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AFFDL-TR-70-10
Volume II, Part II

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LOW ALTITUDE ATMOSPHERIC TURBULENCE

LO-LOCAT PHASE III

Volume II, Part II Frequency Data Plots

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J. W. JONES, R. H. MIELKE, G. W. JONES, et al

THE BOEING COMPANY

TECHNICAL REPORT AFFDL-TR-70-10, VOLUME II, PART II

NOVEMBER 1970

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LOW ALTITUDE ATMOSPHERIC TURBULENCE
LO-LOCAT PHASE III

Volume II, Part II Frequency Data Plots

J. W. JONES, R. H. MIELKE, G. W. JONES, et al

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FOREWORD

This is the final report on the Low-Low Altitude CAT research work conducted under Contract Number F33615-68-C-1468 (LO-LOCAT Phase III). The report was prepared by The Boeing Company, Wichita Division, for the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio.

The LO-LOCAT Phase III project was part of Advanced Development Program 682E (ALLCAT) and was under the direction of ADP 682E Program Director, Mr. E. Brazier, and the Technical Coordinator, Mr. Neal V. Loving. Mr. Jan Garrison, FBE, was the Air Force Project Engineer.

The research effort was conducted under the Boeing supervision of Mr. F. K. Atnip, Program Manager. Mr. C. F. Peterson was the Project Pilot. Mr. D. B. Marshall was in charge of instrumentation, Mr. H. H. Depew directed the data processing effort, Mr. J. D. Gault was in charge of data analysis, and Mr. W. B. Moreland (Boeing-Seattle) directed the meteorological forecasts and analysis. Airplane maintenance and inspection were the responsibility of Mr. J. Strain and Mr. J. Bonawitz, respectively.

Mr. Gerald A. Comstock piloted the observer airplane over the Peterson Field, Colorado, high mountain route and was also backup pilot for this program. While acting in this latter capacity during a data gathering flight over the Griffiss AFB, New York route, Mr. Comstock was fatally injured in a forced landing following an engine flameout.

Authors of this report, other than those shown on the cover, were Messrs D. E. Gunter and K. R. Monson.

The report was submitted by the authors 17 August 1970. It was reviewed by Mr. Jan Garrison and Dr. T. Swaney (Boeing) who made many constructive comments and suggestions.

This technical report has been reviewed and is approved.

GORDON R. NEGAARD, Major, USAF
Chief, Design Criteria Branch
Structures Division
Air Force Flight Dynamics Laboratory

ABSTRACT

This report presents procedures, analysis methods, and final results pertaining to the LO-LOCAT Phase III program. Approximately 150 hours of low altitude (100 - 1000 feet) turbulence and associated meteorological data were recorded from 16 August 1968 through 30 June 1969. The original program was curtailed by approximately six weeks due to the crash of the T-33 research airplane. A model of the turbulence environment at low-level is presented in terms of gust velocity primary peaks, level crossings, amplitude samples, rms values, and gust maxima, as well as derived equivalent gusts, turbulence scale lengths, and power spectra. Mathematical expressions for turbulence spectra, scale length, and primary peak statistics are shown. Correlations between atmospheric gust velocities and meteorological and geophysical phenomena are evaluated. It was found that gust velocity magnitude at low altitude is most affected by atmospheric stability and terrain. Gust velocity rms values above 1.5 fps may be approximated by truncated Gaussian distributions. For wavelengths less than 15,000 feet, turbulence spectra are best represented by the von Karman mathematical expressions. The turbulence, sampled for 4-1/2 minute intervals over a distance of approximately 32 miles at absolute altitudes below 1,000 feet, was found to be basically stationary, isotropic, and homogeneous. A high percentage of Phase III data were recorded over high mountains since very little high mountain data were recorded under contour flight conditions at low level during Phases I and II. Phase III data are compared with data from Phases I and II and with data from other low altitude programs.

This report consists of two volumes with each volume divided into two parts. Parts I and II of Volume I give the techniques and results of data analysis. Part I of Volume II provides the details pertaining to data acquisition, instrumentation, calibrations and checks, data processing, and data quality. Data tabulations and plots and a log of pertinent information concerning the program are also presented in Volume II Part I. Part II of Volume II contains the power spectral density and other frequency data plots.

(Distribution of this abstract is unlimited.)

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SYMBOLS

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Symbols and Abbreviations

cpf	Cycles per foot
L	Turbulence scale length (feet)
PSD	Power Spectral Density
u	Longitudinal gust velocity (feet/second); positive-aft
V_G	True airspeed or ground speed (feet/second)
v	Lateral gust velocity (feet/second); positive-right
w	Vertical gust velocity (feet/second); positive-upward

APPENDIX IX

GUST VELOCITY POWER SPECTRA AND ASSOCIATED DATA

This appendix contains the power spectra plots of the gust velocity components for selected turbulence samples. Plots are shown indicating the homogeneity and isotropy characteristics of the turbulence, and the coherency between the individual gust velocity components. Comparisons of experimental power spectra to theoretical spectra are also shown. The above information is presented in the following figures in the order of test and leg number. Only those turbulence samples considered to be homogeneous are shown.

The following is a brief explanation of each set of data, how it was obtained, and the definition of abbreviated notes and scale identification.

Power Spectra

The ordinate scale, "Normalized PSD," is the power normalized by the square of the time series standard deviation. The abscissa, "Spatial Frequency," was usually computed by dividing frequency by ground speed; however, true airspeed was used when ground speed data were not available.

Scale length values, L, were determined from equations derived from von Karman's mathematical spectra expressions. The wind angle, WA, is that measured with respect to the ground track of the airplane. Angles were positive when directed from the left of the ground track. An angle of zero degrees is defined as a direct tail wind.

Homogeneity

The "Homogeneity Check PSD Ratio" was obtained by dividing the unnormalized power spectra of the middle third of the data sample by the unnormalized power spectra of the entire sample. This ratio will approach unity for a turbulence sample having perfect homogeneity.

Coherency

The "u-w Coherency" and the "v-u Coherency" is a measure of the statistical independence between the lateral and vertical and the lateral and longitudinal gust velocity components, respectively. Ideally, the components should be statistically independent and their coherency equal to zero. However, due to statistical variations in the power spectra and cross spectra calculations and noise in the experimental data, the coherency can only approximate zero.

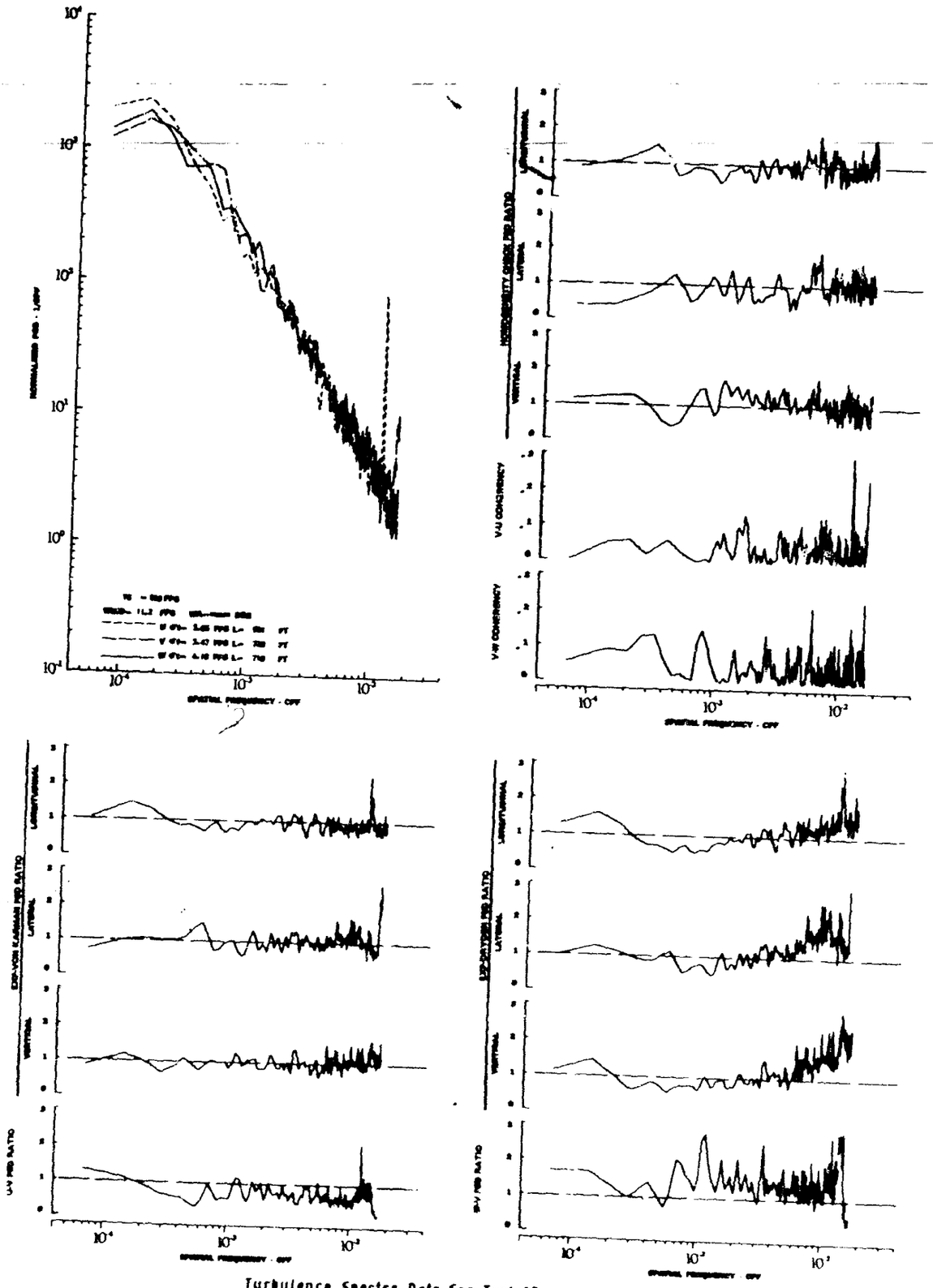
Experimental to Mathematical Comparisons

Plots of "Experimental to von Karman PSD Ratios" and "Experimental to Dryden PSD Ratios" show the relationship of the experimental spectra to mathematical

spectra for each gust velocity component. A ratio equal to unity is indicative of perfect agreement between experimental and mathematical spectra.

Isotropy

The "u-v PSD Ratio" and "w-v PSD Ratio" are indicative of the isotropic characteristics of the turbulence. This relationship was obtained by dividing the unnormalized power spectra of the vertical and longitudinal components by that of the lateral component. Perfect isotropy is indicated when the w-v PSD ratio is equal to unity throughout the frequency range and the u-v PSD ratio is equal to 2.0 at the low frequencies and 0.75 at the high frequencies. This is discussed in detail in Section V of Volume I.



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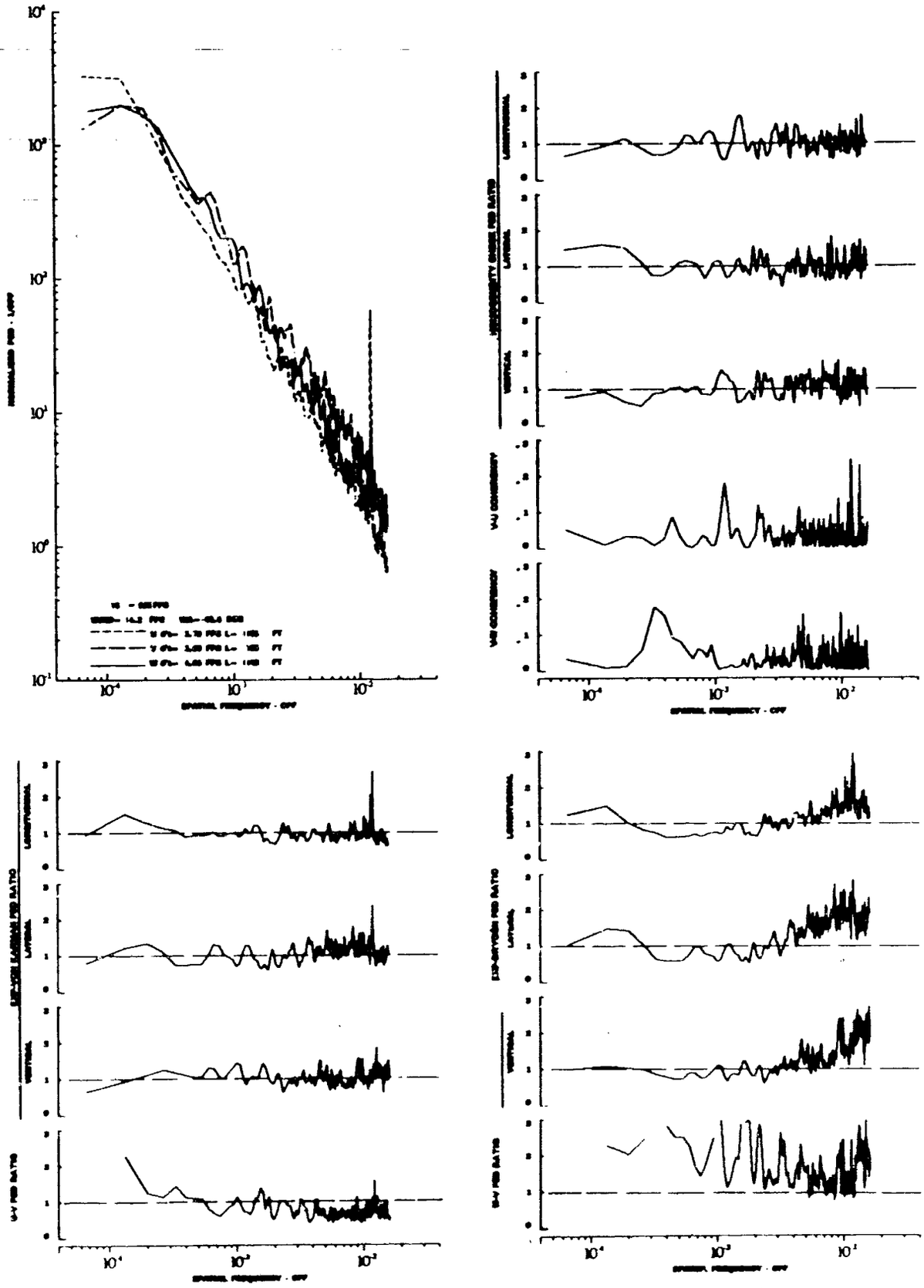

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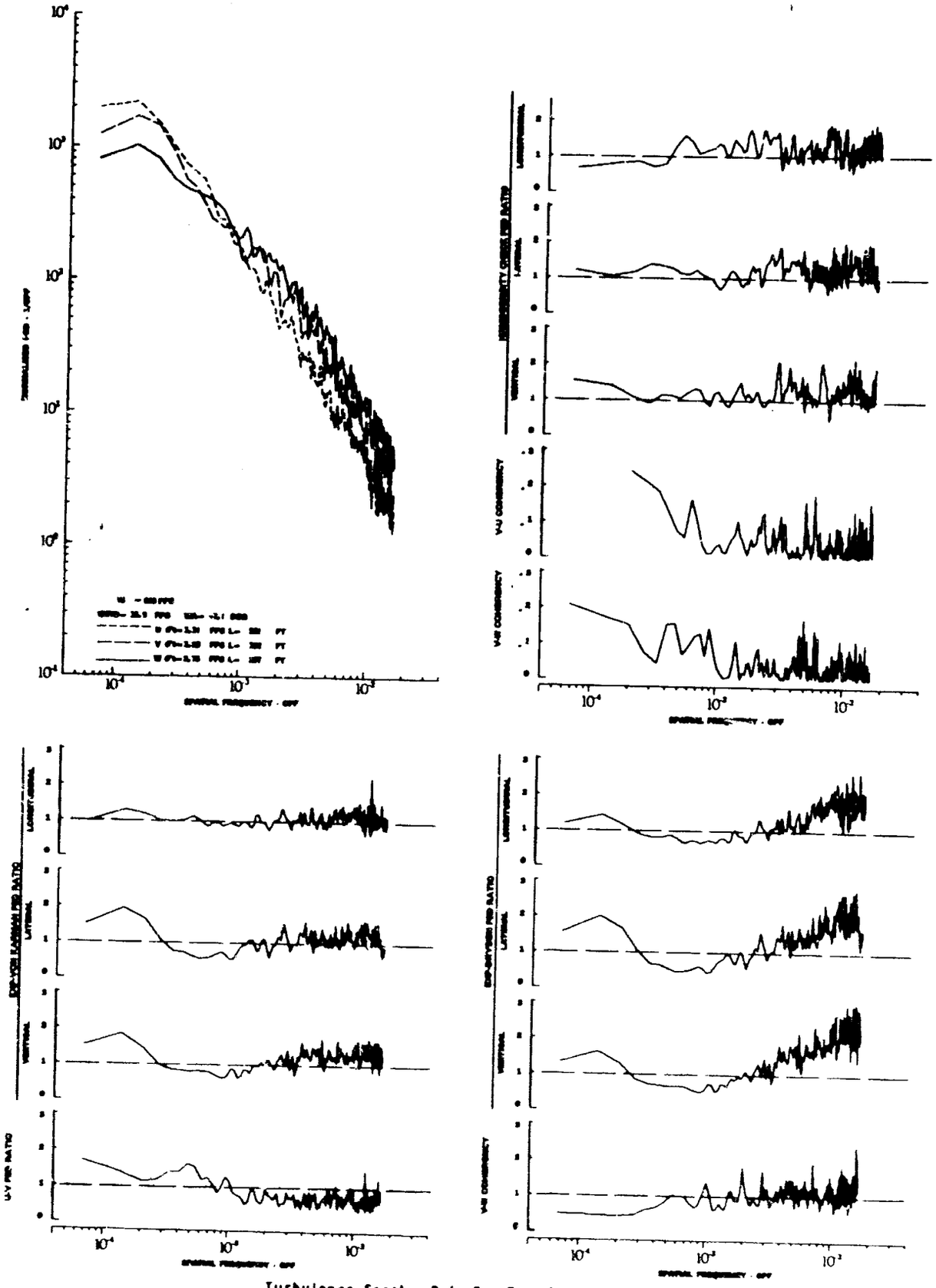

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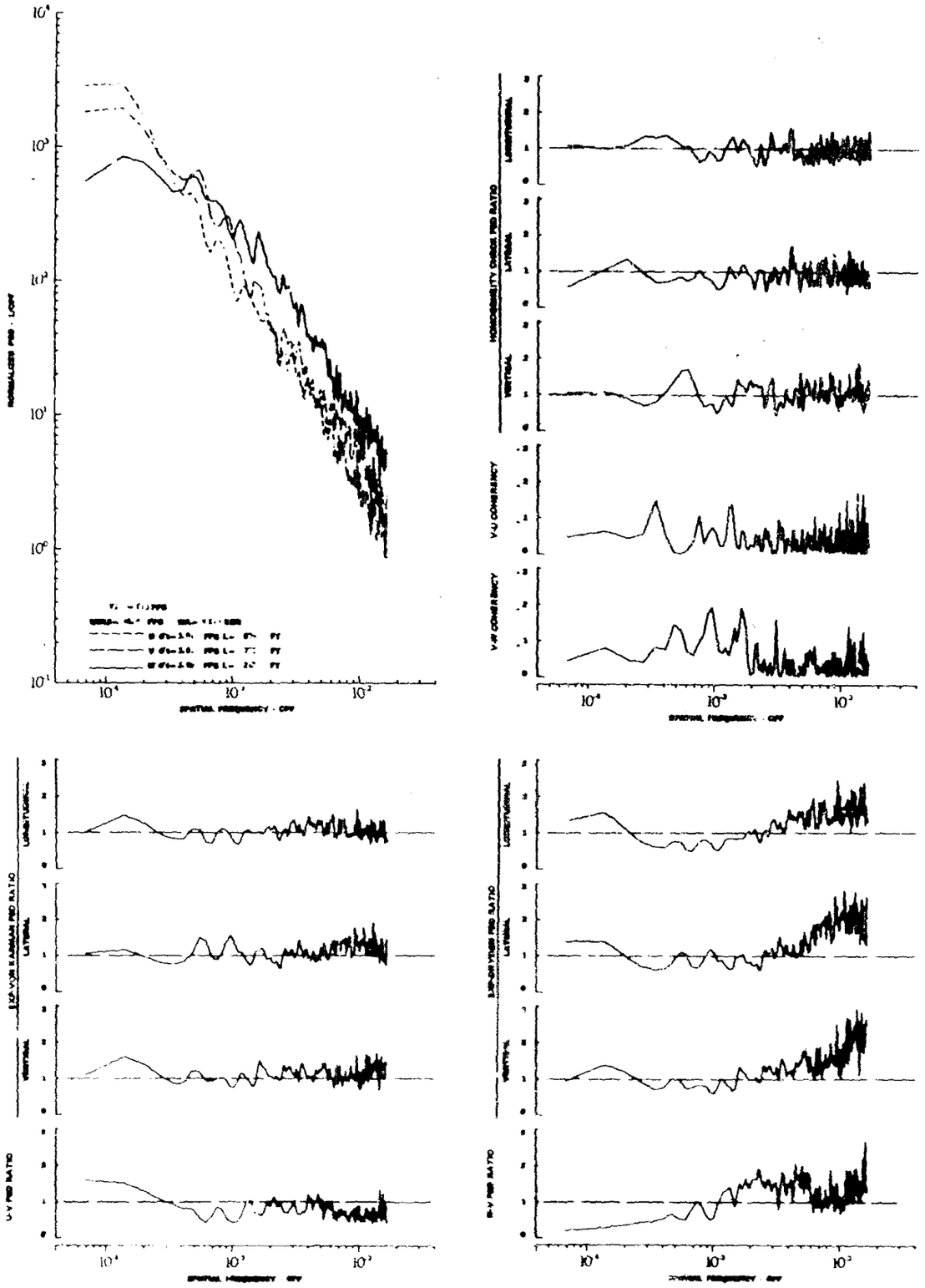

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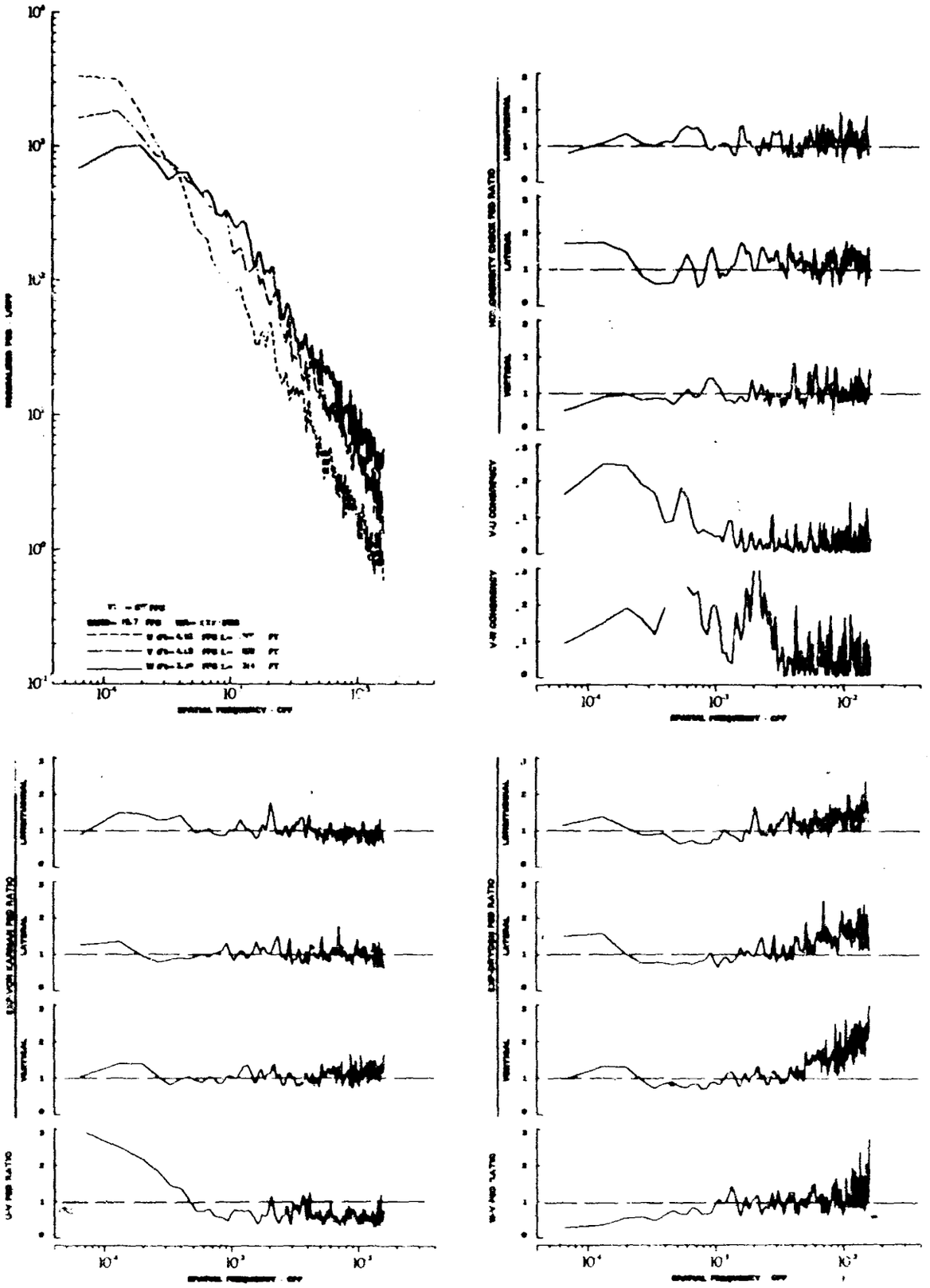

