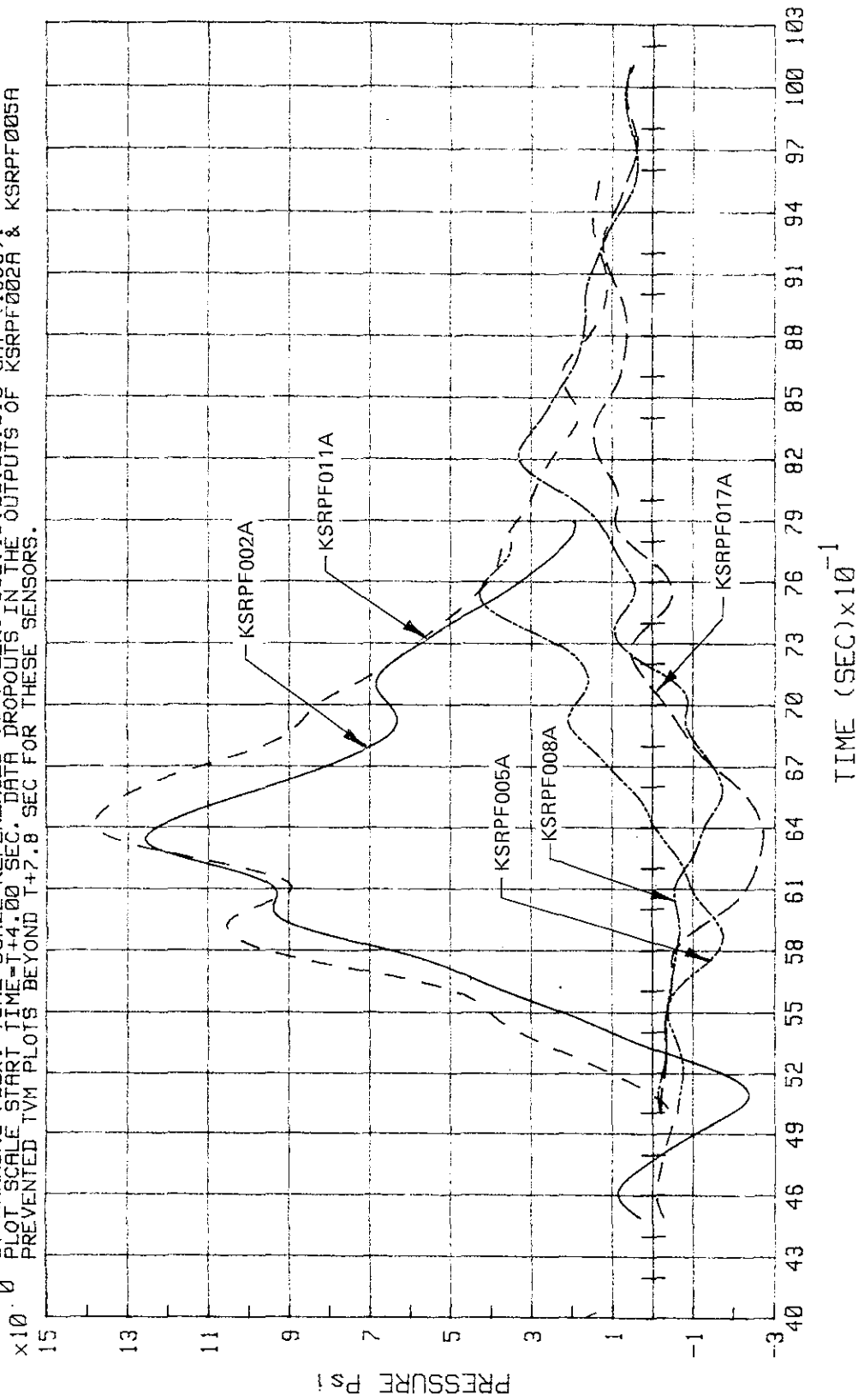
Figure 2-101. STS-9 MLP-1 Deck 0 Impinging Plume Pressure (TVM)

Figure 2-102. STS-1, -2, and -9 MLP-1 Deck 0 Impinging Plume Pressure (TVM)
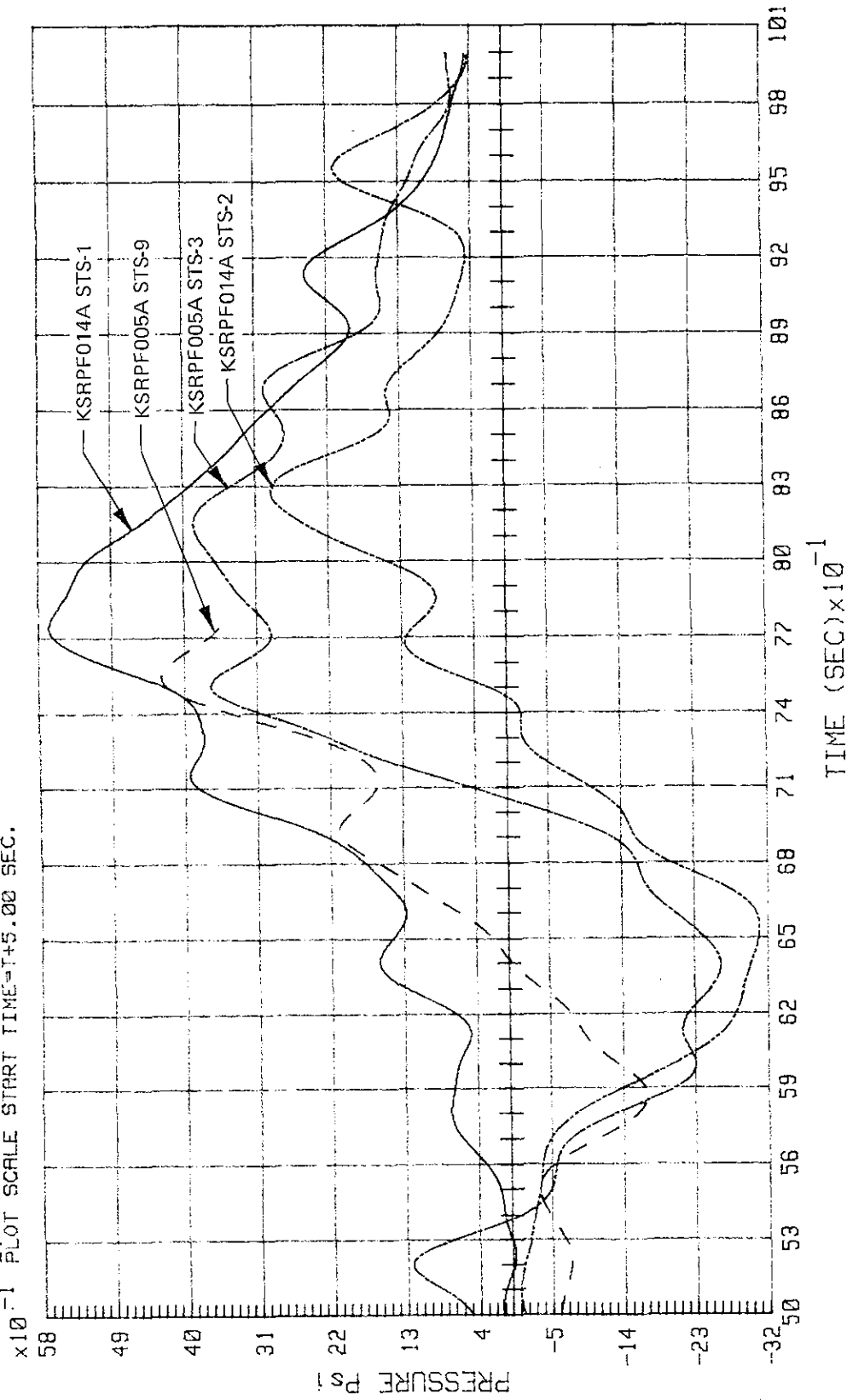
Figure 2-103. STS-1, -2, -3, and -9 MLP-1 Deck 0 Impinging Plume Pressure (TVM)
(Sensors: STS-1 and -2, KSRPF014A; and STS-3 and -09,-005A)
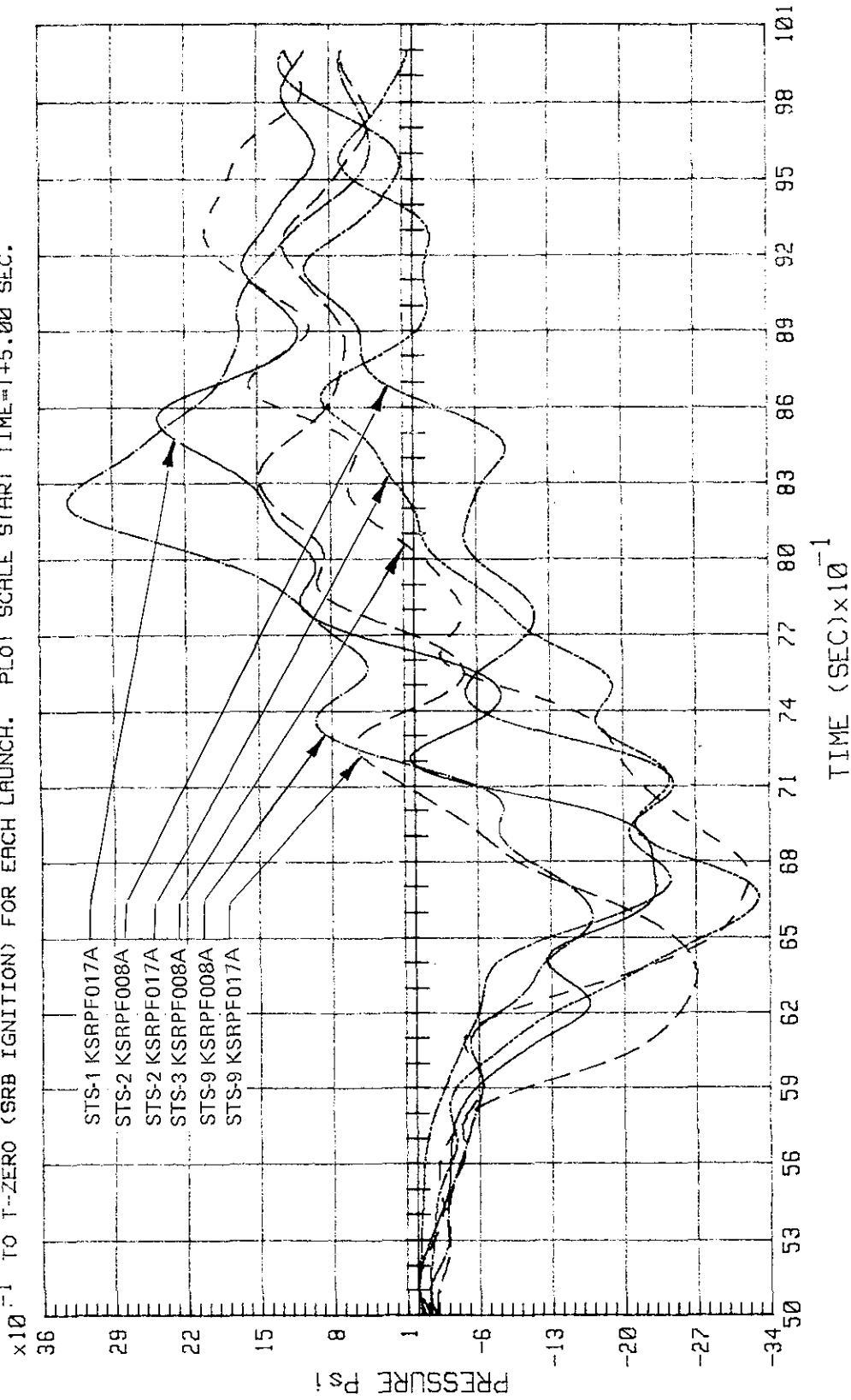
Figure 2-104. STS-1, -2, -3, and -9 MLP-1 Deck 0 Impinging Plume Pressure (TVM)
(Sensors: STS-1, KSRPF017A; STS-2 and -9, -017A and -008A; and STS-3, -008A)
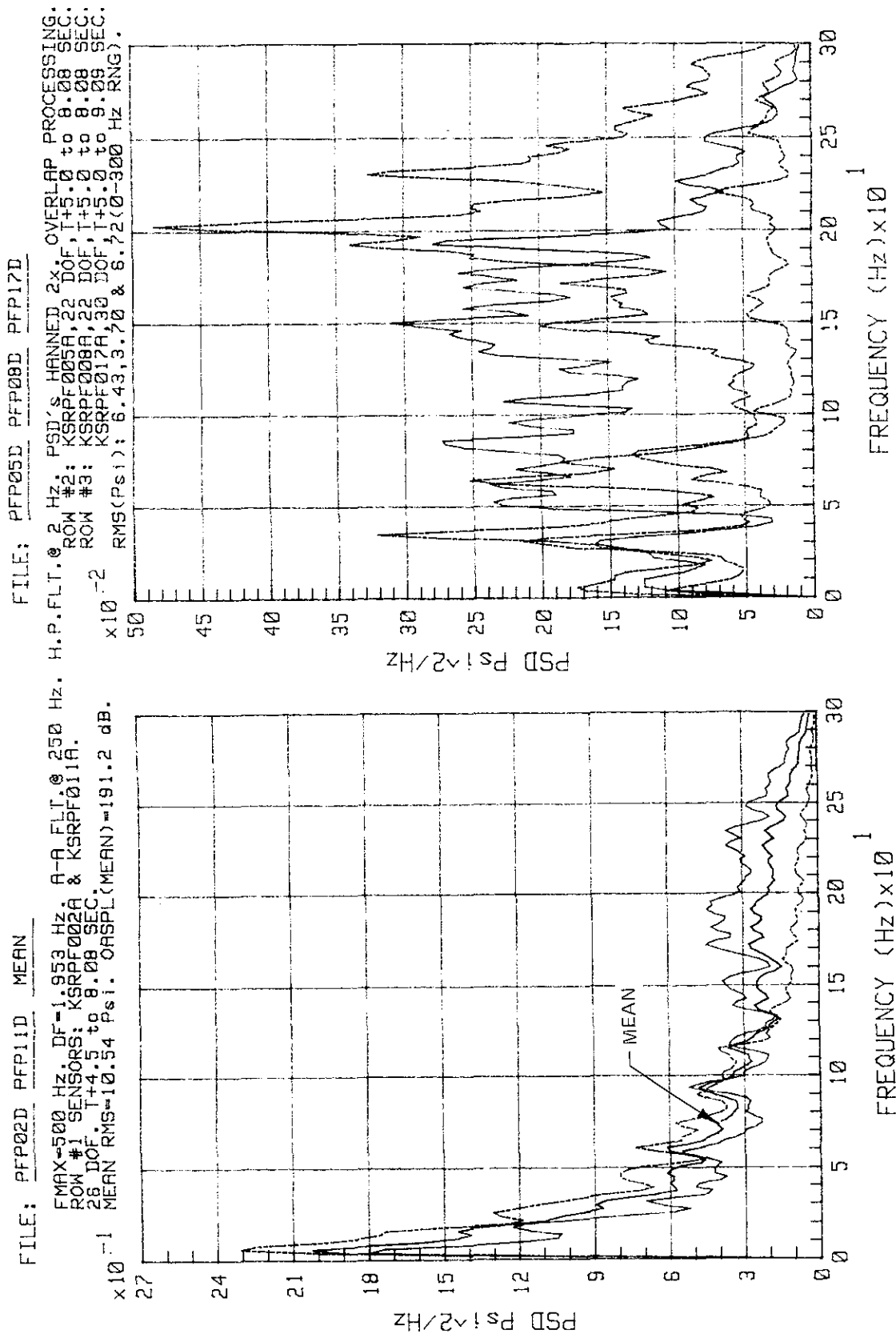
Figure 2-105. STS-9 MLP-1 Deck 0 Impinging Plume Pressure PSD's - Lift-Off Peak
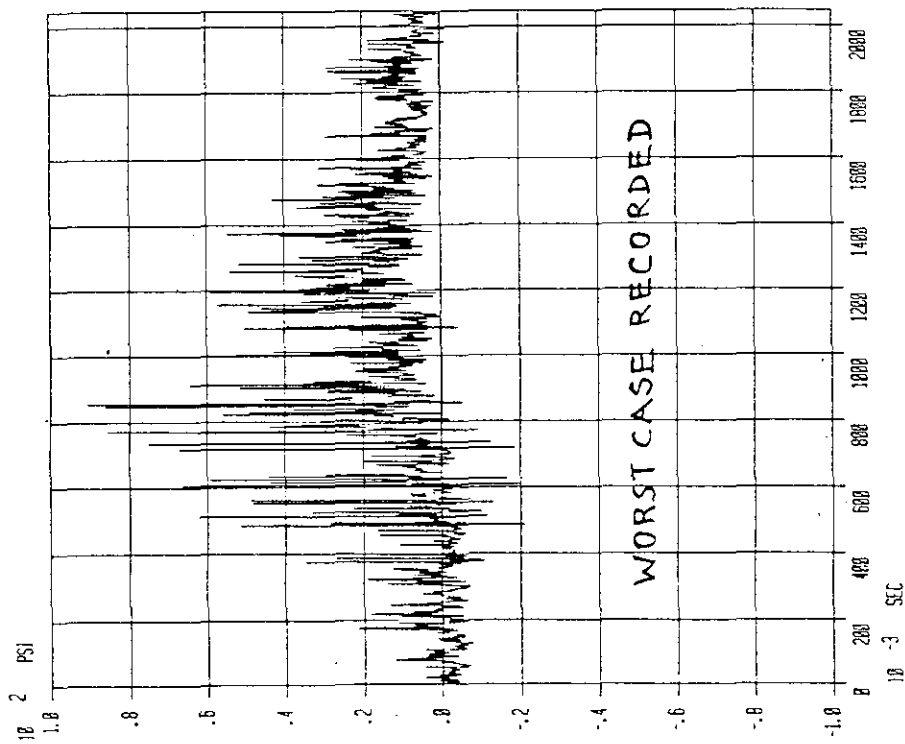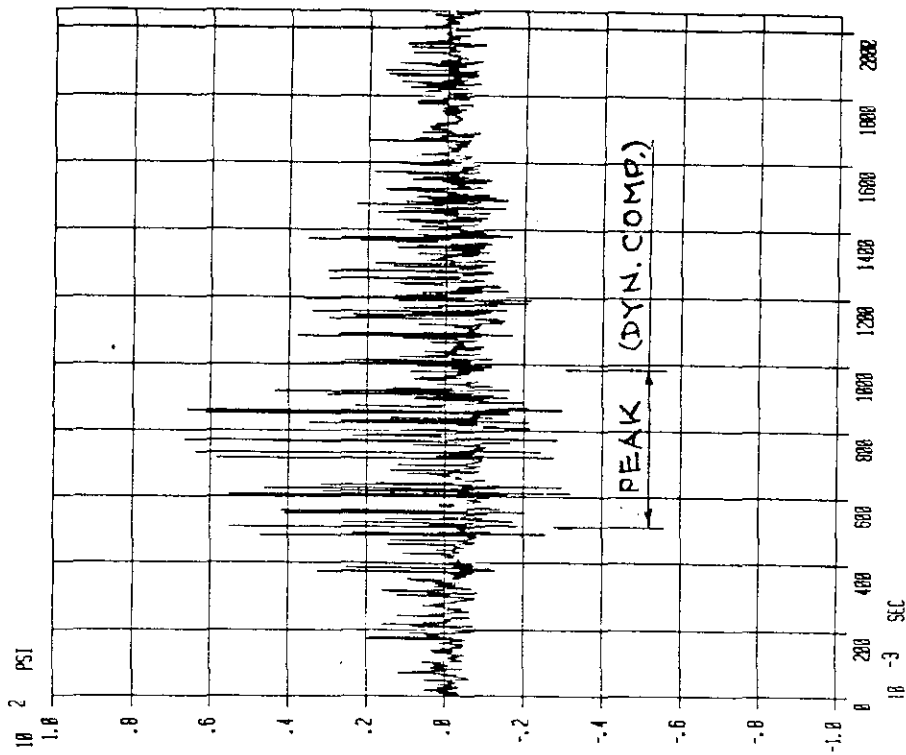
Figure 2-106. STS-1 Lift-Off Peak — KSRPF011A Raw Data and Dynamic Component of Data
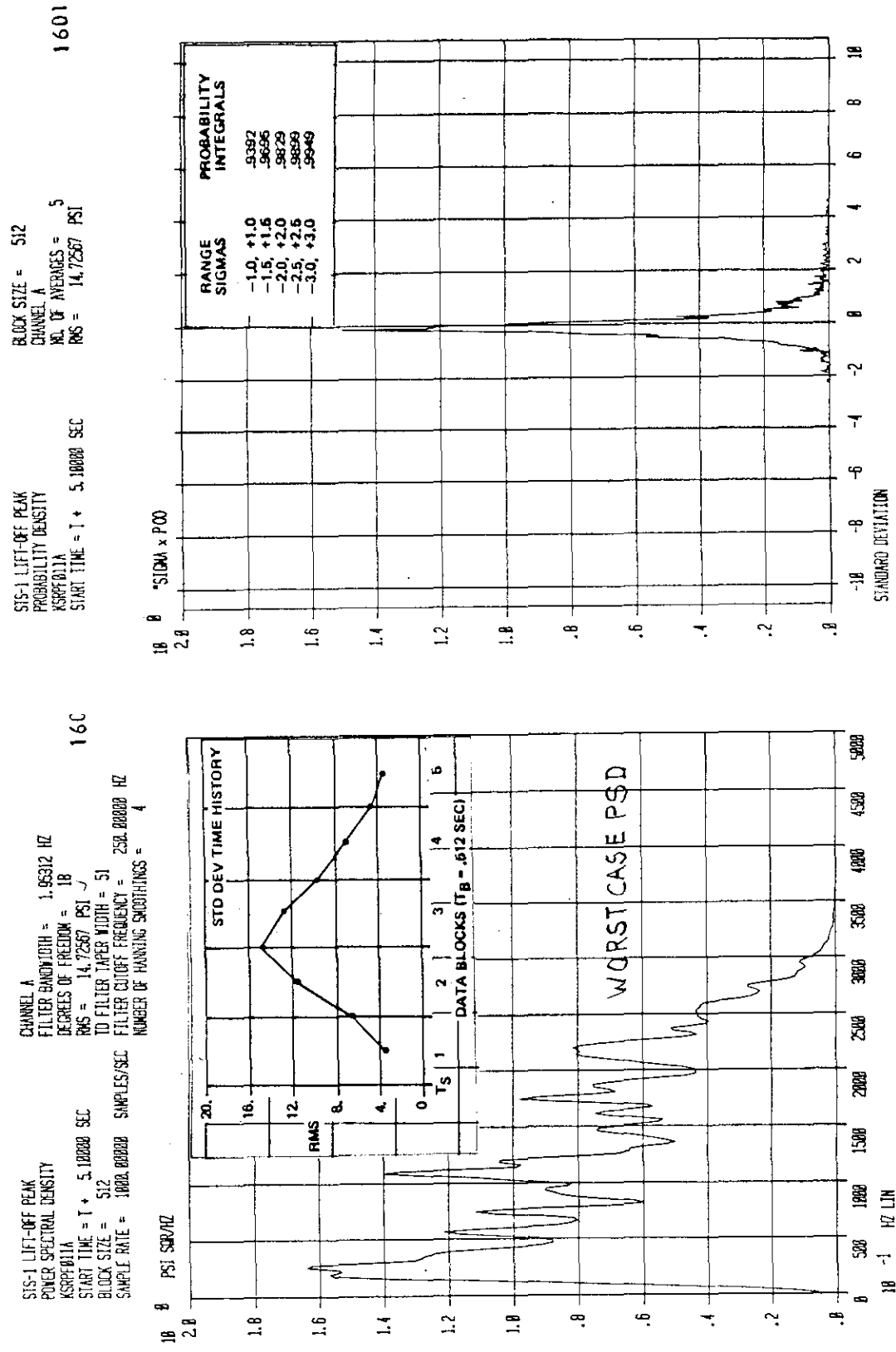
Figure 2-107.   STS-1 Lift-Off Peak - KSRPF011A Power Spectral Density, Probability Density, and Standard Deviation Time History

Figure 2-108. STS-1 Lift-Off Peak - KSRGF002A Raw Data (Filtered),
Time Variable Mean, Dynamic Component of Data, and Power Spectral Density
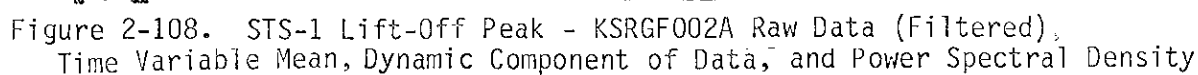
2.6 TSM PRESSURES SUMMARY

This section presents a summary of pressures recorded by sensors on both TSM's (LH$_2$ and LO$_2$) during STS-4 through STS-8 launches. Statistical data in terms of OBSPL's were derived from STS-1 through STS-5 measurements (X- and Y-direction sensors) and are included in this summary. Since the acoustic environment on TSM's is very nonstationary, orientation of sensor orifice (X, Y, or Z) and time intervals selected for processing were major factors affecting the results.

Figures 2-109 and 2-110 present PSD's derived from MLP-2 TSM's sensor data during lift-off peak (T + 1.5 s to T + 5.6 s). Orifices of these sensors were oriented in the -Z direction (looking down). PSD's from the same sensor outputs for processing time interval T + 5.5 s to T + 12.2 s (lift-off peak end) for STS-6 are shown on figures 2-111 and 2-112. Comparing the PSD plots of figures 2-109 and 2-111 reveals significant differences in their frequency composition.

TSM sensors with orifices in the -Z direction recorded apparent "static" pressures as a result of indirect impingement from the SRB plumes after these plumes impinge on the north part of MLP deck 0 (peak at about T + 8 s), and are deflected horizontally toward TSM's. Deflected splash impinges on the base of TSM's where they are again deflected by the TSM's. Thus, apparent "static" pressures are associated with an upward flow of twice deflected and splashing plumes. Figures 2-113 through 2-115 show STS-6 time histories of raw data and TVM extracted from the raw data for the period T + 3.0 s to T + 13.24 s.

When all PSD's from -Z-direction sensors on MLP-1 and MLP-2 recorded during STS-4 through STS-8 are averaged, the resulting PSD's are shown on figure 2-116 and 2-117. These PSD's are similar to those on figures 2-109 and 2-110, thus confirming similarity and validity of TSM pressure data recorded on two different MLP's by two different data acquisition systems.

A number of sensors on the MLP-1 TSM's had their orifices oriented in X and Y directions. Figures 2-118 and 2-119 show PSD's derived from the outputs of X- and Y-direction sensors for STS-4, -5, and -7 launches. These sensors did not record significant "static" pressures mainly because the direction of their orifices is perpendicular to the direction of splash flow. Generally X- and Y-direction sensors recorded higher dynamic pressures within the 0- to 200-Hz range shown on figures 2-118 and 2-119 than did their Z-direction counterparts.

Table 2-1 presents a statistical summary of acoustic pressures on TSM's recorded by X- and Y-direction sensors during STS-1 through STS-5 launches. Data are presented in terms of OBSPL's. A total of 18 measurements comprises these statistics, which essentially reflect data on figures 2-118 and 2-119, except that OBSPL's range is extended to 2.0 kHz.
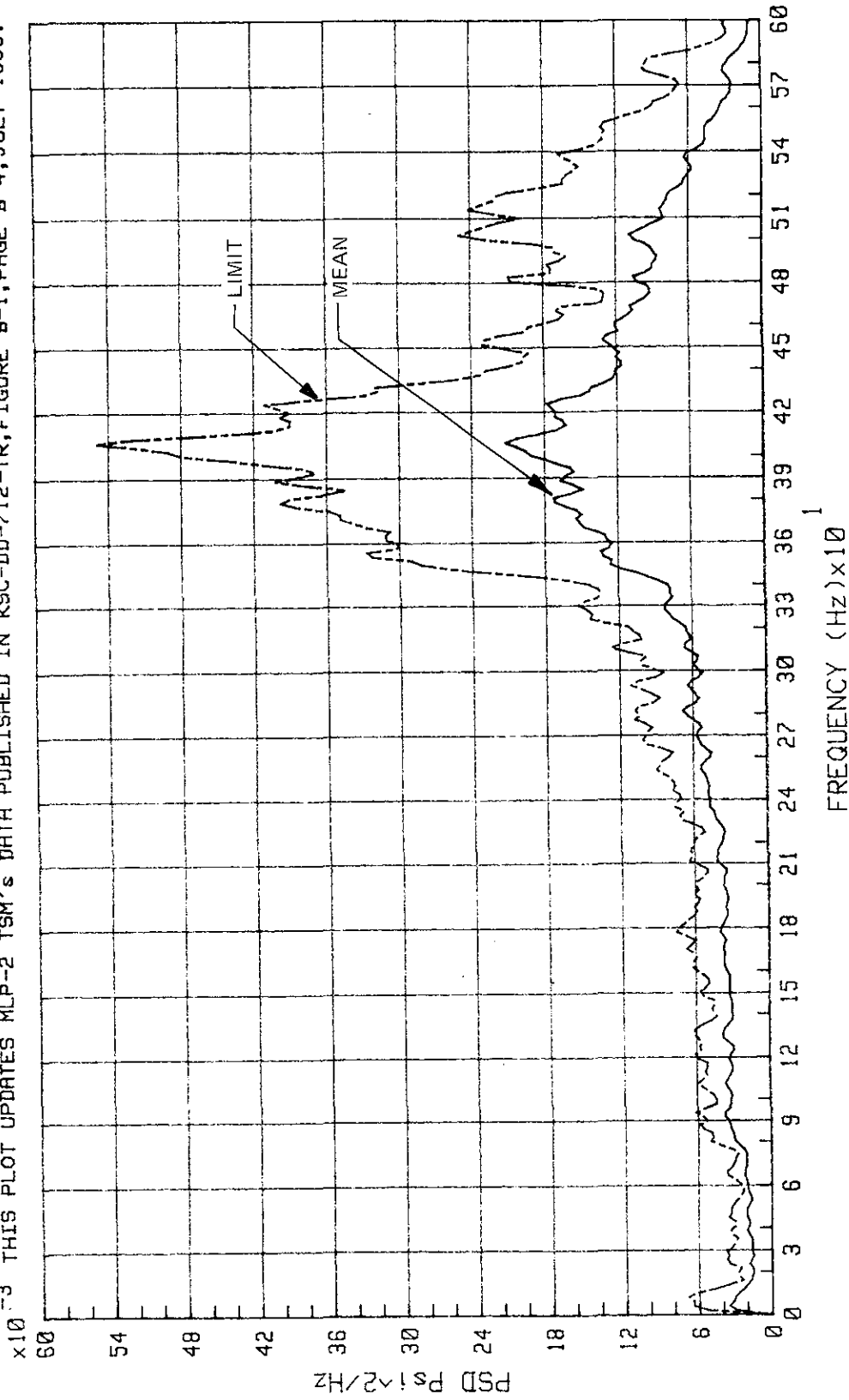
Figure 2-109. STS-6 and -8 Acoustics on TSM's at Lift-Off Peak - Sensors Oriented in -Z Direction (Mean and Limit Only)

KSC-DD-818-TR
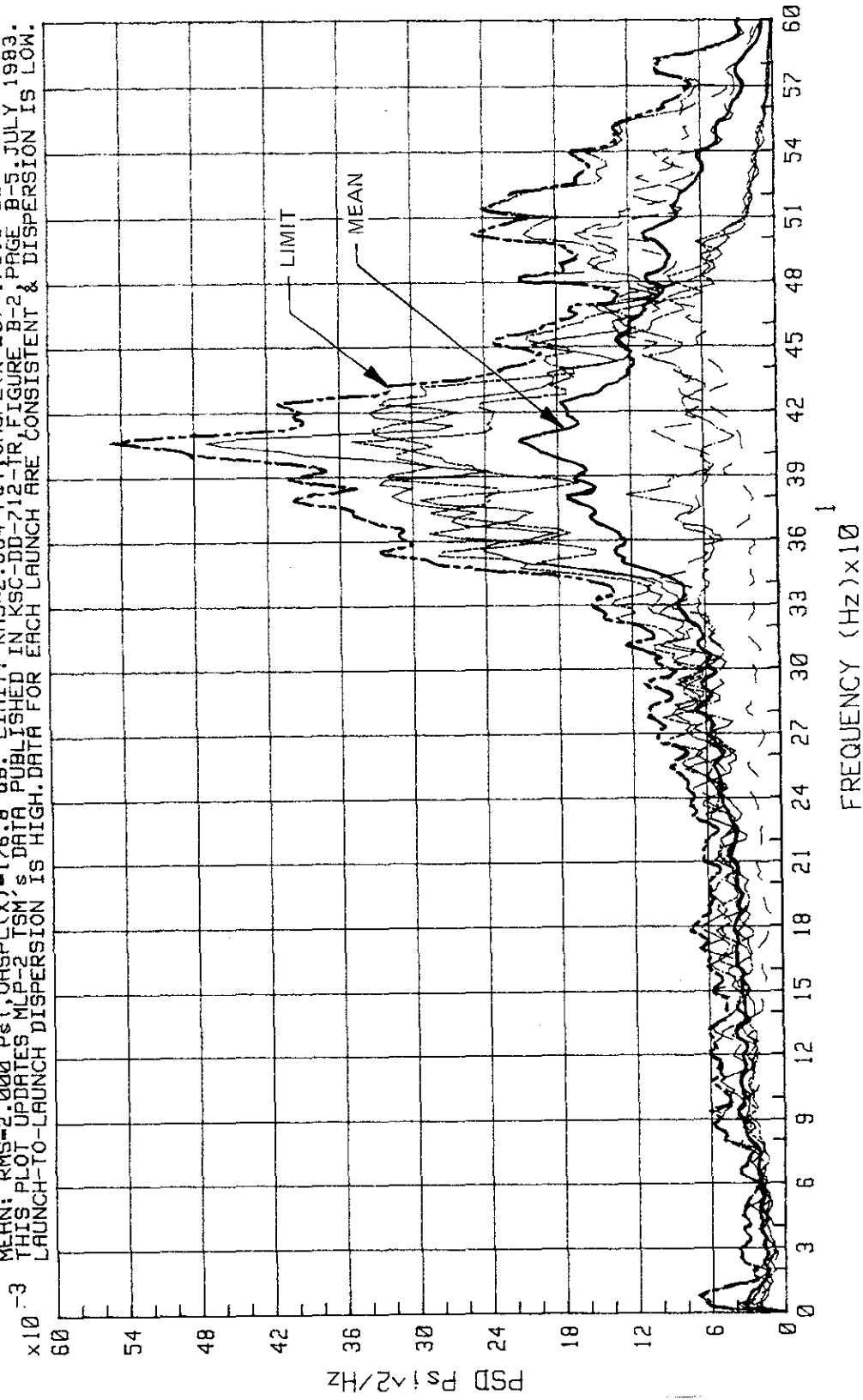
Figure 2-110. STS-6 and -8 Acoustics on TSM's at Lift-Off Peak - Sensors Oriented in -Z Direction

Figure 2-111. STS-6 Acoustics on TSM's at Lift-Off Peak End – Sensors Oriented in –Z Direction (Mean and Limit)

KSC-DD-818-TR
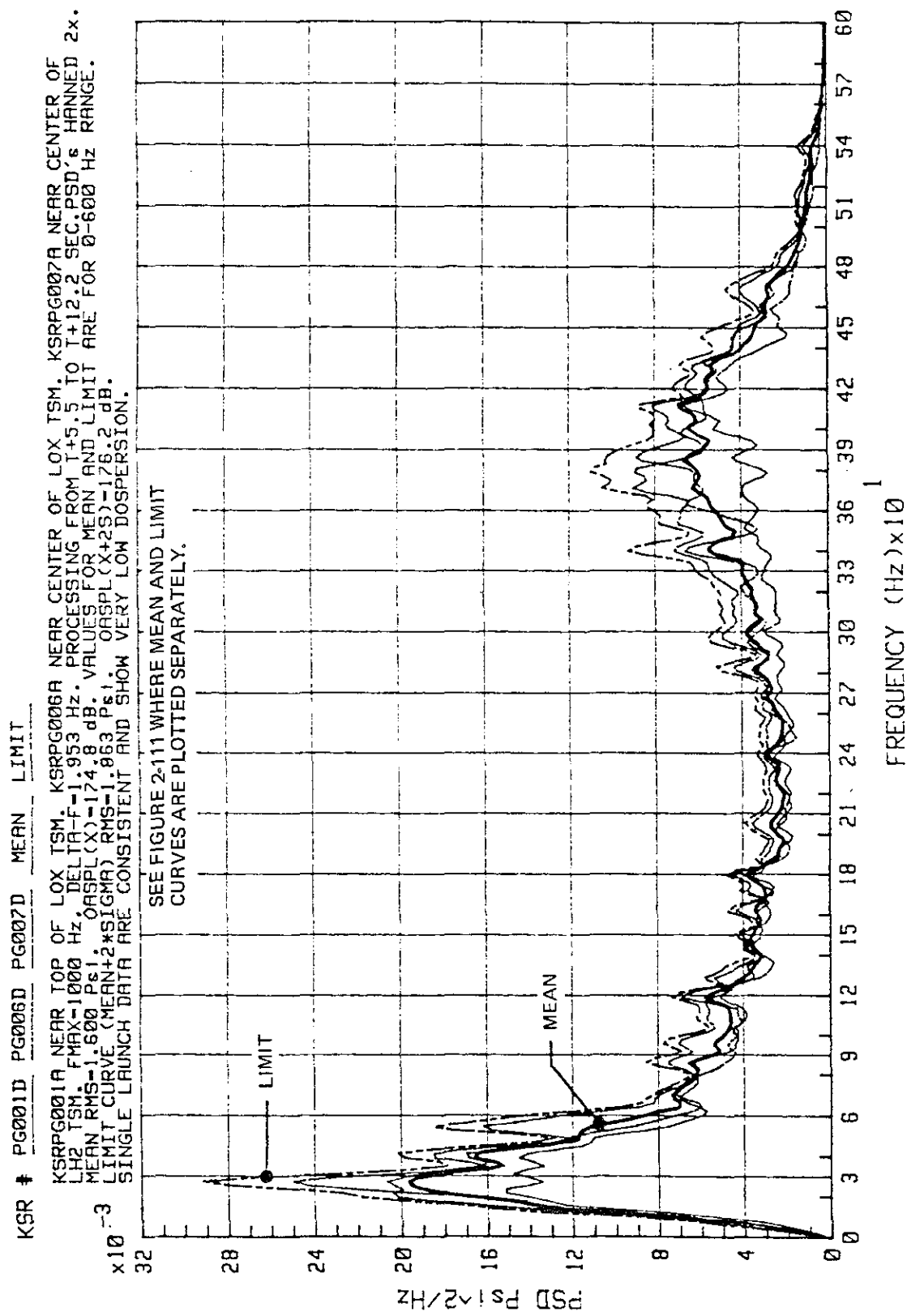
Figure 2-112. STS-6 Acoustics on TSM's at Lift-Off Peak - Sensors Oriented in -Z Direction

2-122
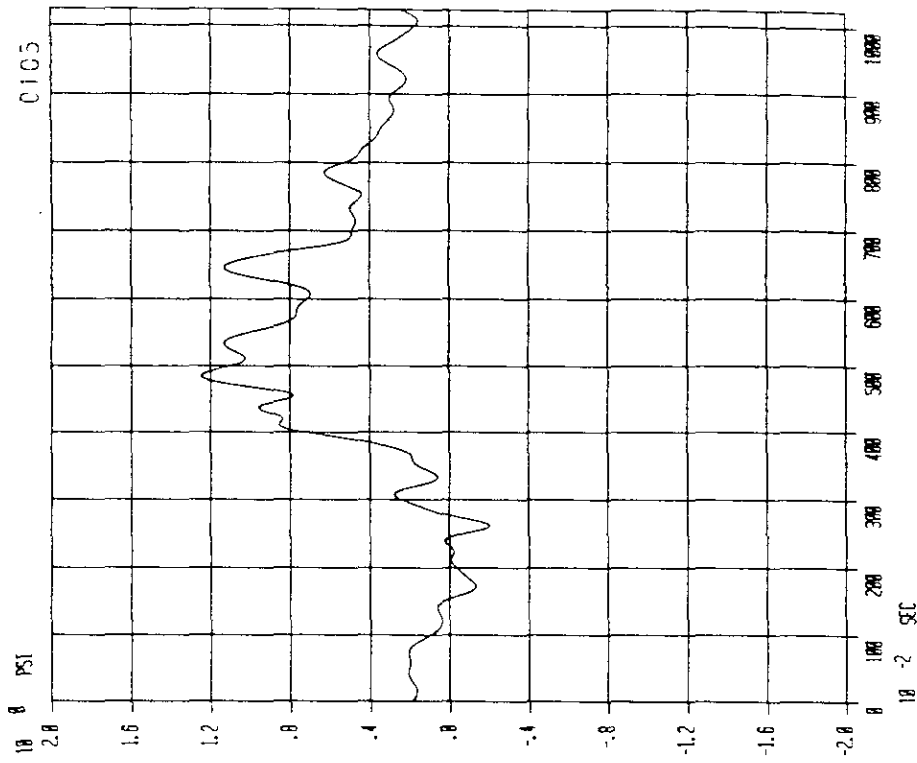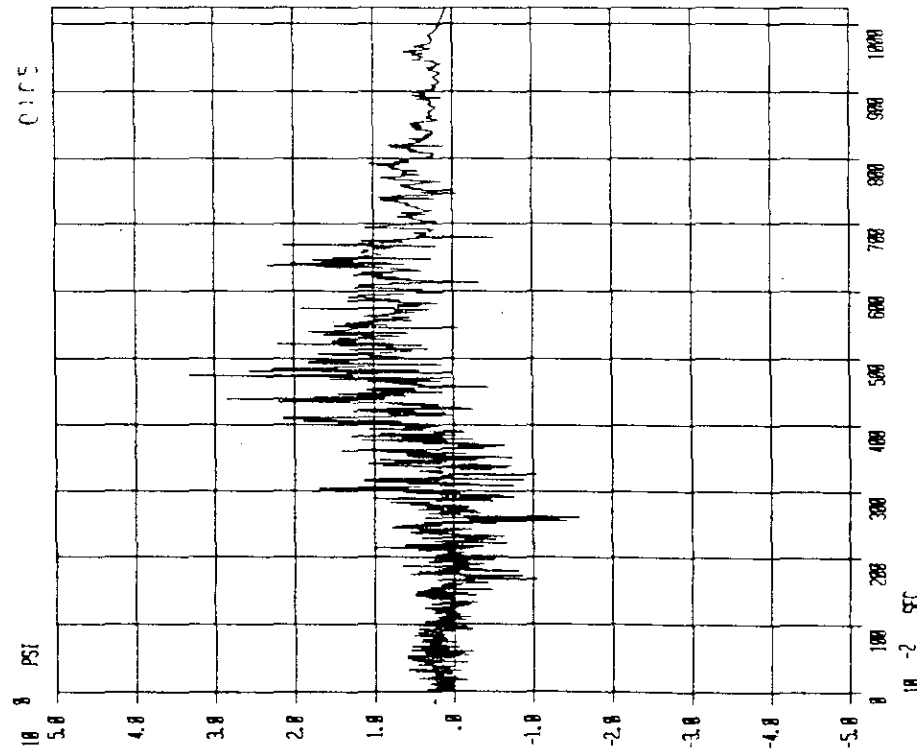
Figure 2-113. STS-6 Lift-Off Peak - KSRPG001A Raw Data and Time Variable Mean

KSC-DD-818-TR
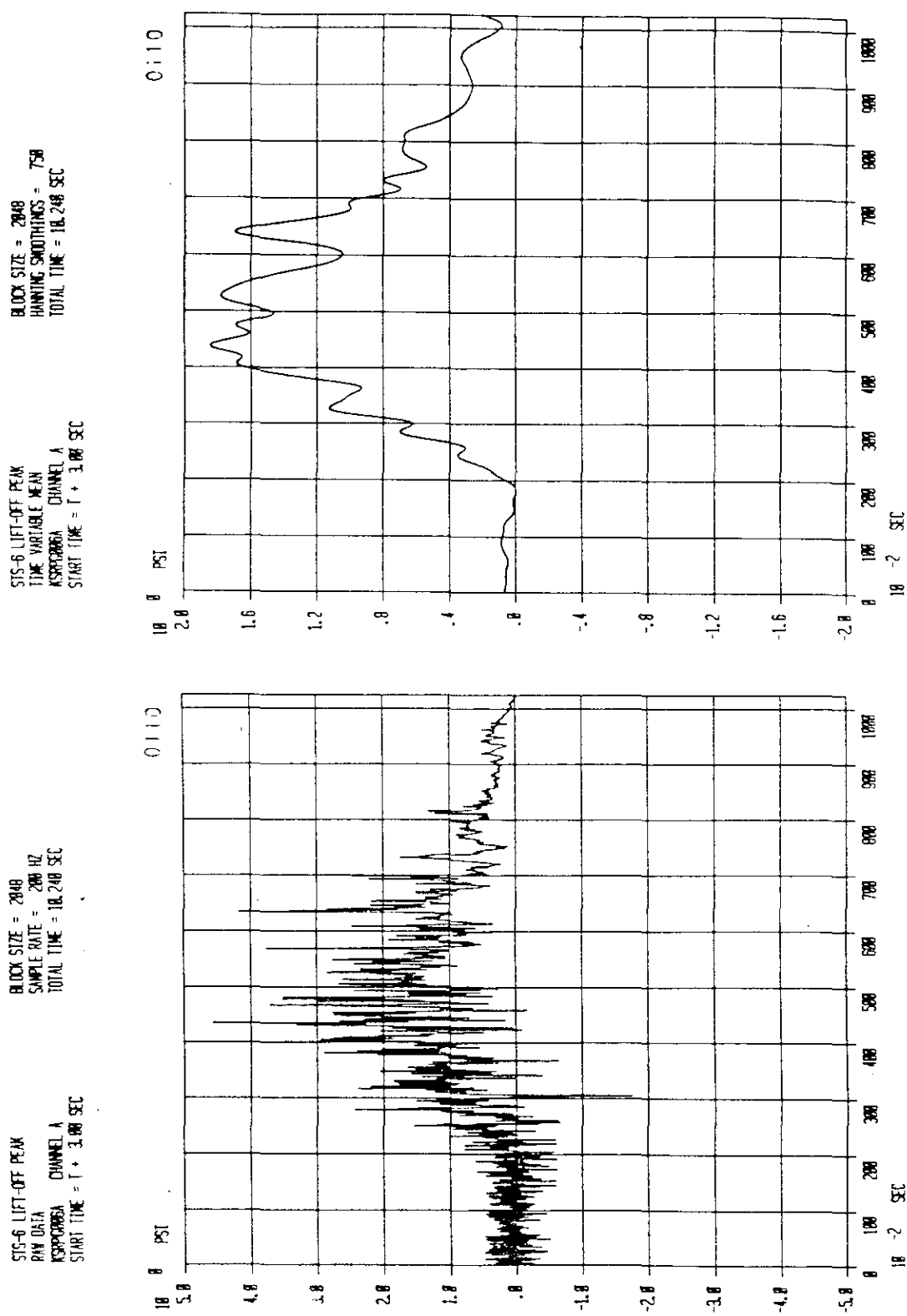
Figure 2-114. STS-6 Lift-Off Peak - KSRPG006A Raw Data and Time Variable Mean
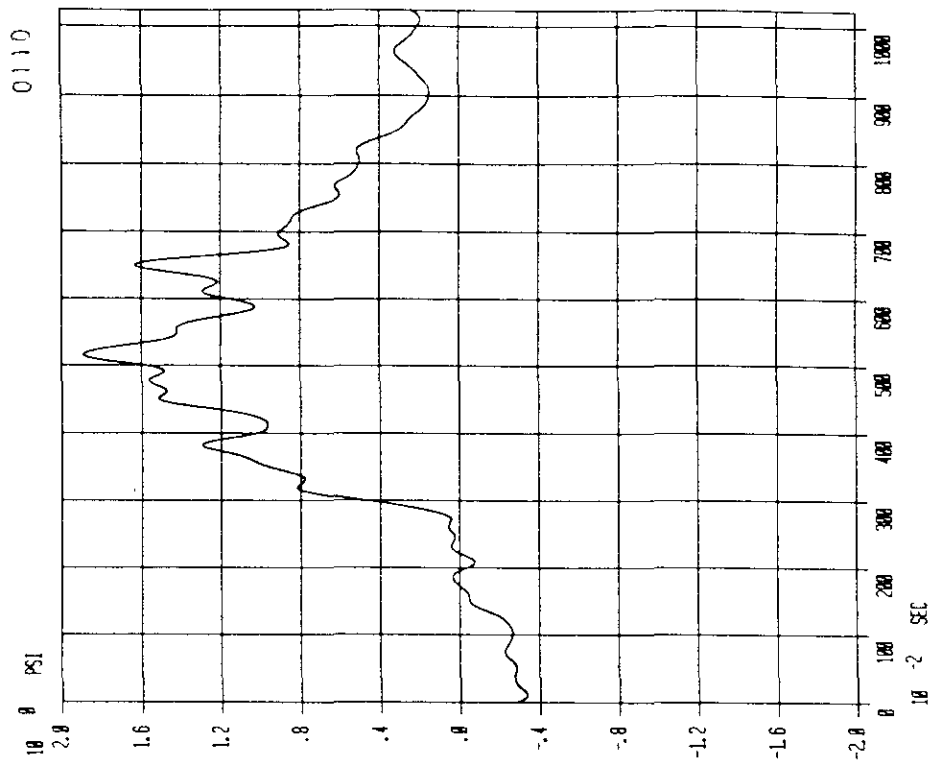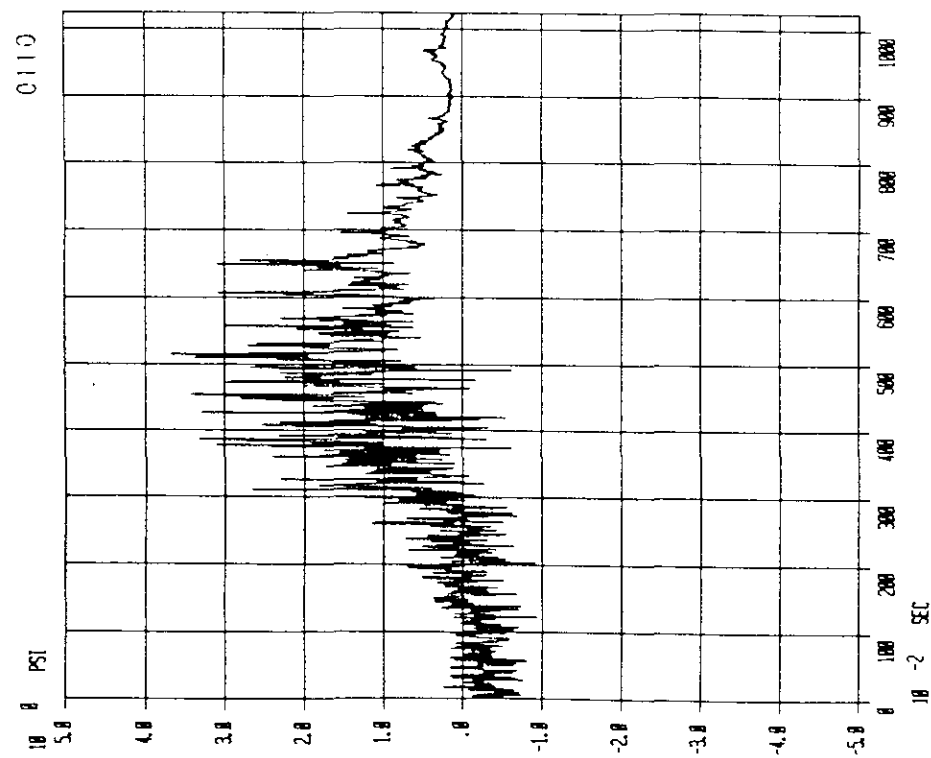
Figure 2-115. STS-6 Lift-Off Peak – KSRPG007A Raw Data and Time Variable Mean
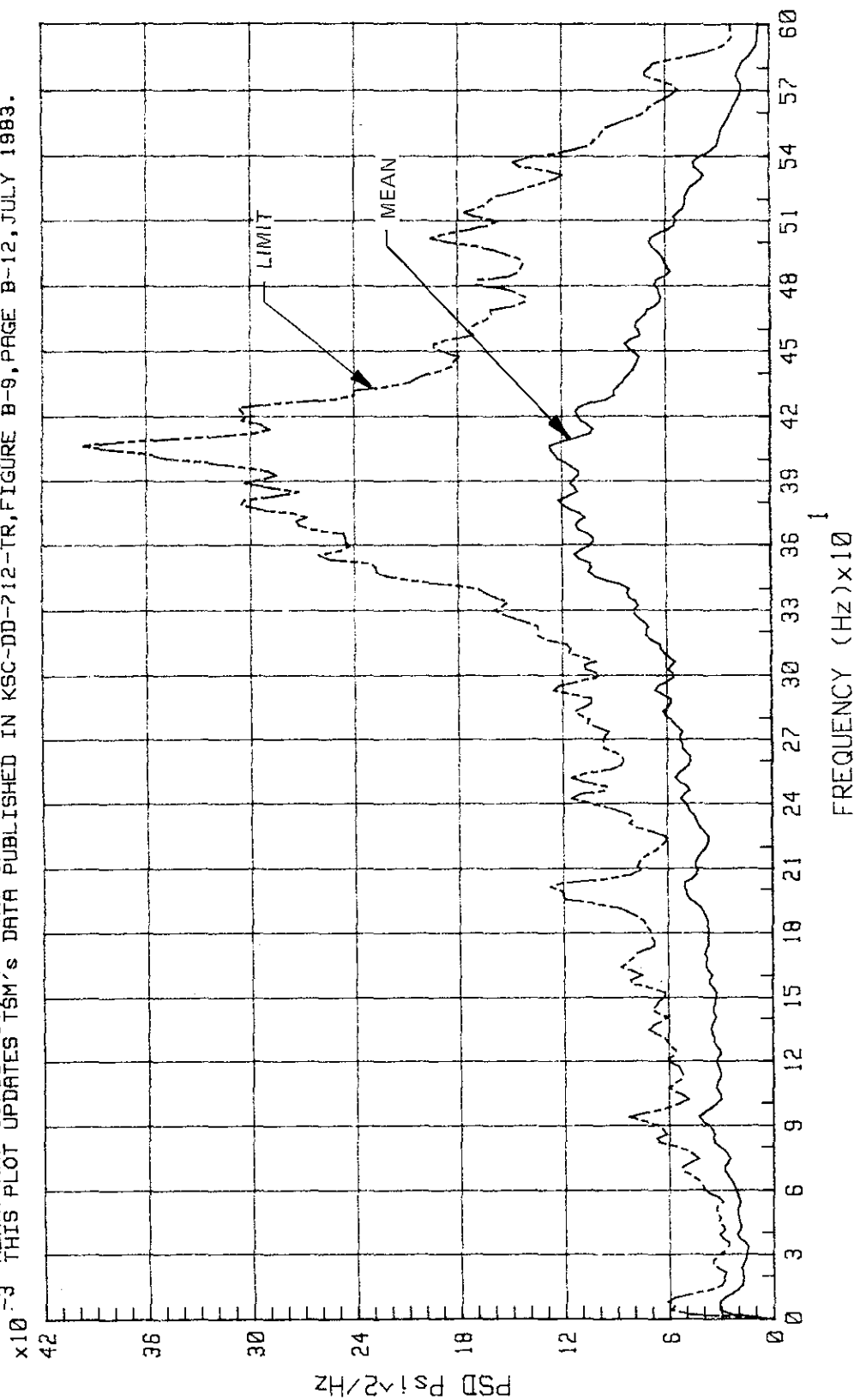
Figure 2-116. STS-4, -5, -7, and -8 Acoustics on Top of TSM's at Lift-Off Peak – Sensors in -Z Direction (Mean and Limit Only)
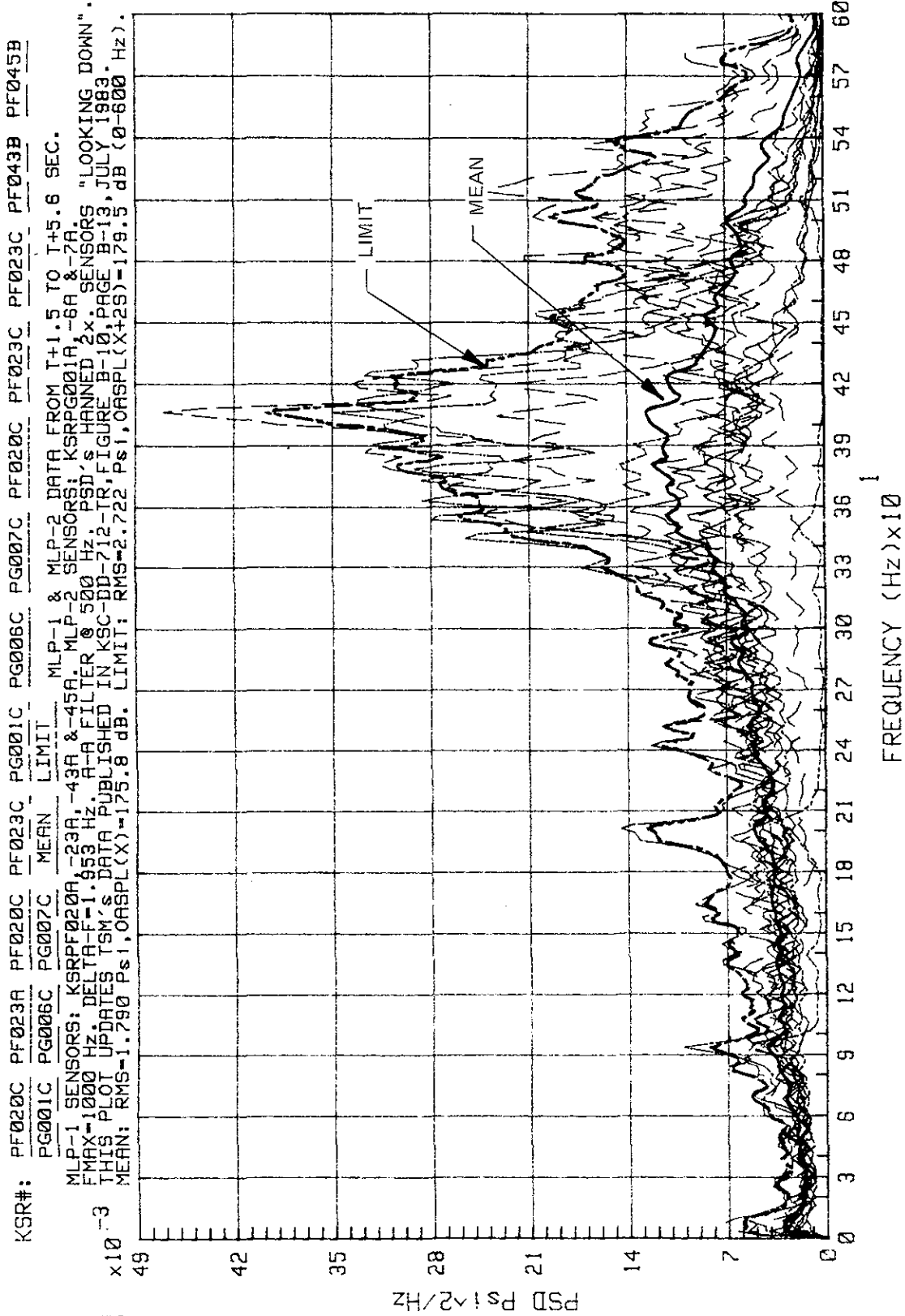
Figure 2-117. STS-4, -5, -6, -7, and -8 Acoustics on Top of TSM's at Lift-Off Peak – Sensors in -Z Direction

KSC-DD-818-TR
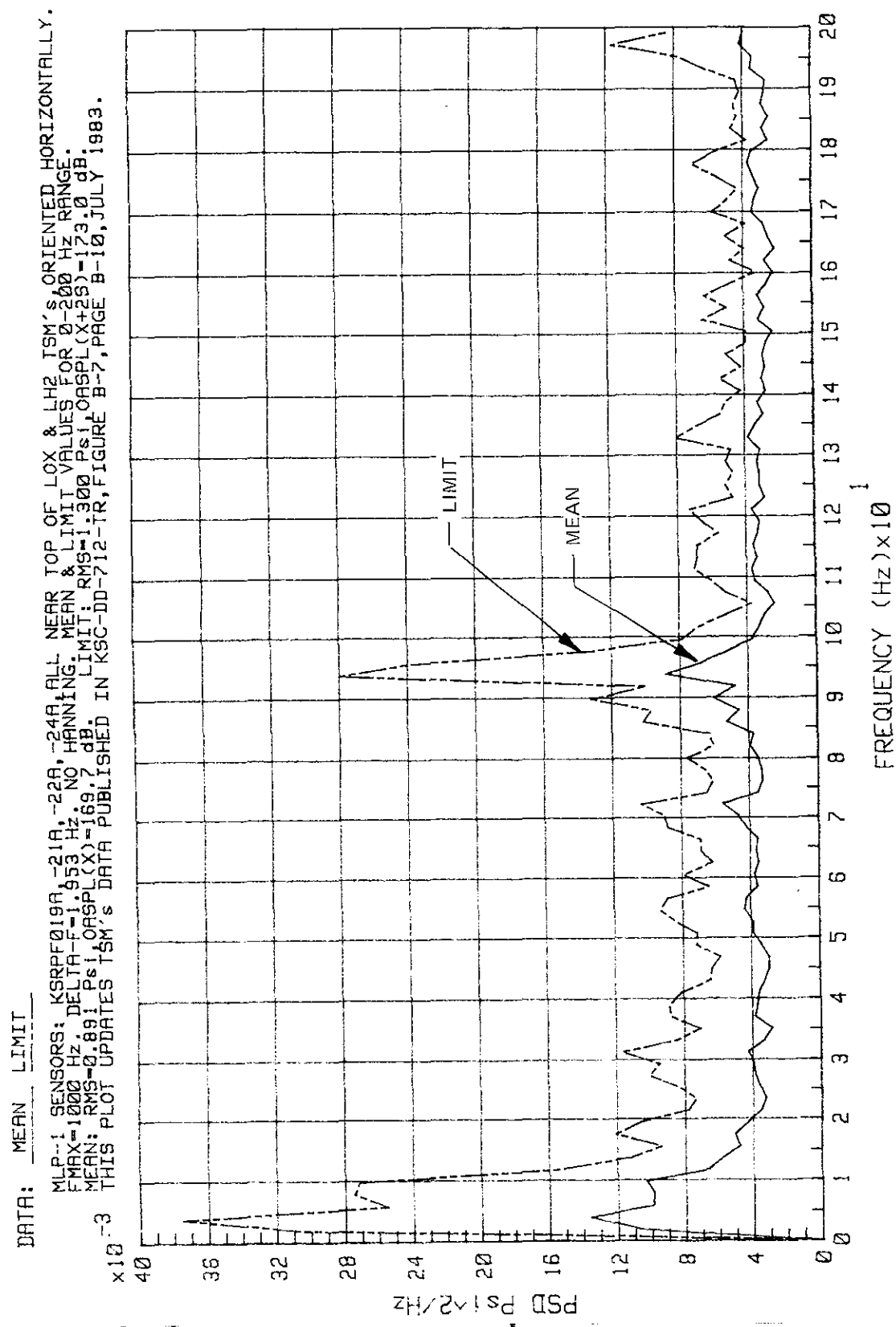
Figure 2-118.   STS-4, -5, and -7 Acoustics on Top of TSM's at Lift-Off Peak -
X and Y Directions (Mean and Limit Only)
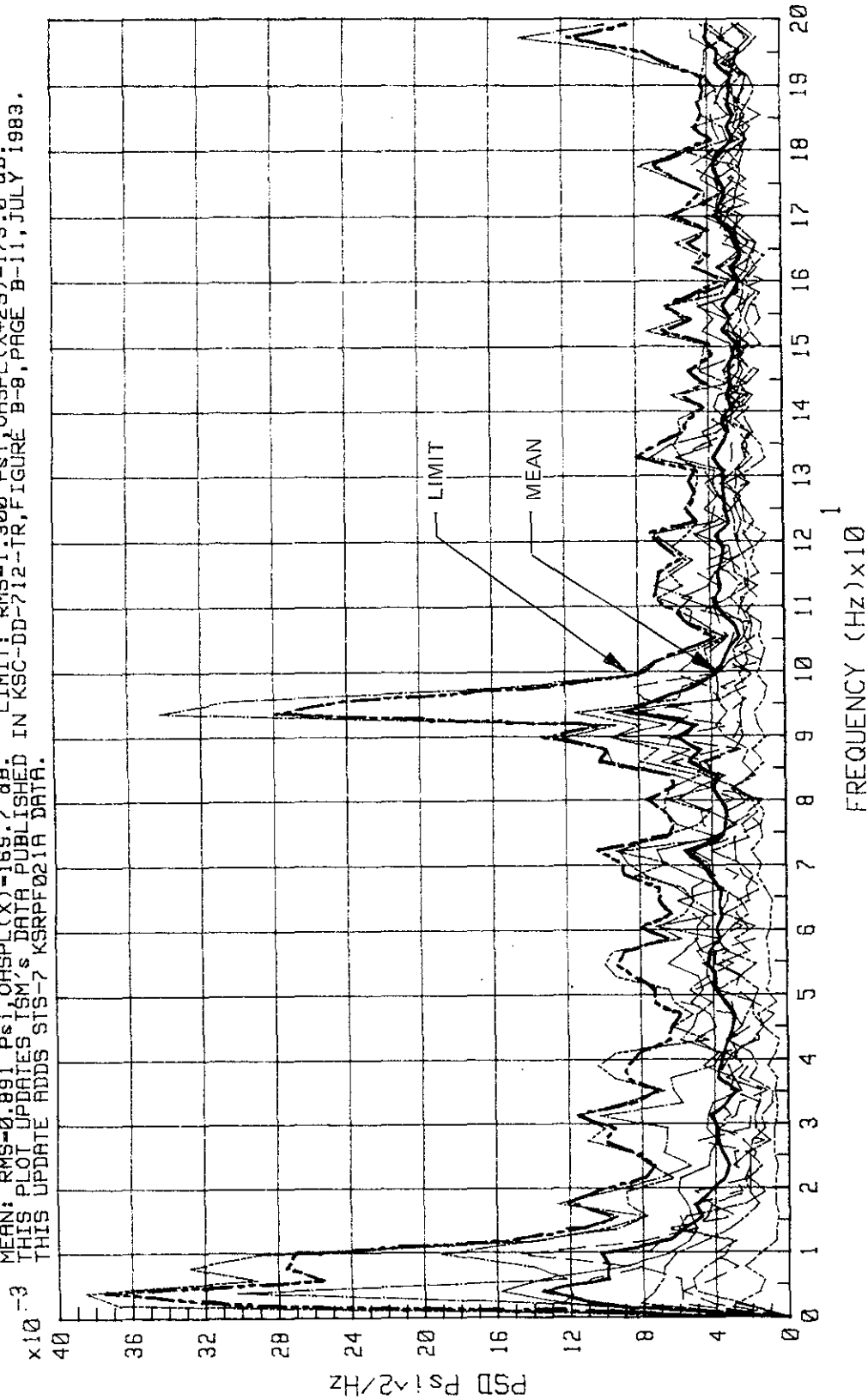
Figure 2-119. STS-4, -5, and -7 Acoustics on Top of TSM's at Lift-Off Peak - X and Y Directions

Table 2-1. Statistical Data From TSM Pressure Sensors
(X and Y Directions) for STS-1 Through STS-5 Launches

Octave Band Center Frequency (Hz)	Statistical Summary		
	Mean (50% CL) Sound Pressure Level ($\overline{X}$) (dB)	97.7% CL Sound Pressure Level ($\overline{X} + 2\sigma$) (dB)	97.7% CL Octave Band Average PSD (psi /Hz)
2	153.1	156.9	2.913 E-2
4	156.8	160.3	3.186 E-2
8	157.9	161.5	2.100 E-2
16	158.8	161.6	1.074 E-2
31.5	160.1	163.4	8.261 E-3
63	163.4	166.1	7.691 E-3
125	165.6	168.5	6.736 E-3
250	172.3	176.3	2.029 E-2
500	173.8	176.9	1.165 E-2
1,000	163.8	166.9	5.825 E-4
2,000	158.7	162.7	1.107 E-4
Overall sound pressure level (OASPL)	177.3	180.7	

NOTE

Statistical summary is applicable to north side of
TSM's, where measurements were made. STS-6 data
are not included because on MLP-2 all TSM sensors
are oriented downward (-Z direction) and data re-
corded at lift-off peak are lower than similar data
recorded on MLP-1 by sensors oriented horizontally
(X and Y directions). Presented data do not in-
clude pressures from impingement of SRB plumes de-
flected by the MLP deck O.

2.7 MLP EXTERIOR PRESSURES (SRB EXHAUST WELLS, SIDES 2 AND 4, AND BOTTOM)

This section presents exterior pressures recorded on MLP-1 and MLP-2 by sensors located in the SRB exhaust wells, on MLP sides 2 and 4, and on the MLP bottom (B-level). Since the pressures are distinctly transient at some locations, the data are presented in the time domain; however, when longer duration data are available, PSD's are plotted. Plot headings provide information on parameters used in data processing and on sensor locations. Figures 1-5 and 1-6 show the overpressure sensor locations for MLP-1 and MLP-2.

Figures 2-120 through 2-124 present STS-8 SRB ignition overpressure transients recorded by MLP-2 sensors at various locations on the sides of SRB exhaust wells. Data processing time interval T + 0.05 to T + 0.35 s includes highest recorded SRB ignition overpressure transients. All raw data were smoothed (Hanned) between 3 and 10 times in order to eliminate high-frequency noise, which obscures underlying pressure pulses. Figures 2-120 through 2-123 present overpressures at sensor locations below water spray nozzles. Figure 2-124 presents overpressures at locations above water spray nozzles and water troughs where pressures are substantially reduced by these devices.

Figures 2-125 through 2-128 present STS-9 SRB ignition overpressure transients recorded by MLP-1 sensors for the same time interval as above, T + 0.05 to T + 0.35 s. Although MLP-1 and MLP-2 sensors do not have an identical correspondence (their corresponding locations are slightly different), pressures recorded by corresponding groups of sensors are similar. Thus, corresponding STS-8 and STS-9 data are on figures 2-120 and 2-125 (south side), 2-121 and 2-126 (west side, primary well), 2-123 and 2-127 (west side, secondary well), and figures 2-124 and 2-128 (locations above water spray nozzles).

Figures 2-129 through 2-132 present STS-9 lift-off (T + 1.0 s to T + 11.0 s) pressures on different sides of the west SRB exhaust well measured by 14 sensors on MLP-1. These pressures, obtained from raw data by digital filtering (extraction of TVM) are slow varying pressure components that, in most applications, may be identified as "static"" loads. In this group, a few sensors were affected by heat, and their outputs did not return to ambient. Corresponding invalid data are noted in plot headings.

Dynamic pressures during STS-9 lift-off, obtained from the outputs of 14 sensors located in the west SRB exhaust well and using high-pass filter at 2 Hz, were processed in terms of PSD's. Figures 2-133 and 2-134 show raw and smoothed (Hanned) PSD's and derived mean and limit (limit = mean + 2 sigma) PSD's. The limit PSD is exceeded by only one measurement, KSRPF074A, located near the bottom of SRB secondary exhaust well. For application, both static (figures 2-129 through 2-132) and dynamic (figures 2-133 and 2-134) pressures should be considered to occur simultaneously, although peak rms pressures usually precede peak TVM by about 1 to 2 s.

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The summary of pressures on MLP sides 2 and 4 obtained from a total of 11 measurements is shown on figure 2-135. Sensors KSRPF037A through -40A were installed on MLP-1 only. They do not have counterparts on MLP-2. Sides 2 and 4 are shielded from direct exhaust impingement and no "static" type pressures were recorded. Recorded maximum rms pressures are below those on the FSS, probably because of diffraction effects and shielding (sensor orifices cannot "see" exhaust plumes).

Pressures on the bottom of MLP were measured by three sensors, KSRPF062A and -60A on MLP-1, and KSRPG014A on MLP-2. Figures 2-136 through 2-138 present typical pulses occurring during SRB ignition. These pulses are higher than TVM pressures occurring at lift-off shown on figure 2-139. Corresponding dynamic pressures at lift-off at locations of KSRPF062A and KSRPG014A (between T-1 and G-13) are shown on figure 2-140 with enlarged plots on figure 2-141 and 2-142. Similarly, pressures between SRB exhausts are shown on figures 2-143 through 2-145. It should be noted that pressure pulses at SRB ignition and TVM at lift-off show highest "static" type, slow varying pressures to be negative; thus, as load, their prevailing effect is downward. PSD's on figures 2-141 and 2-144 have a peak around 4 Hz near fundamental MLP resonance and apparently these pressures, in addition to MLP level 0 pressures, are responsible for relatively large MLP motions in the vertical direction.

Figure 2-120. STS-8 SRB Ignition - West SRB, Main Exhaust Well Pressures,
T + 0.05 s to T + 0.35 s (MLP-2 Sensors on Side 1)
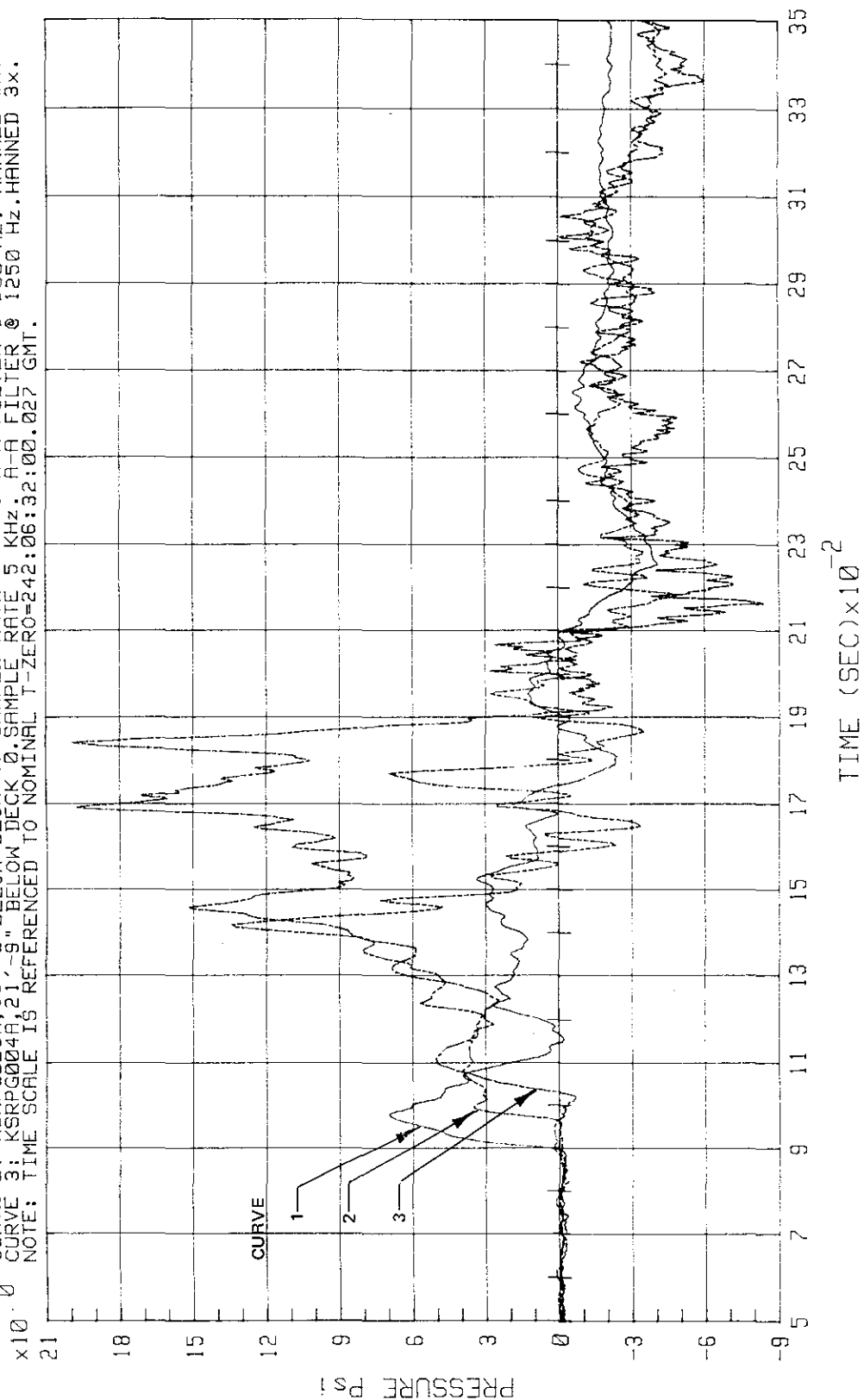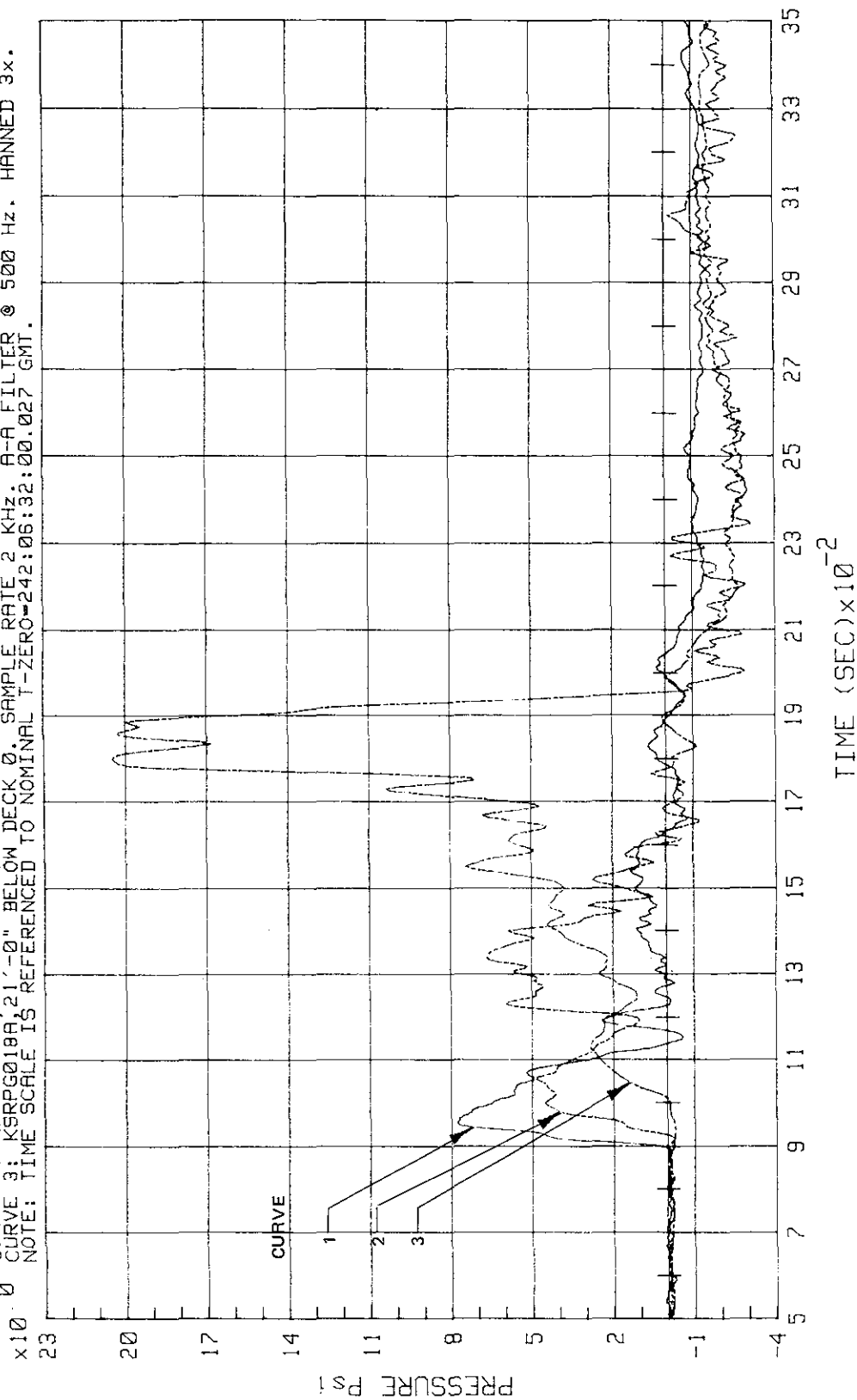
Figure 2-121. STS-8 SRB Ignition - West SRB, Main Exhaust Well Pressures
T + 0.05 s to T + 0.35 s (MLP-2 Sensors on Side 2)
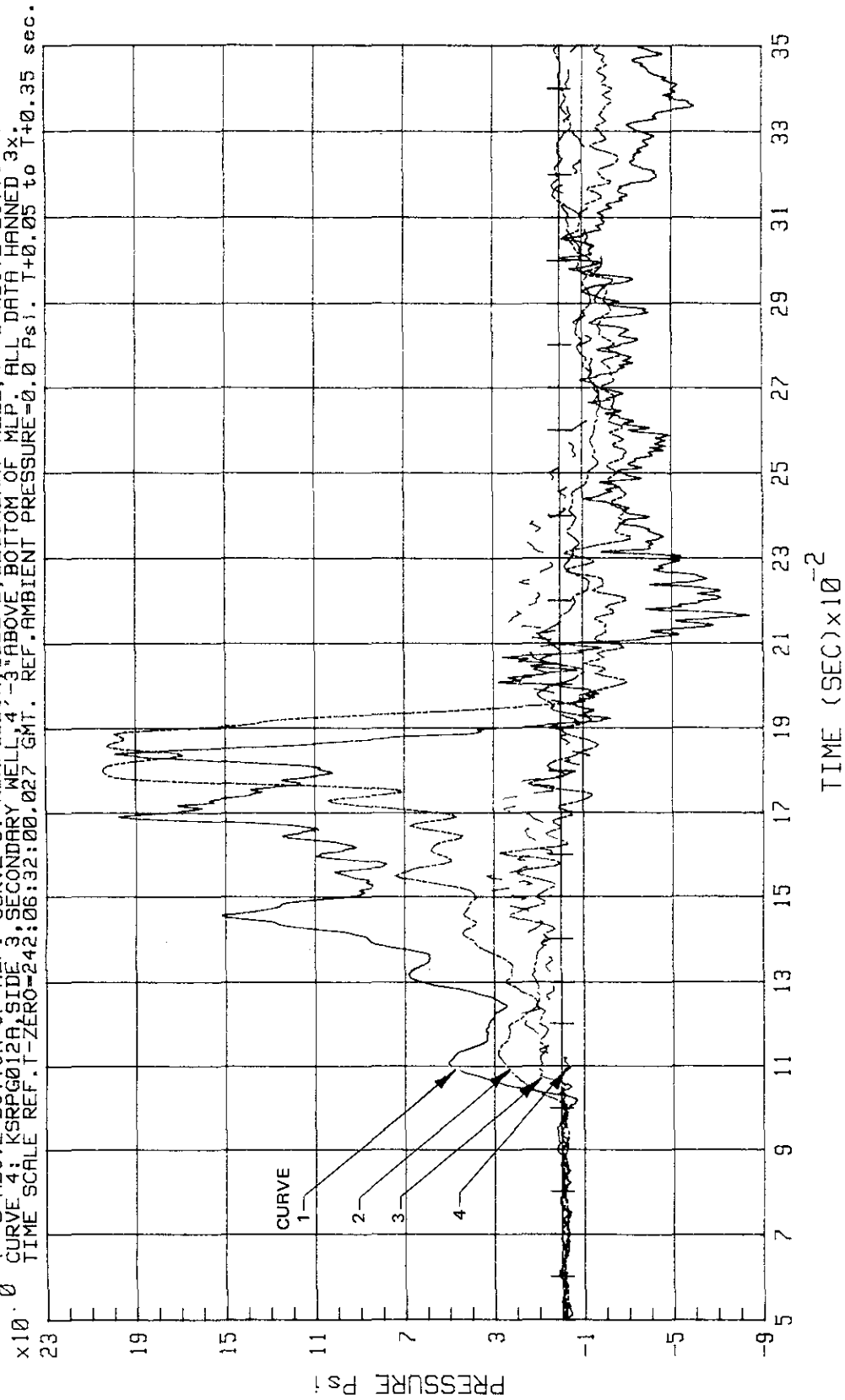
Figure 2-122. STS-8 SRB Ignition – Pressures at Bottom of West SRB Exhaust Well

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Figure 2-123. STS-8 SRB Ignition - West SRB, Secondary Exhaust Well Pressures, T + 0.05 s to T + 0.35 s

2-136

Figure 2-124. STS-8 SRB Ignition - West Exhaust Well Pressures Above Sound Suppression Water System

2-137

Figure 2-125. STS-9 SRB Ignition - West Exhaust Well Pressures Below Sound Suppression Water System (MLP-1 Sensors on South Side of West Exhaust Well)

Figure 2-126. STS-9 SRB Ignition - West Exhaust Well Pressures Below Sound Suppression Water System (MLP-1 Sensors on West Side of Primary West Exhaust Well)

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Figure 2-127. STS-9 SRB Ignition – West Secondary Exhaust Well Pressures Below Sound Suppression Water System

Figure 2-128. STS-9 SRB Ignition - West Exhaust Well Pressures Above Sound Suppression Water System

Figure 2-129. STS-9 Lift-Off - West Primary Exhaust Well Pressures, South Side 1, Static Load