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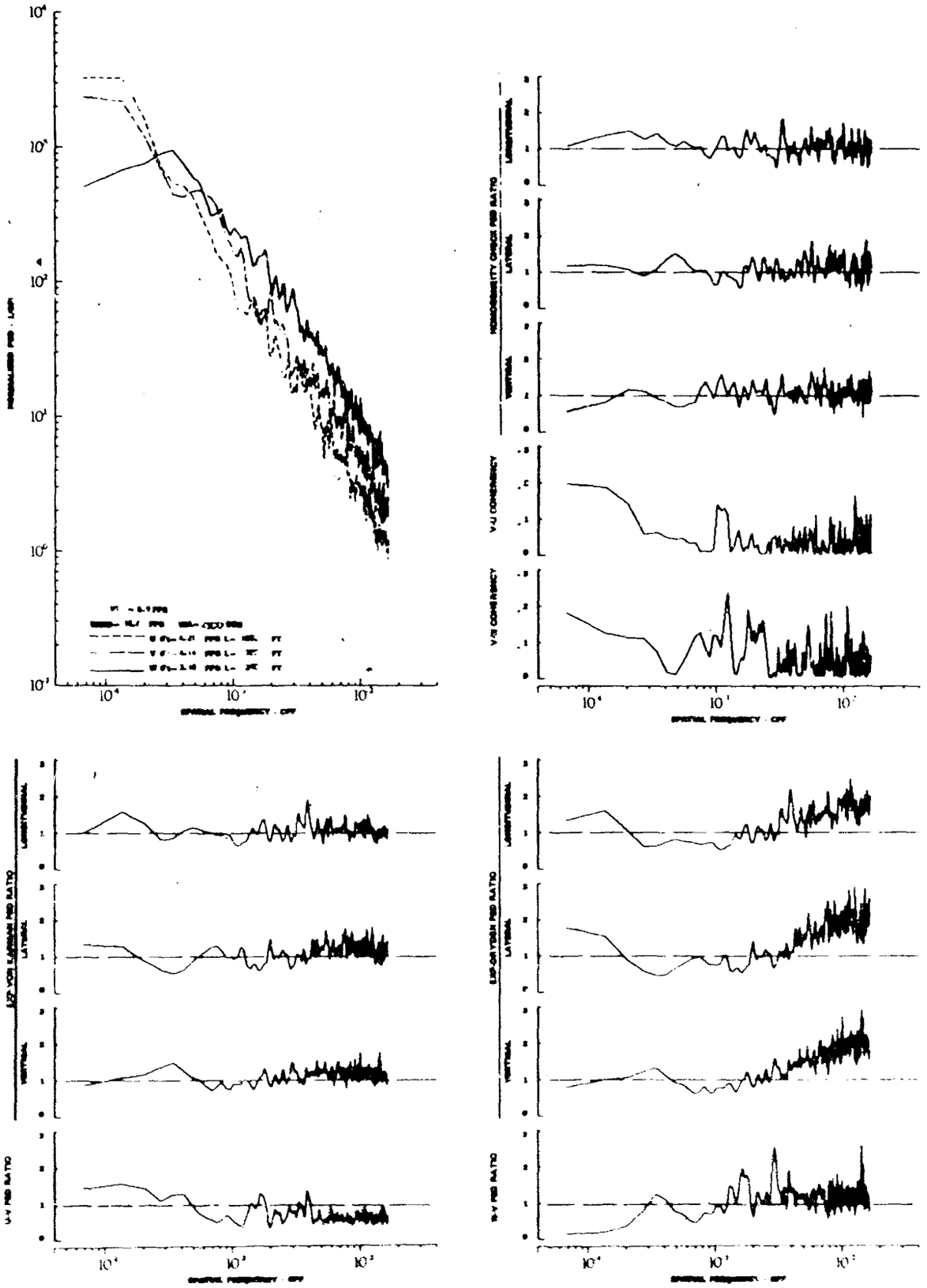

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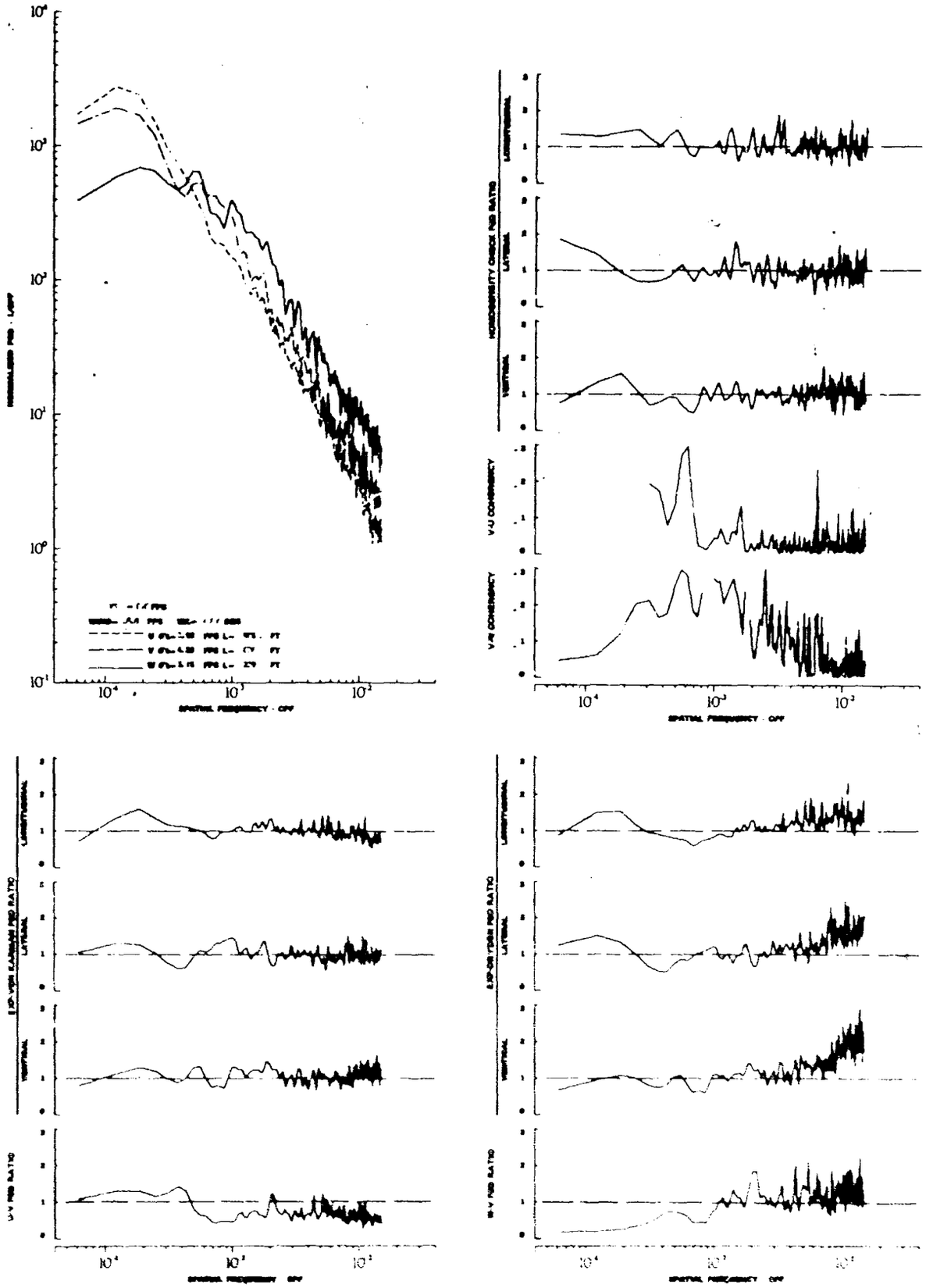

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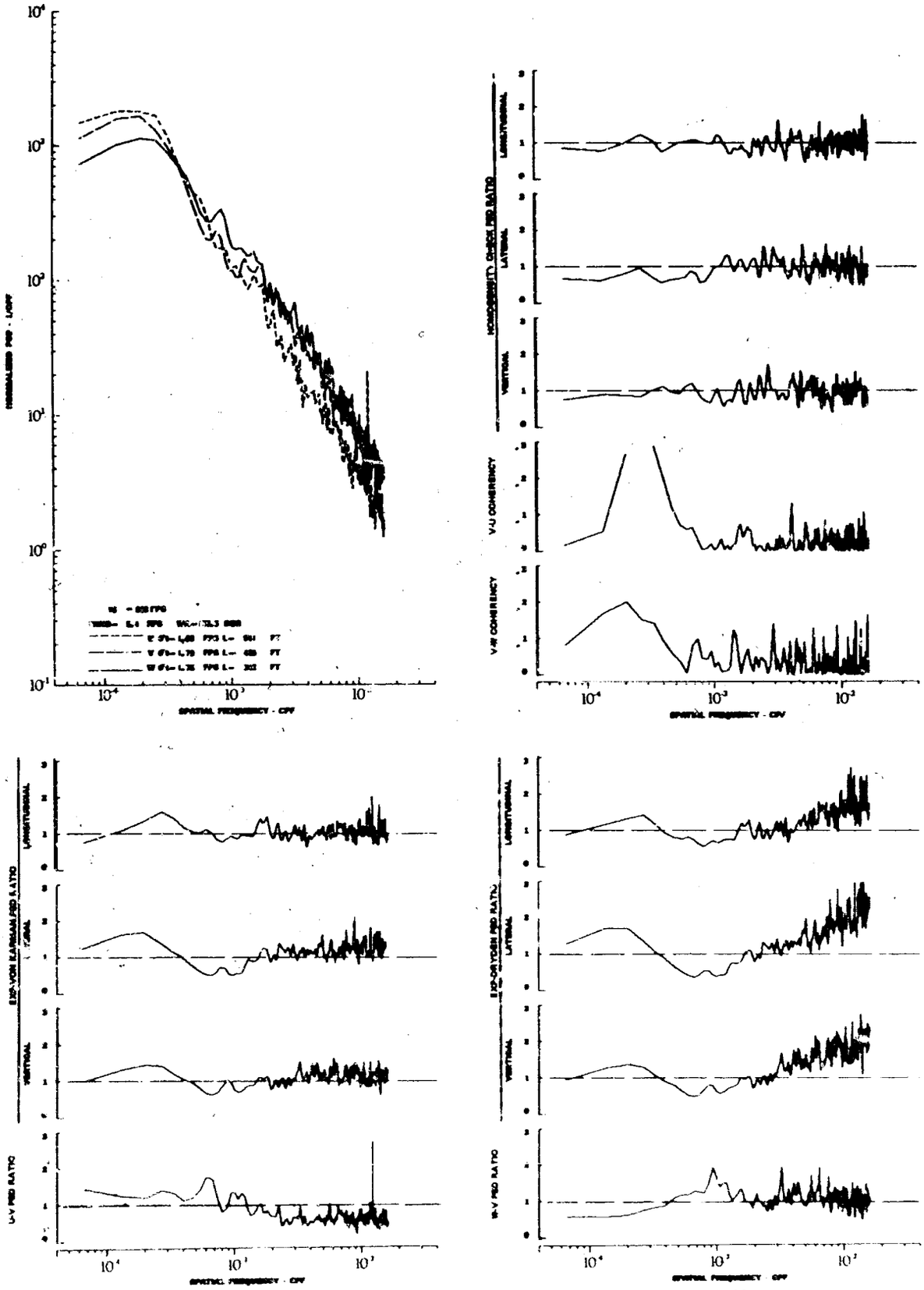

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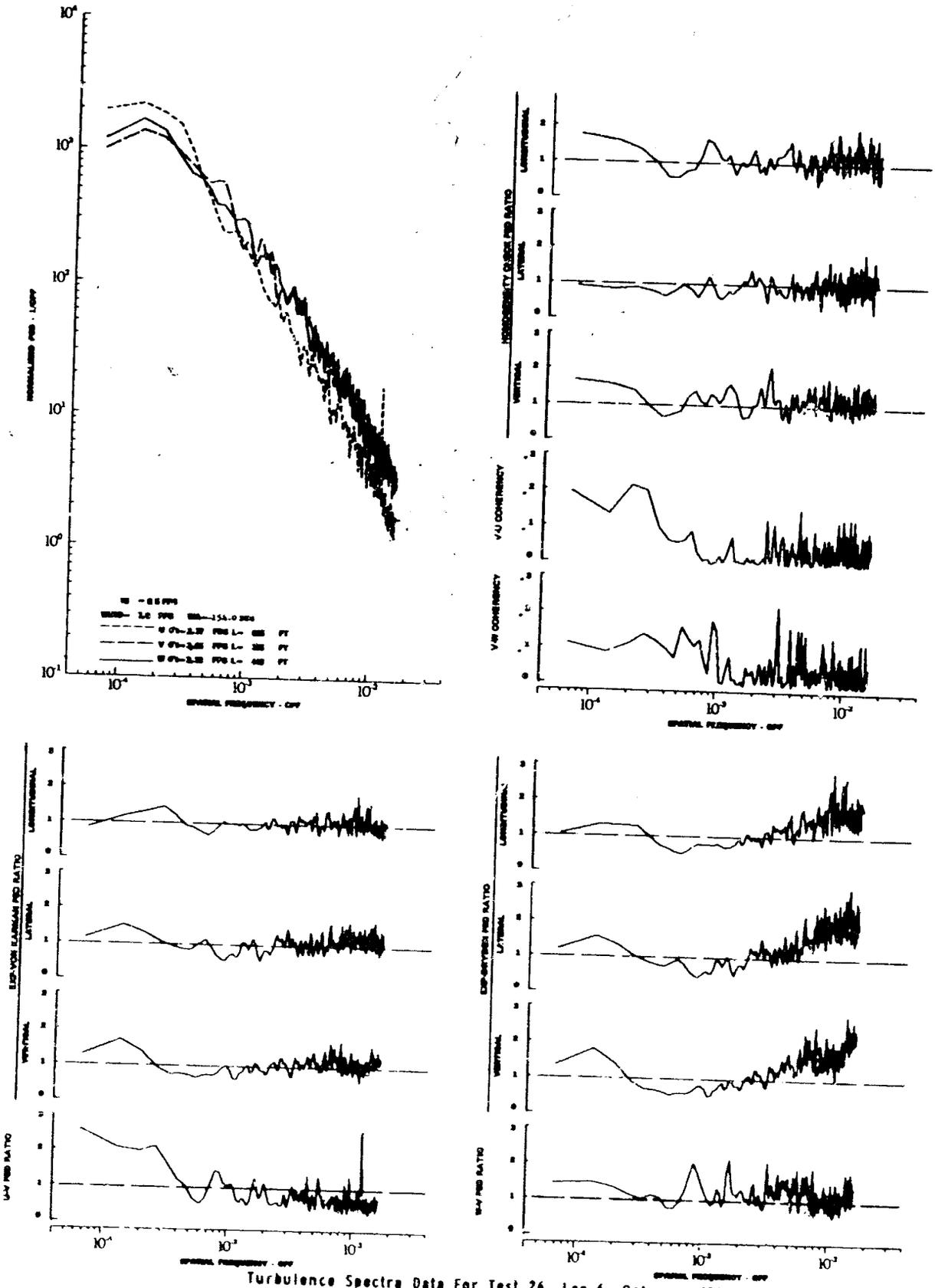

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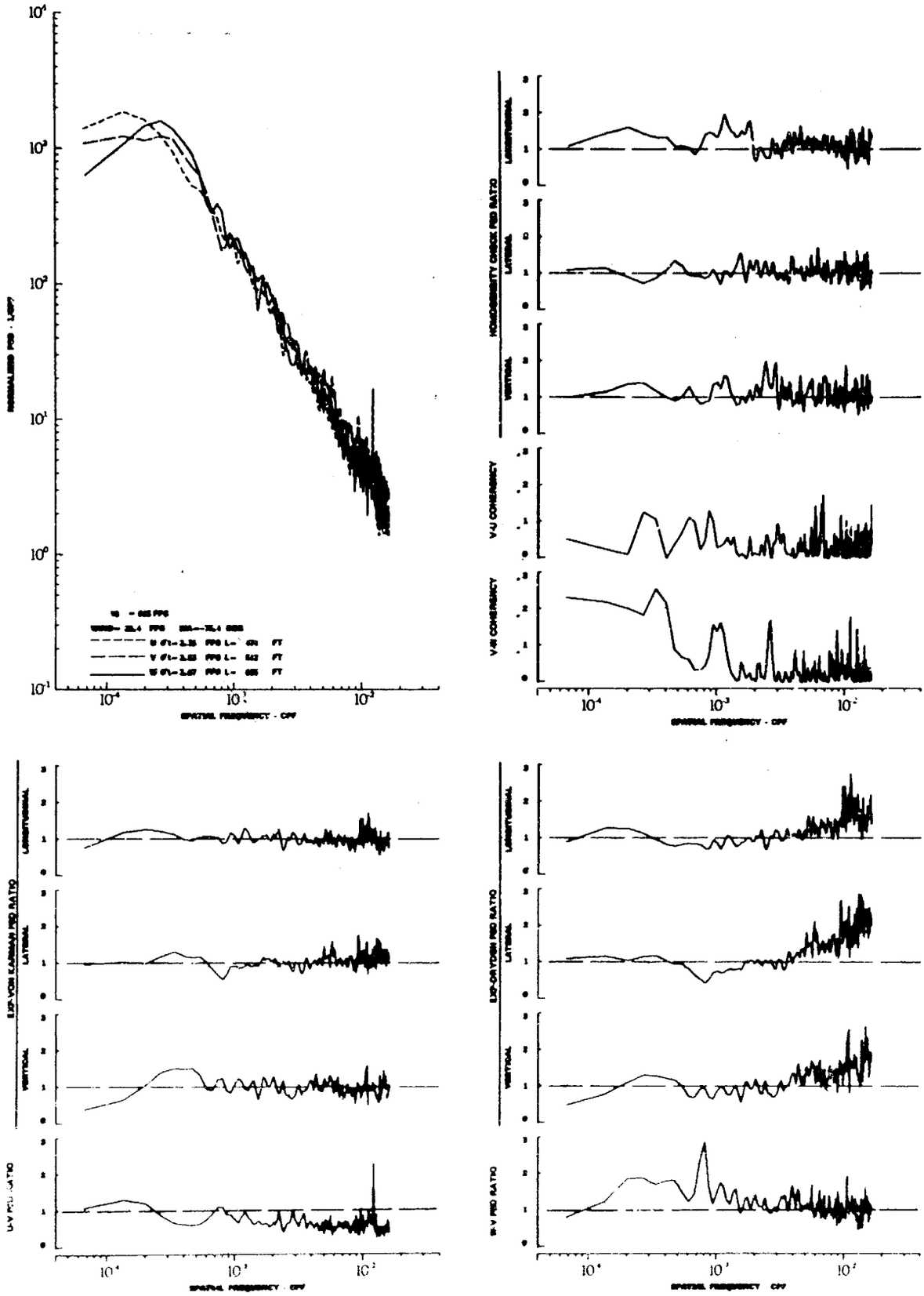

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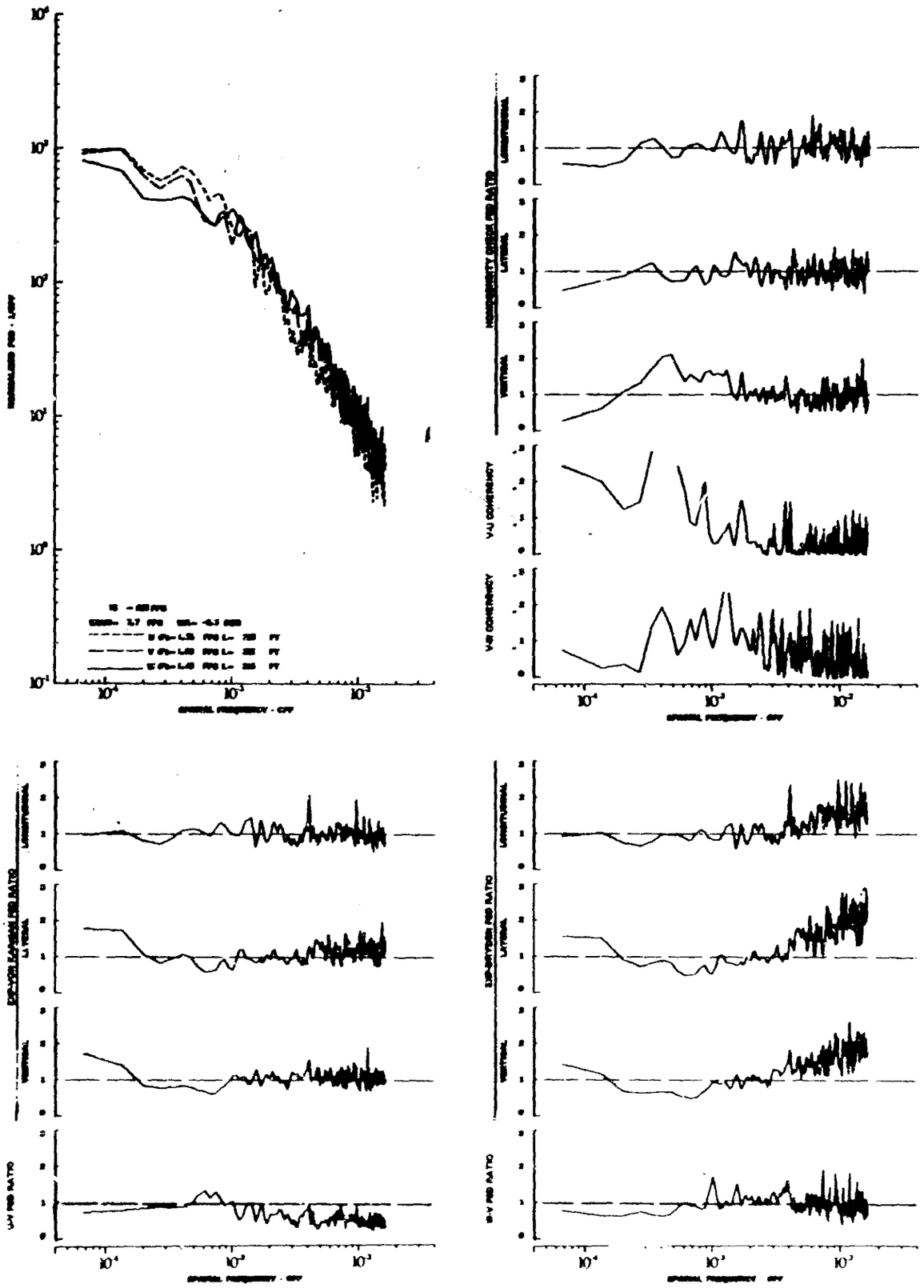

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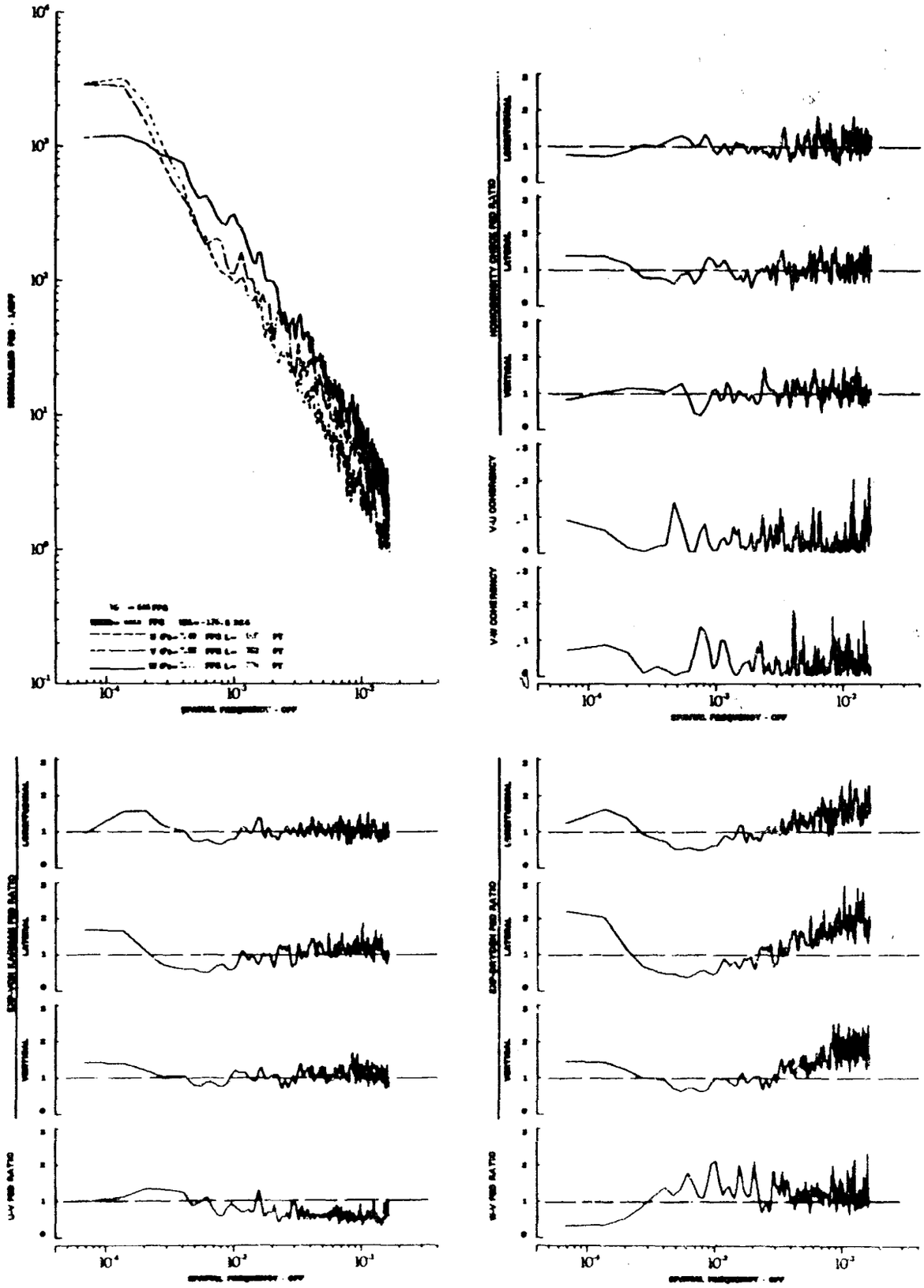

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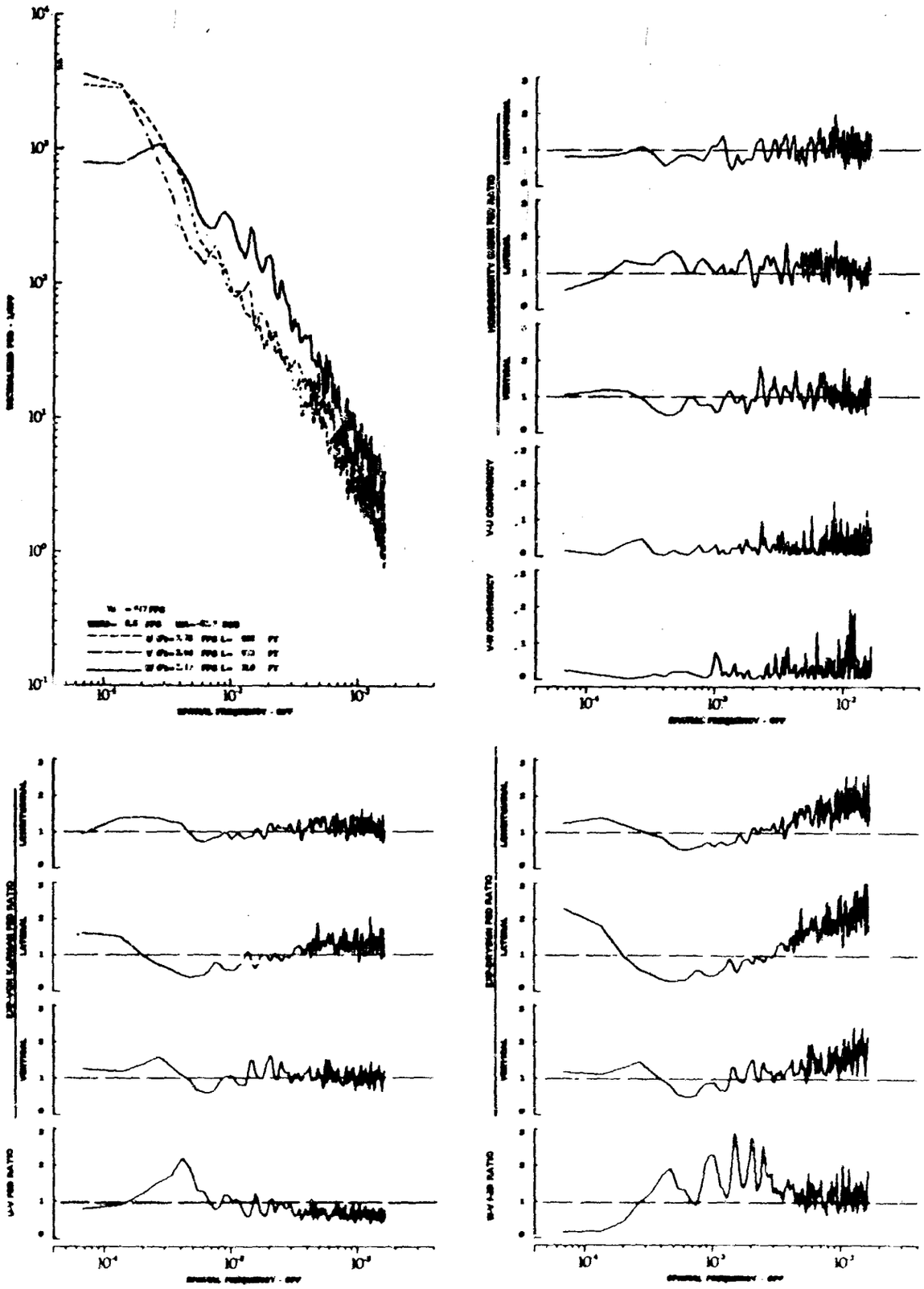

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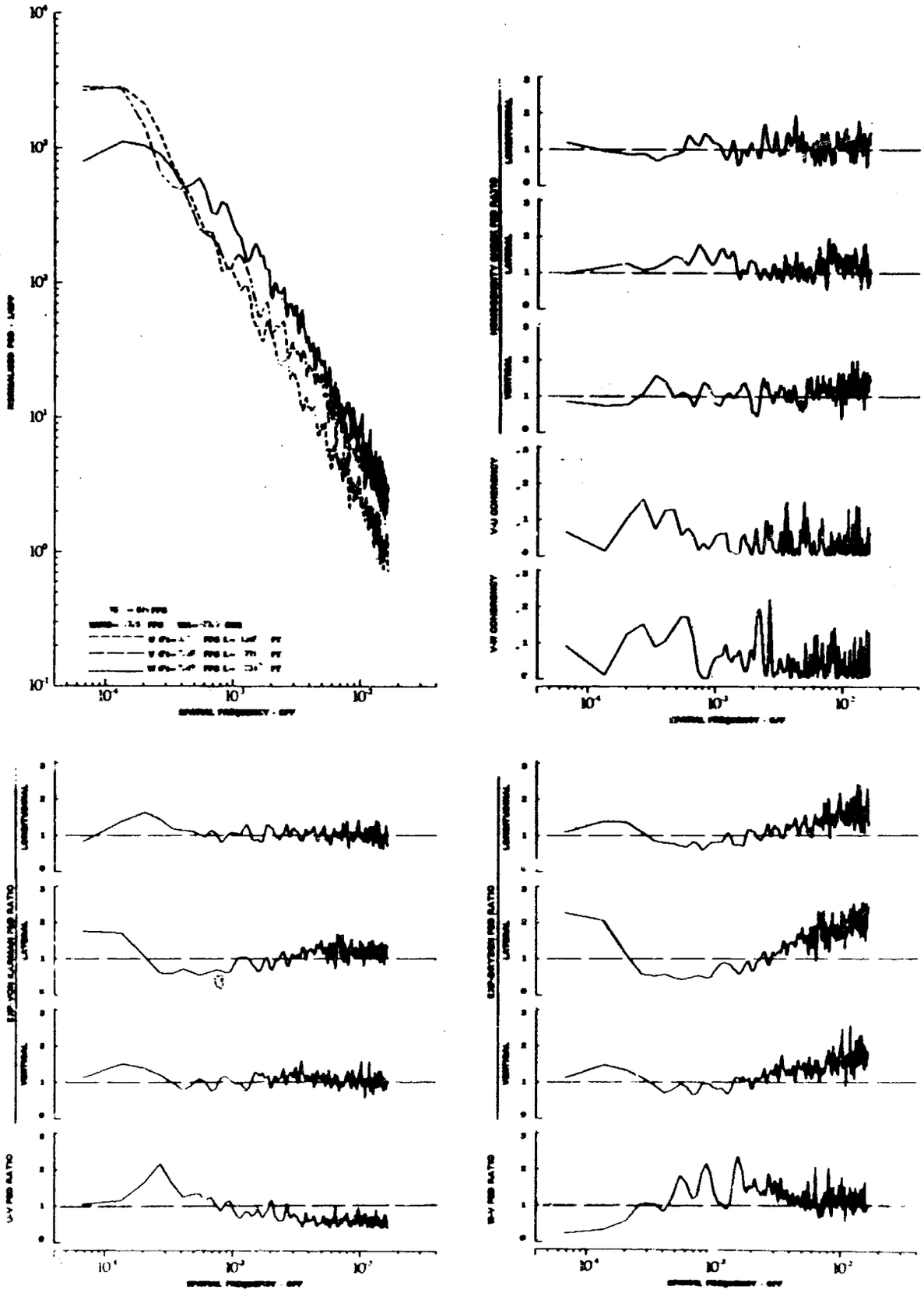

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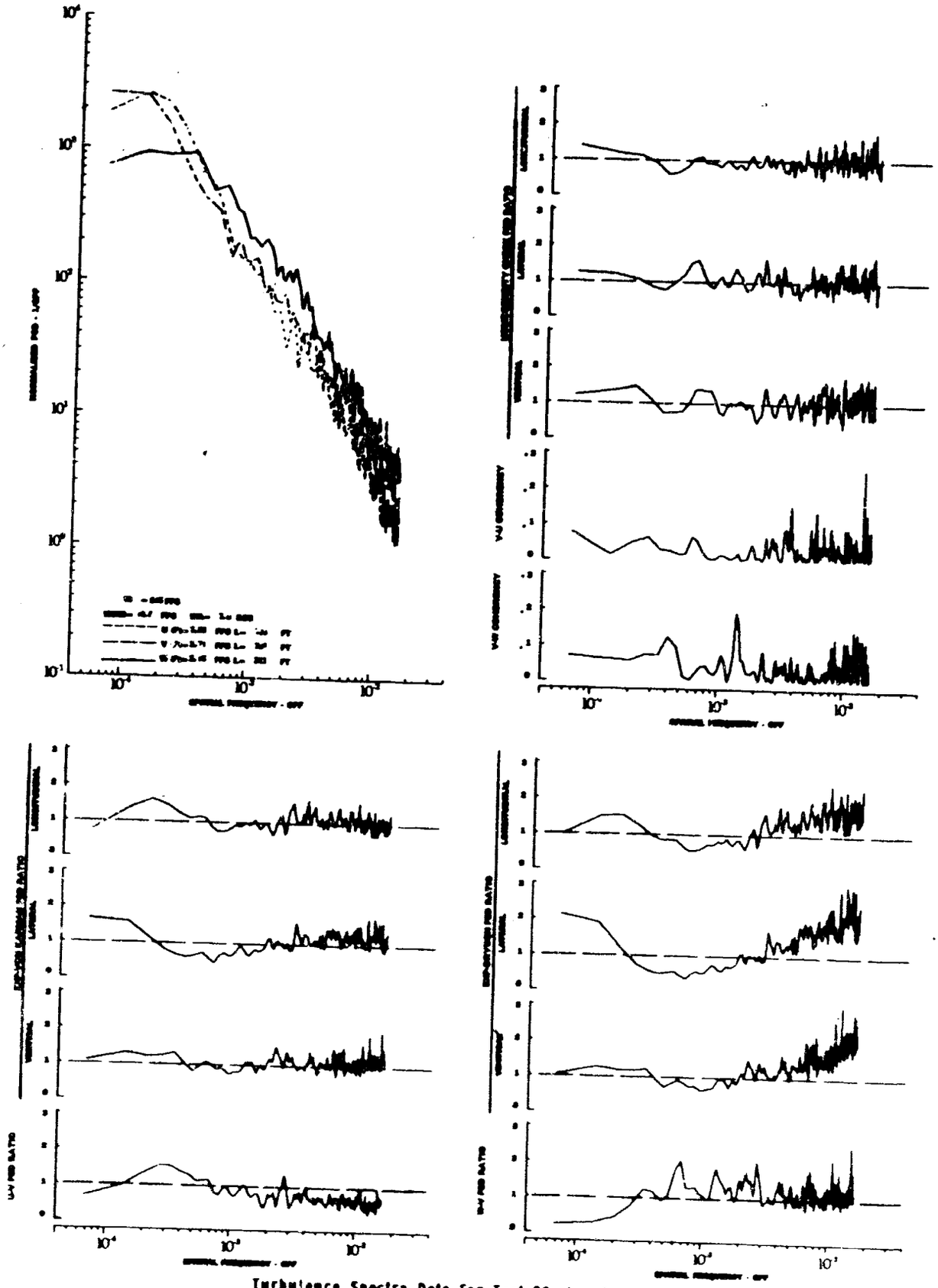

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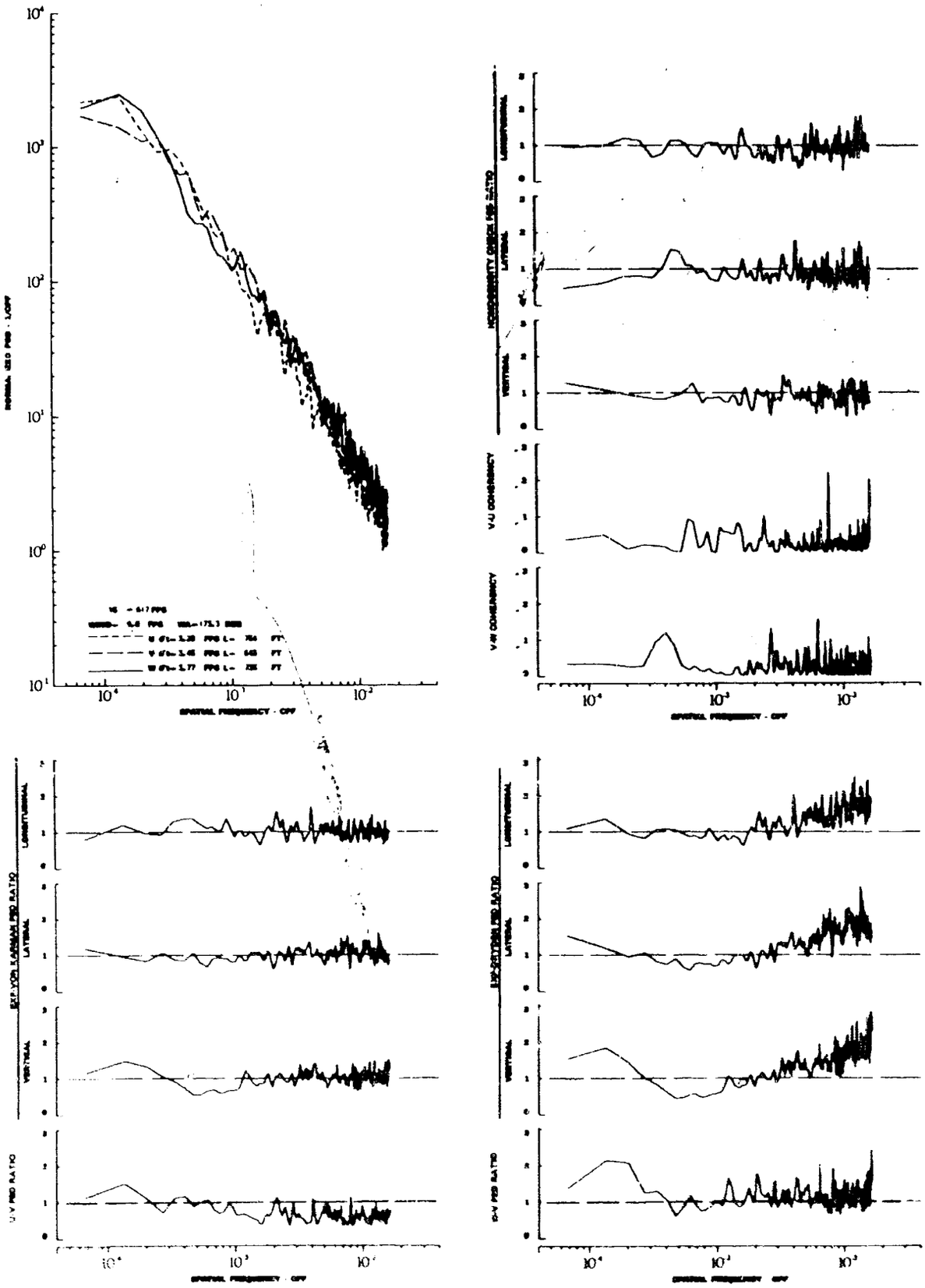

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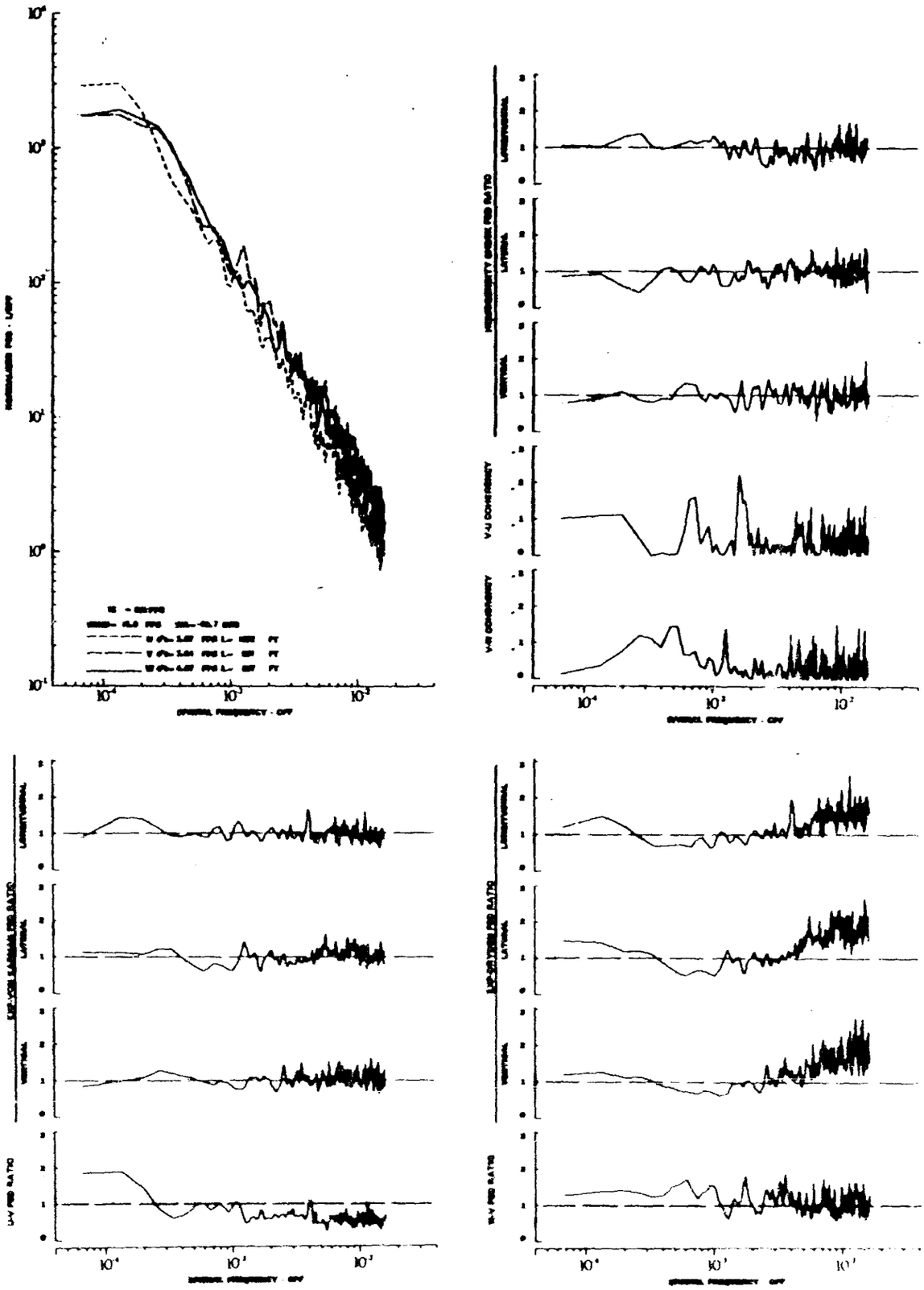

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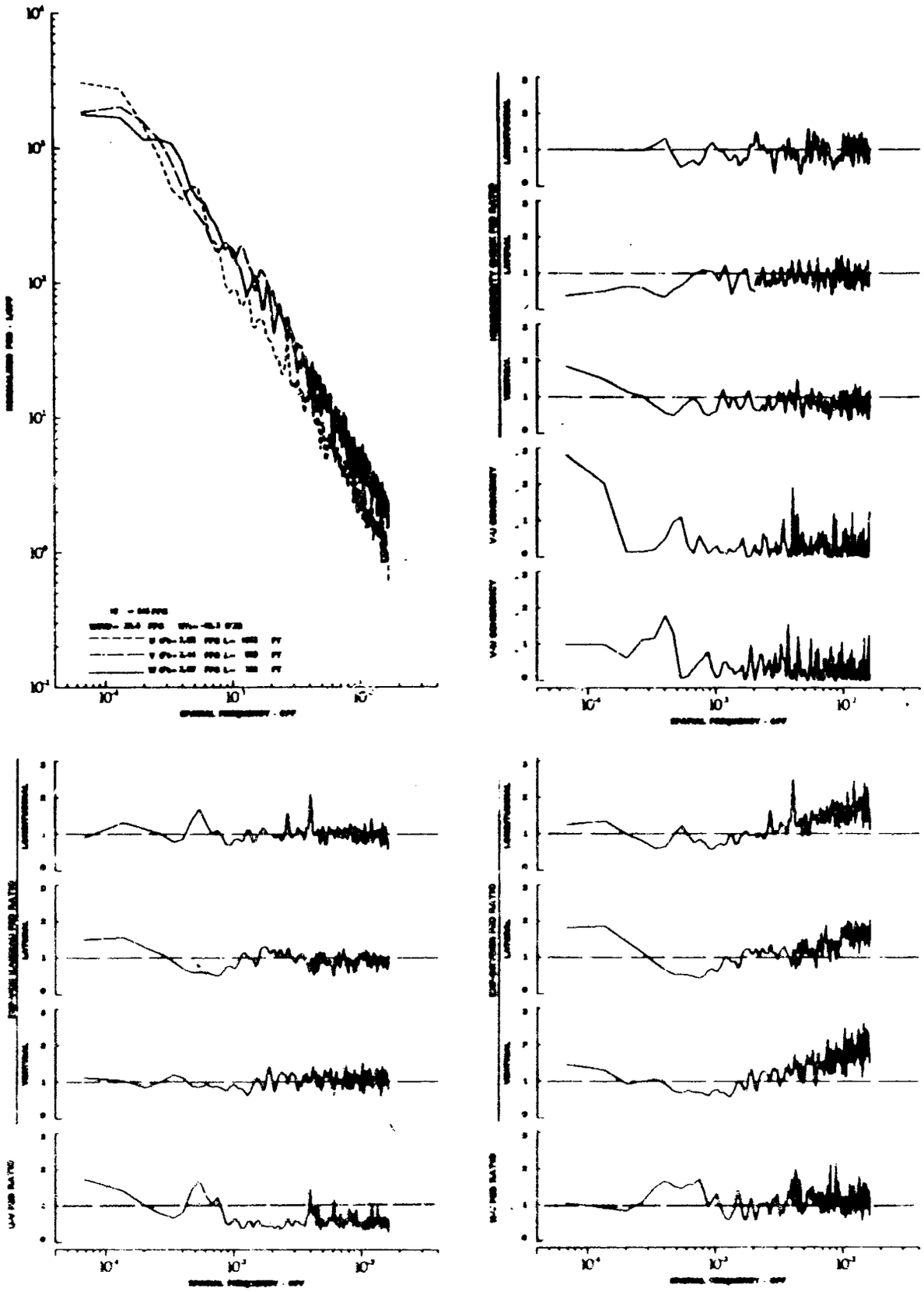