FILE: PFT63C PFT64C PFT65C PFT66C

MLP-1 SENSORS ON WEST SIDE 2 OF PRIMARY WEST EXHAUST WELL. EXTRACTED TIME VARIABLE MEAN.
CURVE 1: KSRPF063A,2.5' BELOW DECK 0. CURVE 2: KSRPF064A,6.3' BELOW DECK 0.
CURVE 3: KSRPF065A,11.0' BELOW DECK 0. CURVE 4: KSRPF066A,16.0' BELOW DECK 0.
SAMPLING RATE 200 Hz. A-A FILTER @ 50 Hz. ALL DATA HANNED 500x. FROM T+1.0 TO T+11.0 sec.
TIME SCALE REFERENCED TO T-ZERO.
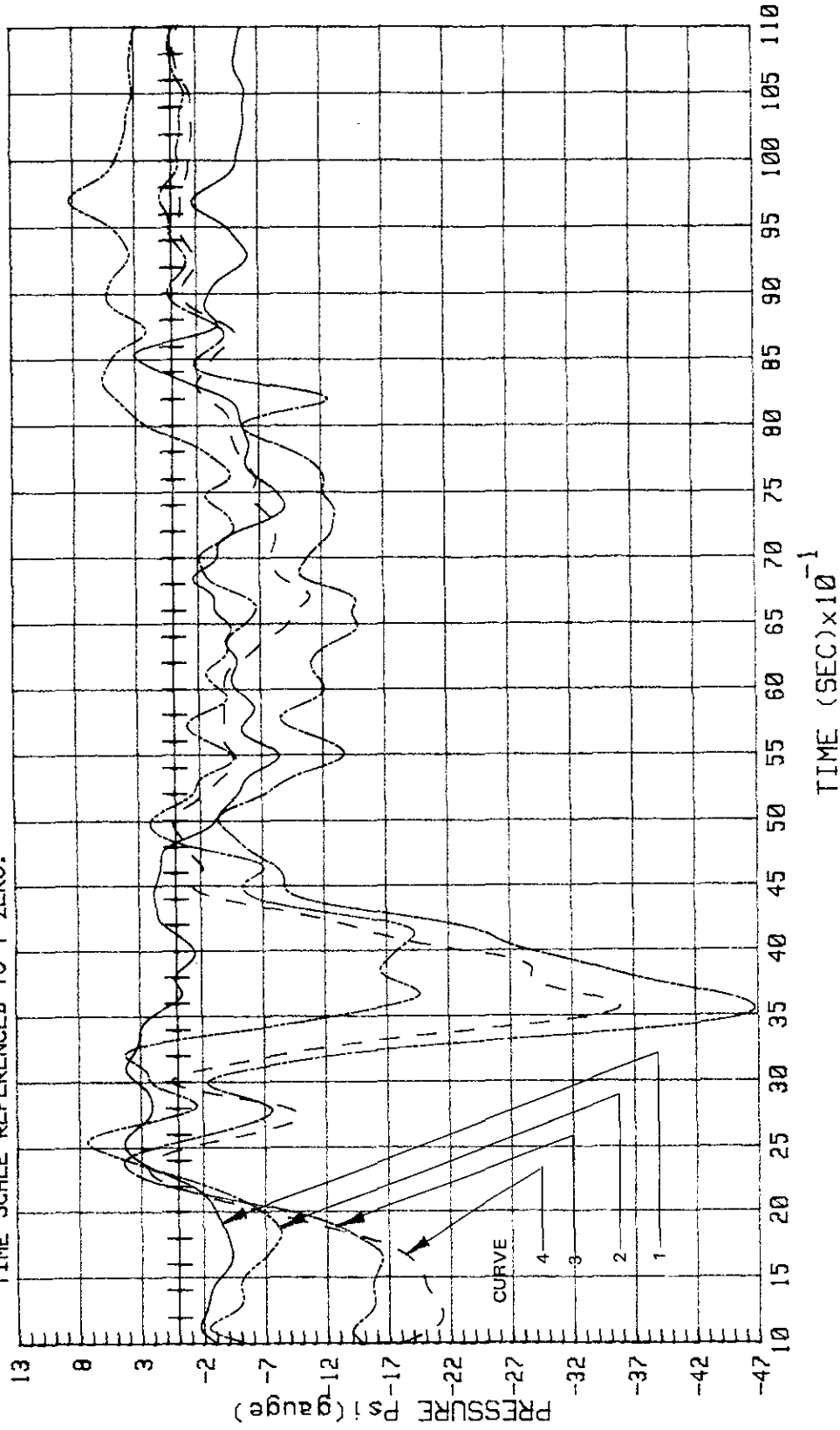
Figure 2-130.   STS-9 Lift-Off - West Primary Exhaust Well Pressures, West Side 2, Static Load
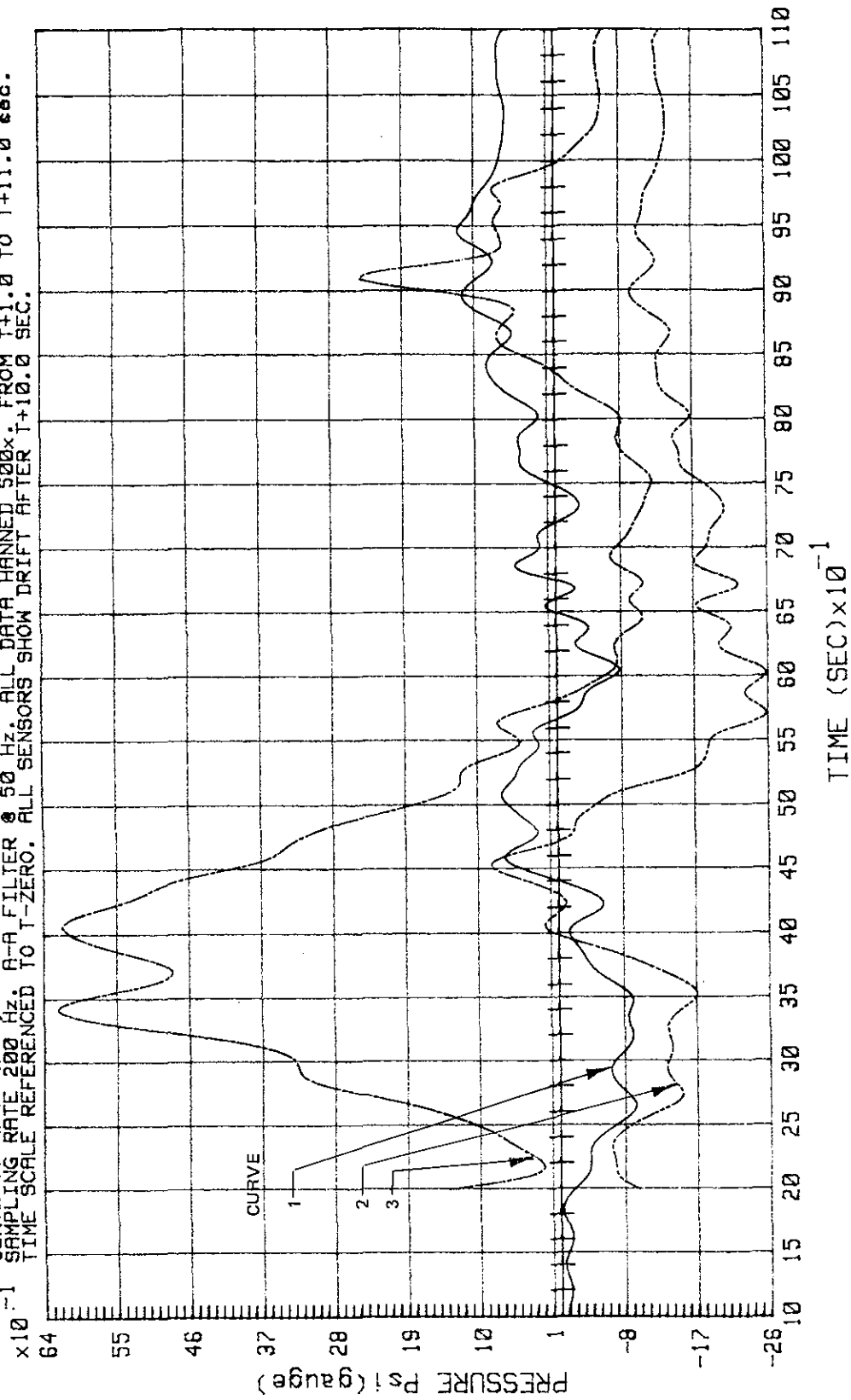
Figure 2-131. STS-9 Lift-Off - West Secondary Exhaust Well Pressures, West Side 2, Static Load
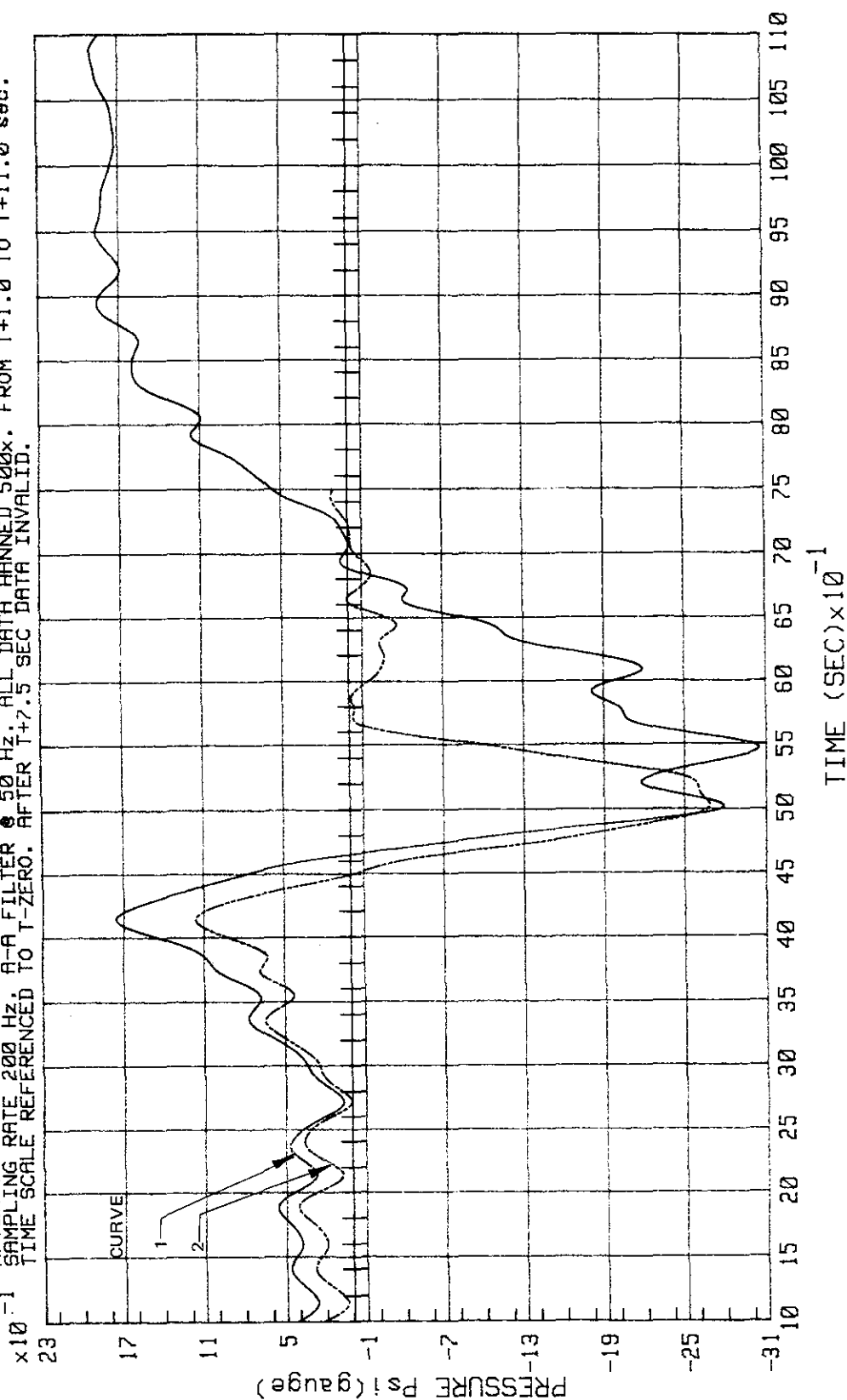
Figure 2-132. STS-9 Lift-Off - West Secondary Exhaust Well Pressures, North Side 3, Static Load
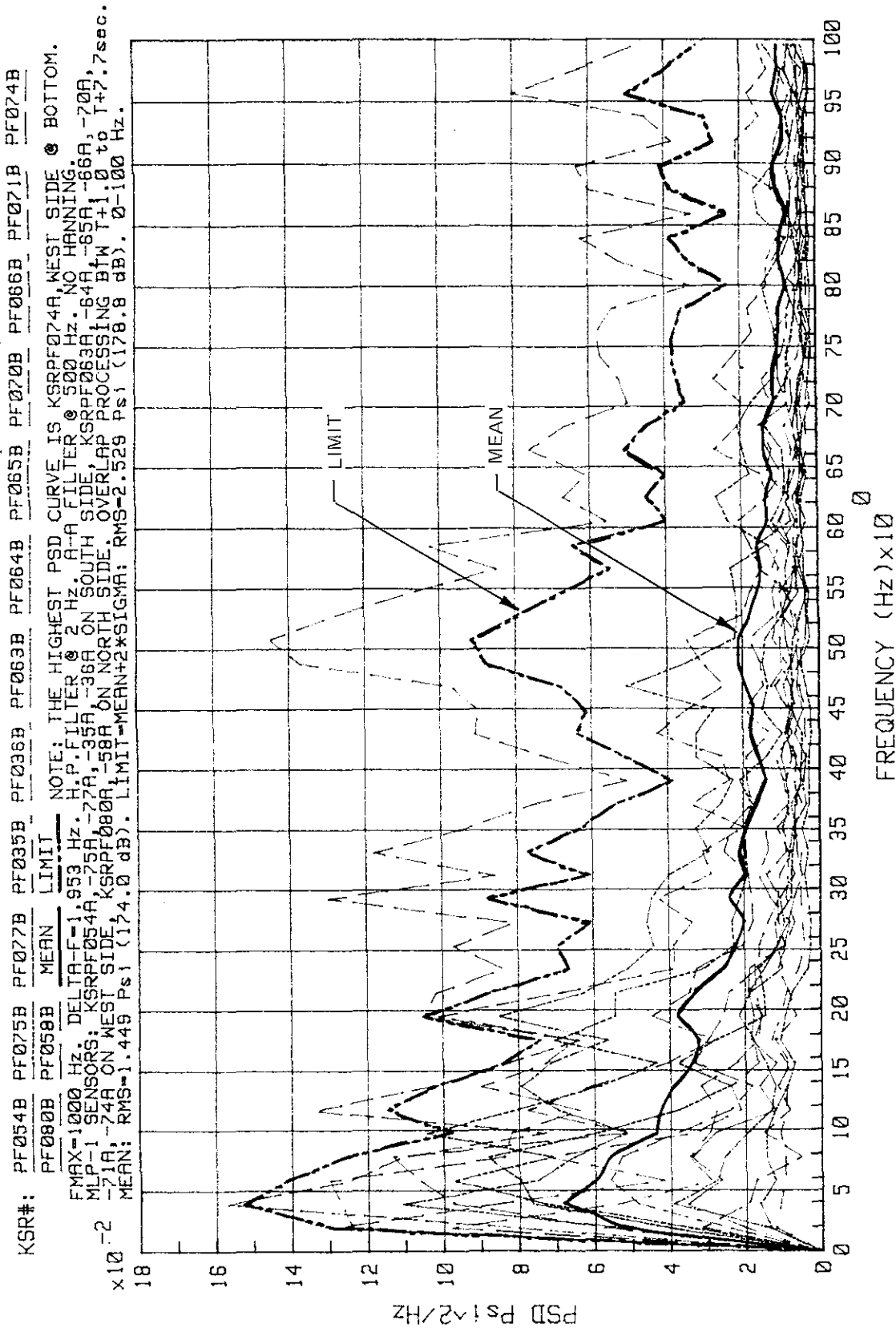
Figure 2-133. STS-9 Lift-Off Peak - West Exhaust Well Pressures, Dynamic Part, Raw PSD's
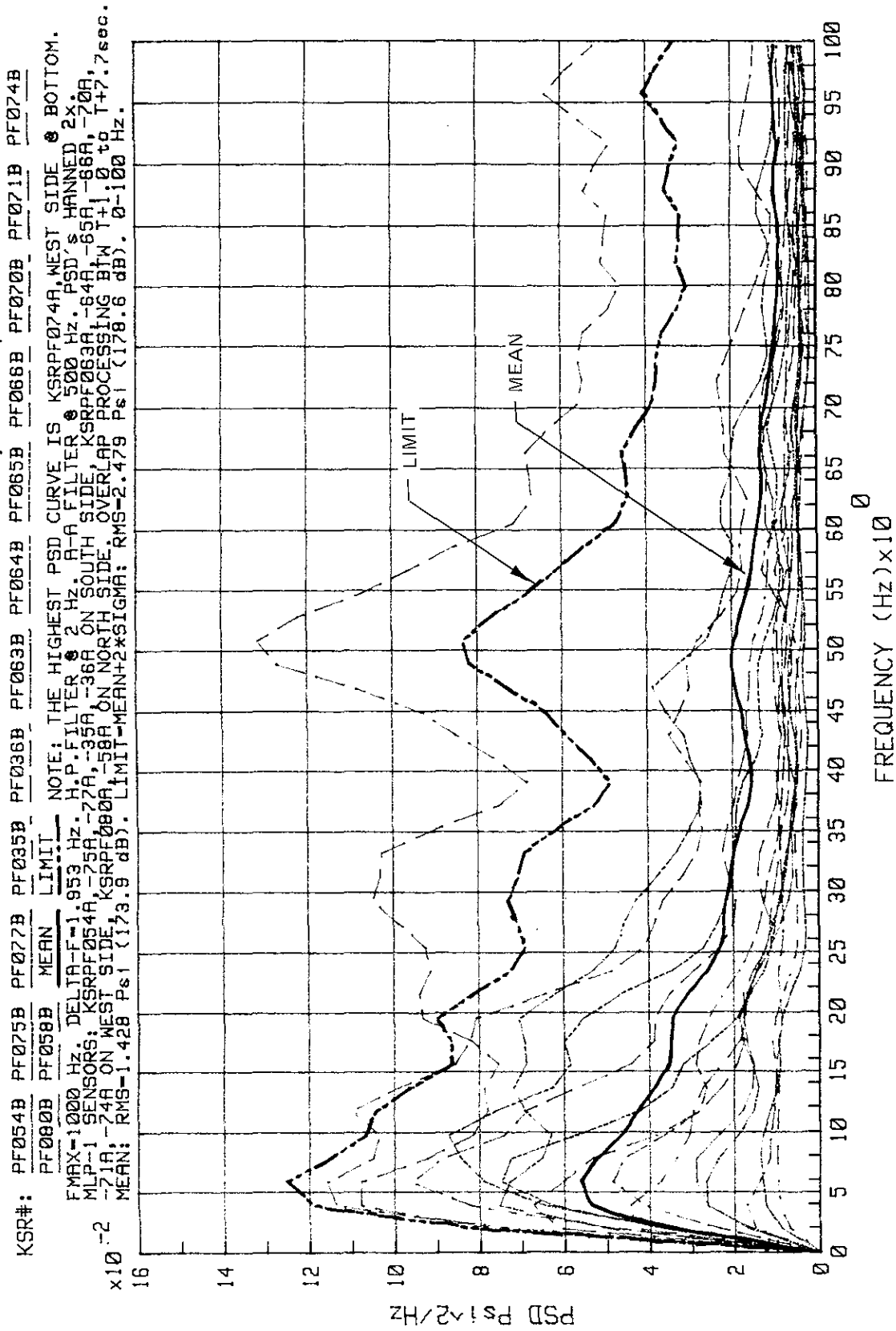
Figure 2-134. STS-9 Lift-Off Peak - West Exhaust Well Pressures, Dynamic Part (Hanned)
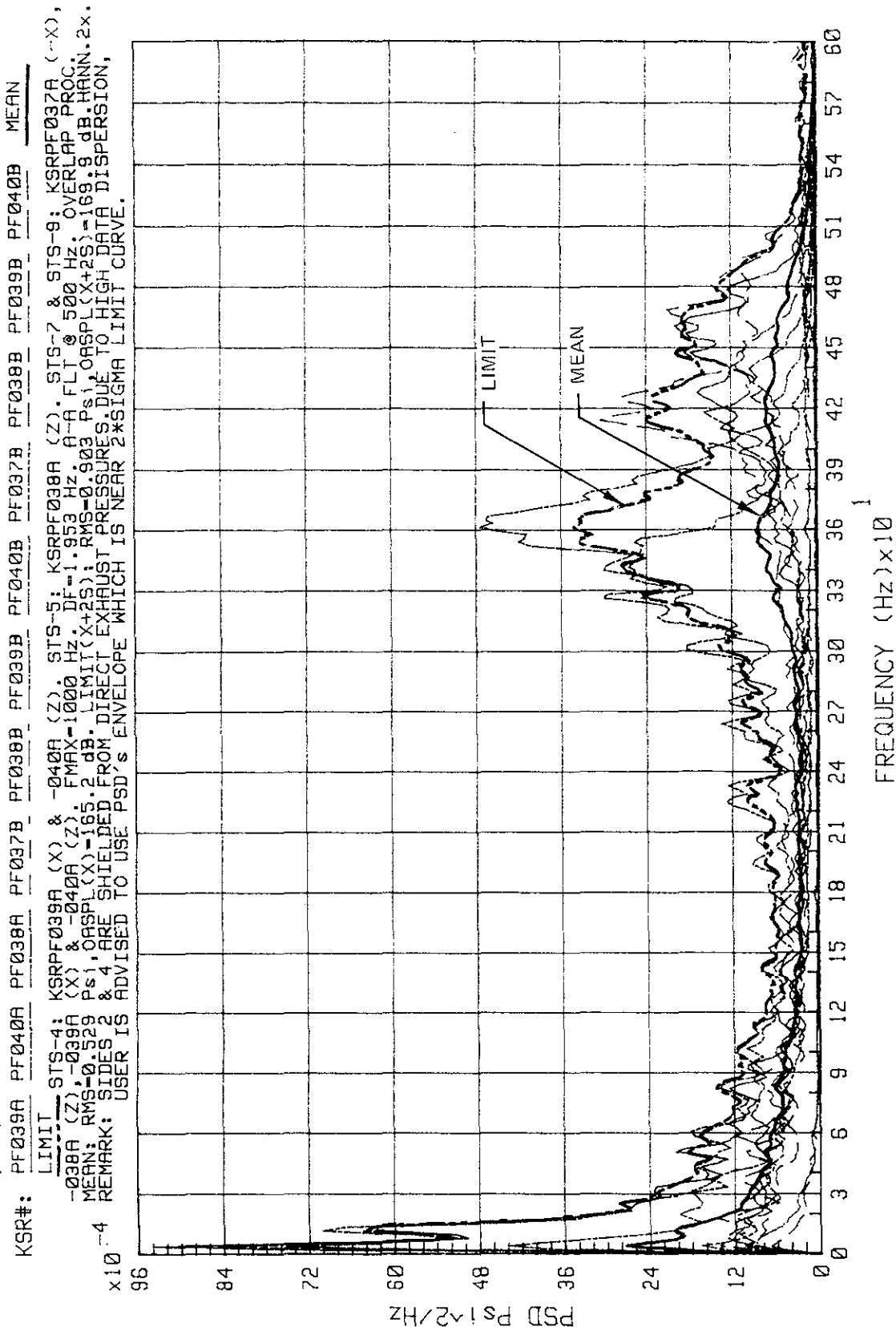
Figure 2-135. STS-4, -5, -7, and -9 Lift-Off Peak - Acoustics on Sides 2 and 4 of MLP-1
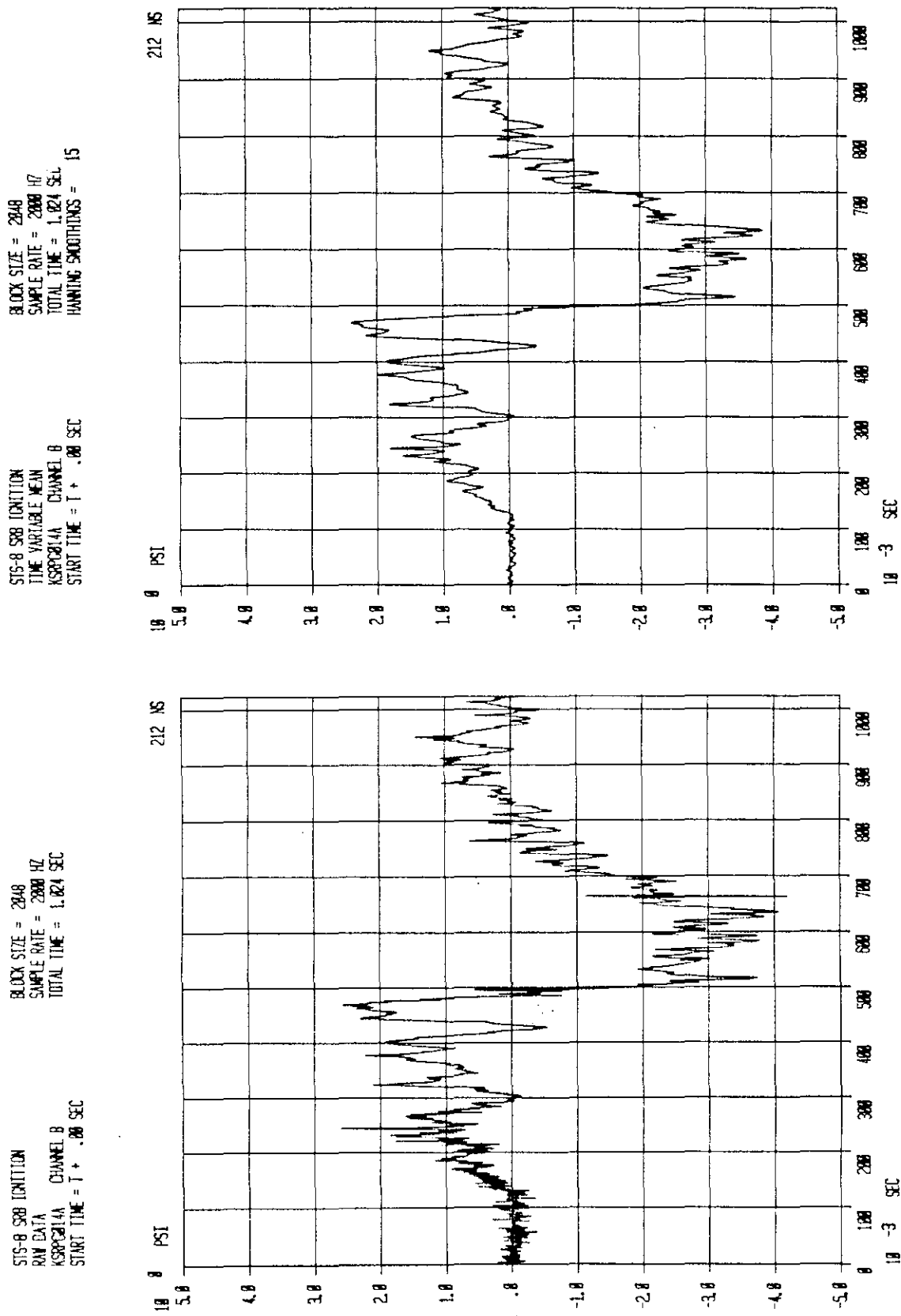
Figure 2-136.   STS-8 SRB Ignition - KSRPG014A Raw Data and TVM
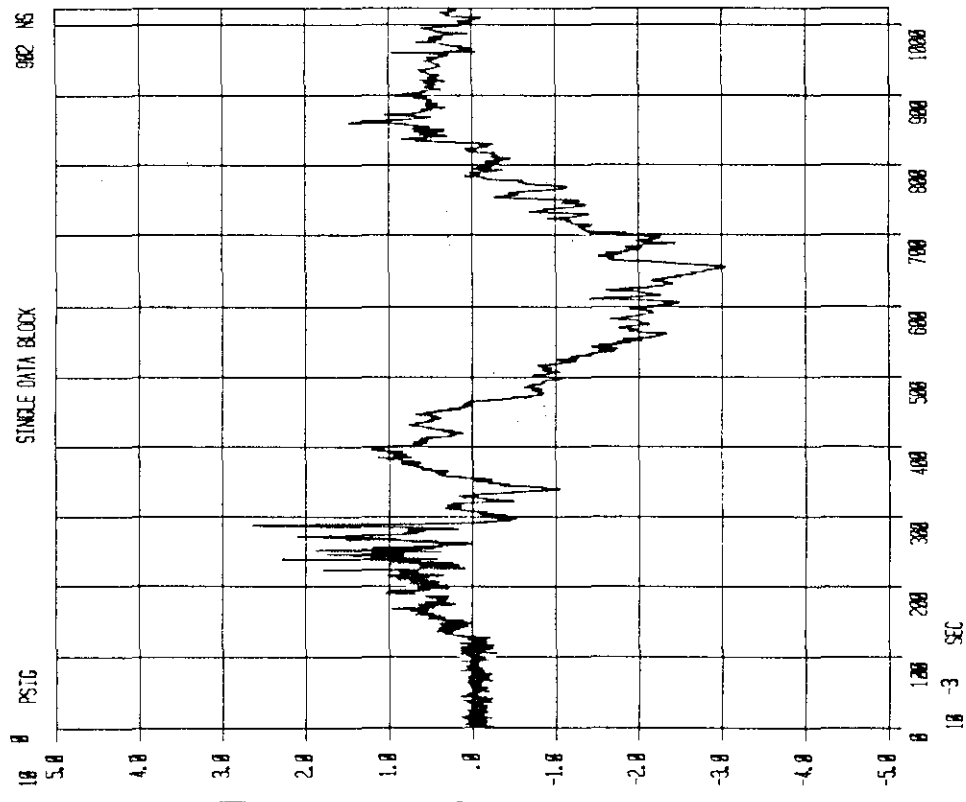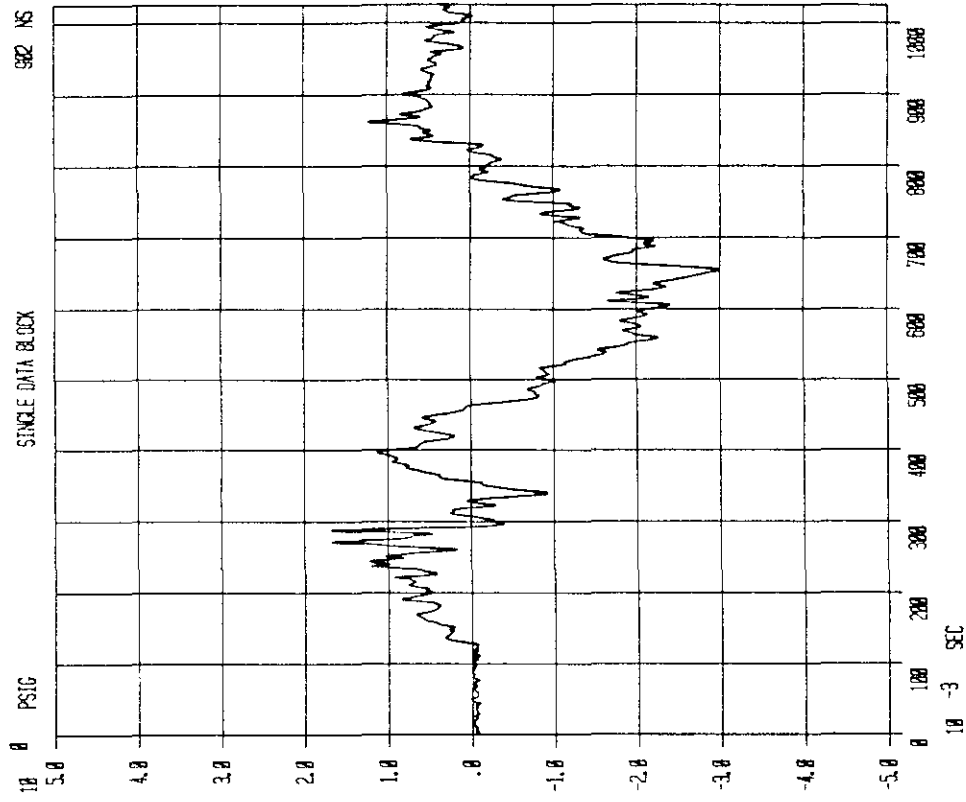
Figure 2-137. STS-9 SRB Ignition - KSRPF062A Raw Data and TVM
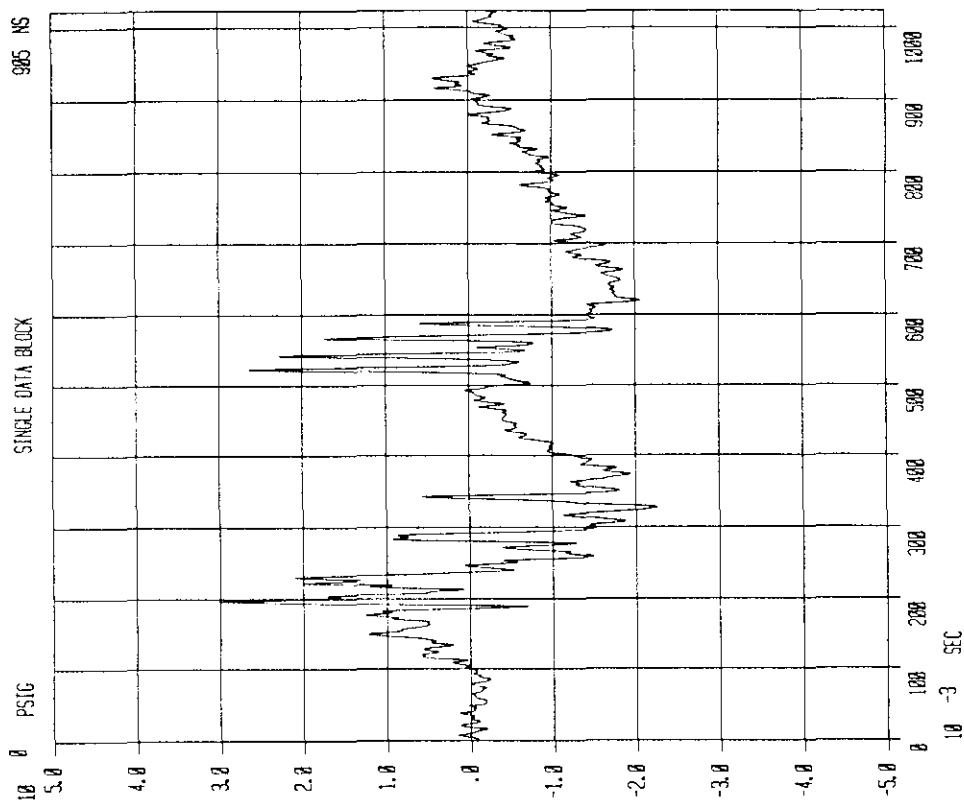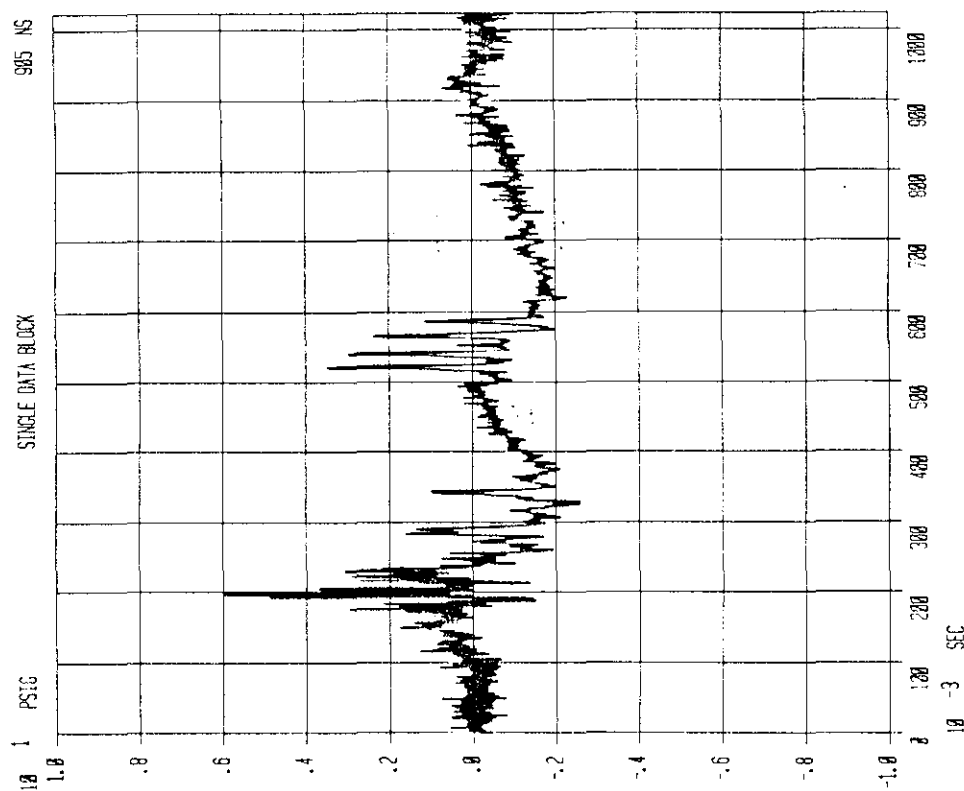
Figure 2-138. STS-9 SRB Ignition - KSRPF060A Raw Data and TVM
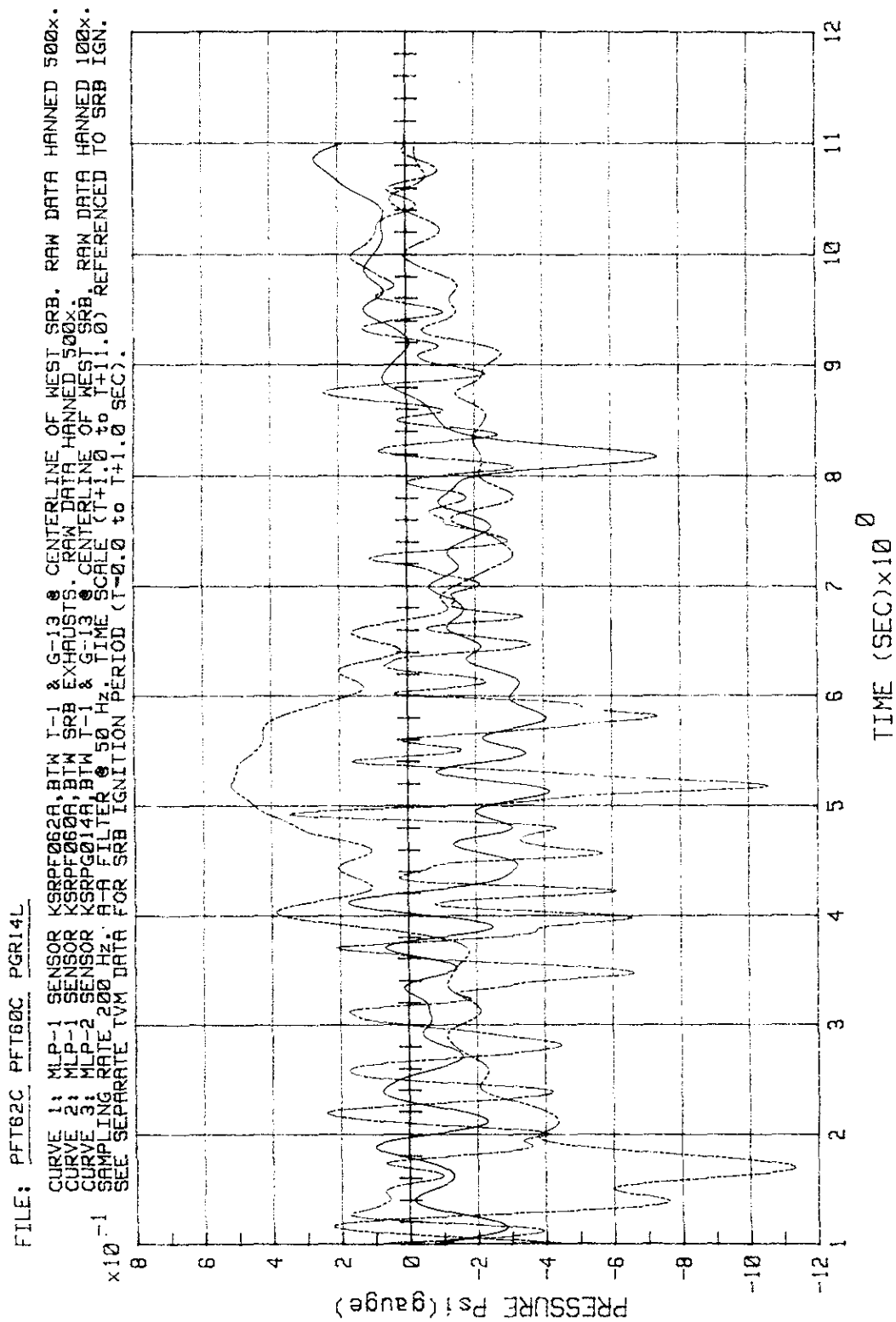
Figure 2-139. STS-8 and -9 MLP-1 and MLP-2 Pressures on B Level, TVM
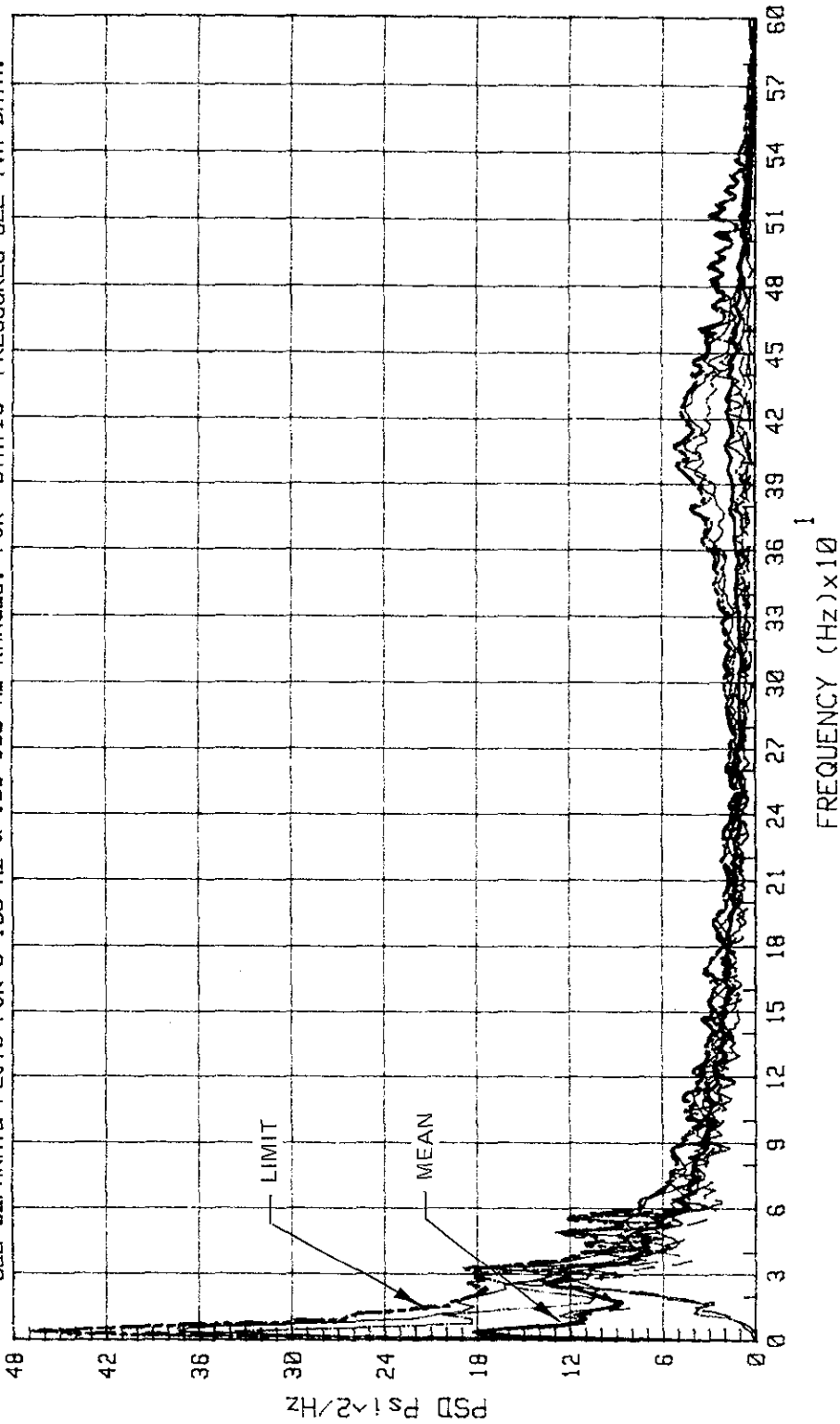
Figure 2-140. STS-4 Through -9 MLP-1 and MLP-2 Pressures on B Level
Between T-1 and G-13, Dynamic Part
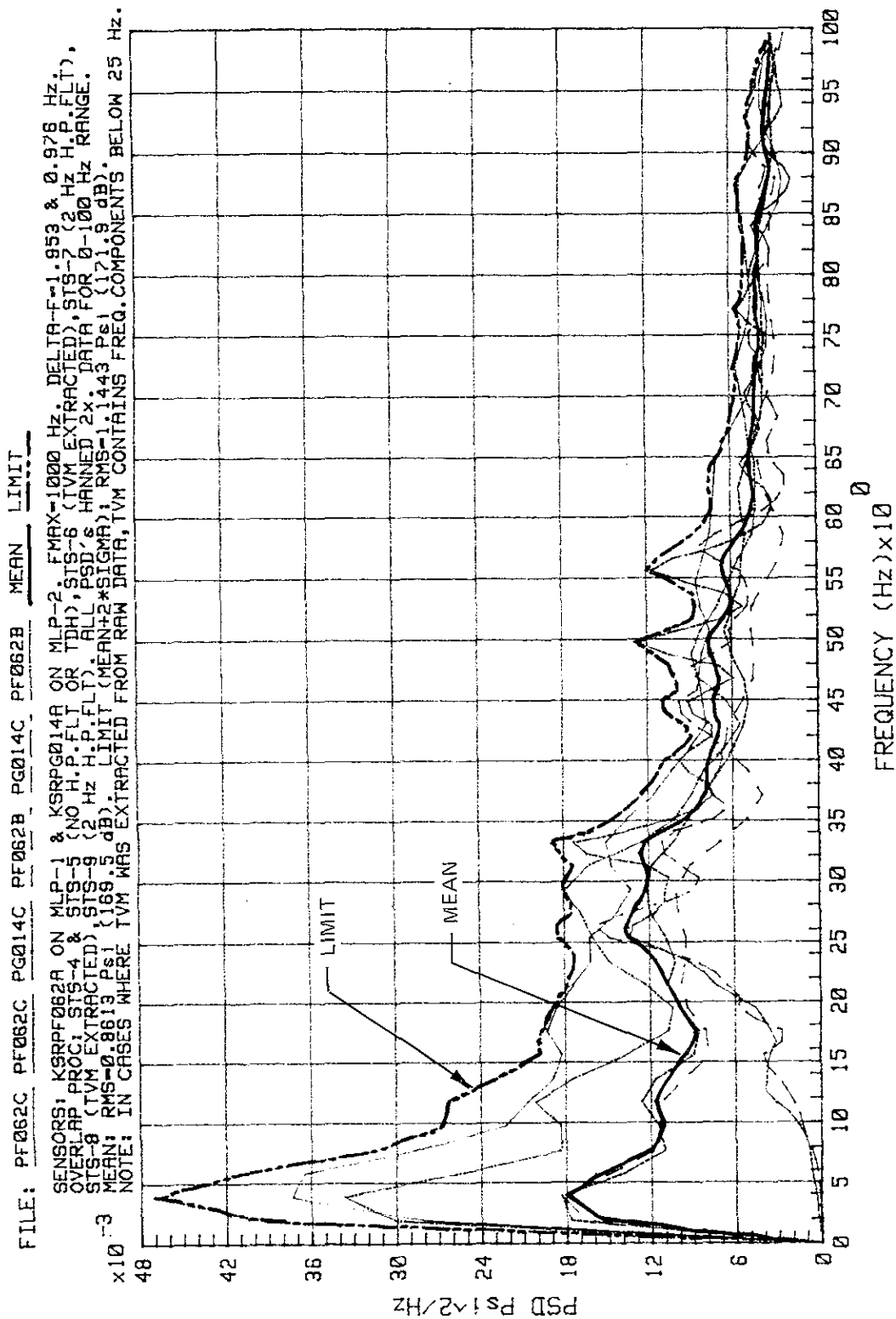
Figure 2-141. STS-4 Through -9 MLP-1 and MLP-2 Pressures on B Level
Between T-1 and G-13, 0 to 100 Hz
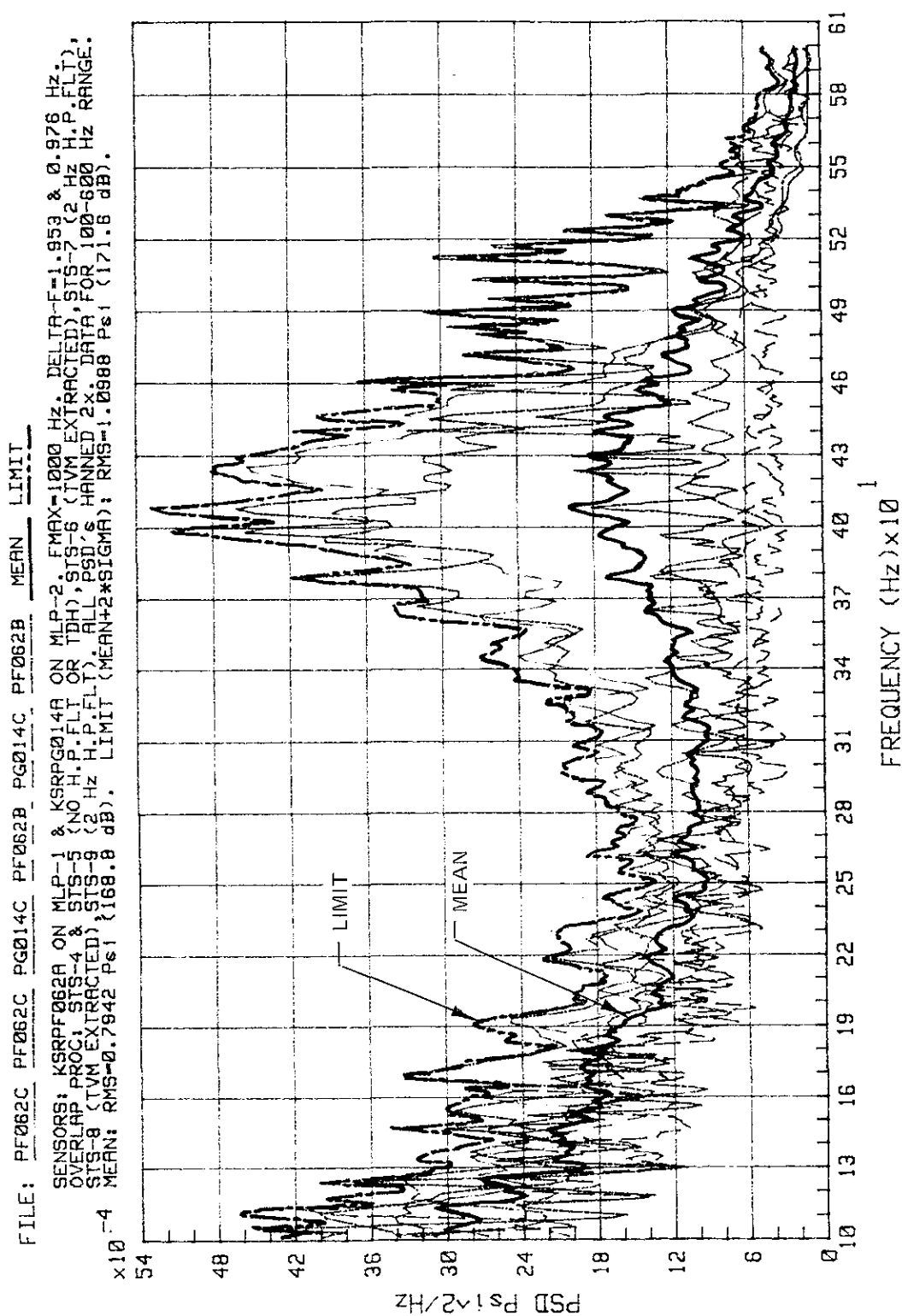
Figure 2-142. STS-4 Through -9 MLP-1 and MLP-2 Pressures on B Level
Between T-1 and G-13, 100 to 600 Hz
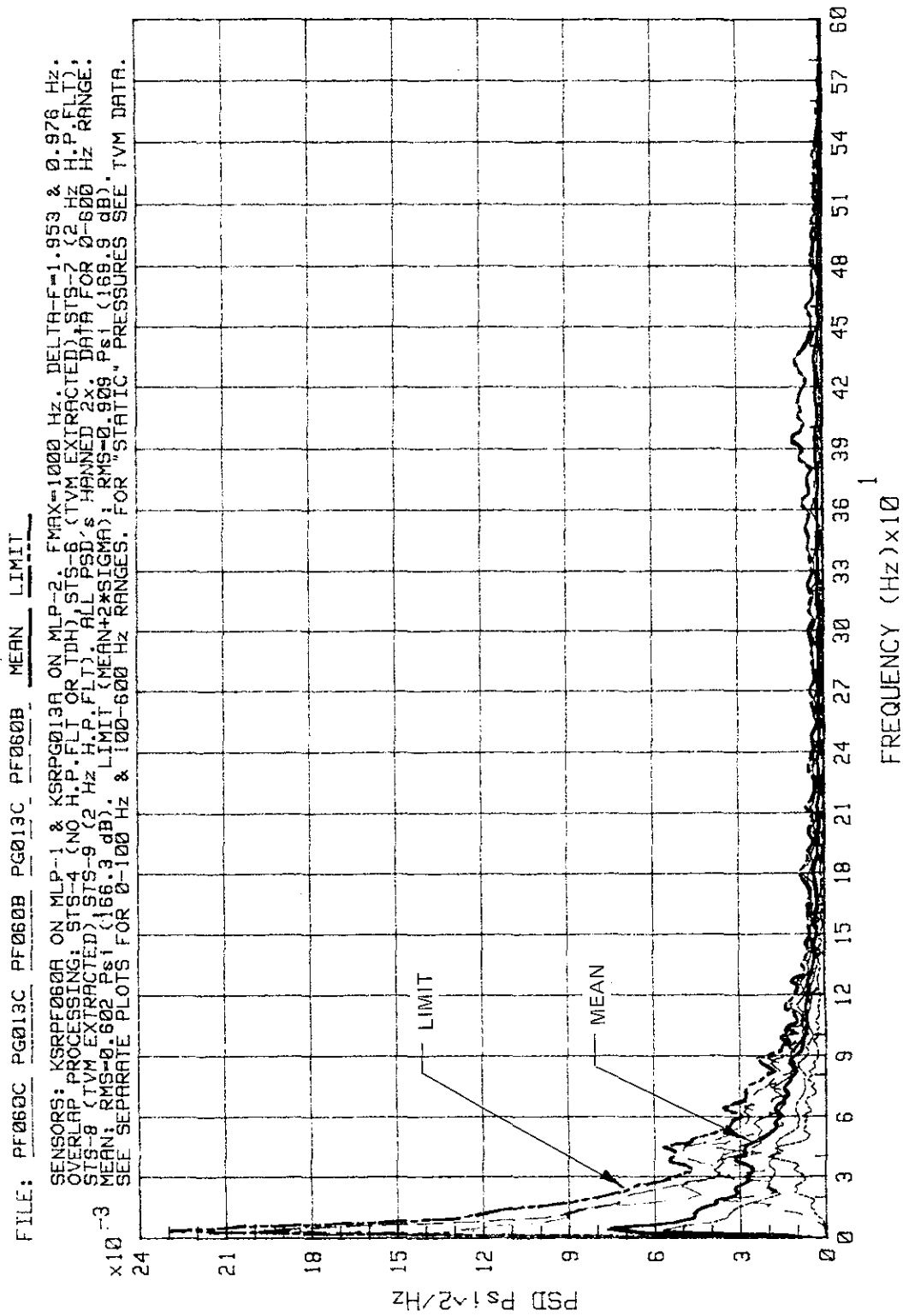
Figure 2-143. STS-4 and -6 Through -9 MLP-1 and MLP-2 Pressures on B Level Between SRB Exhausts, Dynamic Part
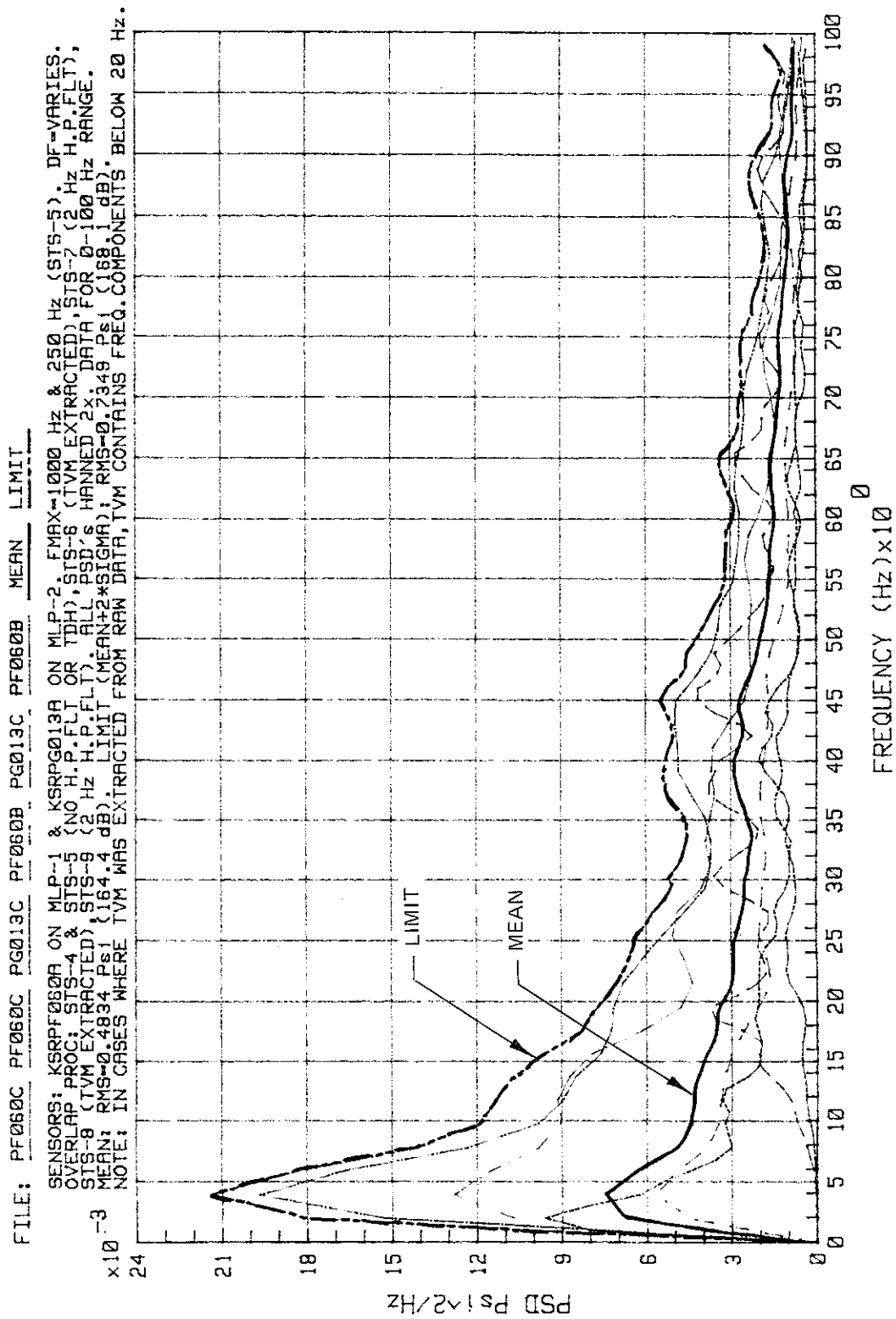
Figure 2-144. STS-4 Through -9 MLP-1 and MLP-2 Pressures on B Level Between
SRB Exhausts, 0 Hz to 100 Hz
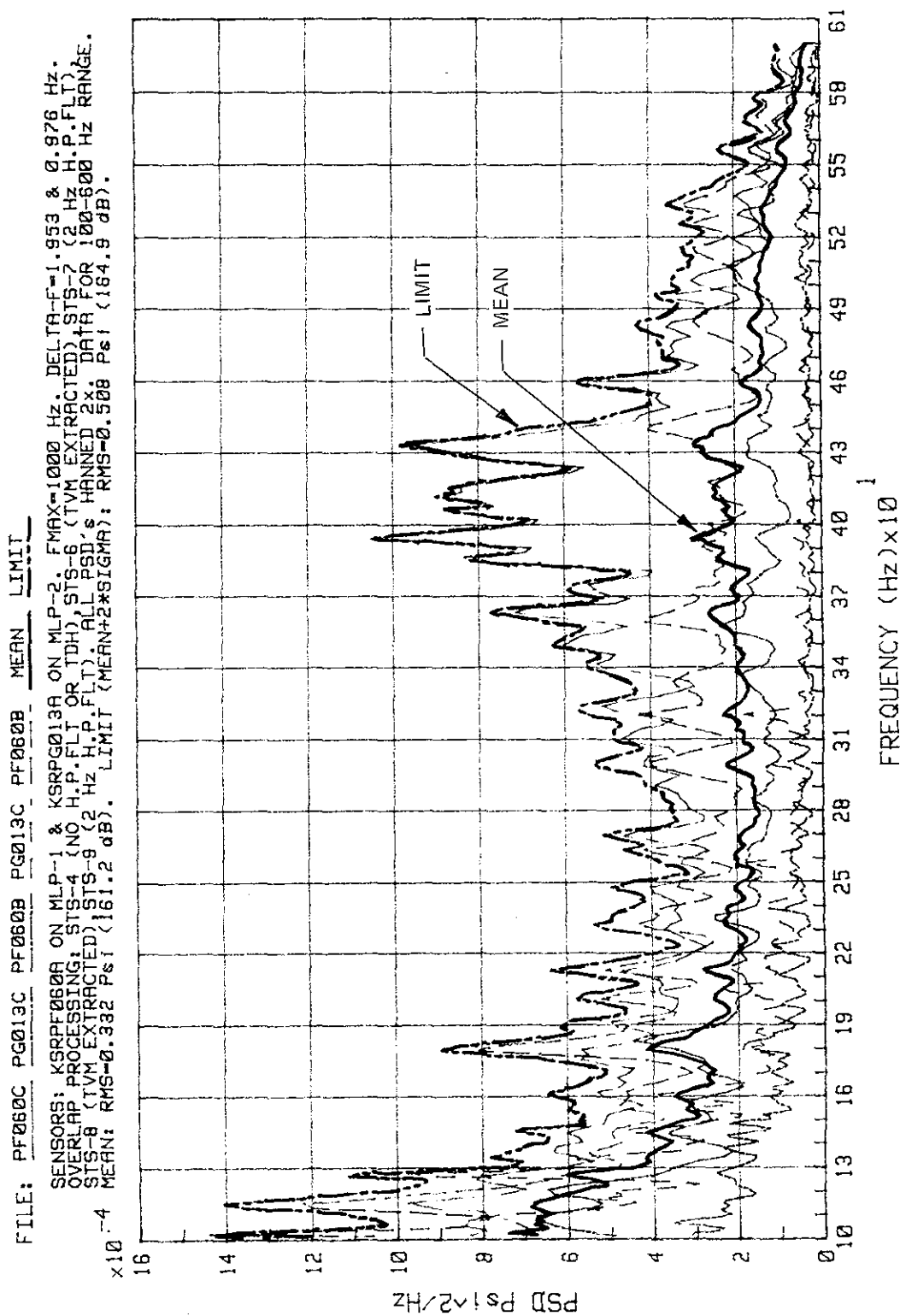
Figure 2-145. STS-4 and -6 Through -9 MLP-1 and MLP-2 Pressures on B Level
Between SRB Exhausts, 100 Hz to 600 Hz

2.8 WEST SIDE DEFLECTOR PRESSURES

This summary of pressures on the west side deflector is based on data from
sensors KRFPA006A, -07A, and -08A, recorded during the launch of STS-8 and
STS-9.

Figures 2-146 and 2-147 present raw data time histories for a short interval
(T + 0.15 s to T + 0.35 s) when the highest pressure pulses occur. Figures
2-148 through 2-150 compare outputs of the same sensors for two launches. Of
interest are the highest pressure peaks on these figures. All three sensors
recorded these peaks for STS-9, while only KFDPA008A recorded such a peak for
STS-8. The timing of these peaks (KFDPA006A with 27 psi at T + 0.269 s,
KFDPA007A with 100 psi at T + 0.272 s, and KFDPA008A with 106 psi at T + 0.293
s) indicates their propagation to occur from the middle of the side deflector
downward with a velocity that is substantially less than the speed of sound.
Thus, the source of these peaks is the main SRB plume at ignition and not the
deflected plume, as supposed.

Figure 2-151 presents a summary of slow varying "static" pressures for time
interval T + 0.5 s to T + 5.6 s. At each sensor location, these pressures are
repeatable between launches. A high pressure gradient exists along the height
of the deflector from T + 0.5 s until T + 3.5 s, with increasing pressures
toward the base of the deflector.

The summary of dynamic pressures is shown on figure 2-152 in terms of PSD's.
A 2-Hz high-pass filter was used to separate dynamic components from the
static components shown on figure 2-151. PSD's show a similar dispersion
along the height of the deflector as do the slow varying pressure components.
Highest dynamic pressures occur at the base of the deflector.

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Figure 2-146. STS-8 SRB Ignition -
West Side Deflector Pressures, T + 0.15 s to T + 0.35 s

2-160

Figure 2-147. STS-9 SRB Ignition -
West Side Deflector Pressures, T + 0.15 s to T + 0.35 s

Figure 2-148. STS-8 and -9 SRB Ignition - West Side Deflector Pressures, T + 0.15 s to T + 0.35 s, Sensor KFDPA006A

FILE: PAR07I PAR07I

SAMPLING RATE 2 KHz. A-A FILTER @ 500 Hz. NO HANNING. TIME SCALE REFERENCED TO T-ZERO.
SENSOR KFDPA007A, BELOW MIDDLE OF DEFLECTOR. SOLID LINE IS STS-8 MEASUREMENT.
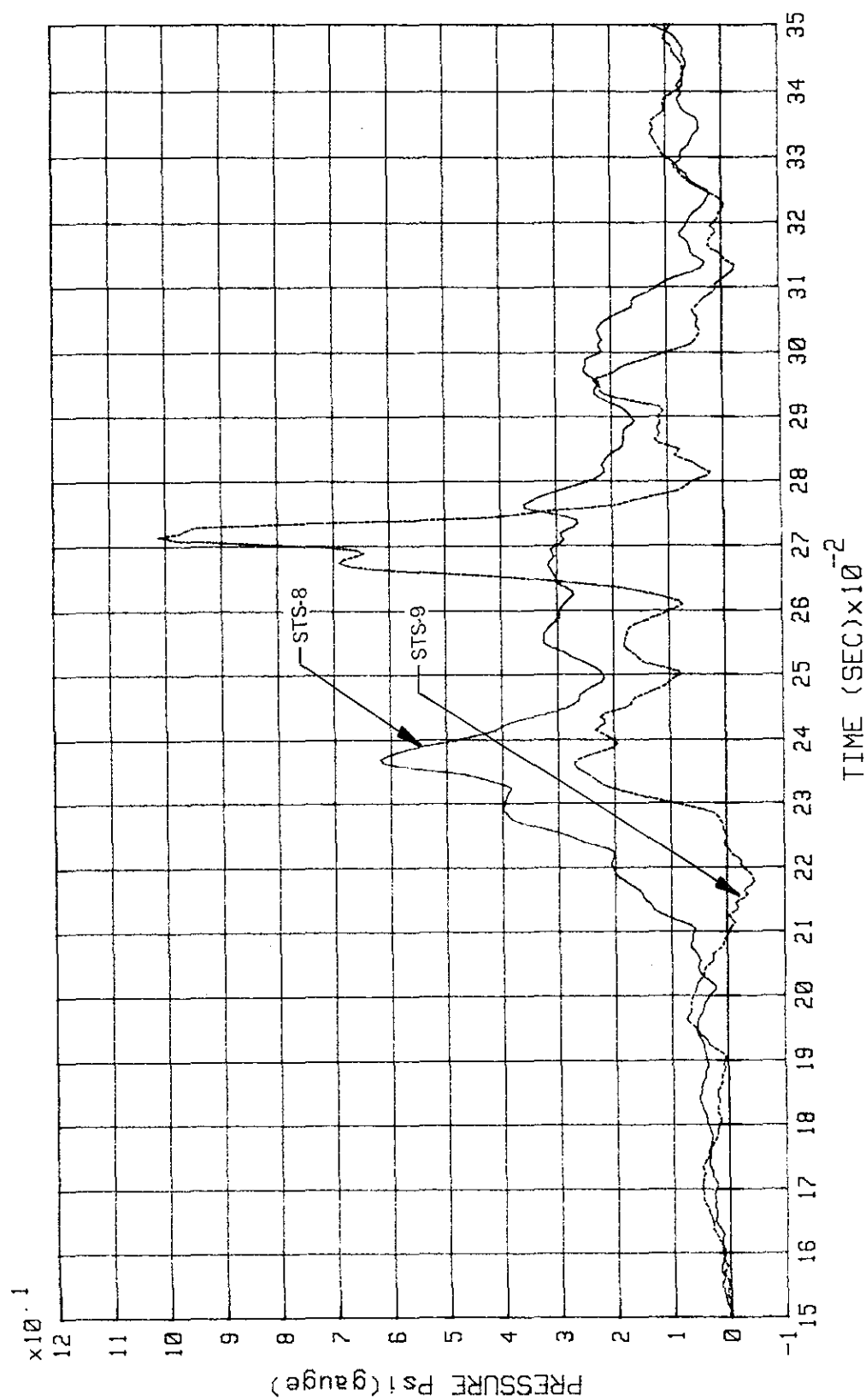
Figure 2-149. STS-8 and -9 SRB Ignition - West Side Deflector Pressures,
T + 0.15 s to T + 0.35 s, Sensor KFDPA007A

KSC-DD-818-TR
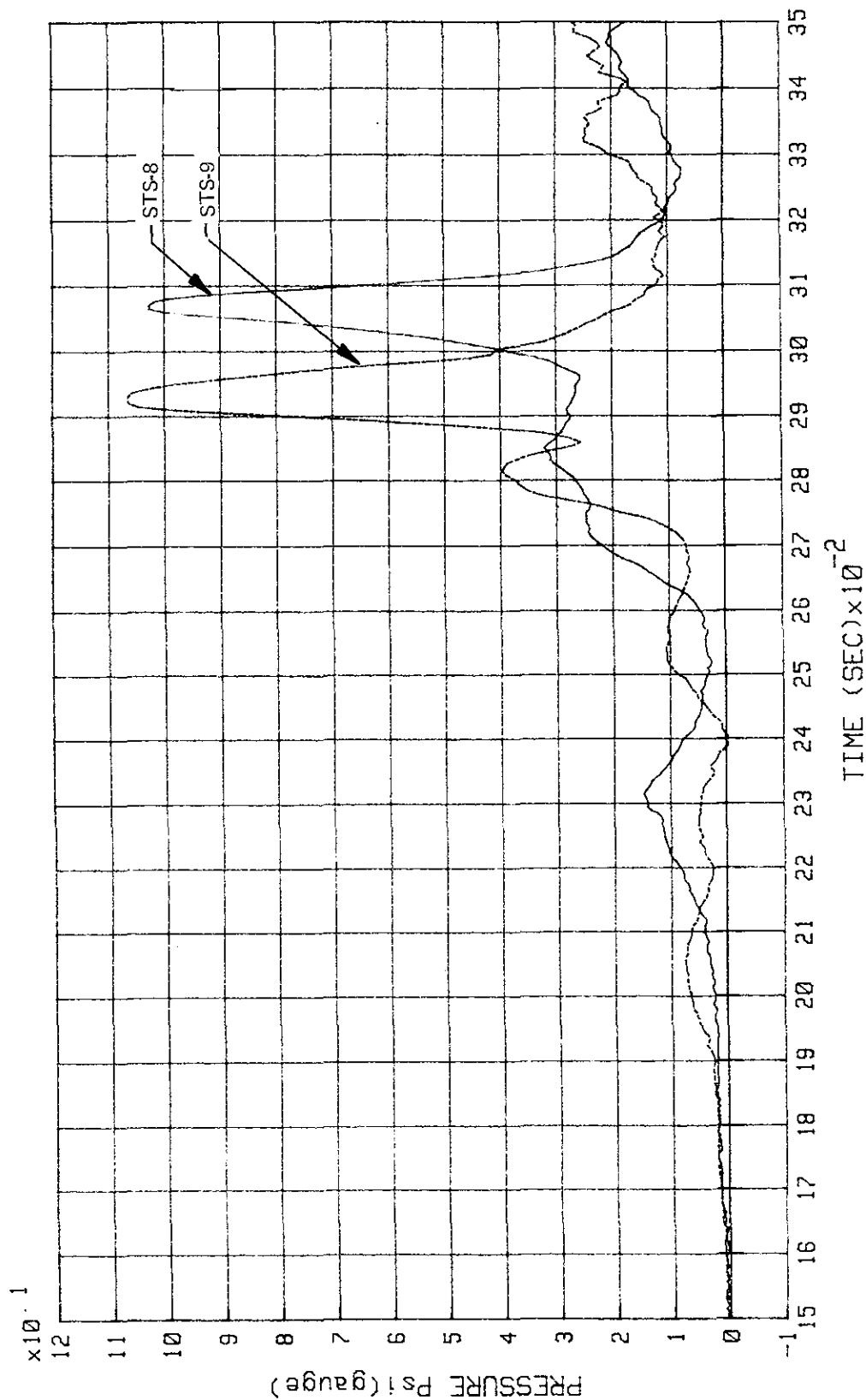
Figure 2-150. STS-8 and -9 SRB Ignition - West Side Deflector Pressures, T + 0.15 s to T + 0.35 s, Sensor KFDPA008A
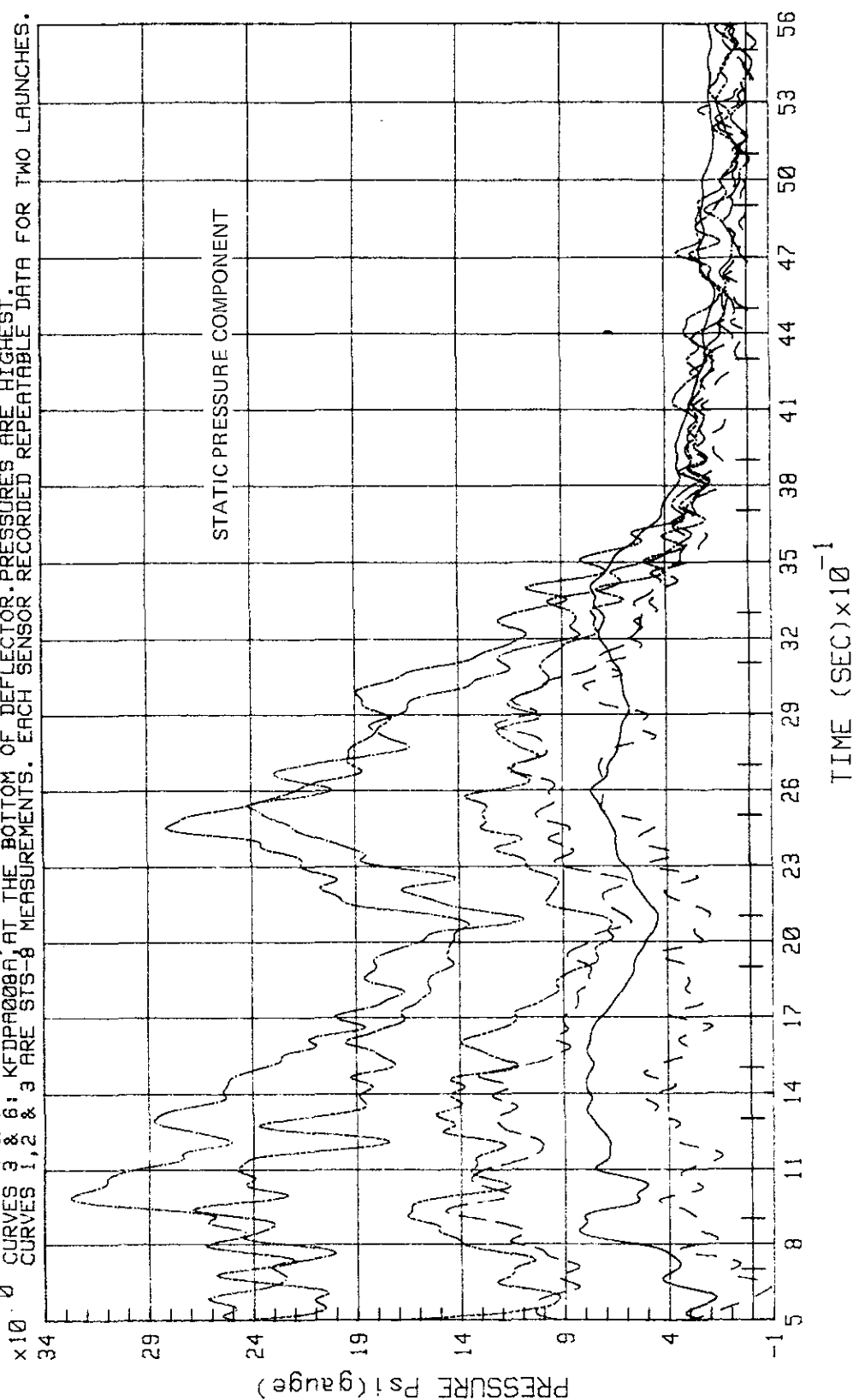
Figure 2-151. STS-8 and — 9 Lift-Off - West Side Deflector Pressures, T + 0.5 s to T + 5.6 s
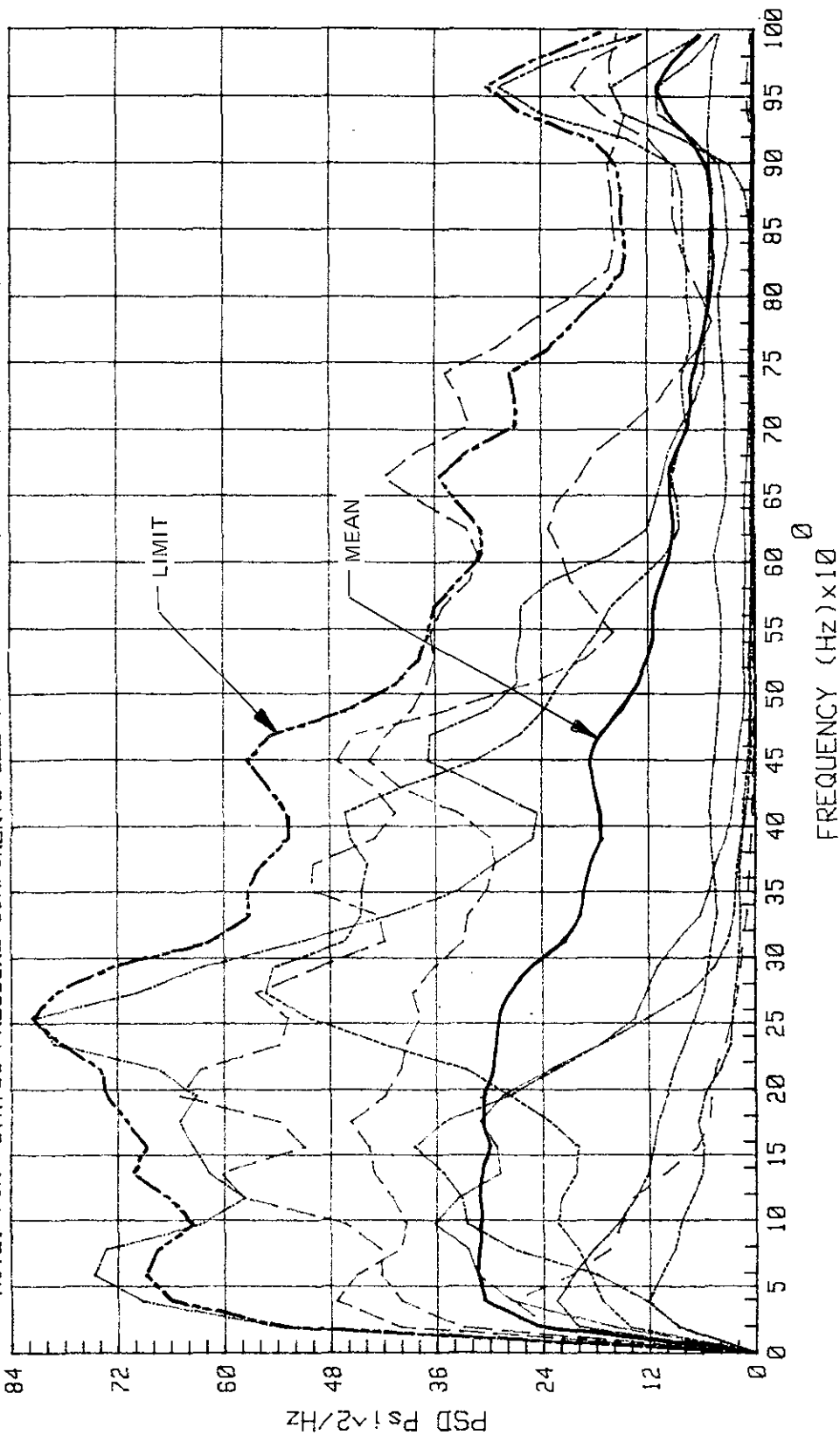
Figure 2-152. STS-7, -8, and -9 Lift-Off Peak -
West Side Deflector Pressures, Dynamic Part

2.9 MLP INTERIOR ACOUSTICS

The summary of MLP (1 and 2) interior acoustics includes STS-4 through STS-11 measurements. All measured acoustic pressures are substantially below predicted OBSPL's. This summary includes only pressure PSD's; because presentation in terms of OBSPL's does not provide necessary resolution, while pressure PSD's contain distinct, repeatable narrow band peaks.

Figures 2-153 through 2-157 contain acoustic pressure summaries for rooms on A and B levels. The right frame on these figures presents separate plots of mean and limit (limit = mean + 2 sigma) curves. Processing parameters and other pertinent information are contained on the plot headings.