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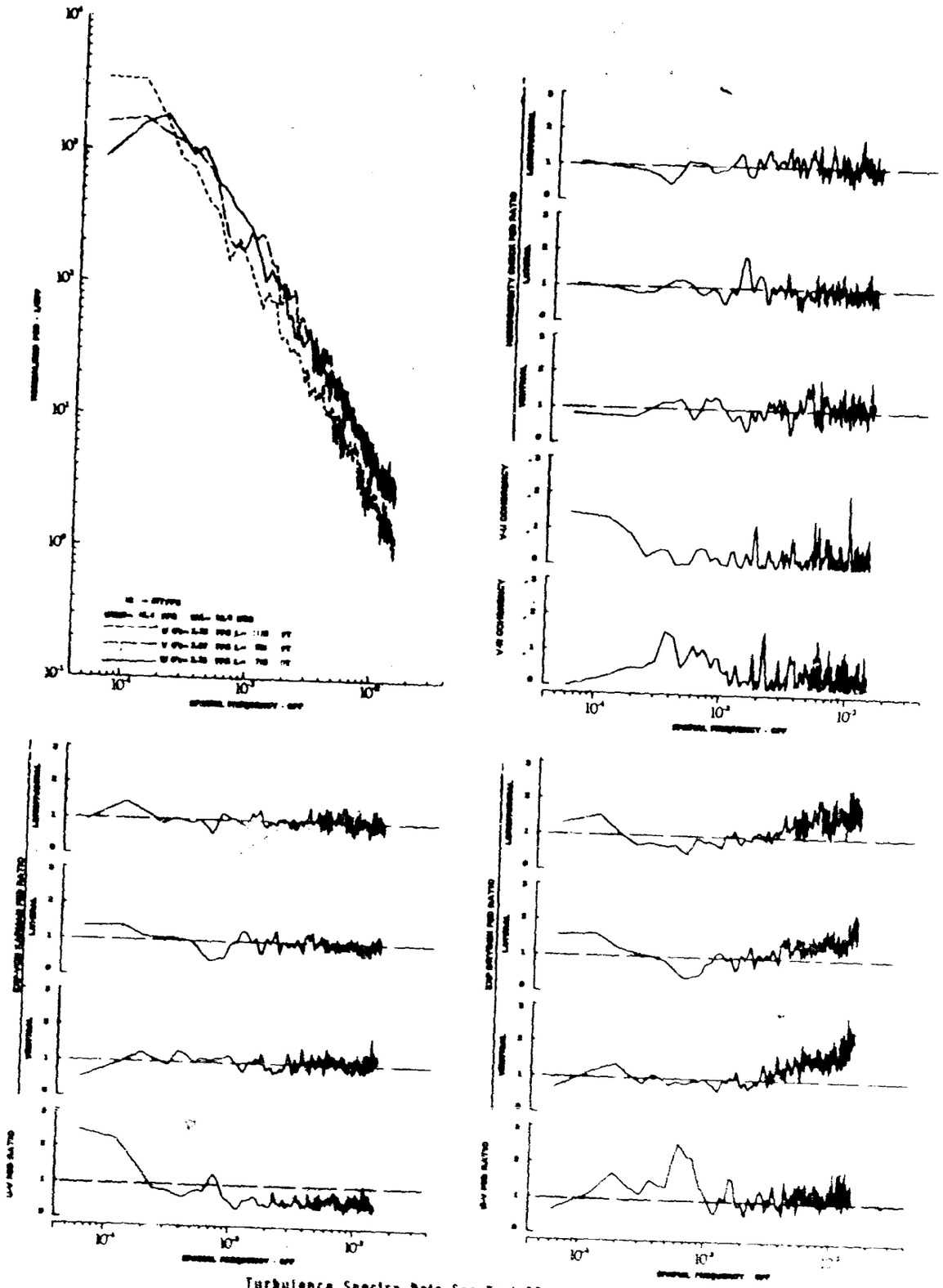

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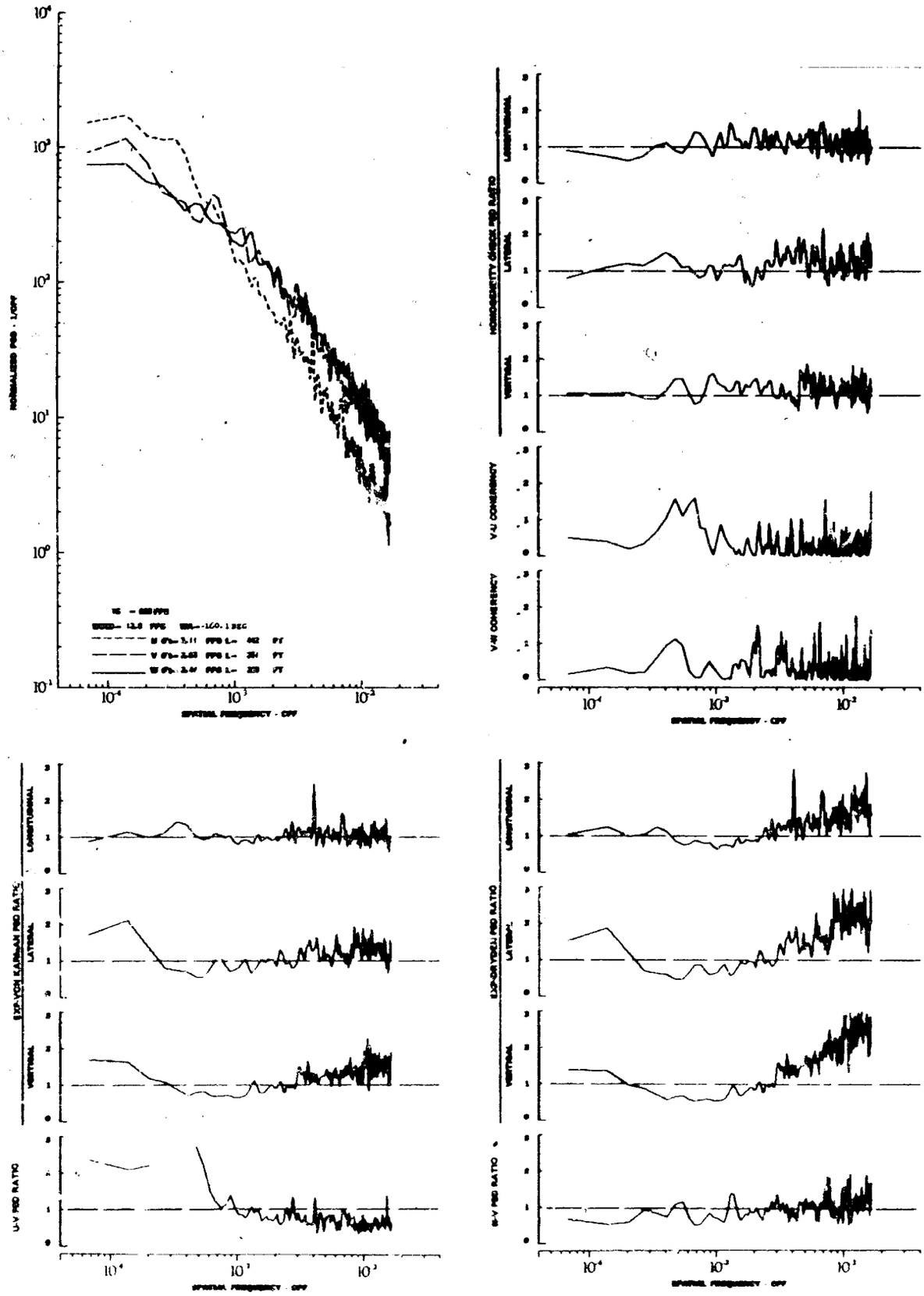

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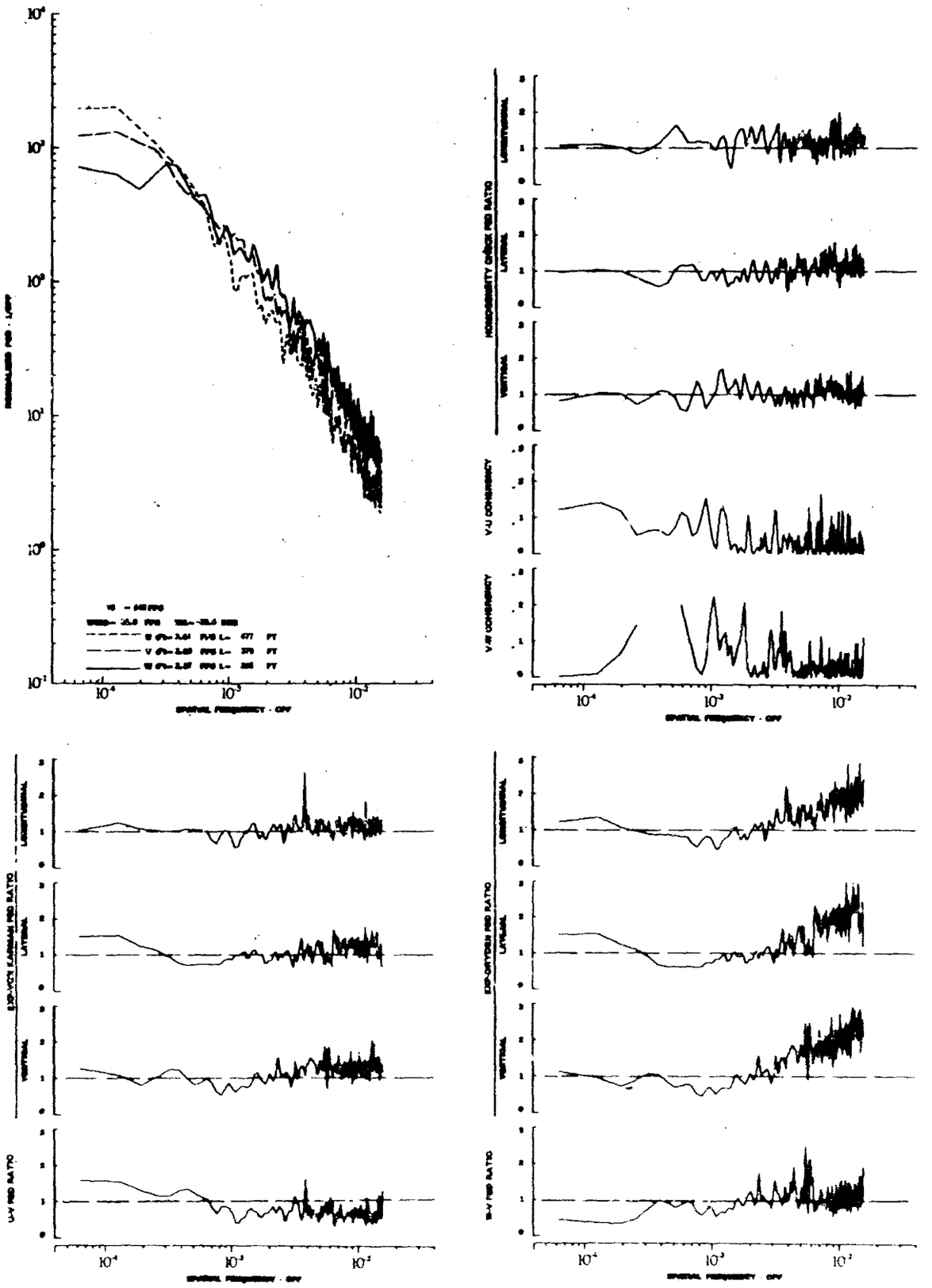

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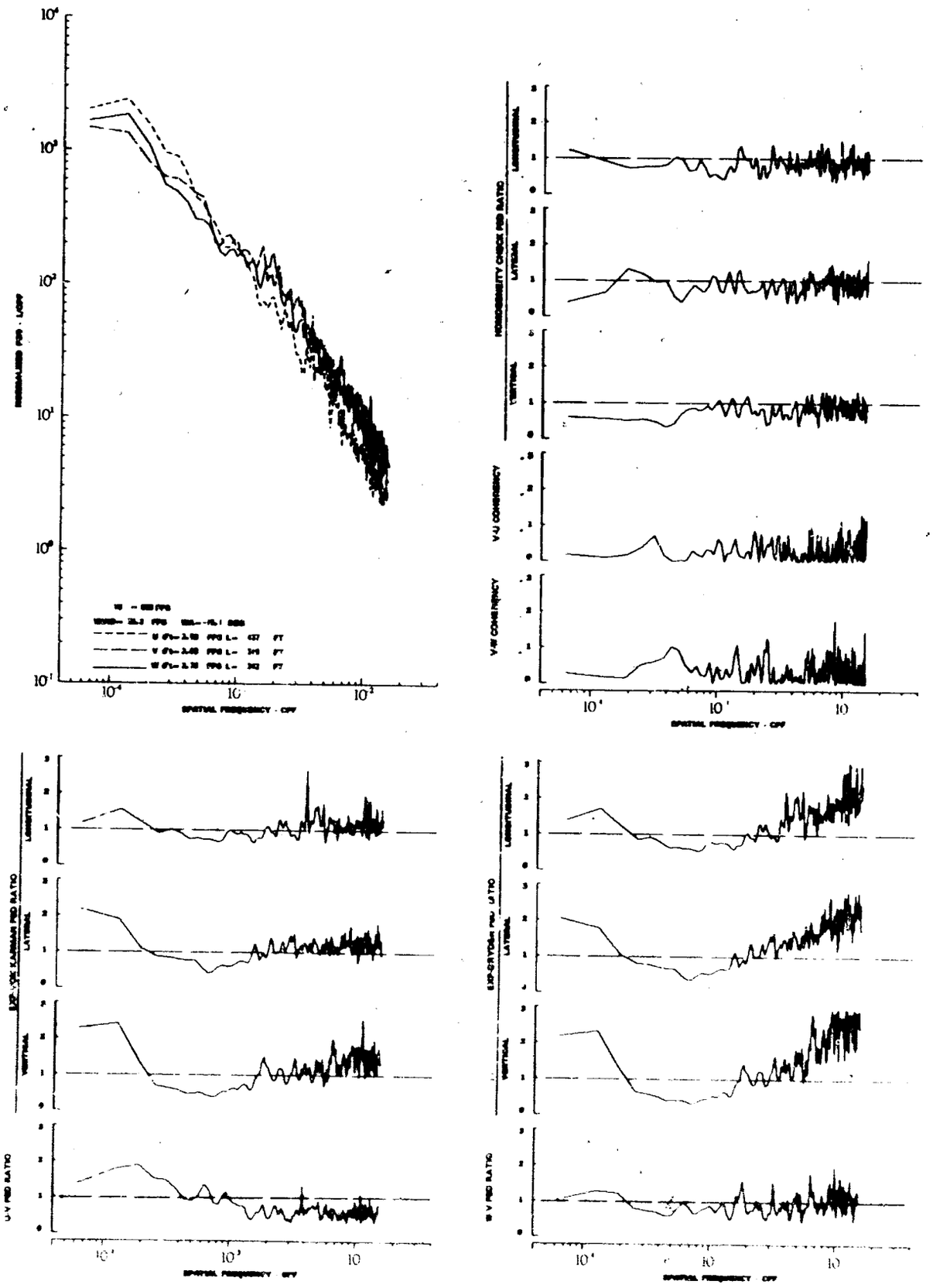

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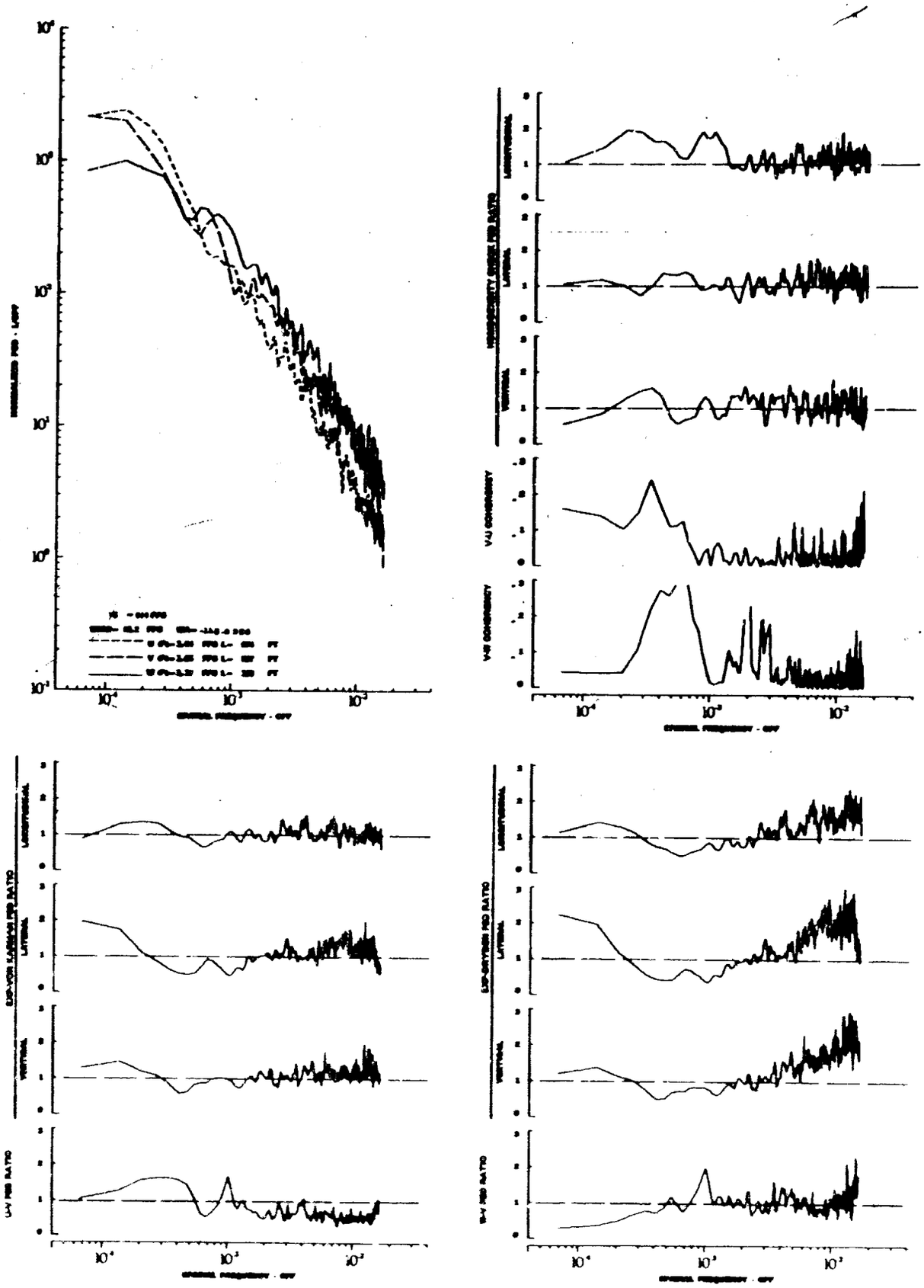

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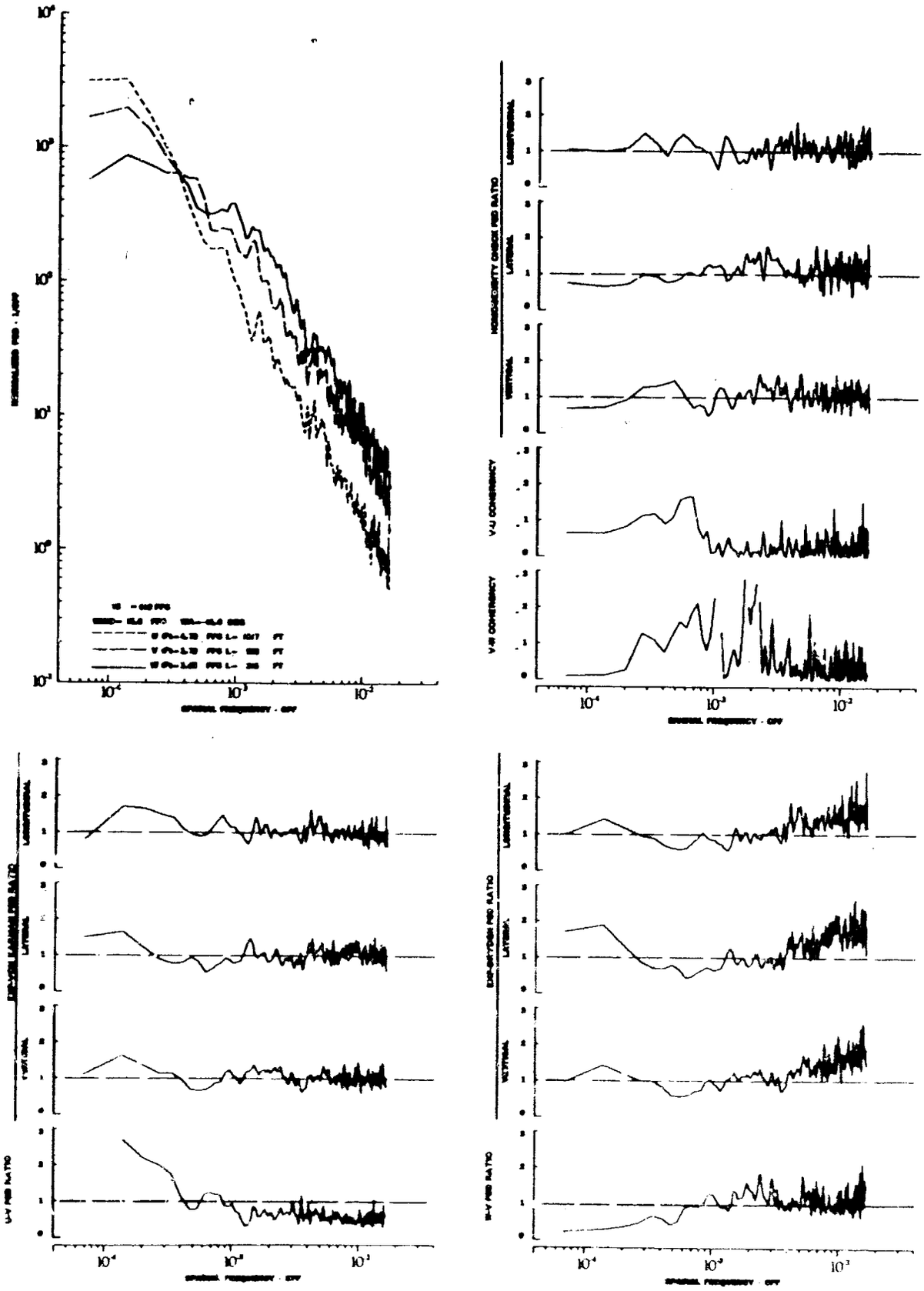

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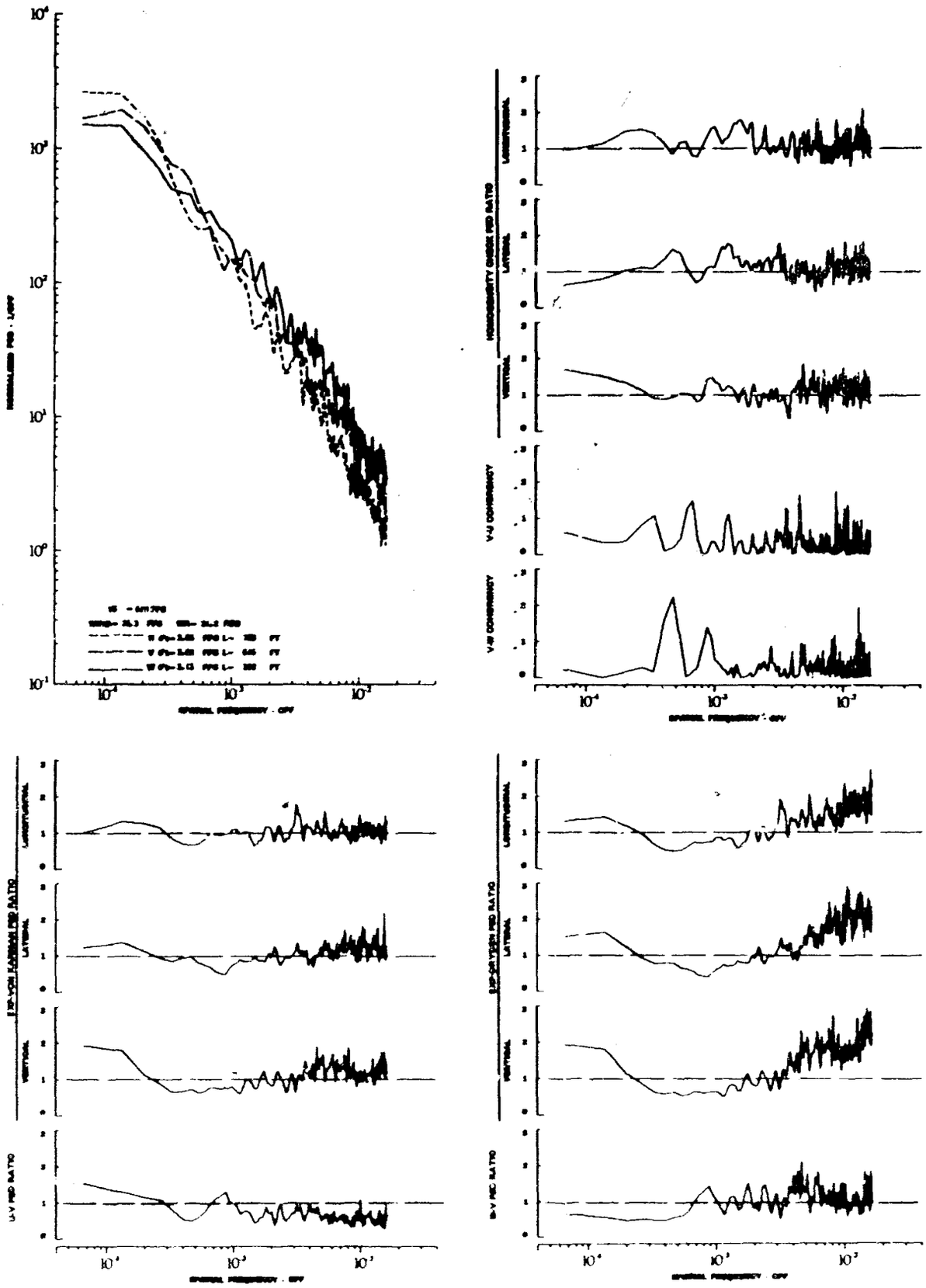