Because of substantial dispersion of acoustic pressures between different MLP rooms and rather low, noncritical acoustic levels in these room, all available measurements were lumped together. Figures 2-158 through 2-161 provide corresponding plots in high-resolution scales. Since the 2-sigma limit curve is below two to three actual measurements, the summary curves on figure 2-162 present both 2- and 3-sigma limits. The dispersion between mean and 3-sigma limit of all MLP measurements is 6.9 dB, and 3-sigma limit OASPL = 147.2 dB, substantially below all predictions which were in the range from 150dB to 164 dB. Figures 2-163 through 2-165 present OBSPL's from STS-1 through STS-4 compared with predictions. For application, curves on figure 2-162 are recommended.
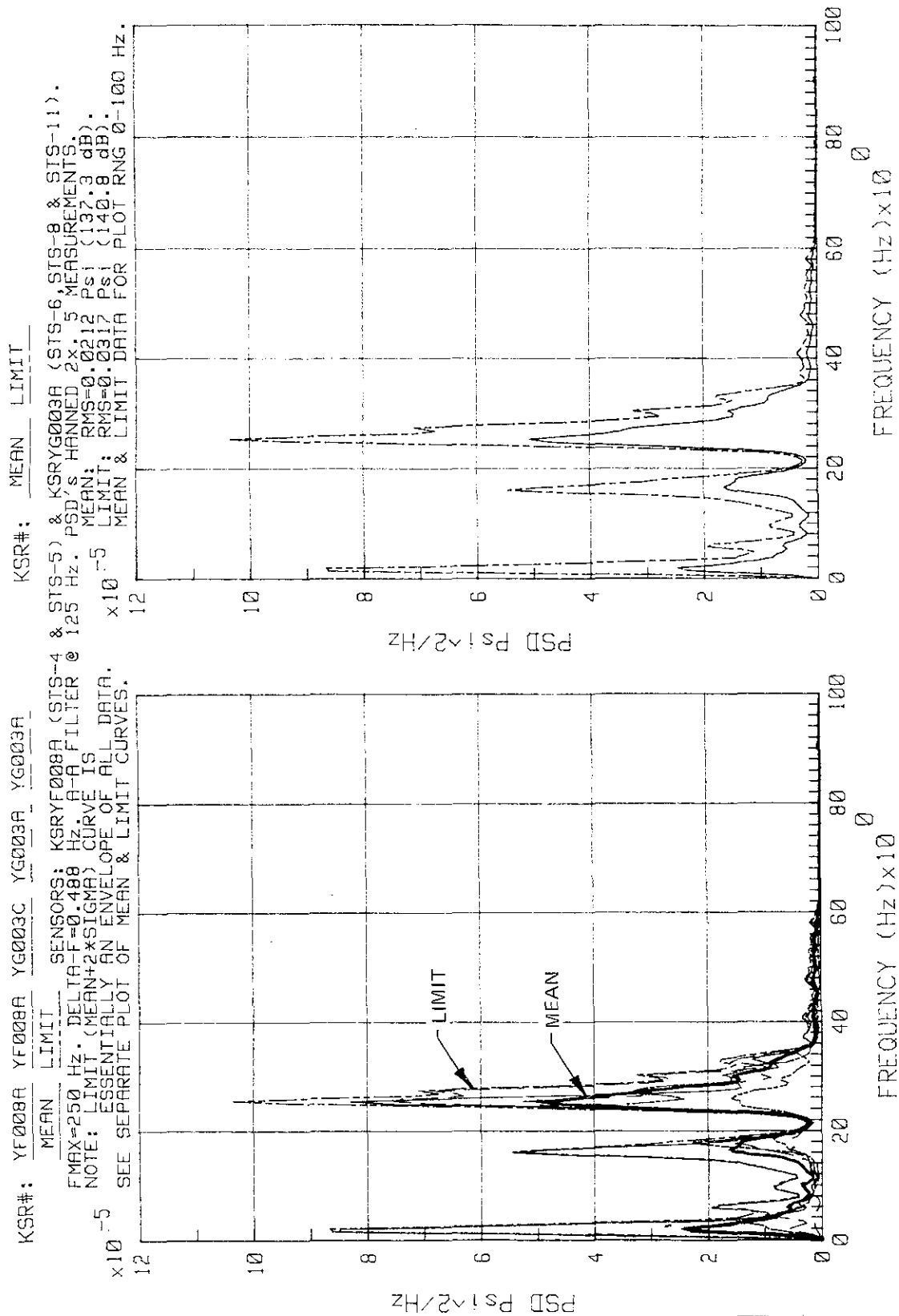
Figure 2-153. Lift-Off Peak - Summary of MLP Interior Acoustics, Room 15A
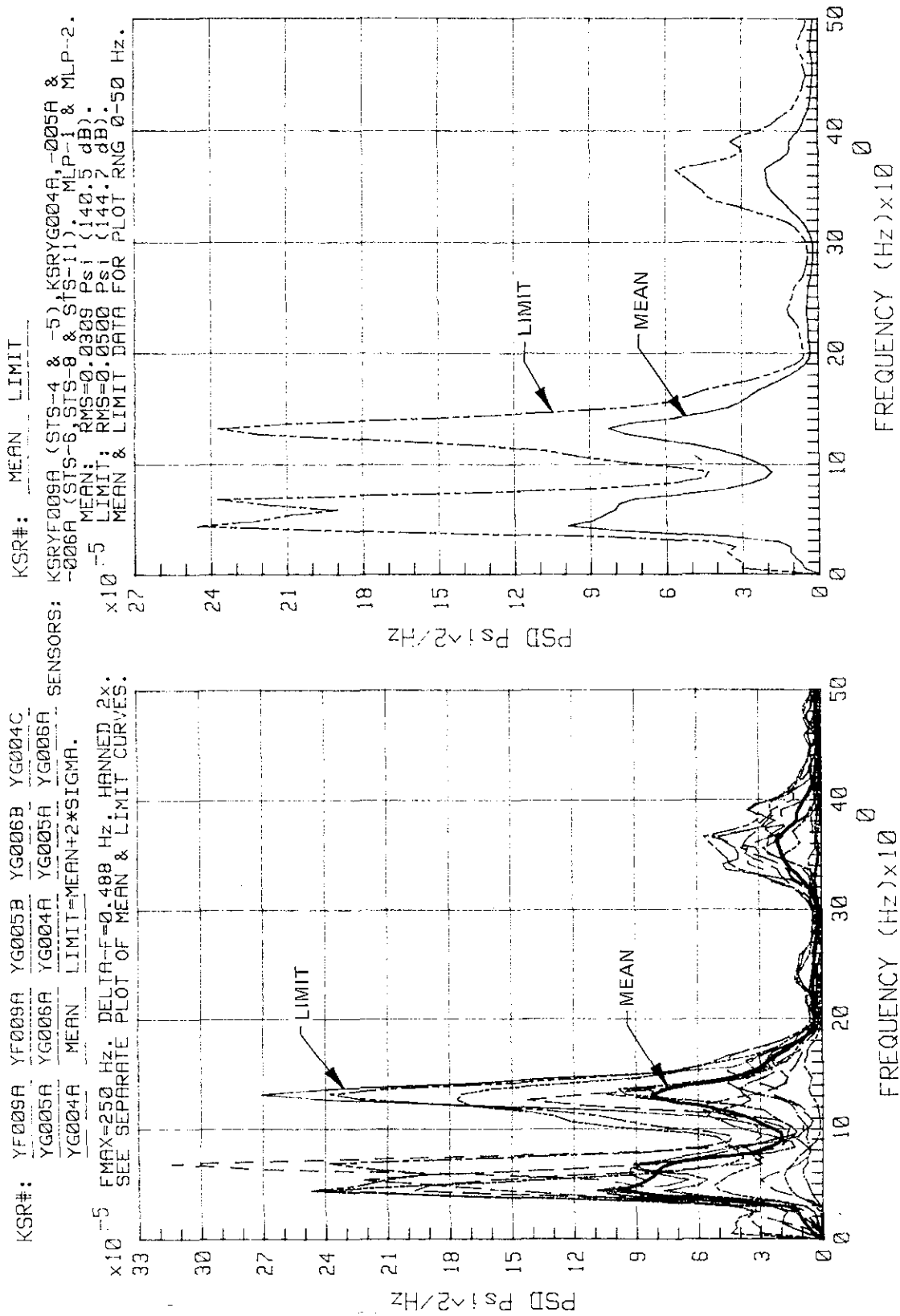
Figure 2-154. Lift-Off Peak - Summary of MLP Interior Acoustics, Rooms 7A, 8A, and 10A
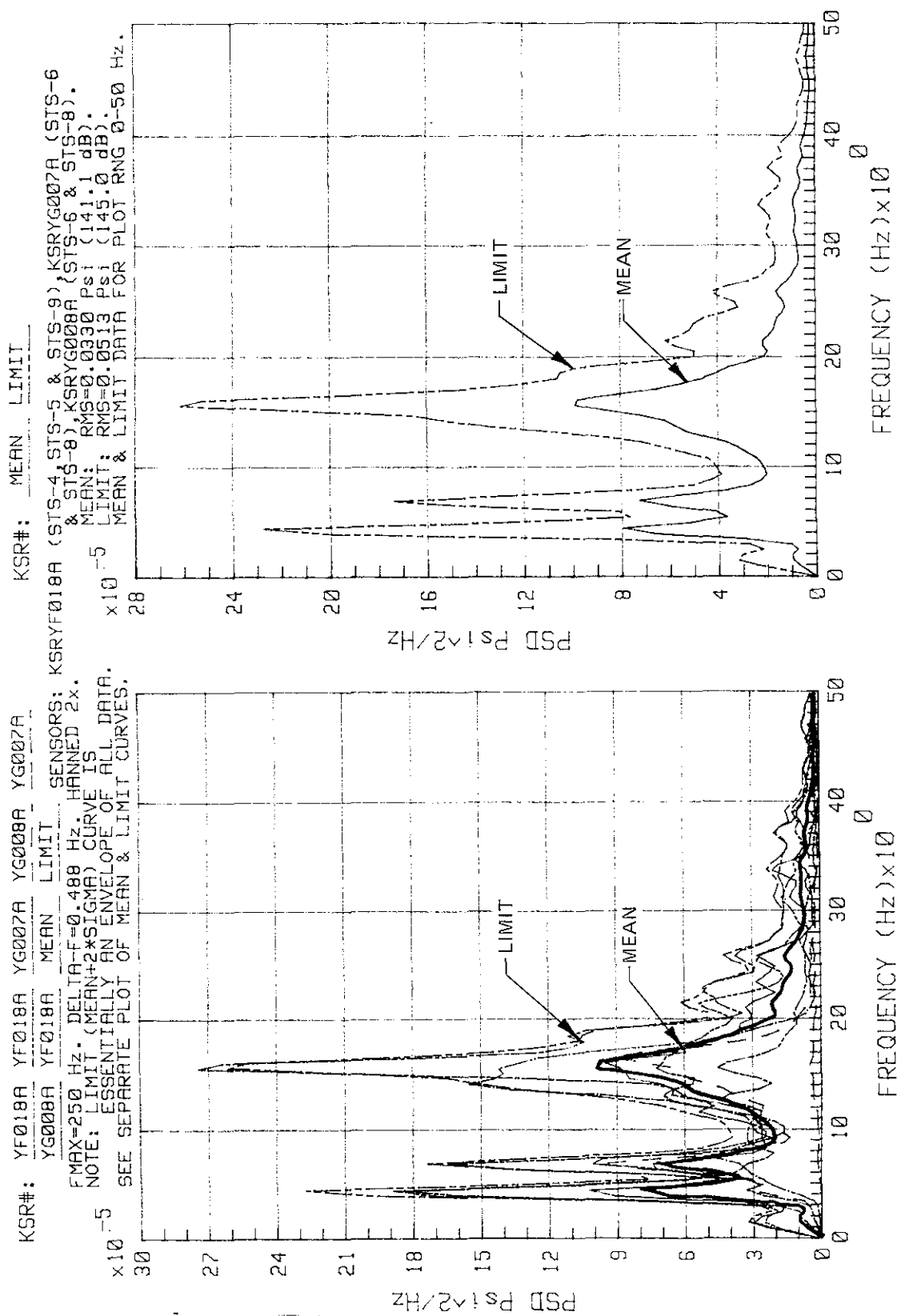
Figure 2-155. Lift-Off Peak – Summary of MLP Interior Acoustics, Rooms 8B and 9B
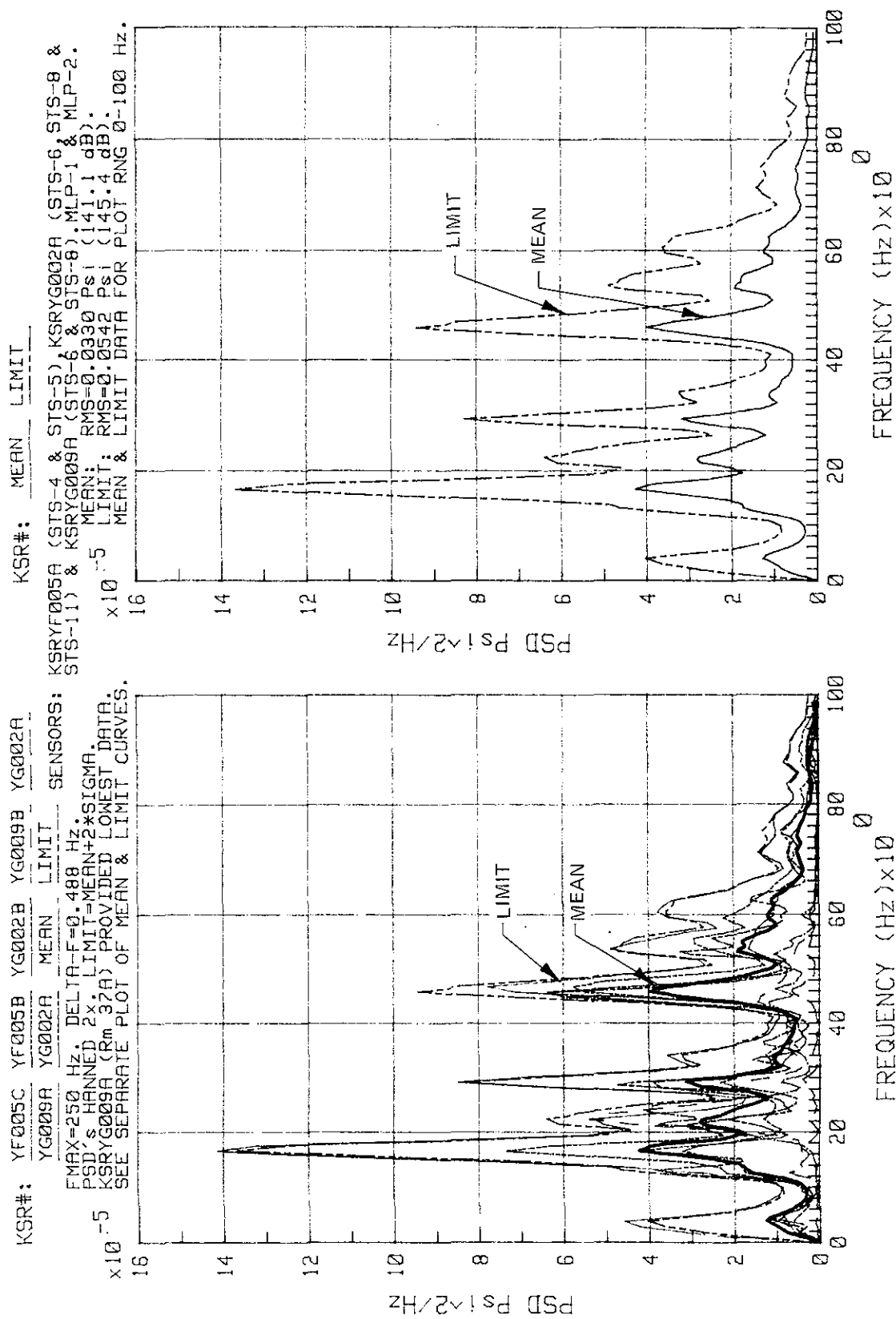
Figure 2-156. Lift-Off Peak - Summary of MLP Interior Acoustics, Rooms 36AB and 37A
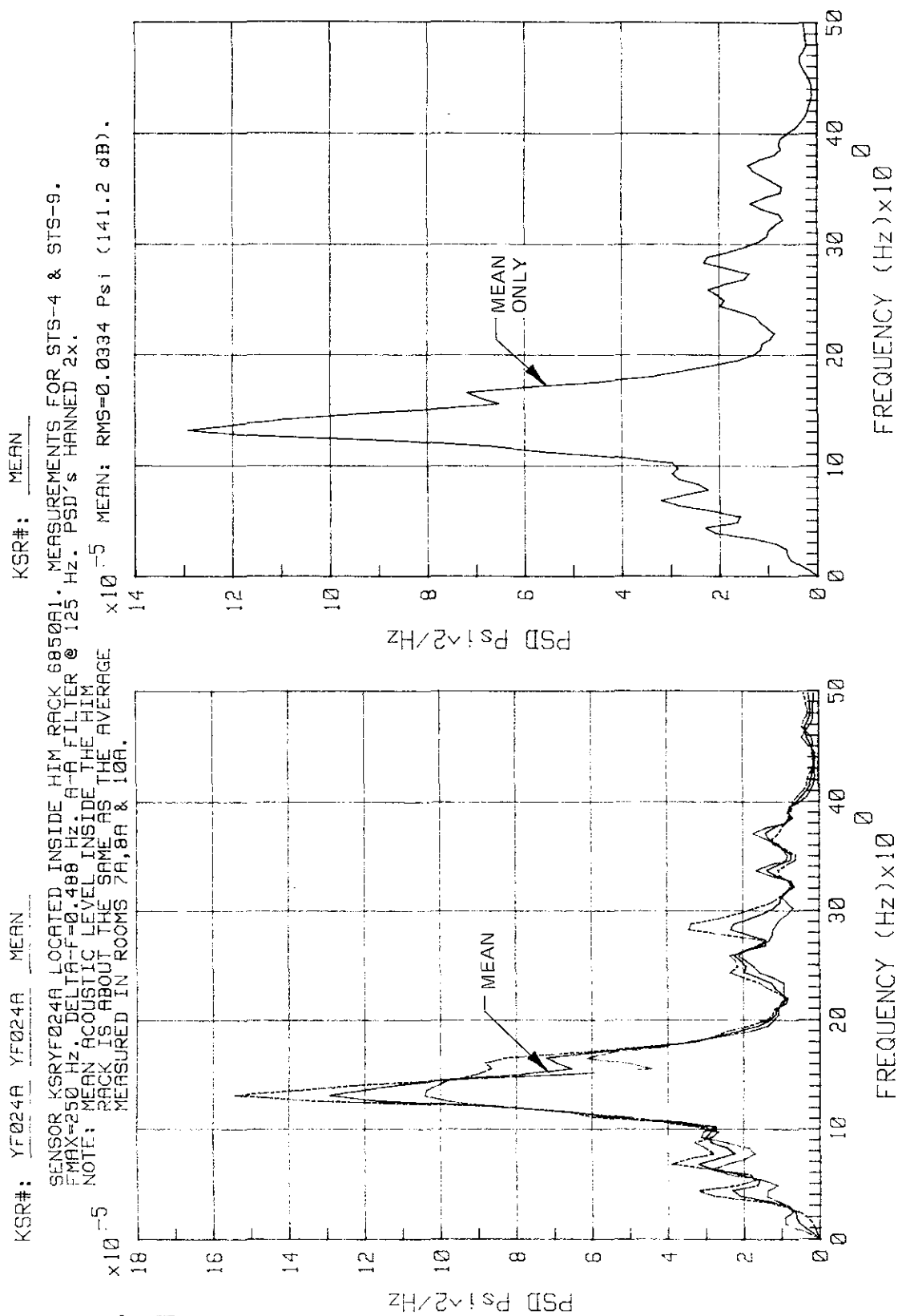
Figure 2-157. Lift-Off Peak - Summary of MLP Interior Acoustics, Room 7A
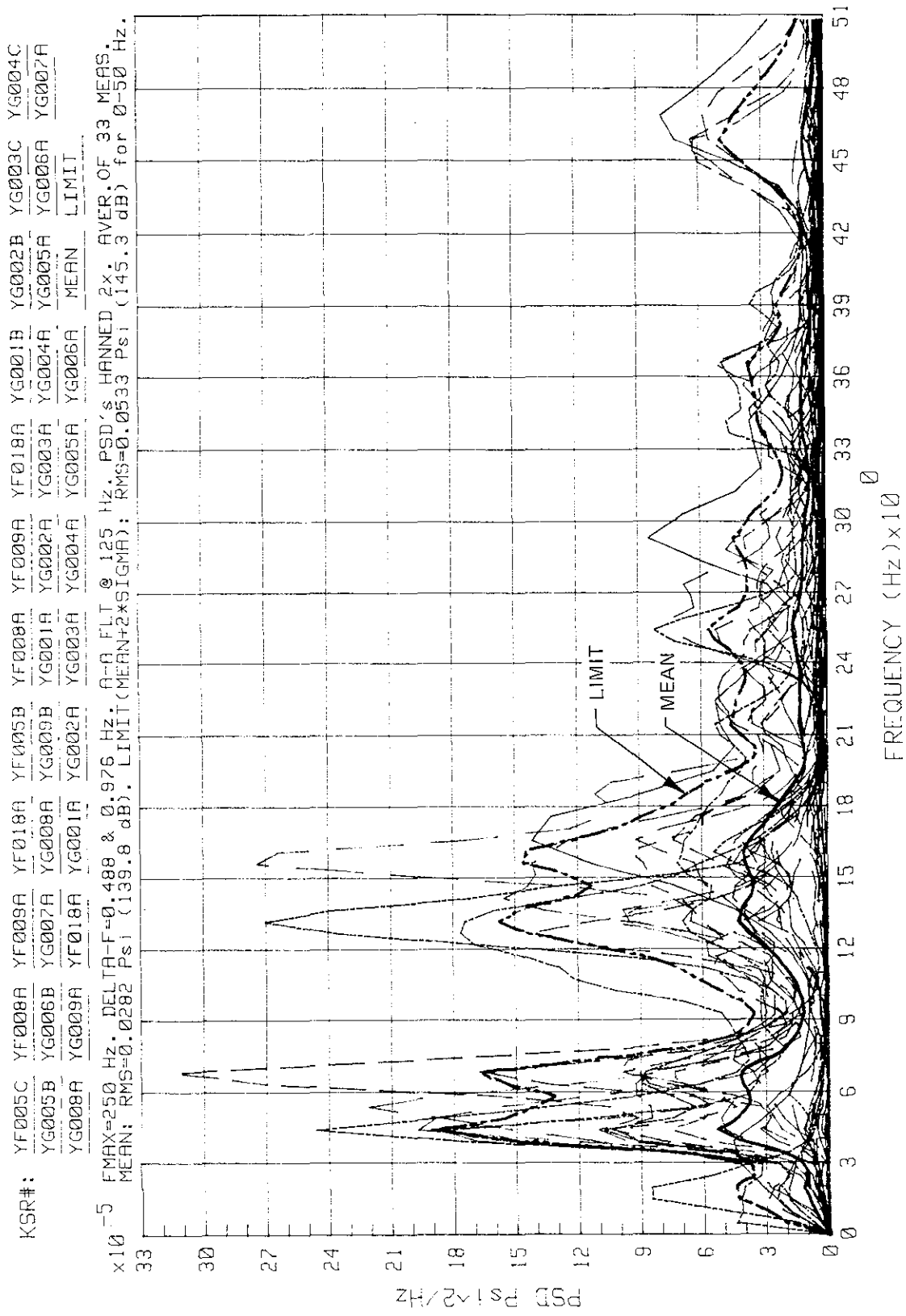
Figure 2-158. STS-4 Through -11 Lift-Off Peak - Summary of MLP Interior Acoustics, PSD's (0 Hz to 51 Hz)
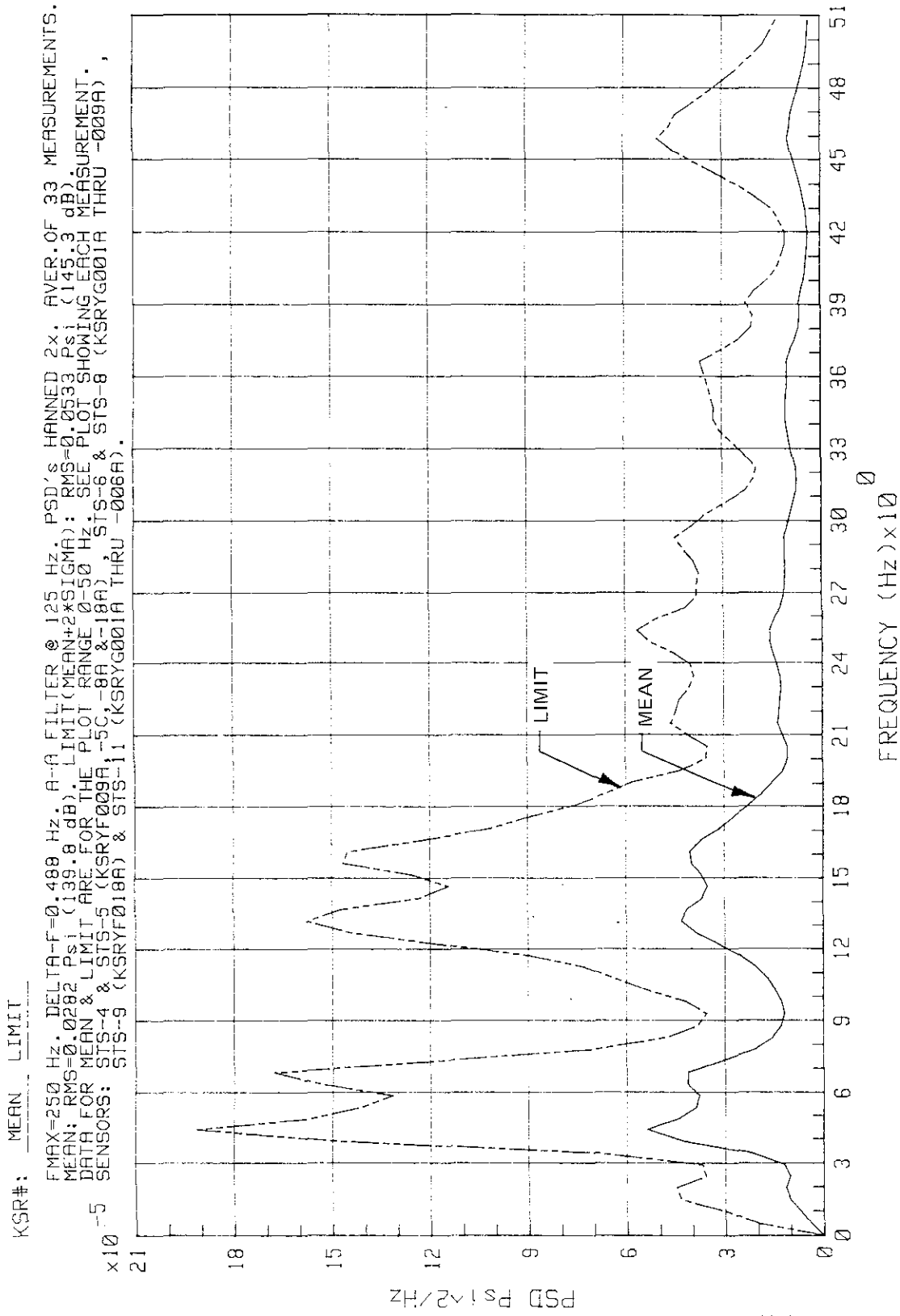
Figure 2-159. STS-4 Through -11 Lift-Off Peak - Summary of MLP Interior Acoustics, PSD's (Mean and Limit Only; 0 Hz to 51 Hz)
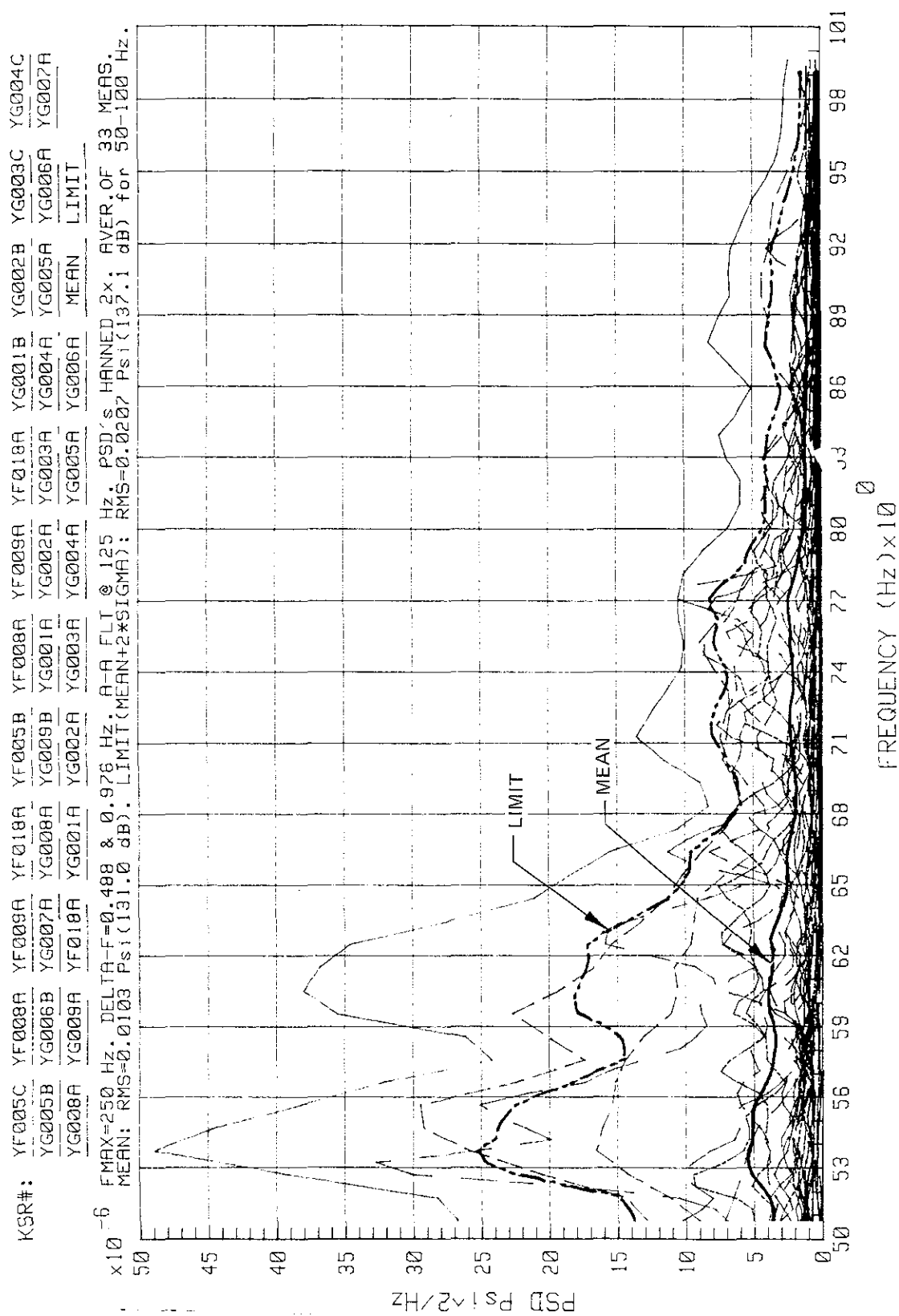
Figure 2-160. STS-4 Through -11 Lift-Off Peak - Summary of MLP Interior Acoustics, PSD's (50 Hz to 100 Hz)
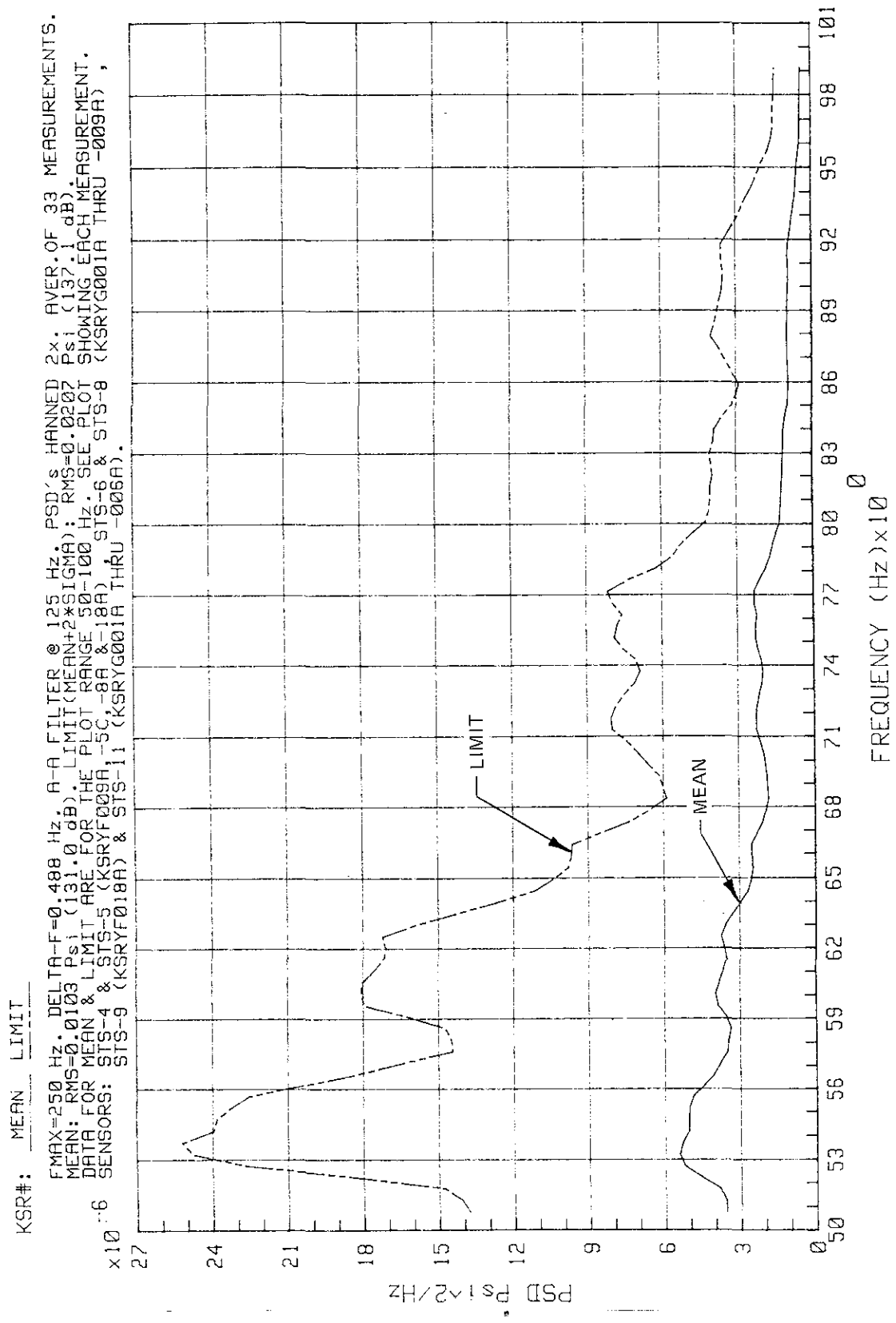
Figure 2-161. STS-4 Through -11 Lift-Off Peak - Summary of MLP Interior Acoustics, PSD's, Mean and Limit Only (50 Hz to 100 Hz)
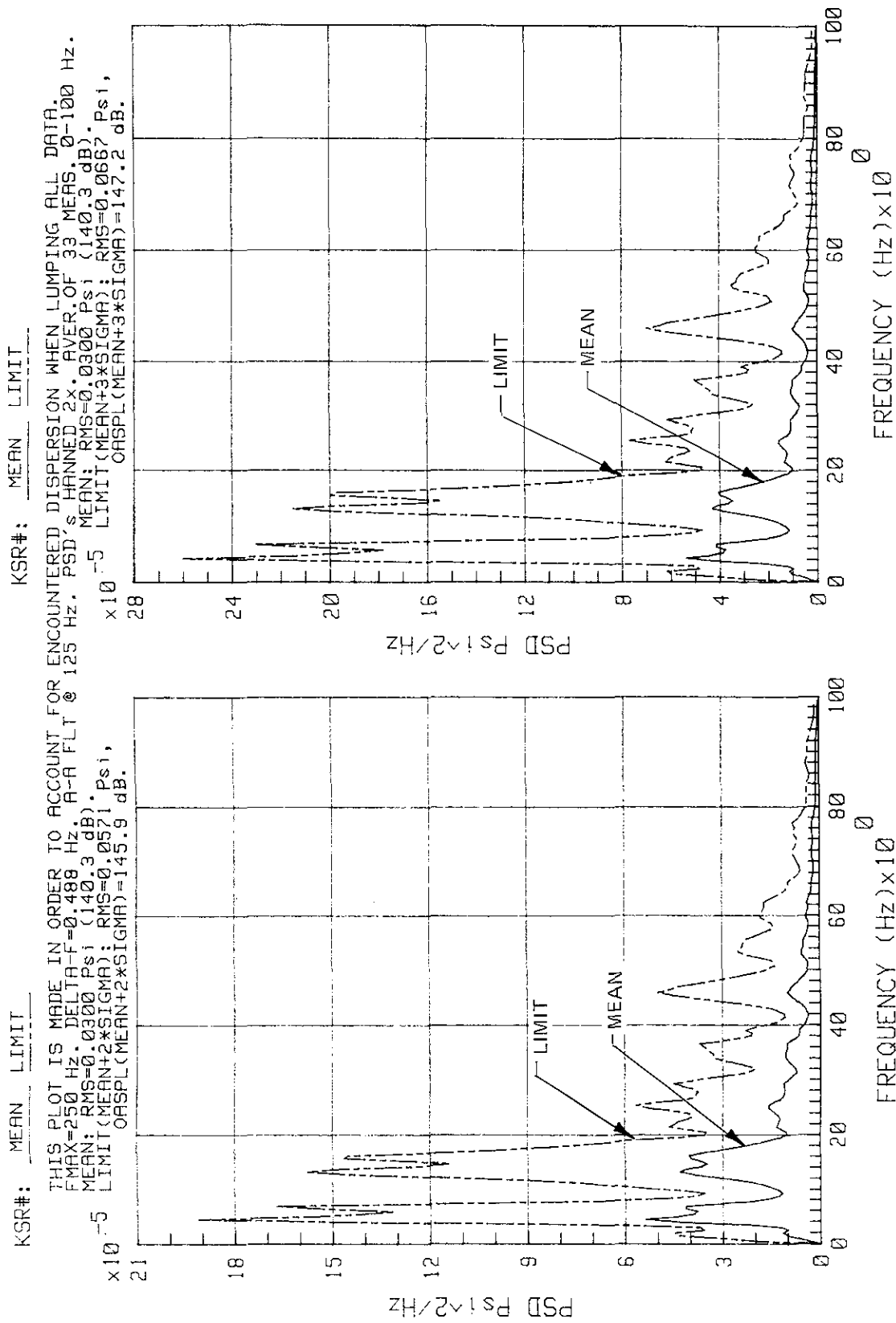
Figure 2-162. STS-4 Through -11 Lift-Off Peak - Summary of MLP Interior Acoustics, 2- and 3-Sigma Limits
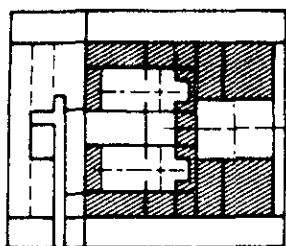
DECKS A & B

ACOUSTICAL SPECIFICATION
ZONE 1.2 AND 1.3
LIFT-OFF PEAK
MOBILE LAUNCHER PLATFORM COMPARTMENTS
AROUND EXHAUST WELLS
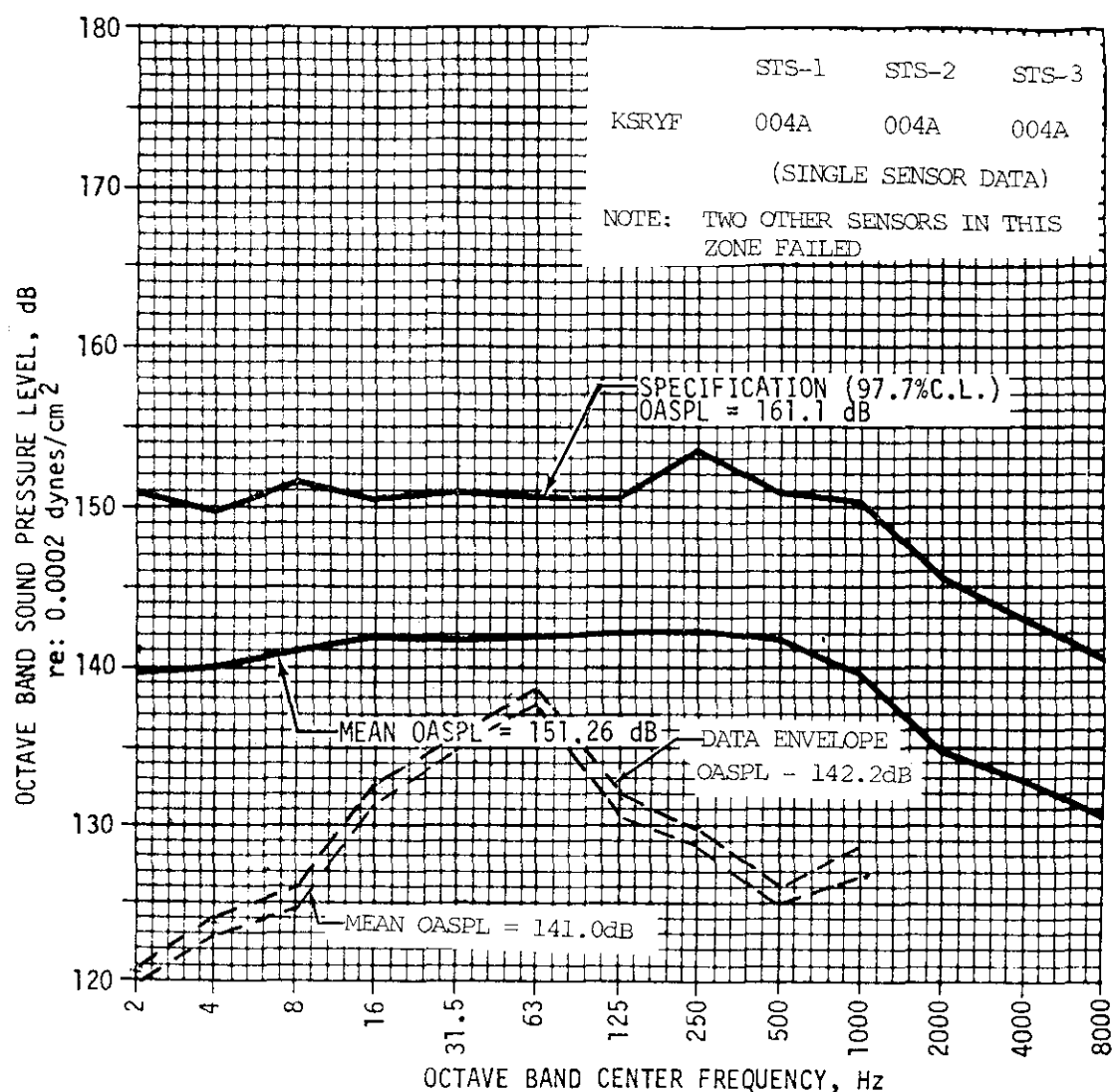
Figure 2-163. Lift-Off Peak - Actual OBSPL's Compared With Predictions, MLP Compartments Around Exhaust Wells
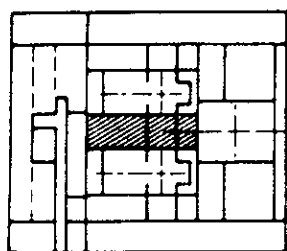
ACOUSTICAL SPECIFICATION
ZONE 1.2 AND 1.3
LIFT-OFF PEAK
MOBILE LAUNCHER PLATFORM COMPARTMENTS 36AB,
37A AND 37B

DECKS A & B

	STS-1	STS-2	STS-3	STS-4
KSRYF	005A	005A	005A	005A
	023A	023A	023A	—

SPECIFICATION (97.7% C.L.)
OASPL = 164.3 dB

MEAN OASPL = 154.7 dB

DATA ENVELOPE
OASPL = 146.5dB

MEAN OASPL = 144.0dB

OCTAVE BAND SOUND PRESSURE LEVEL, dB
re: 0.0002 dynes/cm^2

OCTAVE BAND CENTER FREQUENCY, Hz
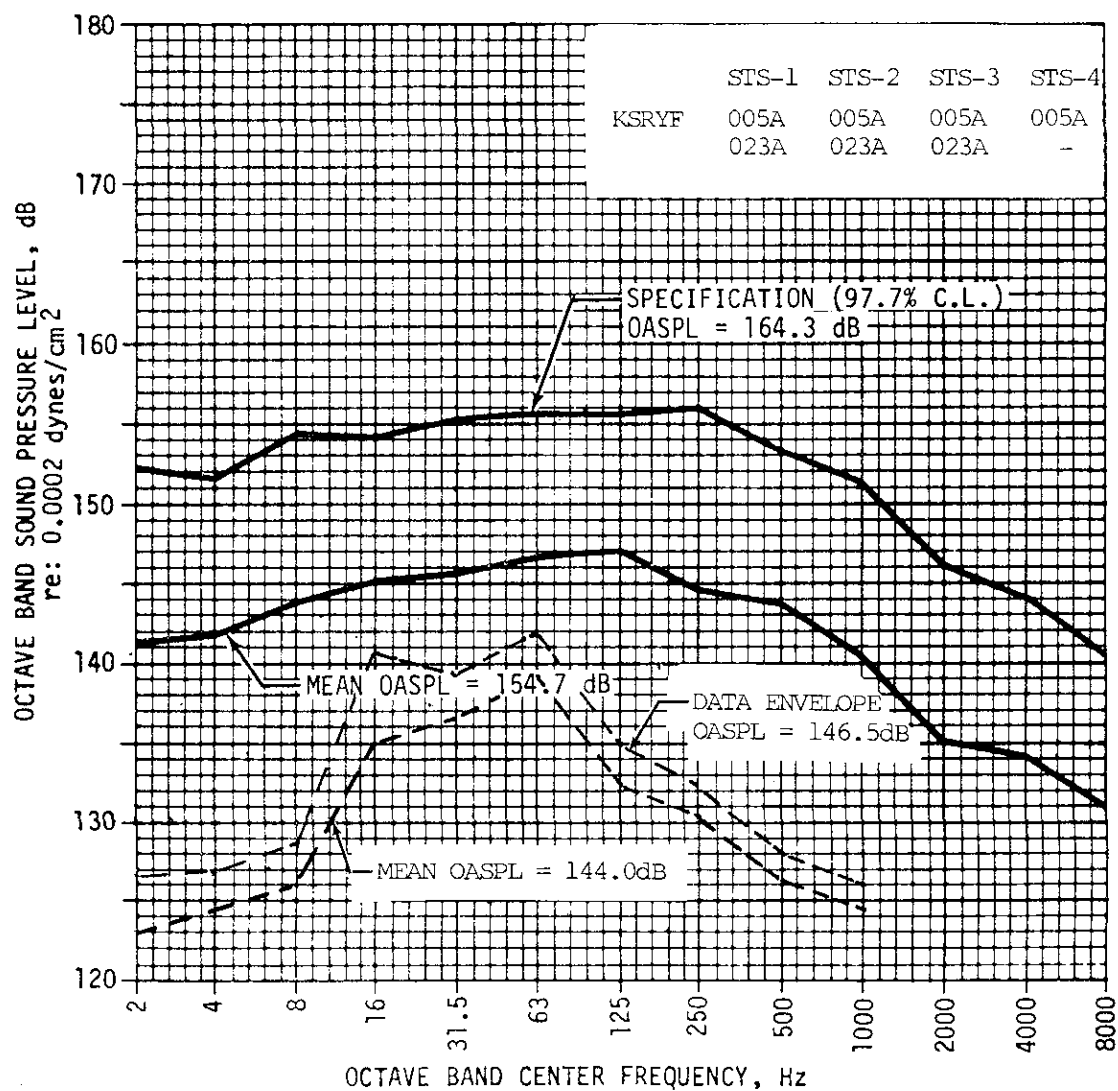
Figure 2-164. Lift-Off Peak - Actual OBSPL's Compared With Predictions,
MLP Compartments 36AB, 37A, and 37B

2-179
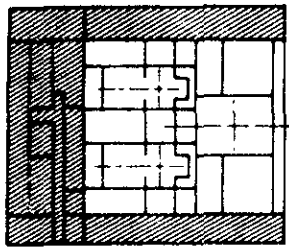
DECKS A & B

ACOUSTICAL SPECIFICATION
ZONE 1.2, 1.3, 2.2 AND 2.3
LIFT-OFF PEAK
MOBILE LAUNCHER PLATFORM COMPARTMENTS
EXCEPT VICINITY OF EXHAUST WELLS

	STS-1	STS-2	STS-3	STS-4
KSRYF	007A	007A	007A	–
	008A	–	–	008A
	009A	009A	009A	009A
	010A	–	–	--
	011A	011A	011A	–
	013A	013A	013A	–
	016A	016A	016A	–
	–	017A	017A	–
	018A	018A	018A	018A
	019A	019A	019A	–
	020A	020A	020A	--

DATA ENVELOPE OASPL = 146.2dB

SPECIFICATION (97.7%C.L.)
OASPL = 149.53 dB

MEAN OASPL = 144.17 dB

MEAN OASPL = 142.0dB

OCTAVE BAND SOUND PRESSURE LEVEL, dB
re: 0.0002 dynes/cm2

OCTAVE BAND CENTER FREQUENCY, Hz
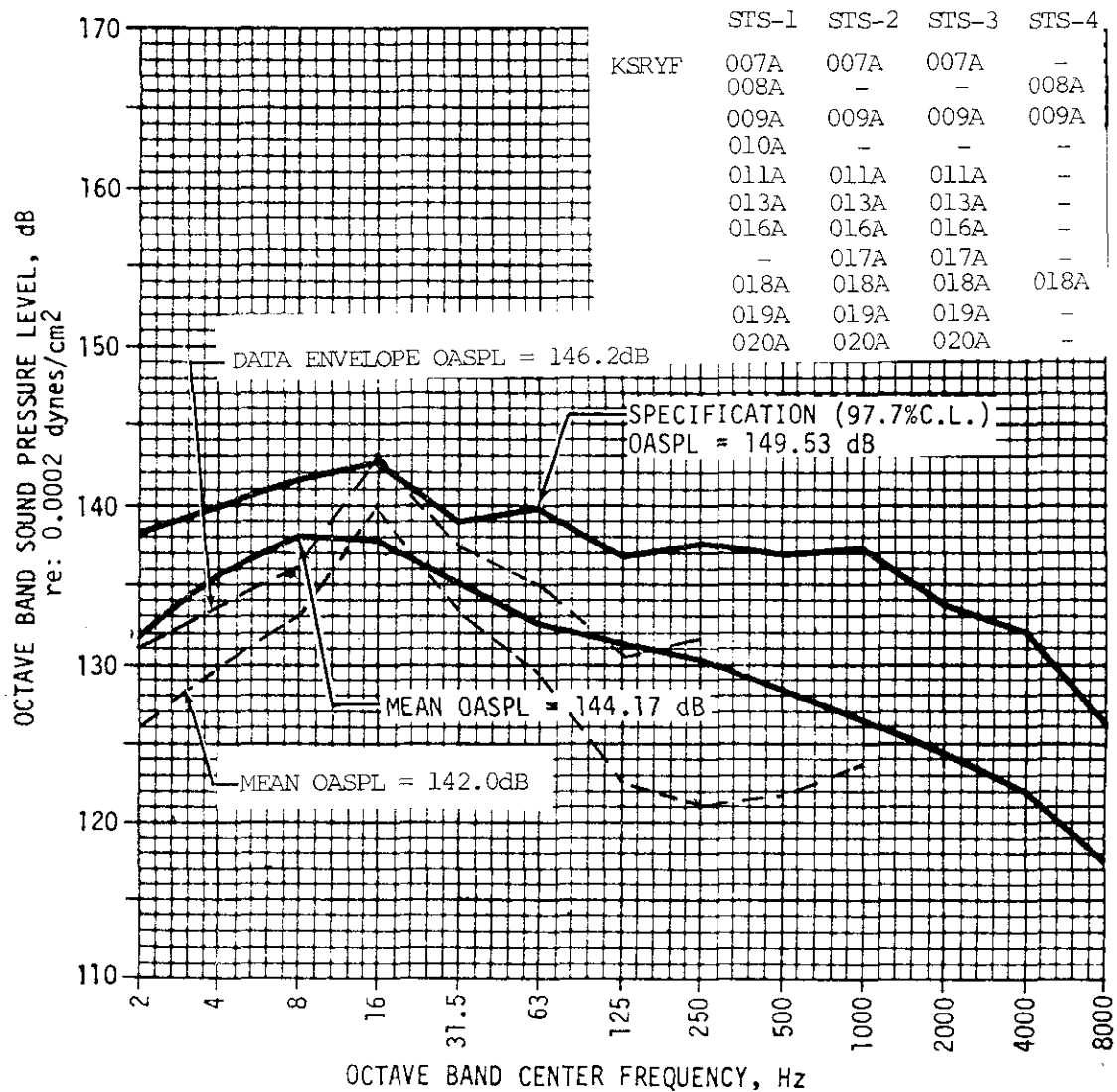
Figure 2-165. Lift-Off Peak – Actual OBSPL's Compared With Predictions, MLP
Compartments Except Vicinity of Exhaust Wells

SECTION III

STRAINS

3.1 SRB HOLDDOWN POST (HDP) PEDESTAL STRAINS ON MLP (STS-6 THROUGH -9)

This summary presents results of strain measurements on the HDP pedestals. Previous publications include similar strain time histories for STS-1 through STS-8. Oscillatory strain components that occur between $T - 0.01$ s to $T + 0.3$ s are presented in terms of their PSD's, using STS-6 through STS-9 data after some of these components were related to dilatational waves generated within SRB's at ignition. The last part of this summary presents text previously published with STS-5 data (KSC-DD-688-TR) pertinent to pedestal loads before SRB ignition and to strain oscillations at SRB ignition.

Each SRB HDP pedestal was instrumented with two sets of strain gages, further designated as either type 1 or type 2. Each set consisted of eight strain gages, wired in a manner ensuring temperature compensation and recording of only axial load-induced strains while eliminating voltage output caused by the bending of the pedestal. Each set, further referred to as a strain gage, represents an uncalibrated load cell.

Figures 3-1 and 3-2 present raw strain time histories sampled at a 200-Hz rate for time interval $T - 4.6$ s to $T + 0.5$ s for STS-9. Each figure contains four time histories corresponding to either type 1 or type 2 gages on east pedestals (nos. 1, 2, 3, and 4) or on west pedestals (nos. 5, 6, 7, and 8). Similar and repeatable time histories were recorded during STS-1 through STS-8. Figure 3-3 presents time histories of type 1 gages sampled at a 5-kHz rate for a short time interval of 25 ms ($T - 0.15$ s to $T + 0.01$ s). This interval includes shocks generated by the activation of explosive bolts. Figure 3-4 presents the four (type 1 gage) time histories for time interval $T - 0.1$ s to $T + 0.31$ s, which show decay of pedestal loads at lift-off to no-load condition beginning at approximately $T + 0.28$ s.

Figures 3-5 through 3-8 present strain time histories from each gage shown on figure 3-4 and extracted TVM (see explanation in figure headings). The dynamic strain components, which are defined as the difference between raw strain data and TVM, were used in subsequent computations of PSD's from STS-6 through STS-9 measurements presented on figures 3-9 through 3-11. It should be noted that the effect of dynamic strain components on the HDP pedestals is insignificant. They may have a significance as dynamic loads on the vehicle, because these strains are a result of longitudinal oscillations of SRB's recorded at the interface between the SRB's and the MLP. High PSD peak, around 70 Hz, may be explained considering propagation of dilatational waves through SRB casings. Measured PSD's on pedestals under either the east SRB (figure 3-9) or the west SRB (figure 3-10) show relatively low dispersion; the limit curves

3-1

are essentially envelopes of all data. When both east and west pedestal measurements are combined (figure 3-11, sheets 1 and 2), the limit (mean + 2 sigma) curve is exceeded by two to three measurements. Therefore, a new limit (mean + 3 sigma) curve is calculated and presented on figure 3-11 (sheet 3). Included in this section is the text portion of appendix B of KSC-DD-688-TR, which discusses a method of calibrating strain gage outputs to represent dynamic loads. The appendix B text contains assumptions about the distribution of dead load on HDP pedestals critical for the calculation of calibration factors to convert recorded strains into loads. Peak load estimates from measured strains cannot be improved without knowledge of actual dead load on each pedestal. If Orbiter weight eccentricity with respect to HDP pedestals were used, it would result in a nonuniform distribution of HDP pedestal dead loads and calibration factors different from those calculated. This information was not available at the time of publication. Information from appendix B, SRB HDP Strains and Loads During the Holddown Period (KSC-DD-688-TR) follows. (3.2 through 3.3).

3.2 SRB HDP STRAINS AND LOADS DURING THE HOLDDOWN PERIOD (STS-1 THROUGH -5)

This paragraph presents Shuttle HDP loads obtained from strain measurements KSRGF013A through -028A during STS-2, STS-3, and STS-5 launches. Each SRB HDP pedestal was instrumented with two sets of strain gages and represents an uncalibrated load cell. Each set consisted of eight strain gages, wired in a manner ensuring temperature compensation and recording of axial load-induced strains while eliminating voltage output caused by the bending. Each set, further referred to as a strain gage, provided an independent measurement of an average axial strain in HDP's. The knowledge of static load carried by each HDP before SSME ignition and recorded strain time histories provide necessary information for the calibration of improvised load cells. Then, recalibrated strain time histories represent dynamic load time histories for each HDP for the period from SSME ignition until the separation of tie-down explosive bolts and lift-off. Required calibration procedure is as follows:

$$CF = \frac{GLOW + \Delta}{8(\epsilon_{DL} - \epsilon_{L/O})} \qquad kips/(\mu in/in)$$

$$P(t) = CF[\epsilon(t) - \epsilon_{L/O}] \qquad kips$$

Where:

CF = load cell calibration factor that converts recorded strain (μin/in) into load (kips). The expression for CF contains an assumption that the total vehicle weight (before SSME ignition) is equally distributed among all eight HDP's. This assumption neglects the eccentricity of Orbiter weight with respect to SRB support.

GLOW = Gross lift-off weight of Shuttle vehicle at nominal lift-off
(approximately 0.21 s after SRB ignition). For STS-2, GLOW =
4,030.4 kips. For STS-3, GLOW = 4,016.6 kips. Estimated numbers
account for a decrease in the total Shuttle weight by the amount of
fuel burned by the SSME's during holddown period and by SRB's until
development of lift-off thrust.

Δ = weight of fuel (LH_2 + LO_2 + about 0.21 s of SRB propellant) burned
during the holddown period and until SRB's thrust develops, esti-
mated to be 441.6 kips for STS-2 and 456.1 kips for STS-3.

GLOW + Δ = 4,472.0 kips for STS-2 and 4,472.7 kips for STS-3 (gross
Shuttle vehicle weights before SSME ignition)

ϵ_{DL} = strain gage output before SSME ignition. For STS-2 and STS-5,
this output was zeroed (ϵ_{DL} = 0).

$\epsilon_{L/0}$ = strain gage output after lift-off. This is a no-load condition
on HDP's and represents a zero reference line for dynamic load
time histories.

P(t) = dynamic load on HDP at time t. Using the sign of recorded
strains in expression for P(t), a positive value of P(t)
represents a downward load on the HDP. A negative P(t)
represents an upward (tensile) load on the HDP.

ϵ(t) = strain gage output at time t. For extreme values of dynamic
loads, ϵ(t) corresponds to either a maximum (ϵmax) or a minimum
(min) of a recorded strain time history.

Figure 3-12 (right side) illustrates strain values required to obtain cali-
bration factors from a typical strain time history. Table 3-1 and figure 3-13
present calibration factors (CF), dead load strain differences (ϵ_{DL} - $\epsilon_{L/0}$),
of peak strain differences (ϵmax/min - $\epsilon_{L/0}$), and peak dynamic loads (and
locations of HDP's) for all strain measurements on SRB HDP pedestals. In
computations, the total dead load on each HDP (GLOW + Δ)/8 = 559.0 kips. For
STS-3 measurements, some roundings and extrapolations were necessary in order
to obtain ϵ_{DL} - $\epsilon_{L/0}$, since ϵ_{DL} was not zeroed and processed data began at T -
4.60 s, while first SSME ignition occurred at approximately T - 6.0 s. For
convenience and reference, STS-2 and STS-3 SRB HDP strain time histories, pre-
viously published in KSC-DD-593-TR and KSC-DD-651-TR, are presented. Strain
time histories for STS-5 can be found elsewhere in this document.

The peak load values presented in table 3-1 show significant differences be-
tween loads obtained by two independent measurements on each HDP pedestal, as
well as differences between loads on different pedestals. The only emerging

pattern is that the second measurement (gage 2) in most cases shows higher loads than gage 1. The output of gage 2 is also more susceptible to bending strains in the pedestals. It appears that the effect of HDP pedestal bending has not been entirely eliminated from sensor outputs. Consequently, peak downward loads appear to be overestimated, and peak upward loads are underestimated. Some differences between the two measurements on the same HDP pedestal may be caused by details in strain gage installations or in their locations with respect to possible asymmetries in the HDP's. Because the pedestal is very short, the assumption about the plane section containing strain gages and remaining plane after the deformation takes place may not be sufficiently accurate, and some warping of the plane cross section may be responsible for differences in the gage 1 and gage 2 outputs.

The assumption of equal dead load distribution (before SSME ignition) on each HDP may be responsible for generally higher loads on HDP's 3 and 7. Because of MLP flexibility, HDP's 3 and 7 are points of lower MLP stiffness than the opposite HDP's 4 and 8. It is possible that, in the statically indeterminate Shuttle support structure, HDP's 3 and 7 carry a lower-than-assumed dead load (559 kips). If so, then the calibration factors (CF) and the peak dynamic loads on these HDP's will be proportionally lower than the values presented in table 3-1, while HDP's 4 and 8 would attain higher-than-presented dynamic loads. Unfortunately, these questions cannot be answered based on available test data. An analysis of HDP dead load, which would consider Shuttle erection procedure, eccentricity of Orbiter weight, and fueling of ET tank, would eliminate the assumption made in this report about equal distribution of Shuttle weight among all HDP's.

3.3 A PLAUSIBLE EXPLANATION OF STRAIN OSCILLATIONS AT SRB IGNITION

Figure 3-12 (left side) shows an enlarged plot of raw data beginning at T - 0.1 s (nominal) for a duration of 0.41 s. Although the sampling rate of analog signal was 5 kHz, the DAS limits the frequency content of data to maximum 2 kHz. Of principal interest is the strain time history from the instant of explosive bolt actuation (T - 0.01 s) until the separation of the SRB from the HDP (approximately T + 0.21 s). Two distinct peaks, a maximum and a minimum, separated by approximately 10 ms, occur in the time history of each HDP pedestal strain. These peaks are followed by a shift of the average strain line (see figure 3-12, left side) about which a few oscillations occur at a frequency of about 82 Hz. Because this is a relatively high frequency, substantially higher than the first longitudinal SRB mode (below 15 to 16 Hz), a few initial and highest oscillations may be caused by propagating waves rather than by a "standard" standing wave-type vibration. If this hypothesis is true, then a strong argument can be made that the stiffness and mass of SRB HDP supporting structure, in this case the MLP, has no significant effect on Shuttle dynamics for the period of about 70 ms, beginning at about T + 0.07 s when large oscillations in the recorded HDP strains occur. For this period, a plausible explanation of the strain time history, presented further, is based on known concepts of wave propagation developed in mechanics of continuum. The explanation is prompted by an unexpected coincidence of three minima peak

(figure 3-1, left side) with the calculated results obtained considering propagation and reflection of dilatational waves within the SRB's solid propellant casing structure. First, we list necessary data:

a. Distance from the top of the SRB casing dome (base of igniter) in the forward segment to the strain gage on HDP's is estimated to be $\simeq 117.8$ ft

b. For SRB steel casing, using standard steel properties, data are:

Modulus of elasticity $E = 29 \times 10^6$ lb/in^2

Poisson's ratio $\nu = 0.3$

Elastic (Lame') constants

$\lambda = E\nu/[(1 + \nu)(1 - 2\nu)]$ $= 16.73 \times 10^6$ lb/in^2

$\mu = E/[2(1 + \nu)]$ $= 11.15 \times 10^6$ lb/in^2

Steel specific density (mass per unit volume) $\rho = 7.324 \times 10^{-4}$ lb/s^2/in^4

c. Velocity of dilatational wave

$$V_1 = [\lambda + 2\mu)/\rho]^{1/2} = 2.3084 \times 10^5 \text{ in/s} = 19{,}237 \text{ ft/s}.$$

Wave travels with the velocity of propagation of dilatation. Displacement is parallel but opposite in direction to wave normal. When reaching a free plane boundary, wave will reflect on itself when wave normal and boundary normal are parallel. Otherwise, a dilatational wave will reflect as two kinds of waves: a dilatational wave with the angle of reflection equal to the angle of incidence, and as a rotational (shear) wave with the angle of reflection smaller than the angle of incidence.

d. Velocity of rotational (shear) wave

$$V_2 = (\mu/\rho)^{1/2} = 1.2338 \times 10^5 \text{ in/s} = 10{,}282 \text{ ft/s}$$

Wave travels with the velocity of propagation of rotation. Displacement is perpendicular to wave normal. When reaching a free plane boundary, wave will reflect on itself when wave normal and boundary normal are parallel. Otherwise, a shear wave will reflect as two kinds of waves: a shear wave with the angle of reflection equal to the angle of incidence, and a dilatational wave with the angle of reflection greater than the angle of incidence. Under certain conditions, shear waves are responsible for bending in plates and shells.

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e.   The time required for a dilatational wave to travel the distance from
     the top of the SRB casing to the strain gage location on the HDP's
     is:

   $\Delta t = 117.0/19,237 = 0.00608$ s

   This is one-half of the period of oscillations recorded by the HDP
   strain gage. The frequency of these oscillations (minima peaks on
   figure 3-1, left side) is:

   $f = 1/(2 \times 0.00608) = 82.2$ Hz

   The coincidence of this frequency with the test data is astonishing,
   and it prompted this analysis.

f.   Wave propagation and reflection solutions developed in mechanics of
     continuum, while very rigorous, are also limited in most cases to
     examples with a single plane boundary. In cases involving multiple
     boundaries, conditions on these boundaries usually cannot be satis-
     fied and solutions do not exist. A less rigorous solution derived
     for a prismatical bar states that the wave velocity propagating
     longitudinally in the bar is:

   $V = (E/\rho)^{1/2} = 1.9899 \times 10^5$ in/s $= 16,582$ ft/s

   Formally, this solution can be obtained from the expression for V_1 by
   assuming Poisson's ratio equal to zero. For steel, the most often
   cited value of V in the elastic range is 17,000 ft/s. Then, the
   values of Δt and f corresponding to those derived under e above are:

   $\Delta t = 117.0/16,582 = 0.0071$ s

   $f = 1/(2 \times 0.0071) = 70.4$ Hz

   Some of the strain time histories show peak oscillations (after the
   first peak) occurring at a frequency of about 70 Hz. We are not
   attempting to provide an explanation why variations in the frequency
   of oscillations occur. The phenomena of wave reflection are too com-
   plex and defy a simplistic explanation. It is worth noting, however,
   that any exceeding of the elastic range by strains inside the SRB
   casing should result in a lower velocity of dilatational waves.
   Frequency domain analysis made with data measured after STS-5 con-
   firms existence of a high peak in PSD's at 70.4 Hz.

Once generated, dilatational wave is reflected from the free boundary of the
SRB skirt and from the curved boundary of the dome (forward SRB segment) where
it should produce some rotational waves and bending. Because there is very
little decay in recorded strain amplitudes (measured about the average strain
line) for at least three cycles, one may conclude that a very small amount of

strain energy is transmitted to the gages on HDP's. All wave reflections at the base of SRB occur mainly from the free boundary of the SRB skirt. There-fore, neither stiffness nor mass of HDP supporting structure can have a sig-nificant effect on these oscillations.

The appearance of the first and most dominant peak on the strain time history at T + 0.08 s requires a different explanation. The time interval between this peak and the first distinct minimum of the incident dilatational wave is about 10 ms. The duration of the peak, the half period, is about:

$$t = 2(10 - 6.08) = 7.84 \text{ ms}$$

which is greater than the half period of dilatational wave. A plausible explanation is that this peak is a result of a pressure shock on the base of the SRB from a rapid ignition. Pressure shock displaces the base of SRB down-ward by the amount depending (among other factors) on the support stiffness. The peak load on the HDP certainly is proportional to the support stiffness. However, at this instant, the load on the SRB above the skirt joint with the casing should be inversely proportional to the support stiffness because this load is caused by the SRB base displacement. Pressure shock on the SRB base may also generate a dilatational wave traveling up the SRB. The amplitude of this wave is proportional to the downward displacement of the SRB base, and thus, inversely proportional to the stiffness of the support (the MLP). The stiffer the support is, the lower will be the amplitude of upward traveling dilatational wave. The same wave may be responsible for high-frequency oscil-lations appearing on the HDP strain time history immediately (within 1 to 2 ms) after the first dominant peak. These oscillations and, probably the entire effect of the base-generated dilatational wave, appear to be insignifi-cant.

By far, the major effect on the SRB's, and probably on the entire Shuttle structure, is due to the pressure shock on the SRB dome in forward segment. This shock displaces the dome upward, and this rapid displacement generates a dilatational wave traveling down the SRB. When part of the wave reaches HDP's, the displacement associated with this wave is upward, the load on the post drops, and the first minimum peak appears on the strain time history. The major part of the wave reflects back from the free boundary of the SRB skirt, while a small amount may be reflected from the joint between the skirt and aft segment casing because of boundary direction change at the joint. Also, some shear waves will be generated at both ends of the SRB where reflec-tions take place. Certainly, the amplitude of this dilatational wave does not depend on the stiffness of SRB supports. Because these strain oscillations are caused by a dilatational wave propagating through the steel casing, they are very little (if any) affected by the mass of attached SRB propellant and/ or by the attachment of ET. Thus, the standard type of finite element model-ing may not be able to explain this phenomenon; or, if forced to do so, it may result in incorrect loads on ET, Orbiter, etc.

In summary, pressure shock at SRB ignition, on the base of SRB, is responsible for the first dominant peak in HDP post strain time history. This peak depends on the stiffness of the SRB supporting structure. The strained part of the SRB is that between its base and supporting structure. The upper part of the SRB, above the joint between the skirt and casing, may be strained, though insignificantly, by the generated dilatational wave at the base.

Peaks in the strain time history, following the first, are caused by a dilatational wave generated at the top of the SRB by the pressure shock on the dome. This wave is bouncing back and forth along the SRB casing, reflecting mainly from the free boundary of the SRB skirt and from the dome; and corresponding base displacements are recorded by the HDP pedestal strain gages. The stiffness and/or mass of the SRB supporting structure has no effect on this wave.
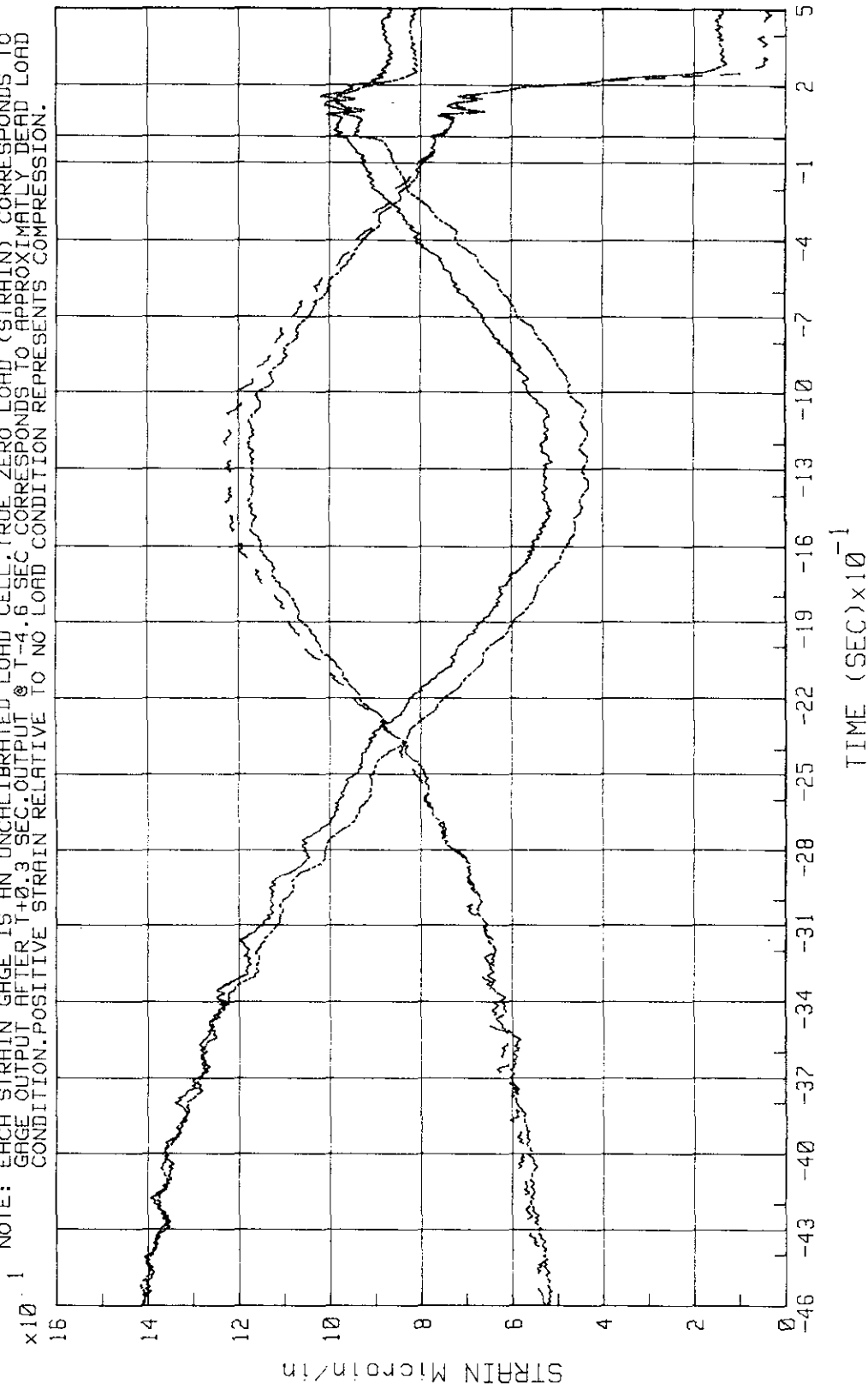
Figure 3-1. STS-9 East SRB HDP Pedestals (1, 2, 3, 4)
Strains (T - 4.6 to T + 0.5 s (Sheet 1 of 2)

Figure 3-1. STS-9 Fast SRB HDP Pedestals (1, 2, 3, 4)
Strains (T - 4.6 to T + 0.5 s (Sheet 2 of 2)

Figure 3-2. STS-9 West SRB HDP Pedestals (5, 6, 7, 8)
Strains (T - 4.6 to T + 0.5 s (Sheet 1 of 2)

Figure 3-2. STS-9 West SRB HDP Pedestals (5, 6, 7, 8)
Strains (T – 4.6 to T + 0.5 s (Sheet 2 of 2)

Figure 3-3. STS-9 East SRB HDP Pedestals (1, 2, 3, 4) Strains (T - 0.015 to T + 0.01 s)

Figure 3-4. STS-9 East SRB HDP Pedestals (1, 2, 3, 4) Strains (T – 0.1 to T + 0.31 s)
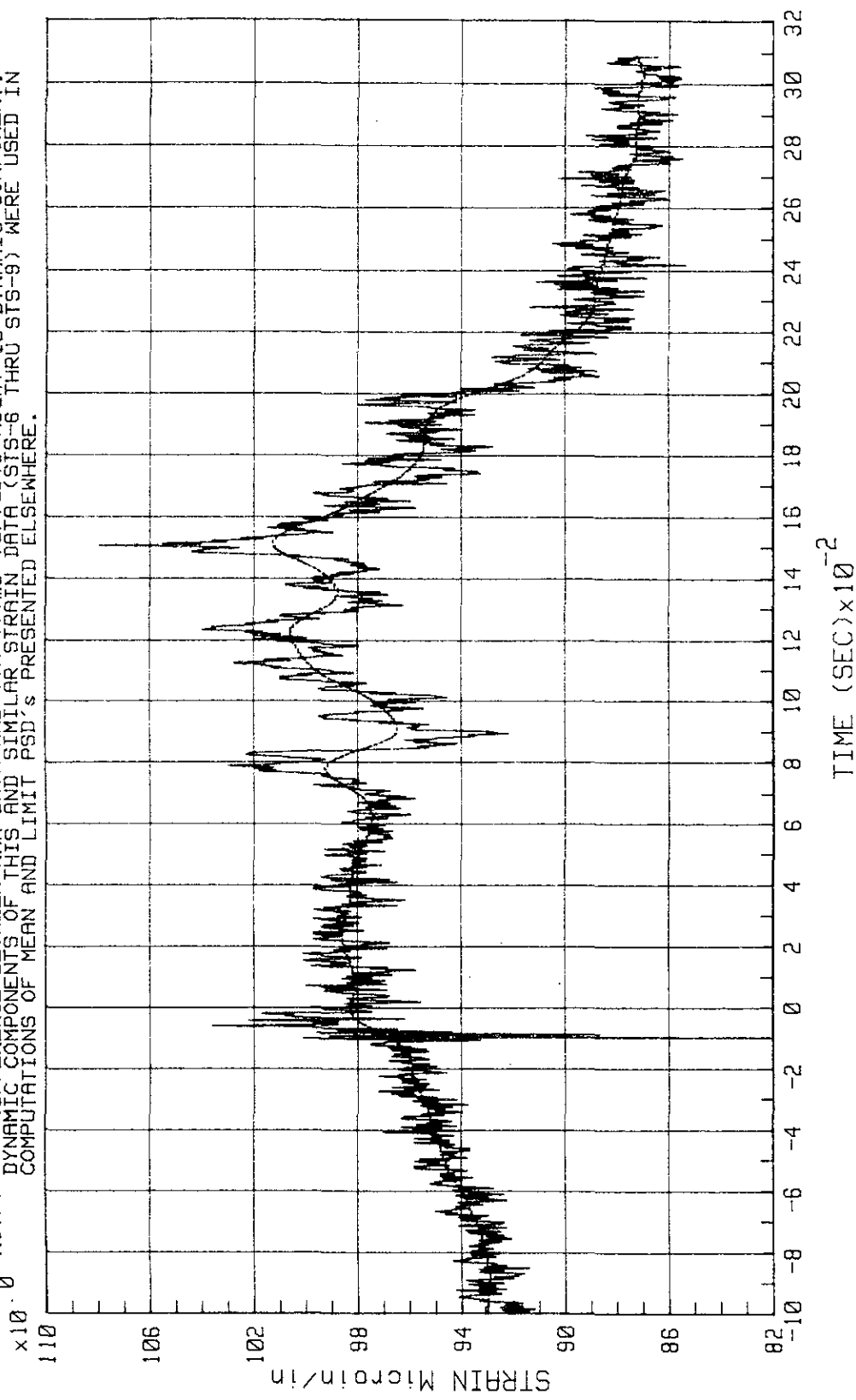
Figure 3-5. STS-9 East SRB HDP Pedestal (1) Strains (T - 0.1 to T + 0.31 s)
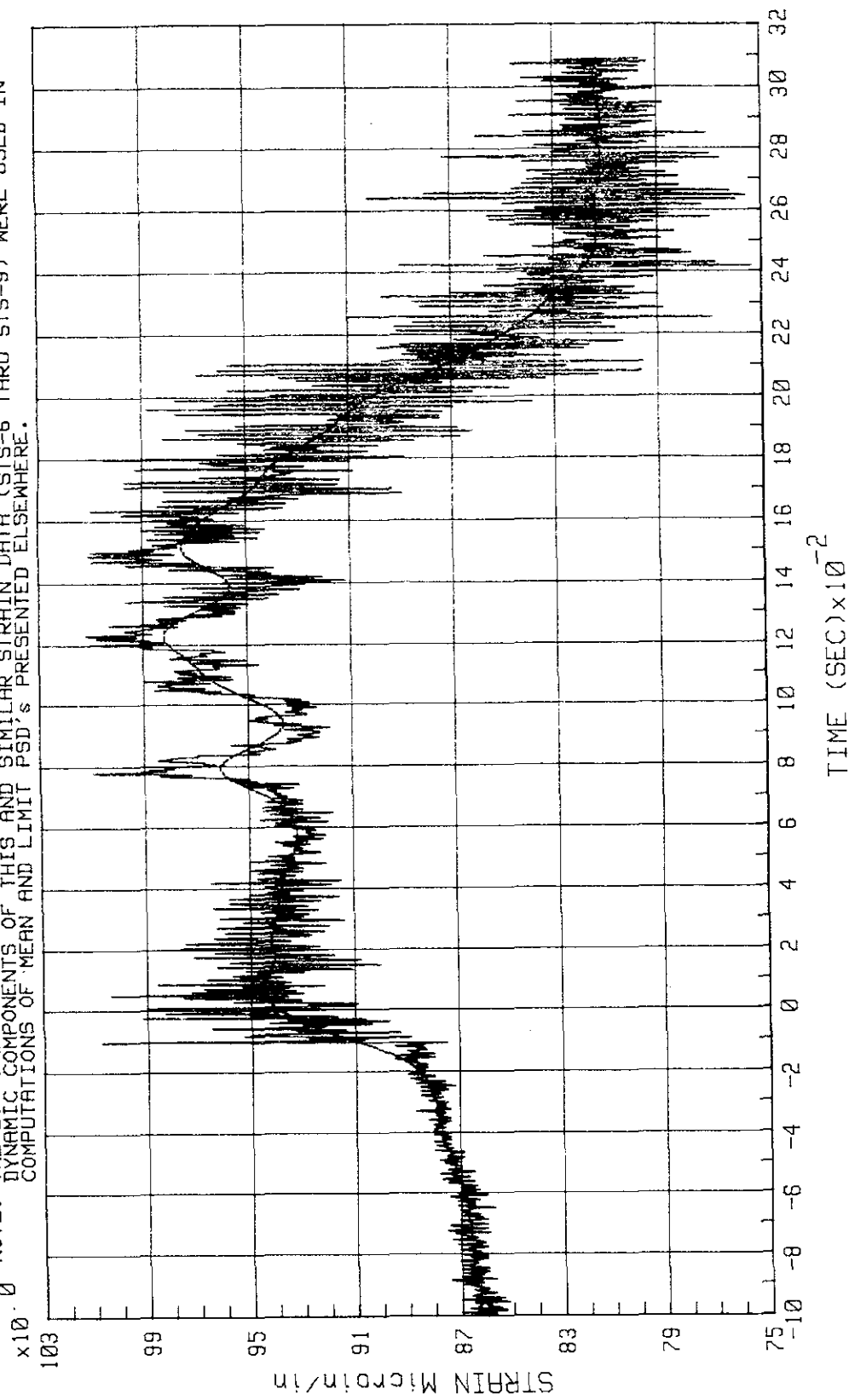
Figure 3-6. STS-9 East SRB HDP Pedestal (2) Strains (T - 0.1 to T + 0.31 s)
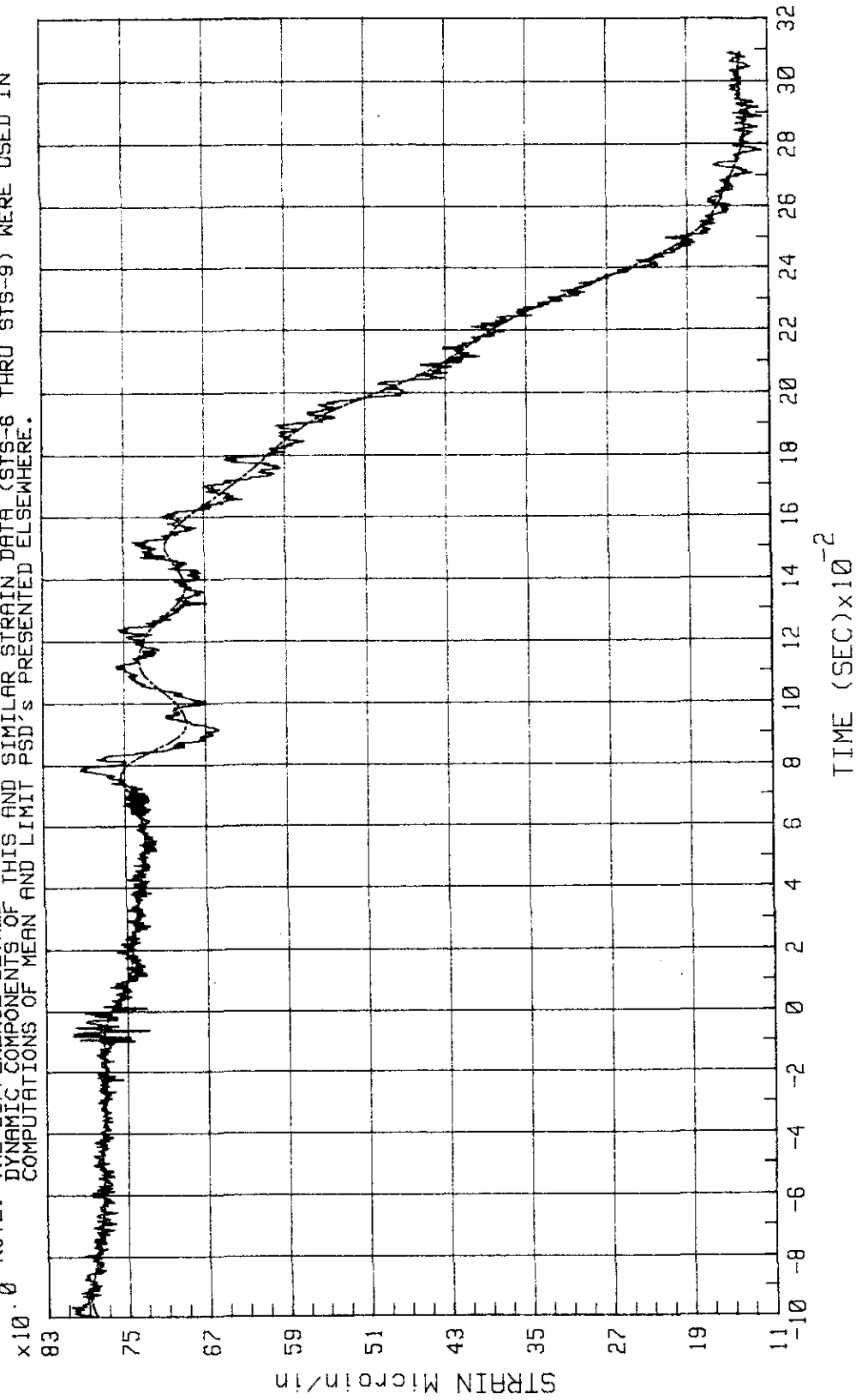
Figure 3-7. STS-9 East SRB HDP Pedestal (3) Strains (T - 0.1 to T + 0.31 s)
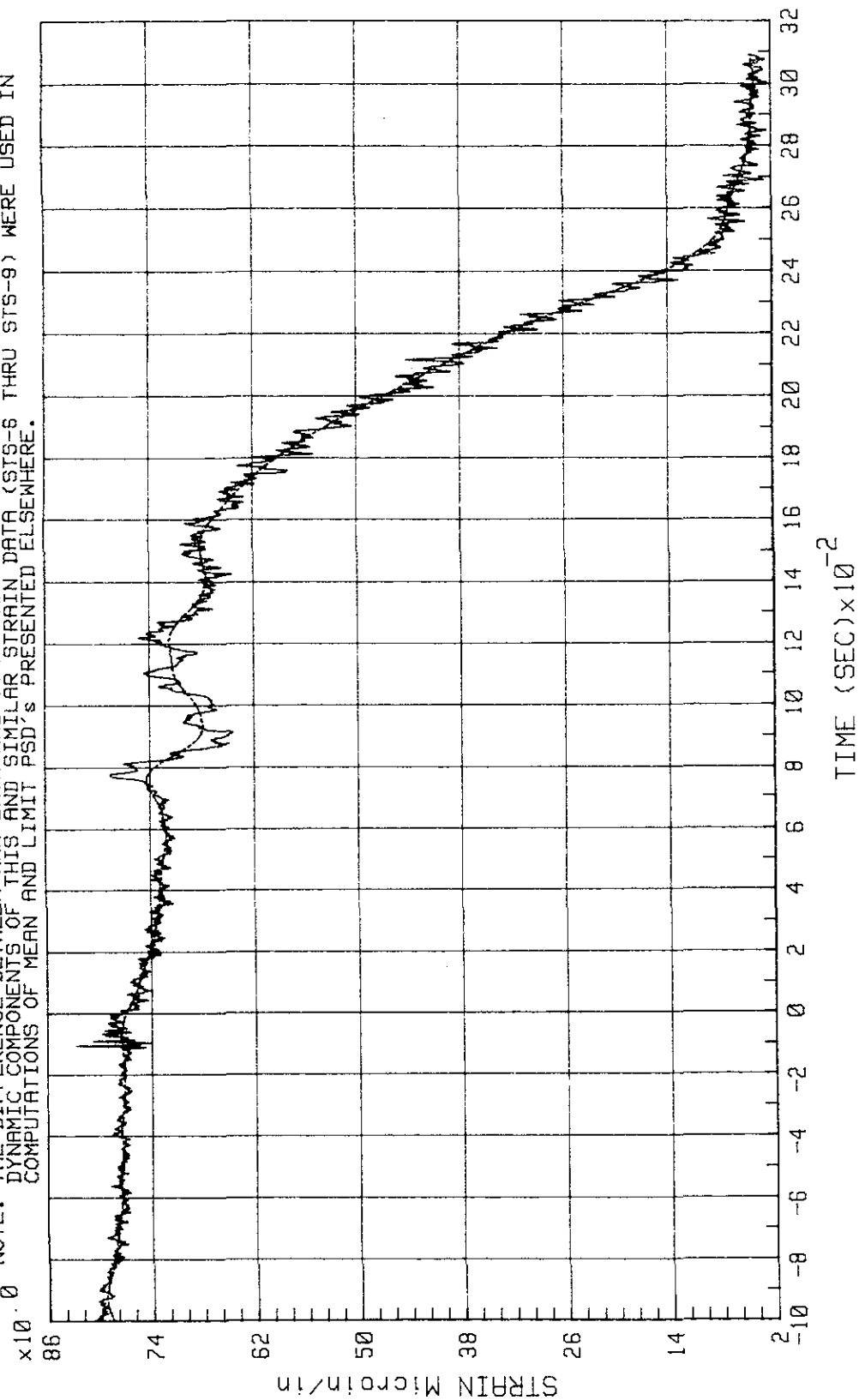
Figure 3-8. STS-9 East SRB HDP Pedestal (4) Strains (T - 0.1 to T + 0.31 s)
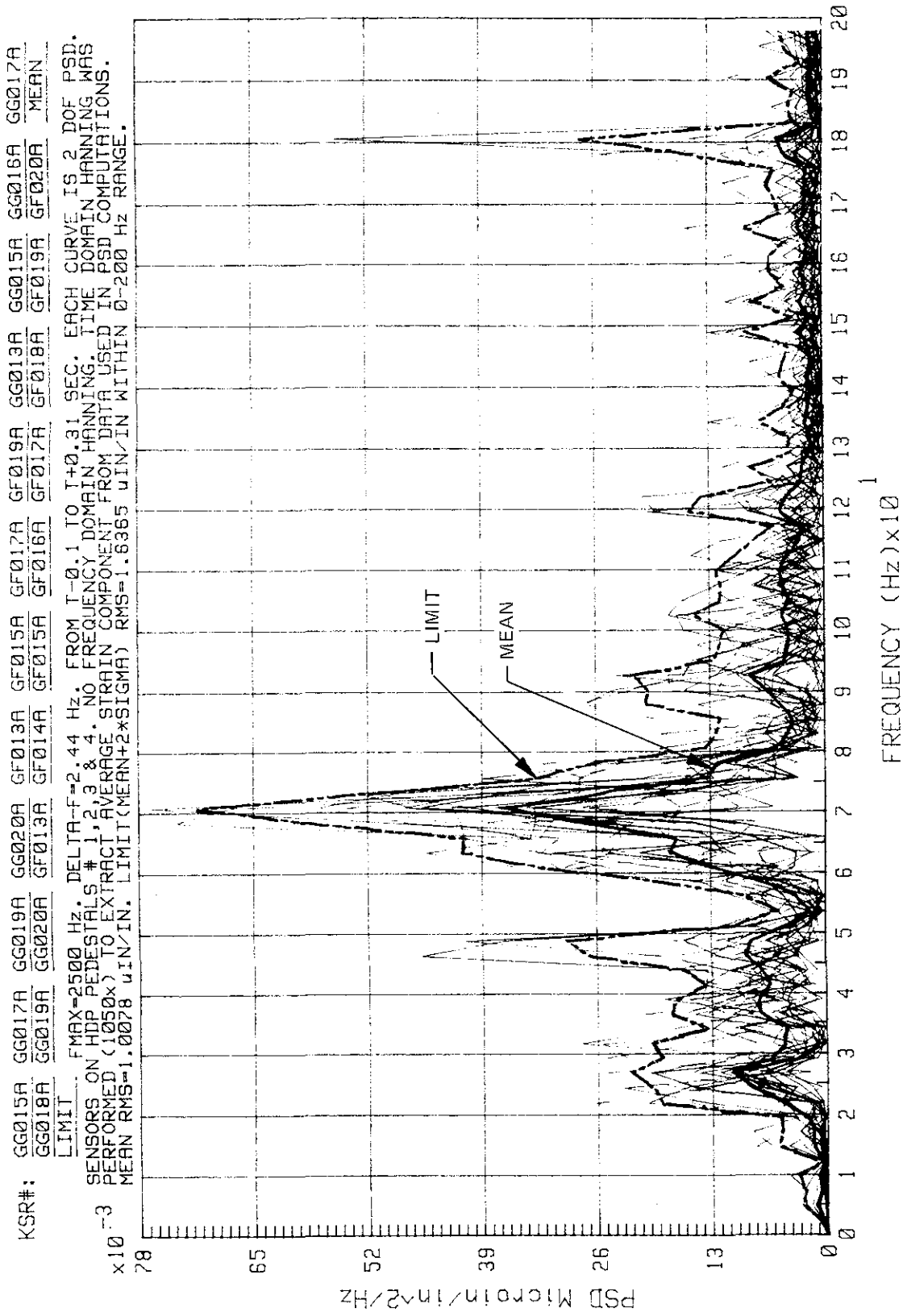
Figure 3-9.   STS-6, -7, -8, and -9 East SRB HDP Pedestal Strains at SRB Ignition (Sheet 1 of 2)
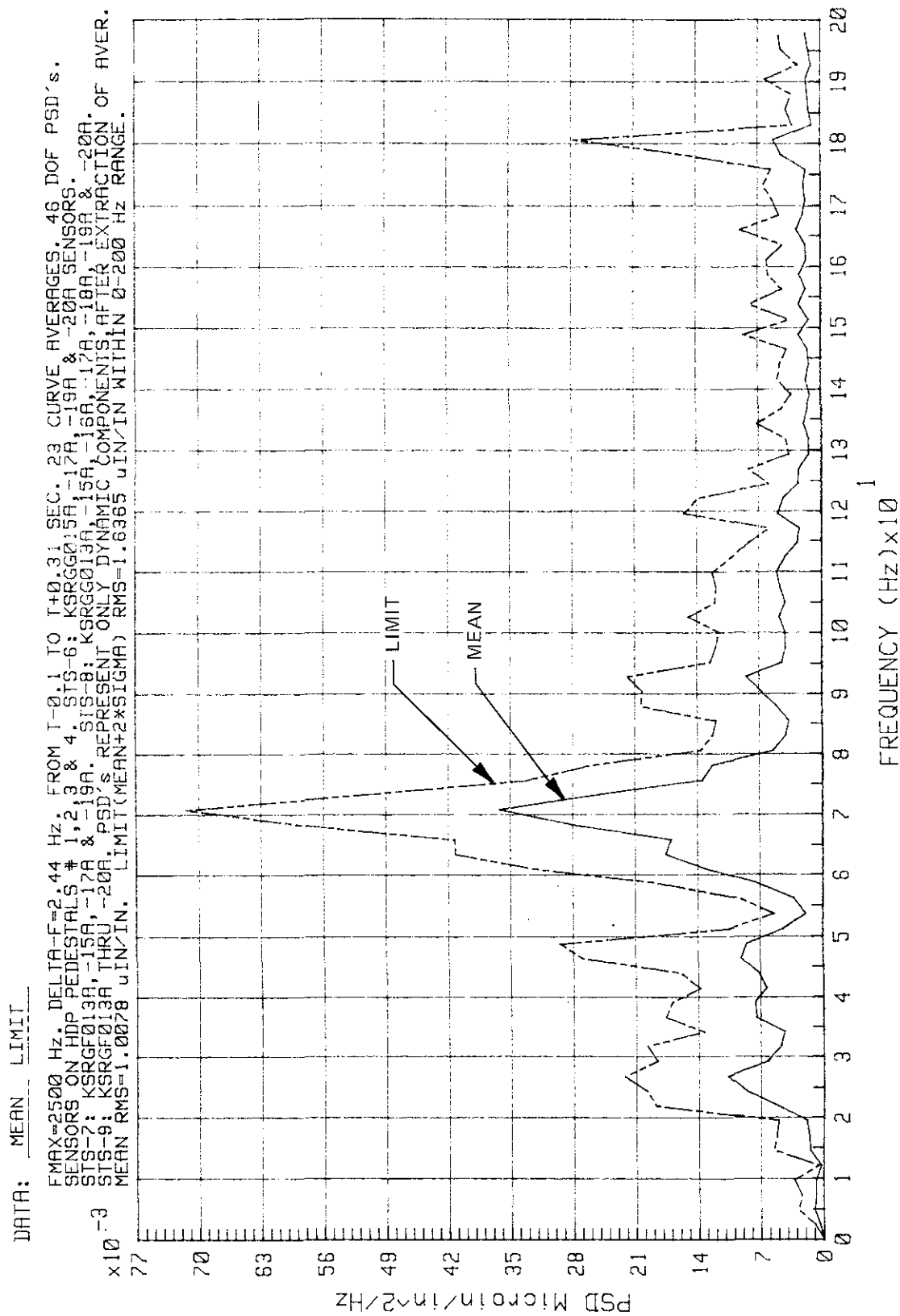
Figure 3-9. STS-6, -7, -8, and -9 East SRB HDP Pedestal Strains at SRB Ignition (Sheet 2 of 2)
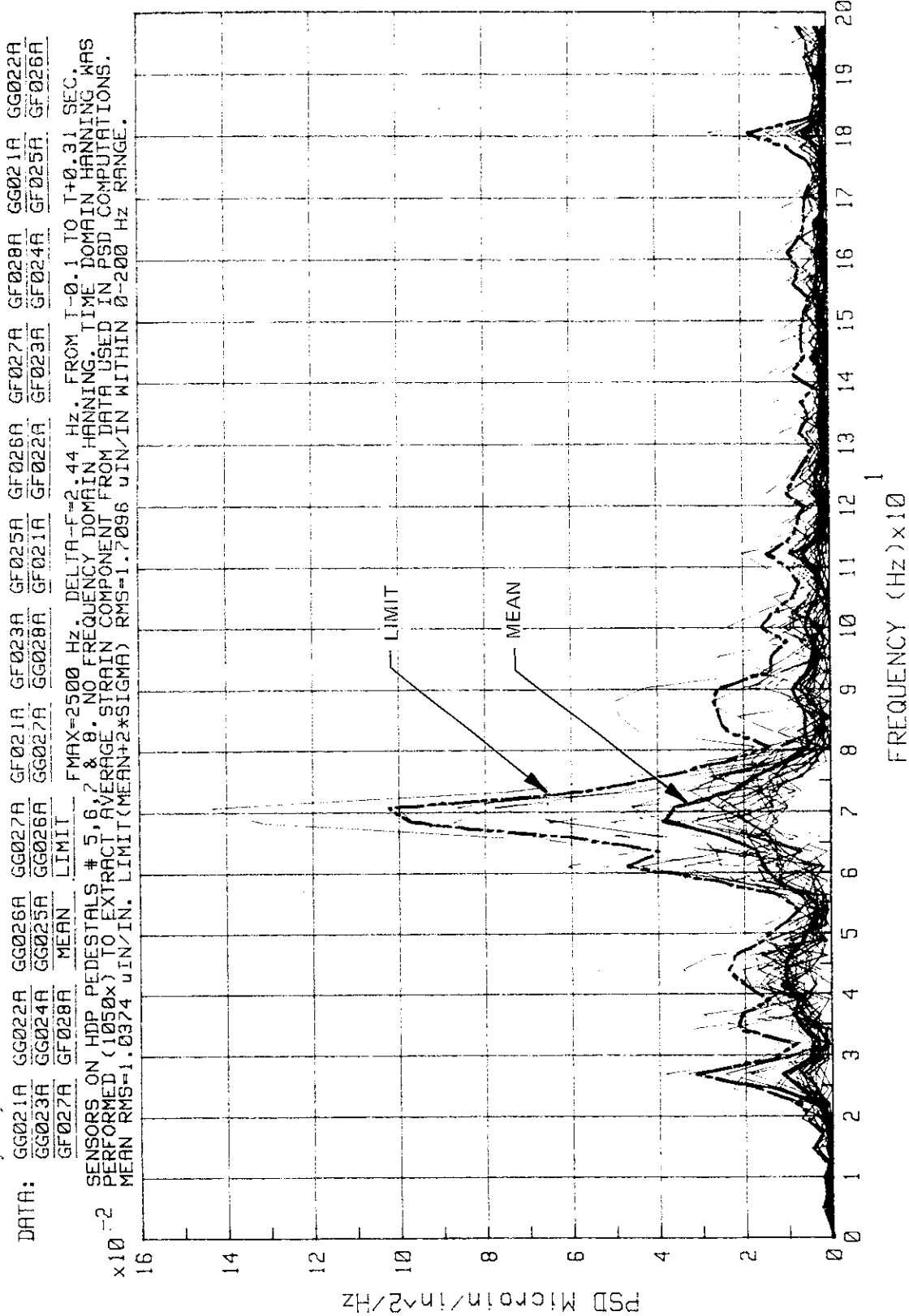
Figure 3-10. STS-6, -7, -8, and -9 West SRB HDP Pedestal Strains at SRB Ignition (Sheet 1 of 2)