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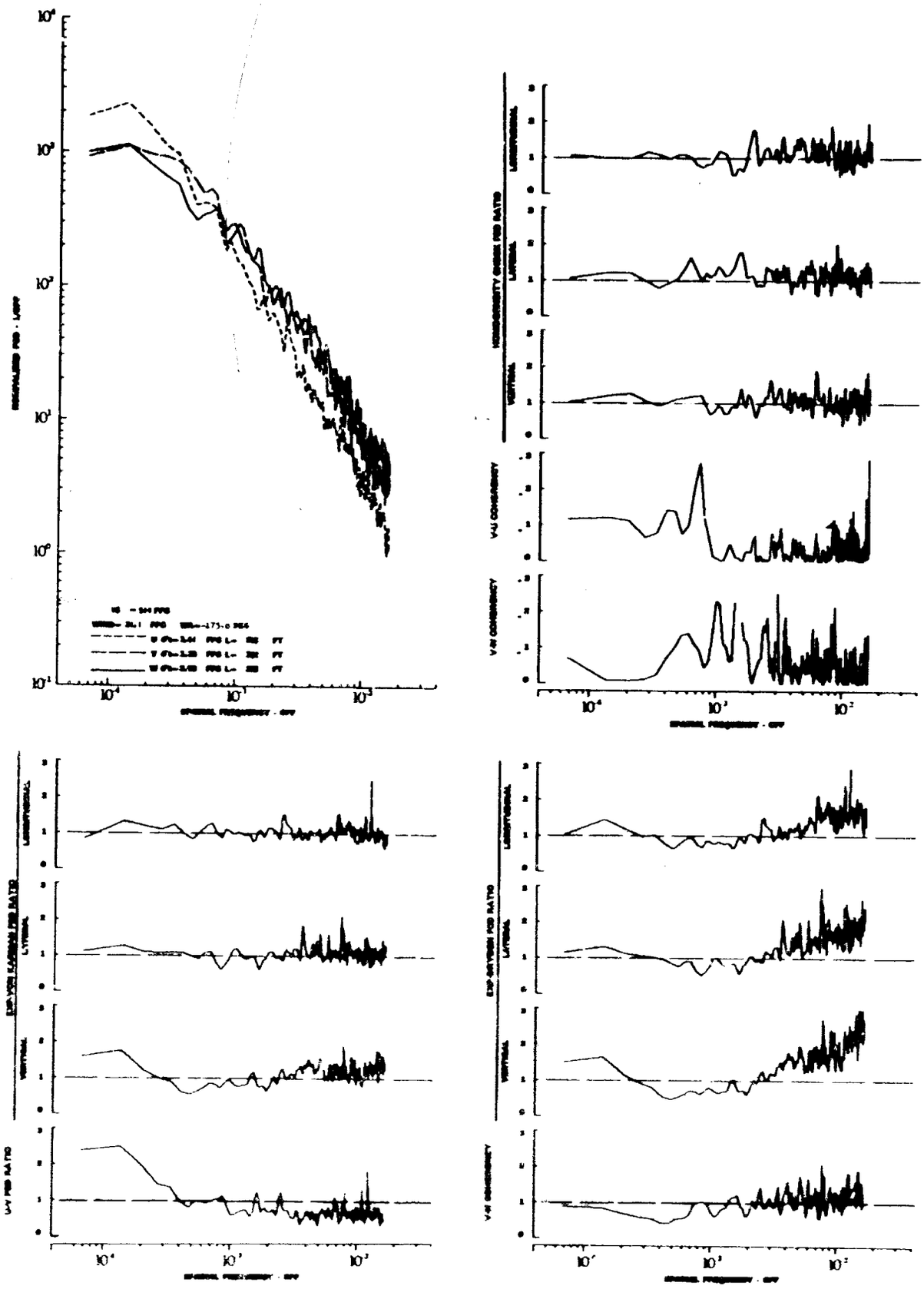

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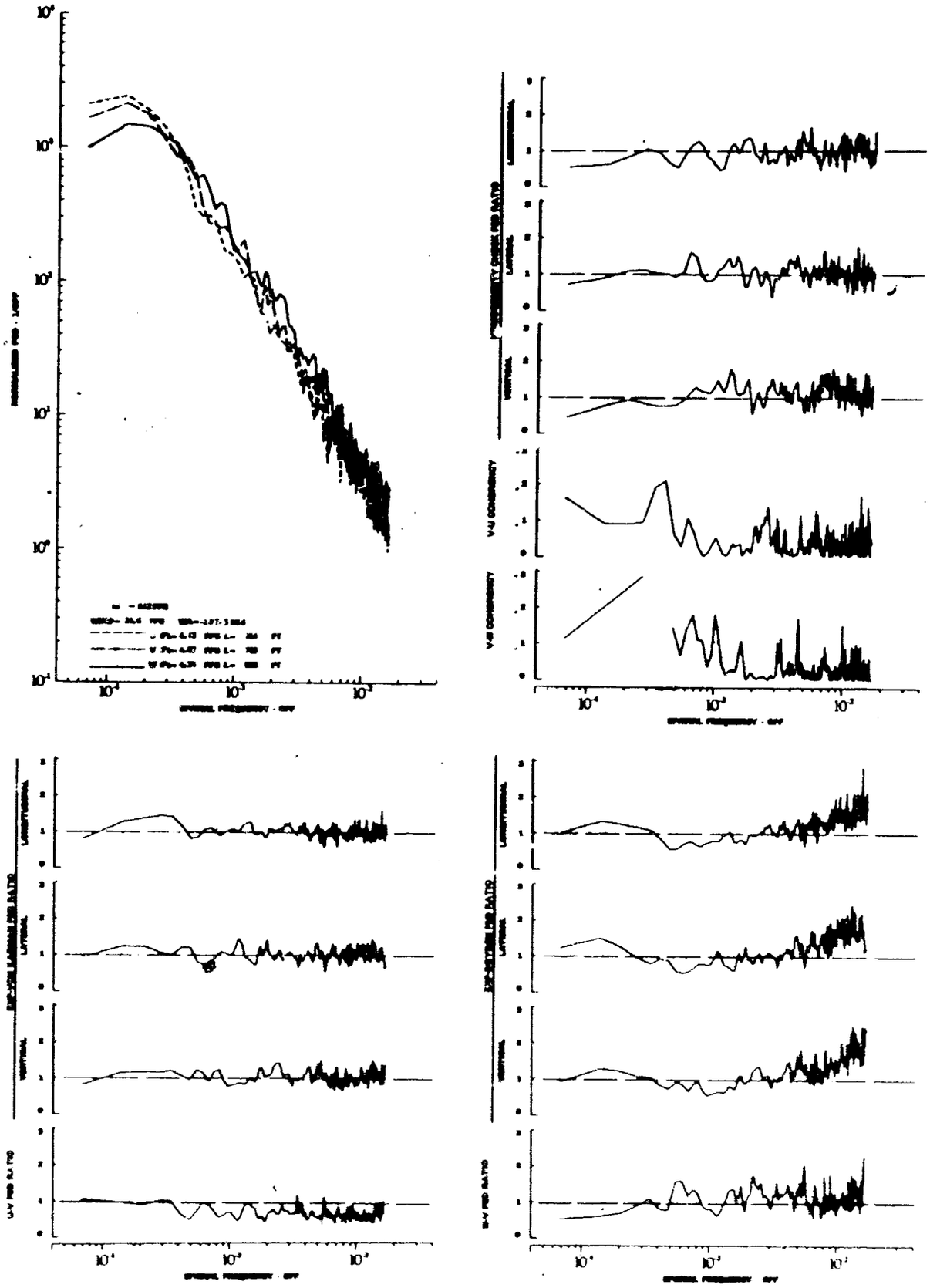
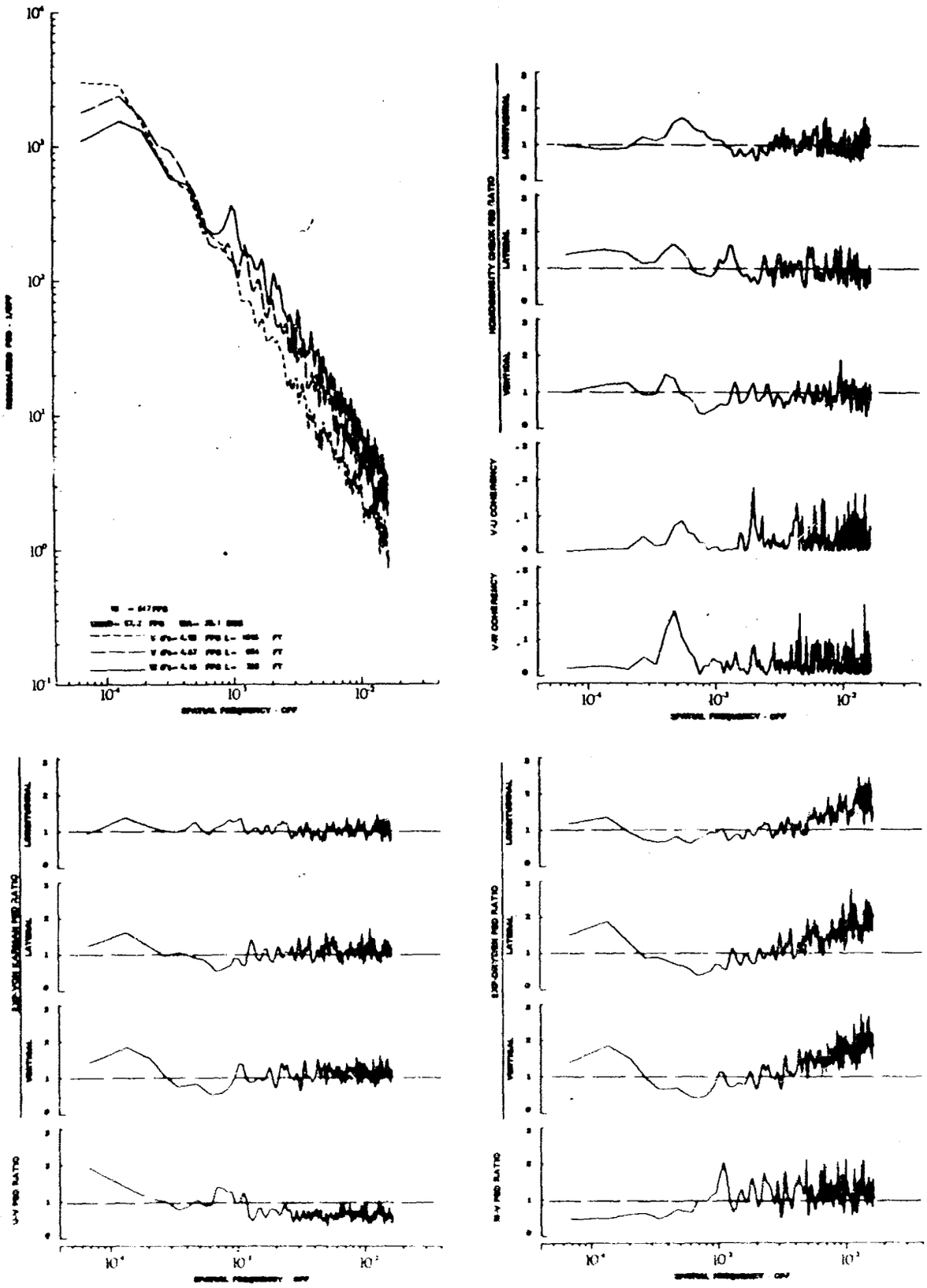


Turbulence Spectra Data For Test 38, Leg 2, Category 424324



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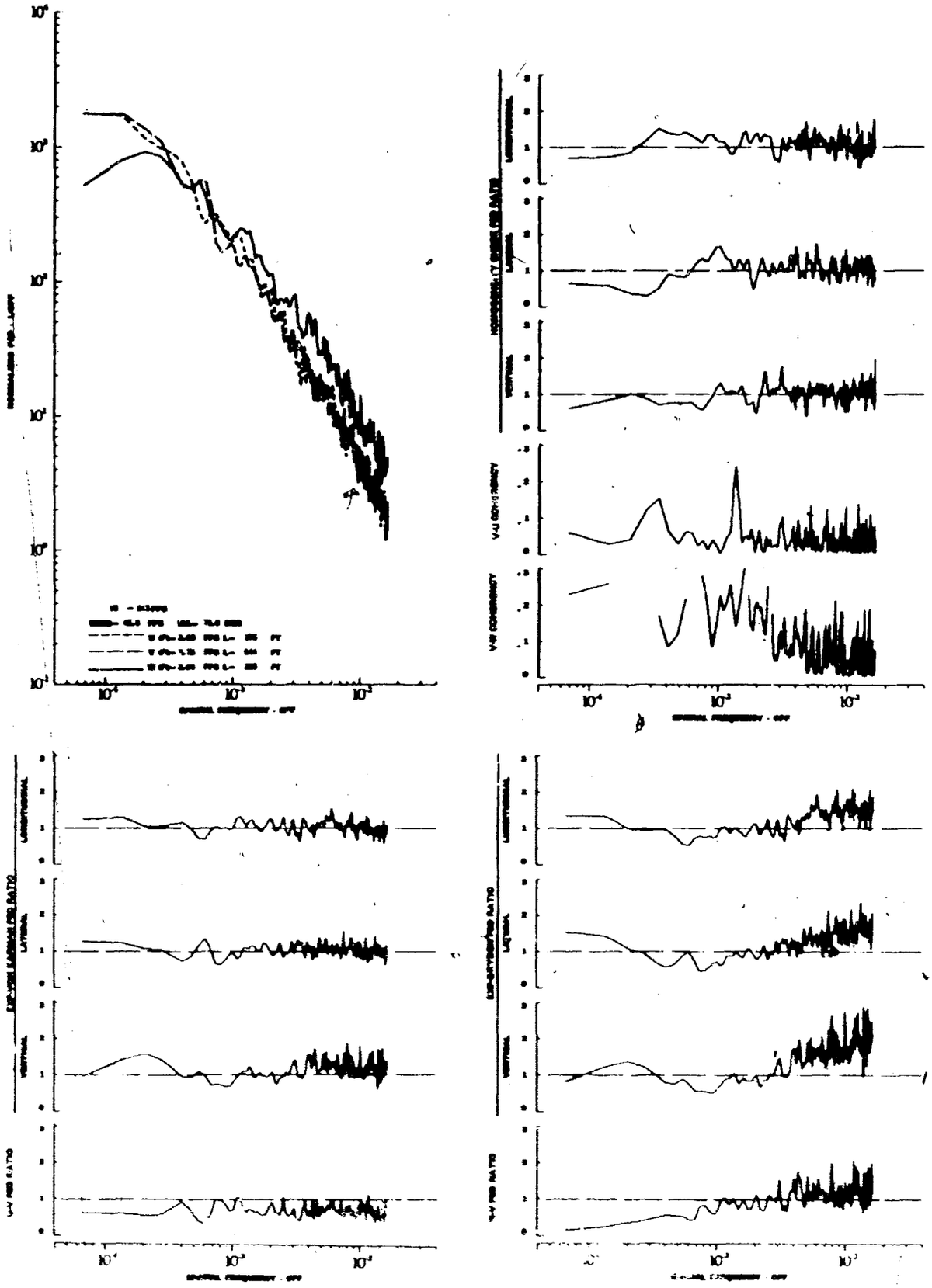

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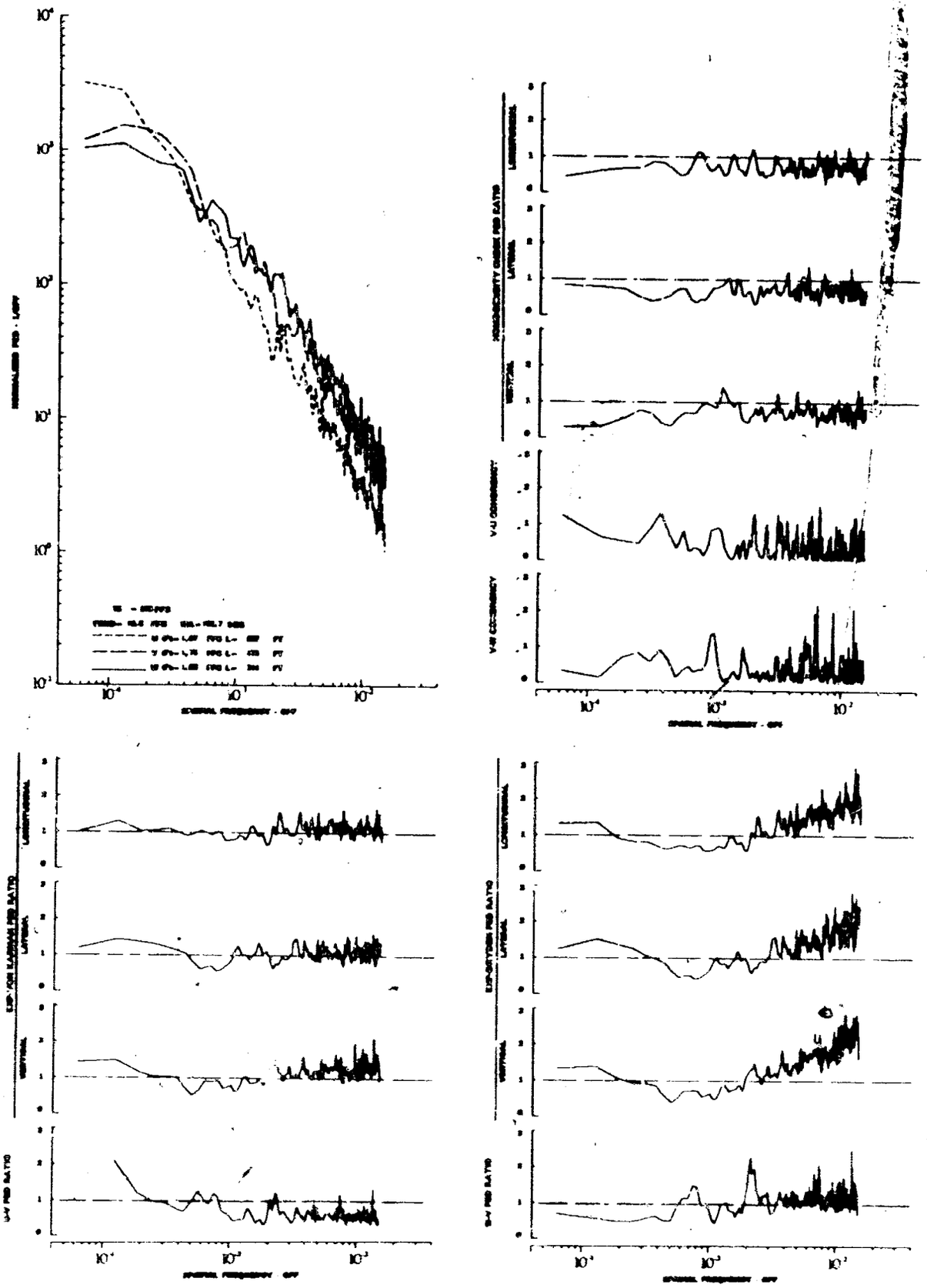

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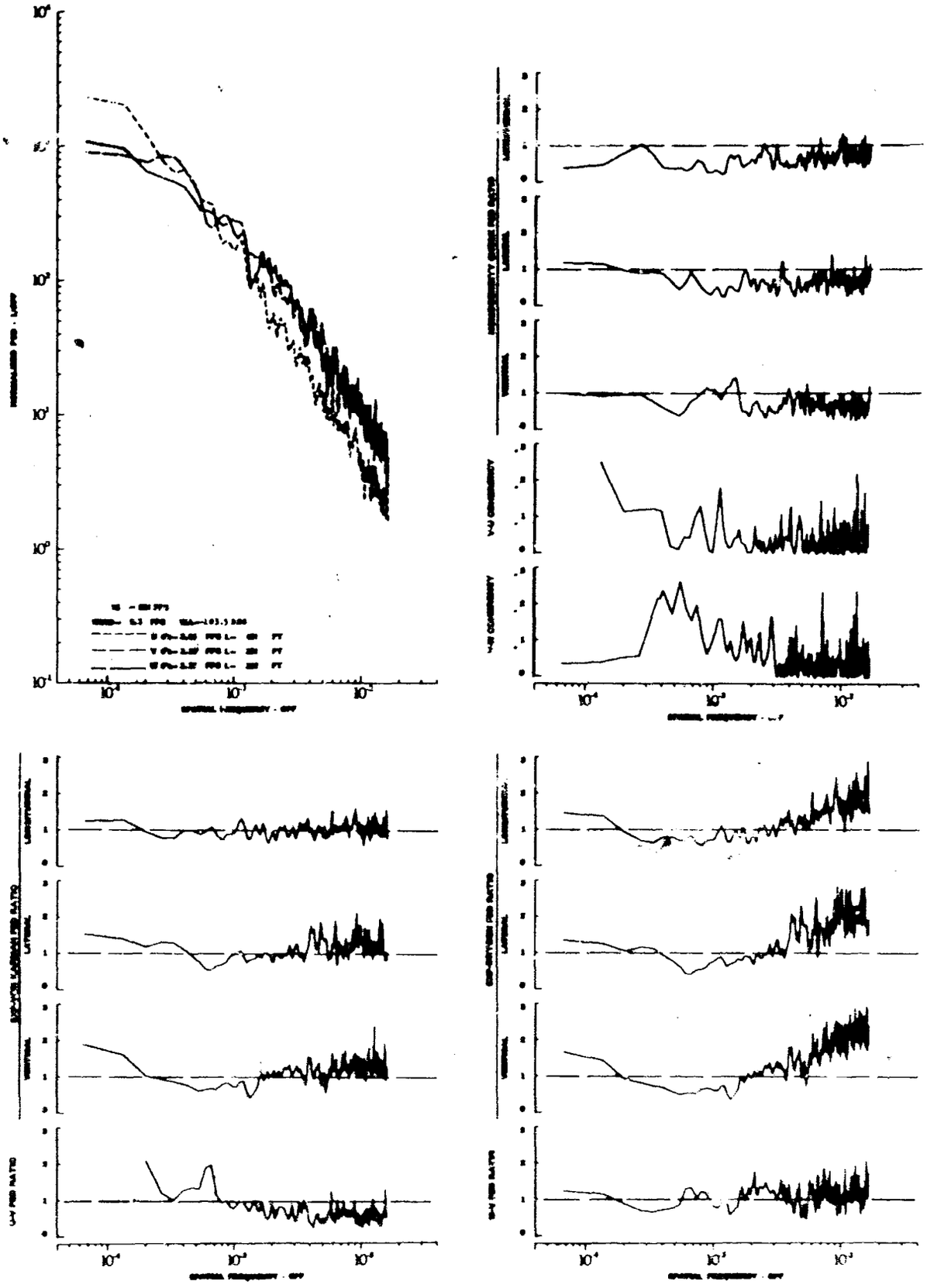

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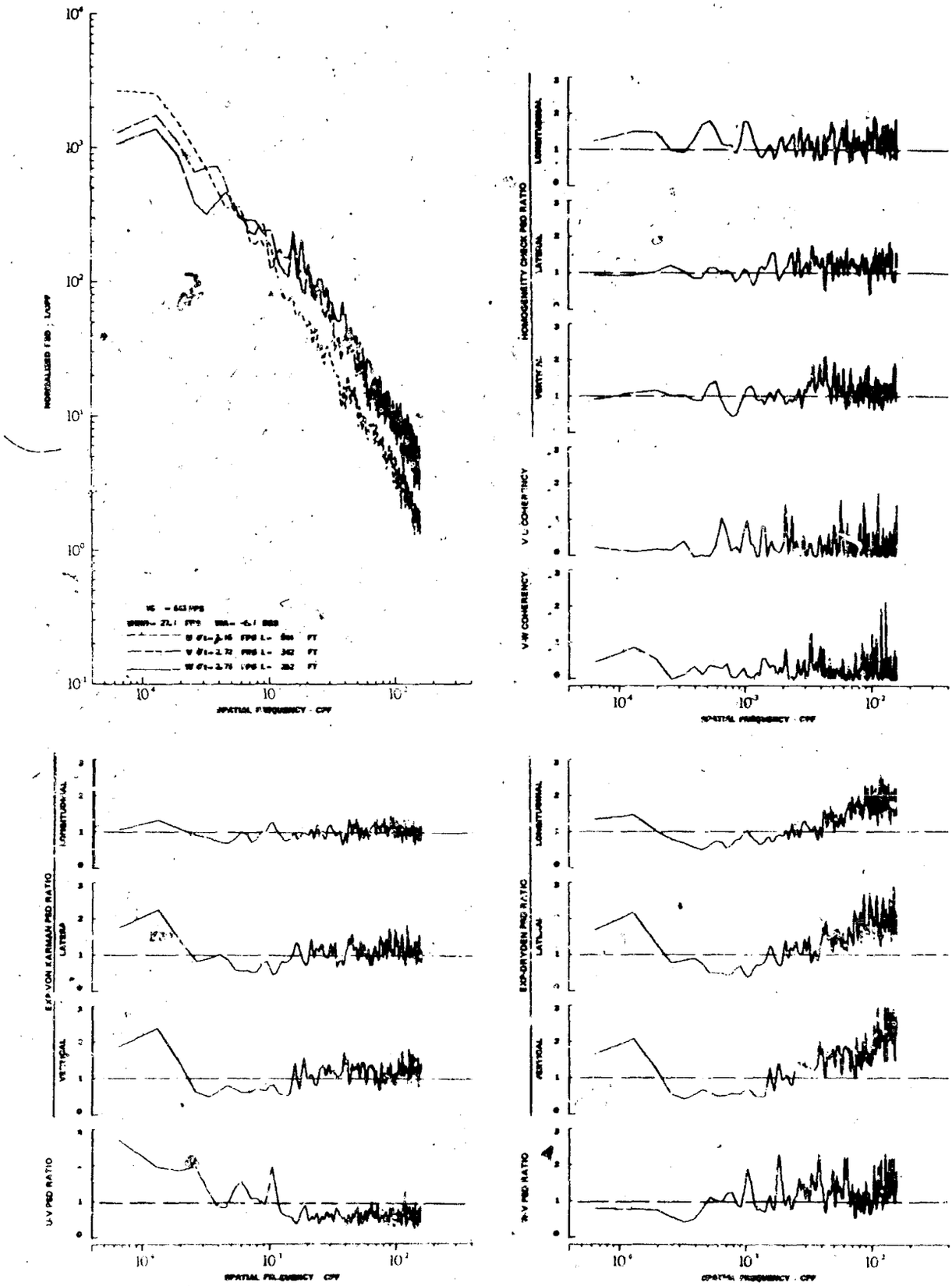

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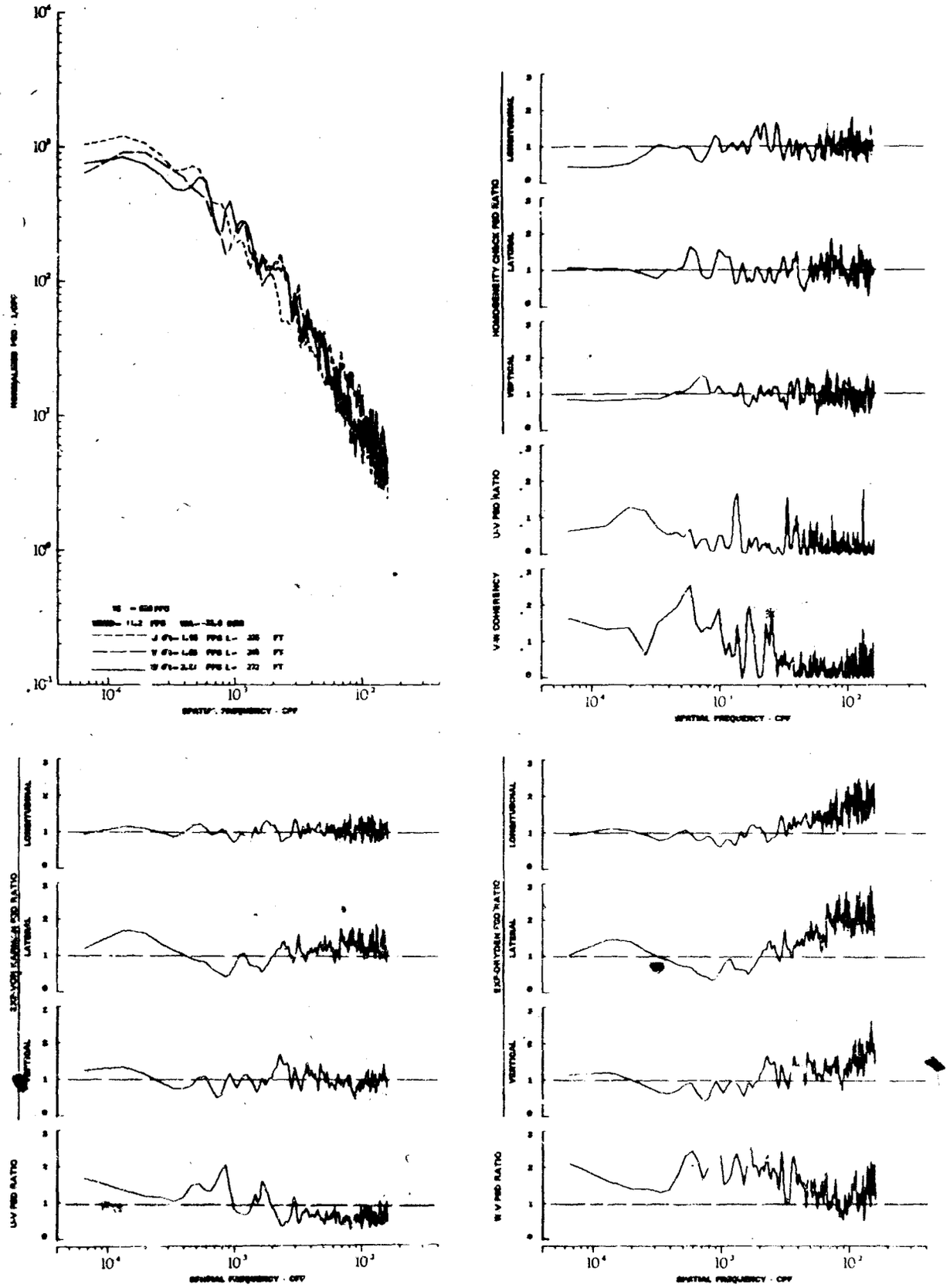

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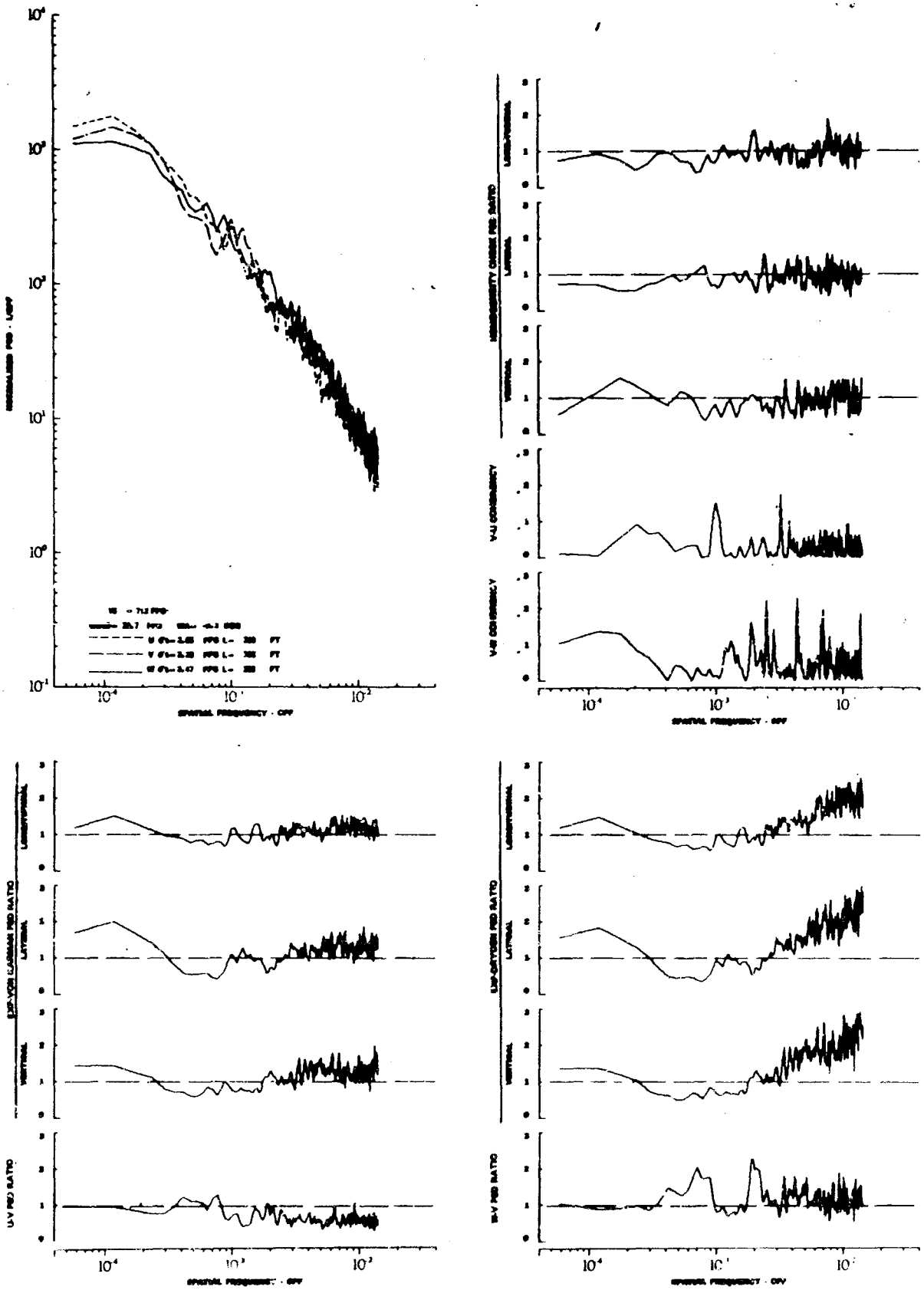

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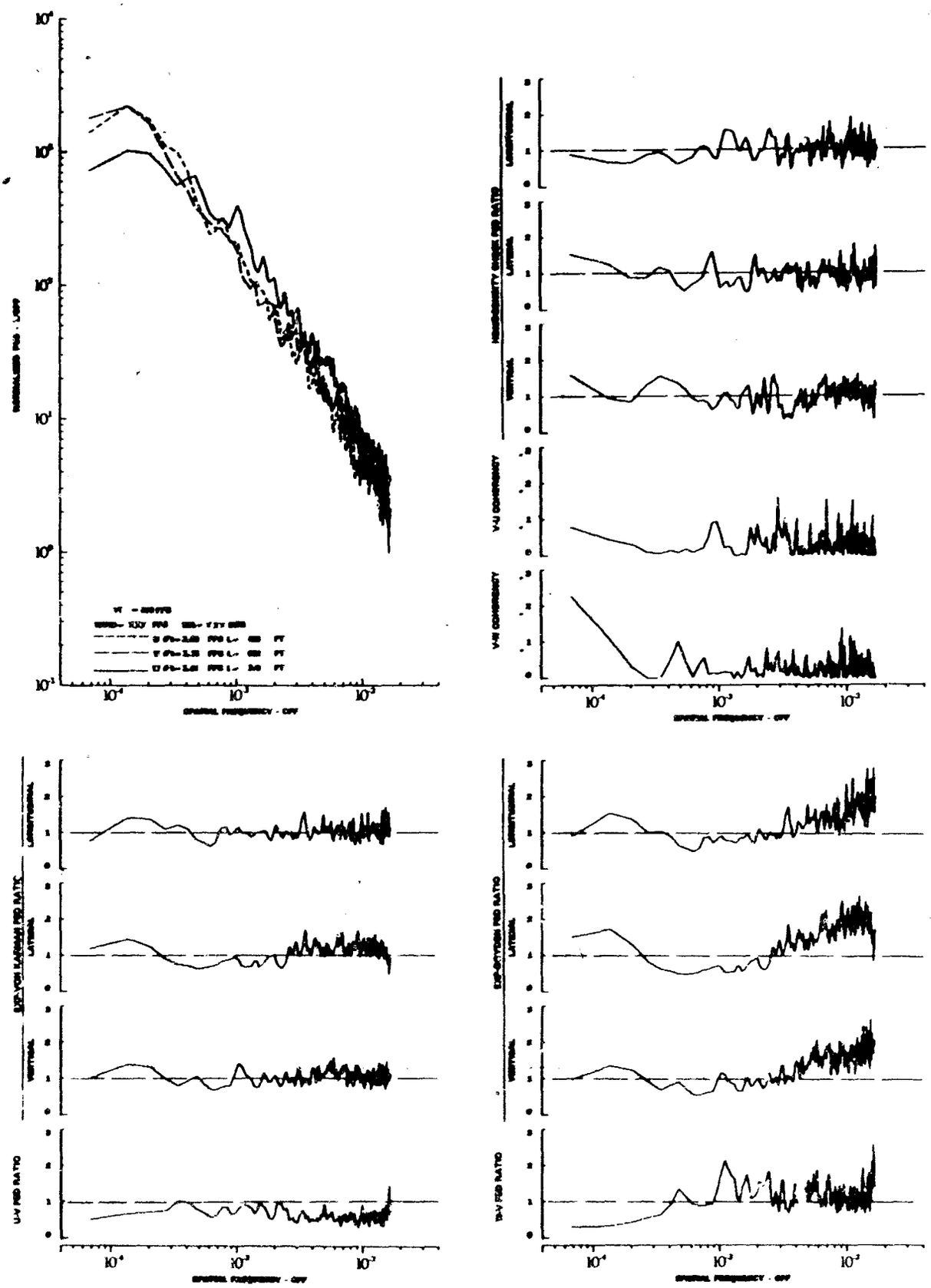

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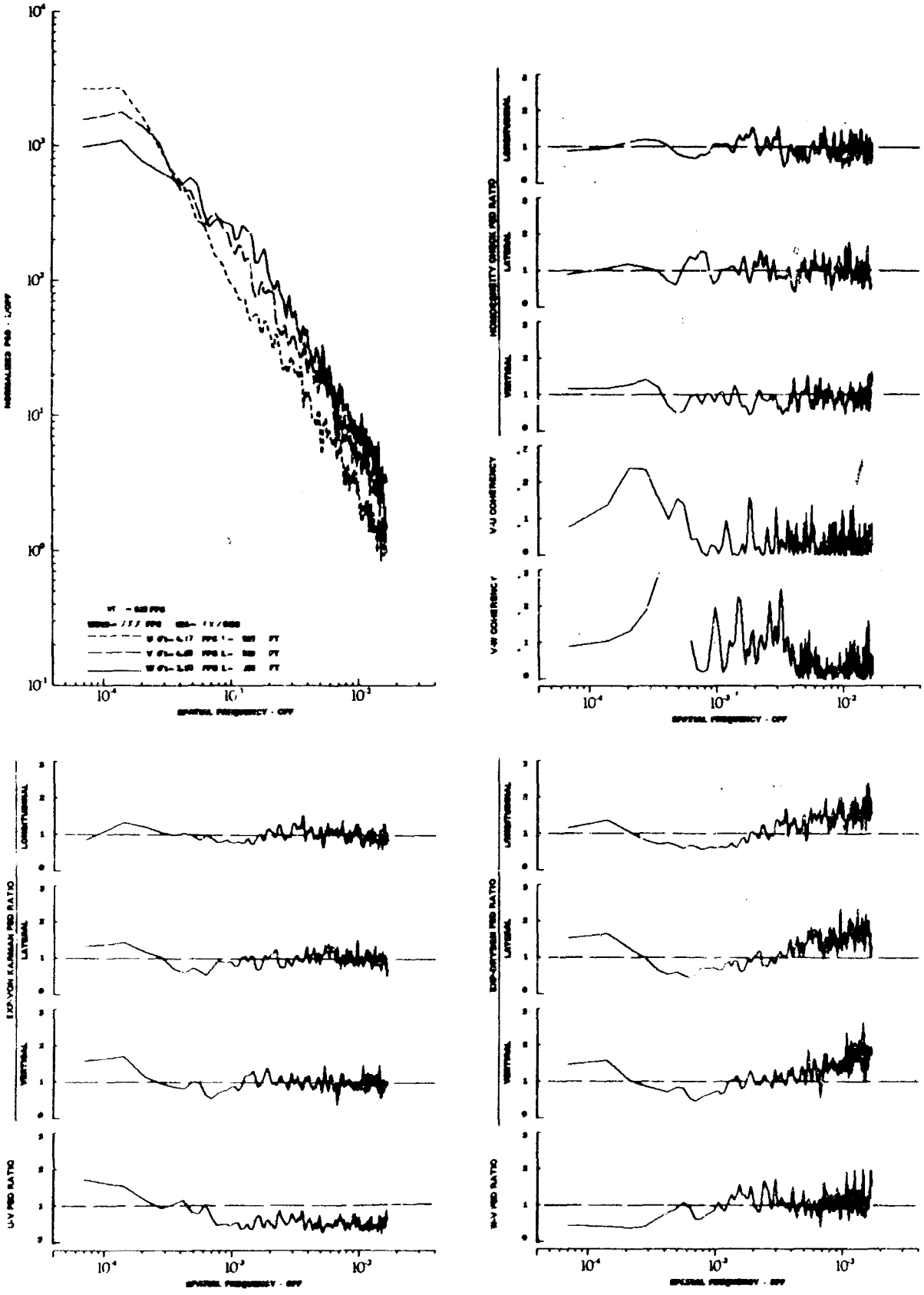

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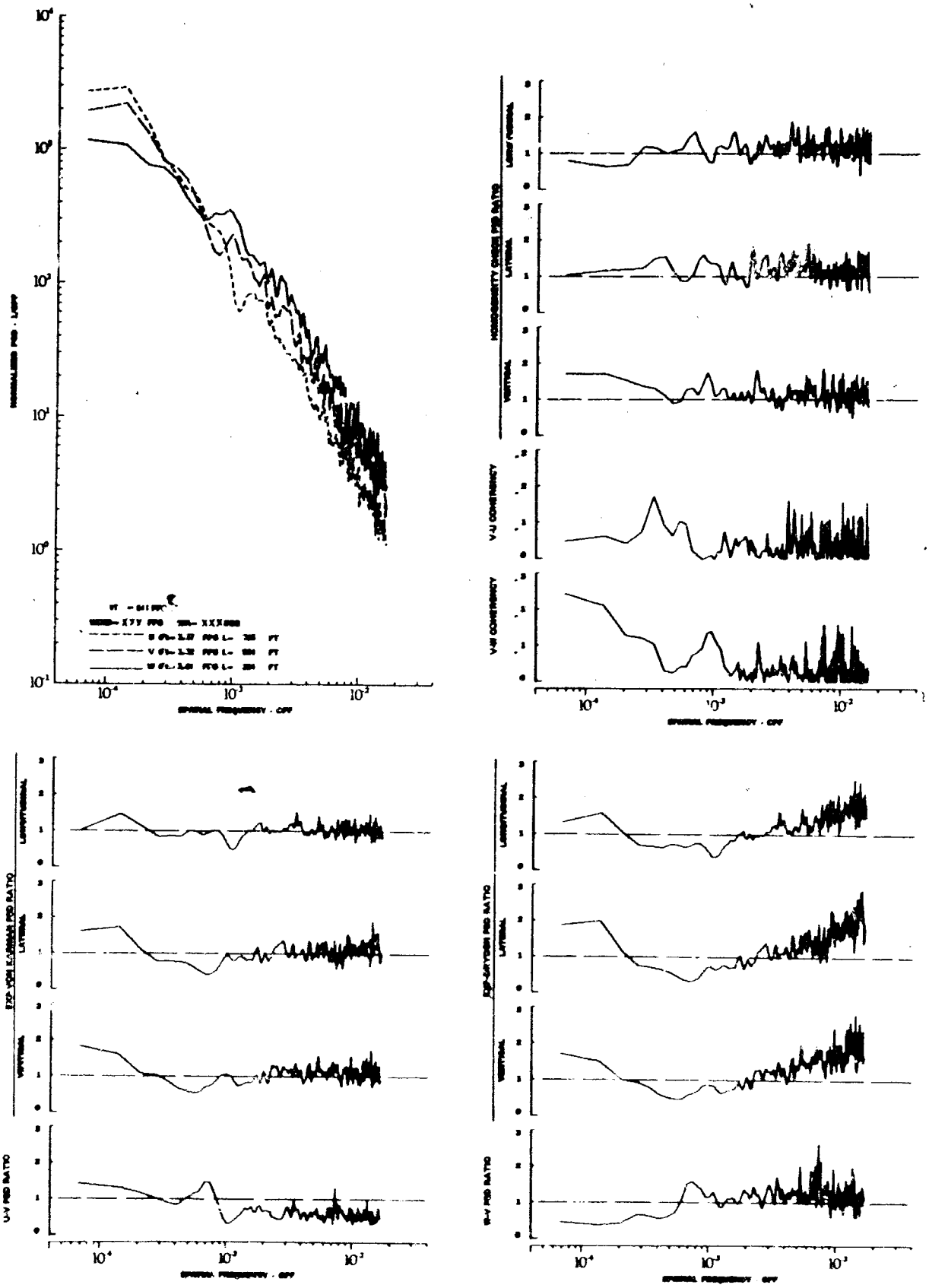

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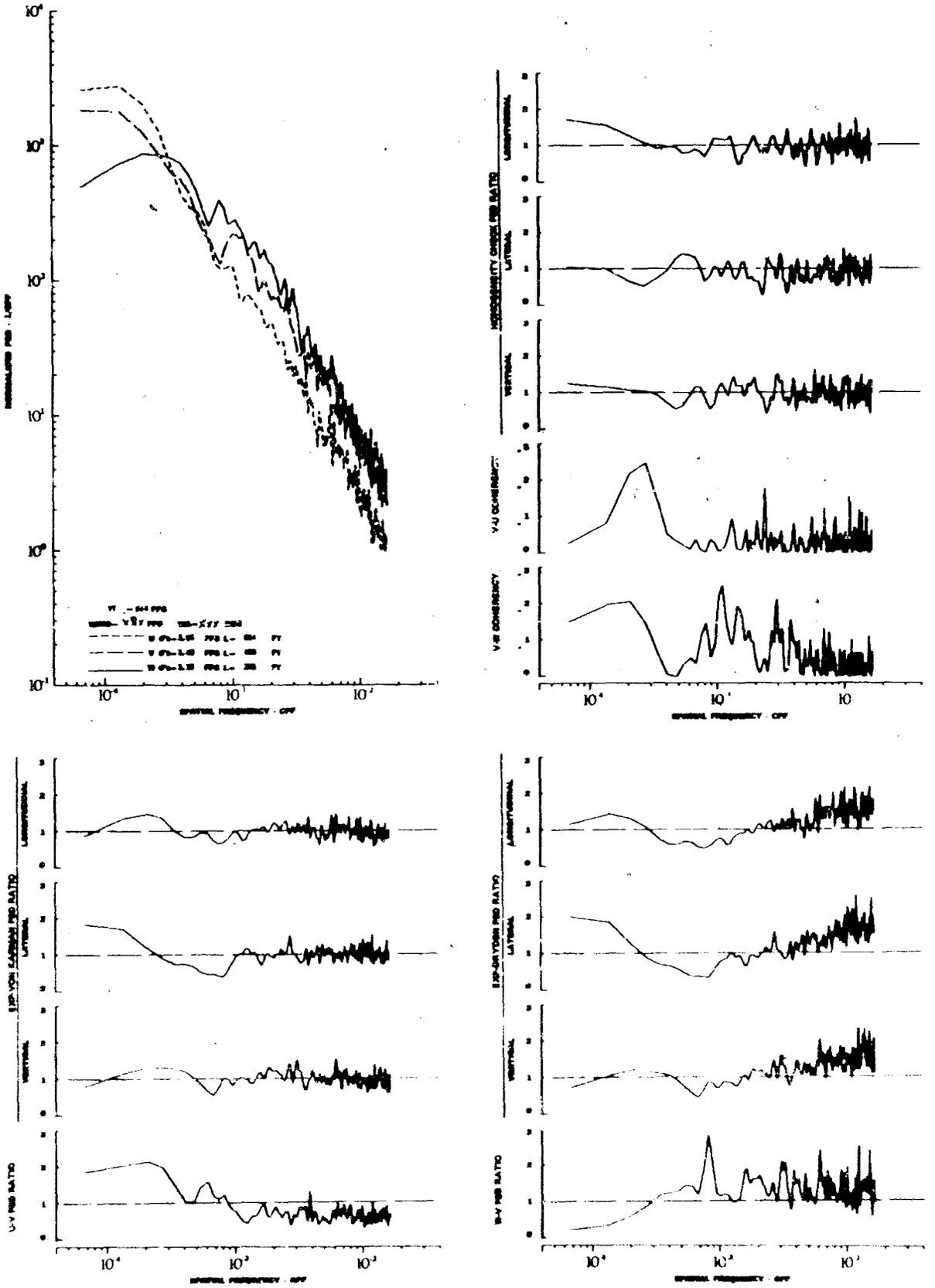