KSC-DD-818-TR
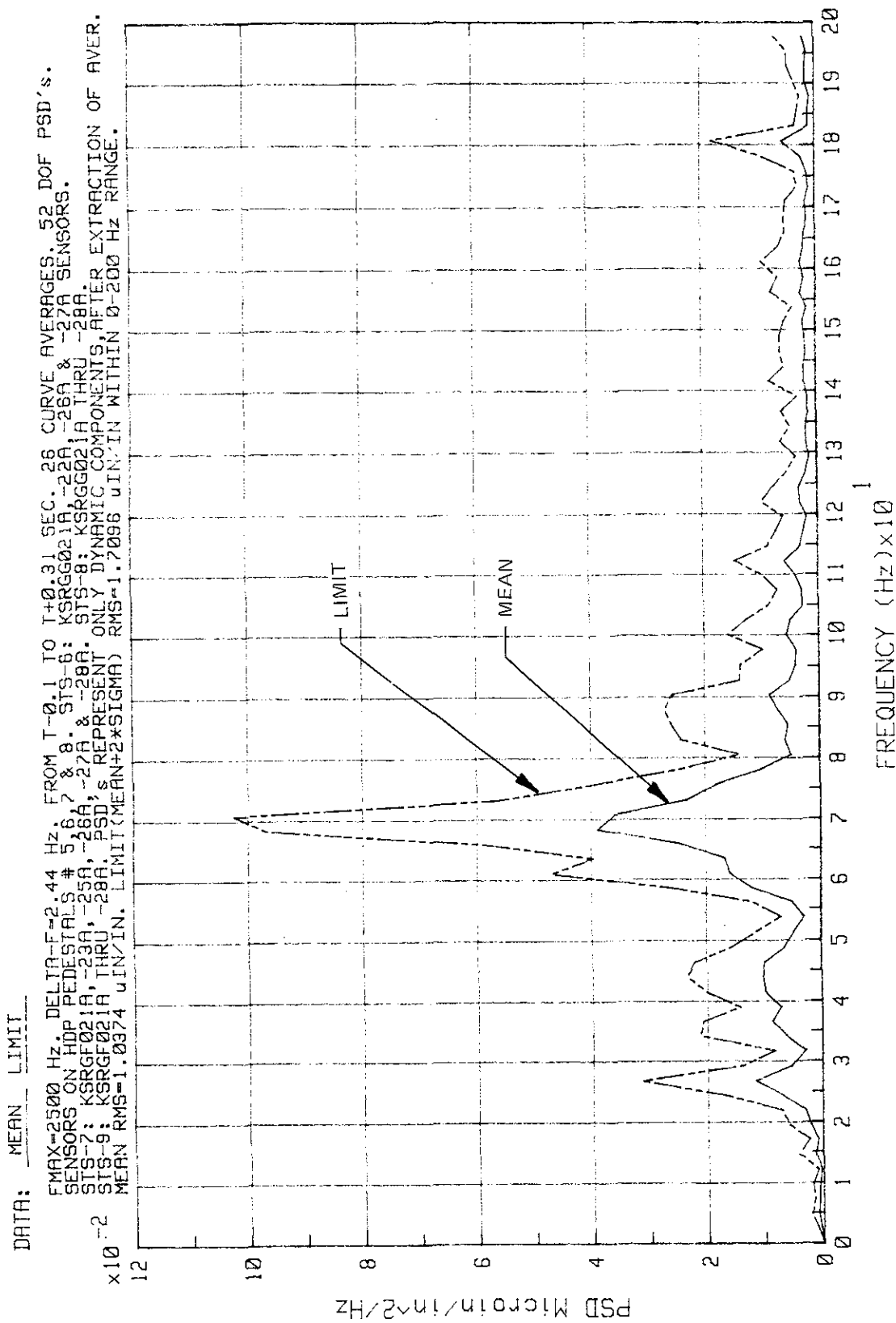
Figure 3-10. STS-6, -7, -8, and -9 West SRB HDP Pedestal Strains at SRB Ignition (Sheet 2 of 2)
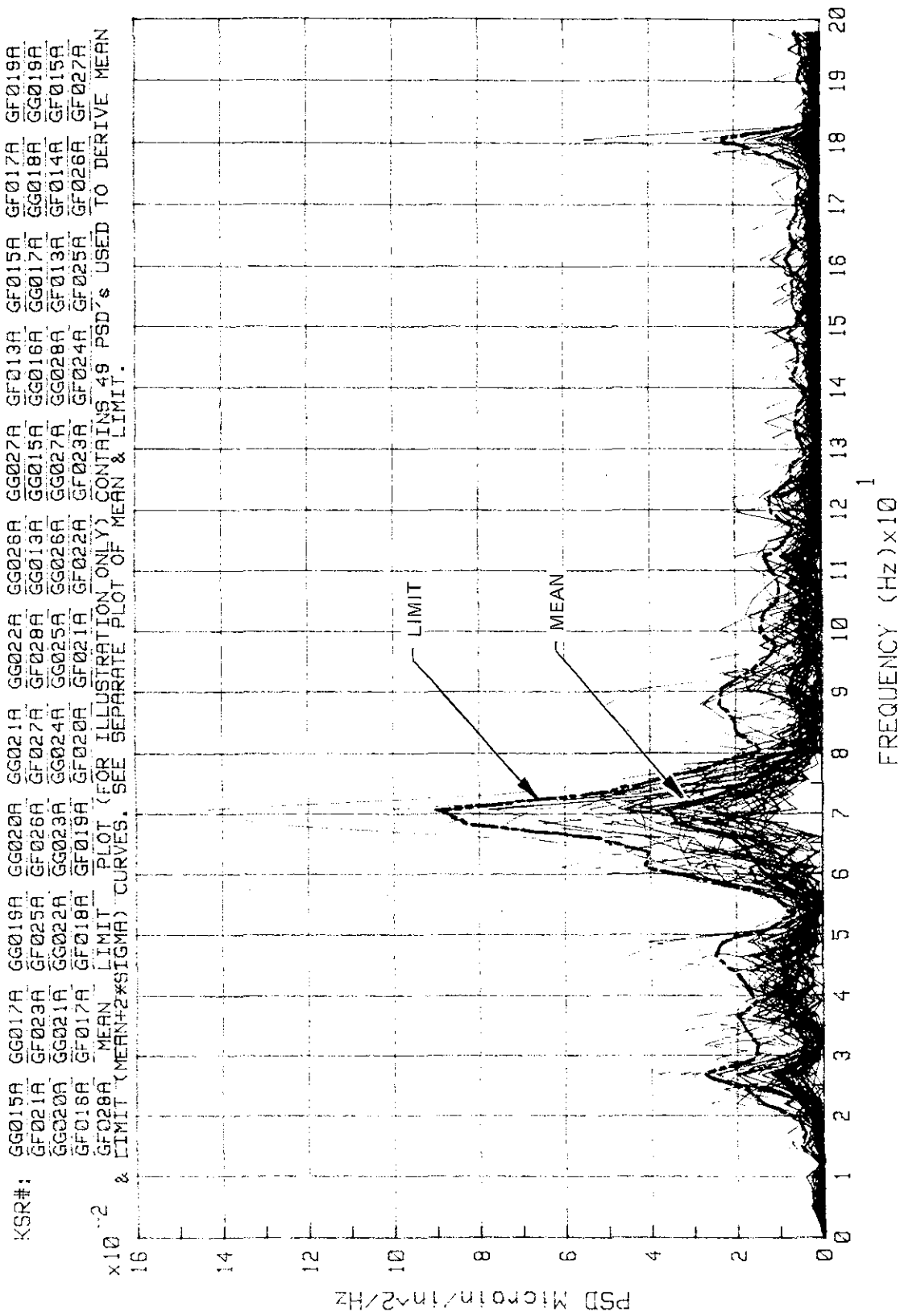
Figure 3-11. STS-6, -7, -8, and -9 Summary of East and West SRB HDP Strains at SRB Ignition
(Sheet 1 of 3)

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Figure 3-11. STS-6, -7, -8, and -9 Summary of East and West SRB HDP Strains at SRB Ignition (Sheet 2 of 3)

3-24
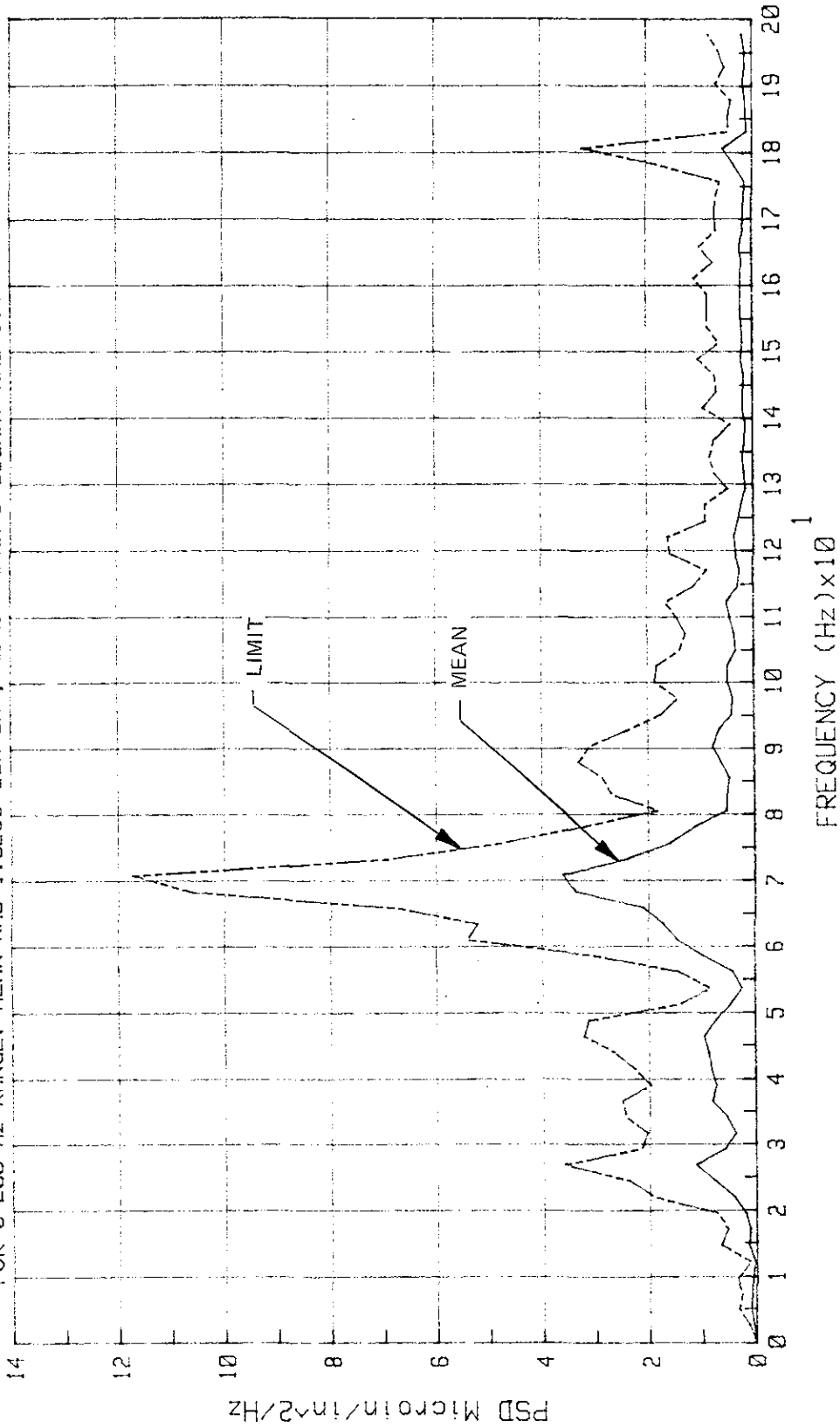
Figure 3-11. STS-6, -7, -8, and -9 Summary of East and West SRB HDP Strains at SRB Ignition
(Sheet 3 of 3)

Figure 3-12. Typical Strain Time History and Illustration of Terms in Text

Table 3-1.   SRB HDP Loads

HDP No.	KSRGF No.	STS-2 CF (kips/μin/in)	STS-2 Dead Load $\epsilon_{DL}-\epsilon_{L/O}$ (μin/in)	STS-2 Peak $\epsilon(t)-\epsilon_{L/O}$ (μin/in)	STS-2 Peak Load (kips)	STS-3 CF (kips/μin/in)	STS-3 Dead Load $\epsilon_{DL}-\epsilon_{L/O}$ (μin/in)	STS-3 Peak $\epsilon(t)-\epsilon_{L/O}$ (μin/in)	STS-3 Peak Load (kips)	STS-5 CF (kips/μin/in)	STS-5 Dead Load $\epsilon_{DL}-\epsilon_{L/O}$ (μin/in)	STS-5 Peak $\epsilon(t)-\epsilon_{L/O}$ (μin/in)	STS-5 Peak Load (kips)
1	13	FAILED				12.70	44	-40	-508.2	11.0	51	-36.5	-401
1	14	9.16	61	-34	-311.6	10.75	52	-45	-483.8	11.0	51	-41.0	-450
2	15	9.81	57	-40	-392.3	6.47	66	-32	-271.0	9.5	59	-48.0	-455
2	16	FAILED				8.60	65	-42	-361.2	8.7	64	-42.0	-367
3	17	15.11	37	104	1,571.2	14.71	38	106	1,559.3	14.3	39	104.0	1,550
3	18	20.70	27	94	1,946.1	18.03	31	107	1,929.5	18.6	30	94.0	1,752
4	19	11.41	49	113	1,289.1	11.89	47	114	1,355.8	12.2	46	110.0	1,337
4	20	15.97	35	110	1,756.9	15.97	35	112	1,789.8	16.9	33	111.0	1,880
5	21	9.02	62	-36	-324.6	9.32	60	-40	-372.7	10.9	52	-42.0	-452
5	22	9.47	59	-31	-293.7	10.75	52	-39	-419.2	11.2	50	-38.0	-425
6	23	8.73	64	-36	-314.4	8.60	65	-34	-292.4	7.8	72	-32.0	-248
6	24	11.18	50	-54	-603.7	10.16	55	-55	-559.0	9.3	60	-50.0	-466
7	25	14.71	38	98	1,441.6	13.63	41	102	1,390.7	14.0	40	108.0	1,510
7	26	16.94	33	103	1,744.8	17.47	32	104	1,816.8	17.5	32	108.0	1,887
8	27	13.98	40	98	1,369.6	14.33	39	92	1,318.7	13.9	40	104.0	1,450
8	28	13.98	40	118	1,649.1	FAILED				12.4	45	113.0	1,400

NOTE: POSITIVE (DOWNWARD) LOADS ARE OVERESTIMATED AND NEGATIVE (UPWARD) LOADS ARE UNDERESTIMATED. SEE TEXT FOR EXPLANATION.
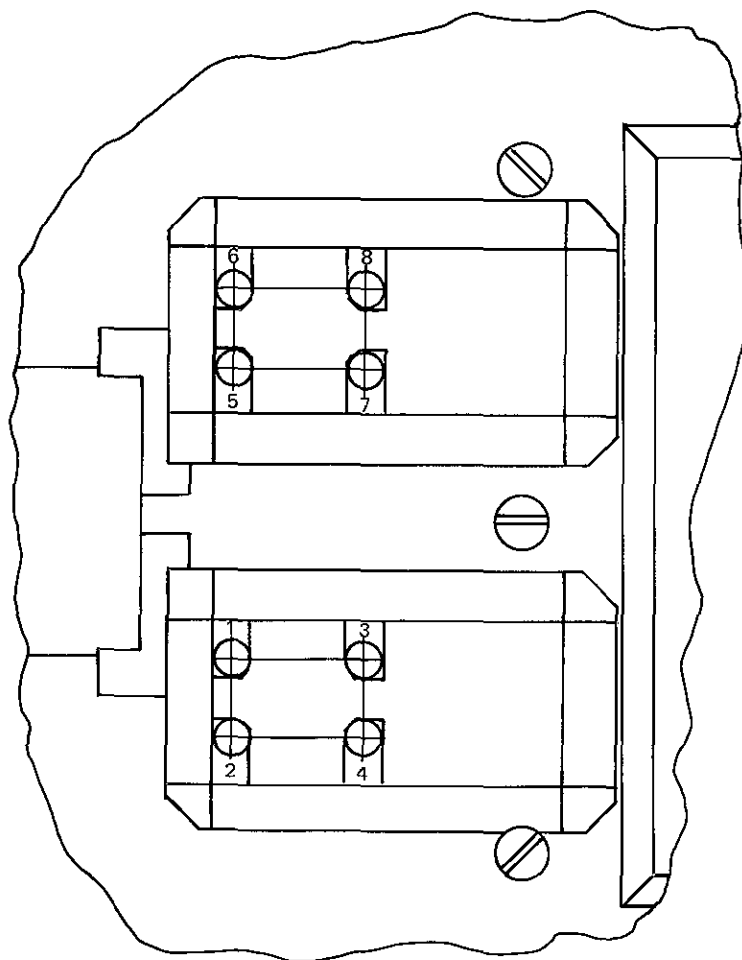
LOCATION OF MLP HOLDDOWN POSTS

Figure 3-13. Location of MLP HDP's

SECTION IV

THERMAL DATA SUMMARY

4.1 MLP

MLP-1 was instrumented with eight thermocouples during the launches of STS-1, -3, -4, -5, -7, and -9. For STS-5 launch, two sets of 6- by 6-in steel plates of varying thicknesses, backed with thermal indicator coating, were exposed to direct flame impingement. Figure 4-1 shows the sensor locations and recorded measurements.

During the launches of STS-1 and -3, MLP-1 was instrumented with six calorimeters to detect ad record heat rate data. Figure 4-2 shows the calorimeter locations and recorded heat rate.

4.2 FSS

The FSS was instrumented with one calorimeter located at the haunch pivot fixture of the ET vent arm. Figure 4-3 shows the measurements of this calorimeter recorded during the launches of STS-3, -6, and -8.
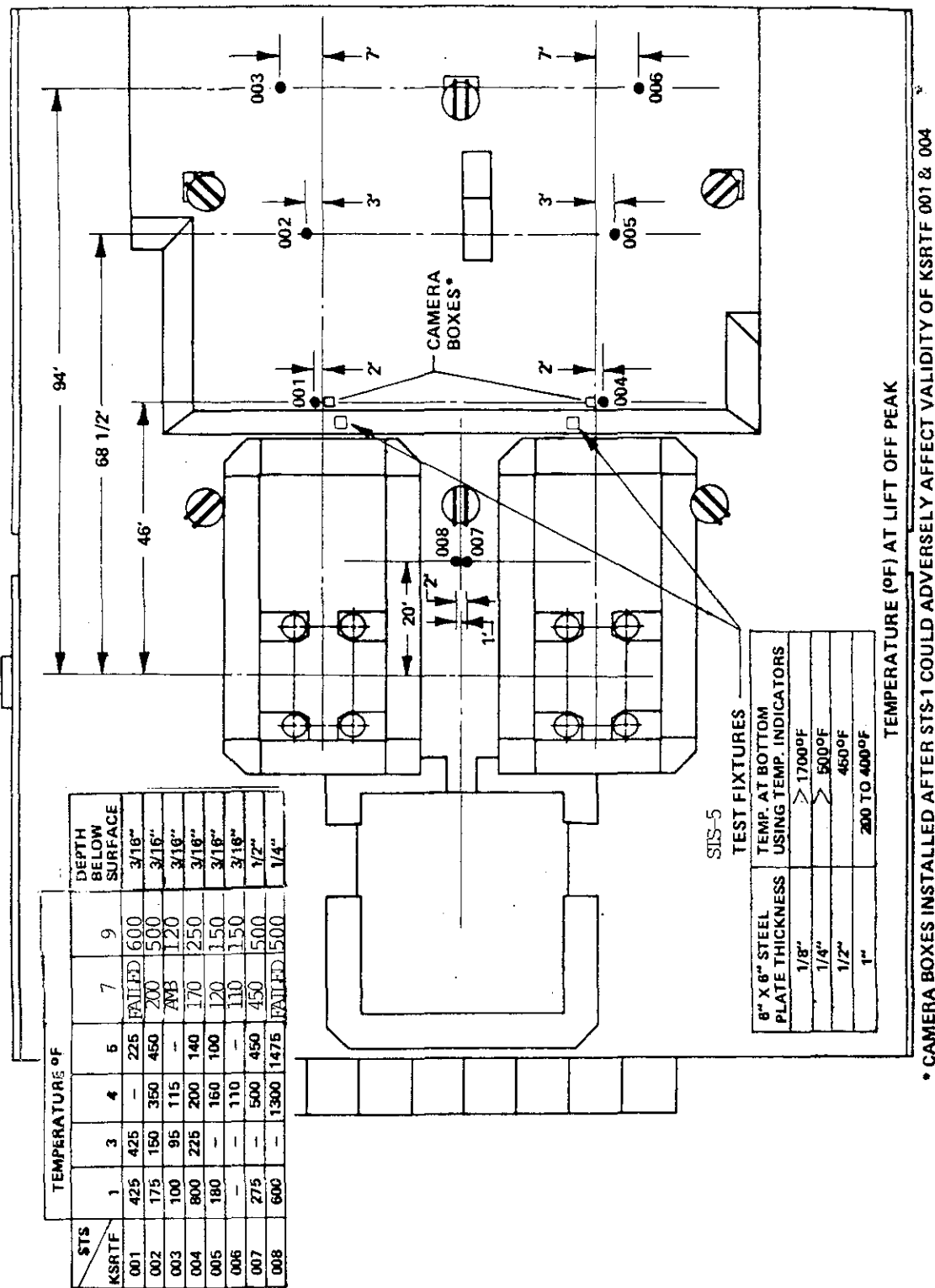
Figure 4-1. MLP-1 Thermal Data Recorded During STS-1, -3, -4, -5, -7, and -9 Launches

	HEAT RATE BTU/FT2/SEC		
STS			
KSRTF	1	2	3
009 *	600		475
010	225		110
011	40		35
012 *	500		650
013	200		140
014	40		25

HEAT RATE BTU/FT2/SEC

*CAMERA BOXES INSTALLED AFTER STS-1 COULD ADVERSELY AFFECT VALIDITY OF KSRTF009 AND -012.

CAMERA BOXES*
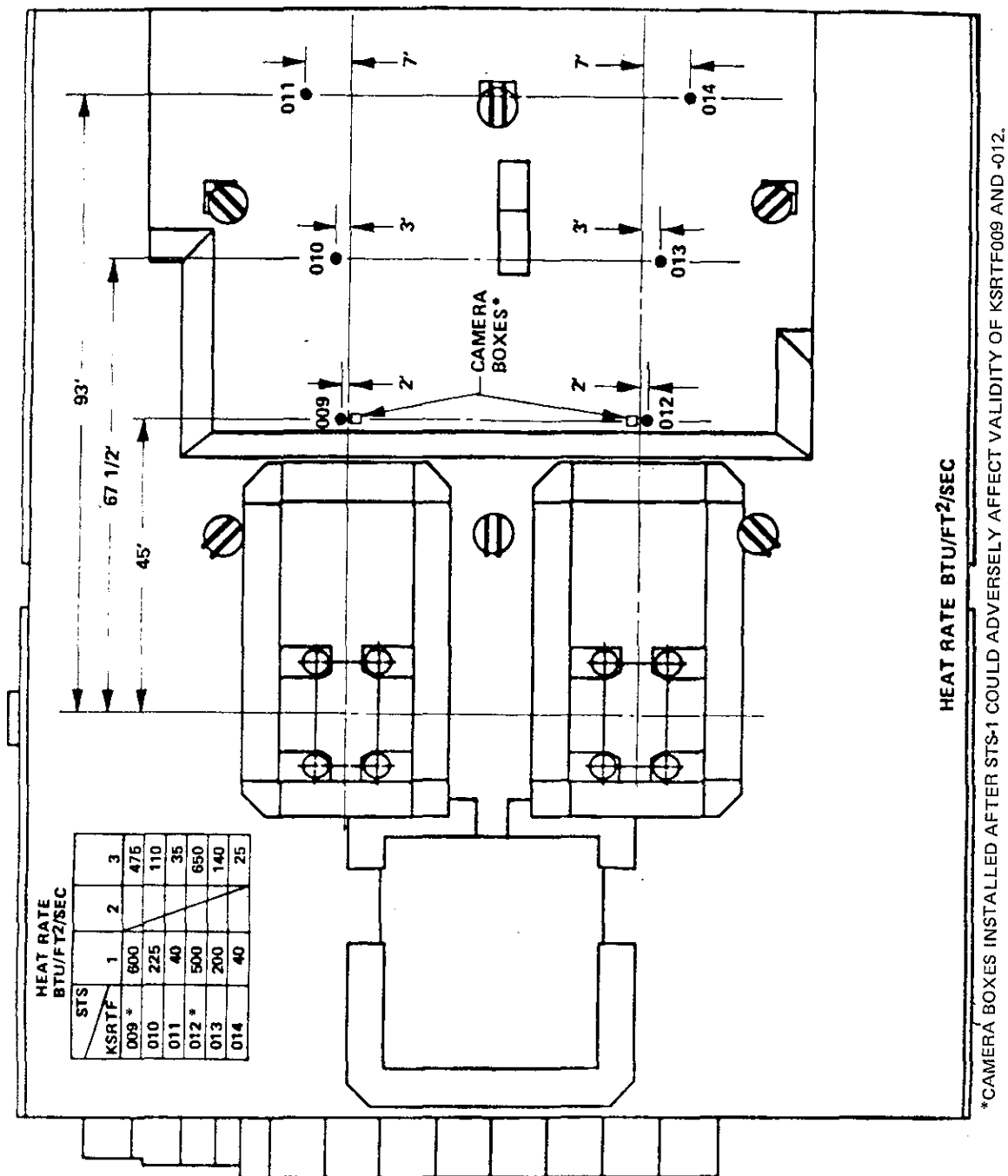
Figure 4-2. MLP-1 Heat Rate Data Recorded During STS-1 and -3 Launches

STS-3 LAUNCH TI-INS 3/22/82

KSATB001A ET HAUNCH PVT FXTR

* 1 15:59:50.526 Z   TIME (SECONDS)

STS-6 LAUNCH TI-INS 4/4/83
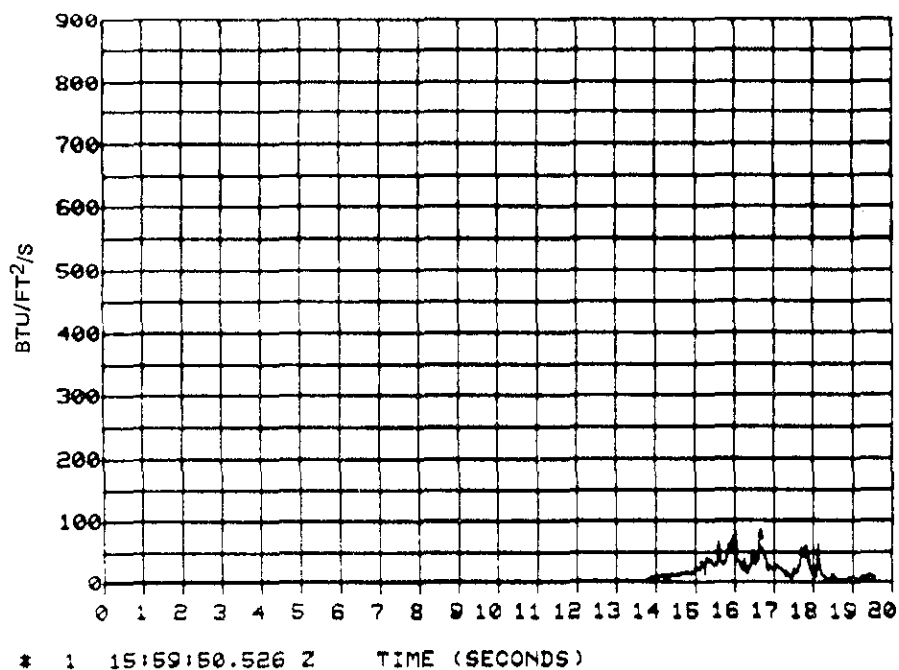
KSATB001A ET VENT

STS-8 LAUNCH SC-INS 8/30/83

KSATB001A ET VENT

* 1 18:29:50.086 Z   TIME (SECONDS)

TIME (SECONDS) 1 6:31:50.483 Z
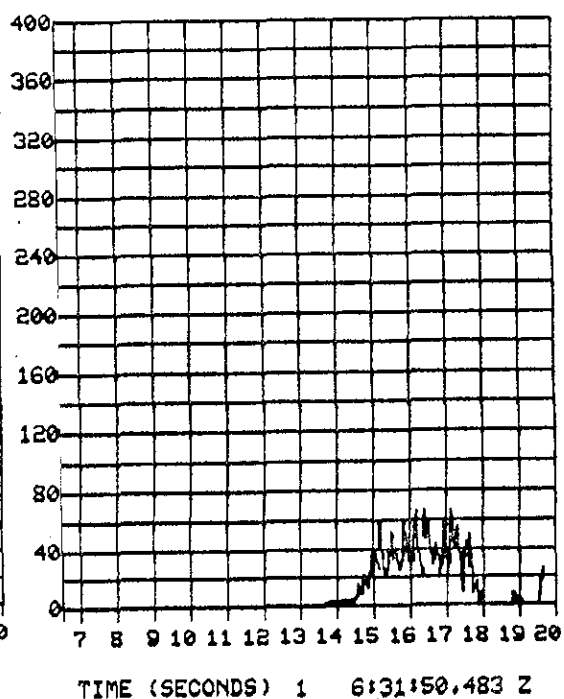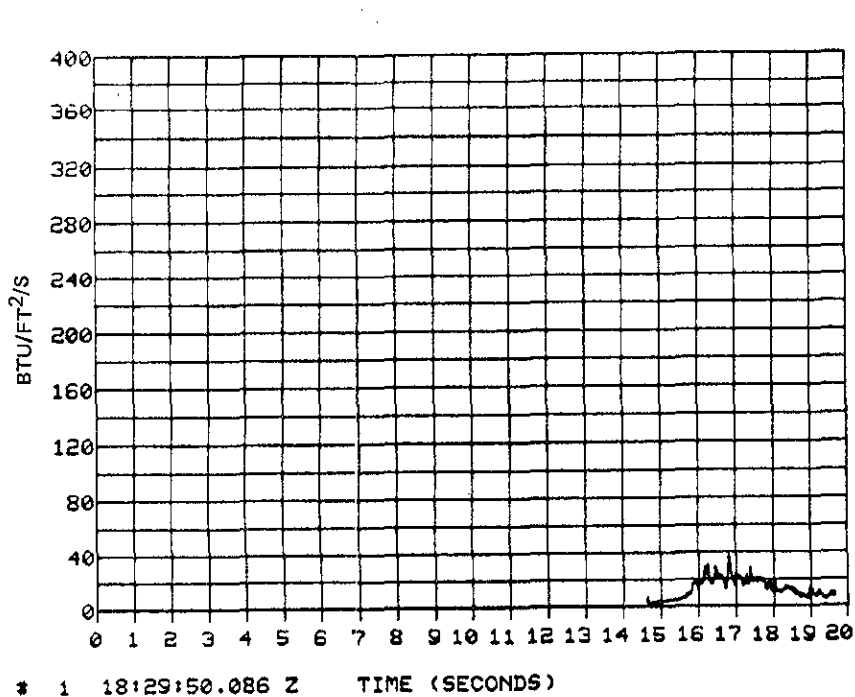
Figure 4-3. FSS Heat Rate Data Recorded During STS-3, -6, and -8 Launches

SECTION V

VIBRATION

5.1   MLP

MLP-1 was instrumented with approximately 182 vibration sensors during the launches of STS-1, -2, and -3. Data that appeared to be valid were processed and published in the documents listed in the bibliography herein. Worst-case samplings of the following elements of the MLP have been selected for this summary and are shown in the applicable figures (figures 5-1 through 5-14). Included are raw data, PD's, PSD's, and rms time histories for the following measurements:

Designation	Location	Room No.	Direction
KSRDF016A	Girder Web Stiffener	43A	Y
KSRDF017A	Girder Web Stiffener	43A	Z
KSRDF021A	6 ft Above Deck B Floor (on wall)	36AB	Z
KSRDF047A	11 ft Above Deck B Floor (on wall)	40AB	X
KSRDF078A	Centerline Bottom Flange Deck O Ceiling Beam	7A	Z
KSRDF079A	Centerline Bottom Flange Deck O Ceiling Beam	9A	Z
KSRDF119A	Center Floor Beam	41B	X
KSRDF120A	Center Floor Beam	41B	Y
KSRDF037A	Truss T_2 Vertical	8A	Z
KSRDF038A	Truss T_1 Vertical	7A	Z
KSRDF080A	Truss T_2 Top Chord	10A	Z
KSRDF081A	Truss T_1 Top Chord	10A	Z
KSRDF159A	Floor Framing Stringer (E) (spring-isolated floor)	9B	Z
KSRDF160A	Floor Framing Stringer (W) (spring-isolated floor)	9B	Z

A comparative summary of the vibration inside MLP-2, previously published as appendix E in KSC-DD-712-TR, follows (5.1.1 and 5.1.2). Not included but recommended for additional information is appendix A of KSC-DD-677-TR, which contains data validation criteria, calculated rms displacements, and zoom plots of significant PSD's.

5.1.1 VIBRATION INSIDE MLP-2. This summary of vibration measurements inside MLP-2 during STS-6 launch presents data acquired for the lift-off peak period. Six sensors installed on three structurally different MLP-2 components were used in the analysis. Measurements established that a fundamental vertical MLP-2 vibration mode (after vehicle lift-off) has a natural frequency near 4.4 Hz.

Since STS-6 was the first Shuttle launched from MLP-2, a comparison is made with similar vibration data obtained on MLP-1 during STS-2 and STS-3 launches. This comparison is used to evaluate the new digital Data Acquisition System (DAS) installed in MLP-2.

Six vibration sensors (KSRDG001A through -006A) were installed for STS-6 on MLP-2 deck 0 beams (two), T-2 truss top chord (two), and on deck B floor beams (two). Chosen locations correspond to MLP-1 sensors KSRDF078A and -079A on deck 0 beams, KSRDF080A and -082A on T-2 truss top chord, and KSRDF128A and -129A on deck B floor beams. All MLP-2 sensors were oriented in vertical (Z) direction. It was established that on the MLP-1, sensor KSRDF082A was mistakenly oriented in Y direction; thus, only five sensors were available for data comparison between MLP-1 and MLP-2 vibration environments.

Output of each MLP-2 sensor was processed three times. Each time, a different set of processing parameters was used in order to define the entire frequency range of data and to obtain an optimal resolution from a relatively short record. Governing parameters, such as F_{max} = Nyquist frequency and Delta-F = resolution frequency, are shown on corresponding data plots. In order to distinguish between various computer files containing processed PSD's, the last character in measurement designation (A) has been made variable (A, B, C, etc.), and these new designations appear in figure 5-15 and on all plots that follow in 5.1. Most meaningful comparisons are obtained between similar measurements processed using the same set of parameters. However, in a few cases of STS-2 and STS-3 data processed earlier, different processing parameters were used, mainly in resolution frequencies, which should be considered when making comparisons.

Figure 5-15 presents data processing parameters and calculated rms displacements for all MLP-2 vibration measurements. Figure 5-15 does not include KSRDG001A through -004A processing case for F_{max} = 5,000 Hz because low data resolution (Delta-F = 4.88 Hz) makes this case unsuitable for displacement calculations. The user is referred to the KSC-DD-677-TR (February 1983) containing a description of the technique used to calculate rms displacements from measured acceleration PSD's and for validation criteria. Displacement data from table E-1, KSC-DD-677-TR appendix A, and some STS-2 data (not previously published) are included into comparisons of MLP-1 and MLP-2 vibration environments presented on figures 5-16 through 5-23.

Figures 5-24 through 5-26 present STS-6 vibration environment on MLP-2 deck O beams recorded by KSRDG001A and -002A sensors. Both sensors recorded essentially the same and a very severe vibration environment in spite of their different locations. RMS accelerations are 23.5 and 27.7 g (0 to 2 kHz), and rms displacements (0.77 and 0.72 in) indicate that peak displacements (at 99% CL) approach 1.5-in amplitude.

Figures 5-27 through 5-29 present STS-6 vibration environment on two adjacent members of T-2 truss top chord, recorded by KSRDG003A and -004A. These truss members also serve as deck O beam supports. Vibration recorded by KSRDG003A located in line with west SRB is slightly more severe than in the midspan of the truss. Also, rms displacement (0.42 in) is greater than that at midspan (0.35 in), indicating that some asymmetric truss modes were excited. The vehicle roll maneuver could be inducing an asymmetric load on the T-2 truss.

Figures 5-30 and 5-31 present STS-6 vibration environment on two deck B floor beams recorded by KSRDG005A and -006A. Both sensors recorded essentially the same vibration environment on floor beams spaced 24 ft apart. These beams have a distinct resonance at 15.6 Hz and about 0.2 in rms displacements associated with local bending of the beams. The total rms displacements are between 0.49 and 0.62 in.

Figure 5-32, left frame, presents PSD's obtained from all MLP-2 vibration sensors when data were processed at the same resolution of 0.781 Hz. All data have a peak at 4.69 Hz, indicating that a fundamental MLP-2 resonance is near this frequency. The right frame on figure 5-24, where data from two measurements have a resolution of 0.39 Hz, shows that a more accurate figure for the MLP-2 resonance is 4.4 Hz.

5.1.2 MLP-1 AND MLP-2 VIBRATION DATA COMPARISON. In an effort to evaluate the new permanent measurement system (PMS), vibration measurements on MLP-2 (STS-6) recorded with the new system were compared to corresponding data recorded on MLP-1 (STS-2 and -3). These comparisons and pertinent comments are presented on figures 5-16 through 5-23.

Comparison of deck O beam and T-2 truss top chord vibration measurements, figures 5-16 and 5-18, shows that the effect of baseline drift (STS-3, KSRDF079A and KSRDF080A) extends up to 25 to 30 Hz. New PMS measurements do not show any effect of baseline drift. Perhaps this could be attributed to different sensors (piezo-resistive versus piezo-electric type) and to different cables used with these sensors.

Figure 5-17 shows that above 30 Hz, STS-6 data on deck O are higher than that of STS-3, while rms displacements, governed by the very low frequency components, remain about the same.

The best data correlation is obtained for measurements on deck B floor beams shown on figures 5-19 through 5-22 and figure 5-23, left frame. Here, good correlation exists within the entire examined range, 0 to 250 Hz, figures 5-20

through 5-22. The fundamental beam resonance frequency of MLP-2 is slightly higher (15.6 Hz) than that of MLP-2 (14.8 Hz), possibly because of different local dead loads on these beams.

Figure 5-23, right frame, presents data on deck B floor beams pertinent to comparison on MLP-1 and MLP-2 fundamental resonances. Both MLP's have a fundamental resonance near 4.4 to 4.6 Hz. However, on deck B, MLP-1 has also a peak around 7.3 Hz, which on MLP-2 is observed only in deck 0 to T-2 truss data. This indicates another MLP mode, possibly local, which is different on each MLP (see figure 5-16 for comparison).

In summary, valid vibration data recorded by fm DAS on MLP-1 and pcm DAS on MLP-2 correlate well in most examined cases. Data recorded by fm DAS often exhibited a baseline drift, which results in too high and invalid PSD amplitudes within 0 to 25 Hz range. MLP-2 data recorded by pcm DAS has a better quality than MLP-1 data, and it is not subject to a malfunction resulting in baseline drift. STS-6 MLP-2 vibration levels are slightly higher than those of MLP-1 (STS-2 and STS-3), but rms displacements governed by PSD components below 5 Hz are lower than on MLP-1.
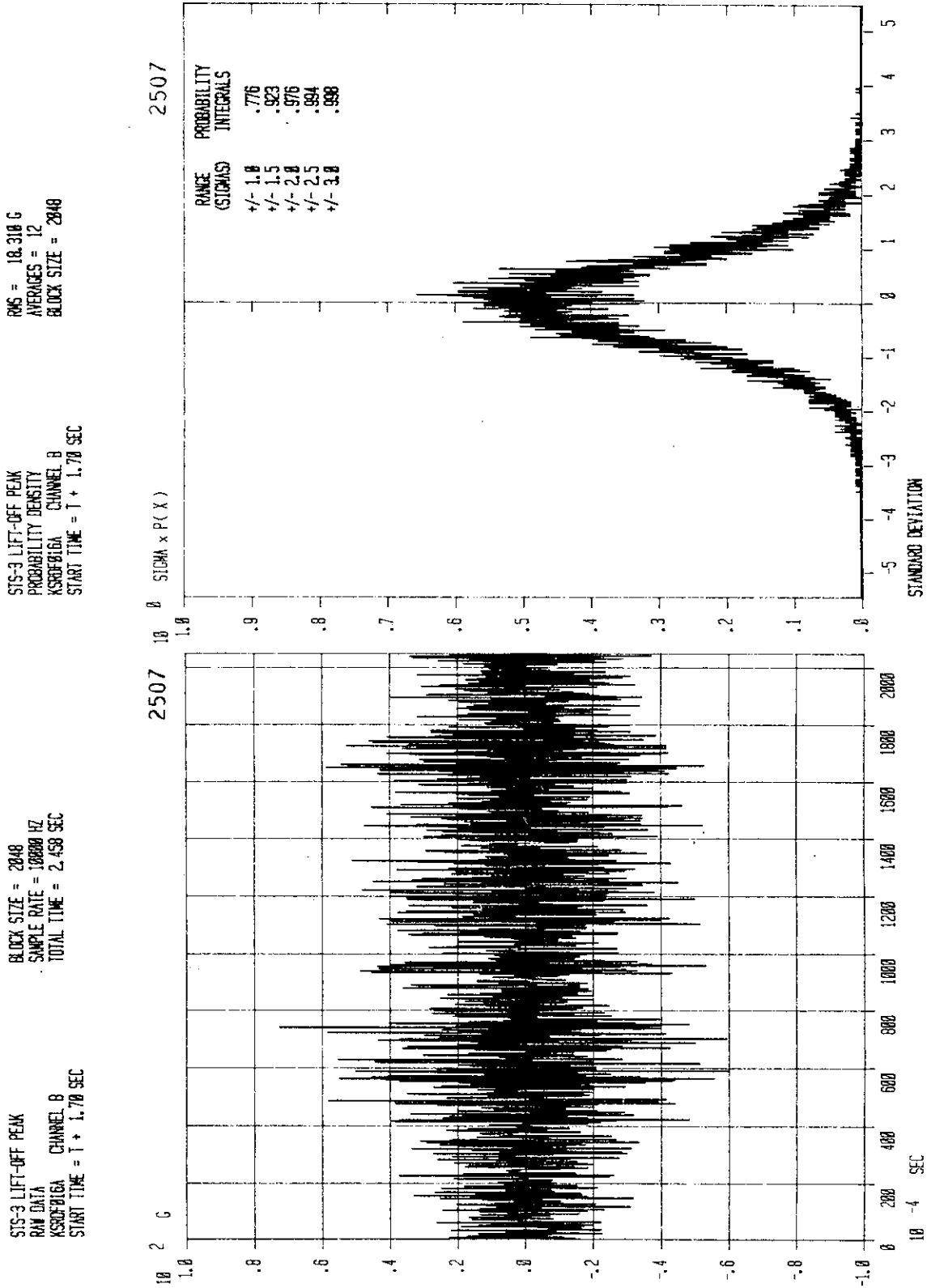
Figure 5-1. Room 43A – Girder Web Stiffener, Y Direction (Sheet 1 of 2)
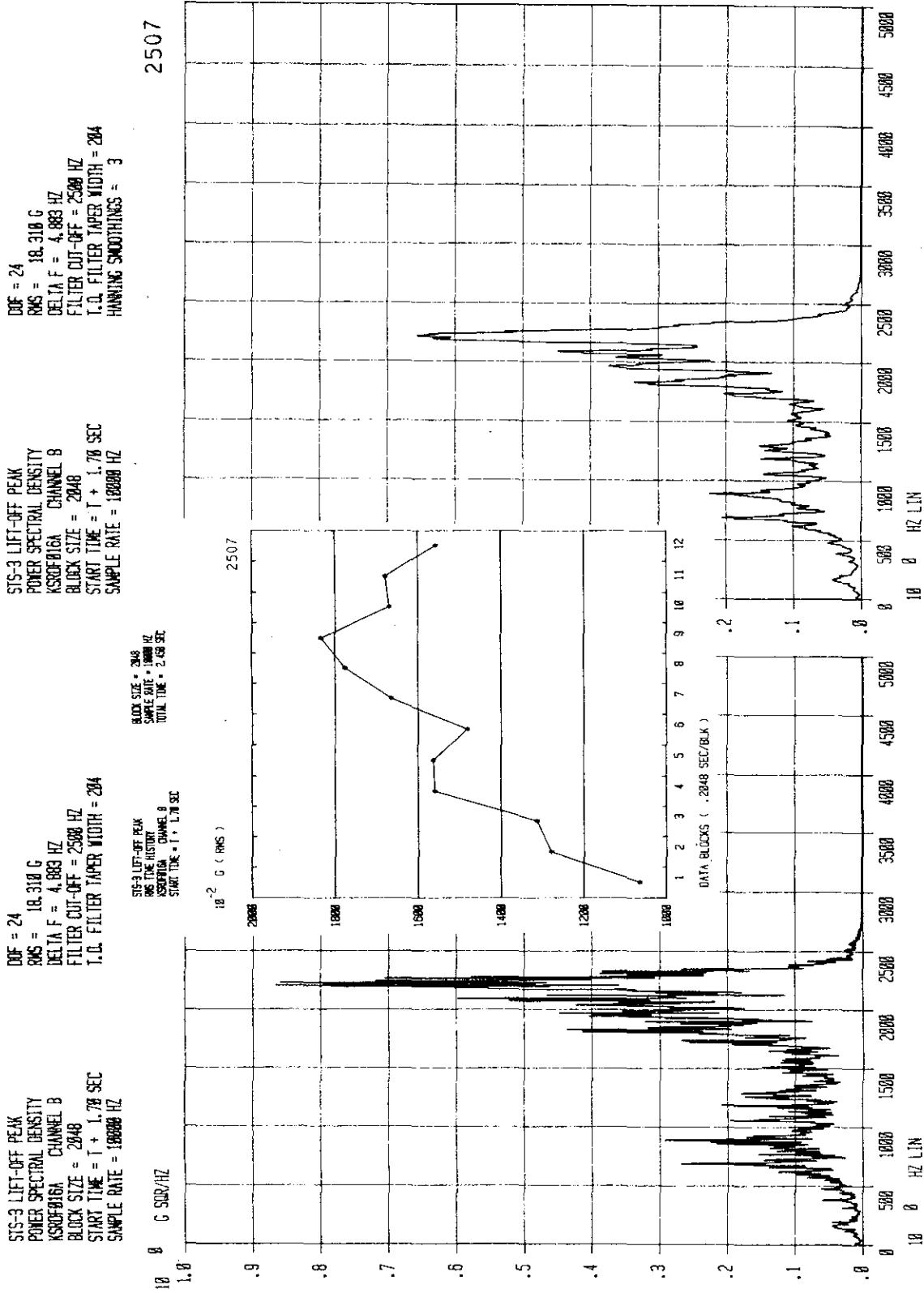
KSC-DD-818-TR

Figure 5-1. Room 43A – Girder Web Stiffener, Y Direction (Sheet 2 of 2)

5-6
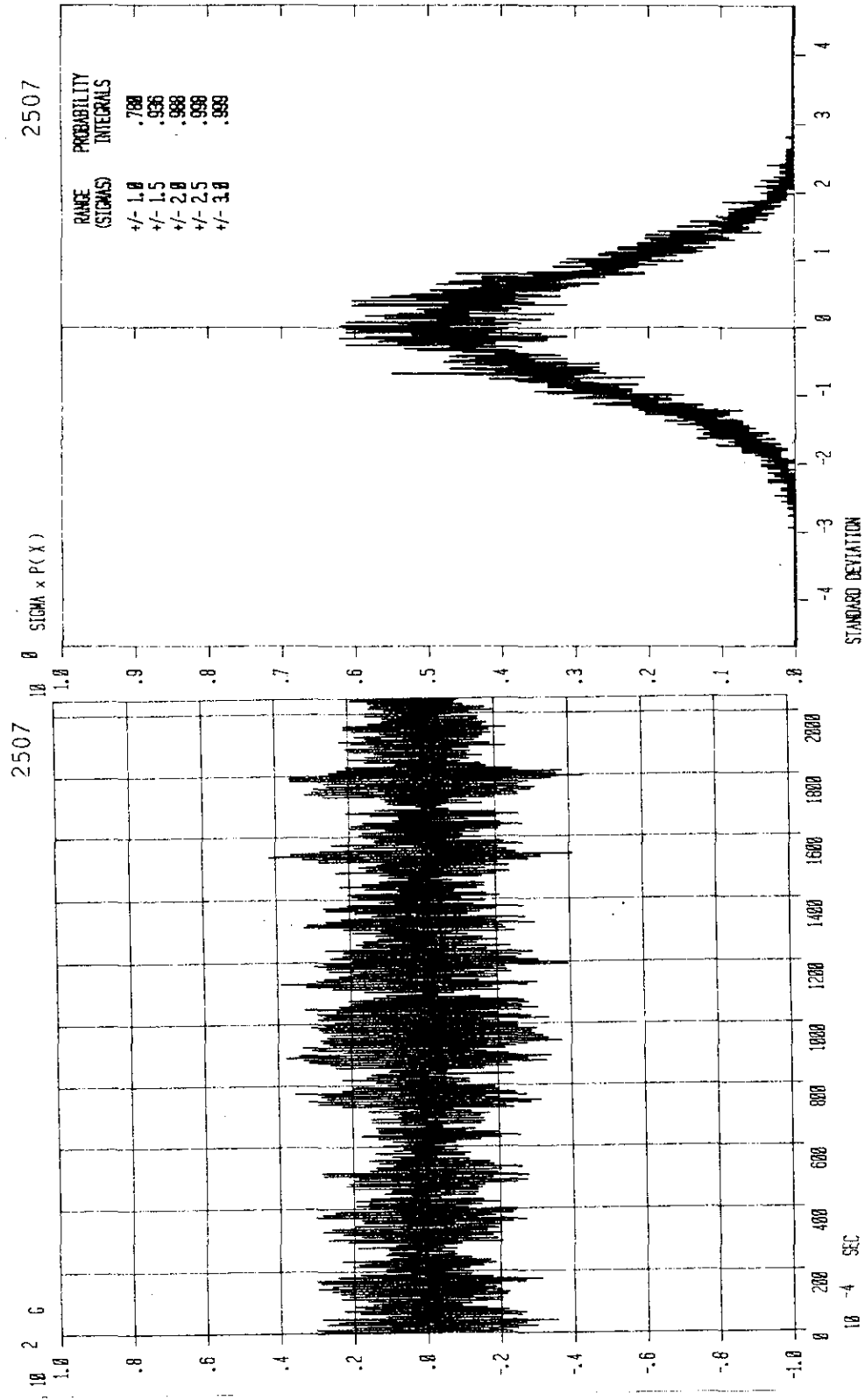
Figure 5-2. Room 43A - Girder Web Stiffener, Z Direction (Sheet 1 of 2)
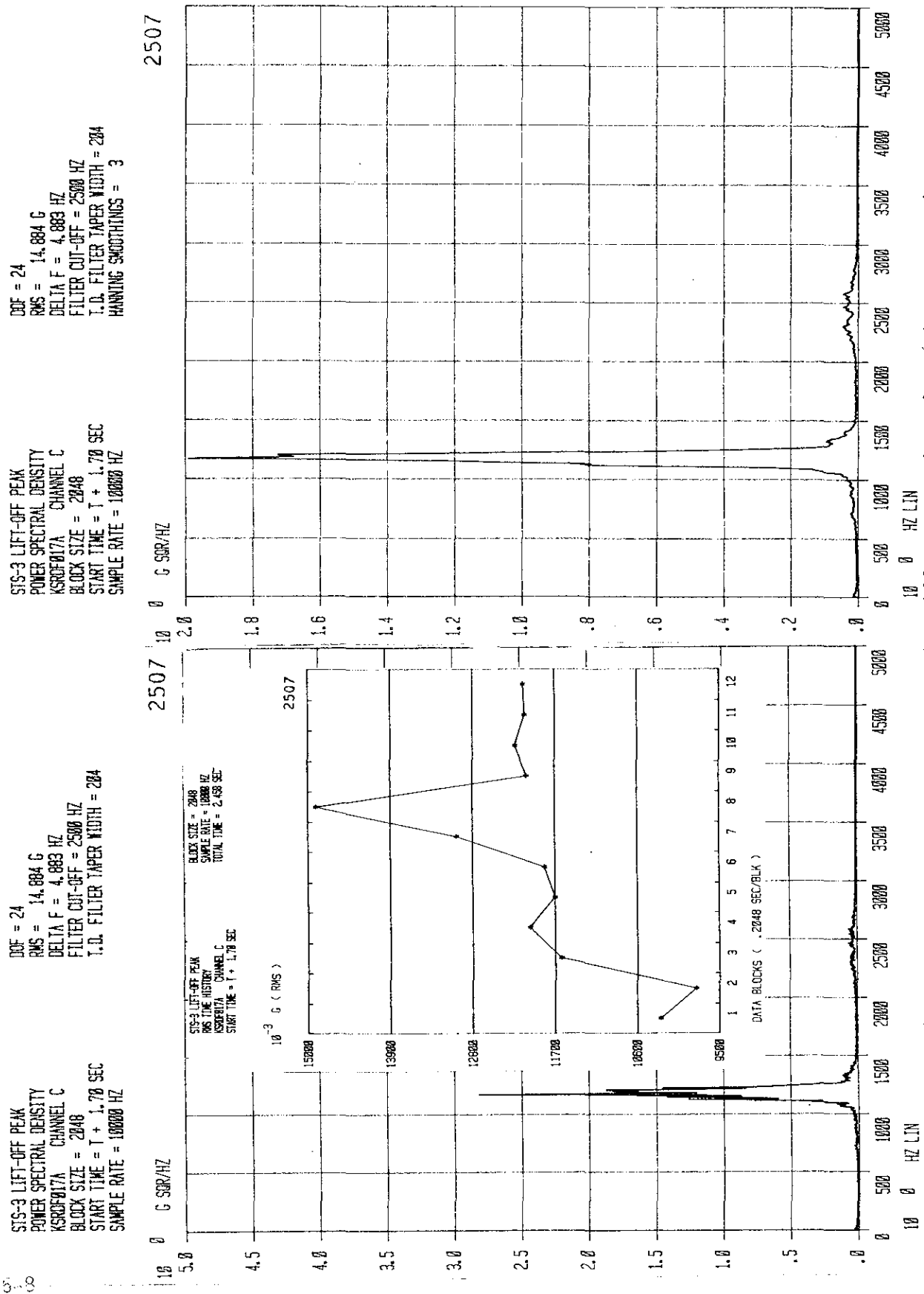
Figure 5-2. Room 45A - Girder Web Stiffener, Z Direction (Sheet 2 of 2)
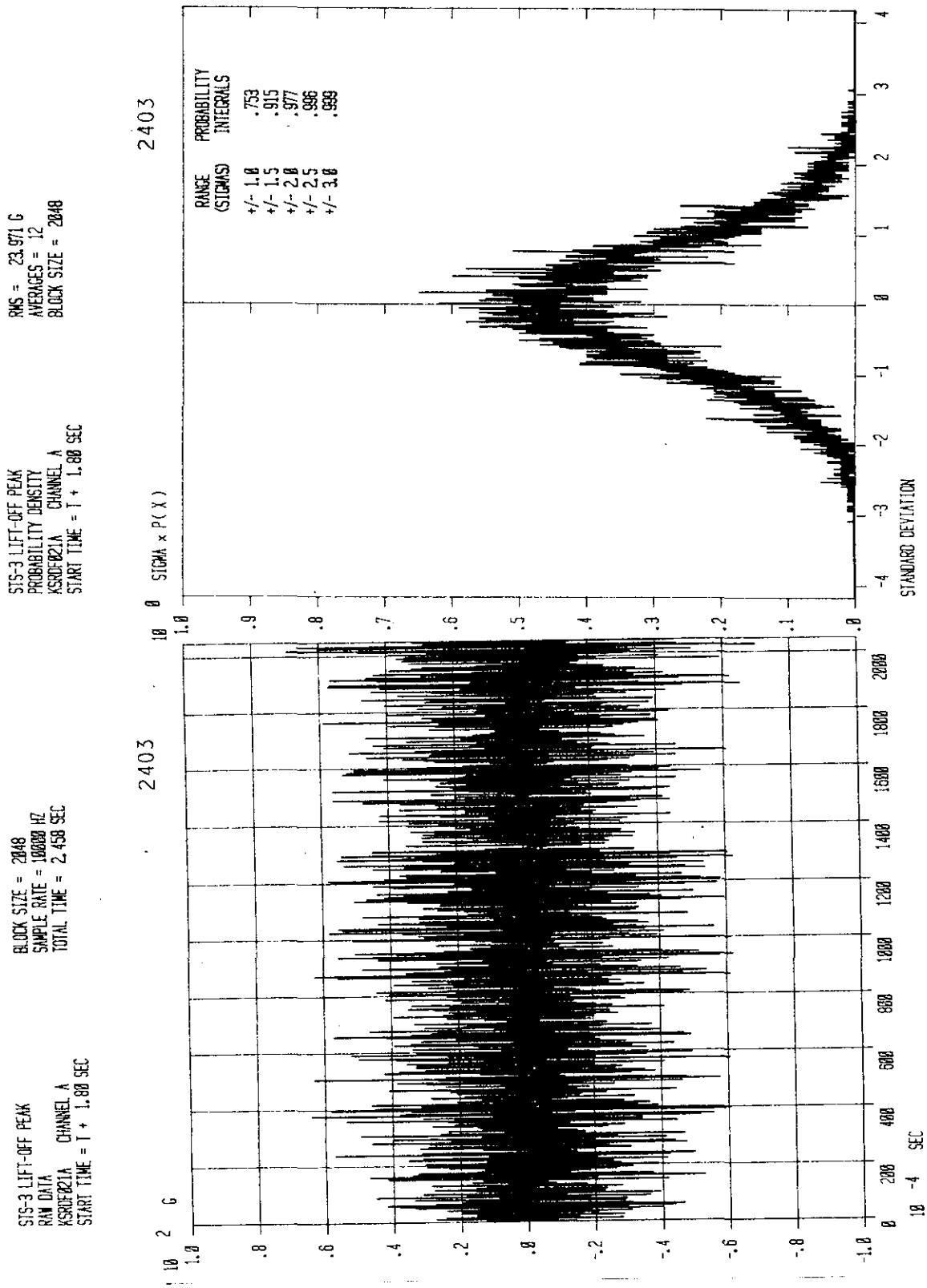
Figure 5-3. Room 36AB - Above Deck B Floor (6 ft), Z Direction (Sheet 1 of 2)
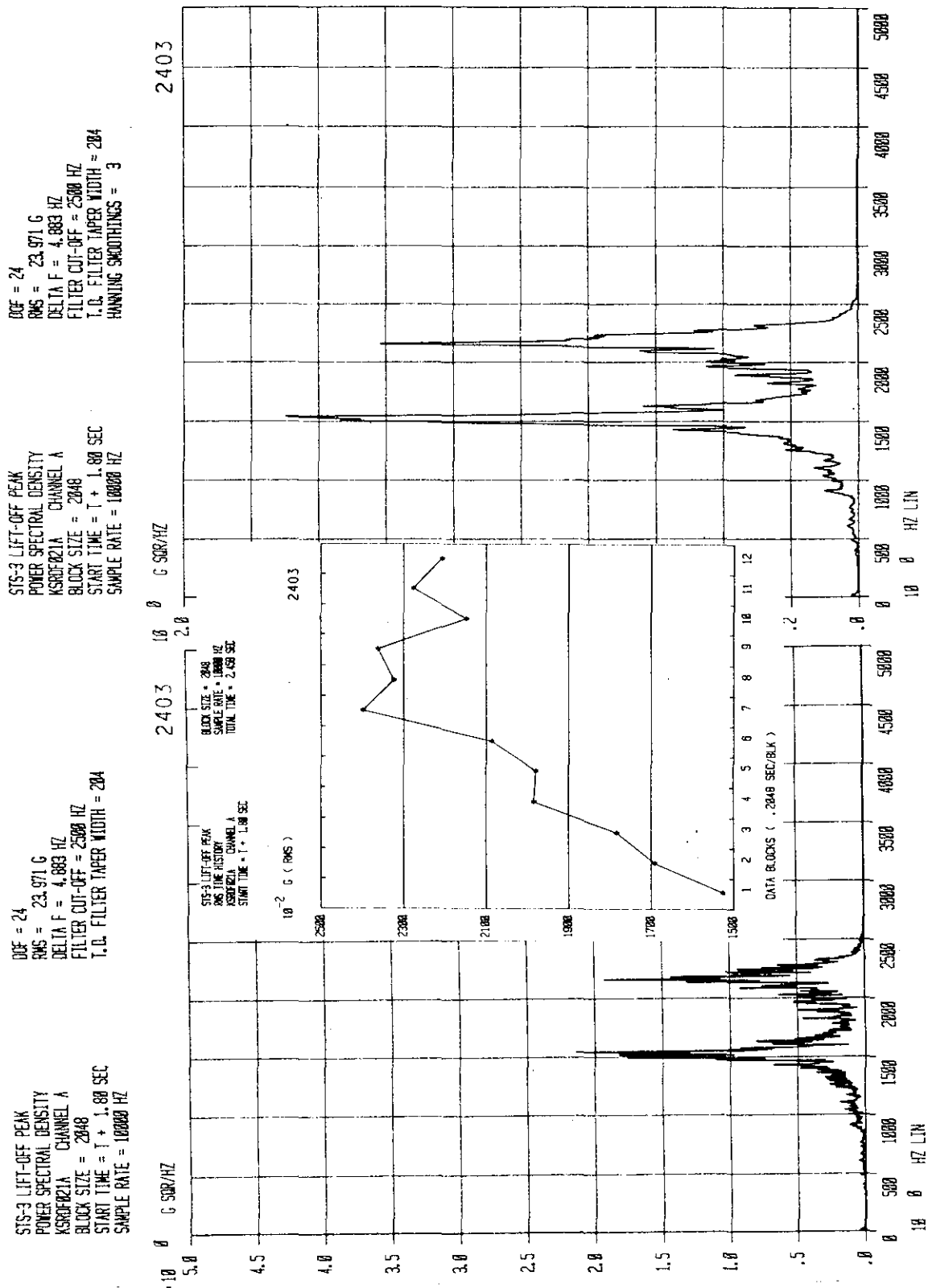
Figure 5-3. Room 36AB — Above Deck 8 Floor (6 ft), Z Direction (Sheet 2 of 2)
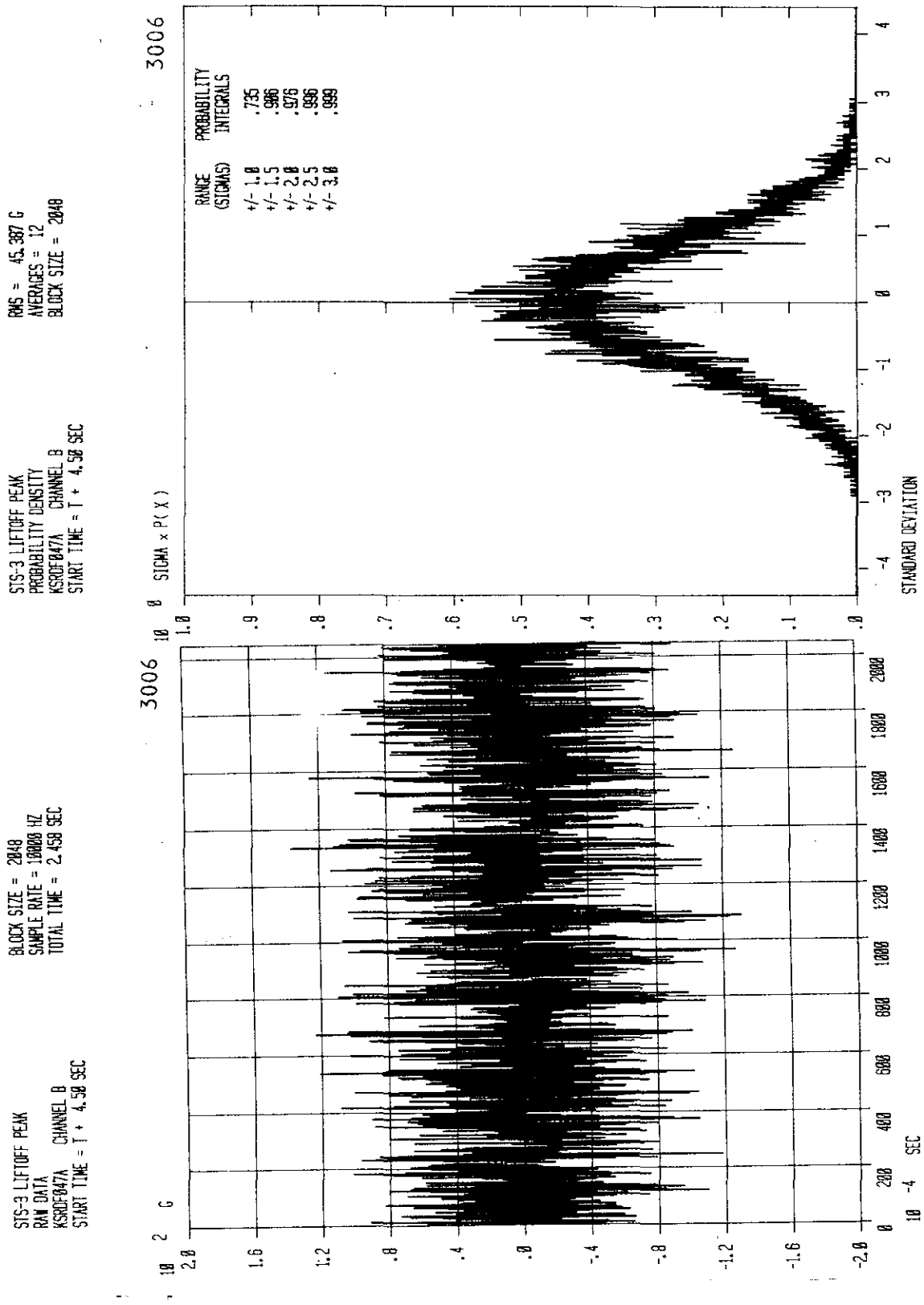
Figure 5-4. Room 40AB — Above Deck B Floor (11 ft), X Direction (Sheet 1 of 2)

Figure 5-4. Room 4OAB - Above Deck B Floor (11 ft), X Direction (Sheet 2 of 2)
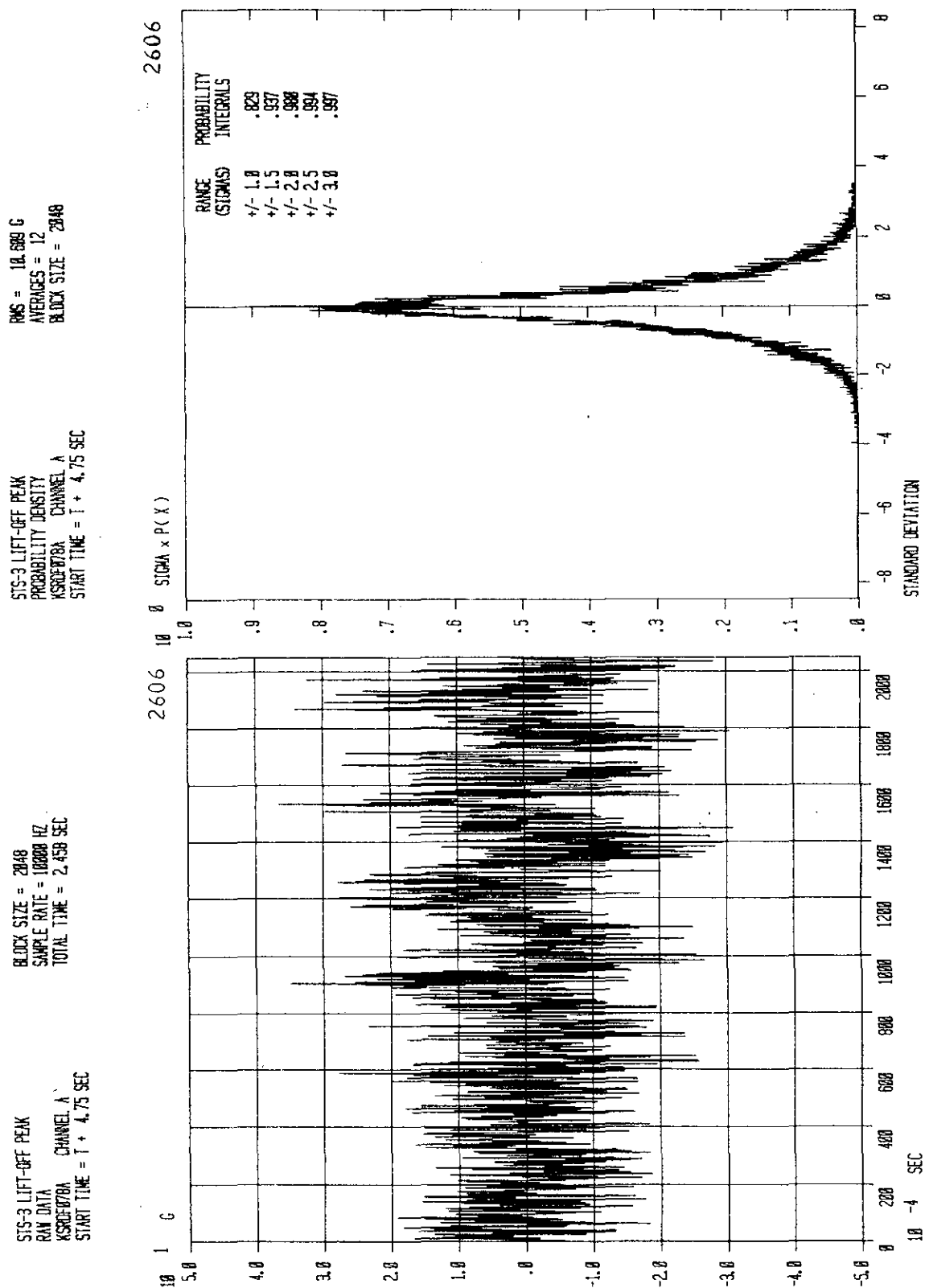
Figure 5-5. Room 7A - C$_L$ Bottom Flange Deck 0 Beam, Z Direction (Sheet 1 of 2)

Figure 5-5. Room 7A - C_L Bottom Flange Deck O Beam, Z Direction (Sheet 2 of 2)
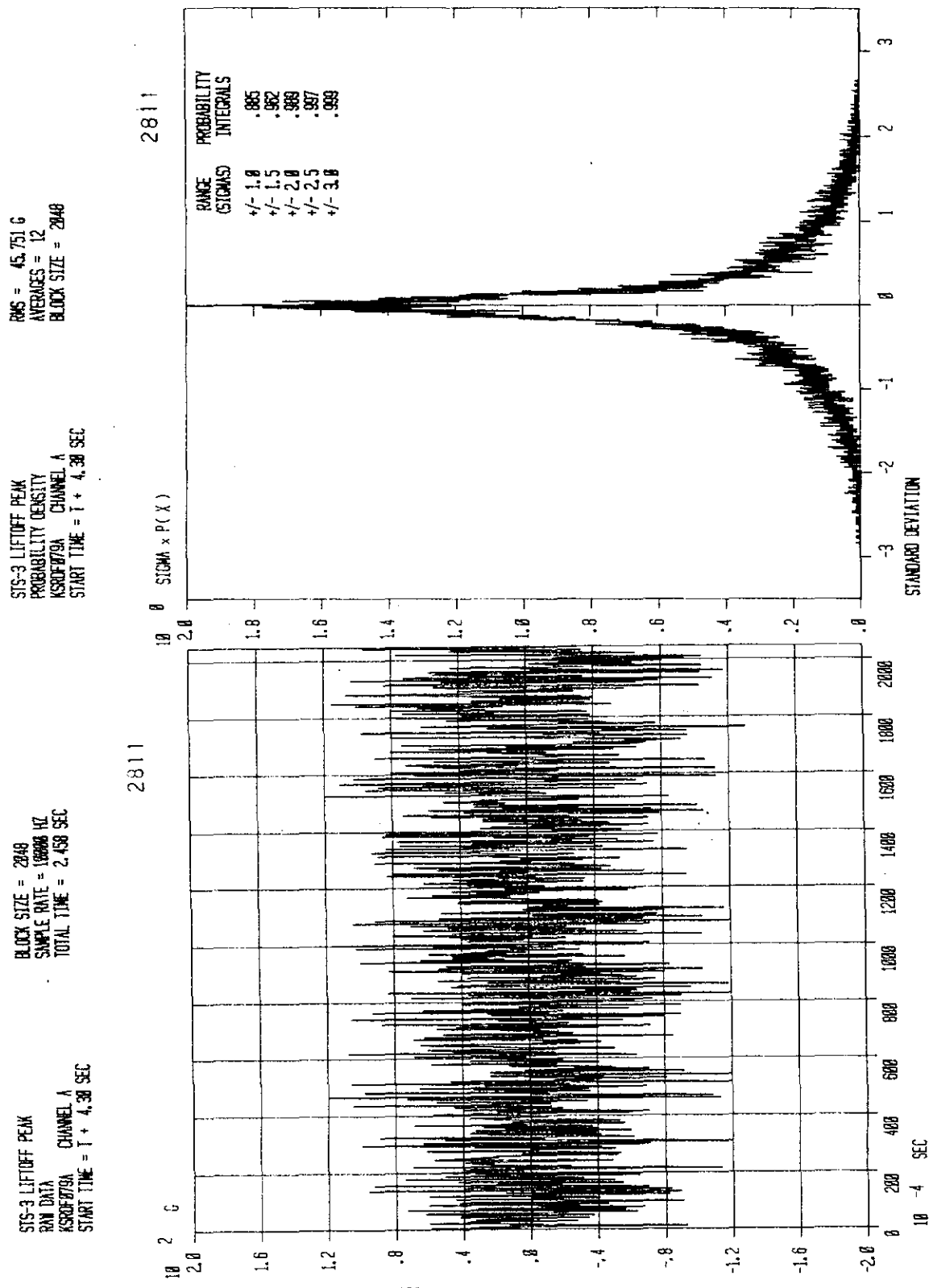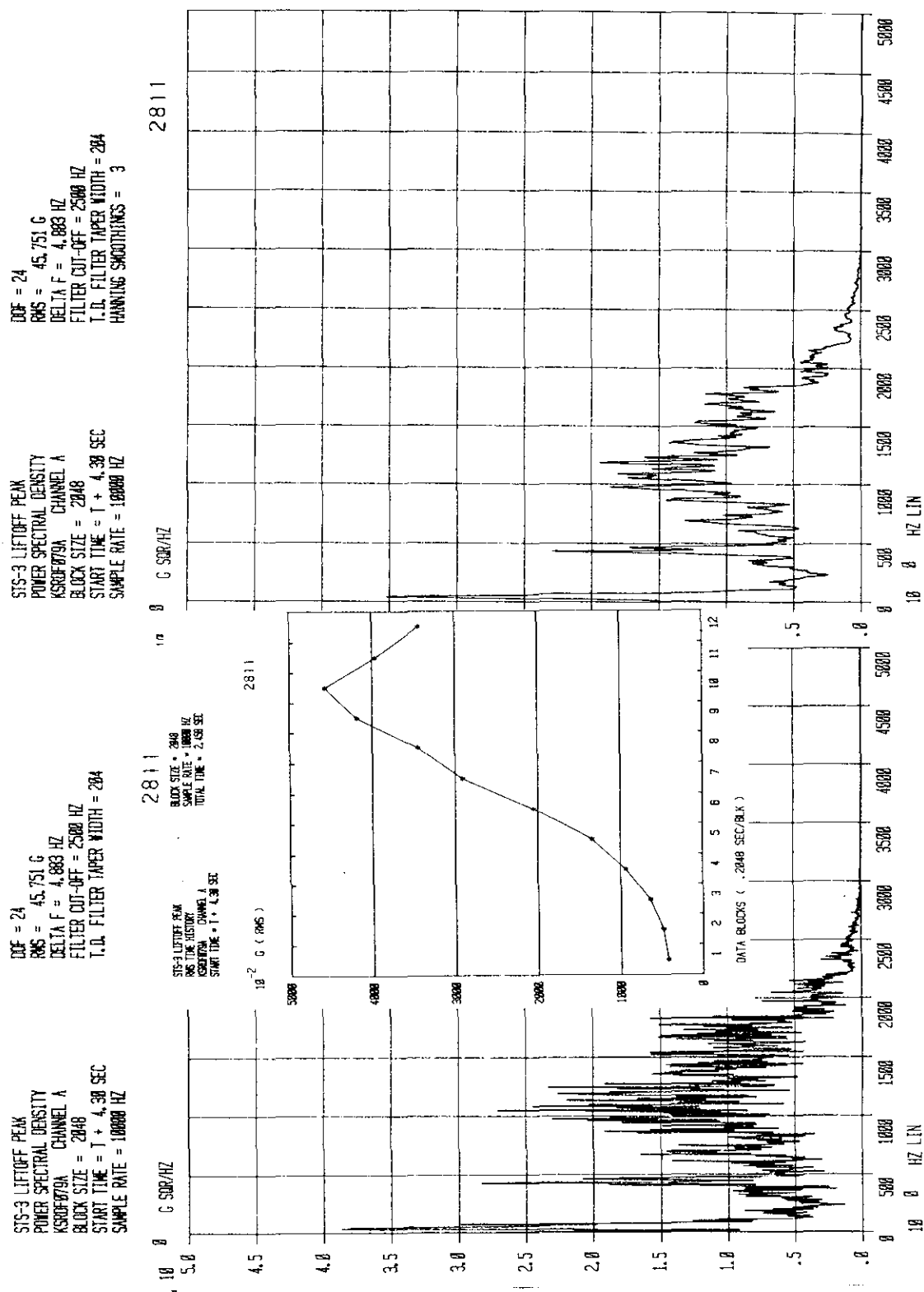
Figure 5-6. Room 9A — C$_L$ Bottom Flange Deck O Beam, Z Direction (Sheet 1 of 2)
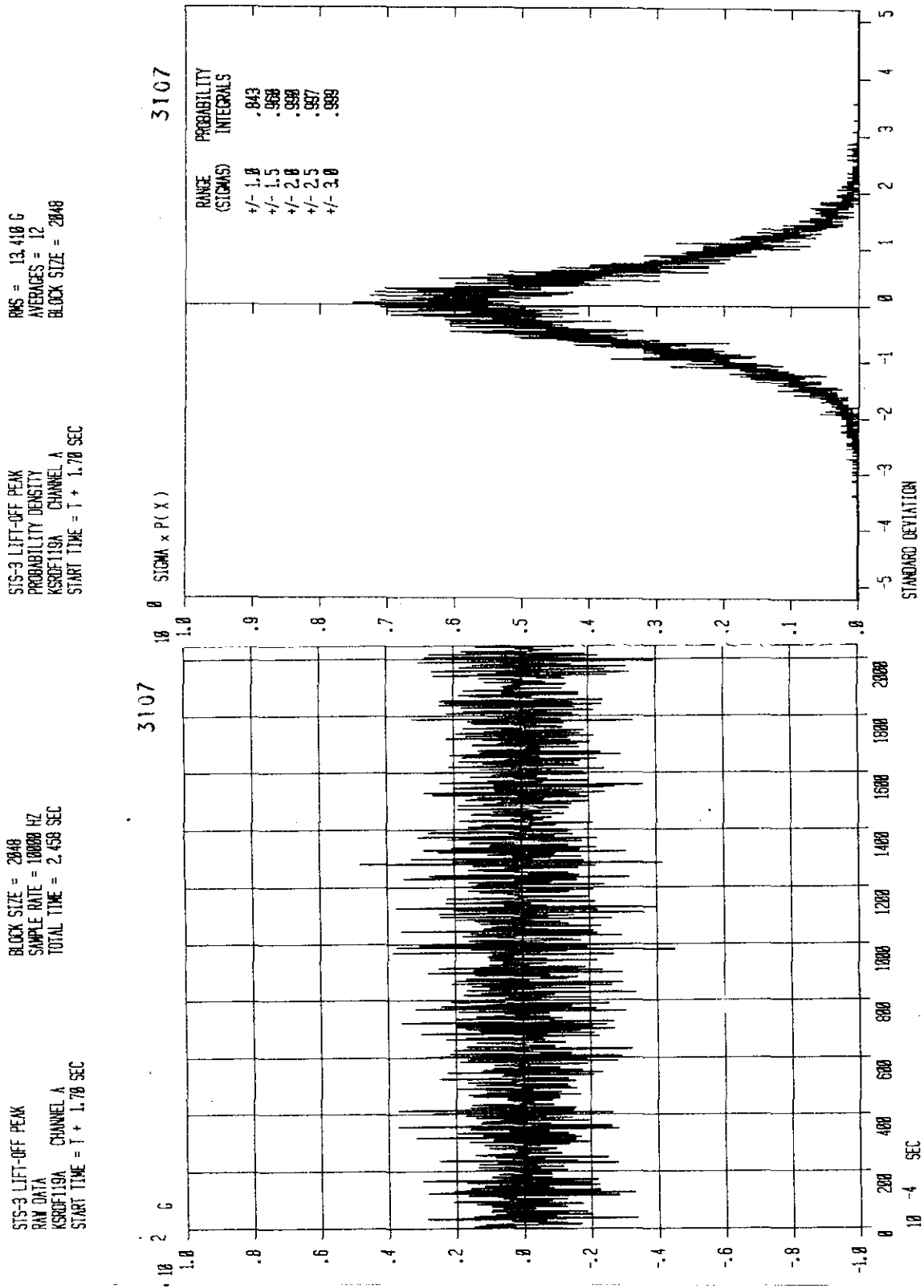
Figure 5-6. Room 9A - C_L Between Flange Deck O Beam (Sheet 2 of 2).

Figure 5-7. Room 41B - Center Floor Beam, X Direction (Sheet 1 of 2)
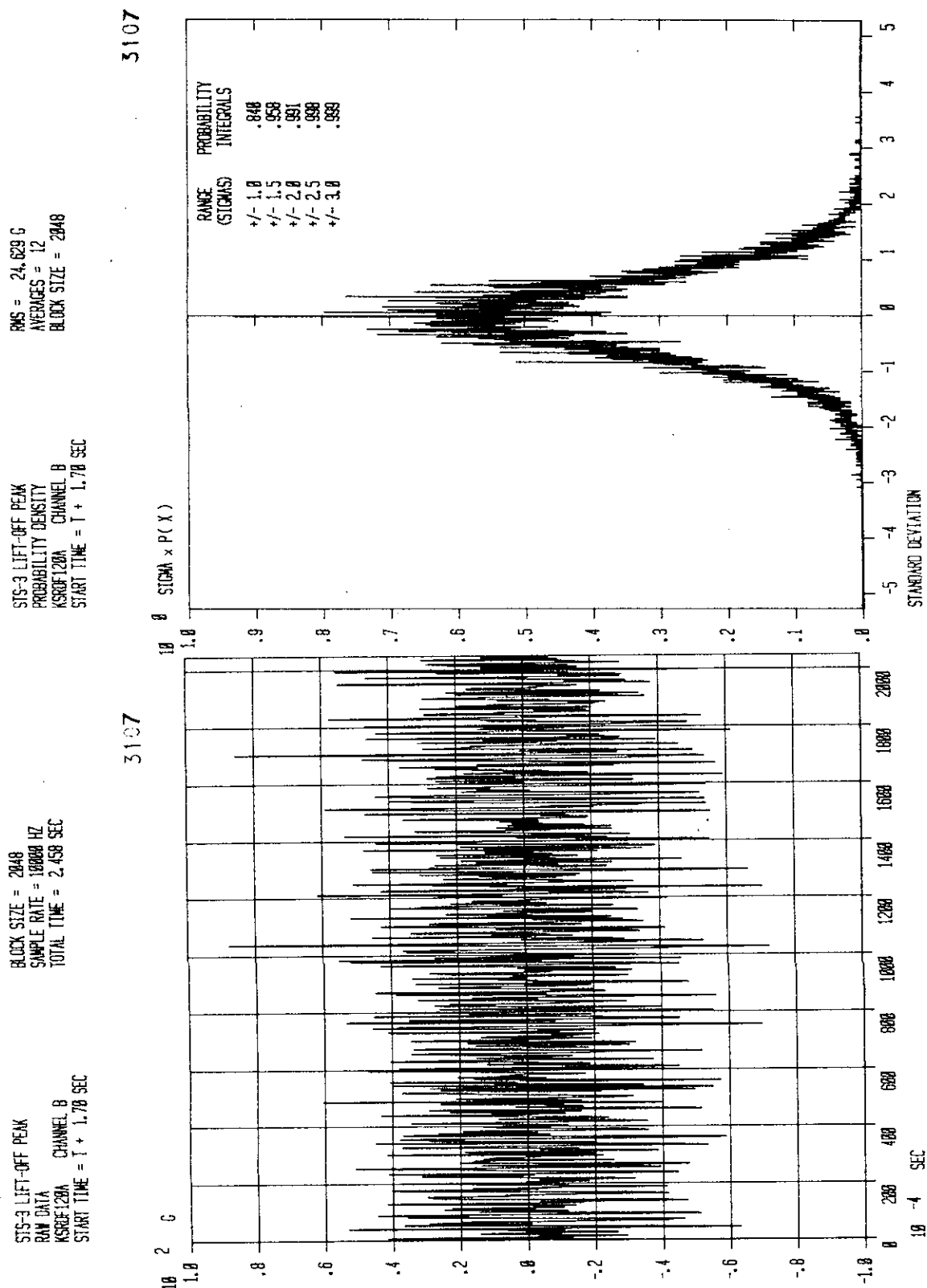
KSC-DD-818-TR

Figure 5-7. Room 41B – Center Floor Beam, X Direction (Sheet 2 of 2)

5-18

Figure 5-8. Room 41B - Center Floor beam, Y Direction (Sheet 1 of 2)
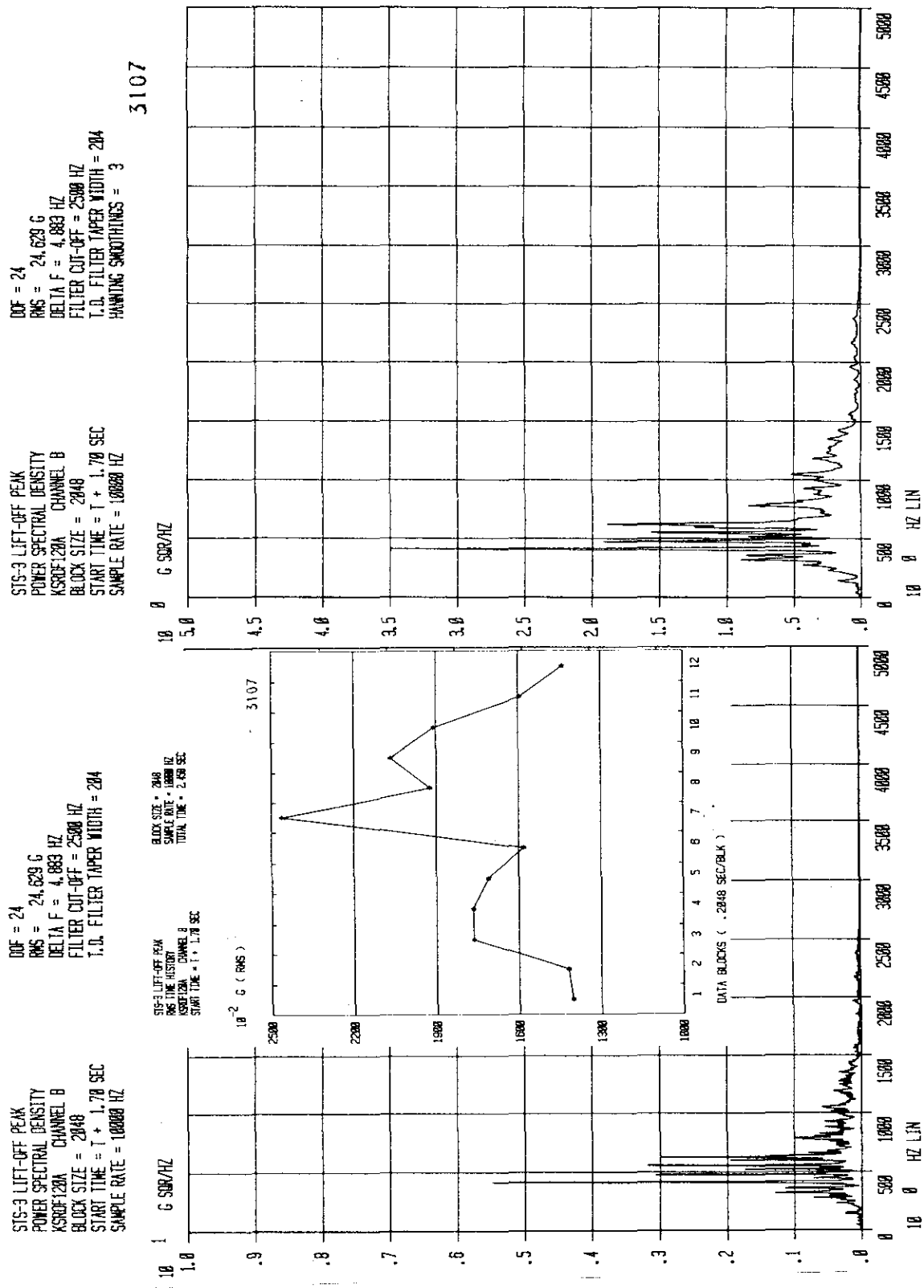
Figure 5-8. Room 41B - Center Floor beam, Y Direction (Sheet 2 of 2)
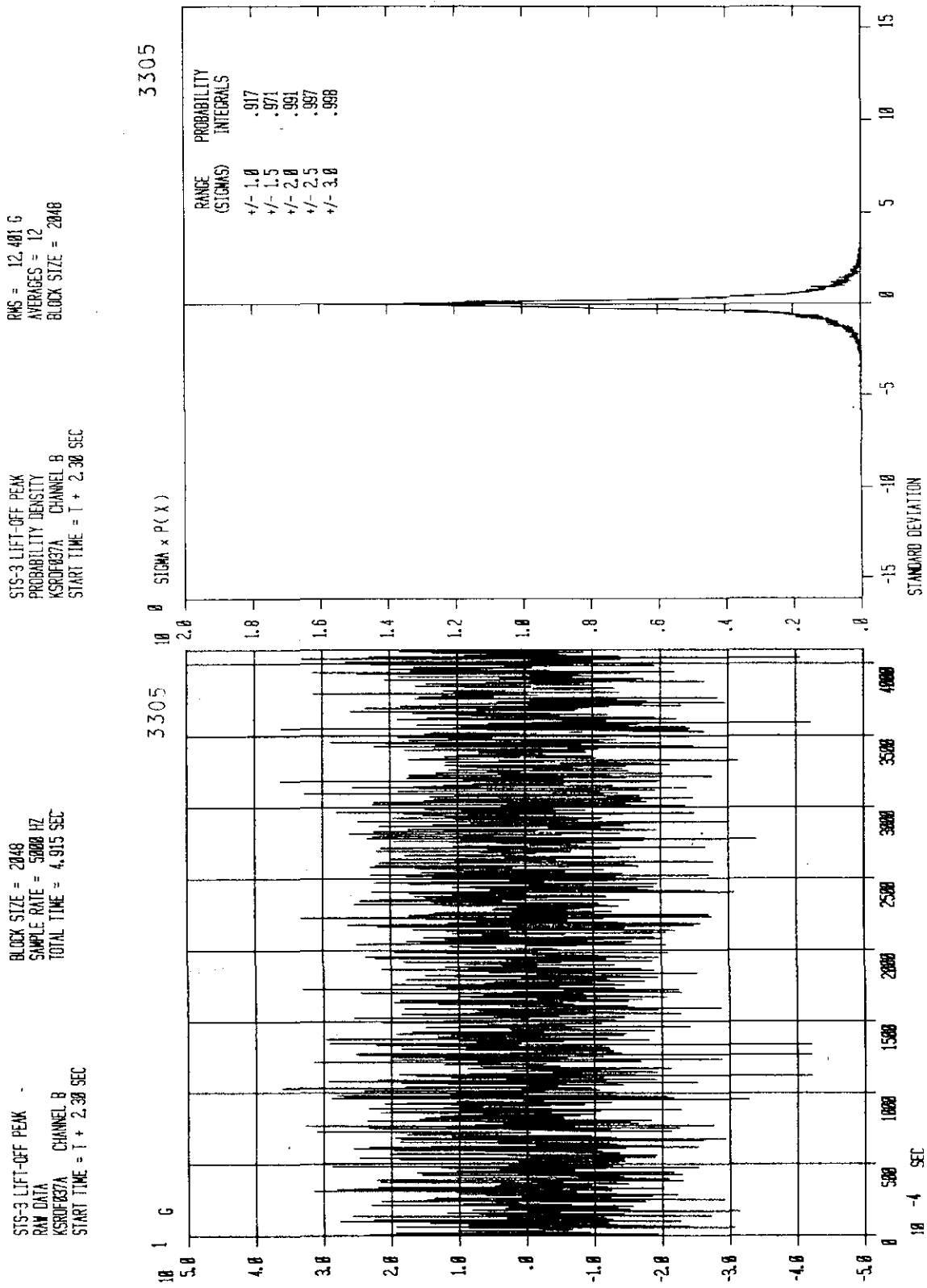
Figure 5-9. Room 8A - Truss T2 Vertical, Z Direction (Sheet 1 of 2)
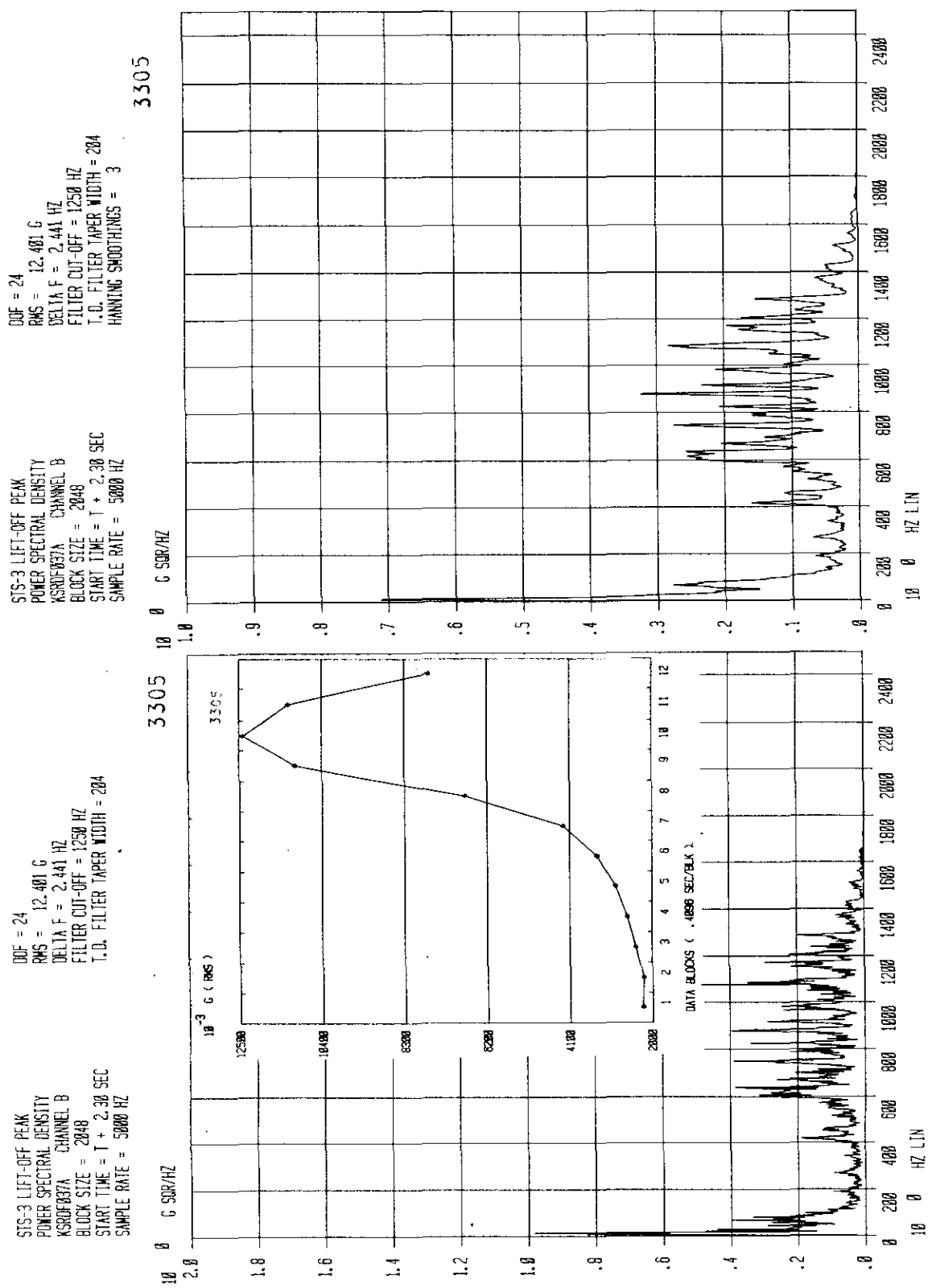
Figure 5-9. Room 8A — Truss T2 Vertical, Z Direction (Sheet 2 of 2)

Figure 5-10. Room 7A - Truss Ti Vertical, Z Direction (Sheet 1 of 2)
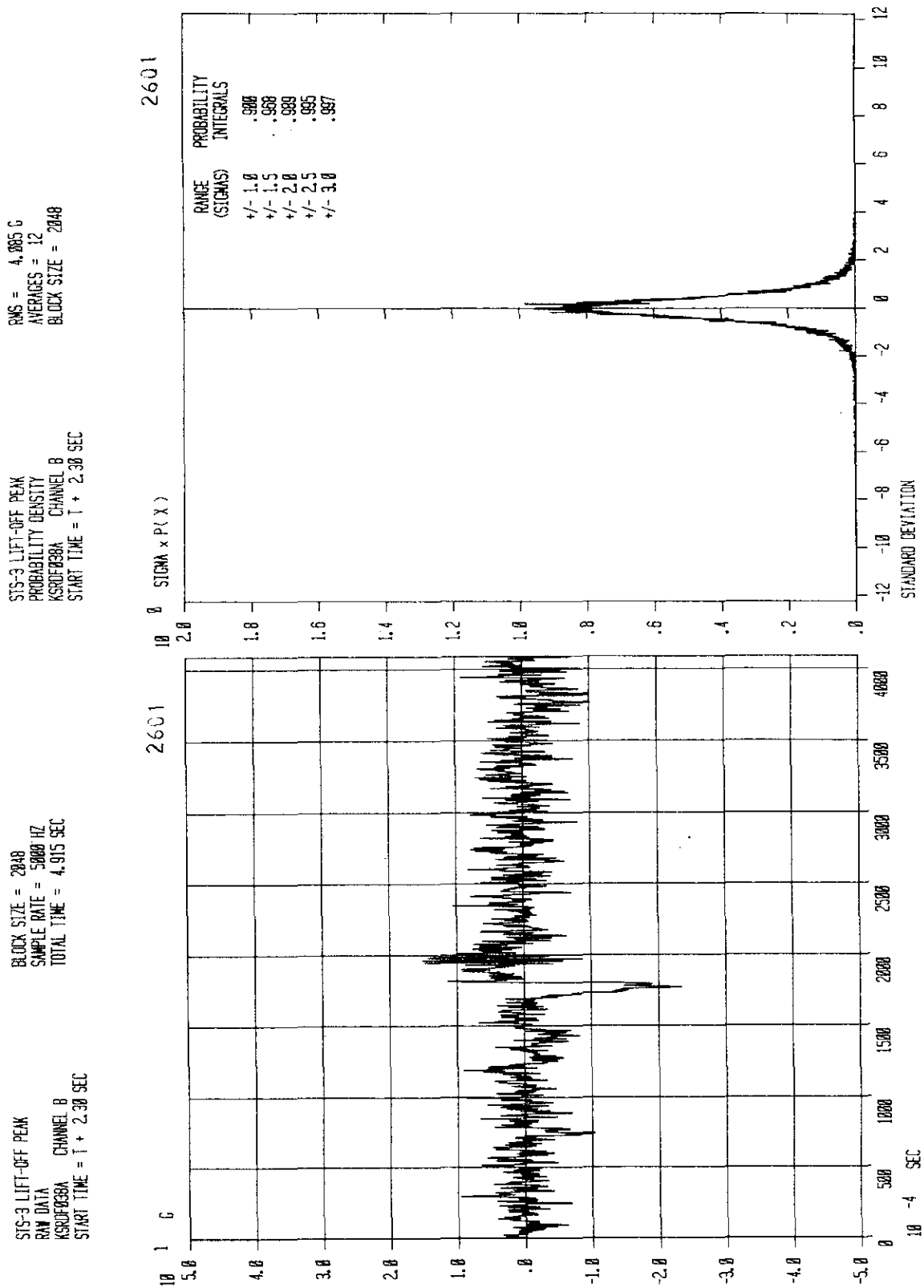
Figure 5-10. Room 7A – Truss T1 Vertical, Z Direction (Sheet 2 of 2)
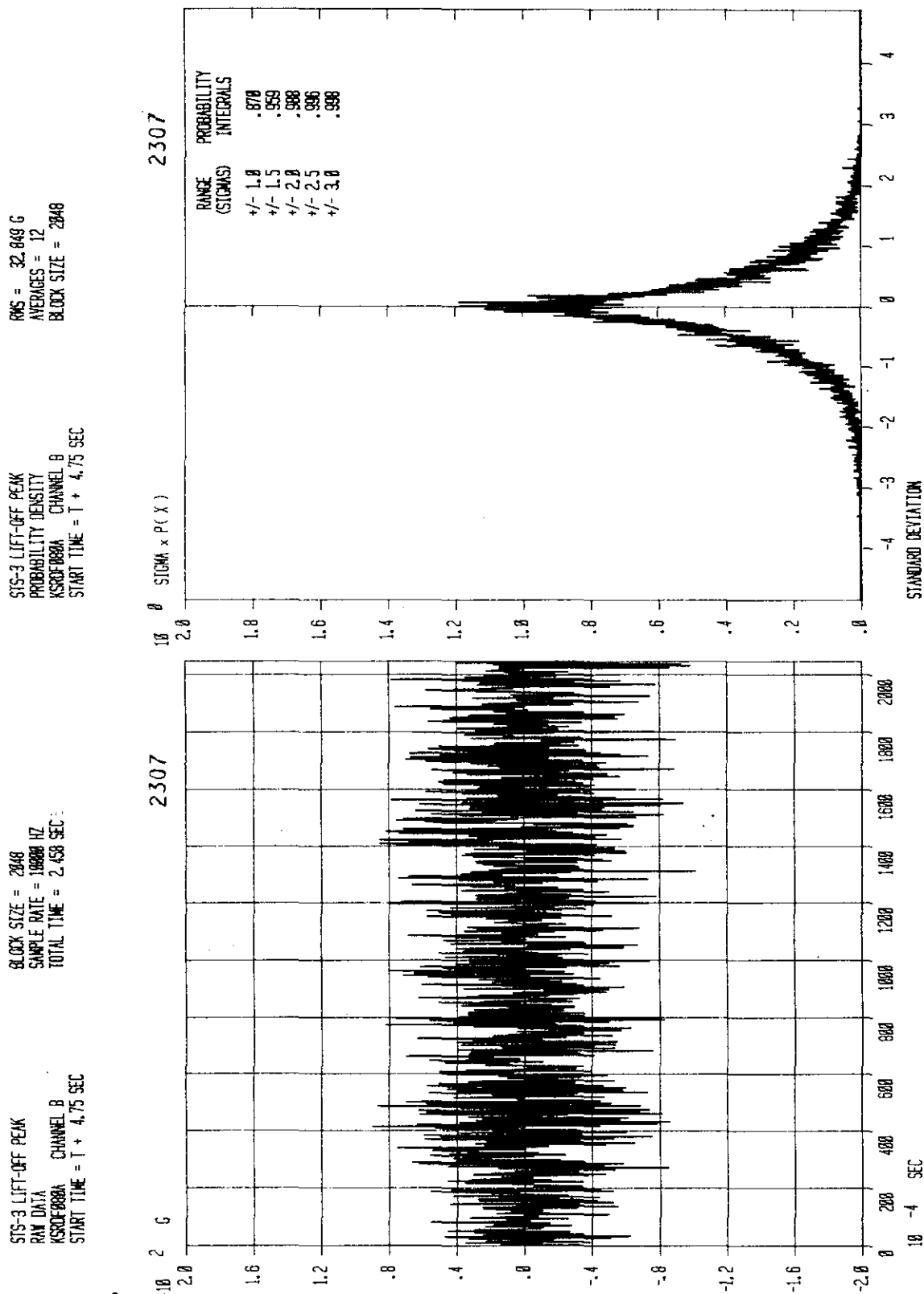
Figure 5-11. Room 10A - Truss T_2 Top Chord, Z Direction (Sheet 1 of 2)
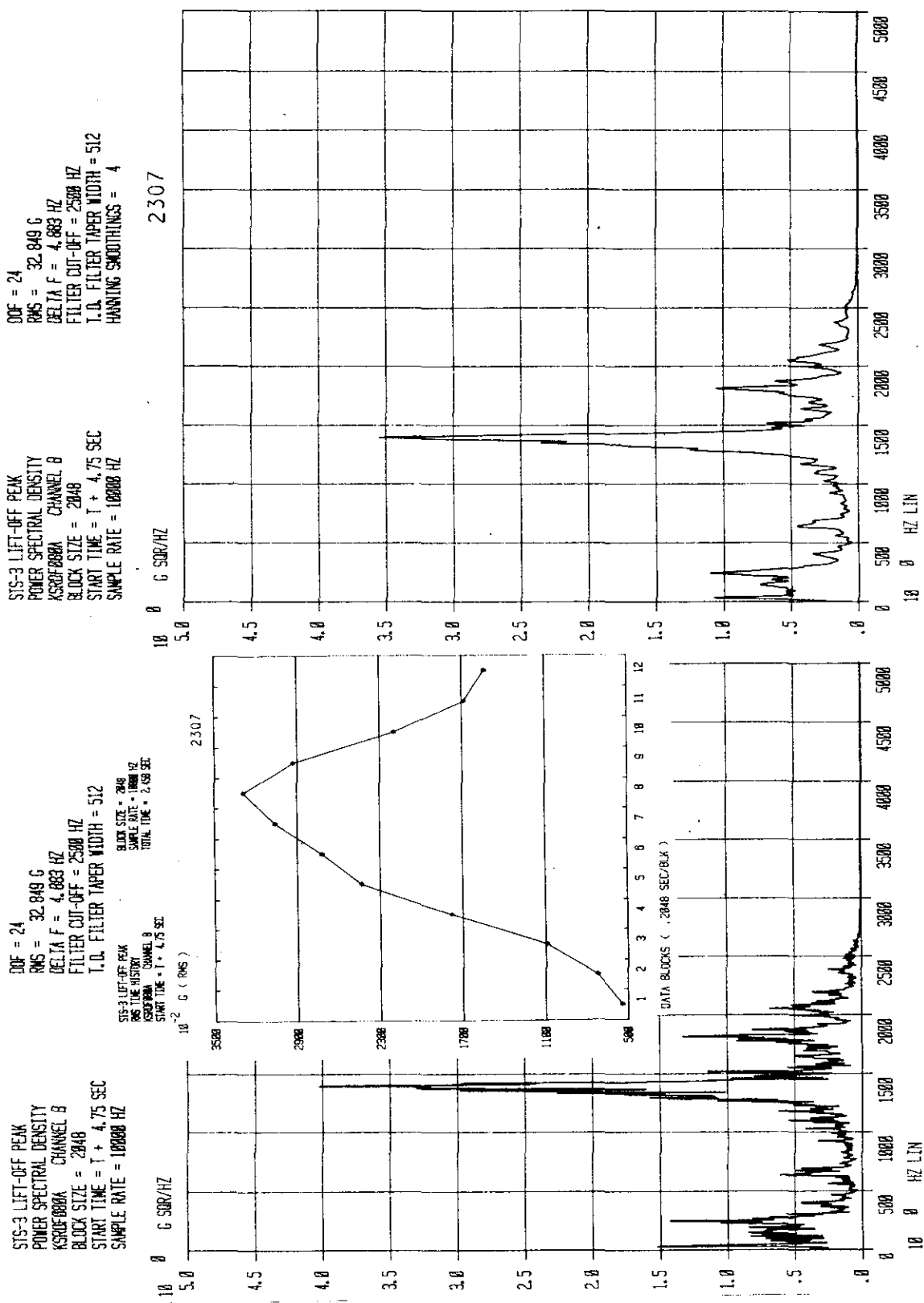
Figure 5-11. Room 10A - Truss T2 Top Chord, Z Direction (Sheet 2 of 2)
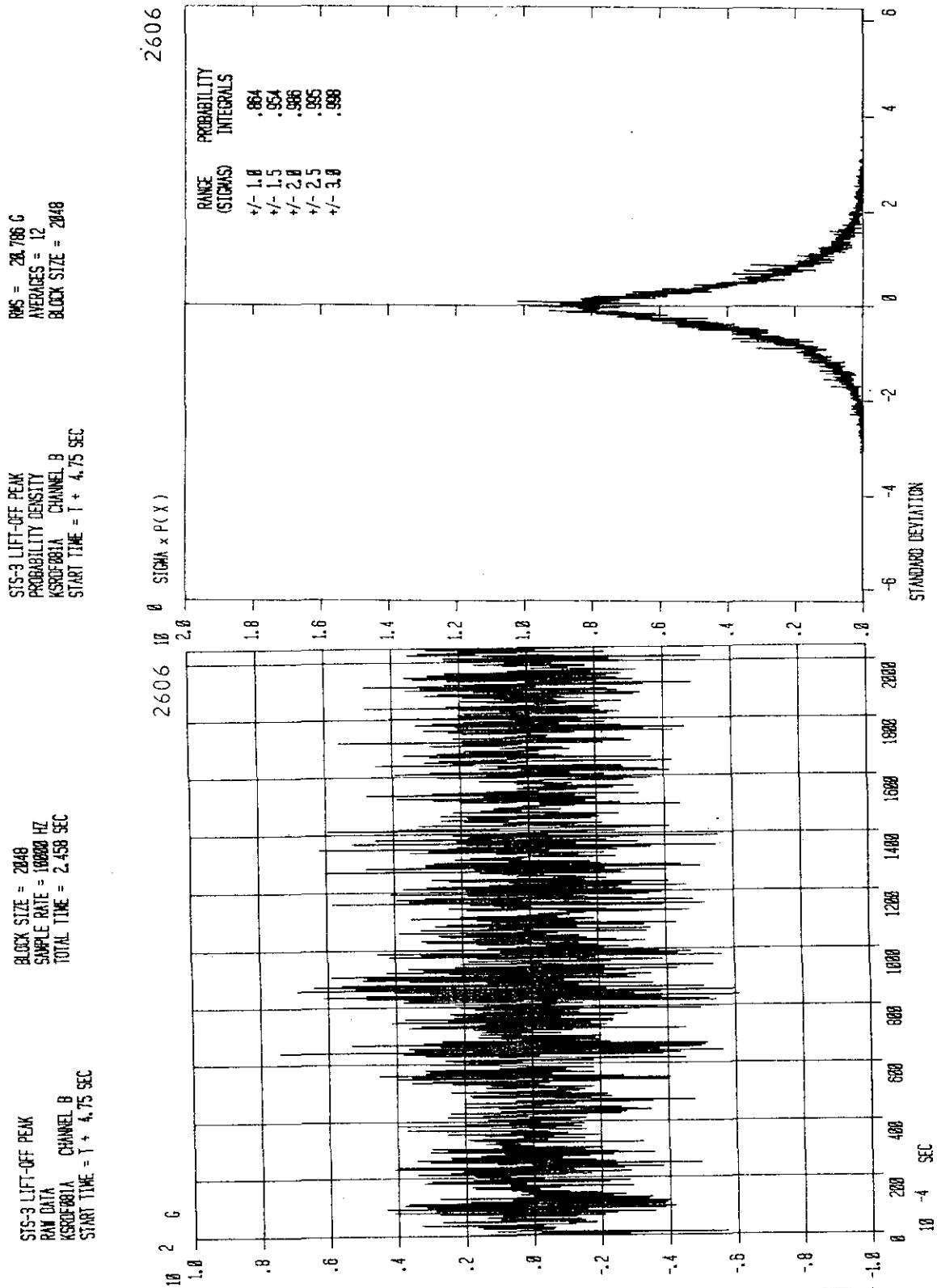
Figure 5-12. Room 10A – Truss T_1 Top Chord, Z Direction (Sheet 1 of 2)
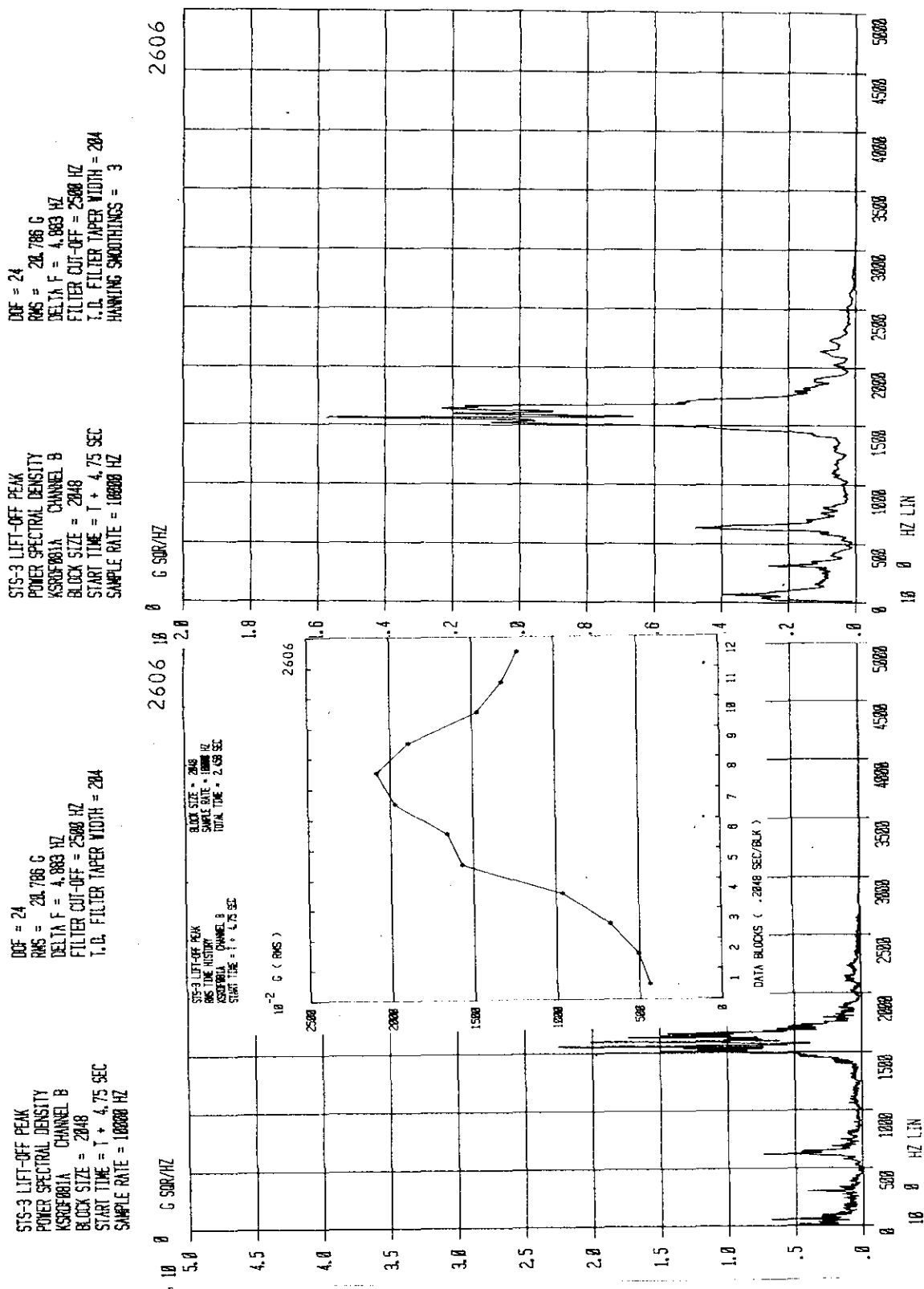
Figure 5-12. Room 10A - Truss T_1 Top Chord, Z Direction (Sheet 2 of 2)
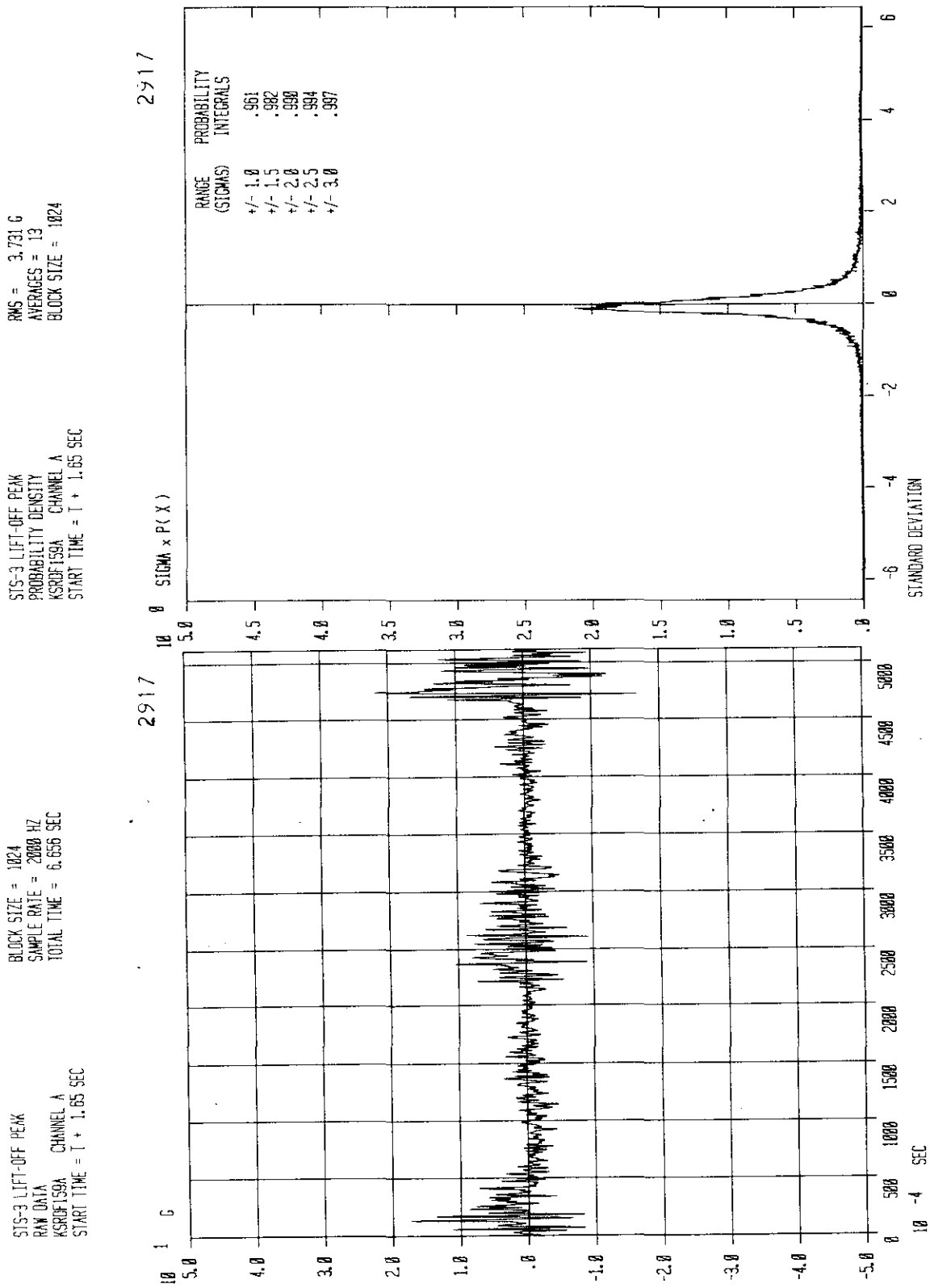
Figure 5-13. Room 9B — Floor Framing Stringer (E), Z Direction (Sheet 1 of 2)
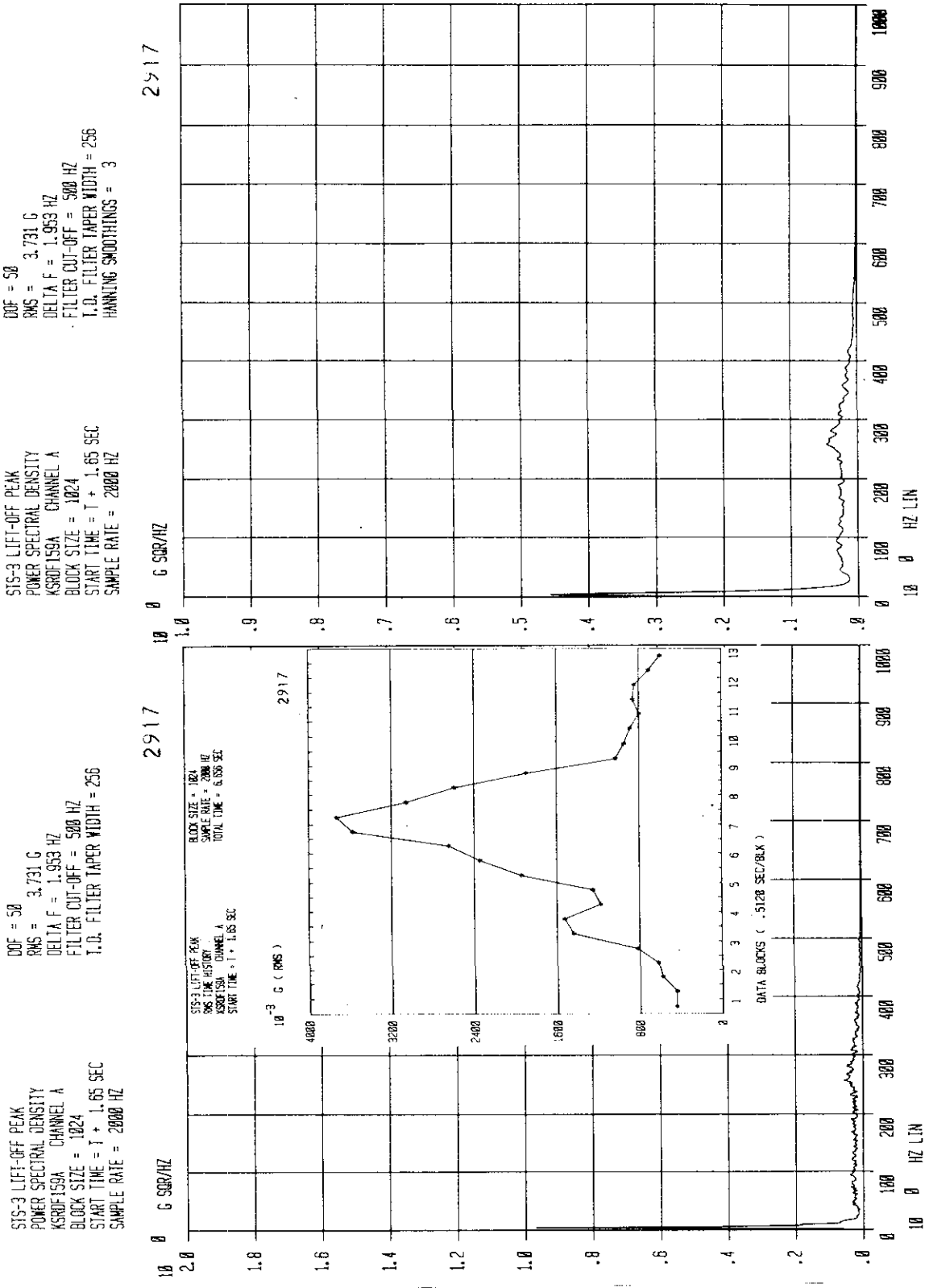
Figure 5-13. Room 9B — Floor Framing Stringer (E), Z Direction (Sheet 2 of 2)
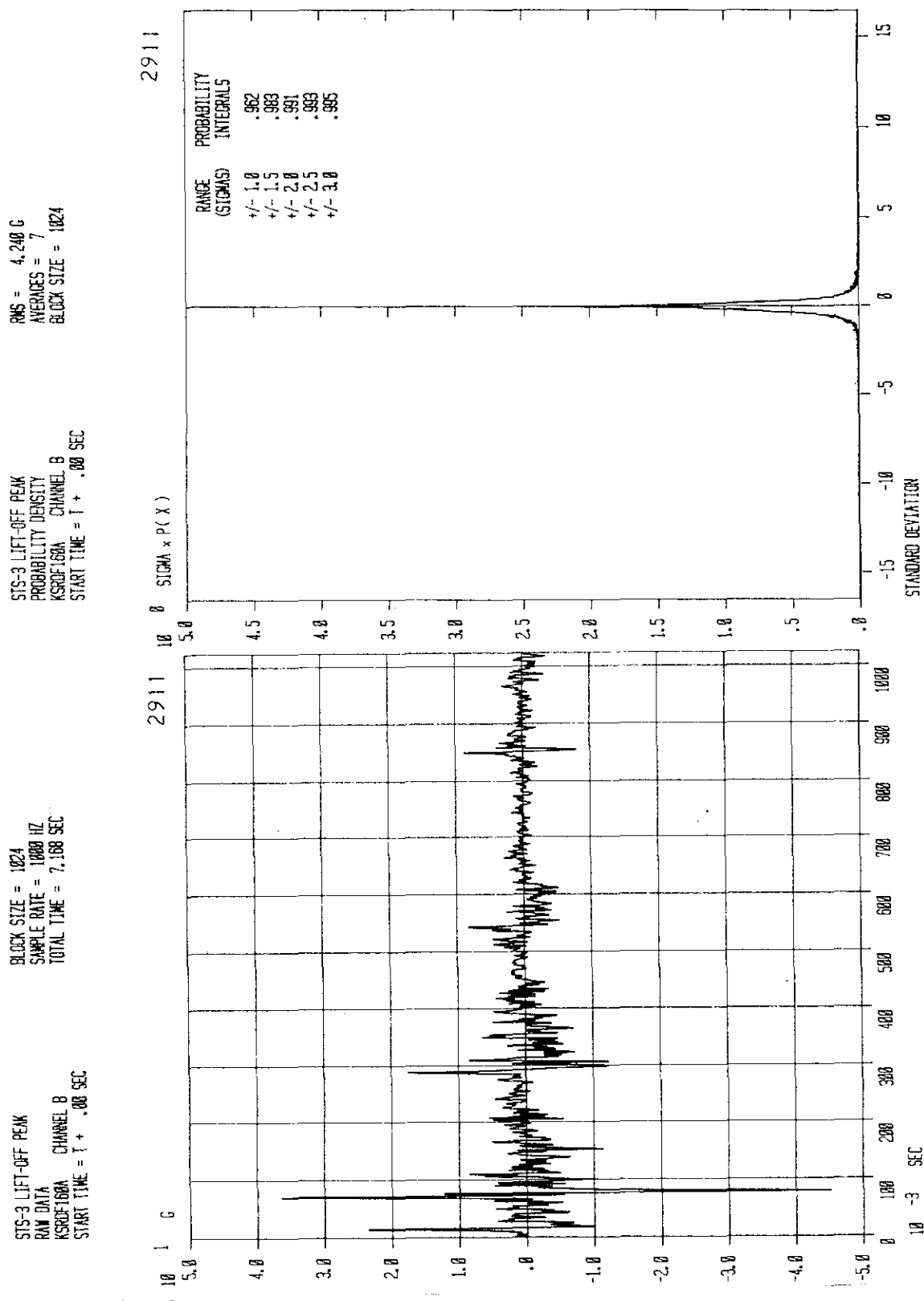
Figure 5-14. Room 9B – Floor Framing Stringer (W), Z Direction (Sheet 1 of 2)
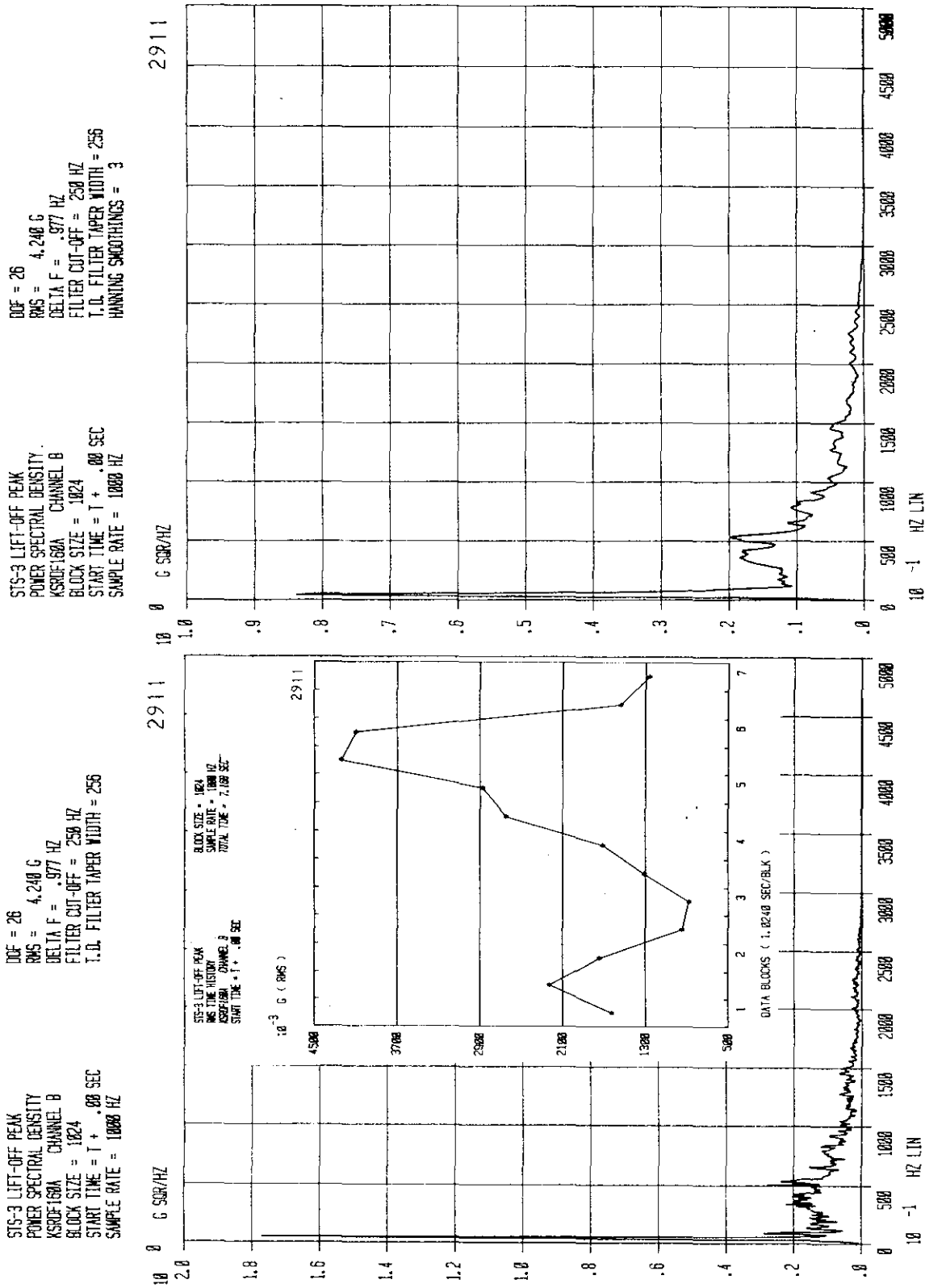
Figure 5-14. Room 9B - Floor Framing Stringer (W), Z Direction (Sheet 2 of 2)

MEAS.KSRDG #			001C	002C	003C	004C	005A
PROC. PARAM.	Fmax(Hz)		100	100	100	100	500
	BLOCK SIZE		256	256	256	256	1024
	DELTA F		.781	.781	.781	.781	.976
	TOTAL TIME		7.69	7.69	7.69	7.69	8.20
	START TIME		To+1.80	To+1.80	To+1.80	To+1.80	To
PERIOD LOCATION DIR/FREQ.RANGE			L/O PEAK LEV 0 Z/0-2K	L/O PEAK LEV 0 Z/0-2K	L/O PEAK T-2 Z/0-2K	L/O PEAK T-2 Z/0-2K	L/O PEAK FL BEAM Z/0-2K
FILTER@(Hz)	0 *	**DISPL.(IN.)**	2.980	5.940	.8970	.7500	1.618
	2		.7706	.7162	.4204	.3504	.707
	3		.7182	.6538	.3960	.3314	.590
	4		.5650	.5393	.3295	.2802	.514
	5		.3768	.3680	.2571	.2304	.398

MEAS.KSRDG #			006A	005B	006B	005C	006C
PROC. PARAM.	Fmax(Hz)		500	100	100	100	100
	BLOCK SIZE		1024	256	256	512	512
	DELTA F		.9770	.7813	.7813	.390	.390
	TOTAL TIME		8.20	8.97	8.97	7.69	7.69
	START TIME		To	To	To	To+1.20	To+1.20
PERIOD LOCATION DIR/FREQ.RANGE			L/O PEAK FL BEAM Z/0-2K	L/O PEAK FL BEAM Z/0-2K	L/O PEAK FL BEAM Z/0-2K	L/O PEAK FL BEAM Z/0-2K	L/O PEAK FL BEAM Z/0-2K
FILTER@(Hz)	0 *	**DISPL.(IN.)**	1.639	1.539	2.158	4.155	4.184
	2		.7340	.4865	.6250	.3471	.4000
	3		.6390	.4307	.5590	.2904	.3514
	4		.5490	.3865	.5005	.2750	.3290
	5		.4233	.3040	.3872	.2325	.2716

*Note: RMS displacements calculated without a filter (filter at 0 Hz) are
        not valid. Refer to KSC-DD-677-TR, page 6, for validation criteria.

Figure 5-15. STS-6 MLP-2 Vibration Data Processing Parameters and Calculated
RMS Displacements (Sheet 1 of 2)

MEAS. KSRDG #			001B	002B	003B	004B	
PROC. PARAM.	Fmax (Hz)		1000	1000	1000	1000	
	BLOCK SIZE		1024	1024	1024	1024	
	DELTA F		1.95	1.95	1.95	1.95	
	TOTAL TIME		6.67	6.67	6.67	6.67	
	START TIME		To+2.00	To+2.00	To+2.00	To+2.00	
PERIOD LOCATION DIR/FREQ. RANGE			L/O PEAK LEV 0 Z/0-2K	L/O PEAK LEV 0 Z/0-2K	L/O PEAK T-2 Z/0-2K	L/O PEAK T-2 Z/0-2K	
FILTER@ (Hz)	0 *	DISPL. (IN.)	.9316	1.102	.8973	.7203	
	2		.8163	.9657	.8000	.6488	
	3		.4750	.5617	.5278	.4546	
	4		.4208	.4965	.4780	.4173	
	5		.2744	.3192	.3582	.3250	

*Note: RMS displacements calculated without a filter (filter at 0 Hz) are not valid. Refer to KSC-DD-677-TR, page 6, for validation criteria.

Figure 5-15. STS-6 MLP-2 Vibration Data Processing Parameters and Calculated RMS Displacements (Sheet 2 of 2)
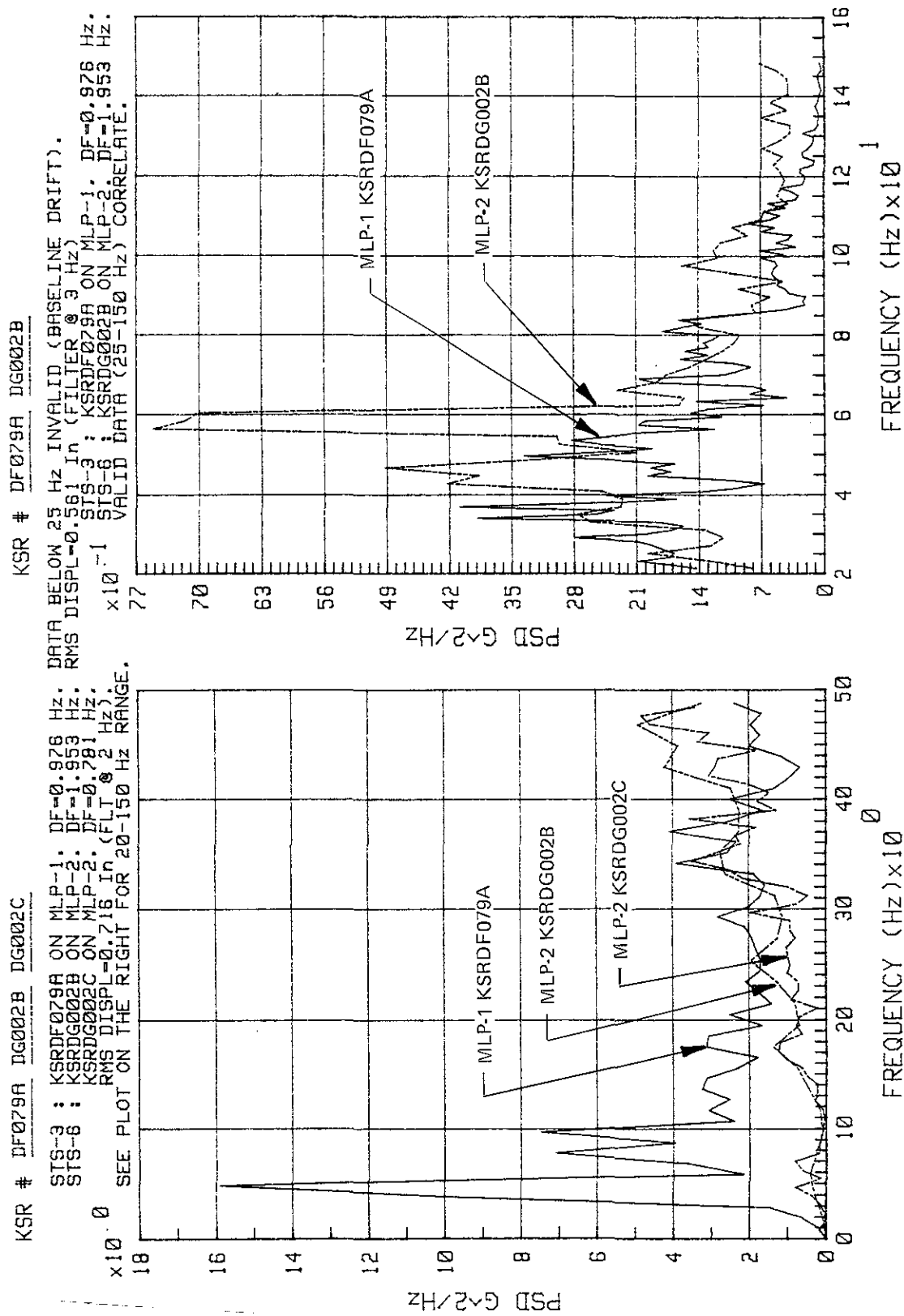
Figure 5-16. MLP-1 and MLP-2 Vibration, Deck 0 Beam, Room 9A at Centerline of East SRB, Z Direction
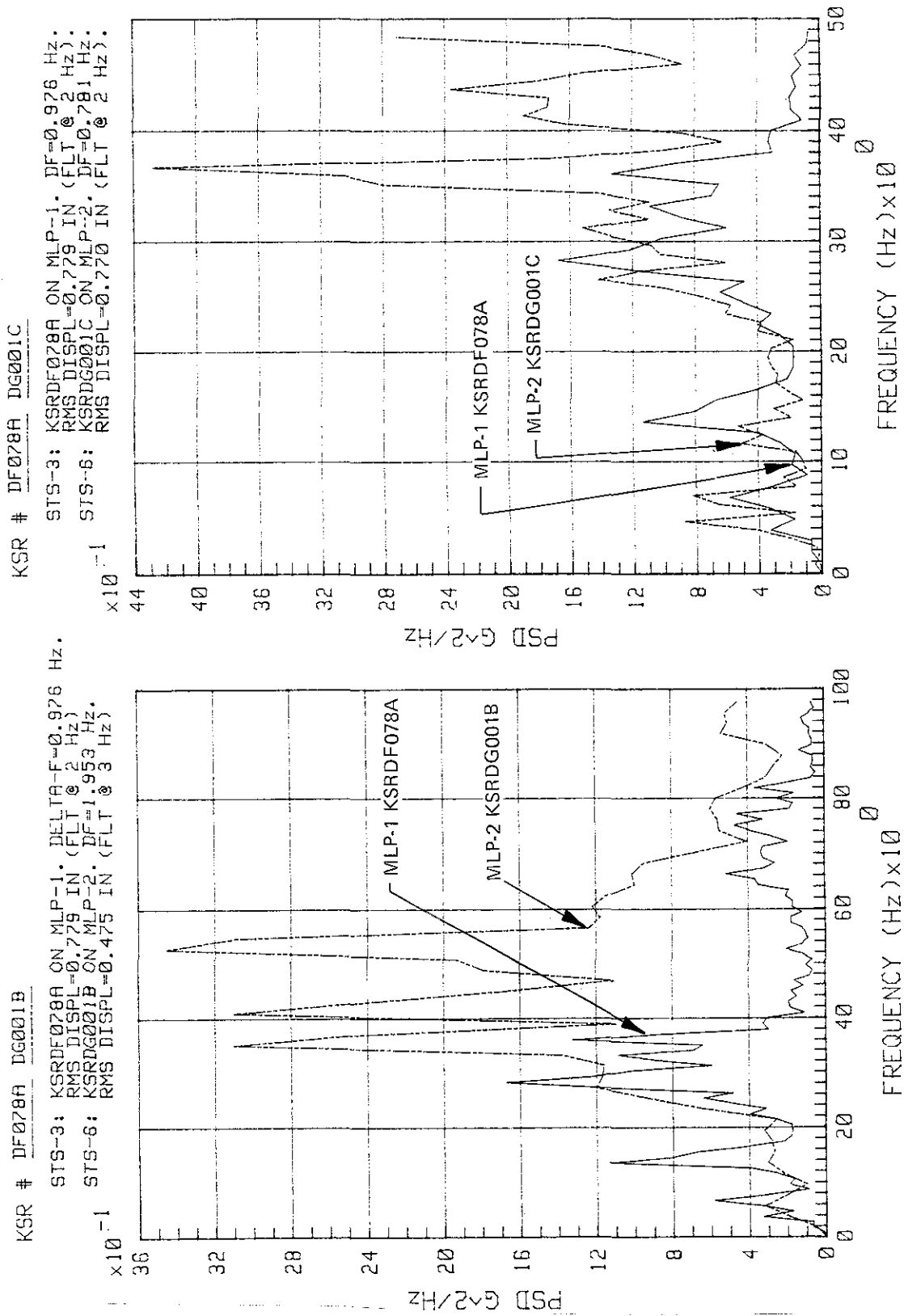
Figure 5-17. MLP-1 and MLP-2 Vibration, Deck 0 Beams, Room 7A, Z Direction
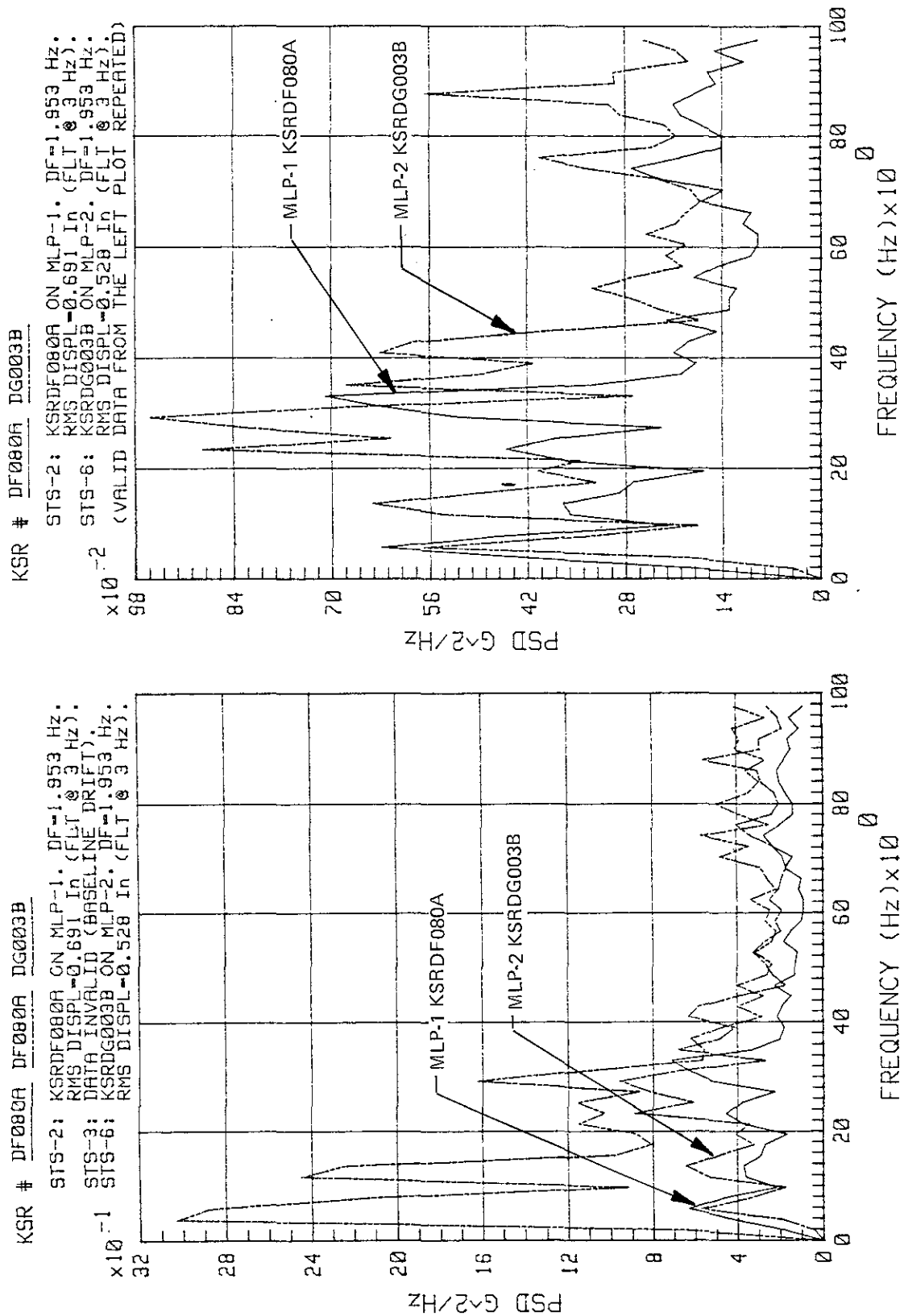
Figure 5-18. MLP-1 and MLP-2 Vibration, T-2 Truss Top Chord, Room 10A, Z Direction

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Figure 5-19. MLP-1 and MLP-2 Vibration, Deck B Floor Beam, Room 9B, Z Direction

5-38
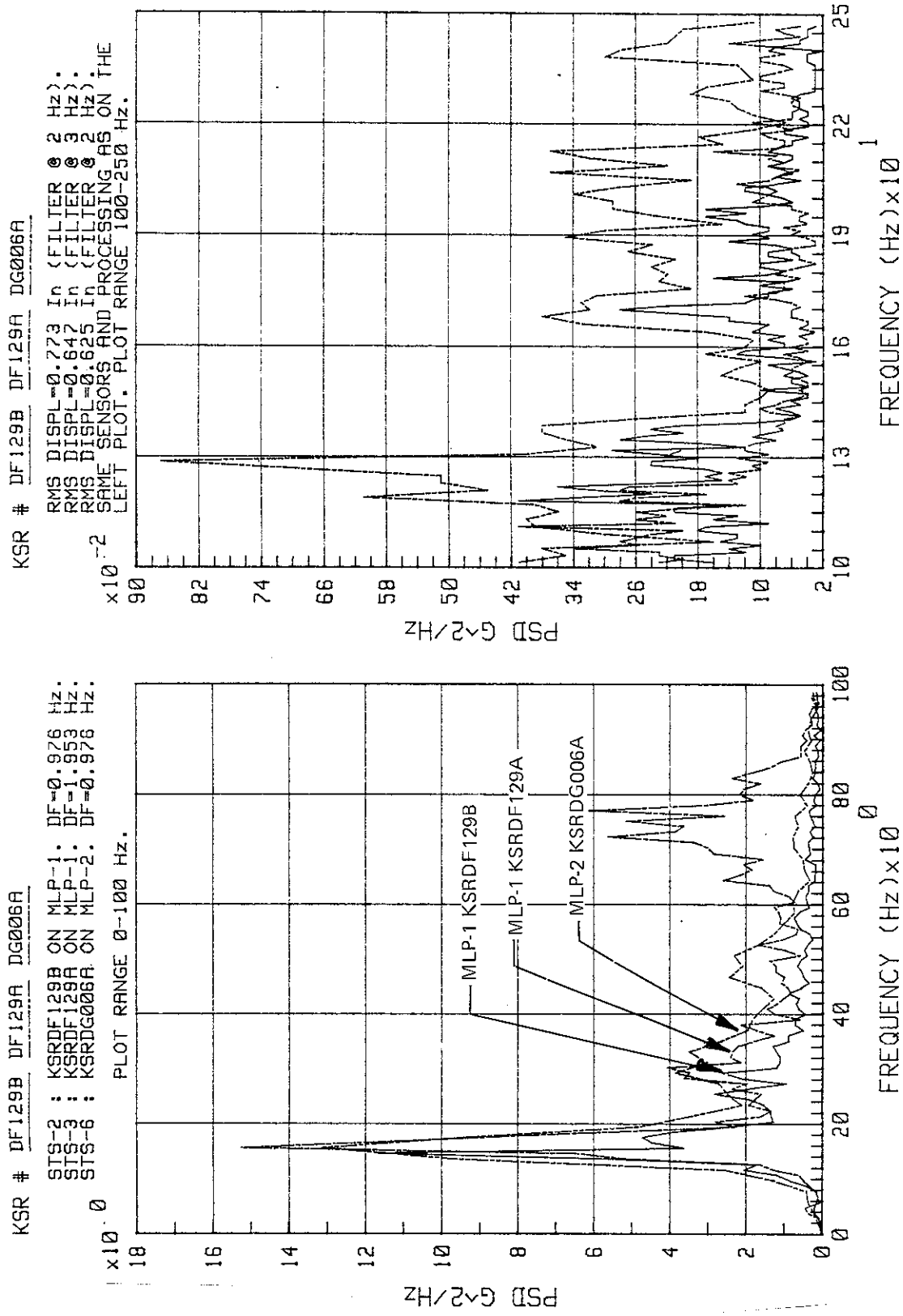
Figure 5-20. MLP-1 and MLP-2 Vibration, Deck B Floor Beam, Room 9B, Z Direction, KSRDF129B, -DF129A, -DG006A
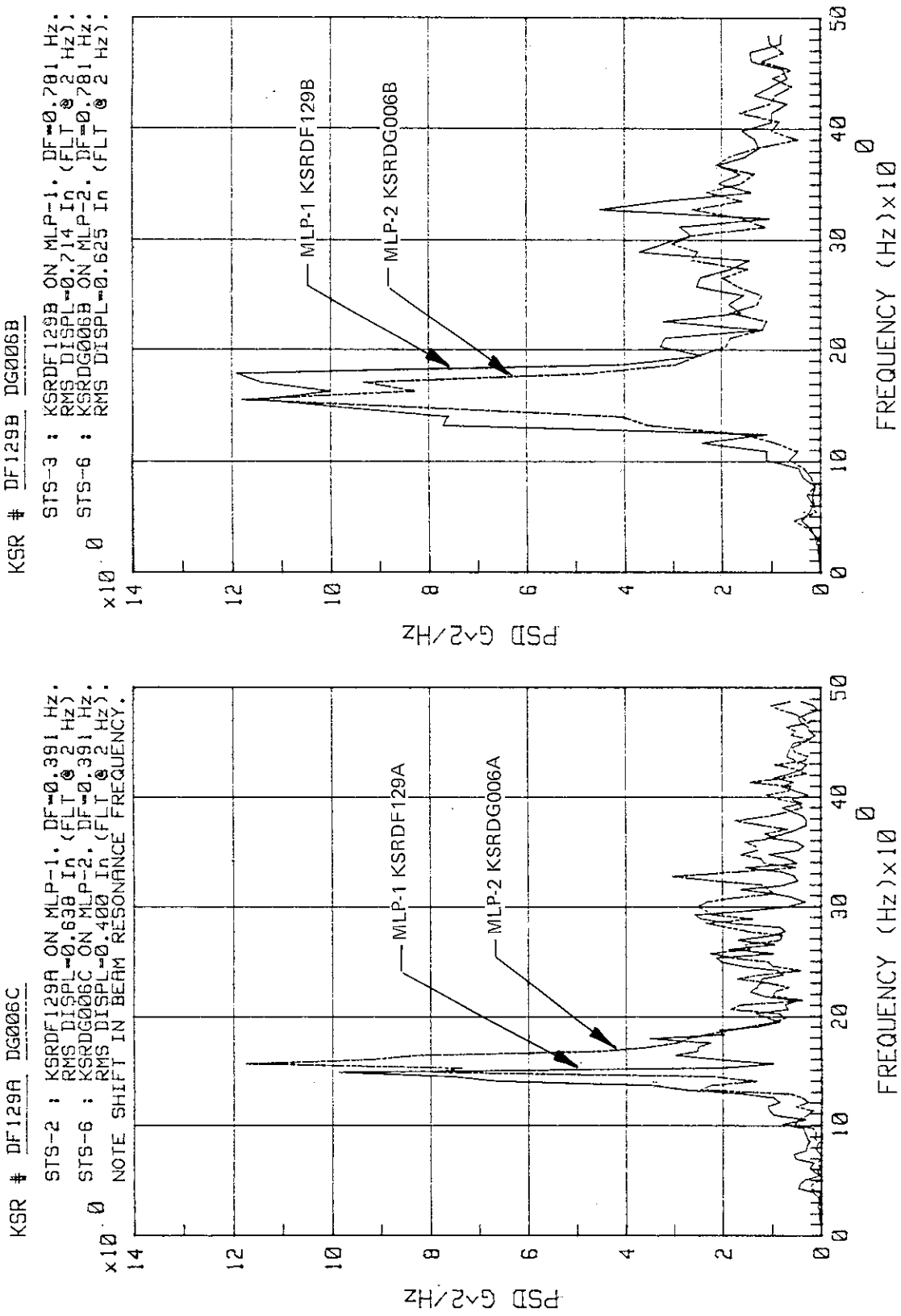
Figure 5-21. MLP-1 and MLP-2 Vibration, Deck B Floor Beam, Room 9B, Z Direction, KSRDF129A, -DG006C, -DF129B, -DG006B
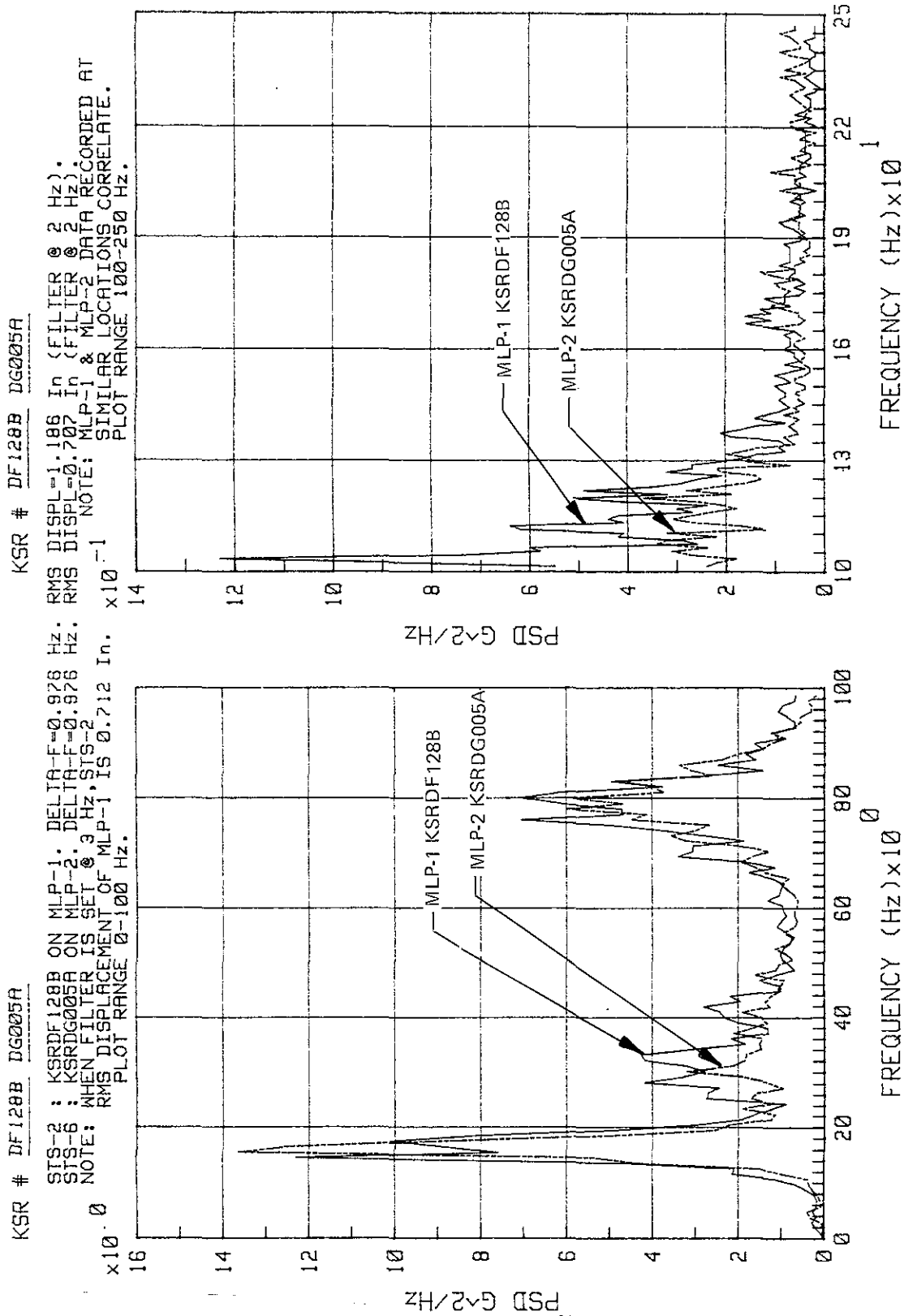
Figure 5-22. MLP-1 and MLP-2 Vibration, Deck B Floor Beam, Room 9B, at West SRB, Z Direction, KSRDF128B, -DG005A

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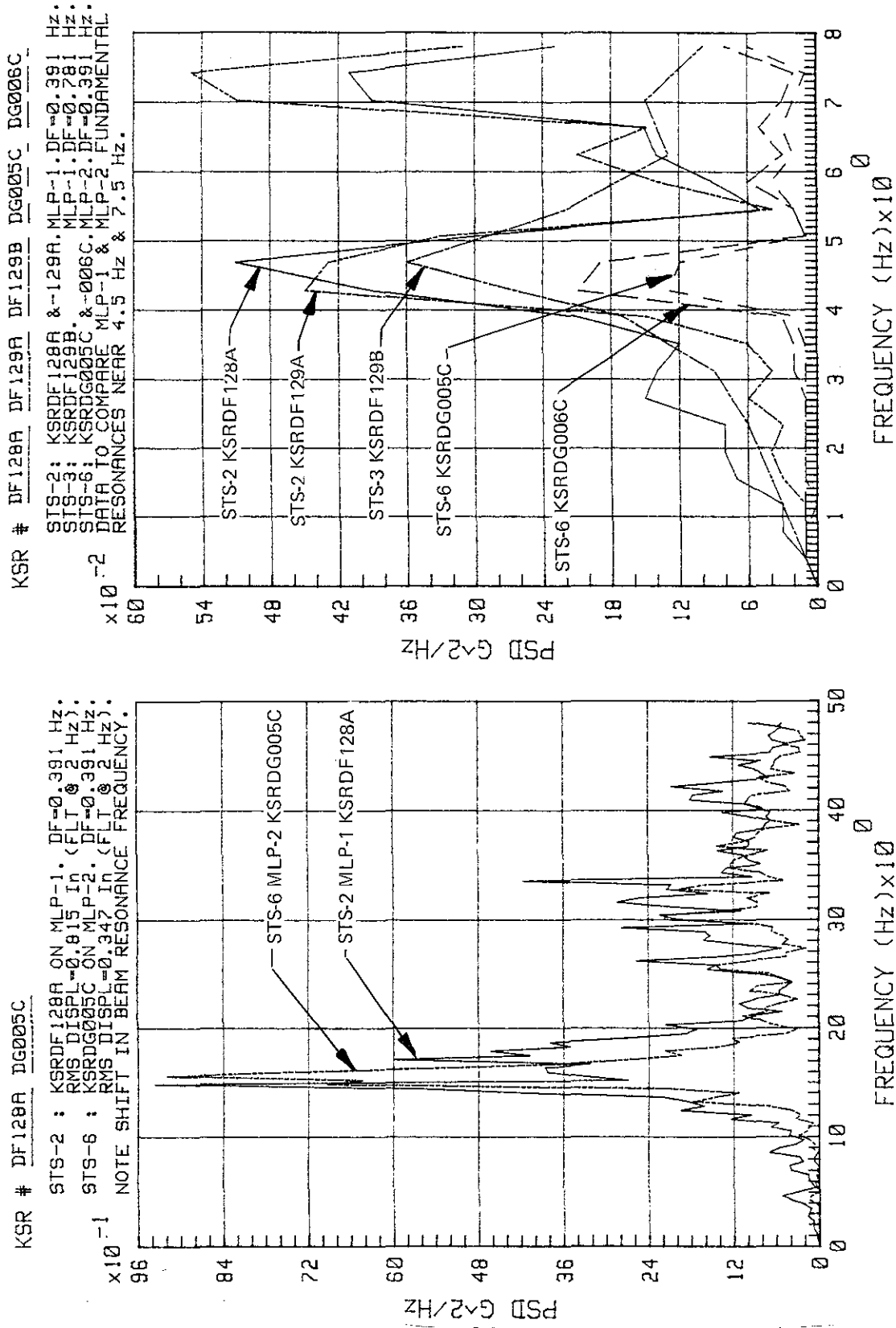
Figure 5-23. MLP-1 and MLP-2 Vibration, Deck B Floor Beam, Room 9B, at West SRB, Z Direction, KSRDF128A, -DG005C, and KSRDF128A, -DF129A, -DF129B, -DG005C, -DG006C

5-42
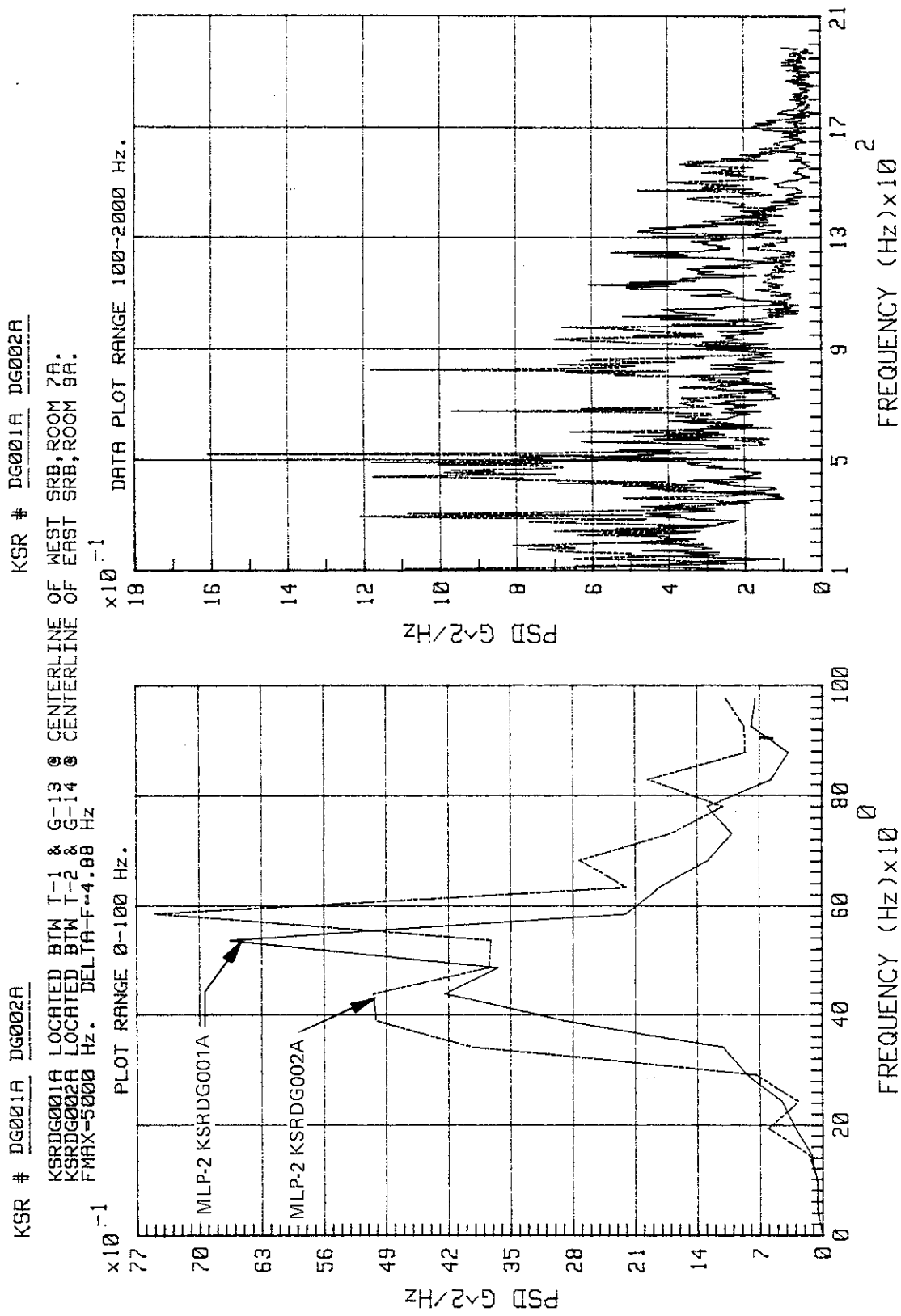
Figure 5-24. STS-6 MLP-2 Vibration of Deck 0 Beams, Z Direction, 0 to 100 Hz and 100 to 2,100 Hz