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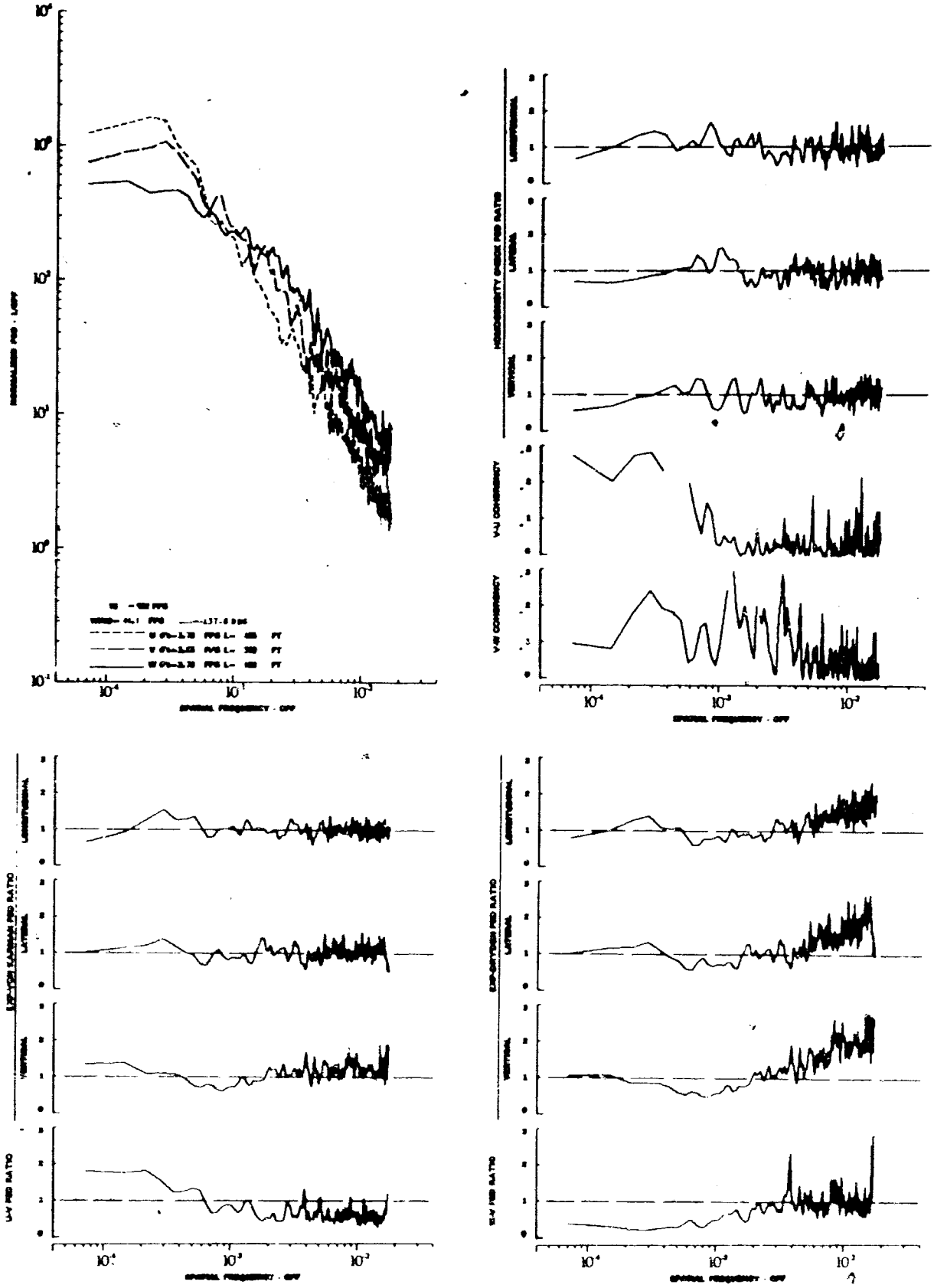

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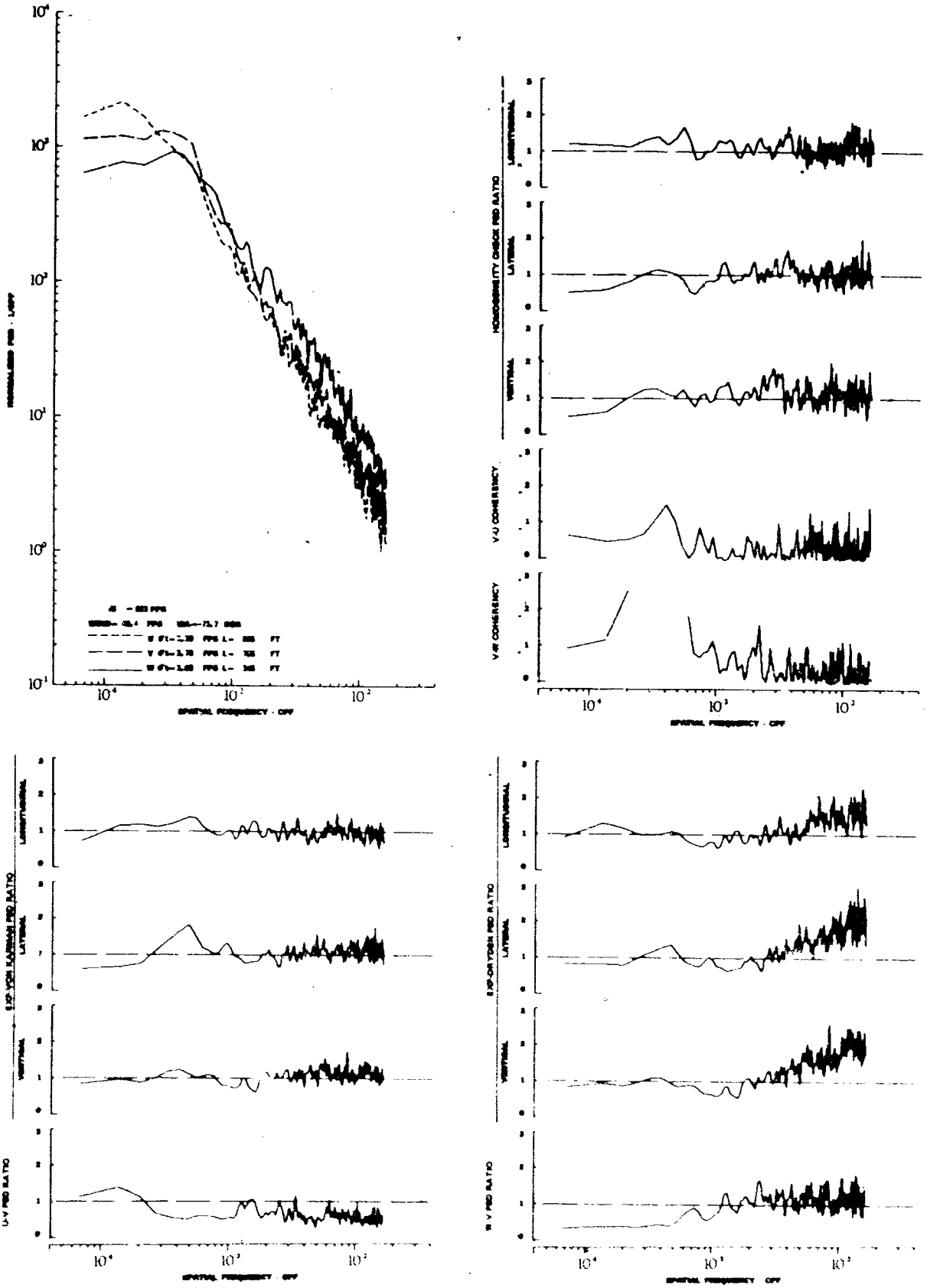

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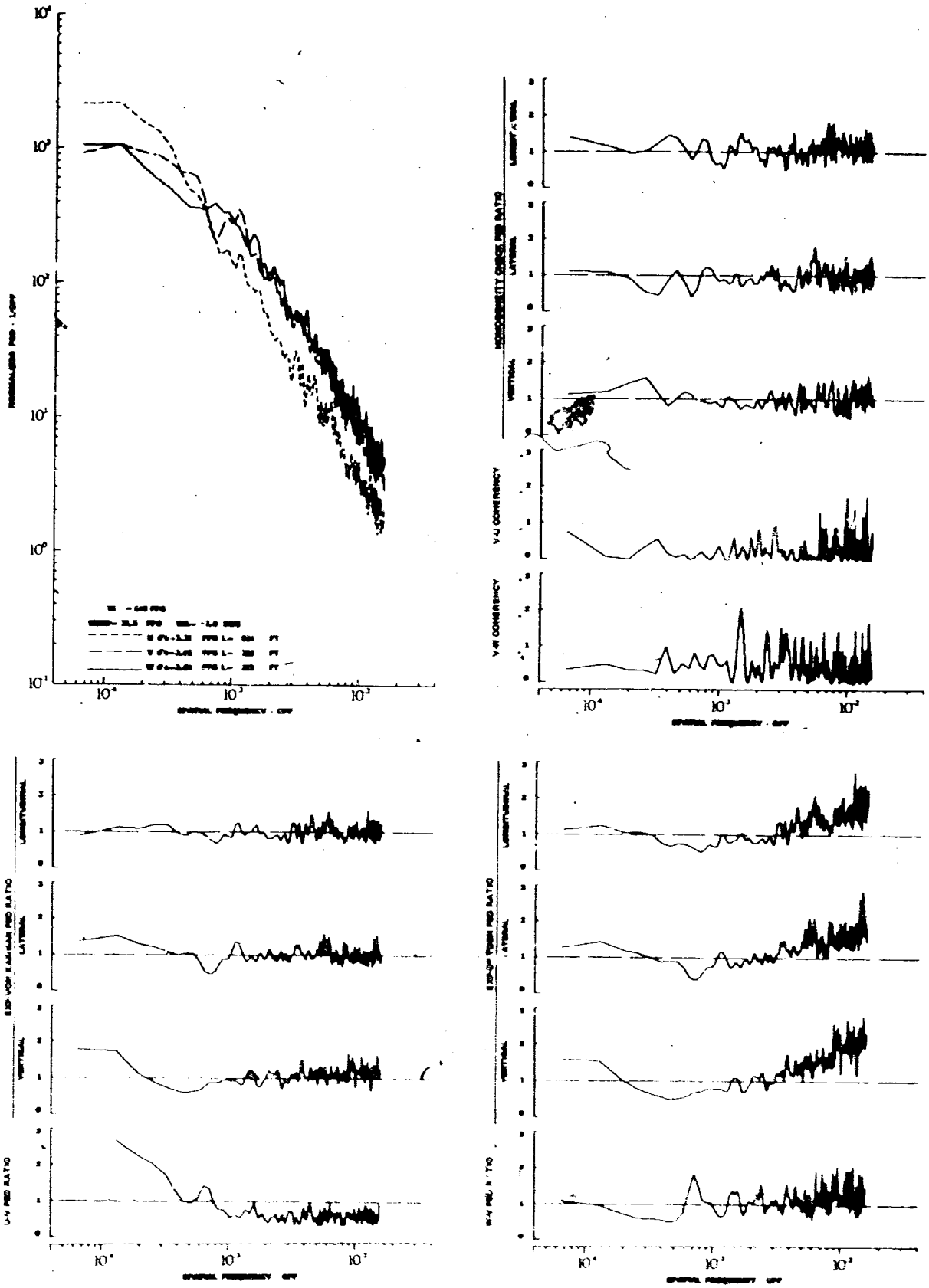
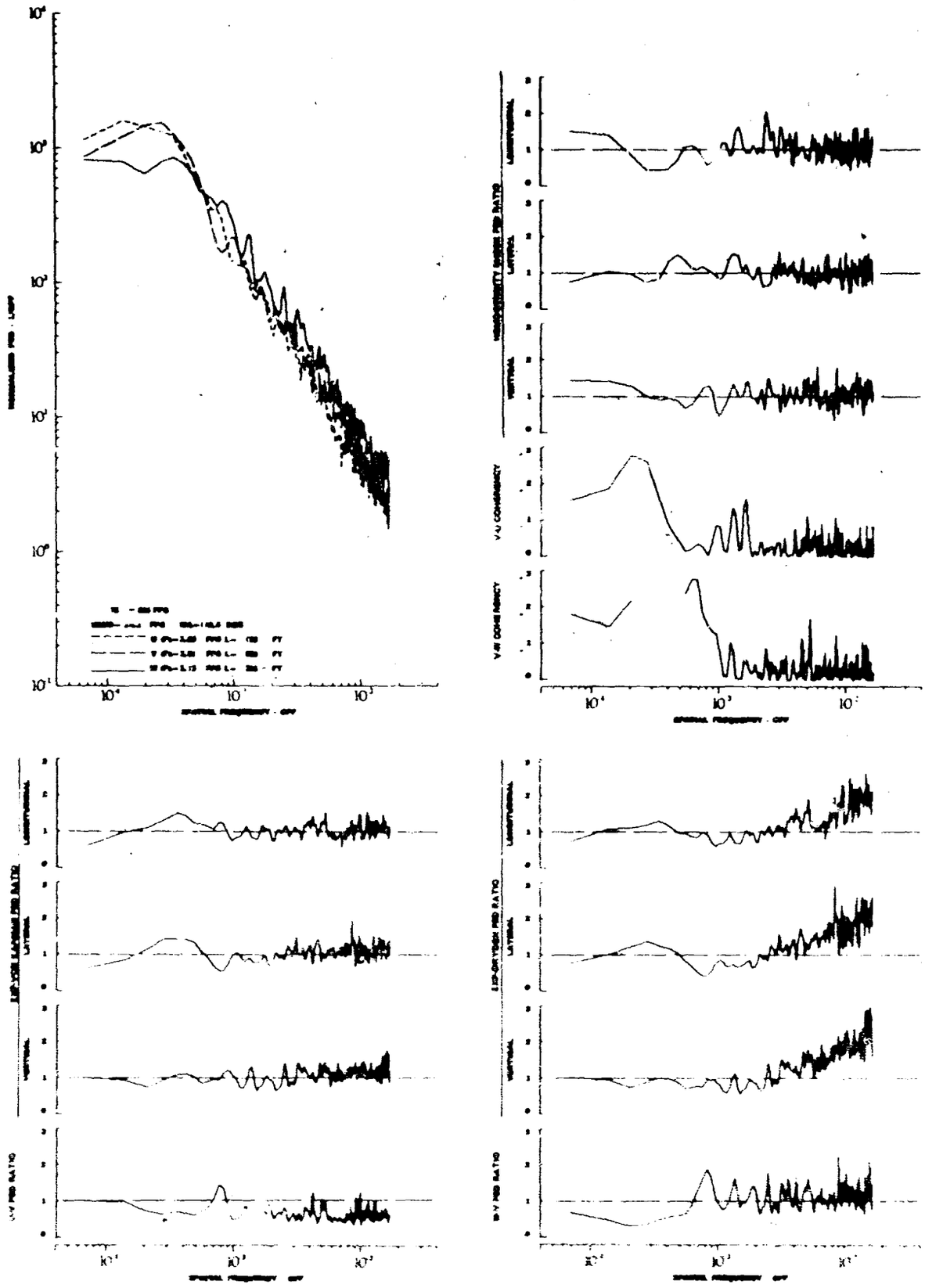


Tu.bulence Spectra Data For Test 43, Leg 5, Category 422224



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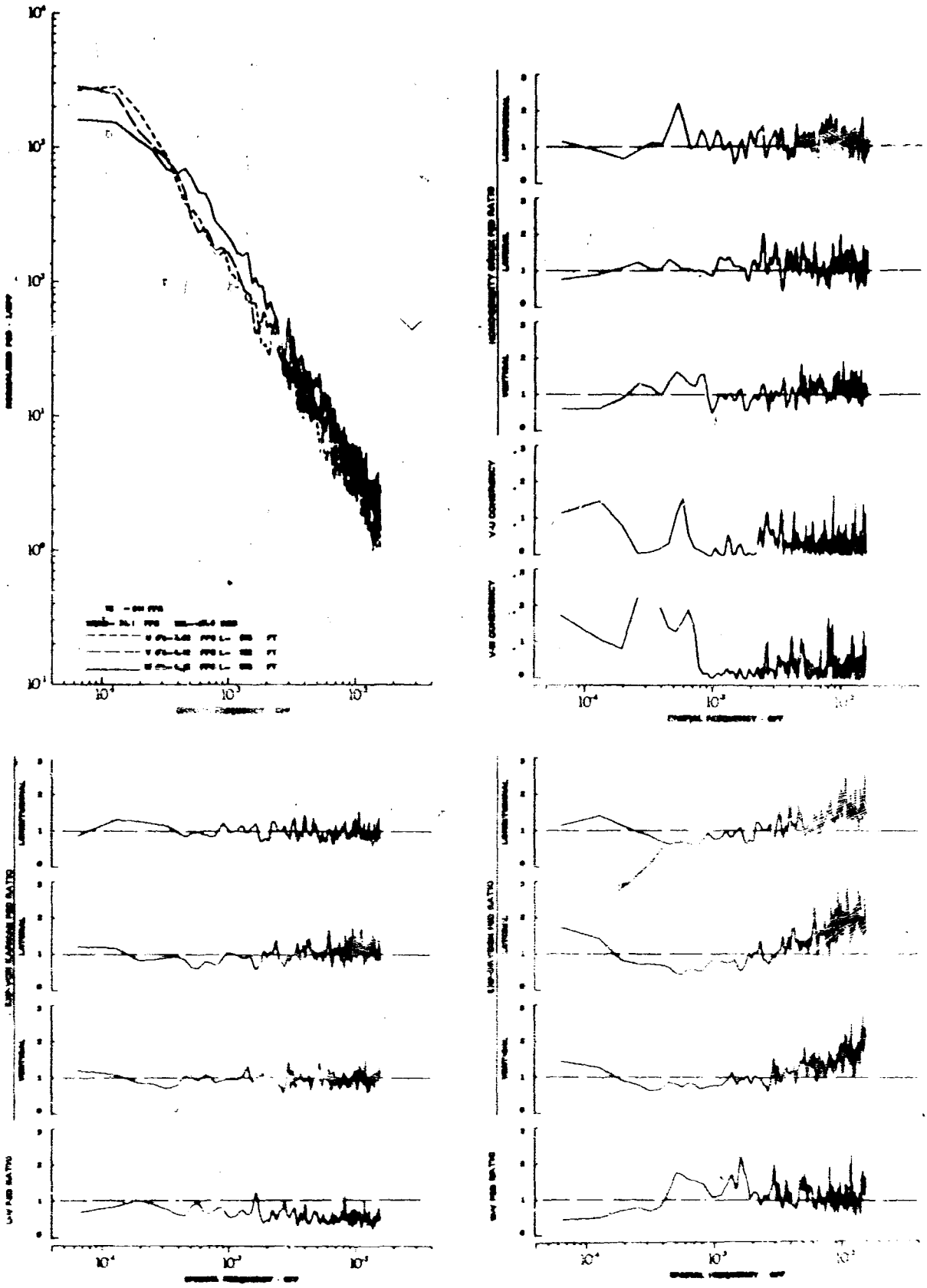
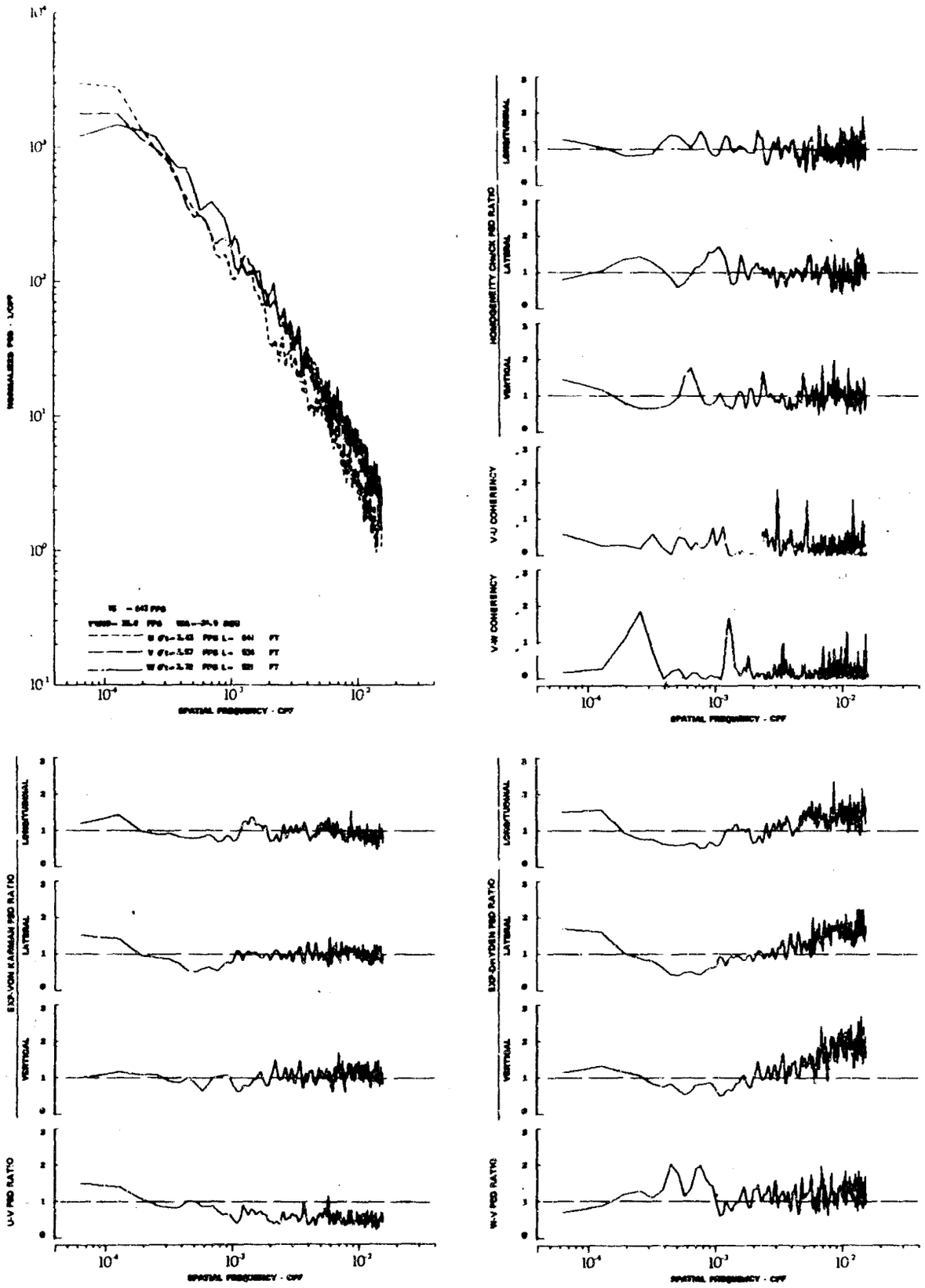