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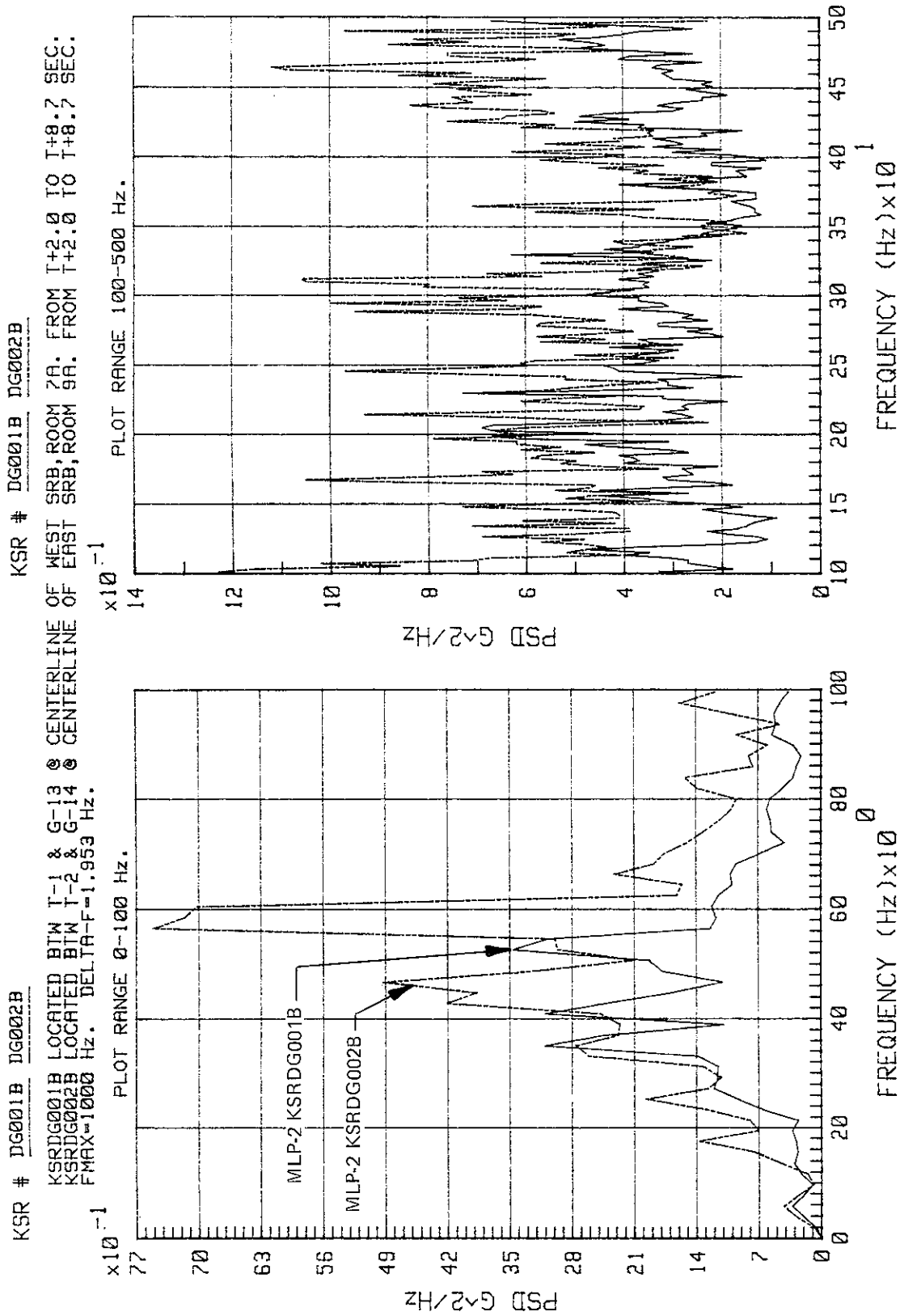
Figure 5-25. STS-6 MLP-2 Vibration of Deck 0 Beams, Z Direction, 0 to 100 Hz and 100 to 500 Hz
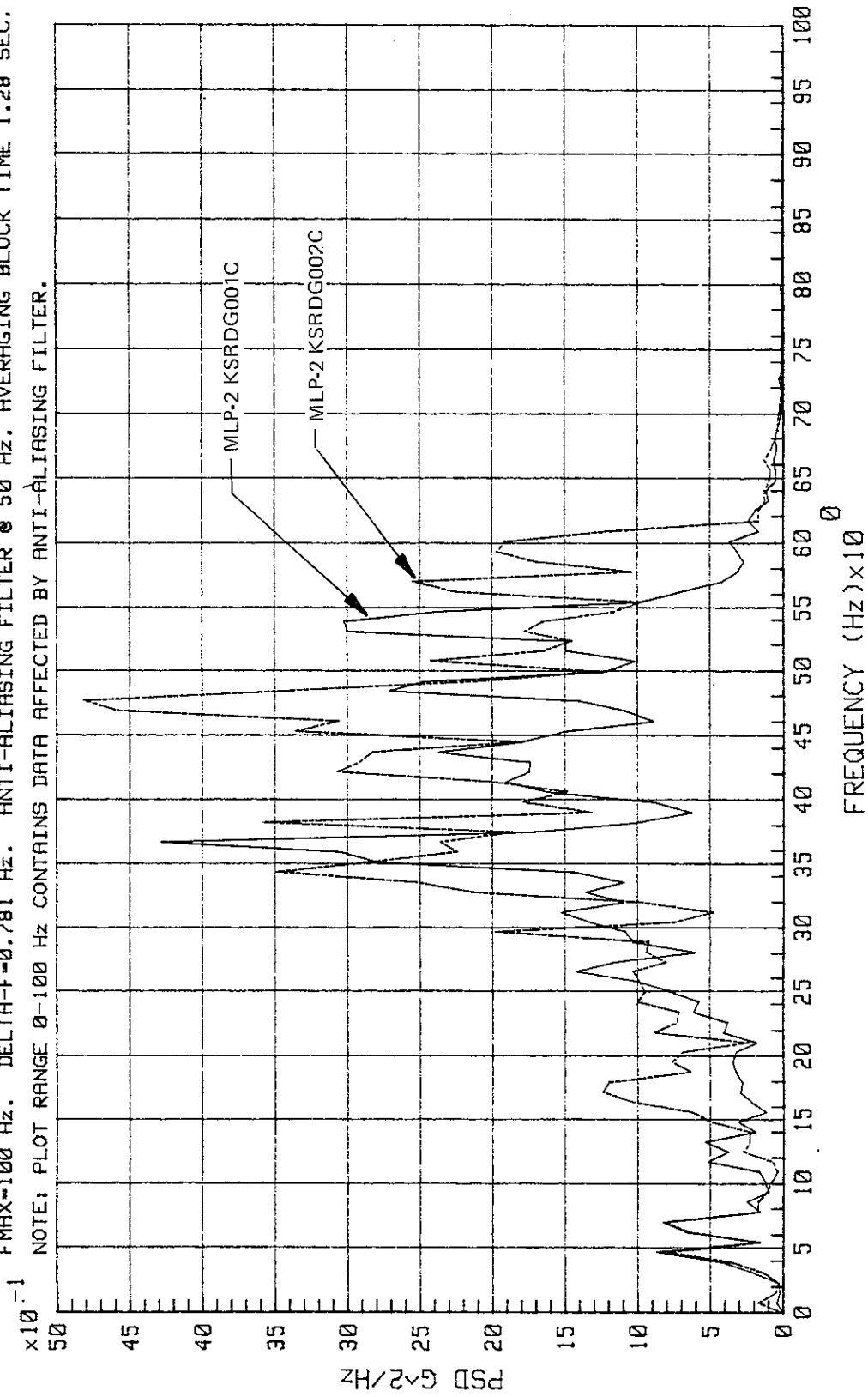
Figure 5-26. STS-6 MLP-2 Vibration of Deck 0 Beams, Z Direction, 0 to 100 Hz
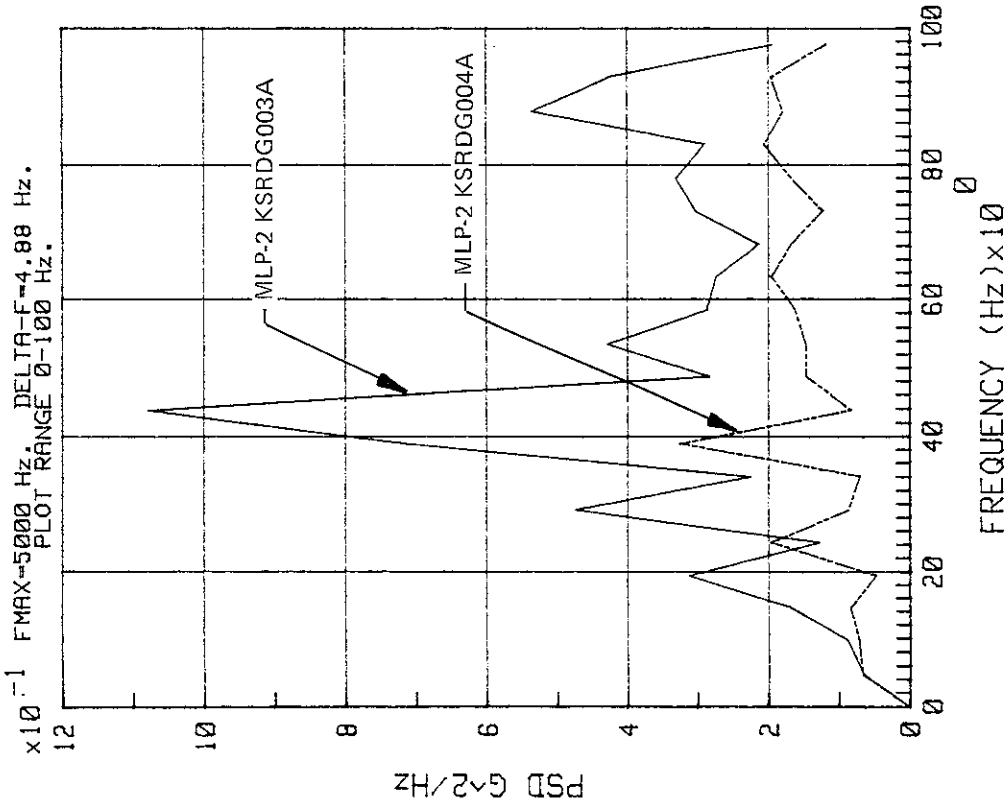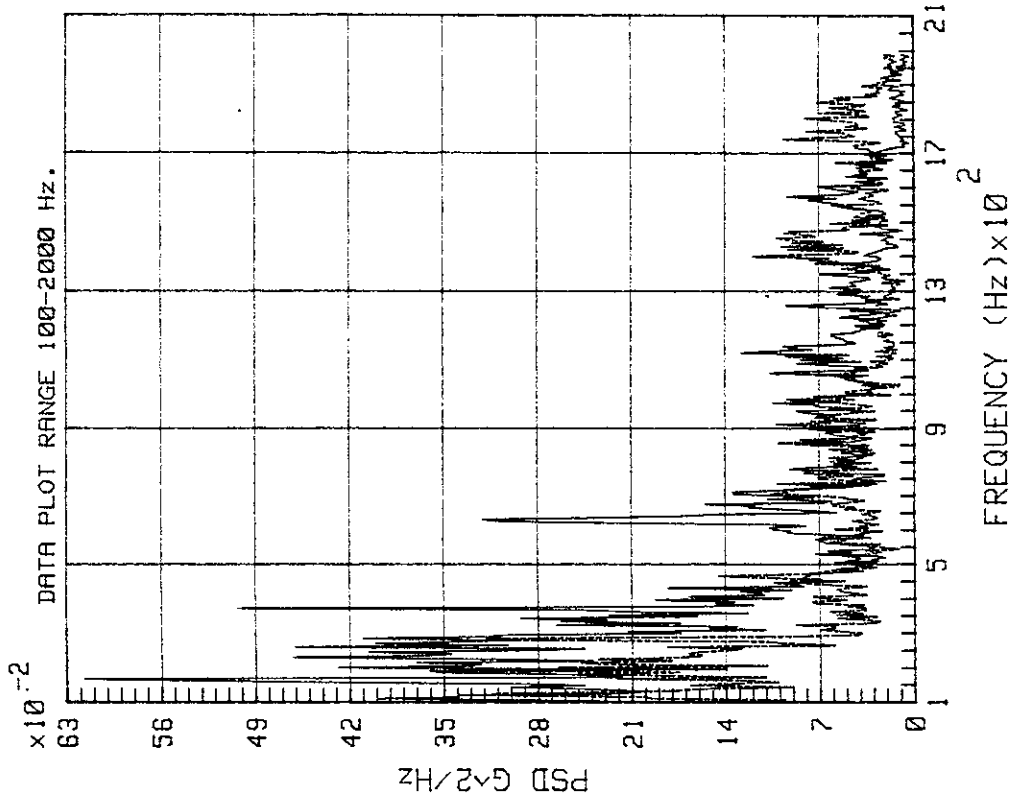
Figure 5-27. STS-6 MLP-2 Vibration of T-2 Truss Top Chord, Z Direction, 0 to 100 Hz and 100 to 2,100 Hz
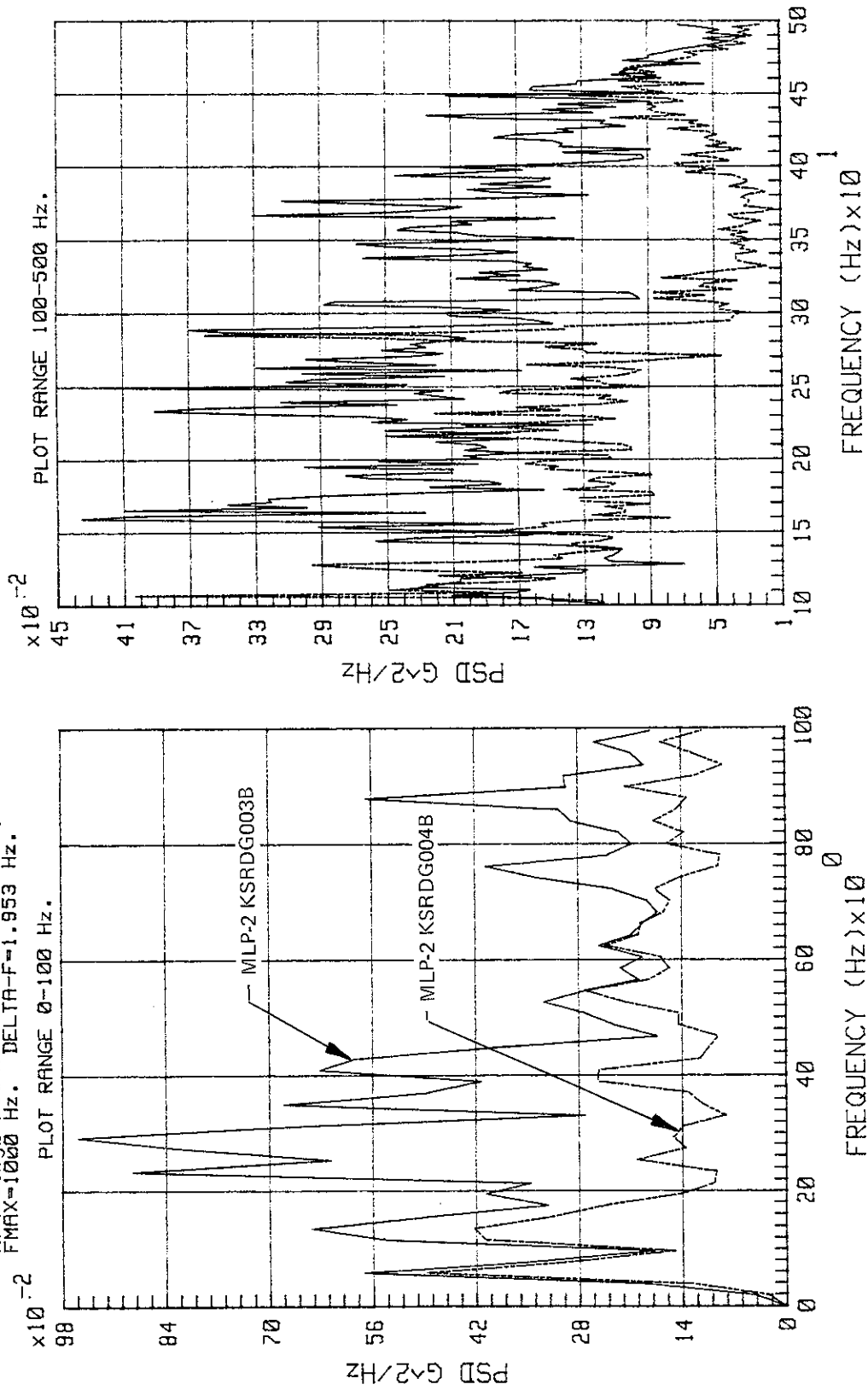
Figure 5-28. STS-6 MLP-2 Vibration of T-2 Truss Top Chord, Z Direction, 0 to 100 Hz and 100 to 500 Hz

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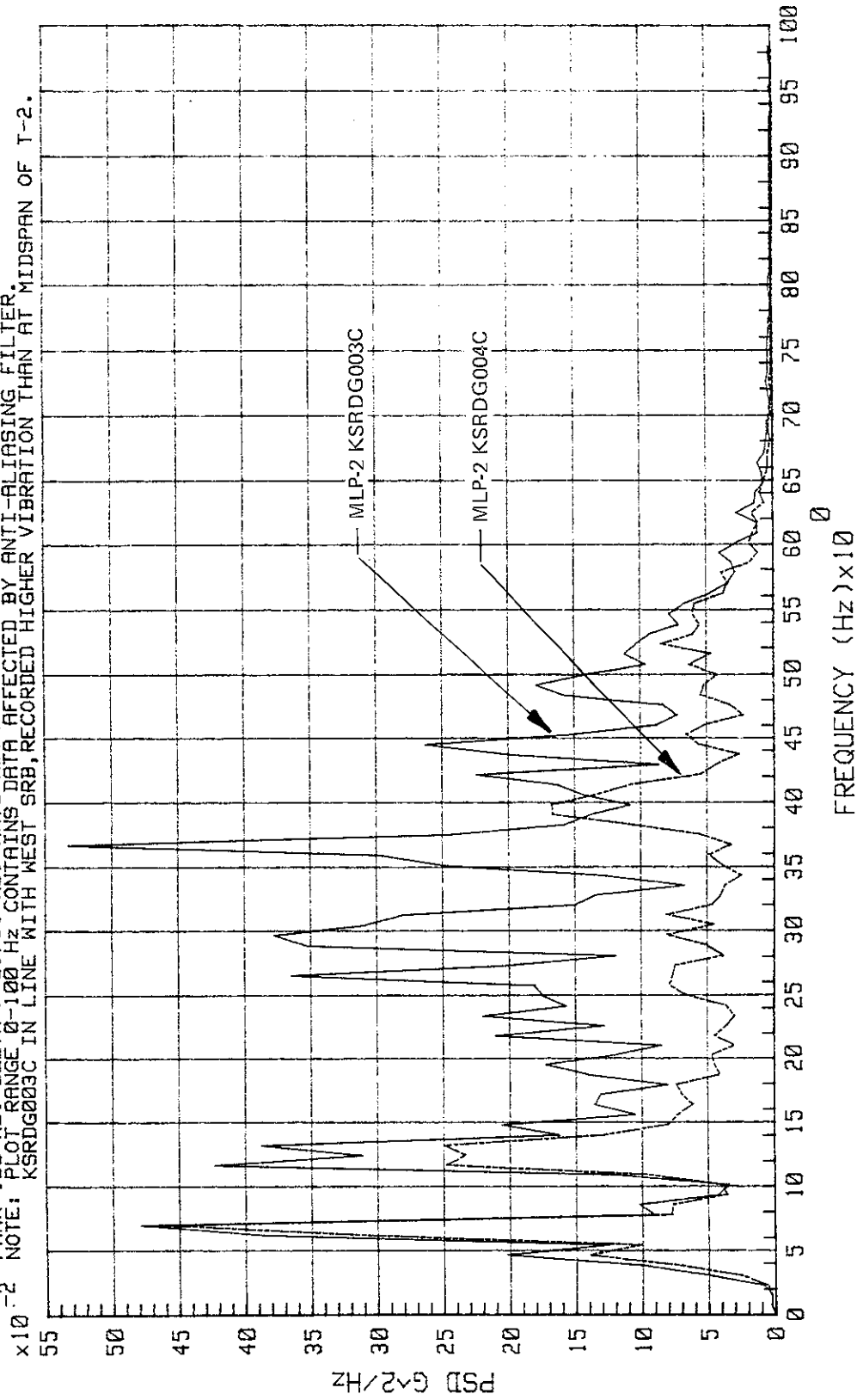
Figure 5-29. STS-6 MLP-2 Vibration of T-2 Truss Top Chord, Z Direction, 0 to 100 Hz

5-48
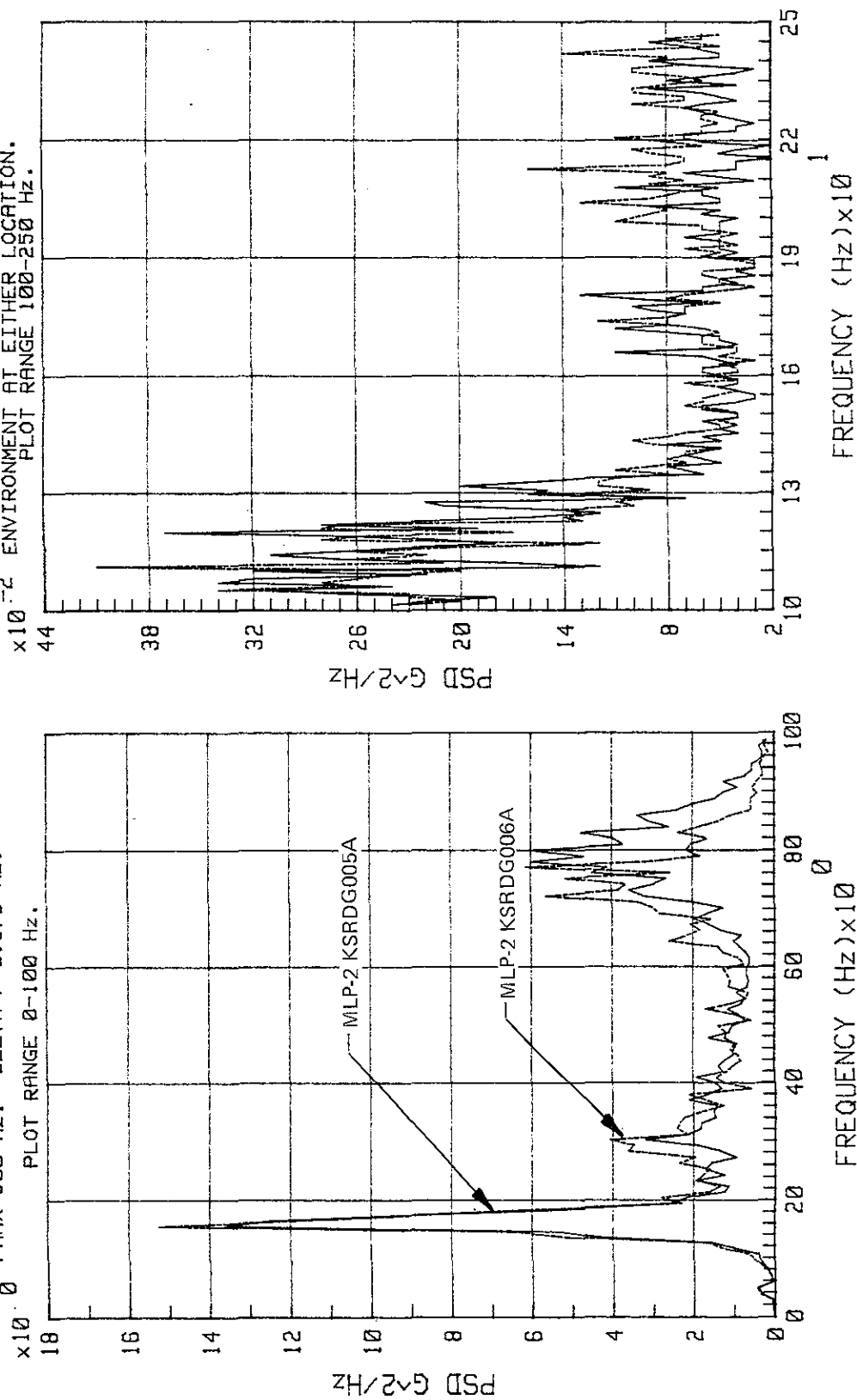
Figure 5-30. STS-6 MLP-2 Vibration of Deck B Floor Beams, Z Direction, 0 to 100 Hz and 100 to 250 Hz

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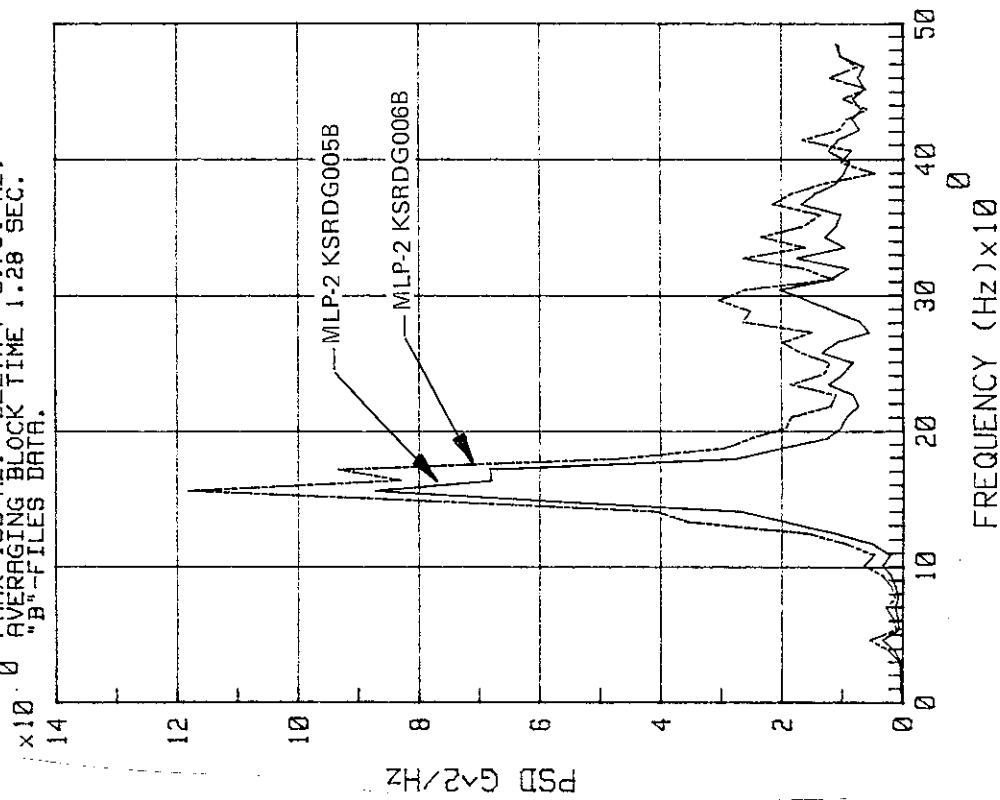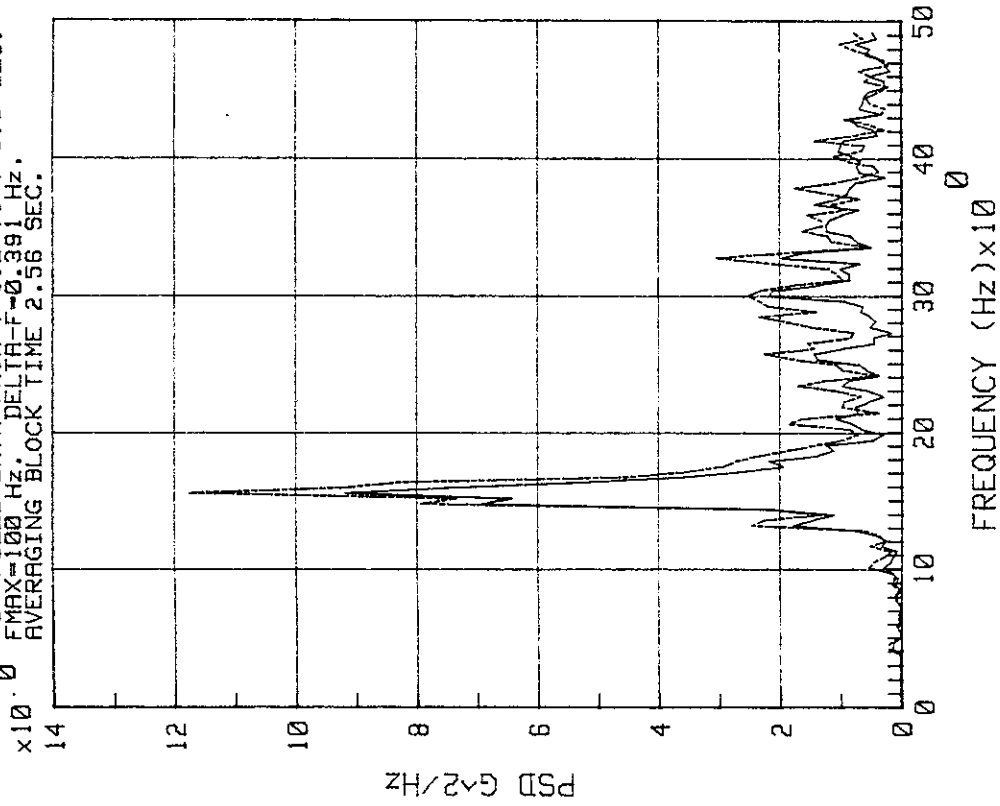
Figure 5-31. STS-6 MLP-2 Vibration of Deck B Floor Beams, Z Direction, 0 to 50 Hz
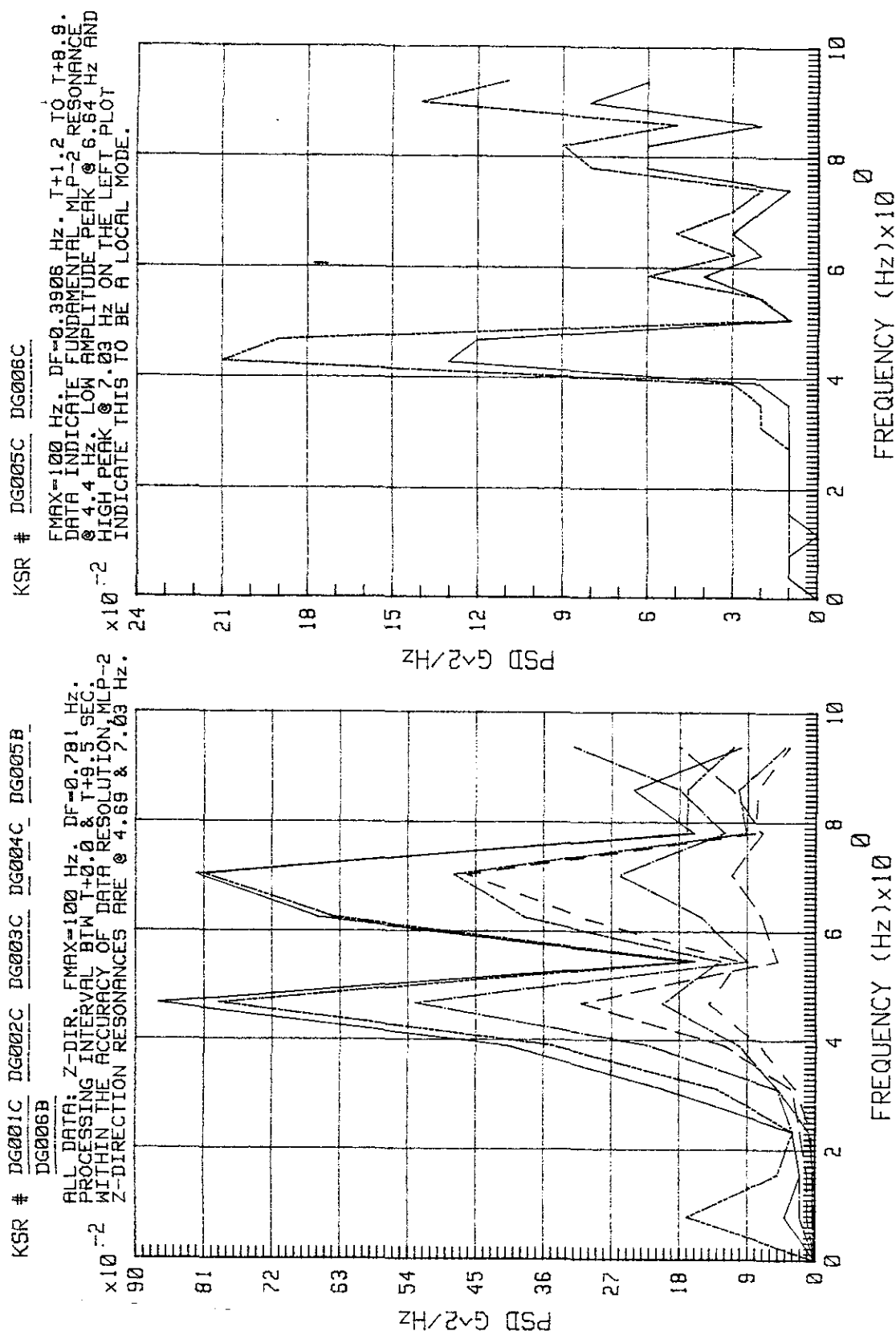
Figure 5-32. STS-6 Data Pertinent to MLP-2 Fundamental Resonances After SRB Ignition

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5.2 FSS

The FSS was instrumented with approximately 50 vibration sensors during the launches of STS-1, -2, and -3. All sensors were located on floor beams and at 75-, 115-, 145-, 215-, and 255-ft levels except for a triaxial sensor that was mounted on the ET arm vertical member at the 215-ft level. During STS-4 and -5 launches, the LH_2 and LO_2 Dewar gage panels were instrumented with 18 vibration sensors located on the 155-ft level. The resulting data were processed and published in the documents listed in the bibliography herein. Worst-case samplings of the following elements of the FSS have been selected for this summary and are shown in the applicable figures (figures 5-33 through 5-42). Included are raw data, PD's, PSD's, and rms time histories for the following measurements:

Designation	Location	Level (ft)	Direction
KSADB002A	Floor Beam - Side 2 (between supports)	75	Z
KSADB013A	Floor Beam - Side 4 (between supports)	115	Z
KSADB014A	Floor Beam Center - Side 1 (near main structural support)	115	Z
KSADB033A	Floor Beam - Side 1 (between supports)	195	Z
KSADB035A	Floor Beam Center - Side 1 (near main structural support)	195	Z
KSADB046A	Floor Beam - Side 1 (between supports)	255	Z
KSADB047A	Floor Beam Center - Side 1 (near main structural support)	255	Z
KSADB050A	ET Arm (vertical member)	215	Z
KFHDB007A	LH_2 Dewar (gage panel center)	155	X
KFODB007A	LO_2 Dewar (gage panel center)	155	X

STS-3 FSS multiple plot summary PSD's for various levels and directions, previously published as appendix C in KSC-DD-651-TR, are included in this summary (figures 5-43 through 5-61). Not included, but recommended for additional information is appendix C of KSC-DD-677-TR, which contains data validation criteria, calculated rms displacements, and zoom plots of significant PSD's.
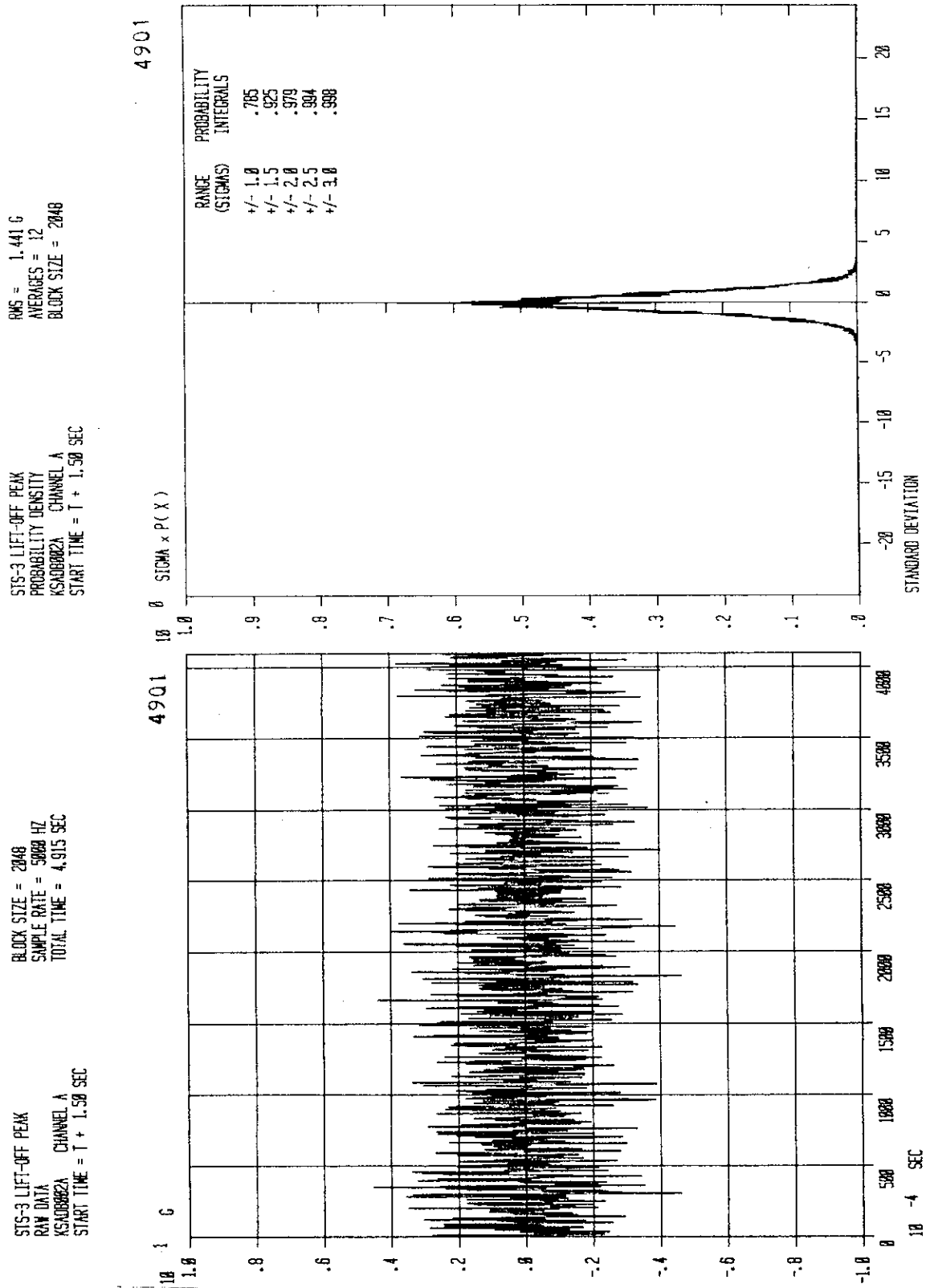
Figure 5-33. Floor Beam Side 2, 75-ft Level, Z Direction (Sheet 1 of 2)
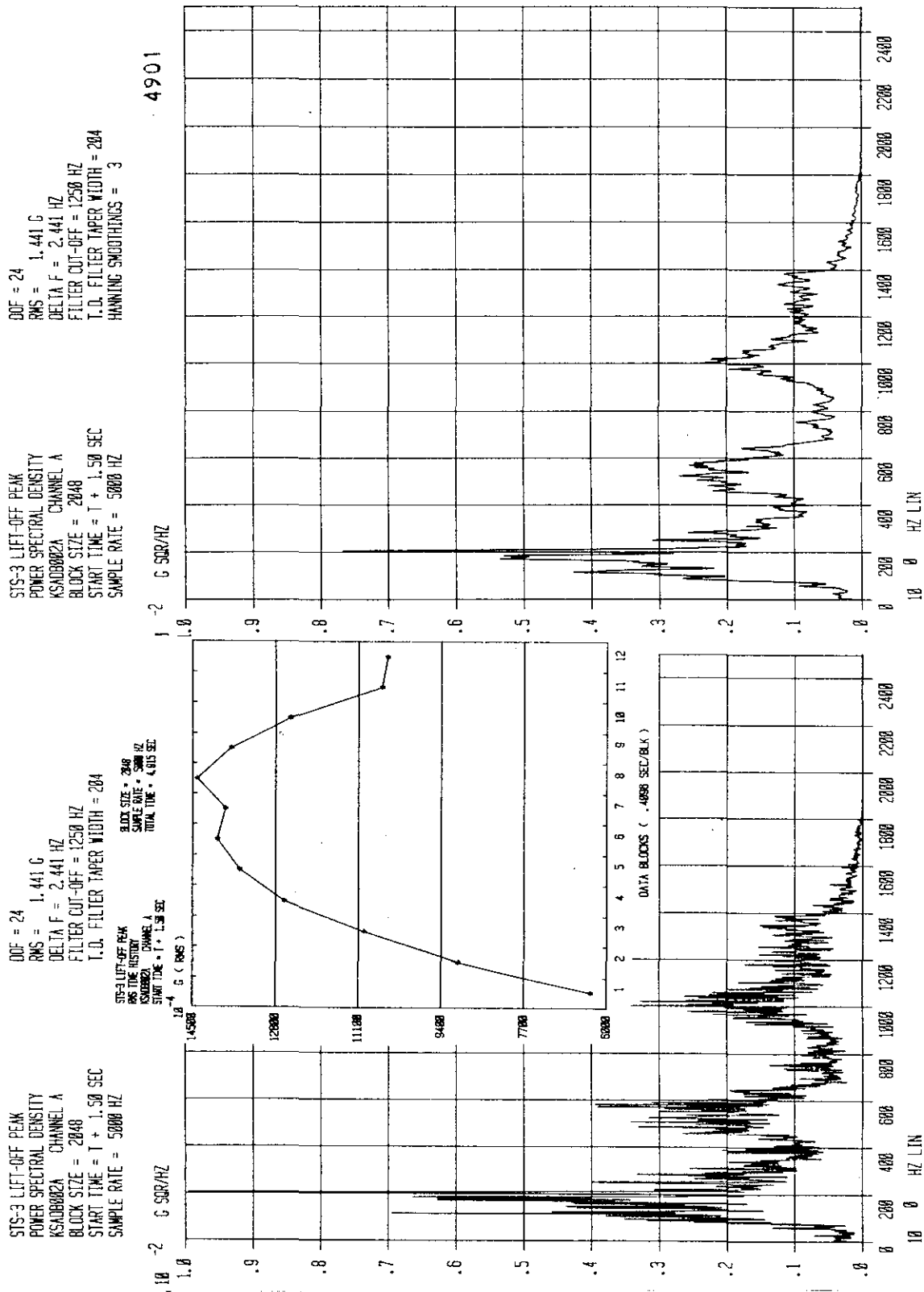
Figure 5-33. Floor Beam Side 2, 75-ft Level, Z Direction (Sheet 2 of 2)
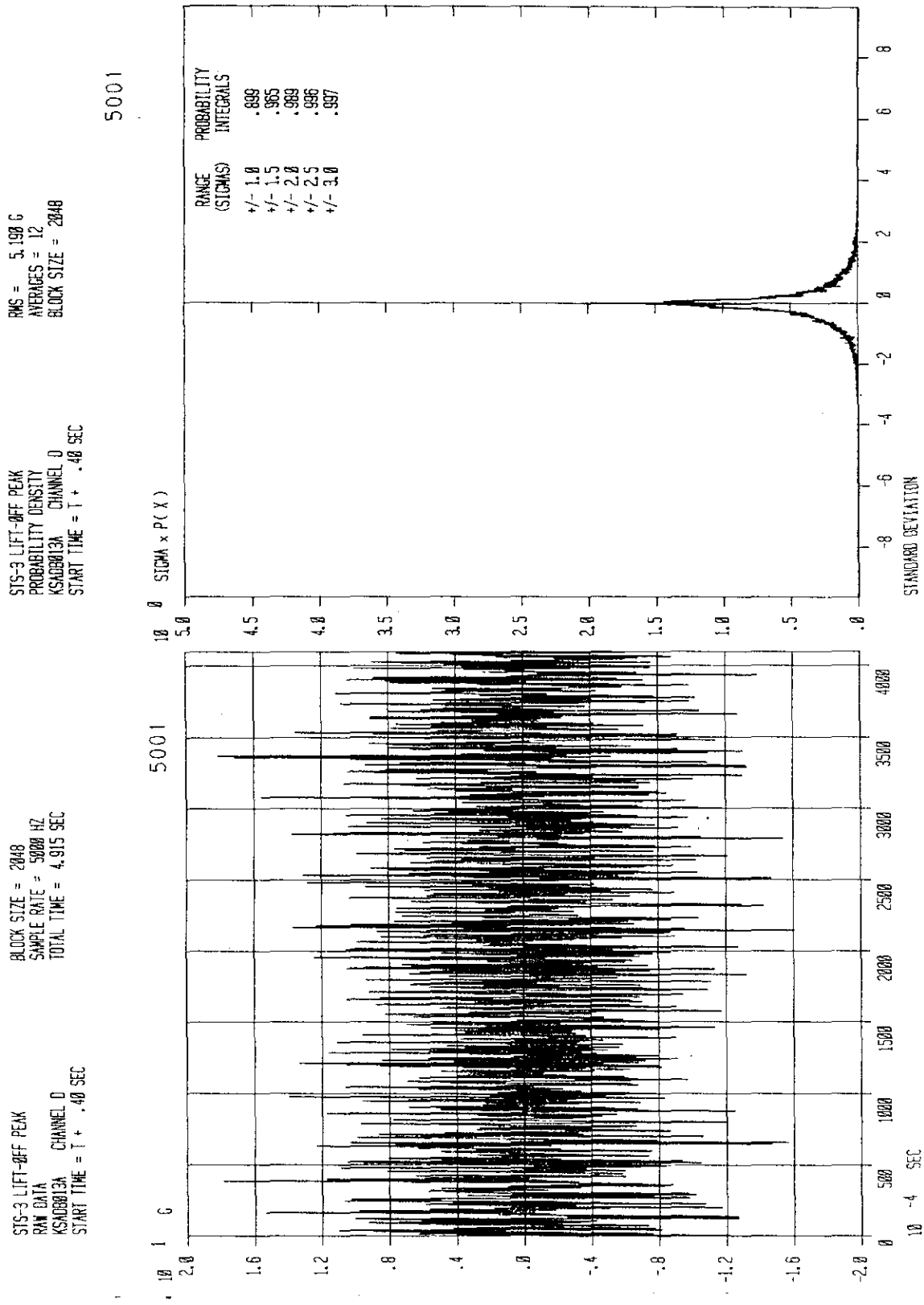
Figure 5-34. Floor Beam Center Side 4, 115-ft Level, Z Direction (Sheet 1 of 2)
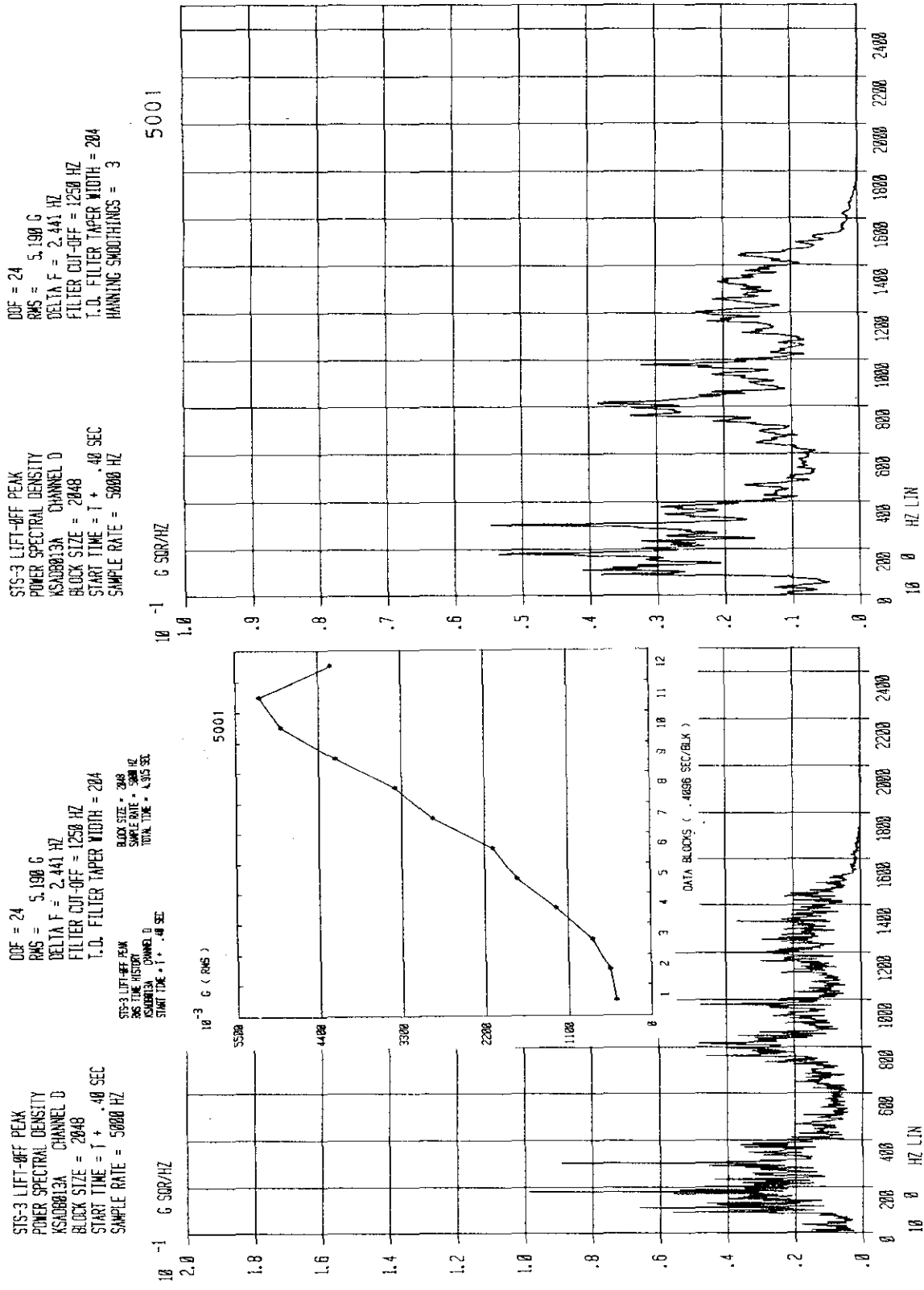
Figure 5-34. Floor Beam Center Side 4, 115-ft Level, Z Direction (Sheet 2 of 2)
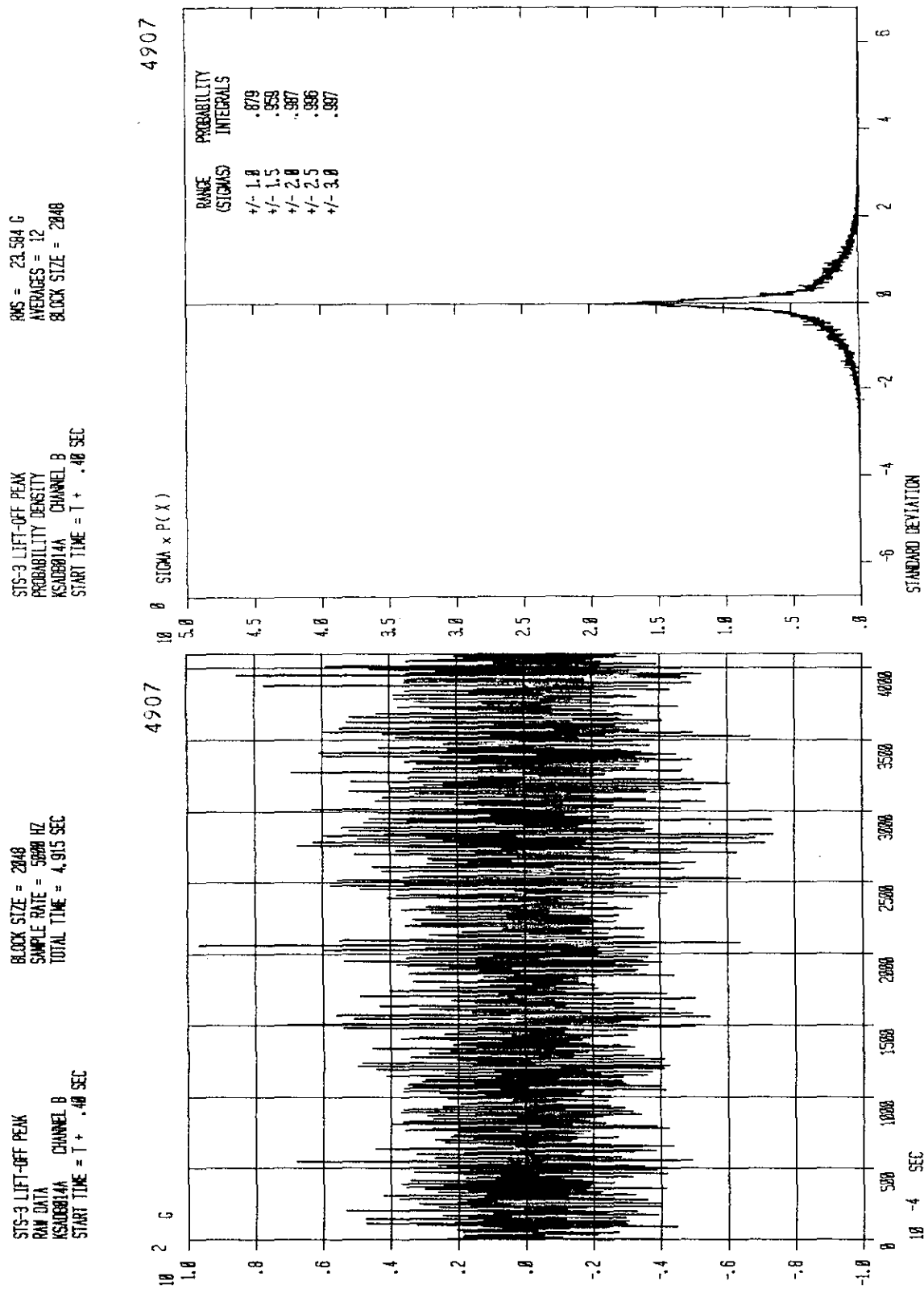
Figure 5-35. Floor Beam Center Side 1, 115-ft Level, Z Direction (Sheet 1 of 2)
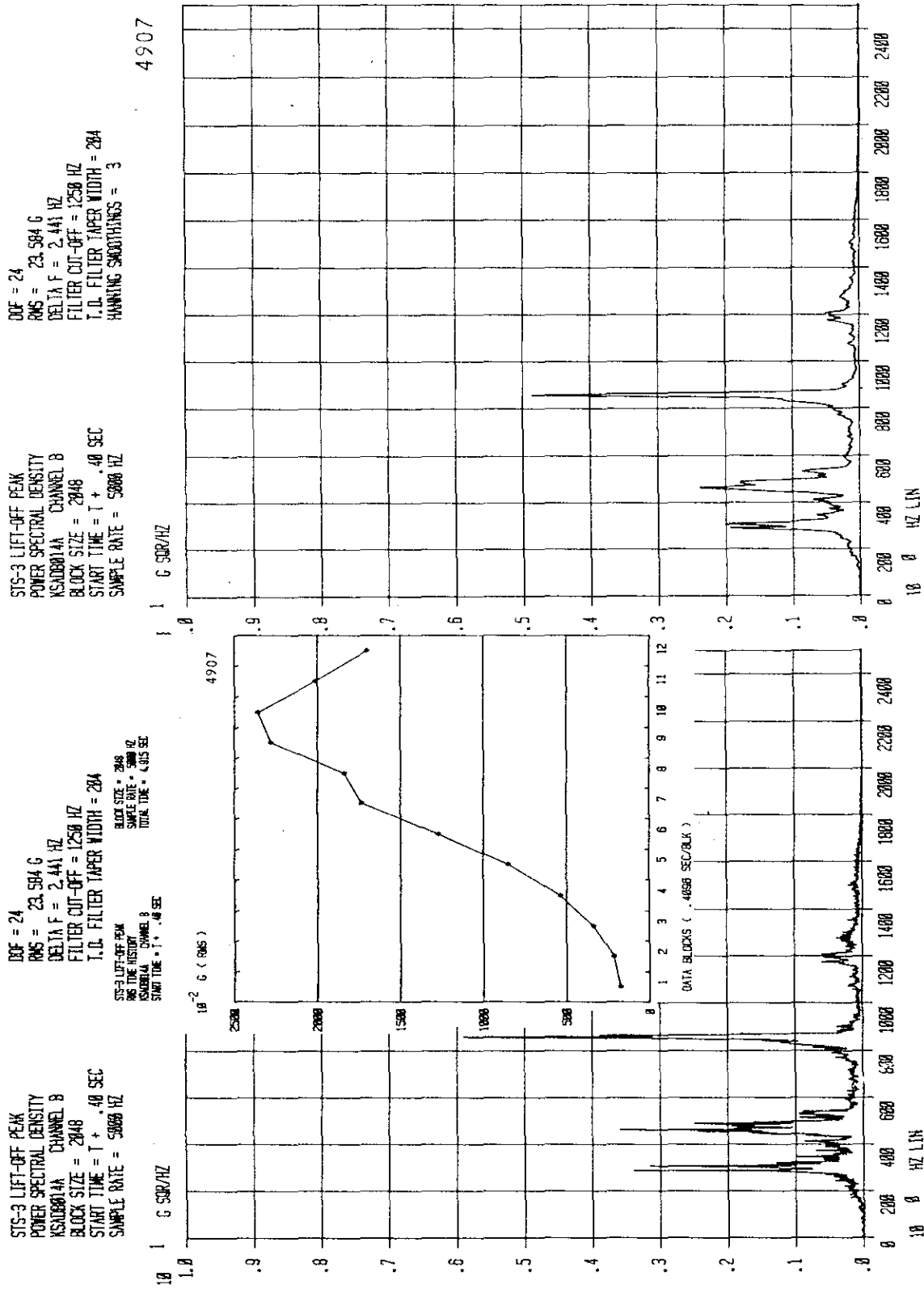
Figure 5-35.   Floor Beam Center Side 1, 115-ft Level, Z Direction (Sheet 2 of 2)
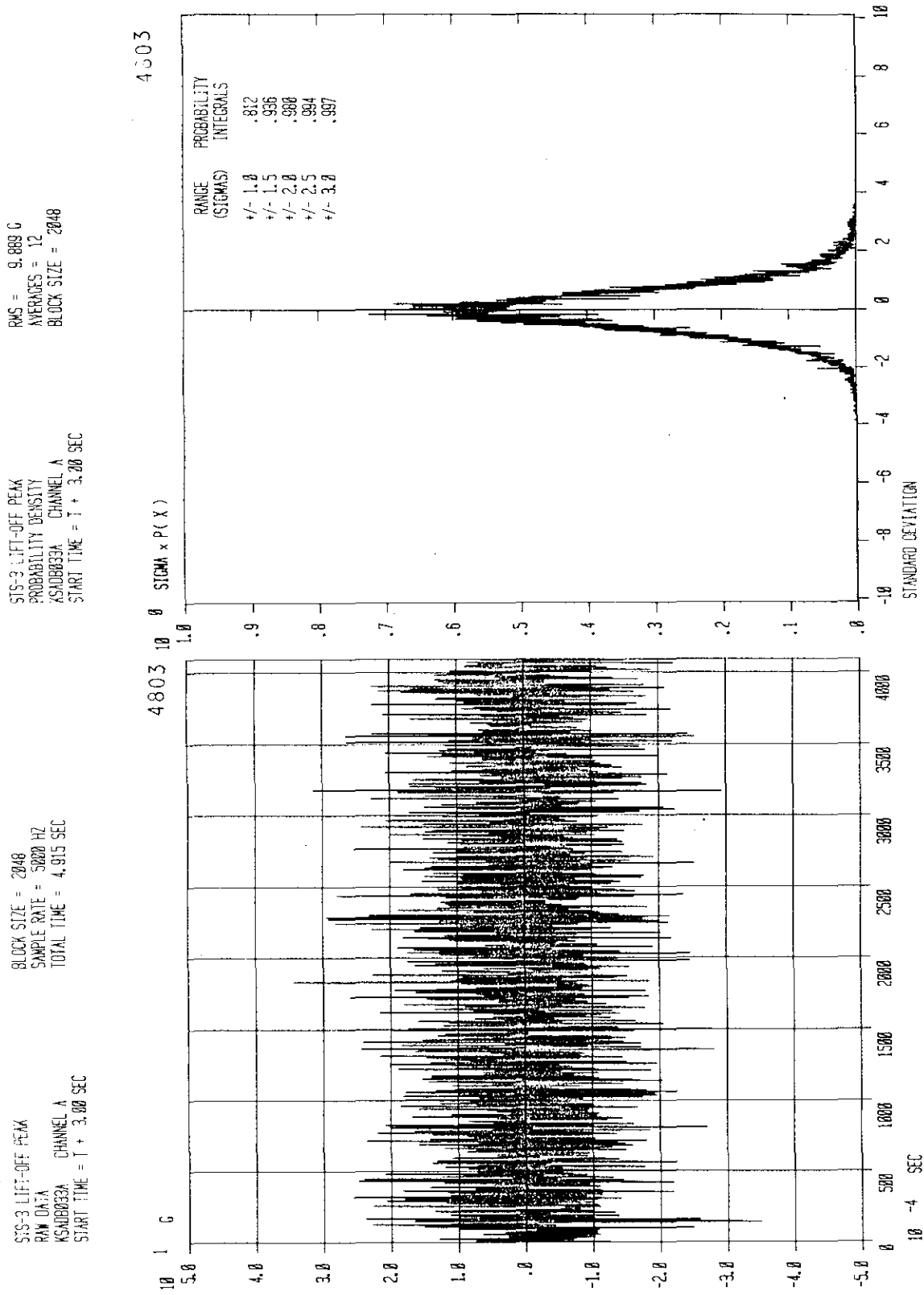
Figure 5-36. Floor Beam Side 1, 195-ft Level, Z Direction (Sheet 1 of 2)
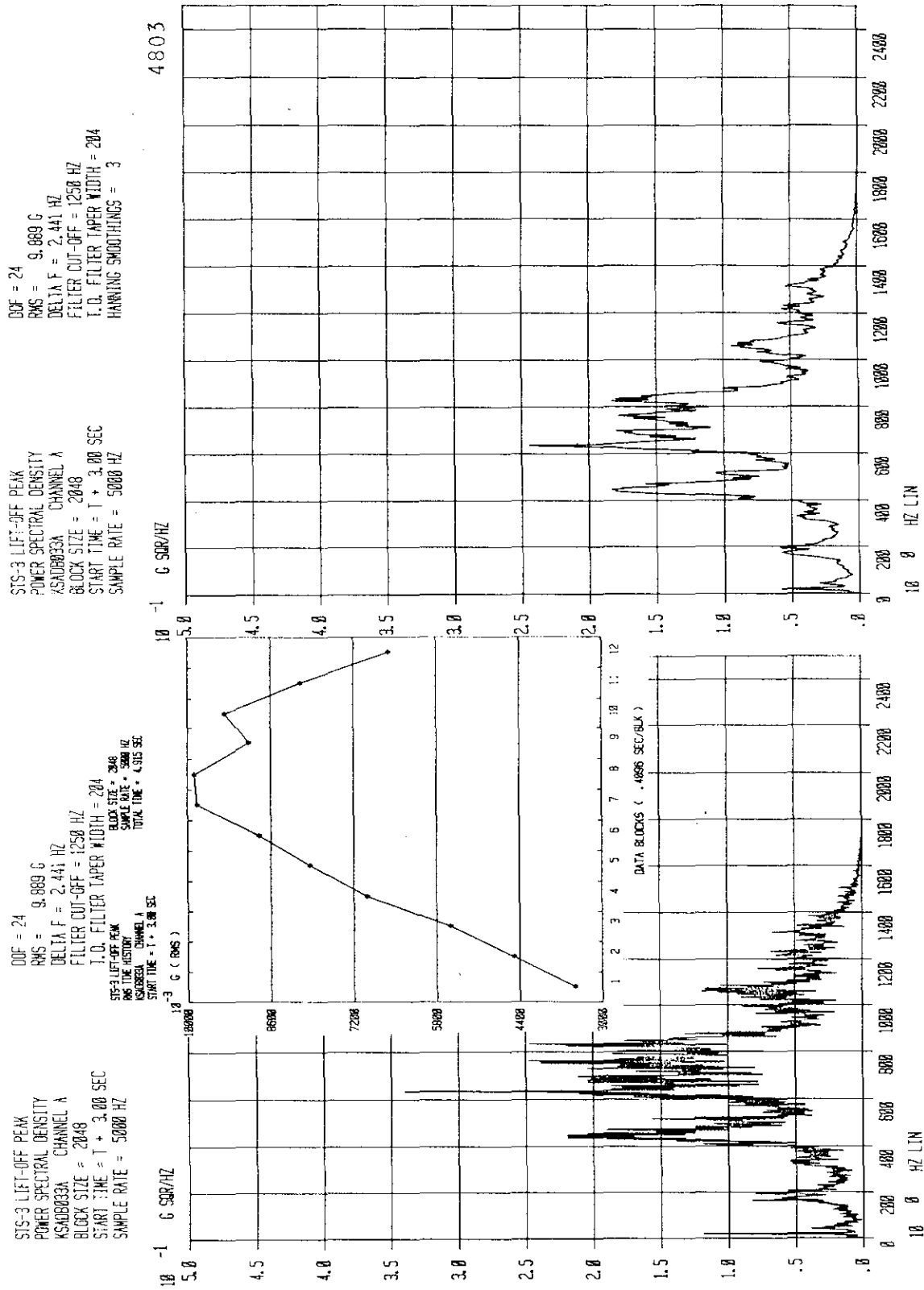
Figure 5-36. Floor Beam Side 1, 195-ft Level, Z Direction (Sheet 2 of 2)
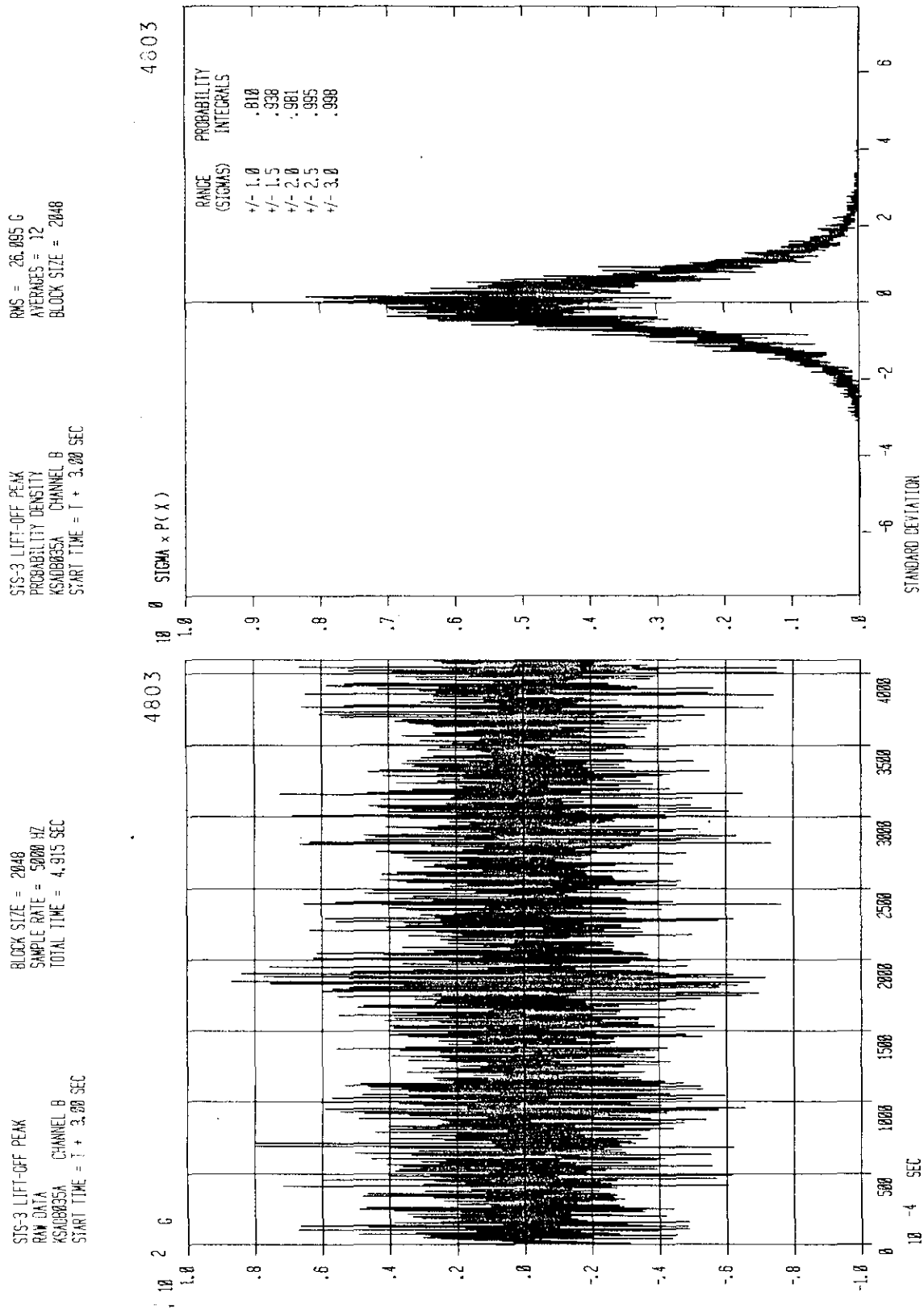
Figure 5-37. Floor Beam Center Side 1, 195-ft Level, Z Direction (Sheet 1 of 2)
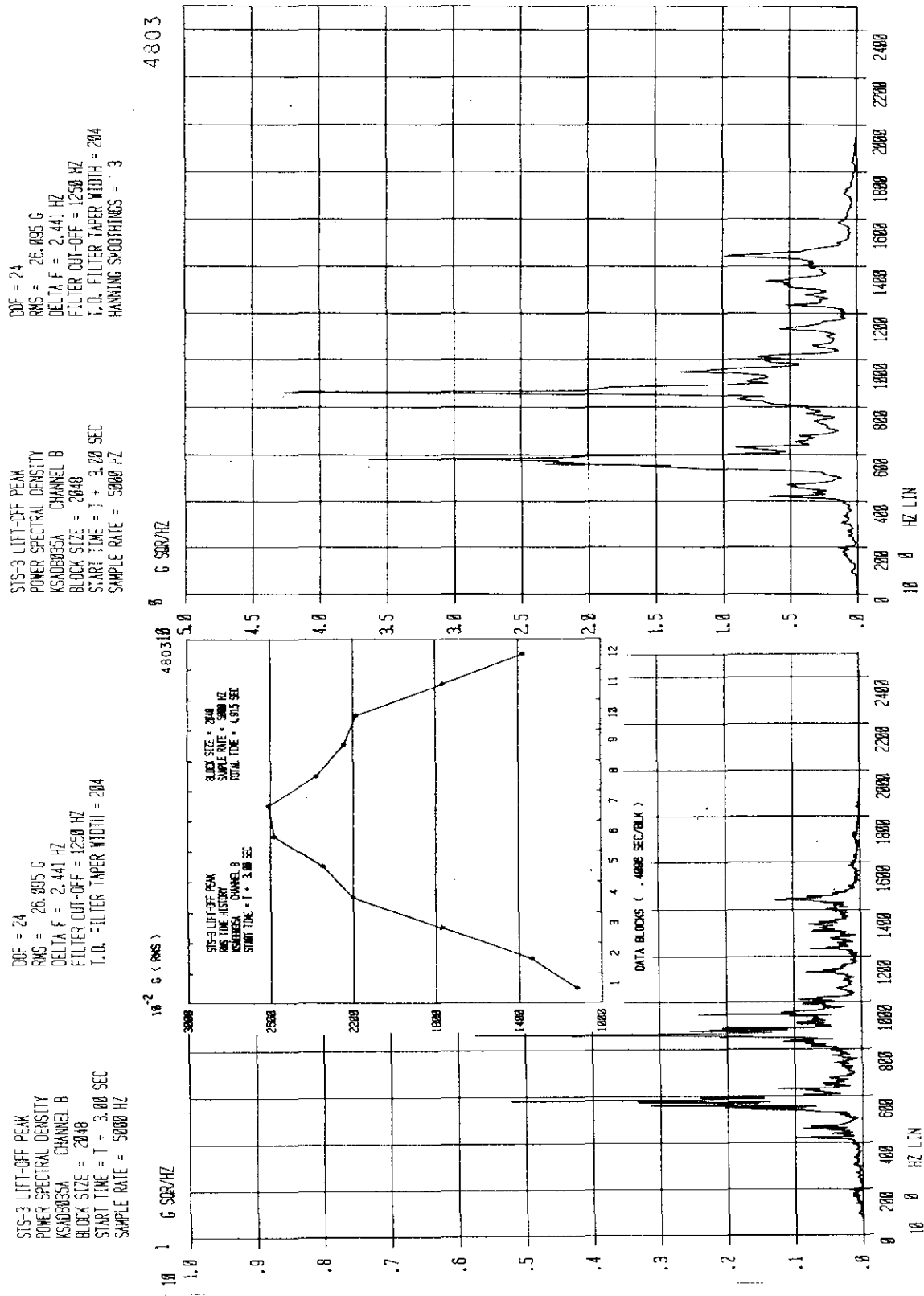
Figure 5-37. Floor Beam Center Side 1, 195-ft Level, Z Direction (Sheet 2 of 2)
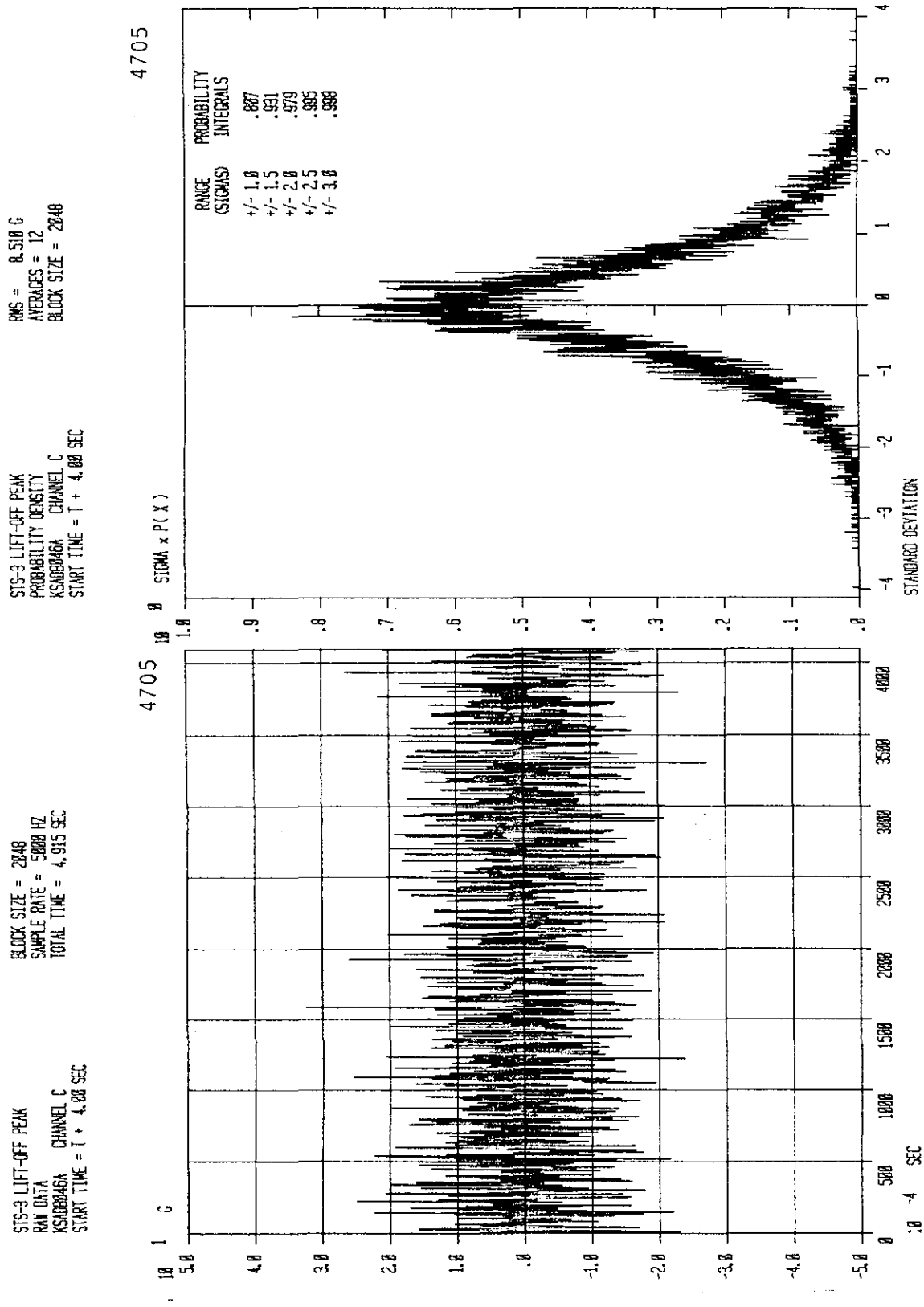
Figure 5-38. Floor Beam Side 1, 255-ft Level, Z Direction (Sheet 1 of 2)
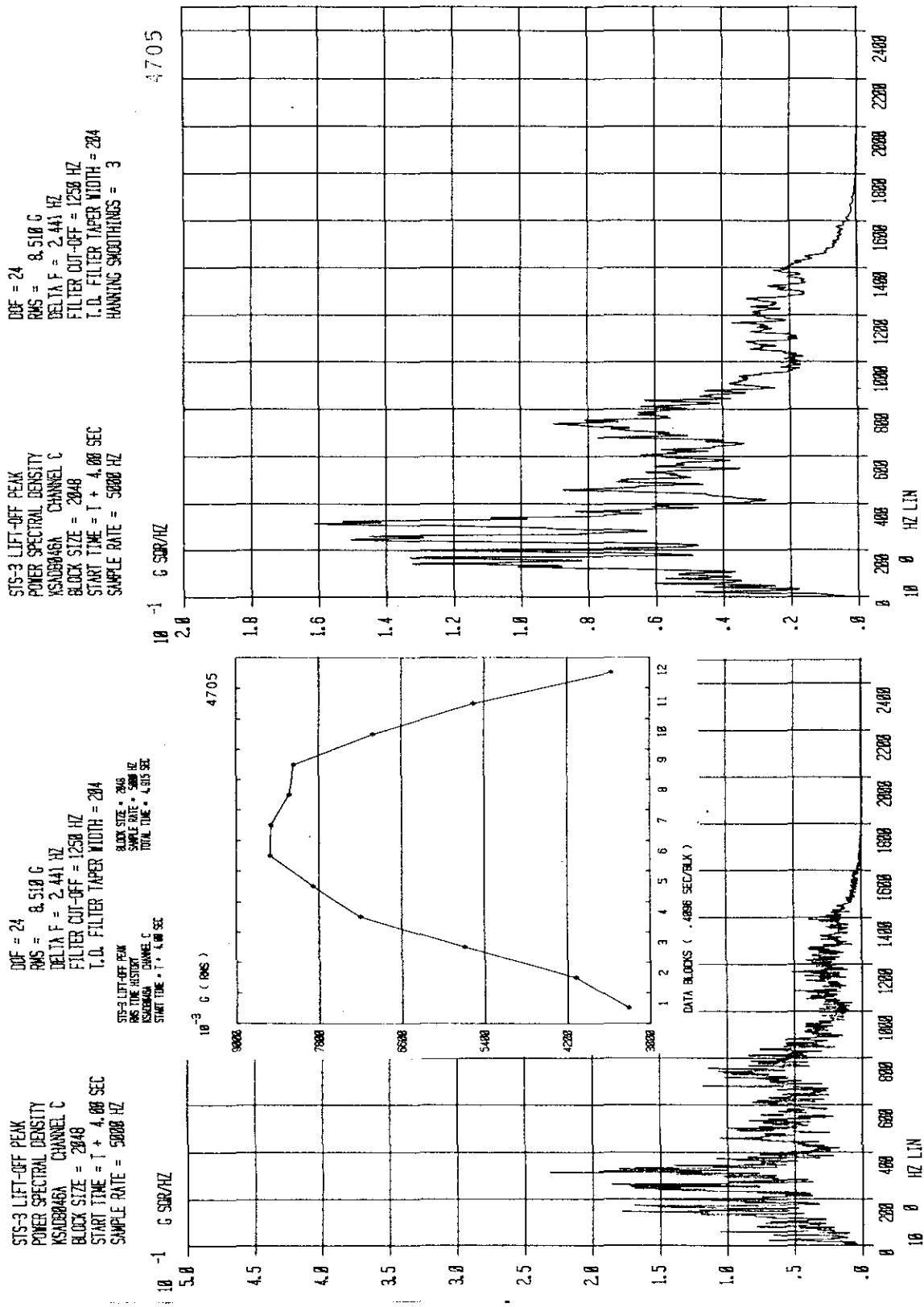
Figure 5-38. Floor Beam Side 1, 255-ft Level, Z Direction (Sheet 2 of 2)
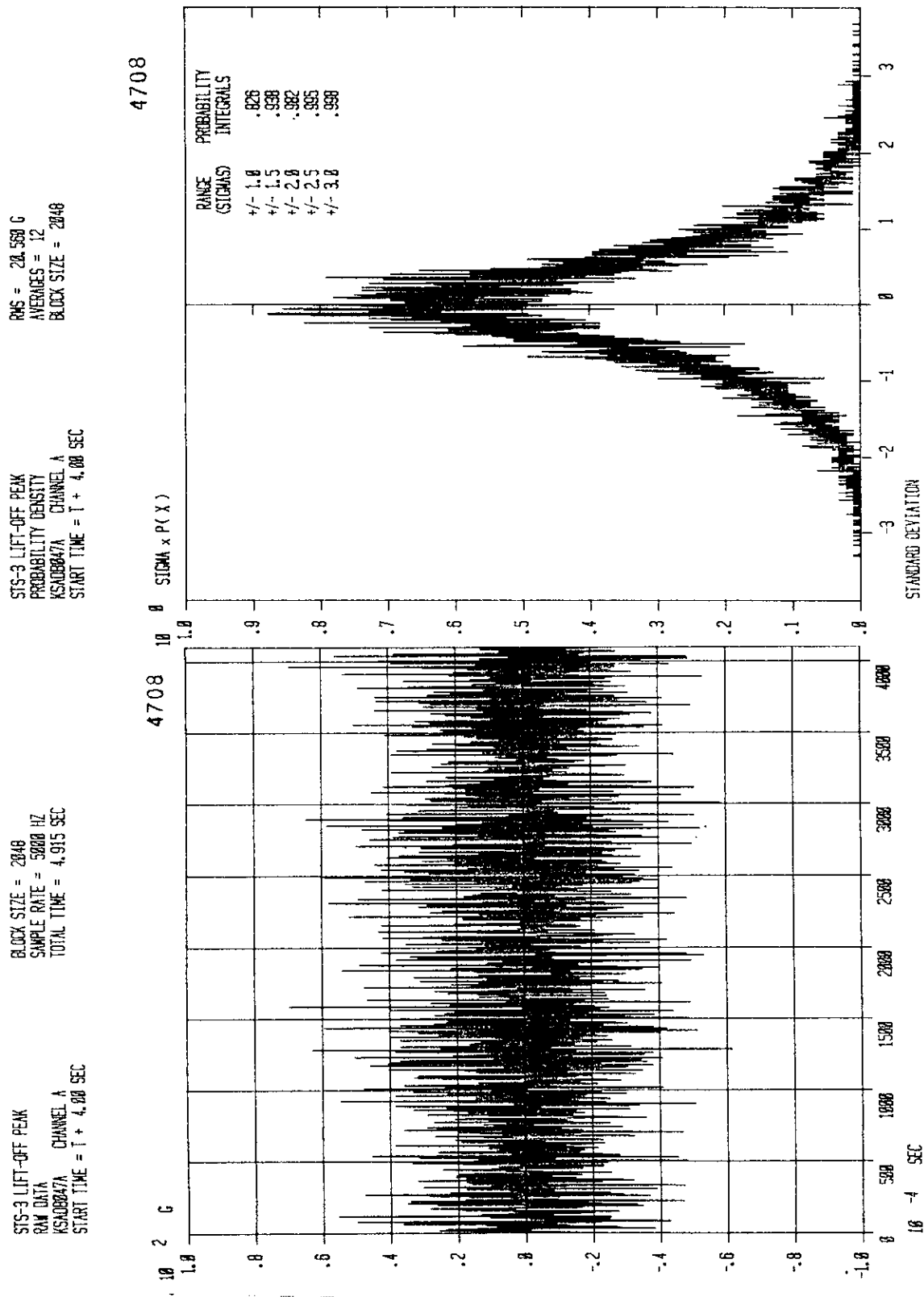
Figure 5-39. Floor Beam Center Side 1, 255-ft Level, Z Direction (Sheet 1 of 2)
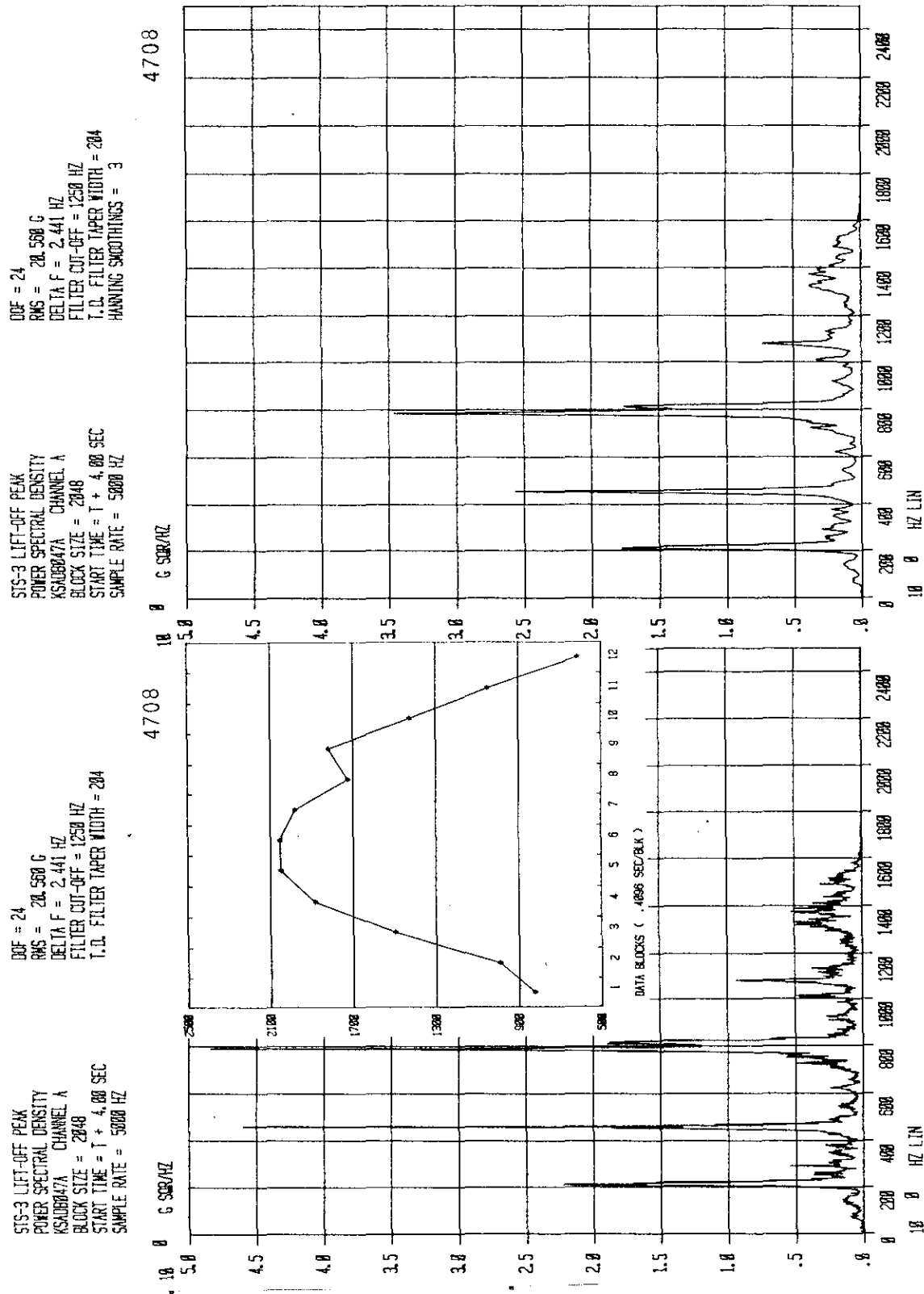
Figure 5-39. Floor Beam Center Side 1, 255-ft Level, Z Direction (Sheet 2 of 2)
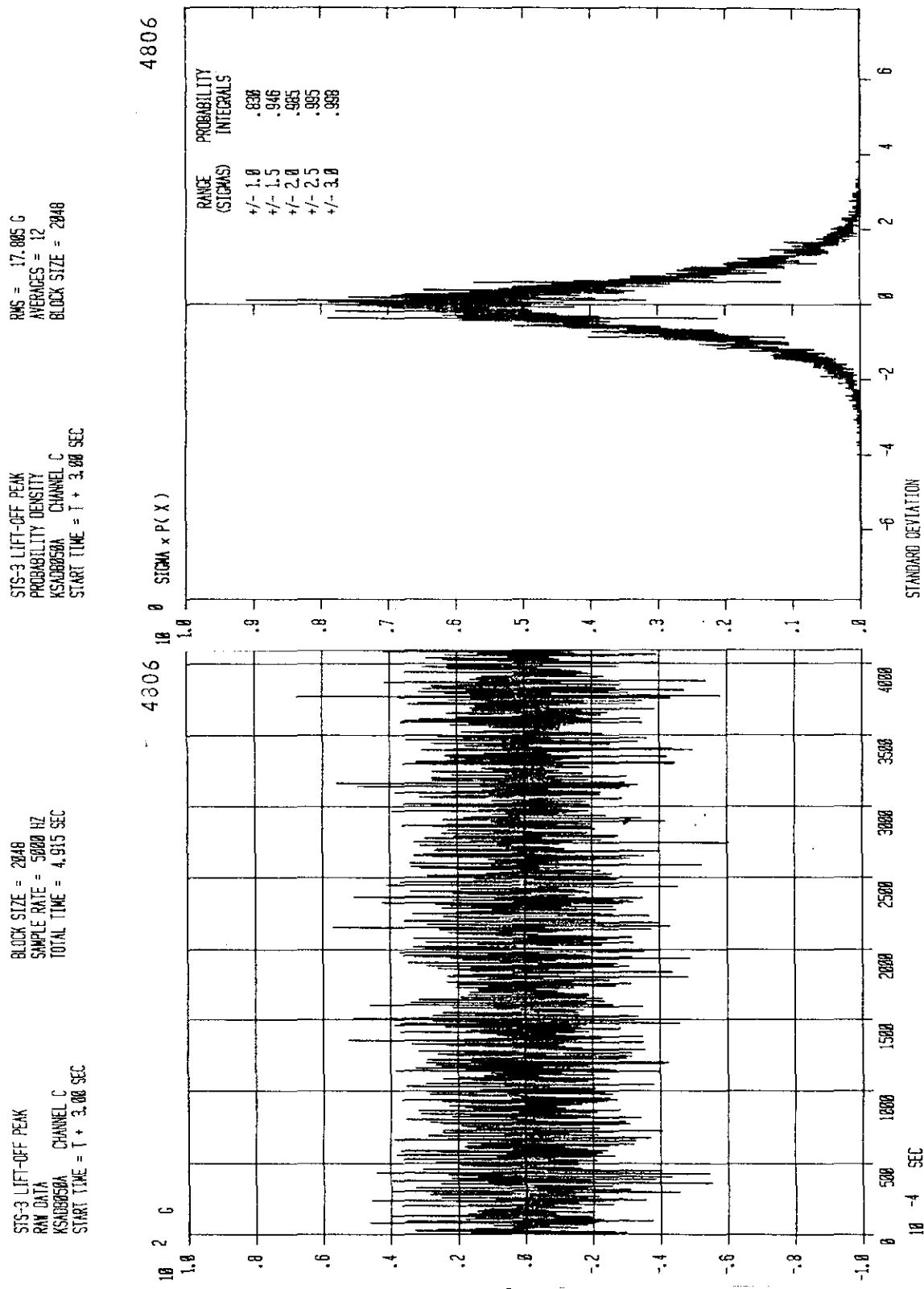
Figure 5-40. ET Arm Vertical Member, 215-ft Level, Z Direction (Sheet 1 of 2)
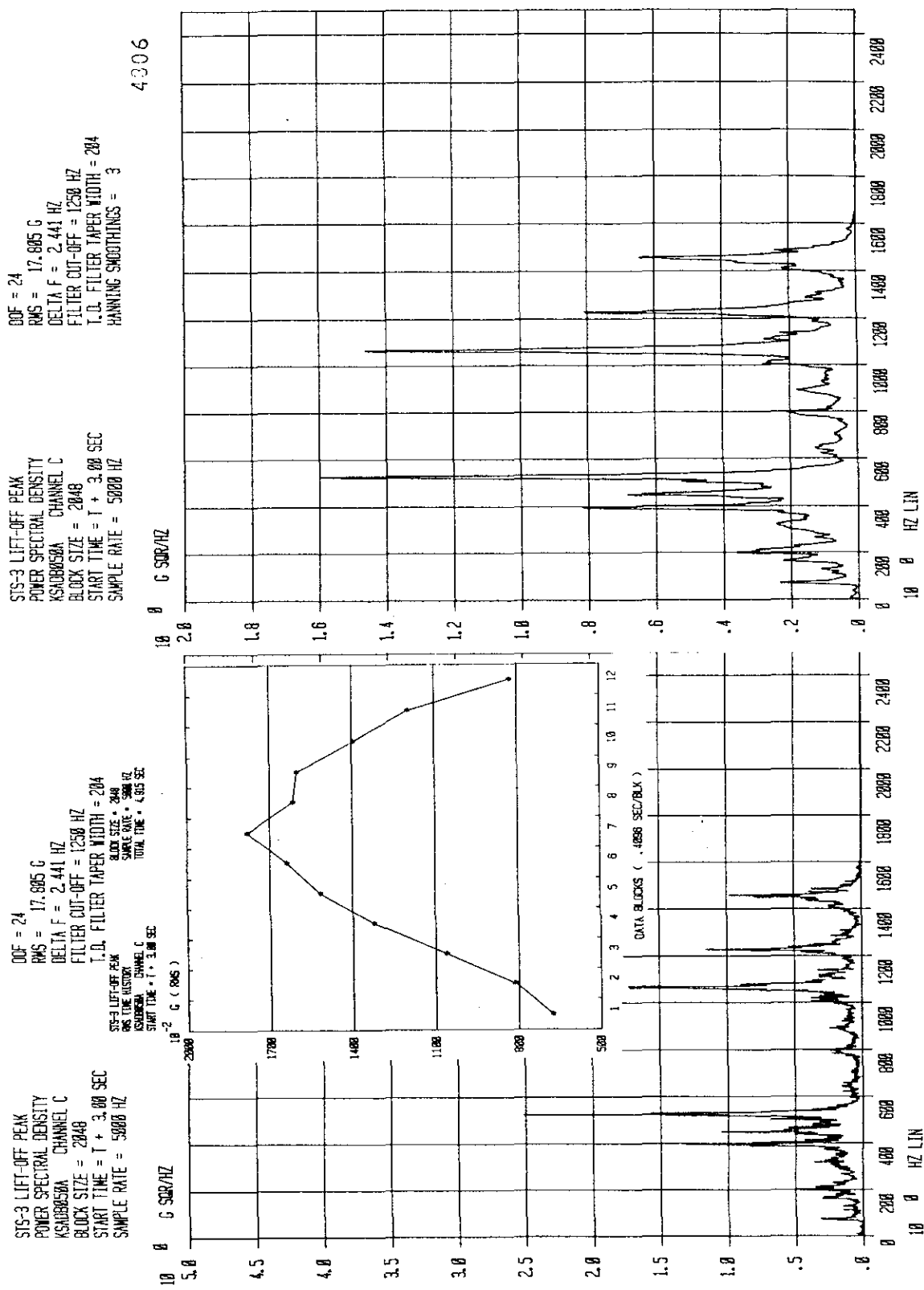
Figure 5-40. ET Arm Vertical Member, 215-ft Level, Z Direction (Sheet 2 of 2)
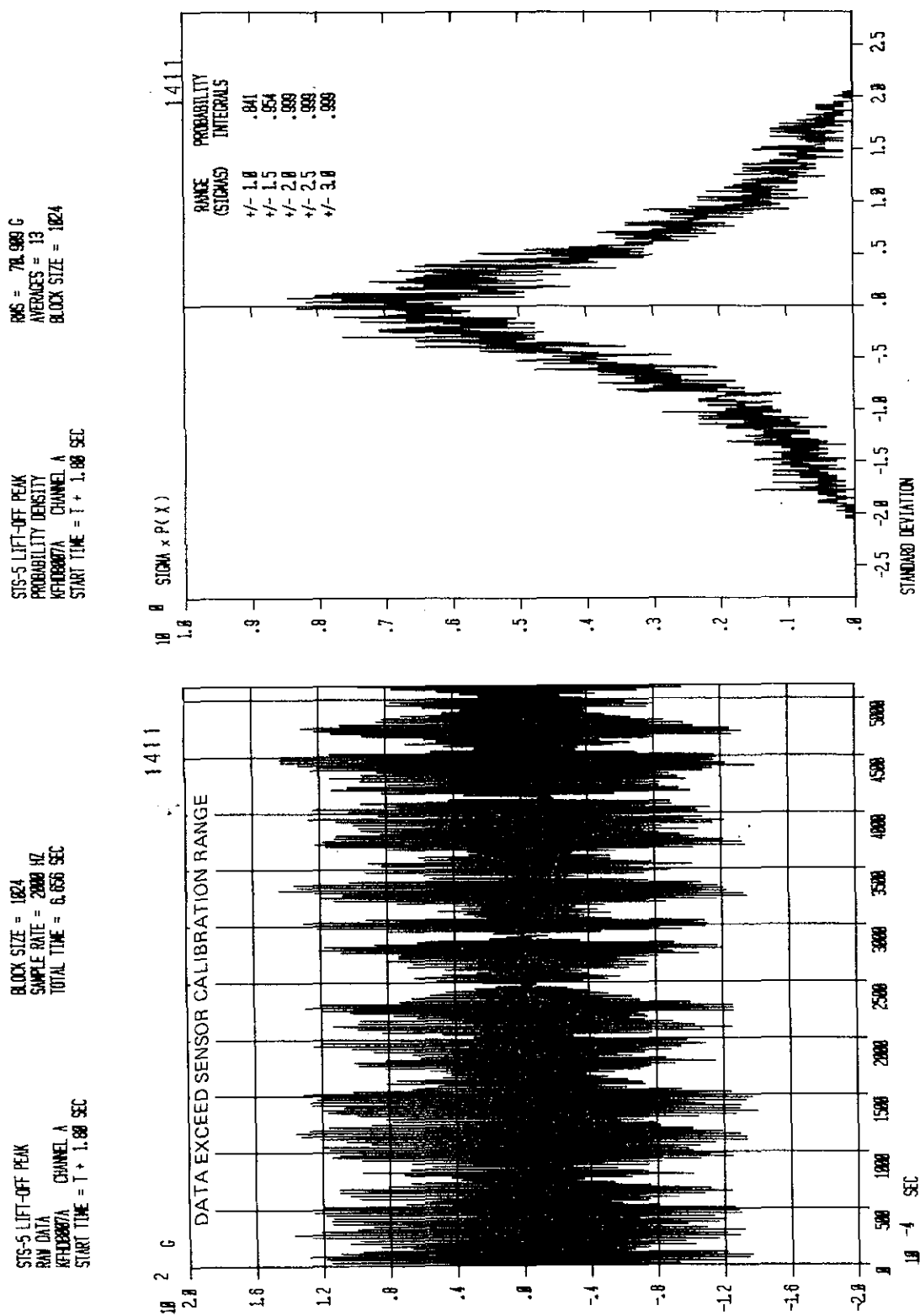
Figure 5-41. LH2 Dewar Gage Panel Center, 155-ft Level, X Direction (Sheet 1 of 2)
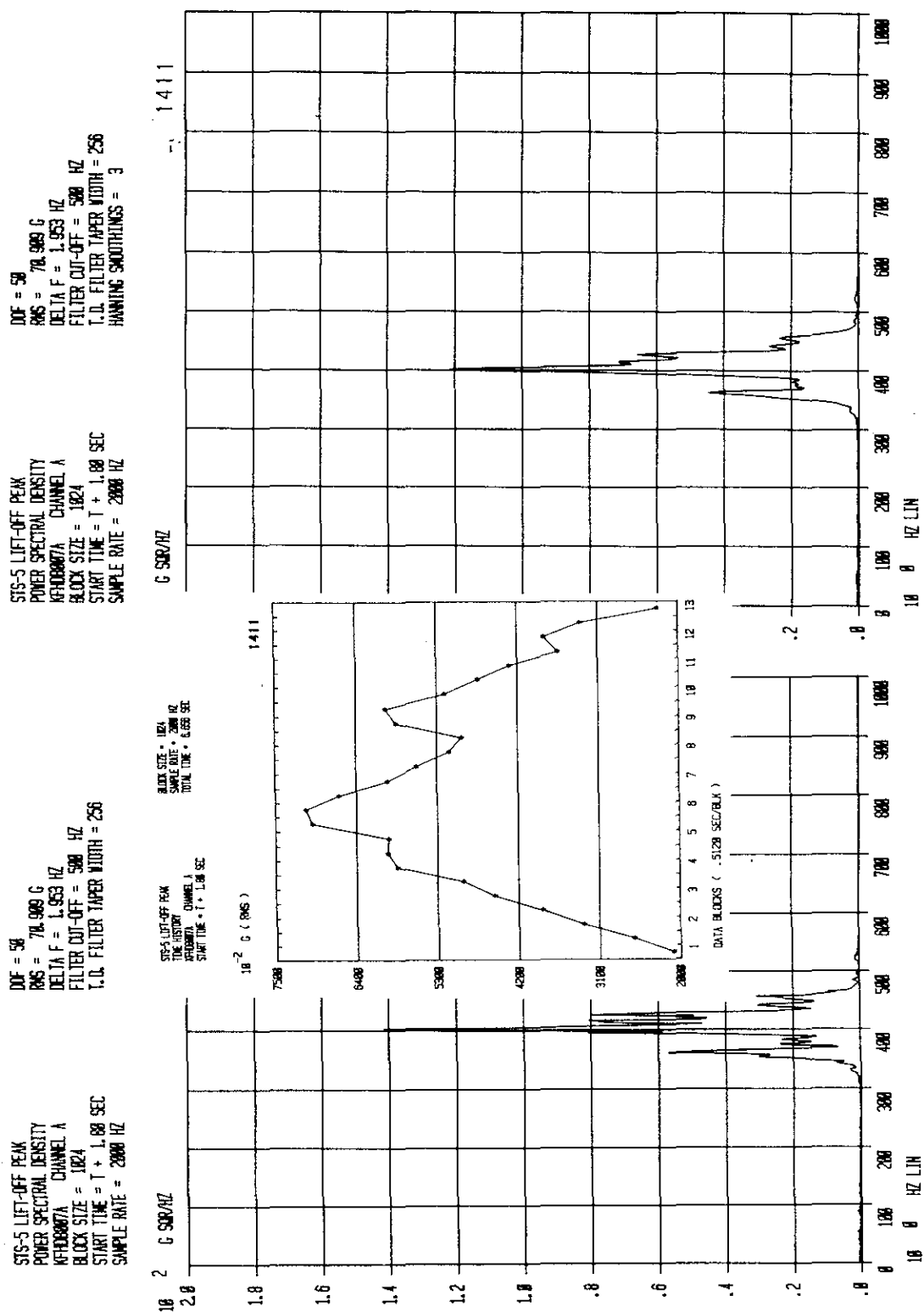
Figure 5-41. LH2 Dewar Gage Panel Center, 155-ft Level, X Direction (Sheet 2 of 2)
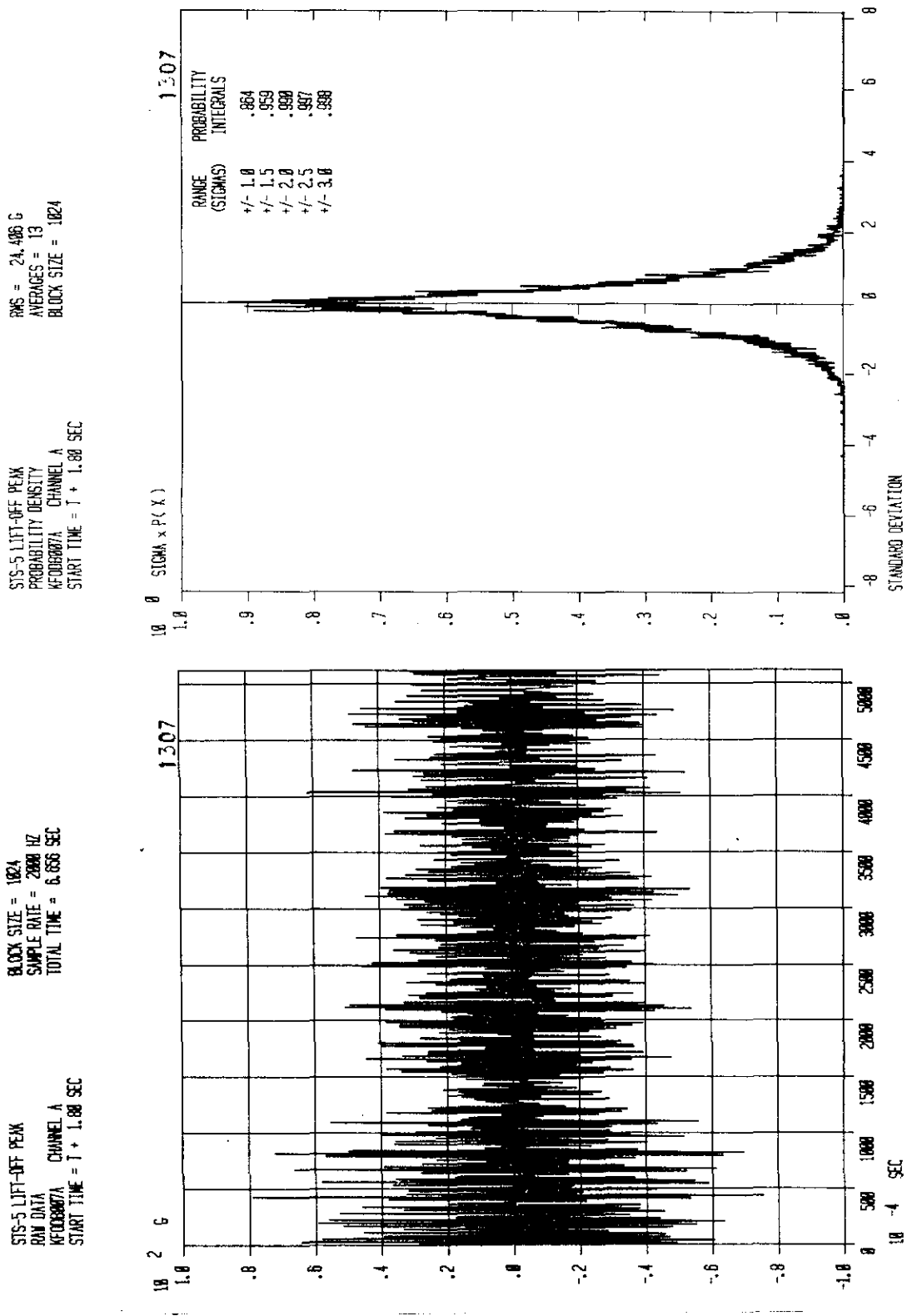
Figure 5-42. LO₂ Dewar Gage Panel Center, 155-ft Level, X Direction (Sheet 1 of 2)

Figure 5-42. LO2 Dewar Gage Panel Center, 155-ft Level, X Direction (Sheet 2 of 2)
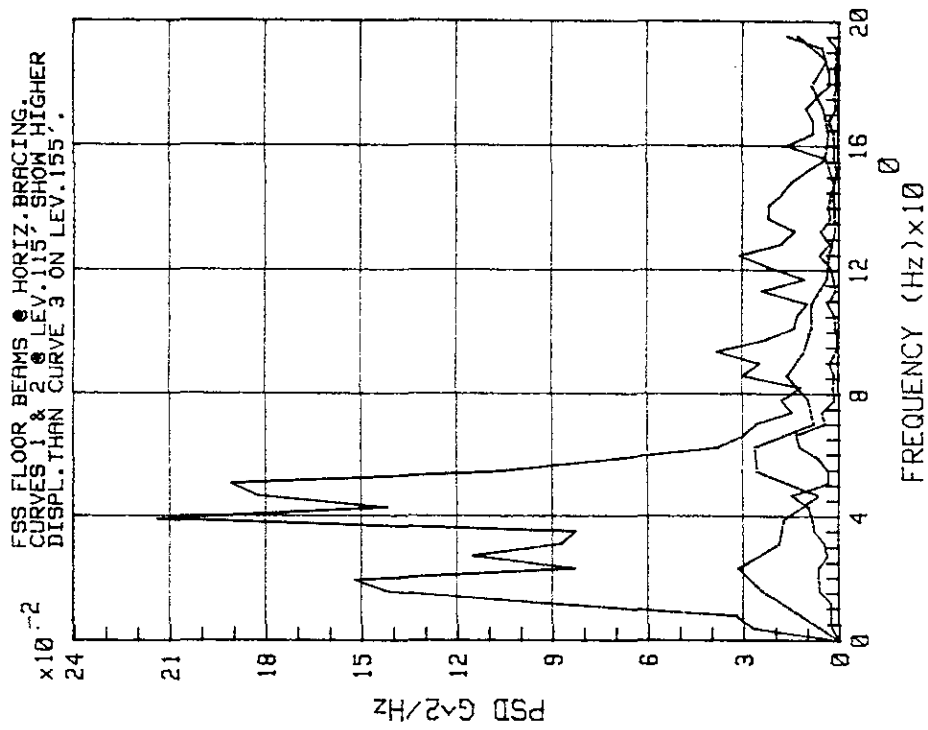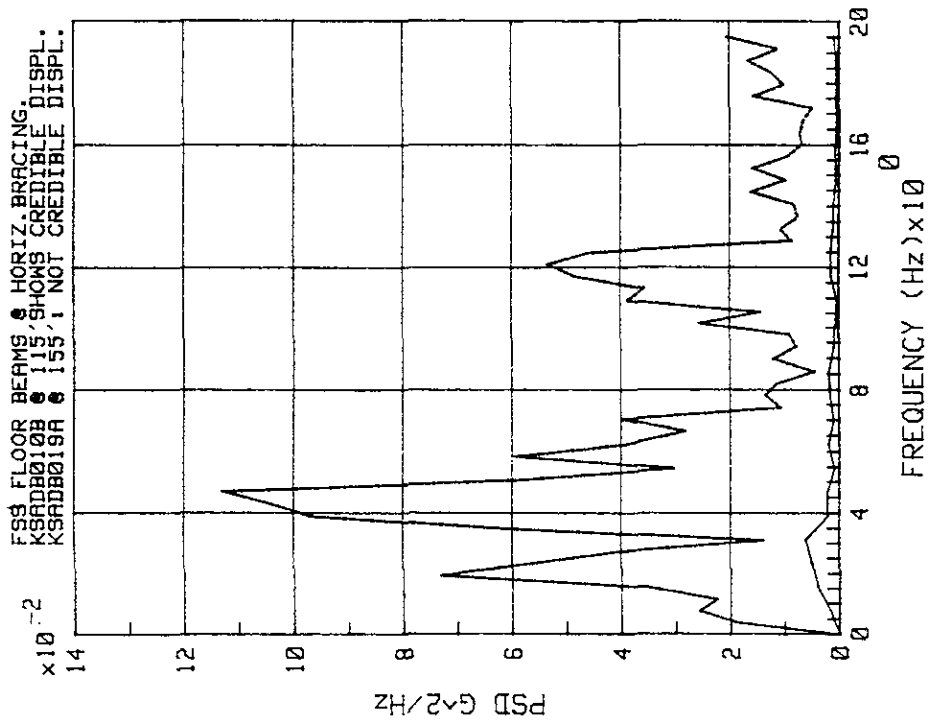
Figure 5-43. STS-3 FSS Vibration at 115- and 155-ft Levels, X and Y Directions

KSC-DD-818-TR
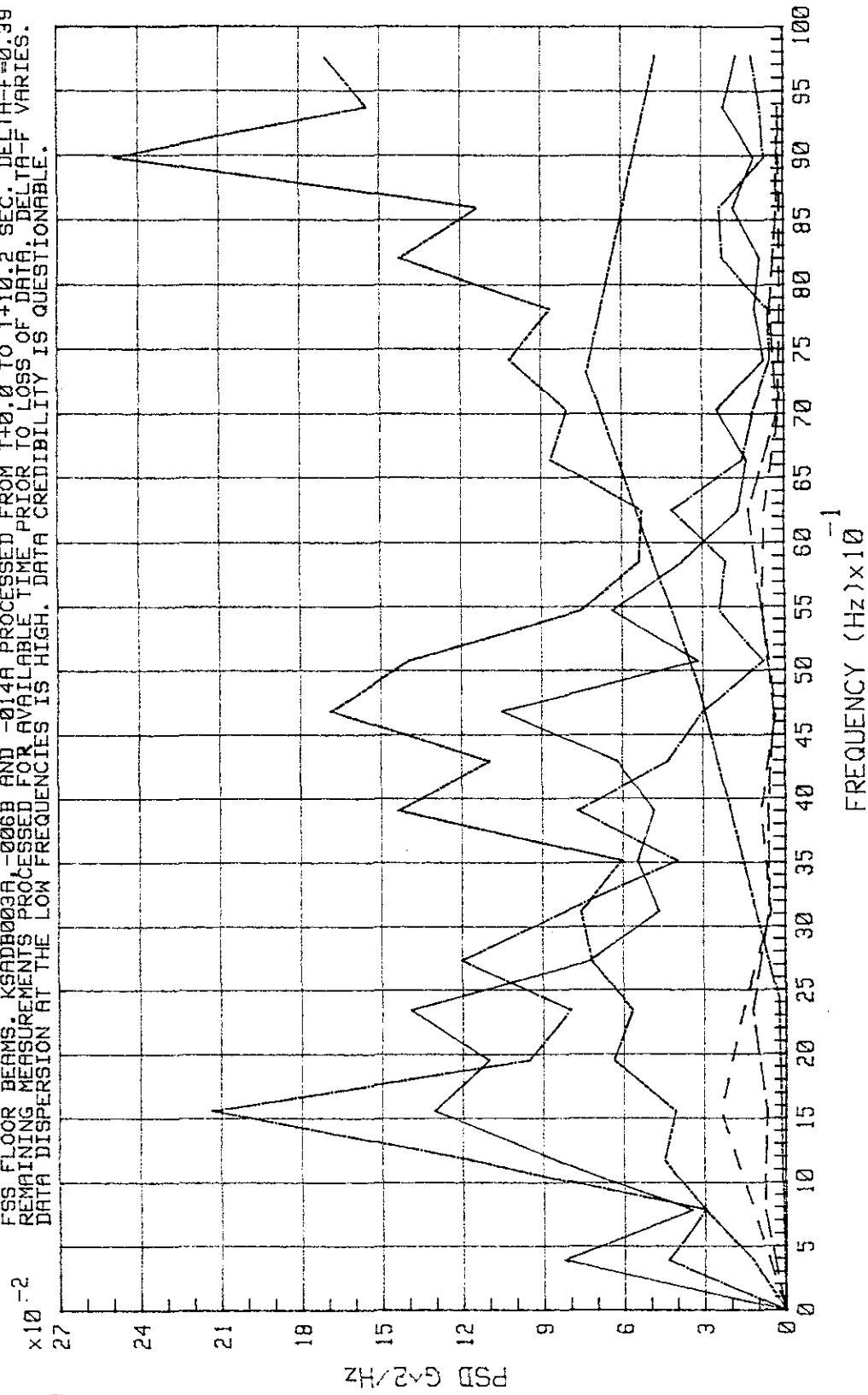
Figure 5-44. STS-3 Lift-Off Peak - FSS Vibration at 115-ft Level, Z Direction

5-74
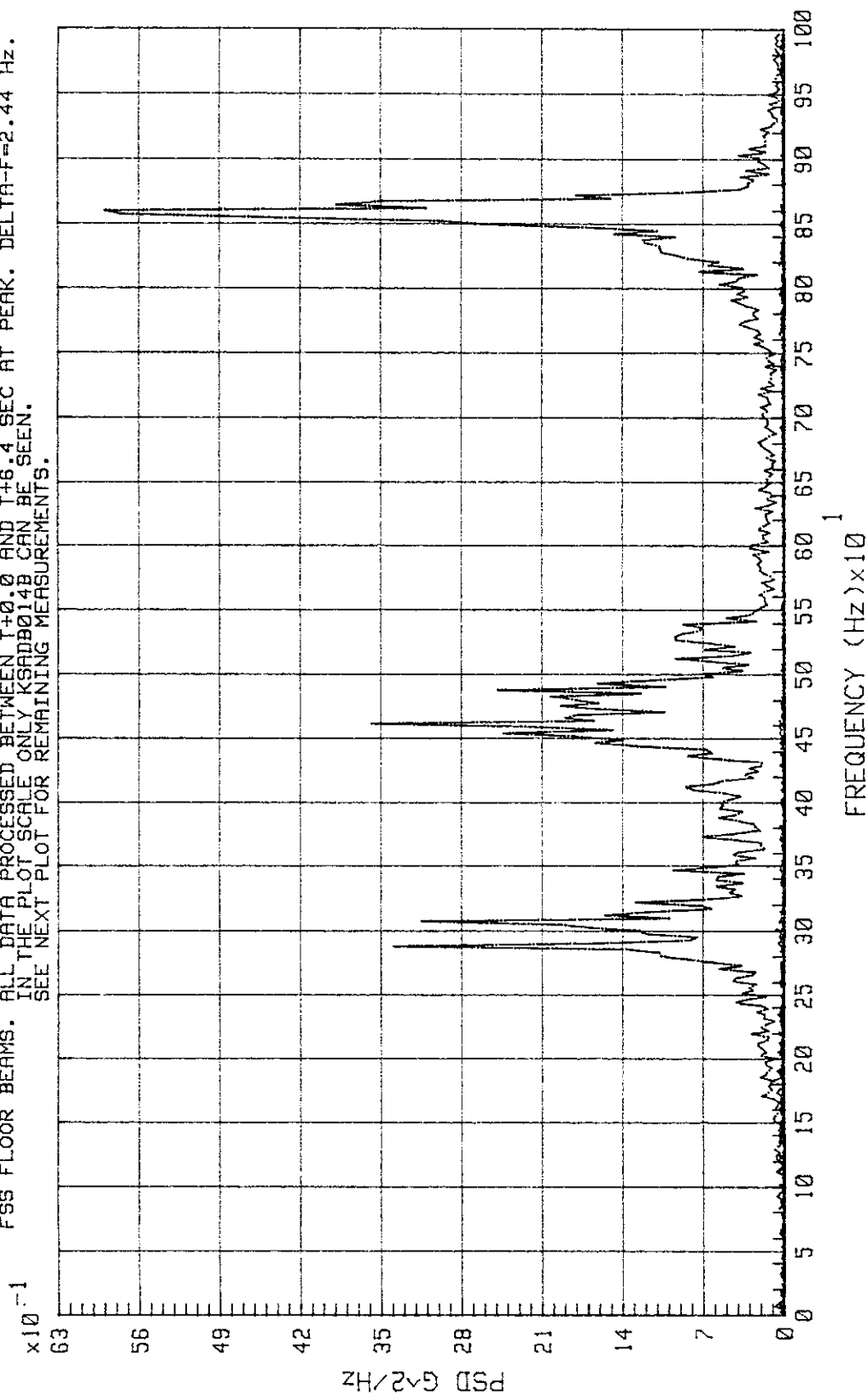
Figure 5-45. STS-3 Lift-Off Peak -- FSS Vibration at 115-ft Level,
Z Direction (Only KSADB014B Is Visible)
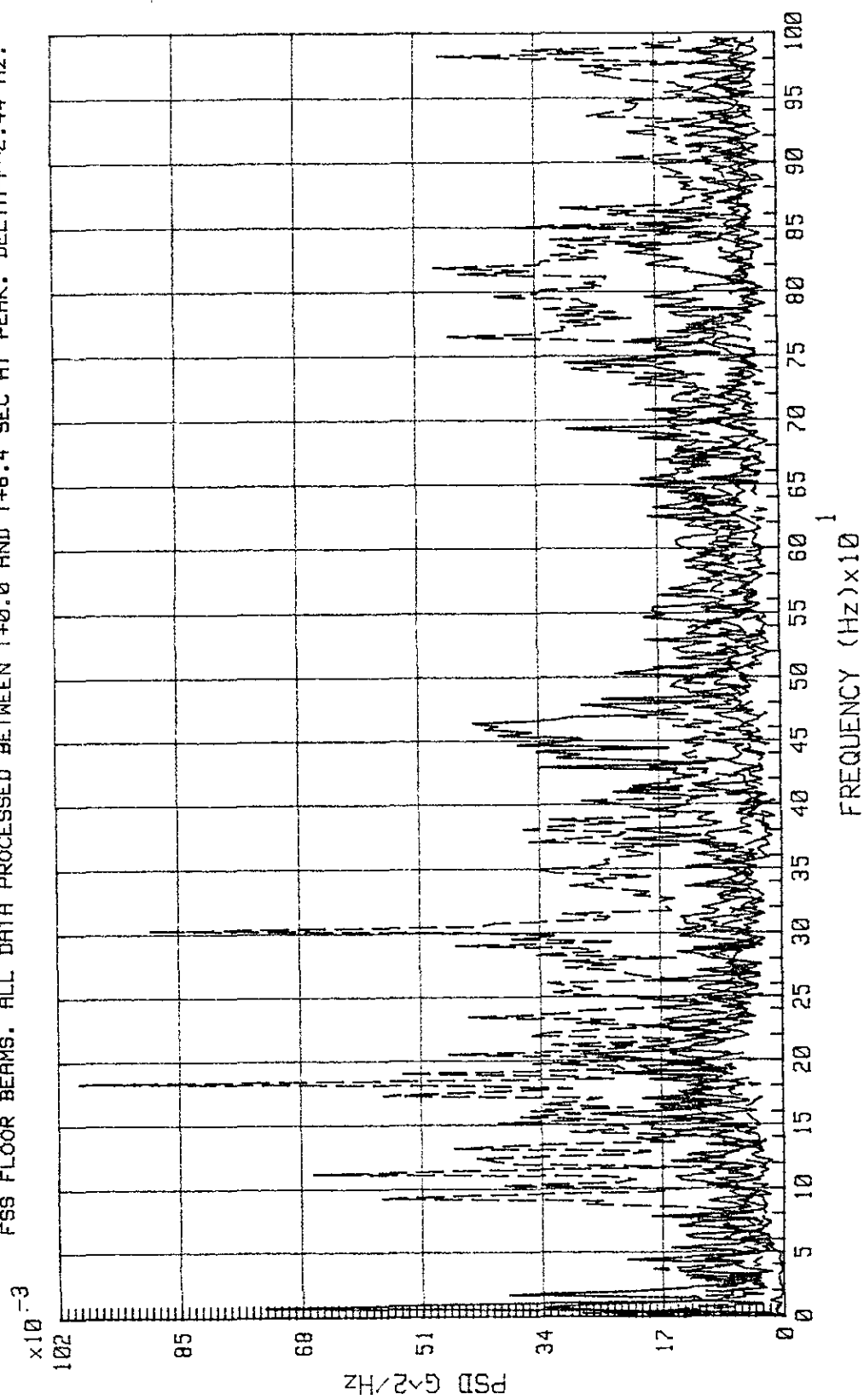
Figure 5-46. STS-3 Lift-Off Peak - FSS Vibration at 115-ft Level, Z Direction
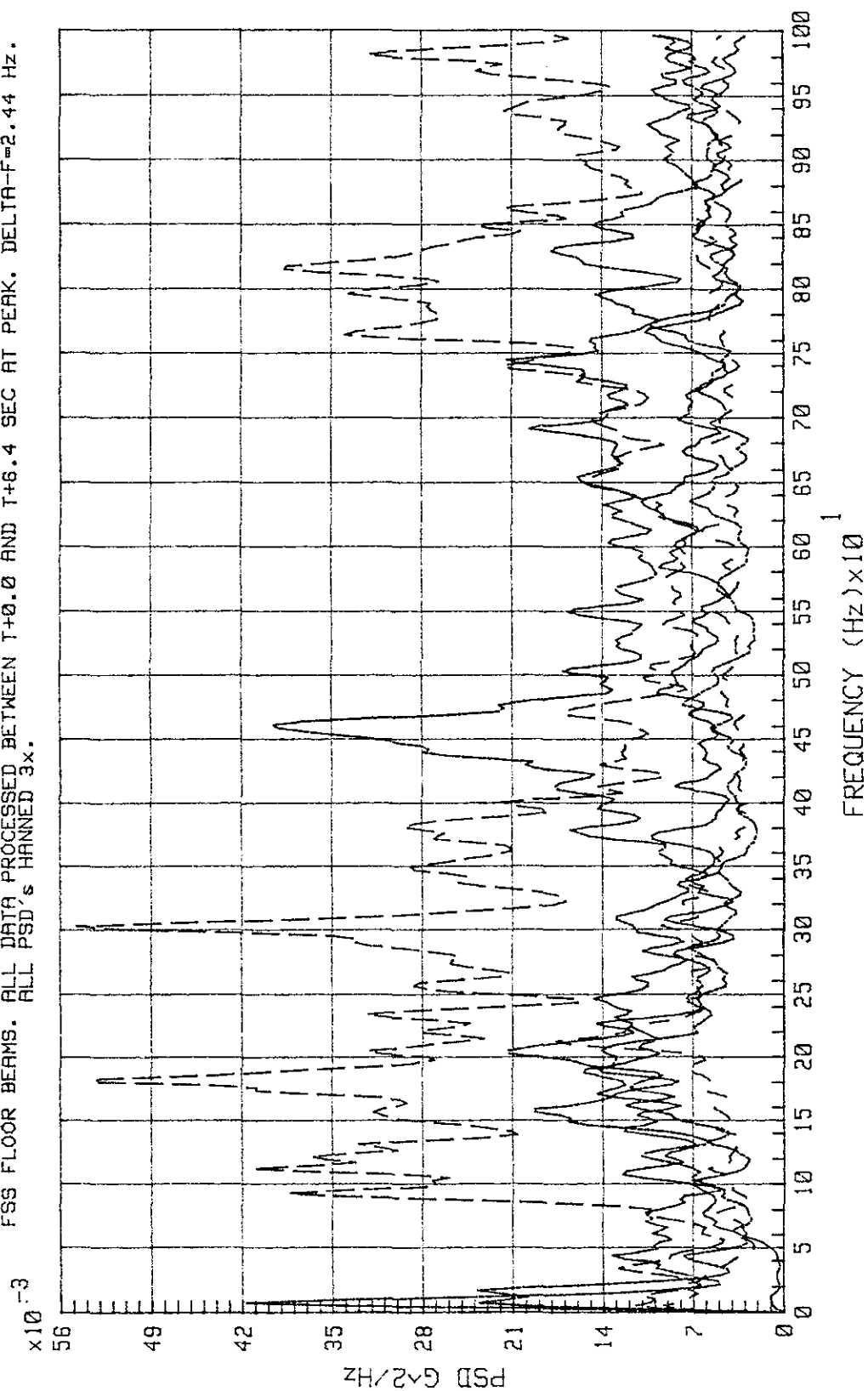
Figure 5-47. STS-3 Lift-Off Peak - FSS Vibration at 115-ft Level, Z Direction (All PSD'S Hanned)

Figure 5-48. STS-3 Lift-Off Peak - FSS Vibration at 155-ft Level, Z Direction (KSADB015A, -16A, -17A, -21B, and -22B)
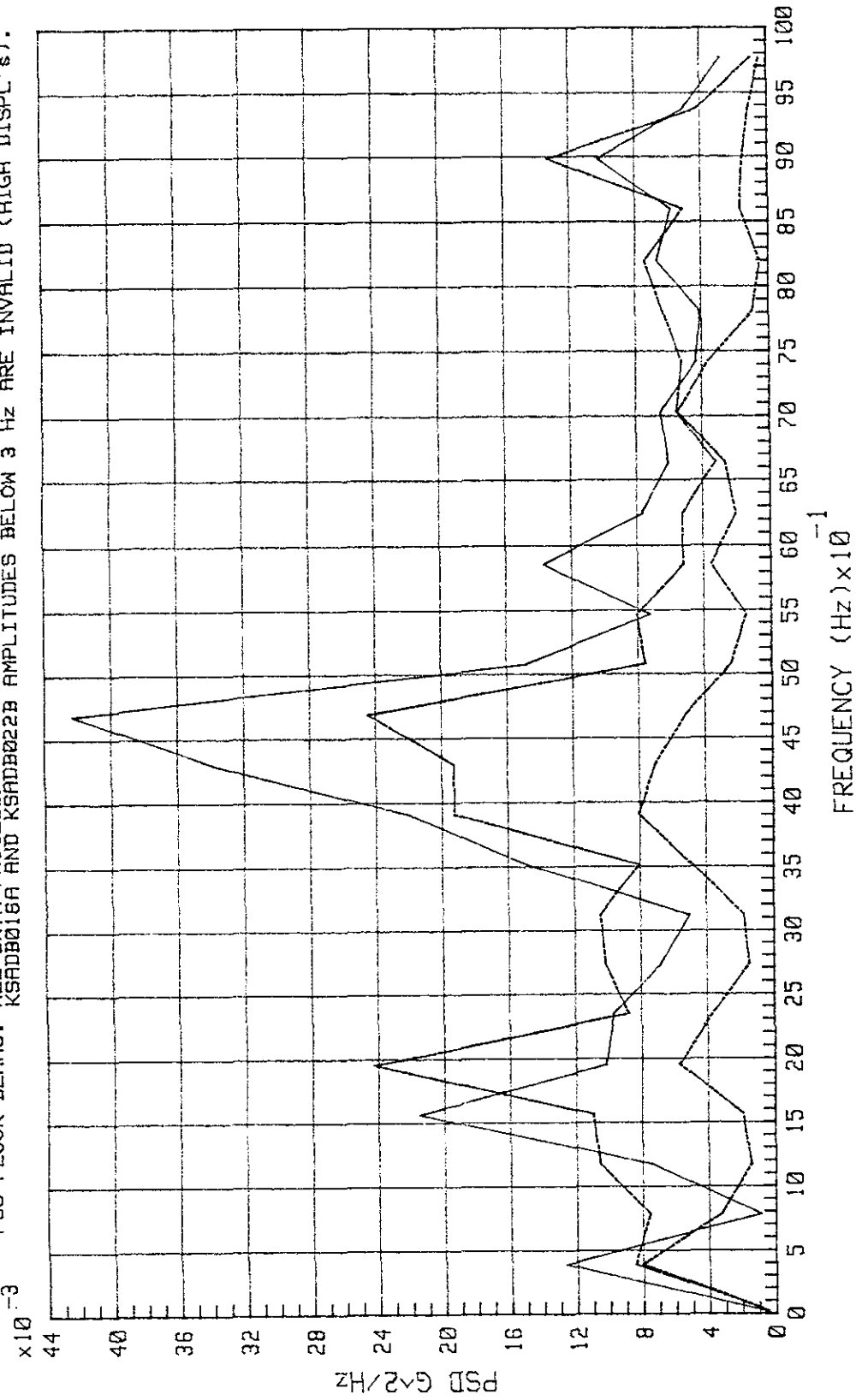
Figure 5-49. STS-3 Lift-Off Peak -
FSS Vibration at 155-ft Level, Z Direction (KSADB016A, -21B, and -22B)

KSC-DD-818-TR
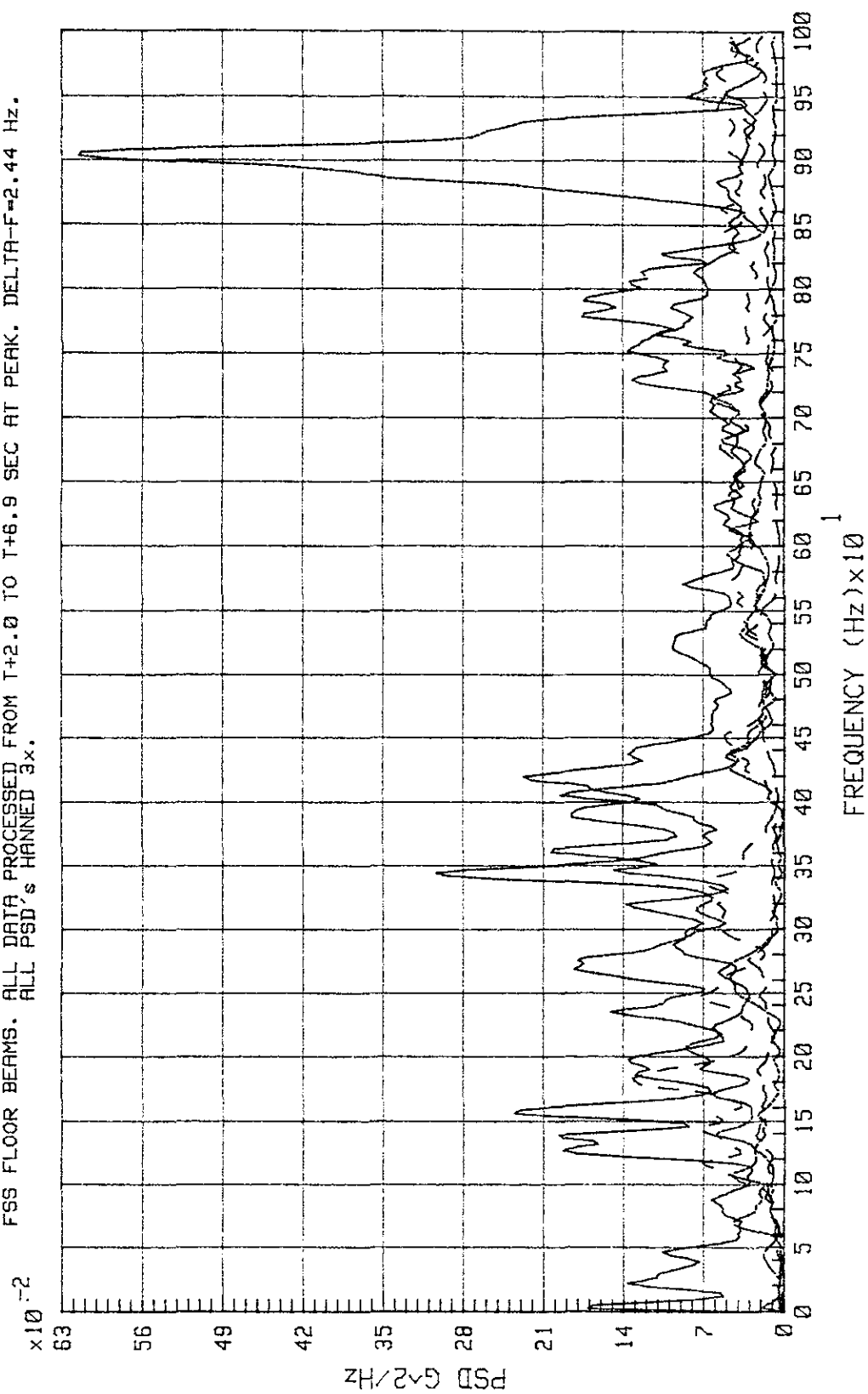
Figure 5-50. STS-3 Lift-Off Peak – FSS Vibration at 155-ft Level, Z Direction (All PSD's Hanned)

5-80
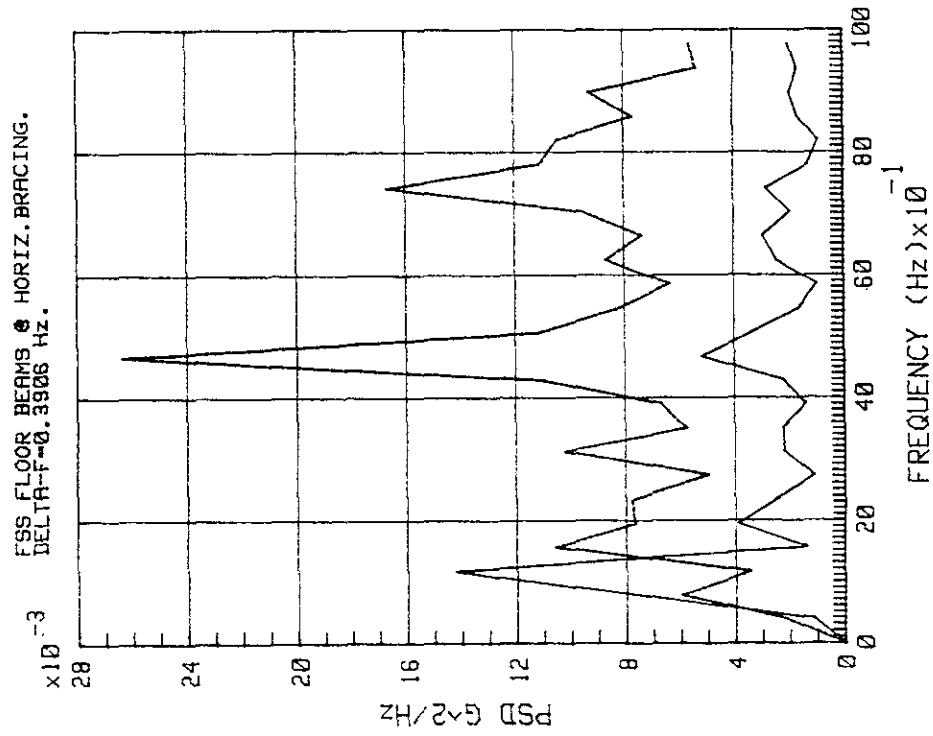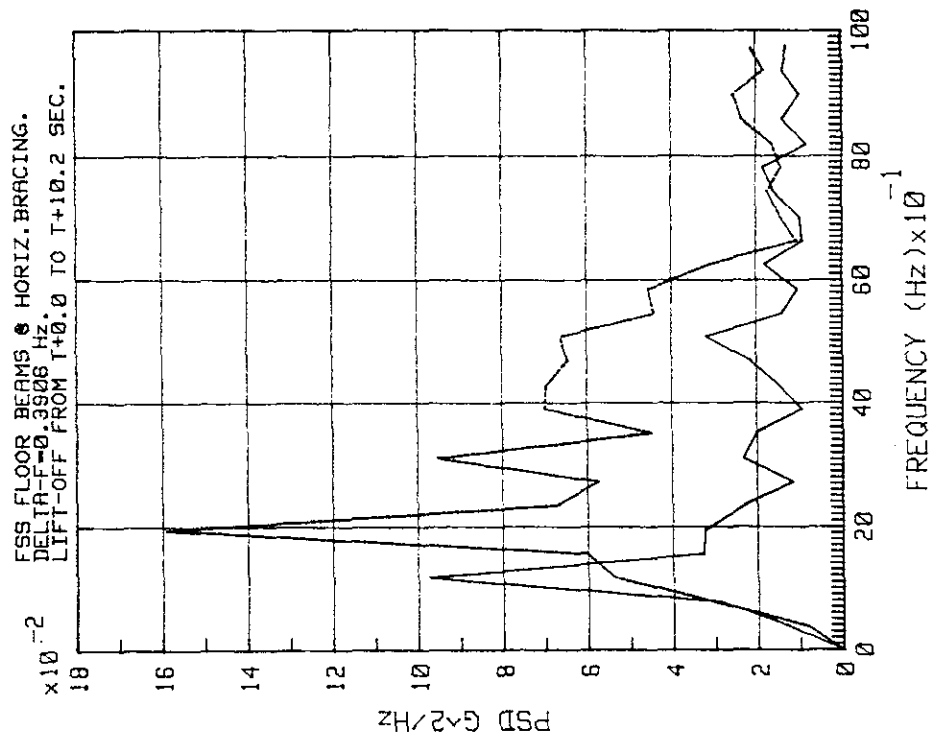
Figure 5-51. STS-3 FSS Vibration at 195-ft Level, X and Y Directions

KSC-DD-818-TR
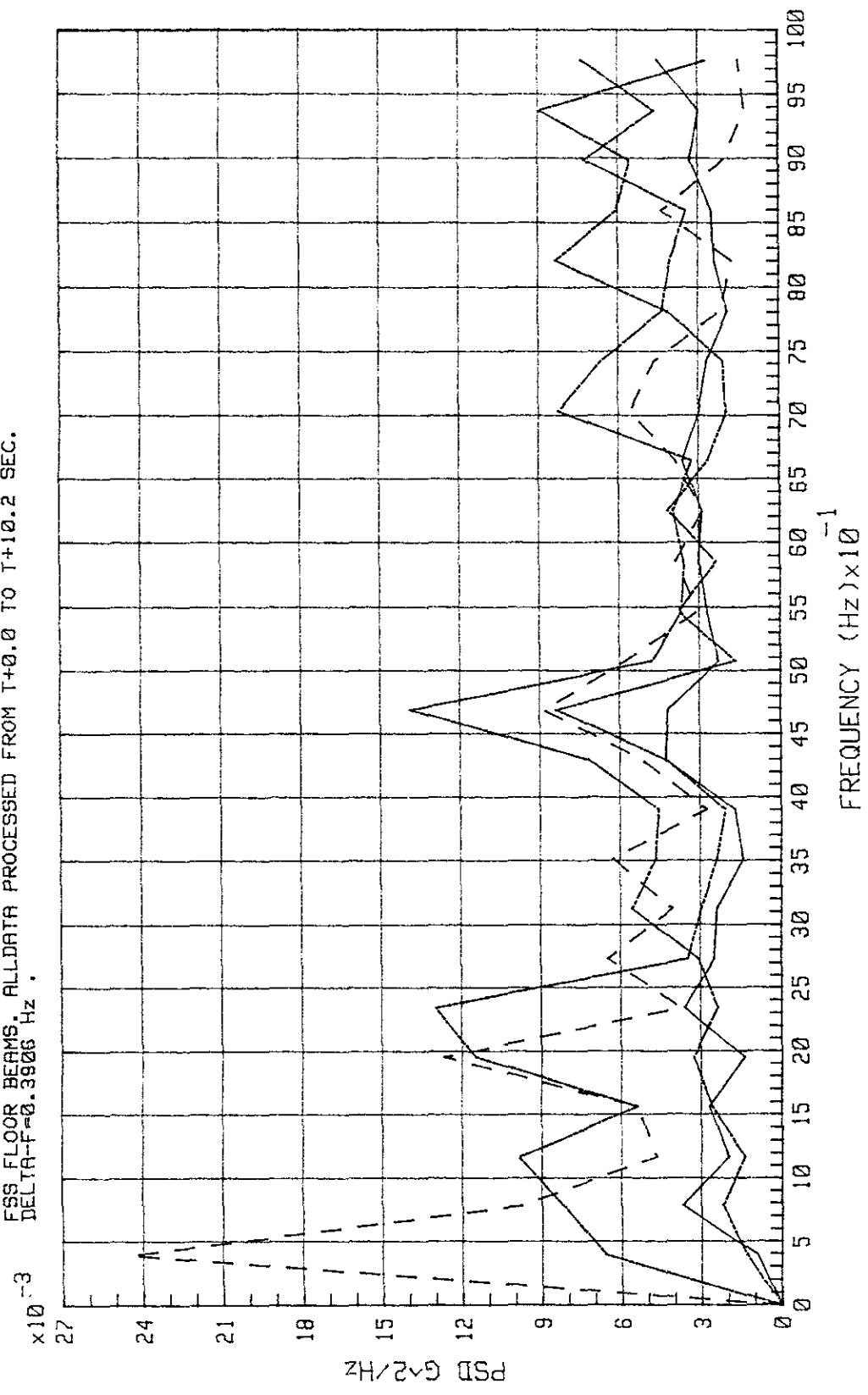
Figure 5-52. STS-3 Lift-Off Peak - FSS Vibration at 195-ft Level, Z Direction (KSADB023A, -29A, -24B, and -35B; Delta F = 0.3906 Hz)
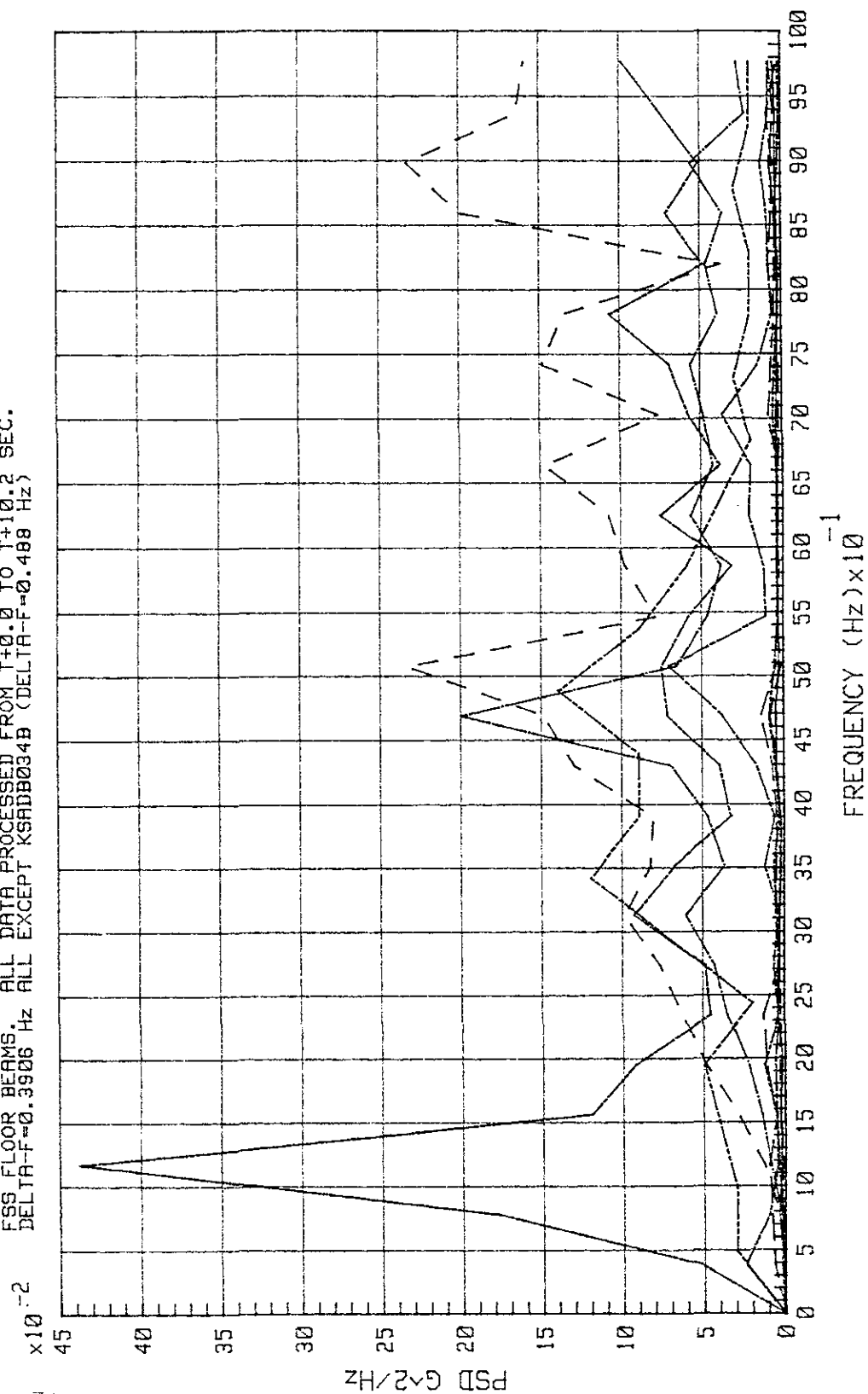
Figure 5-53. STS-3 Lift-Off Peak – FSS Vibration at 195-ft Level, Z Direction
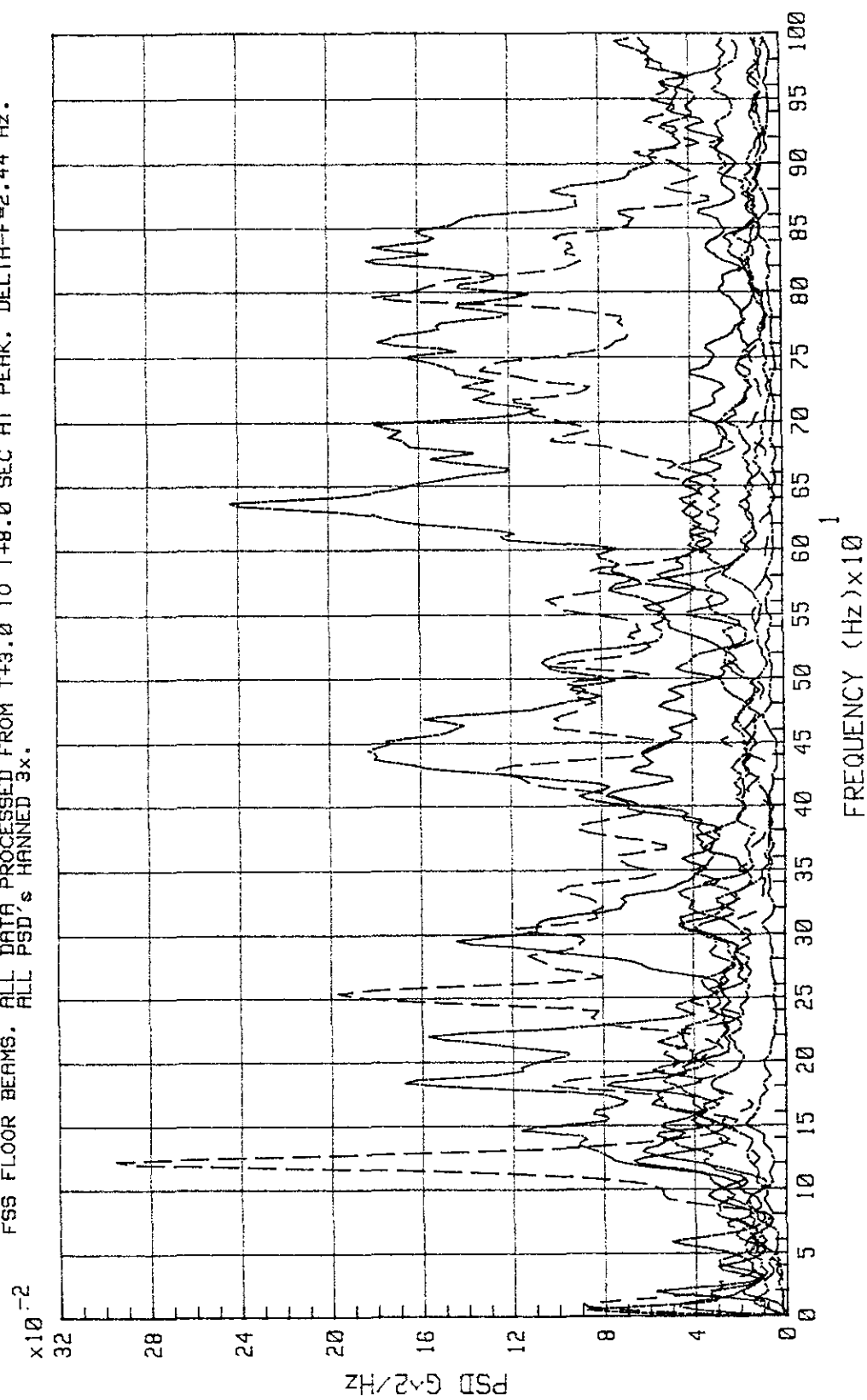
Figure 5-54. STS-3 Lift-Off Peak – FSS Vibration at 195-ft Level, Z Direction (All PSD's Hanned)

Figure 5-55. STS-3 FSS Vibration at 215-ft Level, Z Direction

KSC-DD-818-TR
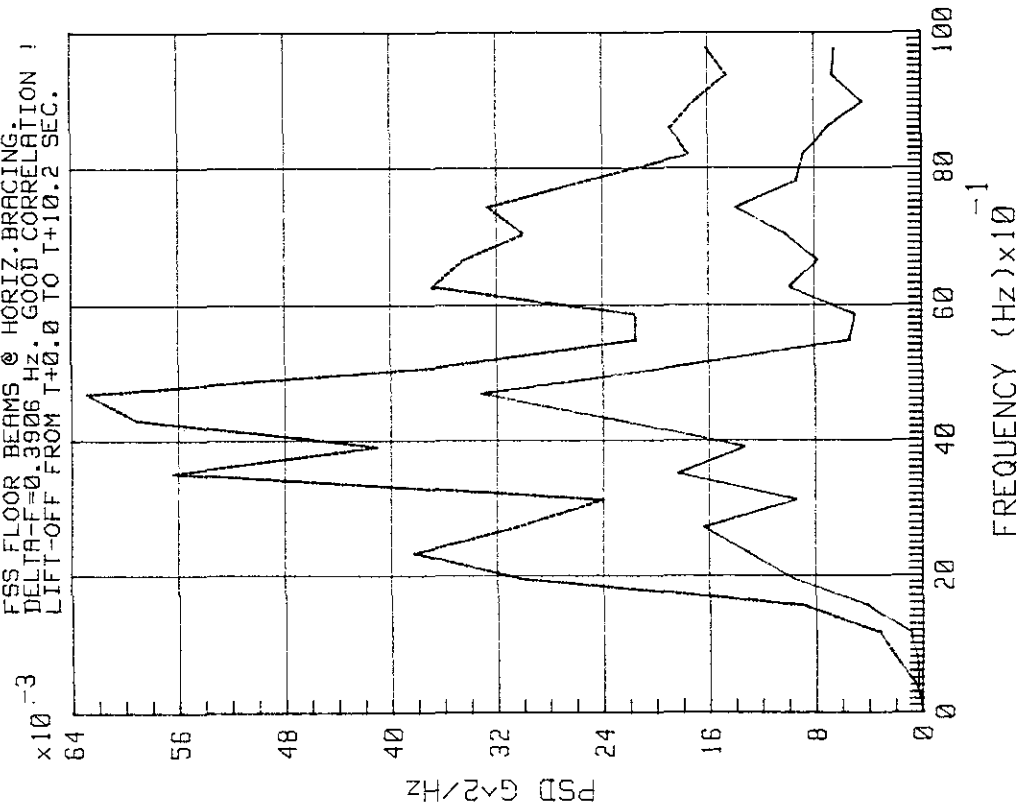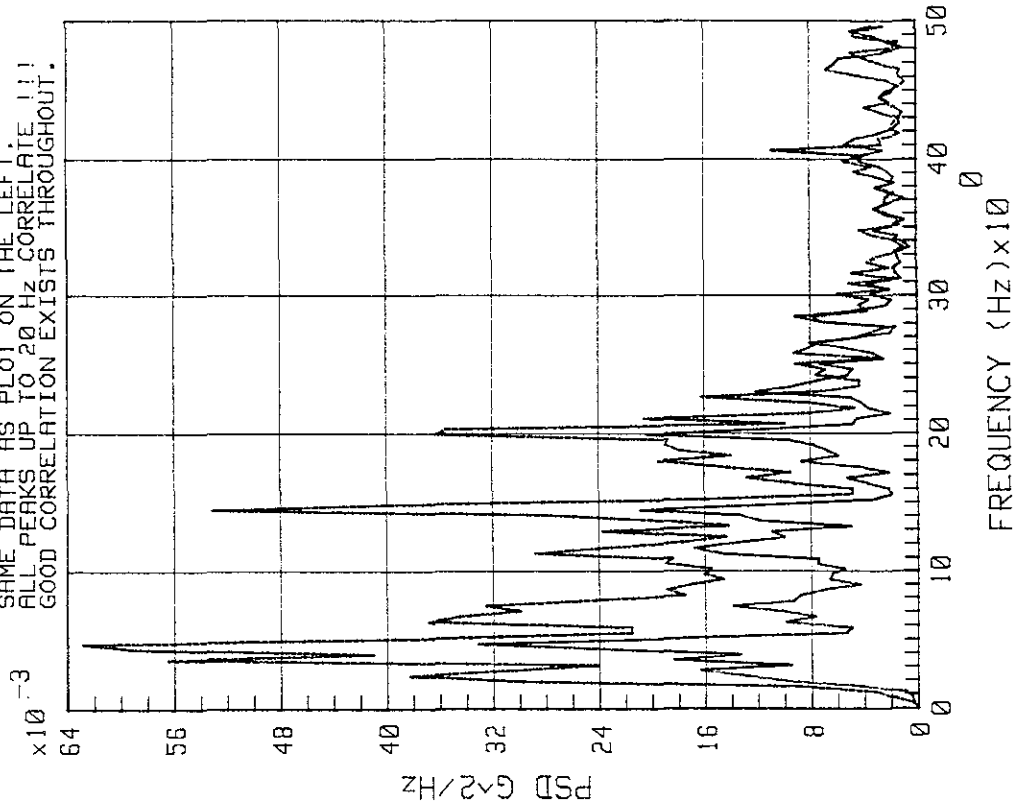
Figure 5-56. STS-3 FSS Vibration at 255-ft Level, X Direction
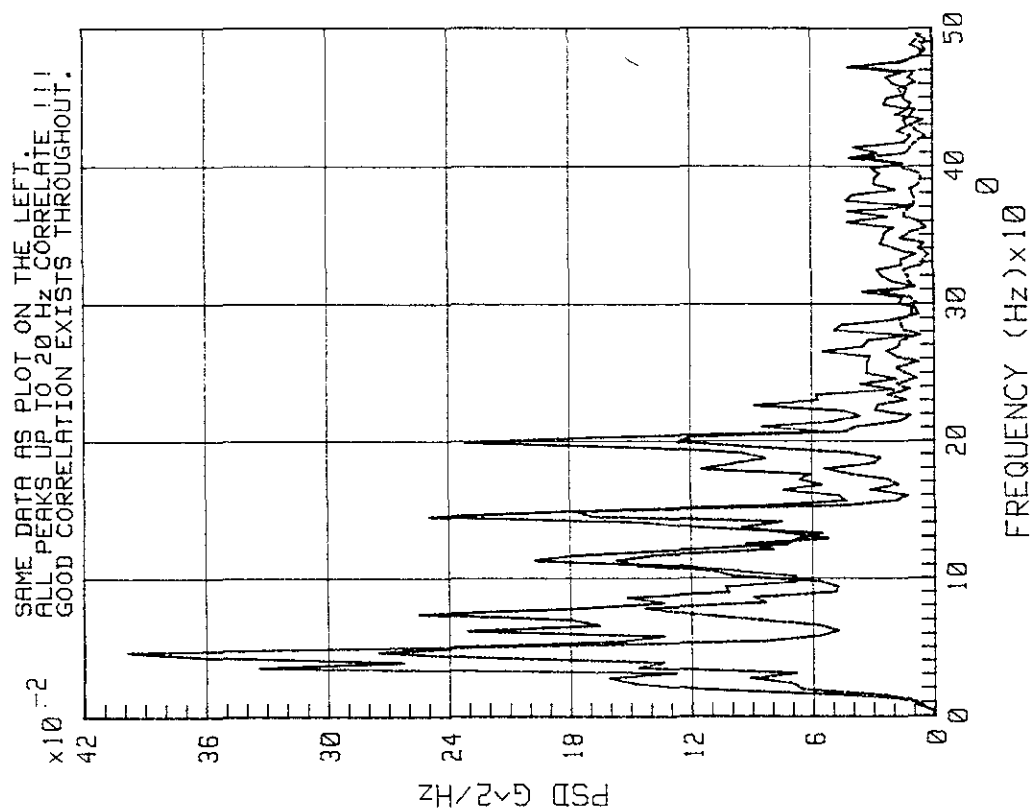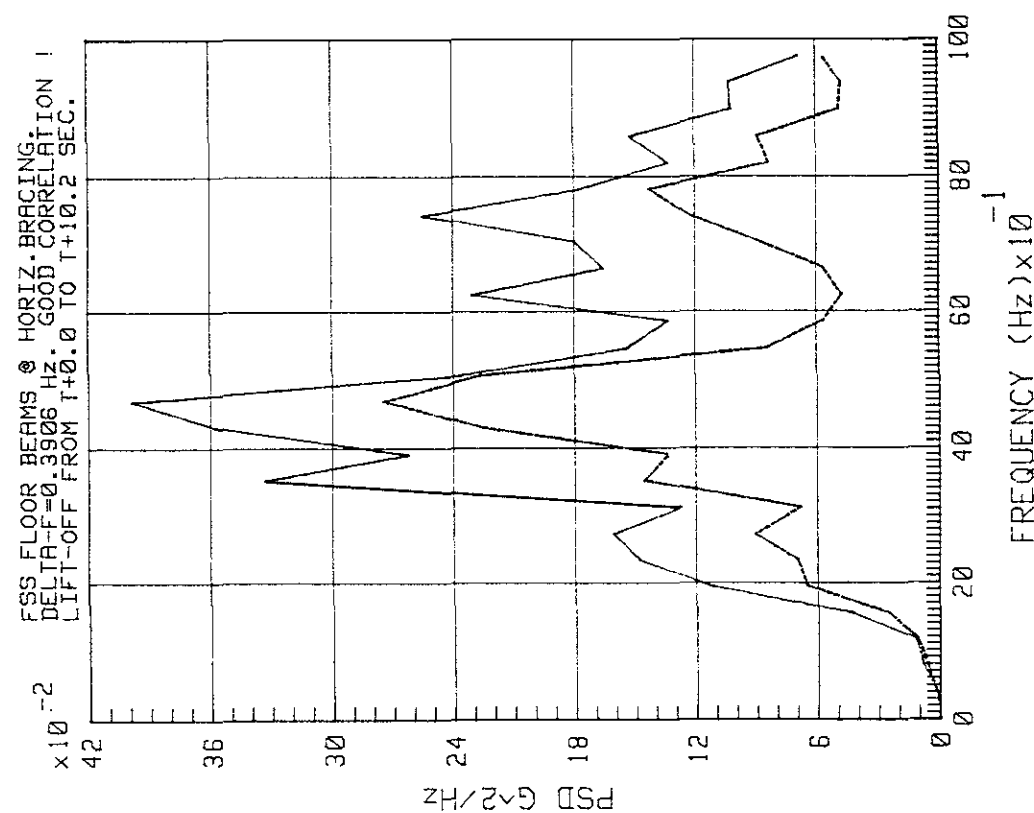
Figure 5-57. STS-3 FSS Vibration at 255-ft Level, Y Direction
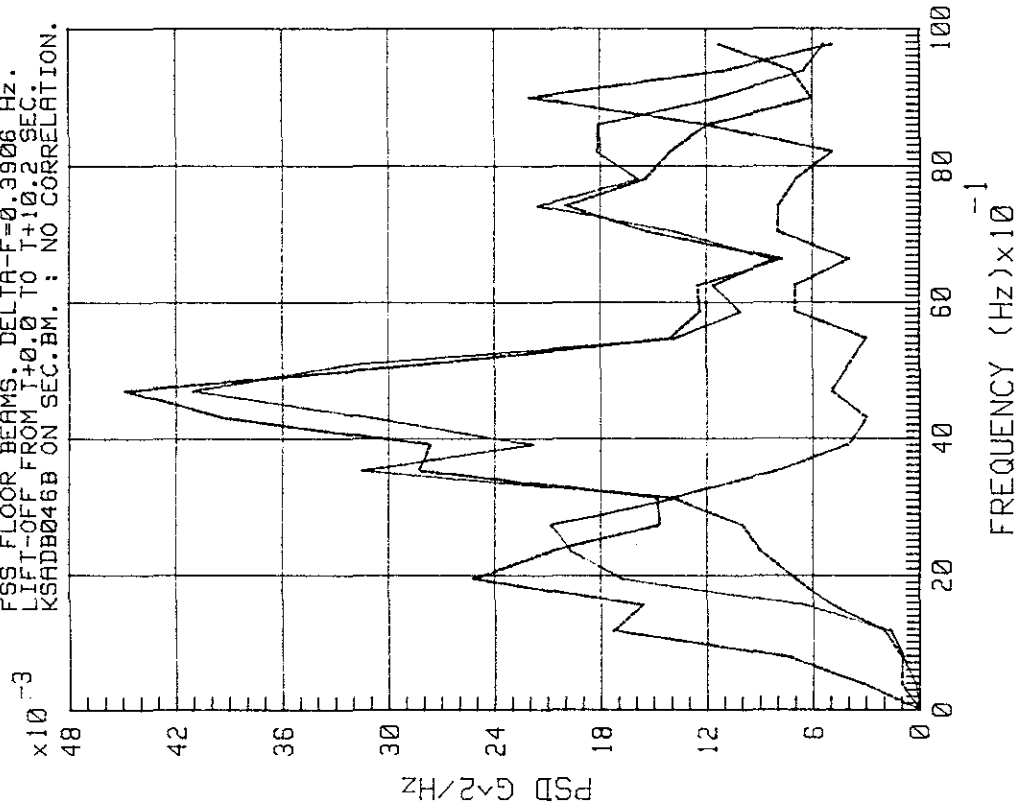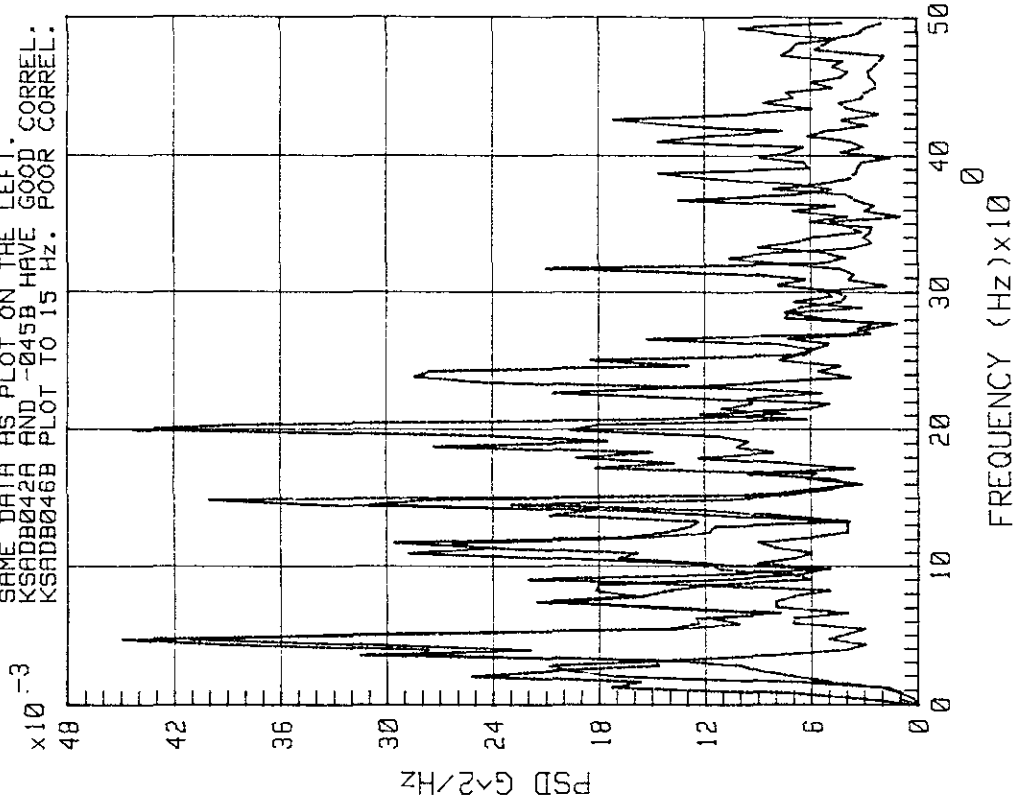
Figure 5-58. STS-3 FSS Vibration at 255-ft Level, Z Direction

Figure 5-59. STS-3 Lift-Off Peak - FSS Vibration at 255-ft Level, Z Direction (All PSD's Hanned)

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Figure 5-60. STS-3 Lift-Off Peak –
FSS Vibration on Side 1 at 115-, 195-, and 255-ft Levels, Z Direction

5-90

KSA # DB047B

$\times 10^{-2}$

FSS SIDE 1 MAIN BEAM @ MIDSPAN,@ JOINT WITH DIAGONAL MEMBER. DELTA-F=2.44 Hz.
PSD HANNED 3x. DATA PROCESSED FROM T+4.0 TO T+8.9 SEC AT PEAK. STS-3 DATAFREQ.
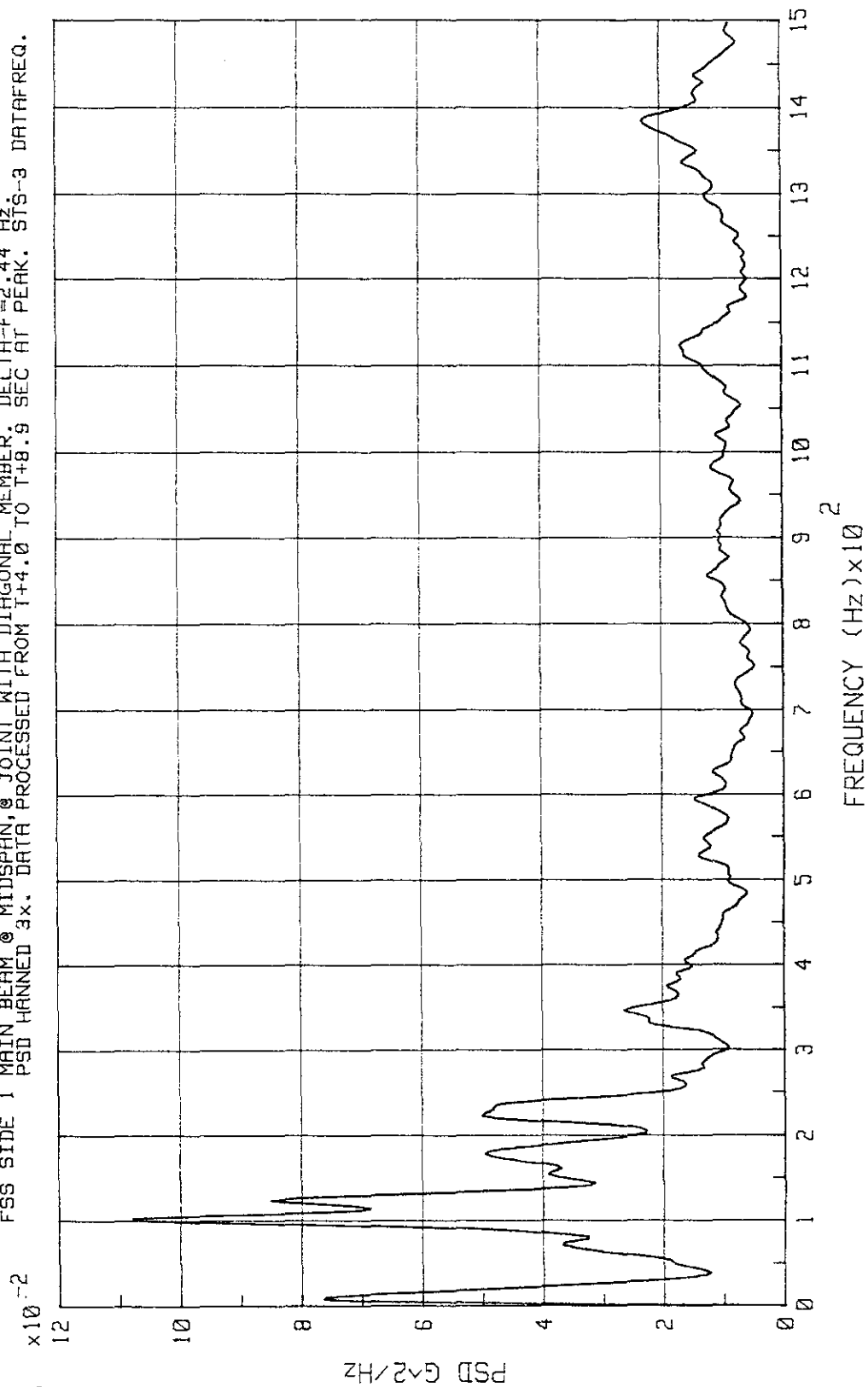
Figure 5-61.   STS-3 Lift-Off Peak - FSS Vibration on Side 1 at 255-ft Level, Z Direction

5.3 RSS

The RSS was instrumented with approximately 50 vibration sensors during the launches of STS-1, -2, and -3. Sensors were installed at various levels on floor beams, bottom flanges, and outside flanges. The resulting data were processed and published in documents listed in the bibliography herein. This summary contains sampling data from various levels, recorded during the lift-off peak of STS-3 (figures 5-62 through 5-68). Included are raw data, PD's, PSD's, and rms time histories for the following measurements:

Designation	Location	Level	Direction
KSRDC011A	Main Floor Beam	107-ft	Z
KSRDC015A	Floor Beam, Side 4	158-ft, 5-in	Z
KSRDC016A	Platform 2-In Floor Beam, Side 3	131-ft	Z
KSRDC019A	Outside Flange, Side 4	135-ft	Y
KSRDC025A	Platform Floor Beam	107-ft	X
KSRDC032A	Platform Floor Beam	107-ft	X
KSRDC041A	Platform Floor beam, Middle	120-ft	X

Multiple plot summary PSD's for various levels and directions, published as appendix B in KSC-DD-651-TR, are included (figures 5-69 through 5-93). Not included but recommended for additional information is appendix B of KSC-DD-677-TR, containing data validation criteria, zoom plots of significant PSD's, and calculated rms displacements.
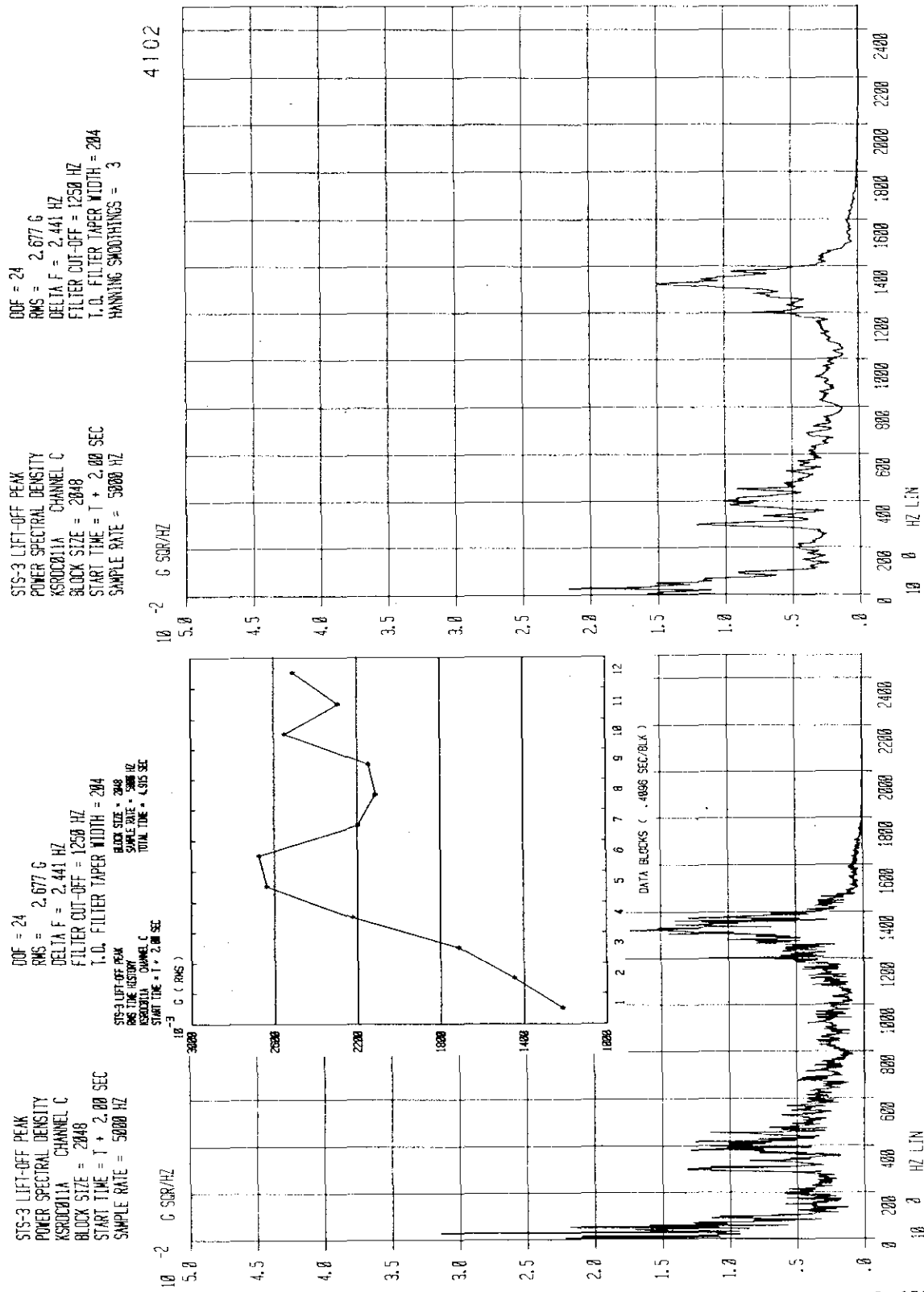
Figure 5-62. Main Floor Beam, 107-ft Level, Z-Direction (Sheet 1 of 2)

Figure 5-62. Main Floor Beam, 107-ft Level, Z-Direction (Sheet 2 of 2)

Figure 5-63. Floor Beam, Side 4, 158-ft 5-in- Level, Z-Direction (Sheet 1 of 2)

Figure 5-63.   Floor Beam, Side 4, 158-ft 5-in- Level, Z-Direction (Sheet 2 of 2)

Figure 5-64. Platform 2-in-Floor Beam, Side 3, 131-ft Level (Sheet 1 of 2)

Figure 5-64. Platform 2-in-Floor Beam, Side 3, 131-ft Level (Sheet 2 of 2)
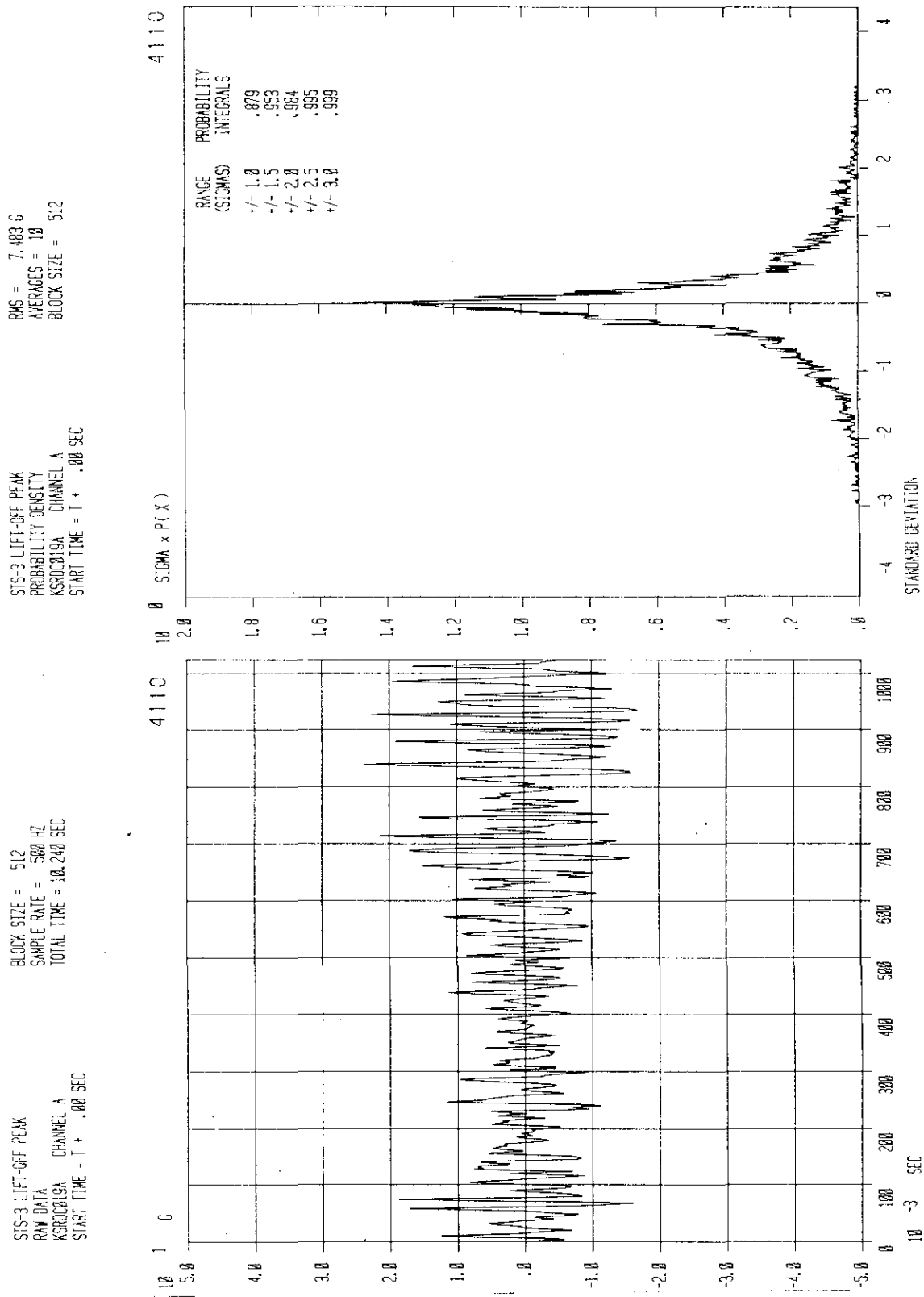
Figure 5-65. Outside Flange, Side 4, 135-ft Level (Sheet 1 of 2)

Figure 5-65. Outside Flange, Side 4, 135-ft Level (Sheet 2 of 2)

Figure 5-66. Platform Floor Beam (Point 1), 107-ft Level (Sheet 1 of 2)

Figure 5-66. Platform Floor Beam (Point 1), 107-ft Level (Sheet 2 of 2)

Figure 5-67. Platform Floor Beam (Point 2), 107-ft Level (Sheet 1 of 2)

Figure 5-67. Platform Floor Beam (Point 2), 107-ft Level (Sheet 2 of 2)

5-104
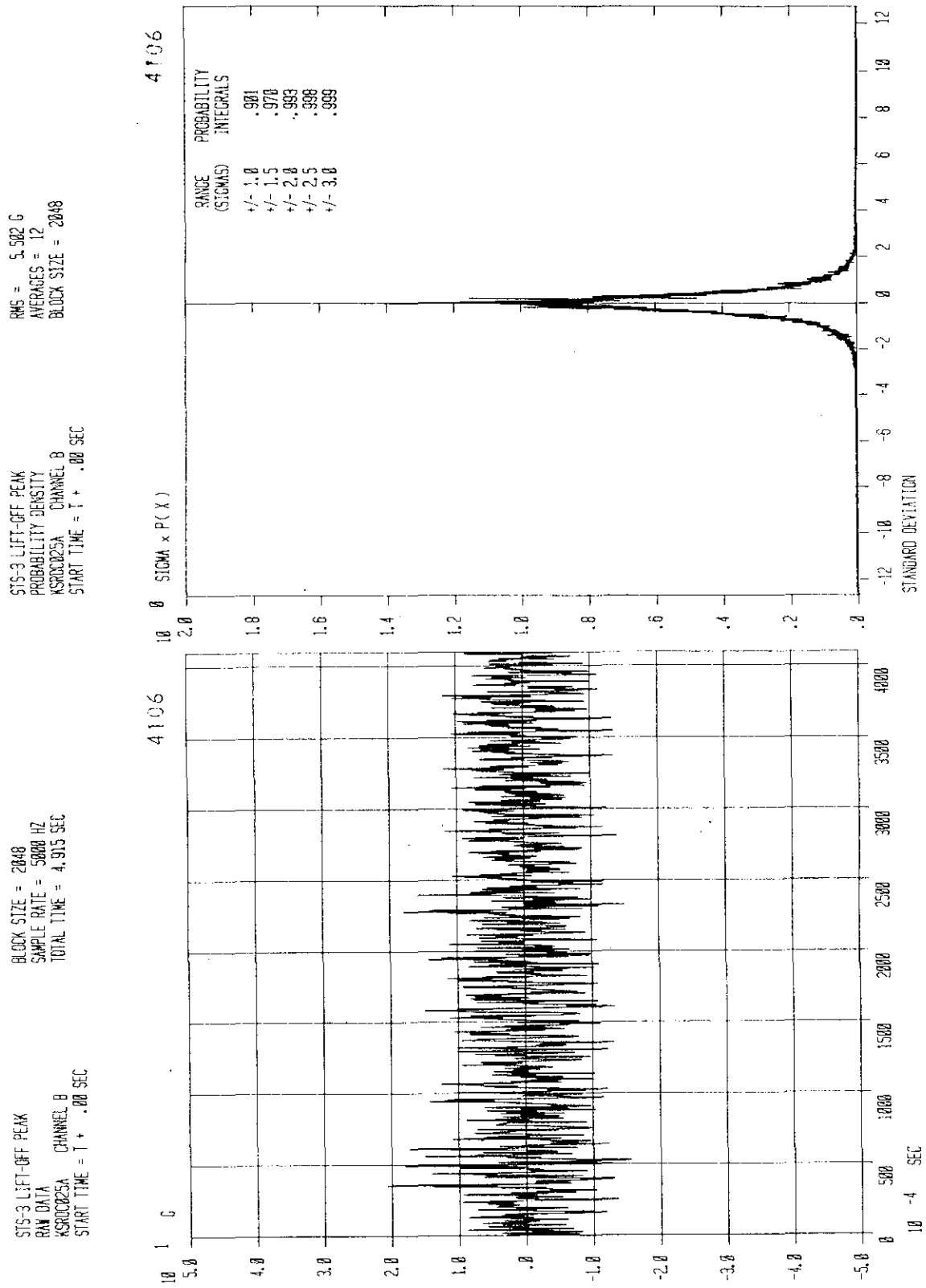
Figure 5-68. Platform Floor Beam (Middle), 107-ft Level (Sheet 1 of 2)

KSC-DD-818-TR
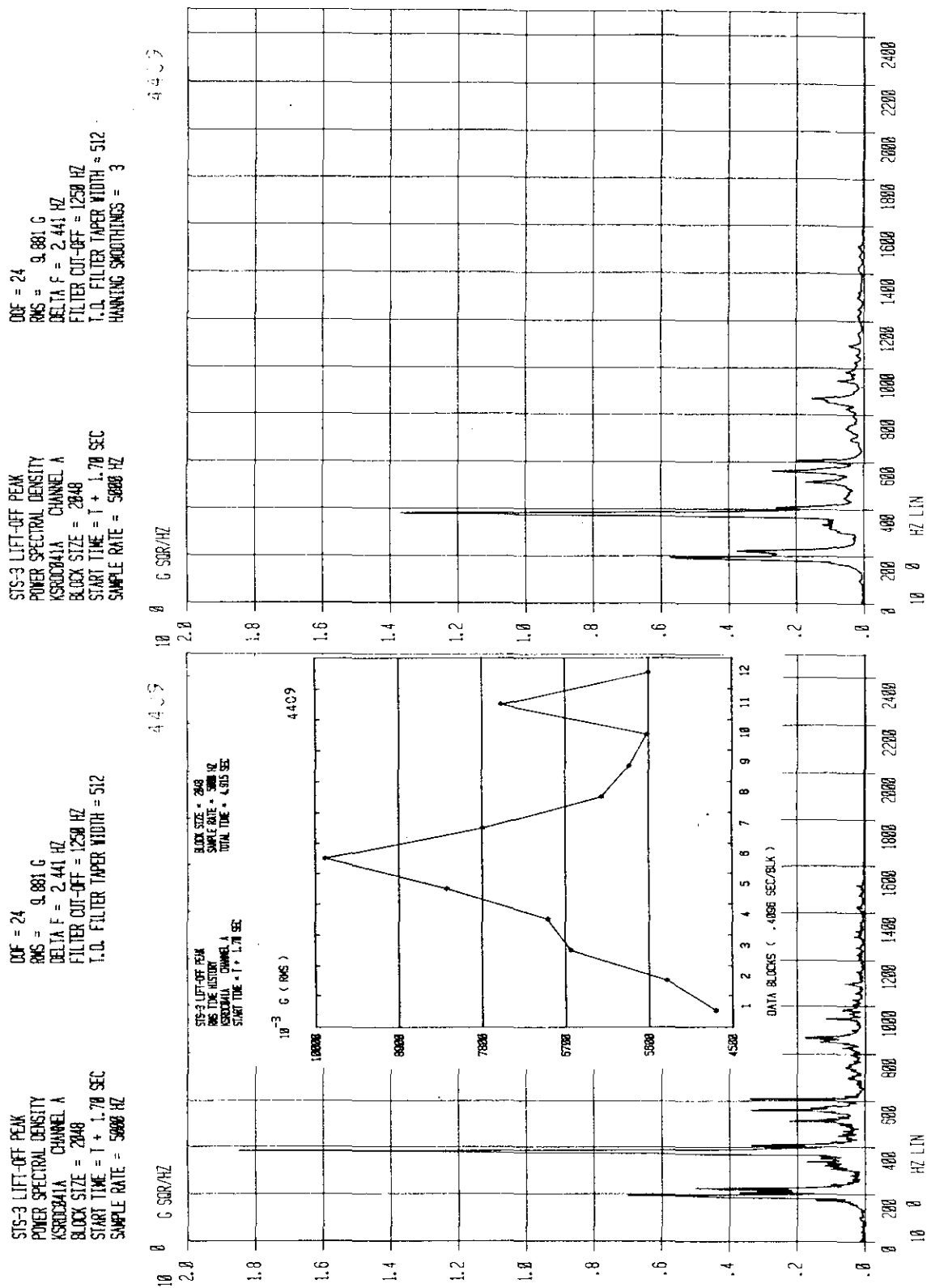
Figure 5-68. Platform Floor Beam (Middle), 107-ft Level (Sheet 2 of 2)
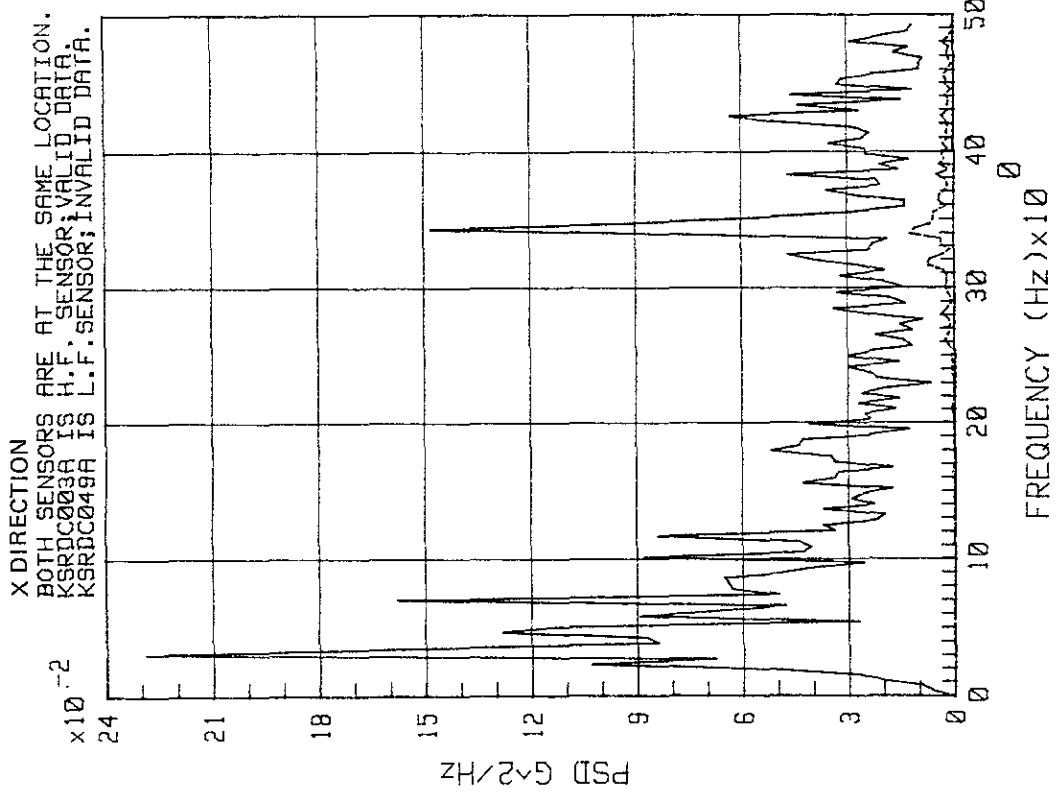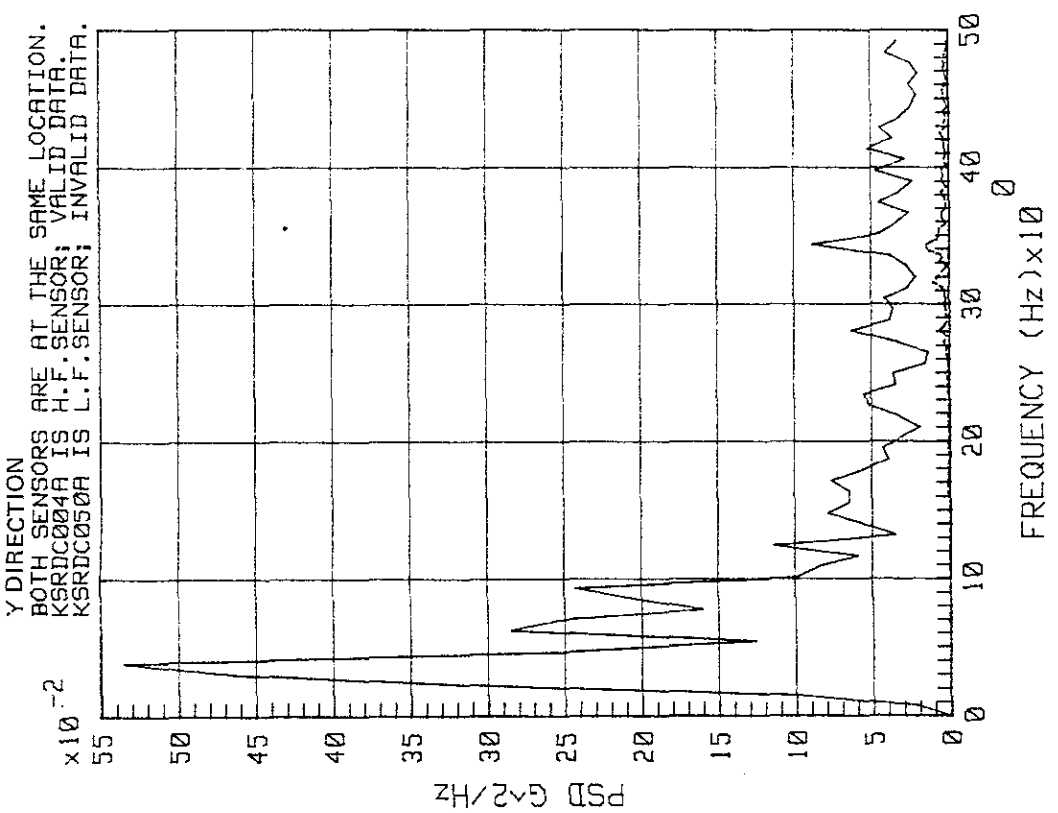
Figure 5-69. STS-3 RSS Vibration Data Comparison, Bottom Flange, 130-ft 7-in Level

KSC-DD-818-TR
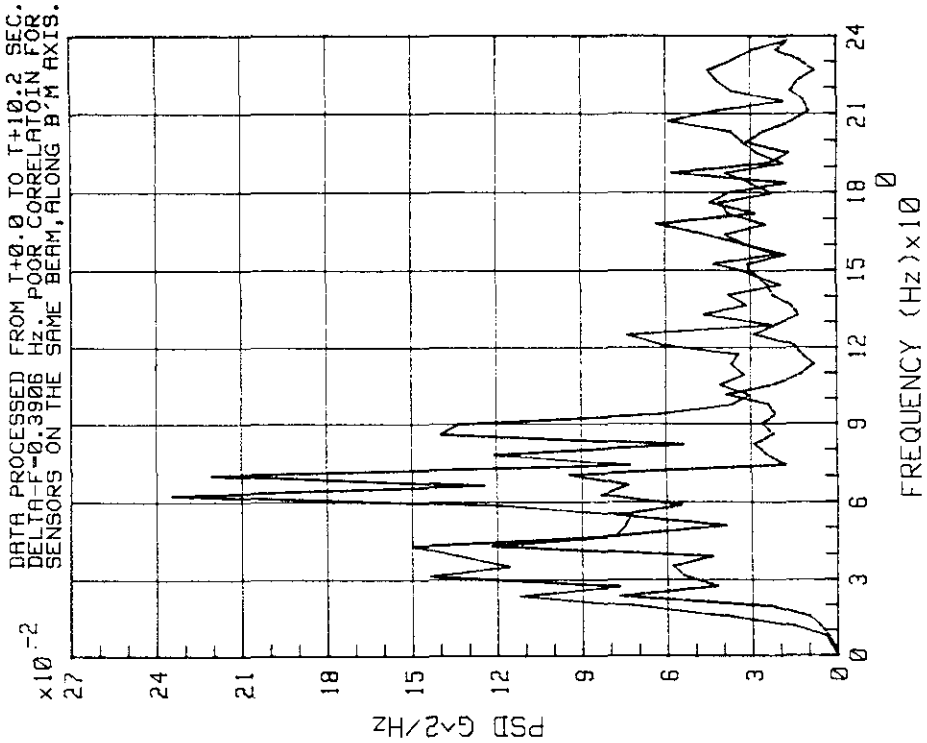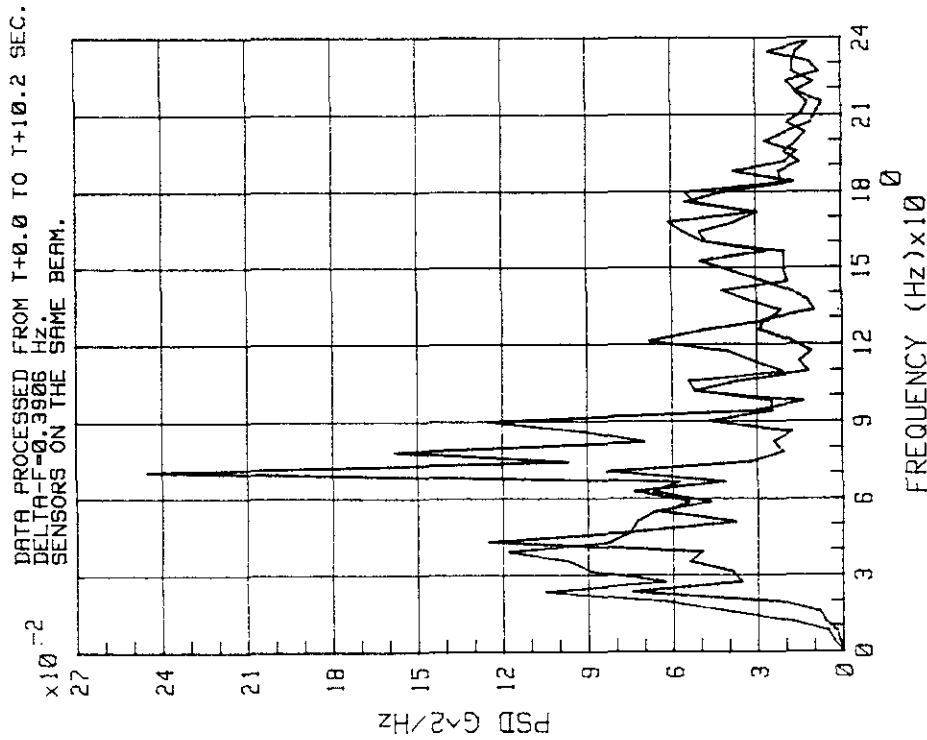
Figure 5-70. STS-3 RSS Vibration on Hypergol Platform, X and Y Directions

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Figure 5-71. STS-3 RSS Vibration on Hypergol Platform, Z Direction (Sheet 1 of 2)

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Figure 5-71. STS-3 RSS Vibration on Hypergol Platform, Z Direction (Sheet 2 of 2)

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Figure 5-72. STS-3 RSS Vibration on APU Platform, Z Direction (Sheet 1 of 2)

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Figure 5-72. STS-3 RSS Vibration on APU Platform, Z Direction (Sheet 2 of 2)

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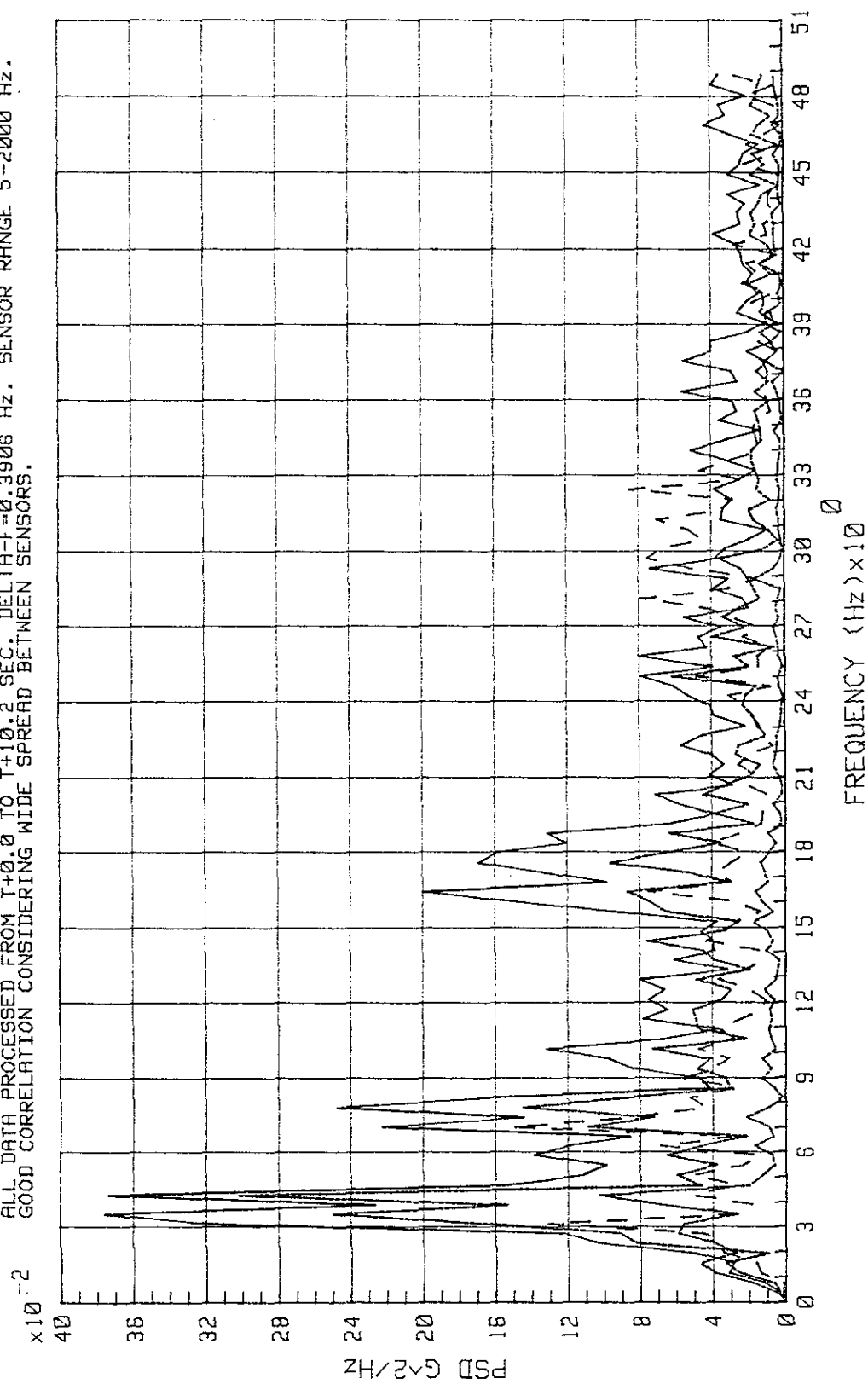
Figure 5-73. STS-3 RSS Vibration on PCR Floor, Z Direction
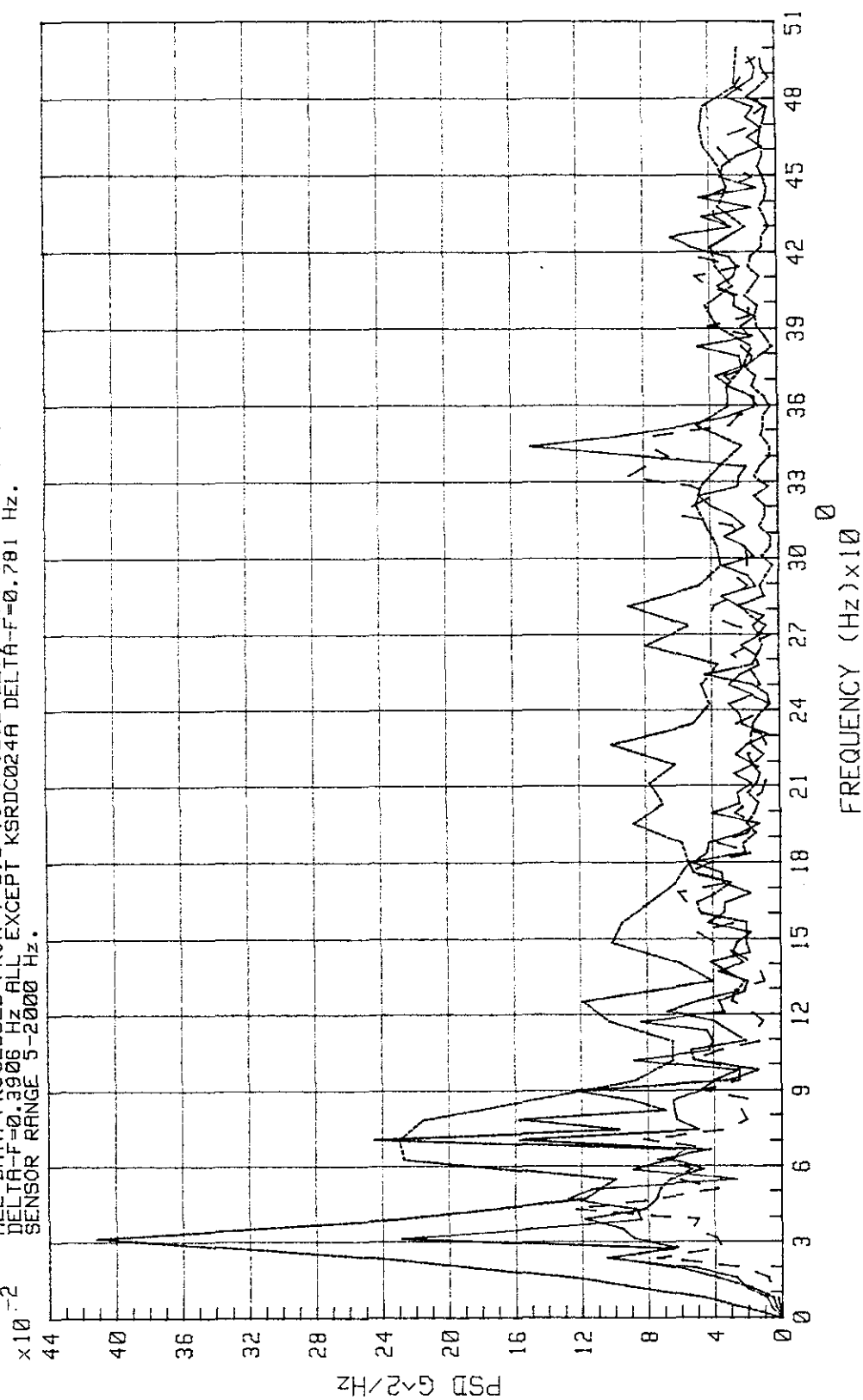
Figure 5-74. STS-3 RSS Vibration, High-Frequency Sensors on Floors, X Direction

Figure 5-75. STS-3 RSS Vibration, High-Frequency Sensors on Floors, Y Direction (Sheet 1 of 2)

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Figure 5-75. STS-3 RSS Vibration, High-Frequency Sensors on Floors, Y Direction (Sheet 2 of 2).

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Figure 5-76. STS-3 RSS Vibration, Side 4 Girts, X Direction

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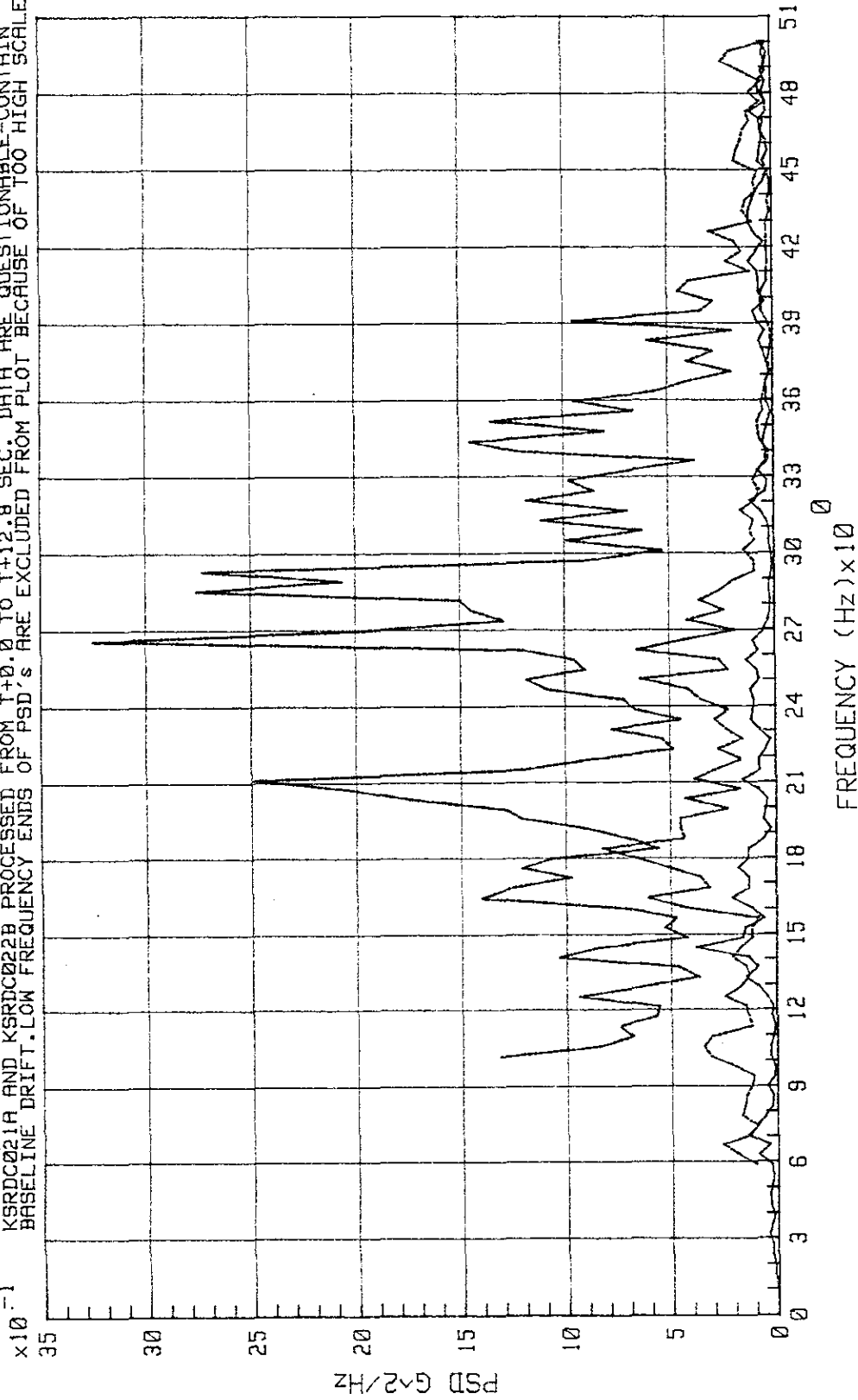
Figure 5-77. STS-3 RSS Vibration, Side 3 Girts, Y Direction
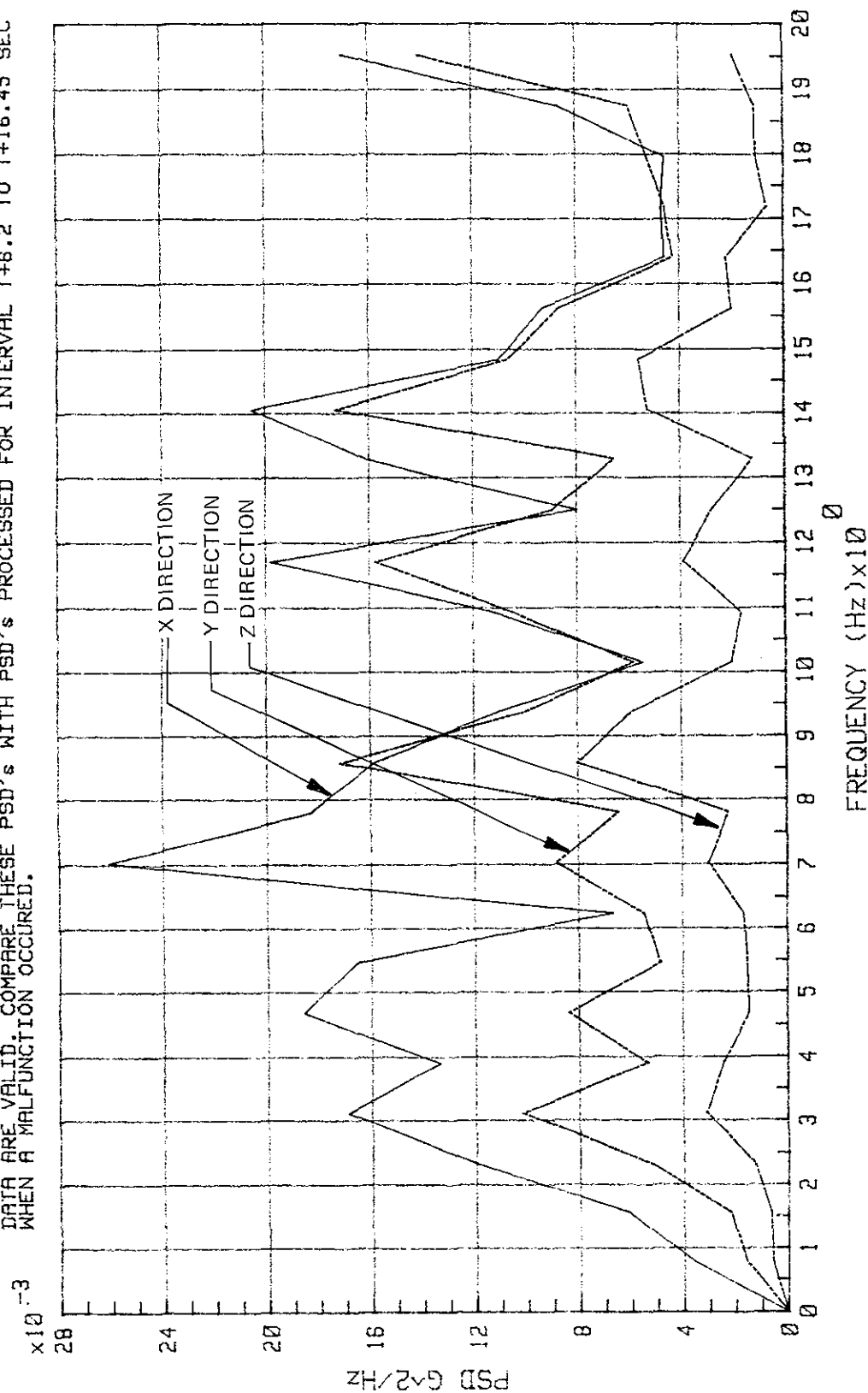
Figure 5-78. STS-3 Lift-Off – Vibration Inside HIM Rack 6396A1, Sensors in X, Y, and Z Directions

KSC-DD-818-TR
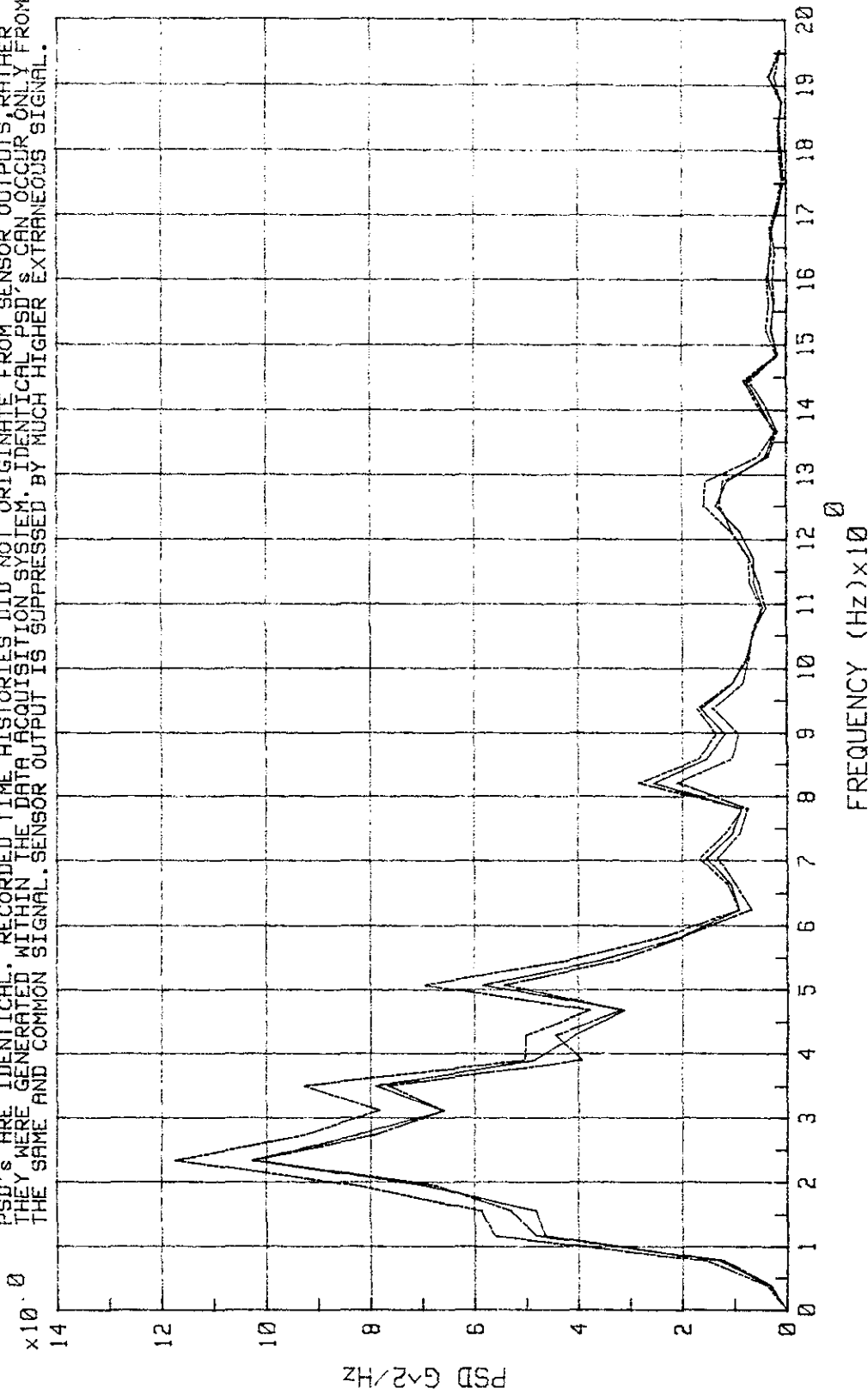
Figure 5-79. STS-3 Malfunction of High-Frequency Sensors KSRDC042A (X), -43A (Y), and -44A (Z)
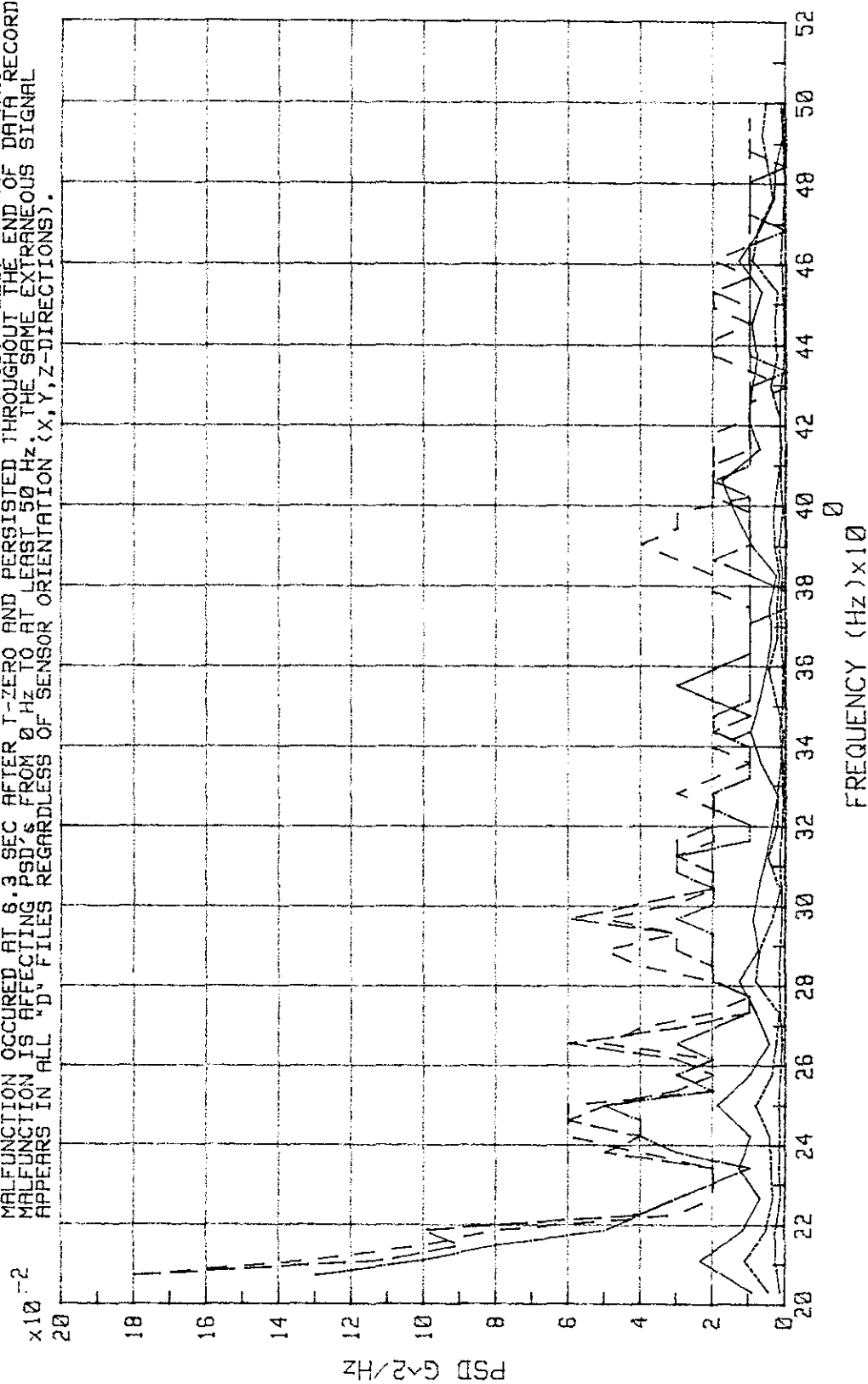
Figure 5-80. STS-3 KSRDC042A (X), -43A (Y), and -44A (Z) Before and After Malfunction
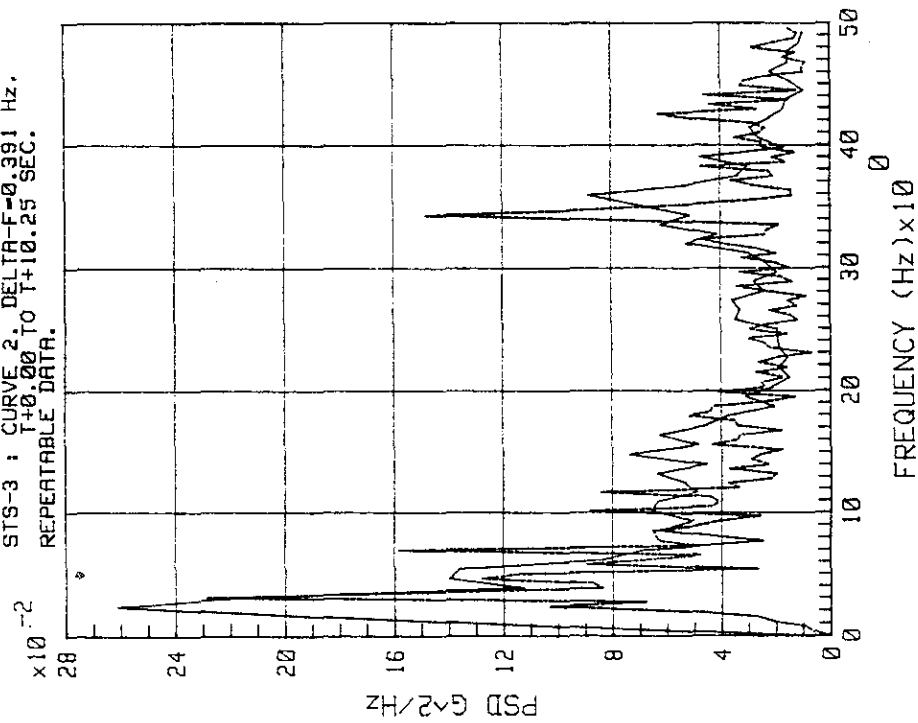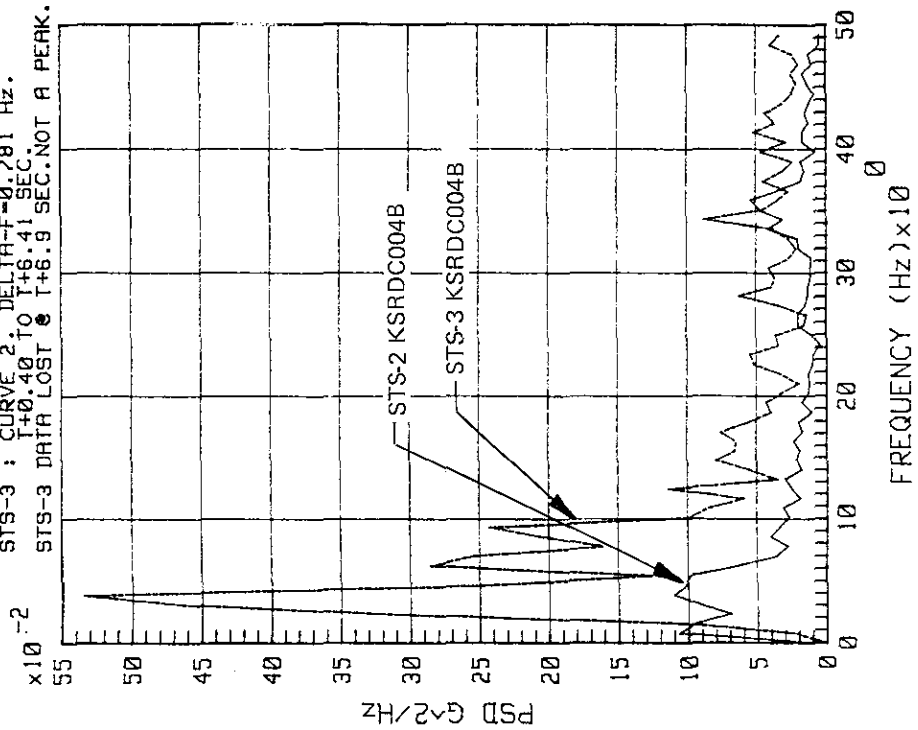
Figure 5-81. STS-2 and -3 PCR Floor Beam, X and Y Directions
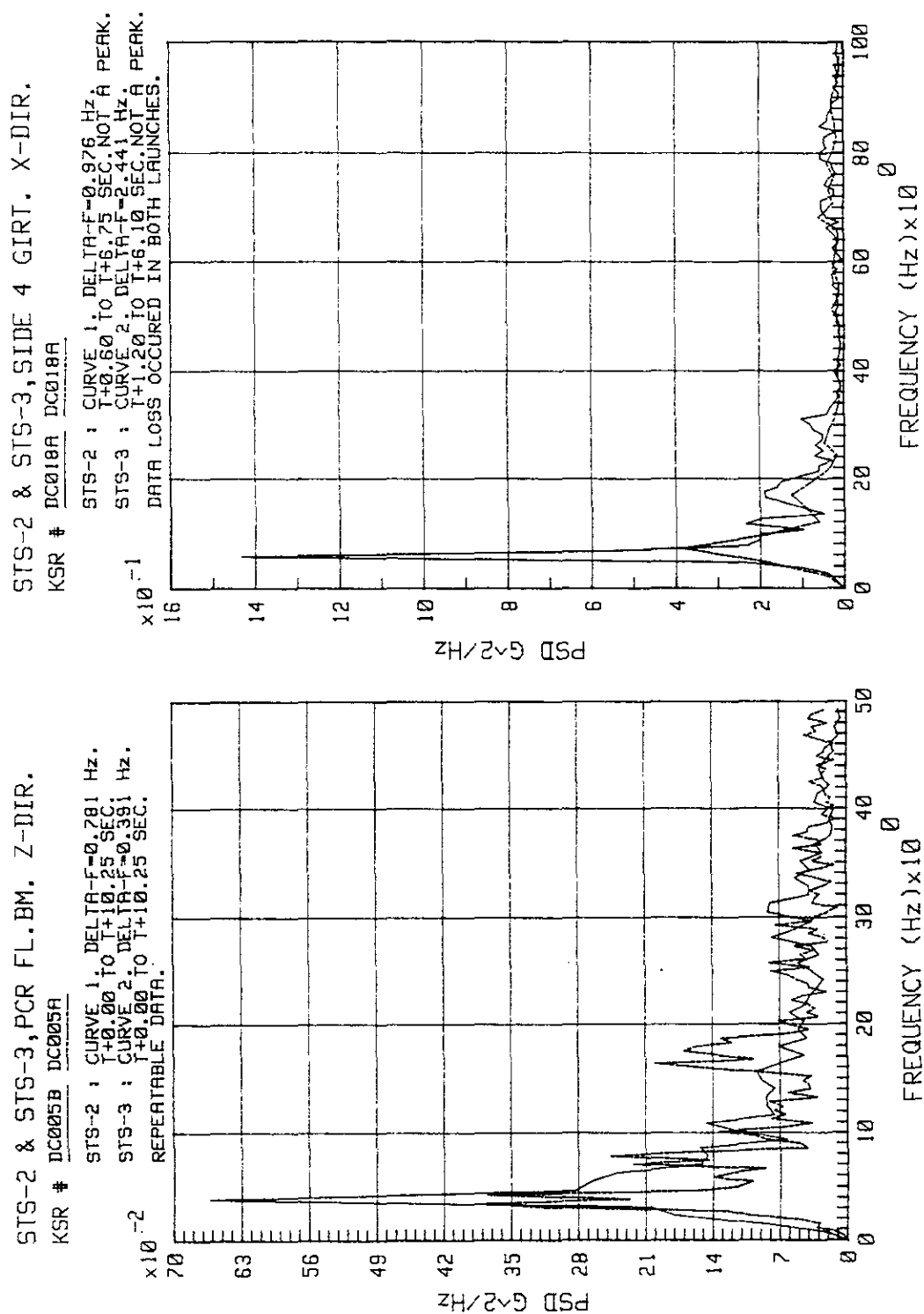
Figure 5-82. STS-2 and -3 PCR Floor Beam, Z Direction, and Side Girt, X Direction

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Figure 5-83. STS-2 and -3 Side 3 Girt, Y Direction (Sheet 1 of 2)

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Figure 5-83. STS-2 and -3 Side 3 Girt, Y Direction (Sheet 2 of 2)

Figure 5-84. STS-2 and -3 APS Floor Beam, X and Y Directions
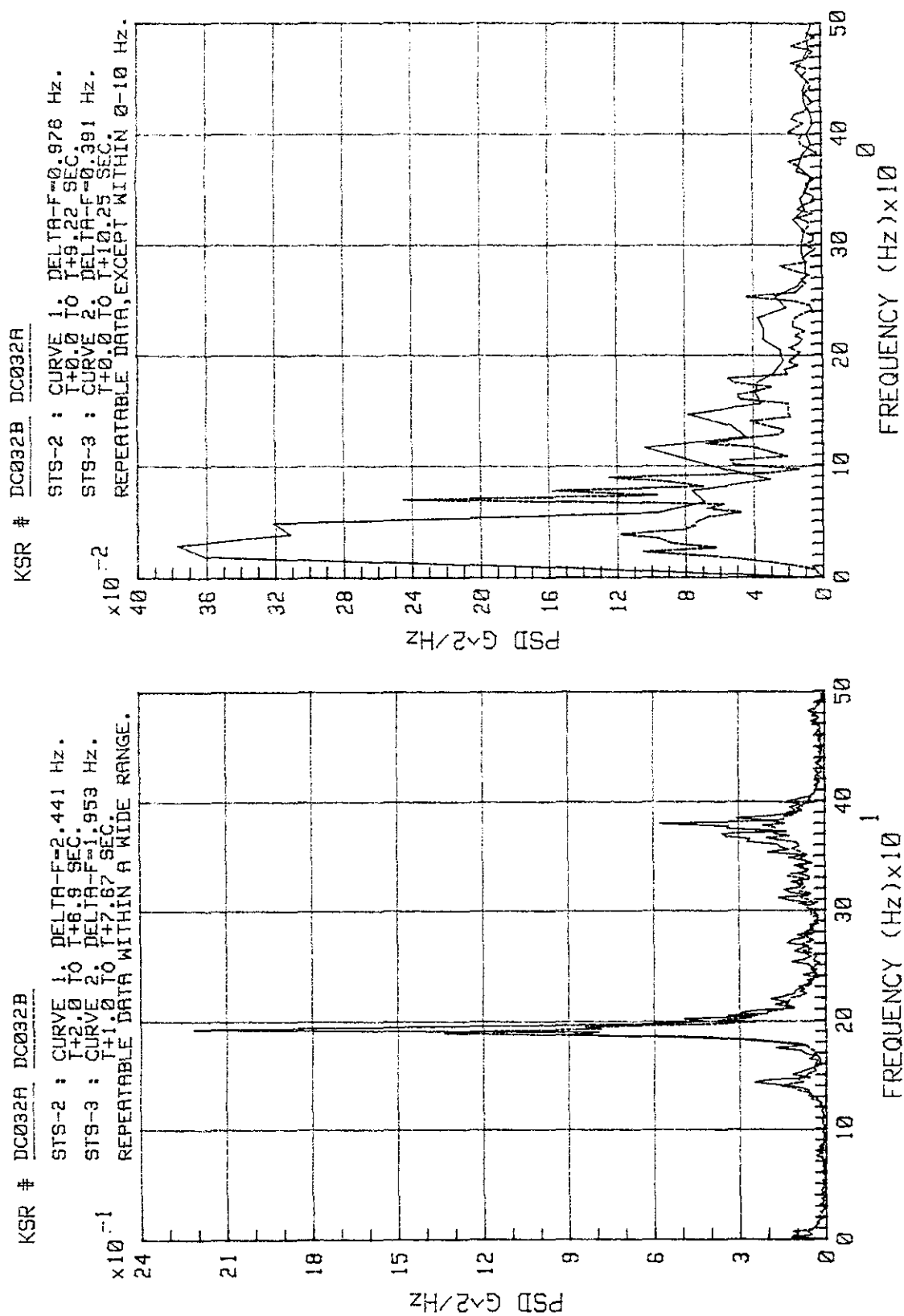
Figure 5-85. STS-2 and -3 Hypergol Electronic Equipment Platform Floor Beam at 117-ft Elevation, X Direction
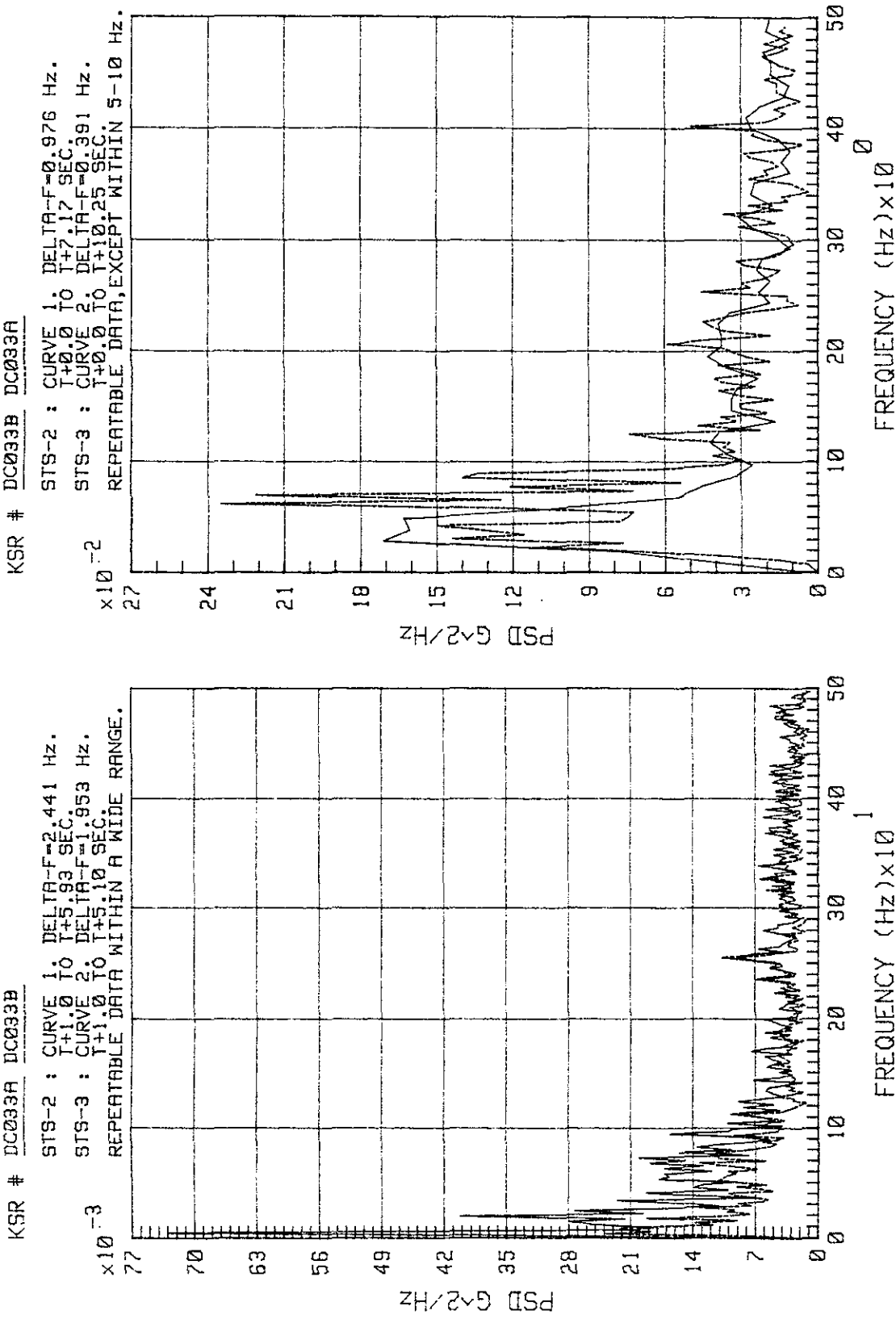
Figure 5-86. STS-2 and -3 Hypergol Electronic Equipment Platform Floor Beam at 117-ft Elevation, Y Direction
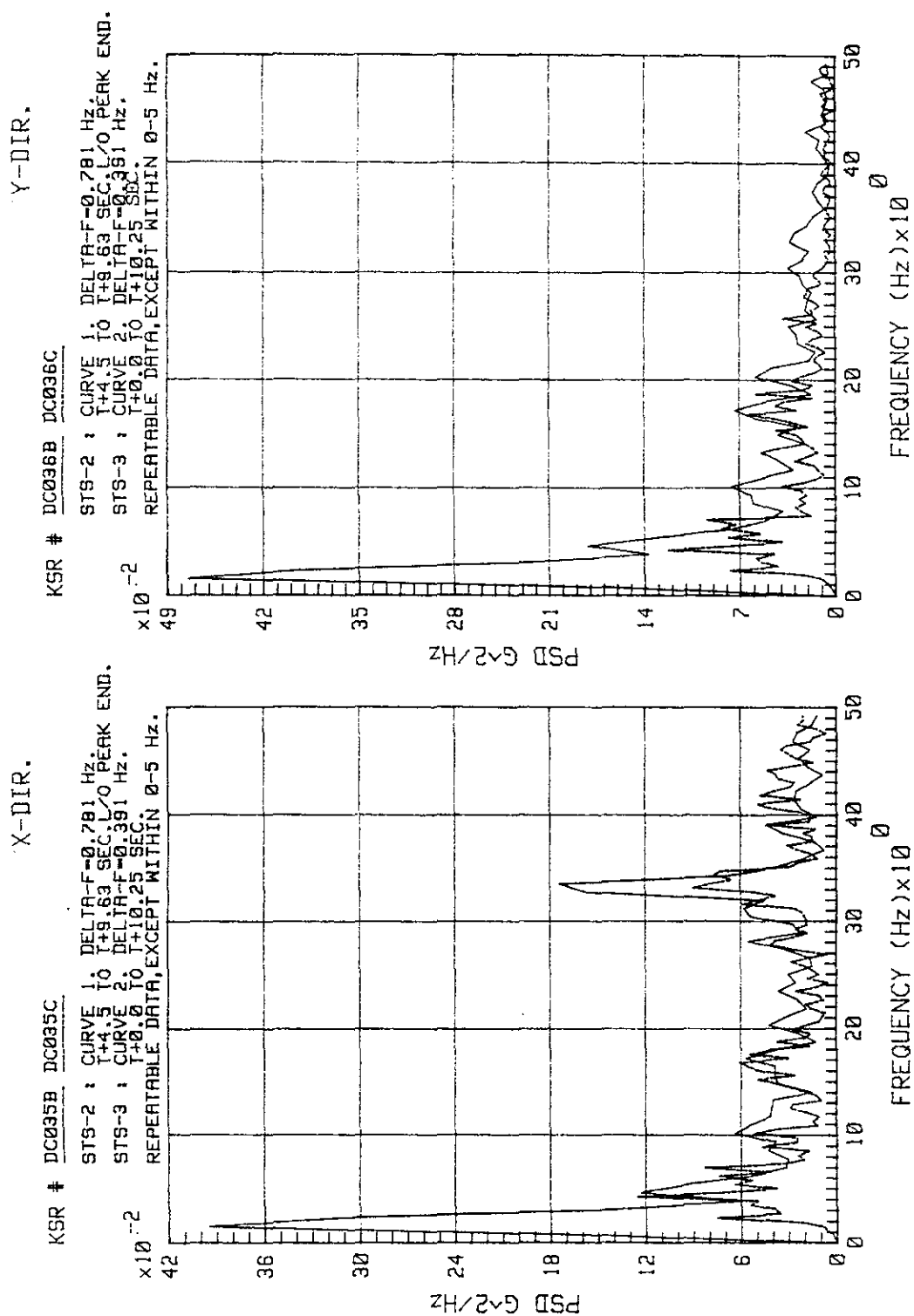
Figure 5-87. STS-2 and -3 Hypergol Electronic Equipment Platform Floor Beam, X and Y Directions
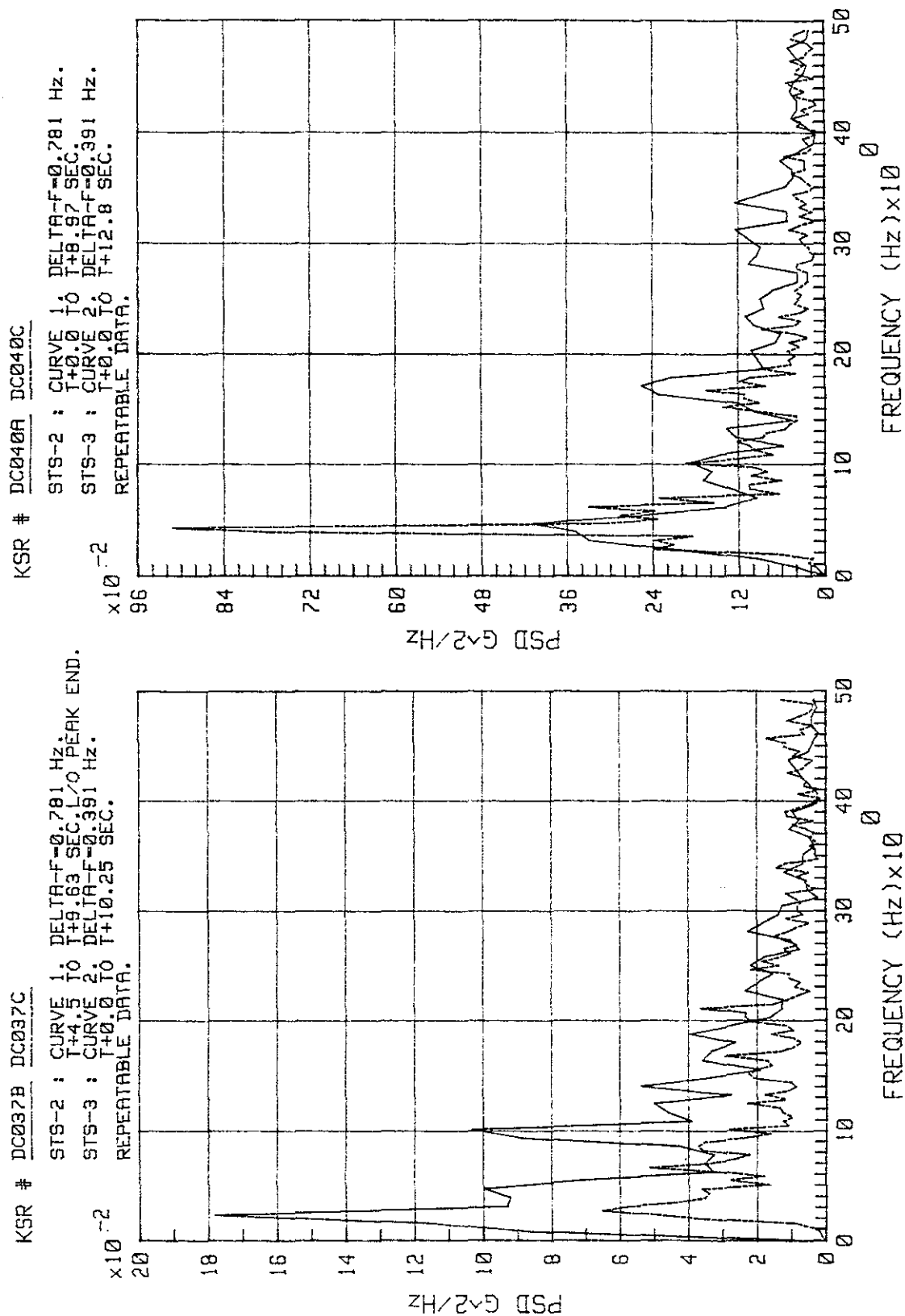
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Figure 5-88. STS-2 and -3 Hypergol Electronic Equipment Platform Floor Beam, Z Direction

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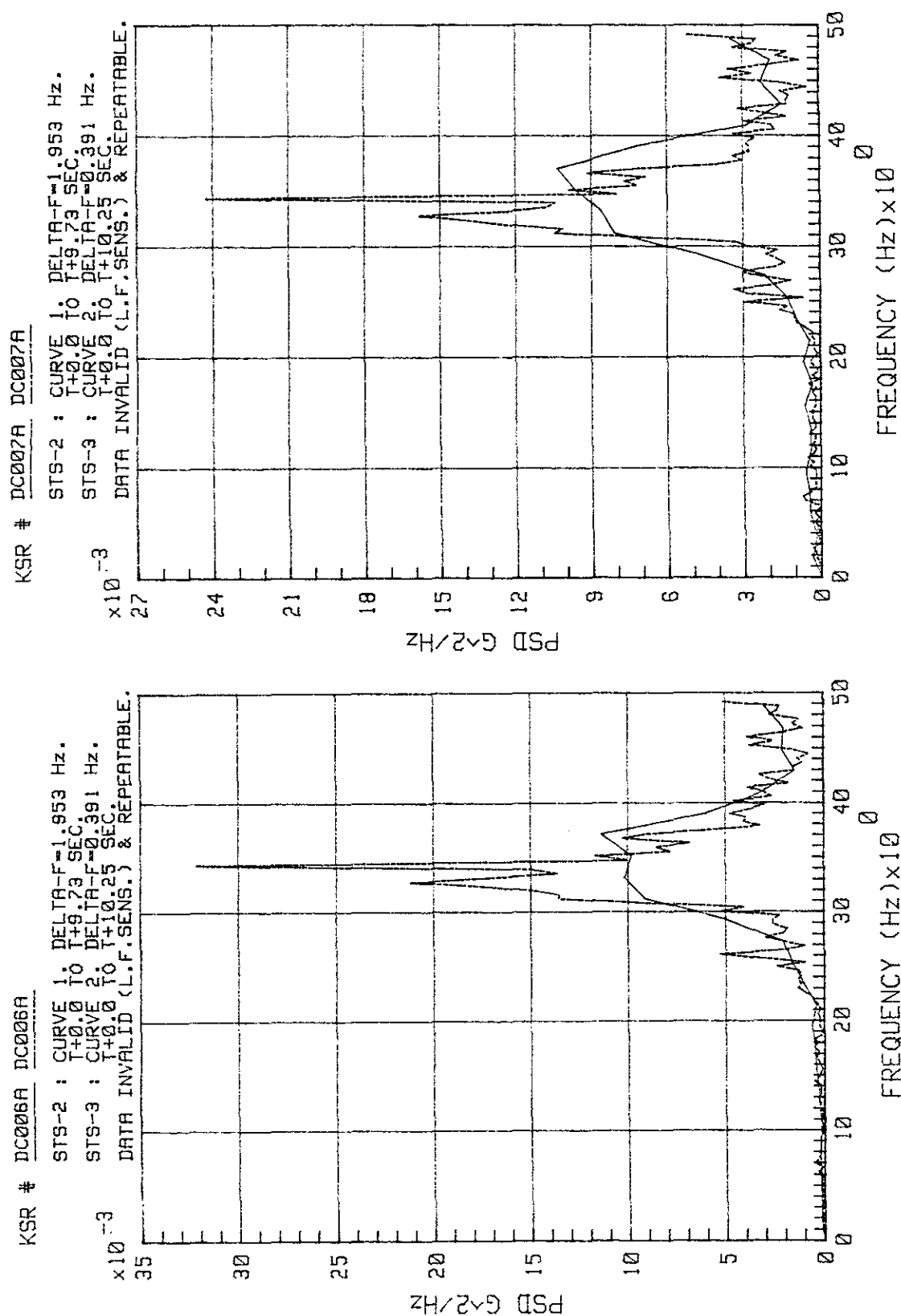
Figure 5-89. STS-2 and -3 PCR Floor Beam, X and Y Directions

Figure 5-90. STS-2 Lift-Off Peak — Comparison Between KSRDC006A (X) and —007A (Y) (Sheet 1 of 2)

Figure 5-90. STS-2 Lift-Off Peak - Comparison Between KSRDC006A (X) and -007A (Y) (Sheet 2 of 2)

Figure 5-91. STS-3 Lift-Off Peak - Comparison Between KSRDC049A (X) and -050A (Y) (Sheet 1 of 2)

Figure 5-91. STS-3 Lift-Off Peak - Comparison Between KSRDC049A (X) and -050A (Y) (Sheet 2 of 3)

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Figure 5-91. STS-3 Lift-Off Peak - Comparison Between KSRDC049A (X) and -C50A (Y) (Sheet 3 of 3)

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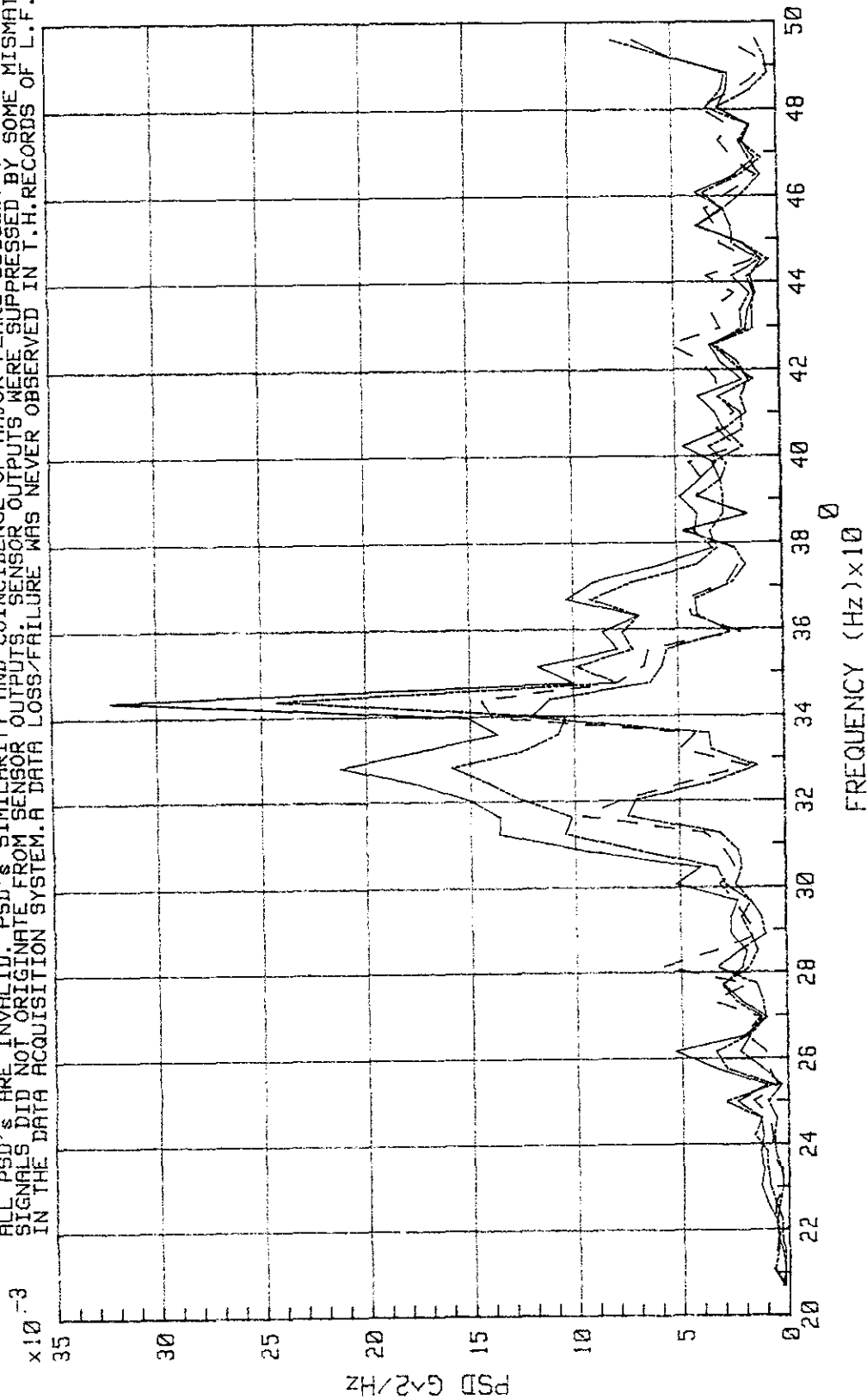Figure 5-92. STS-3 Lift-Off Peak - Low-Frequency Sensors KSRDC006A (X), -007A (Y), -049A (X),
and -050A (Y) (Sheet 1 of 2)

Figure 5-92. STS-3 Lift-Off Peak - Low-Frequency Sensors KSRDC006A (X), - 007A (Y), -049A (X), and -050A (Y) (Sheet 2 of 2)
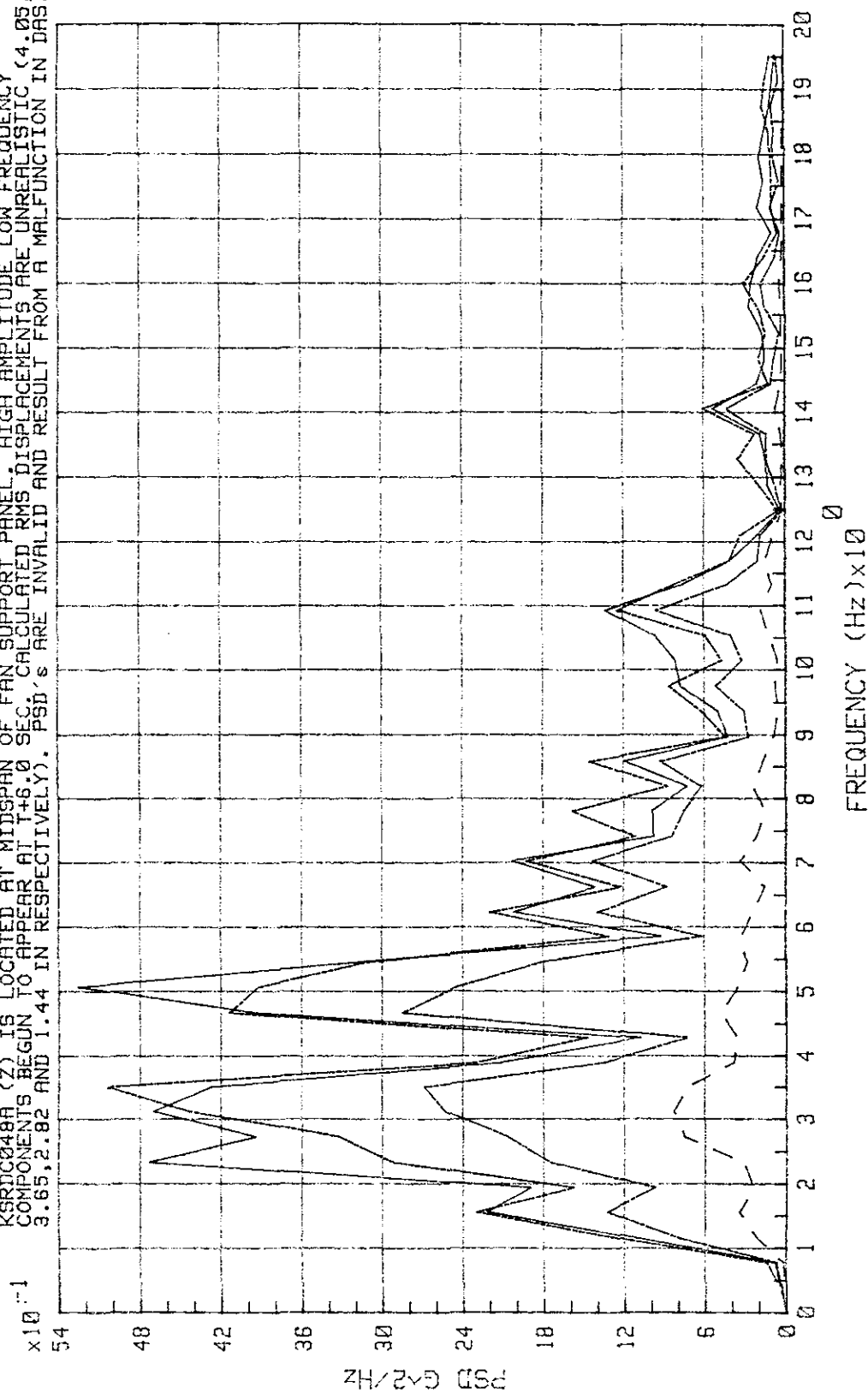
Figure 5-93. STS-2 Lift-Off Peak End - High-Frequency Sensors Inside HIM Rack 6396A1