Turbulence Spectra Data For Test 44, Leg 4, Category 424324



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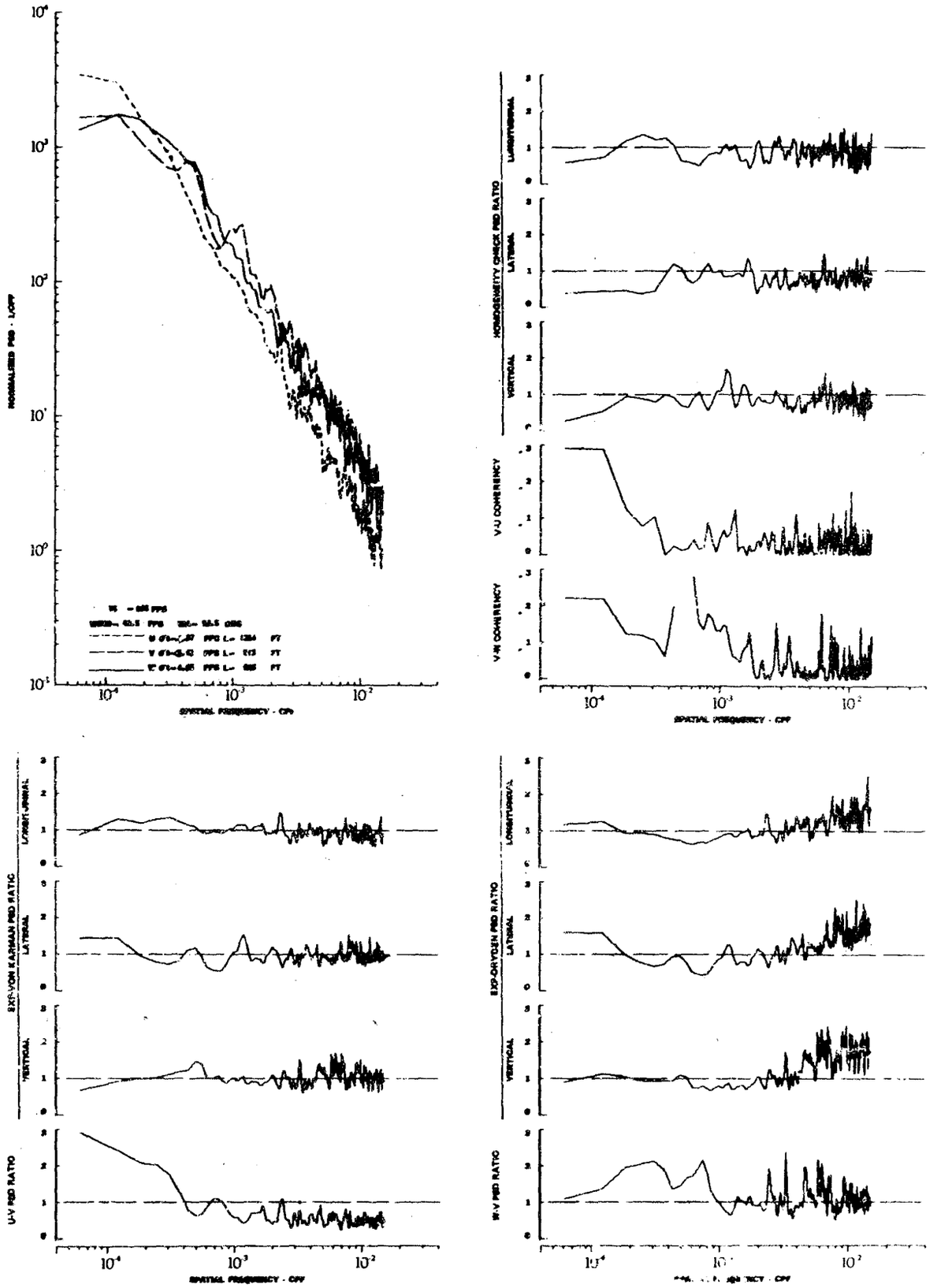

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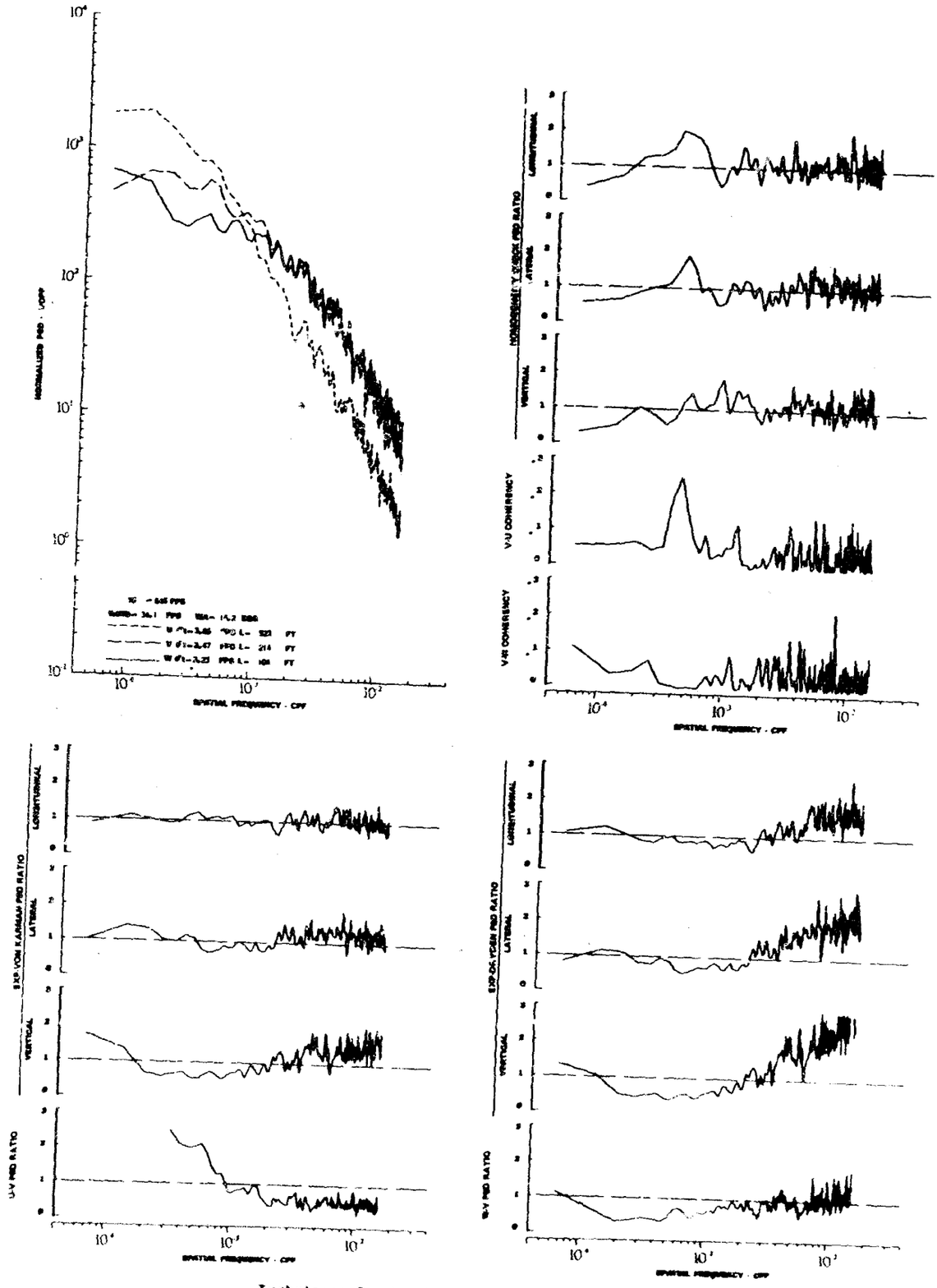

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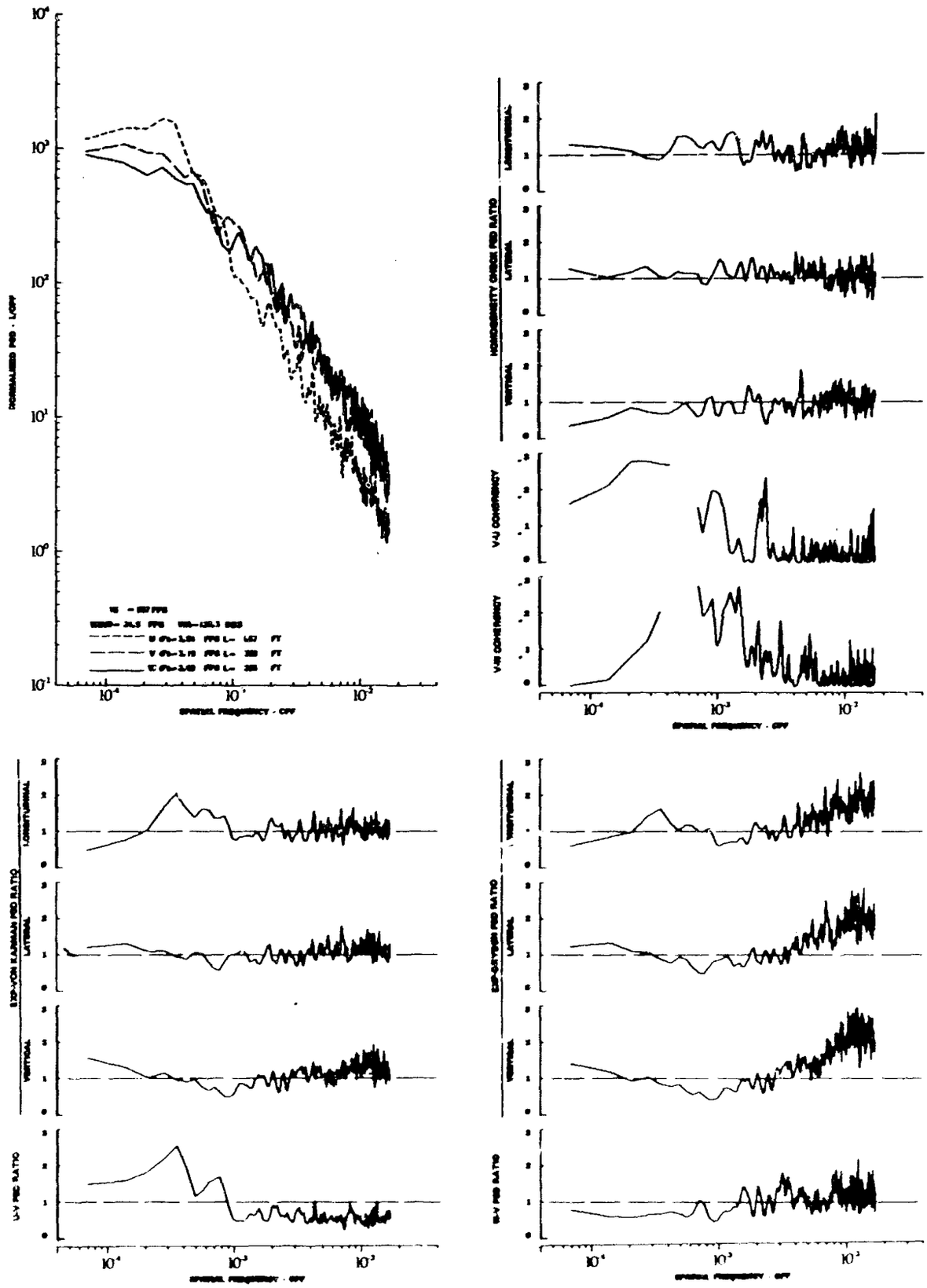

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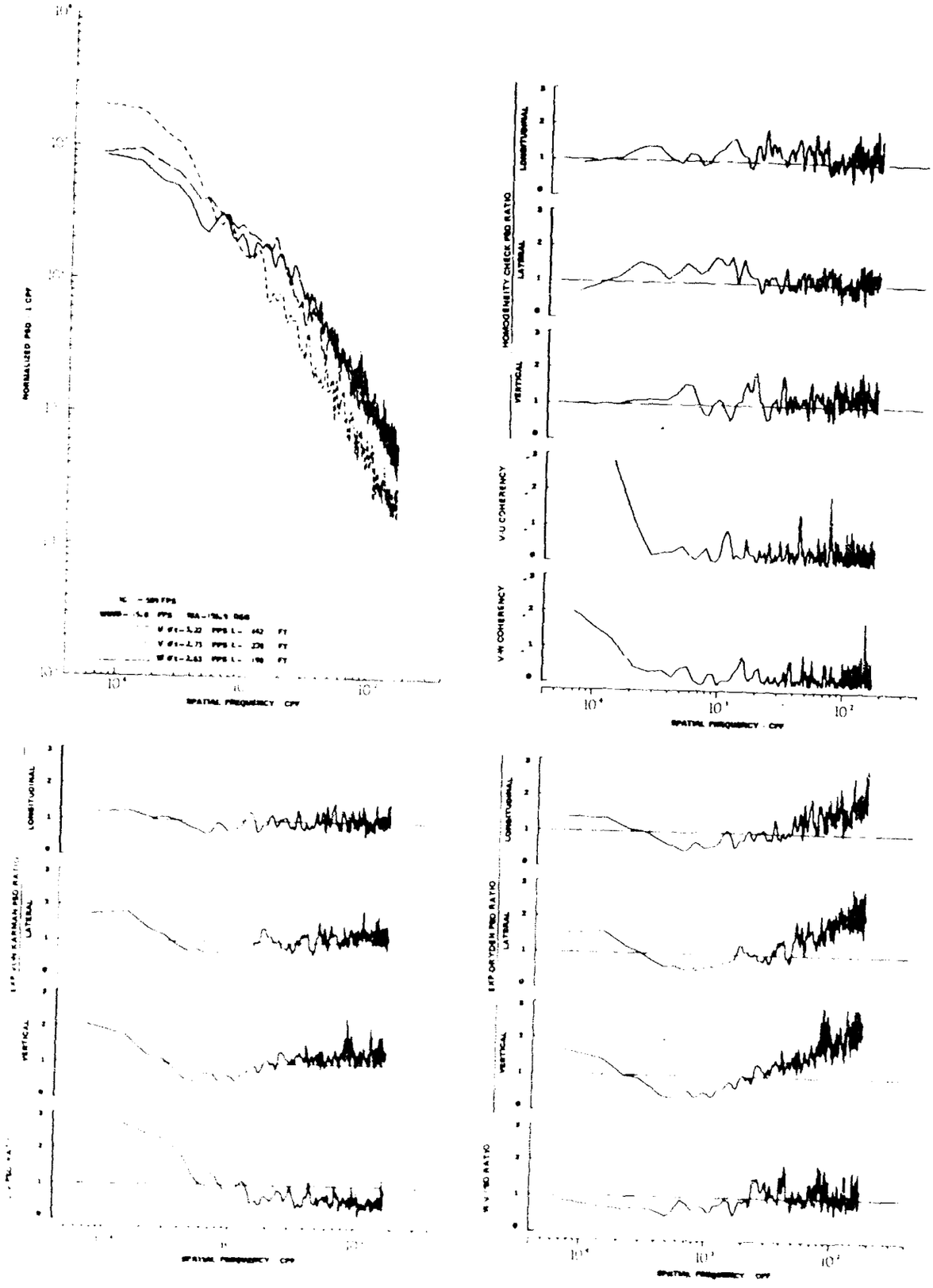

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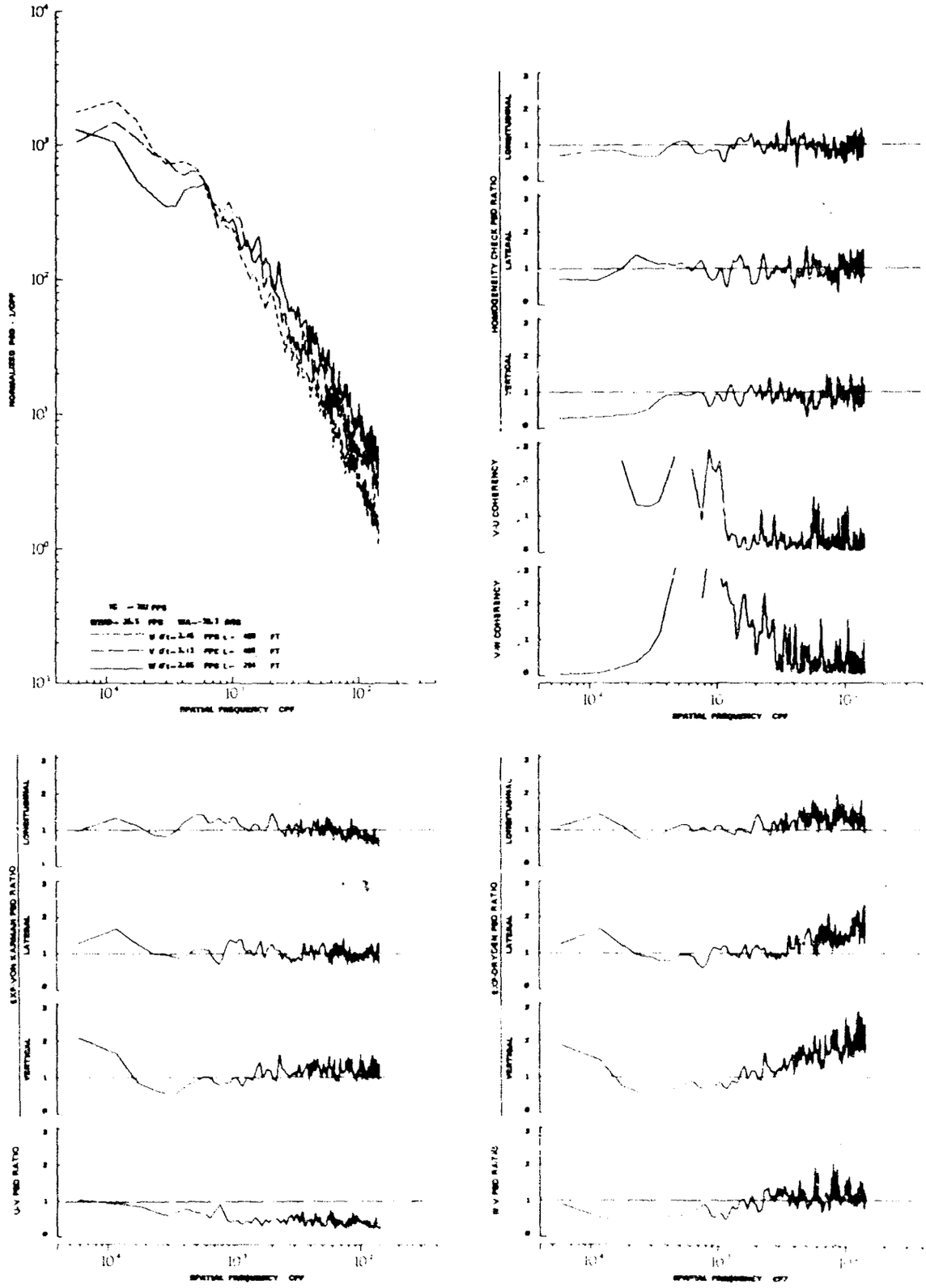

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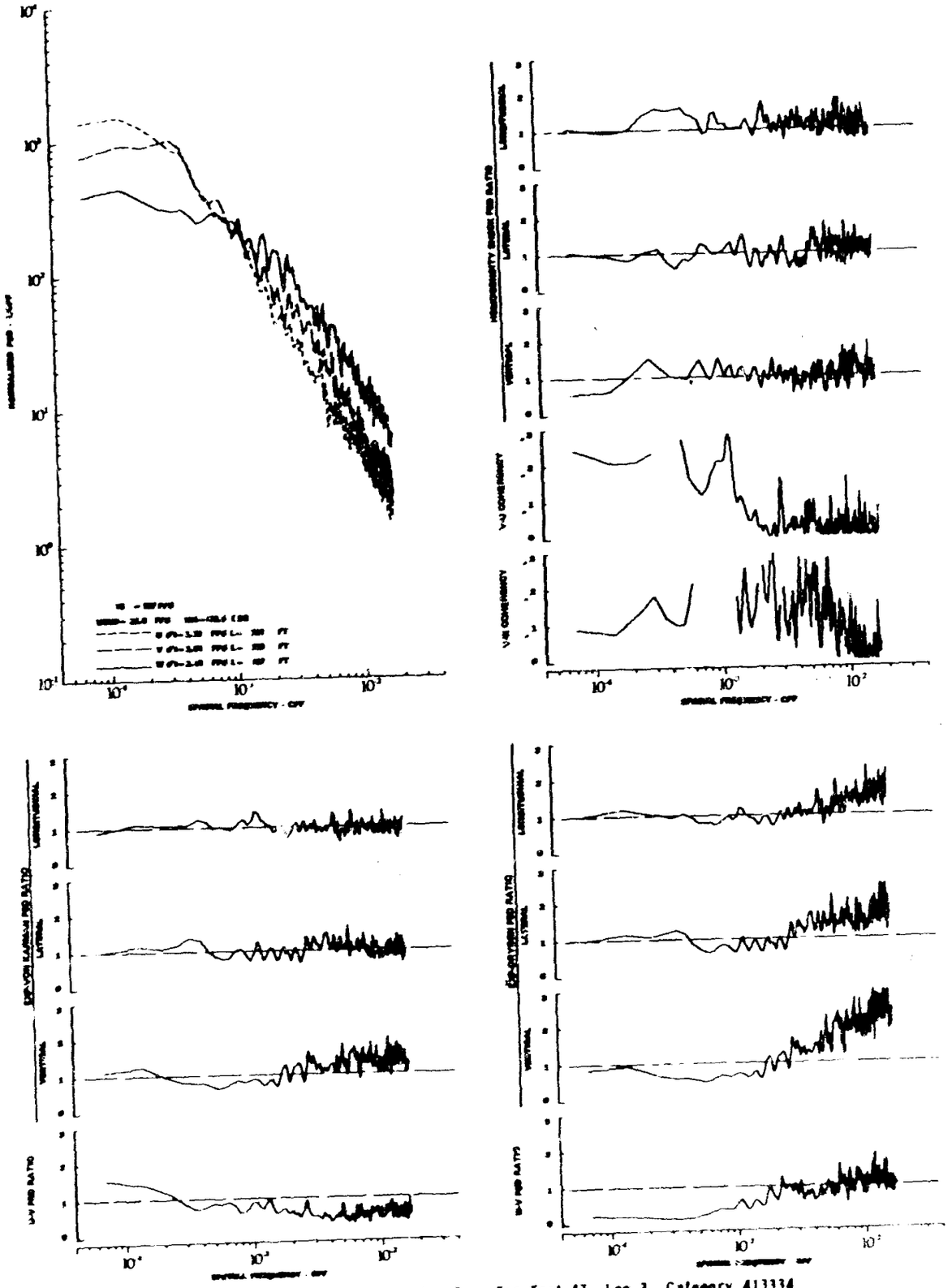

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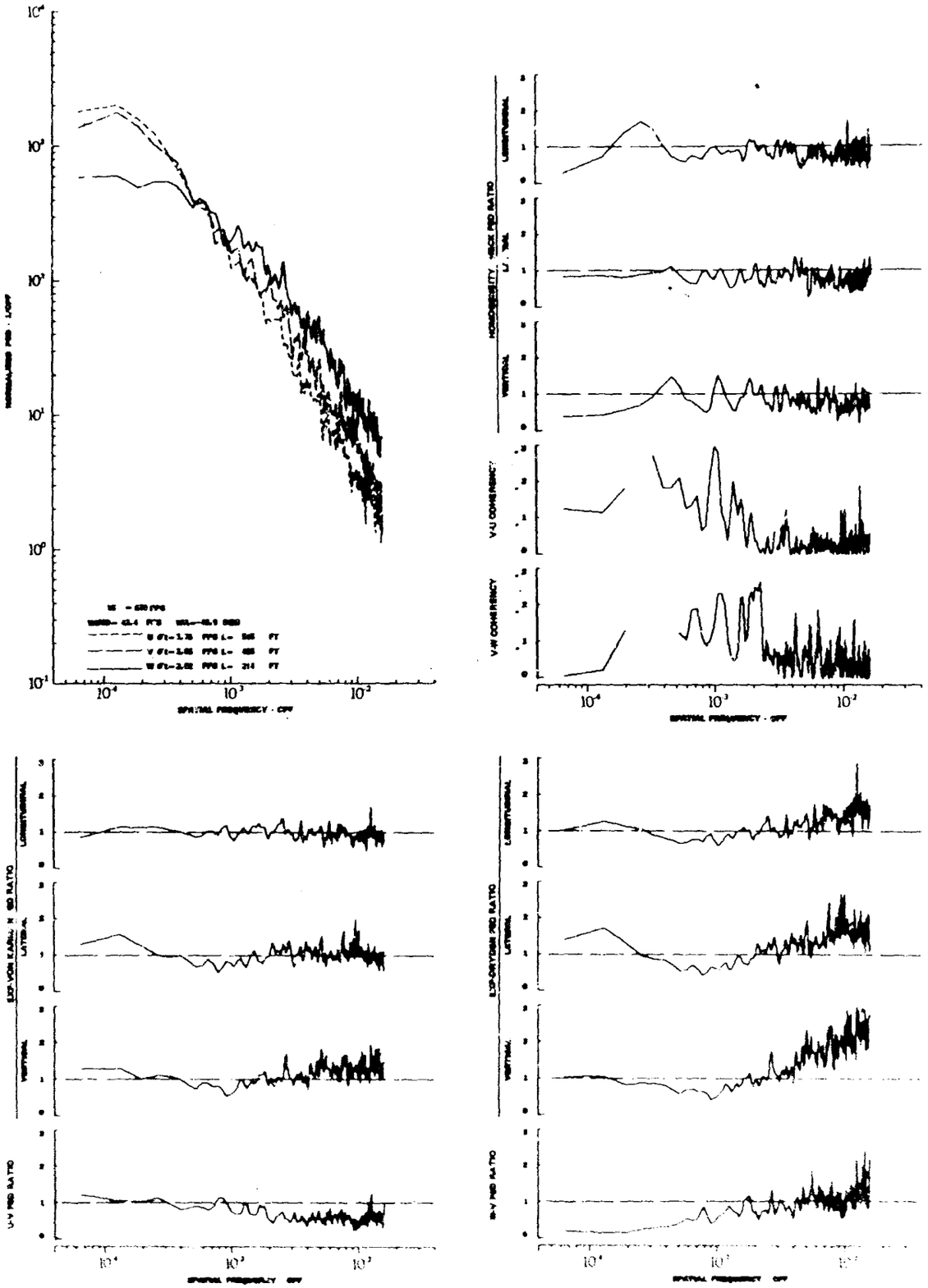
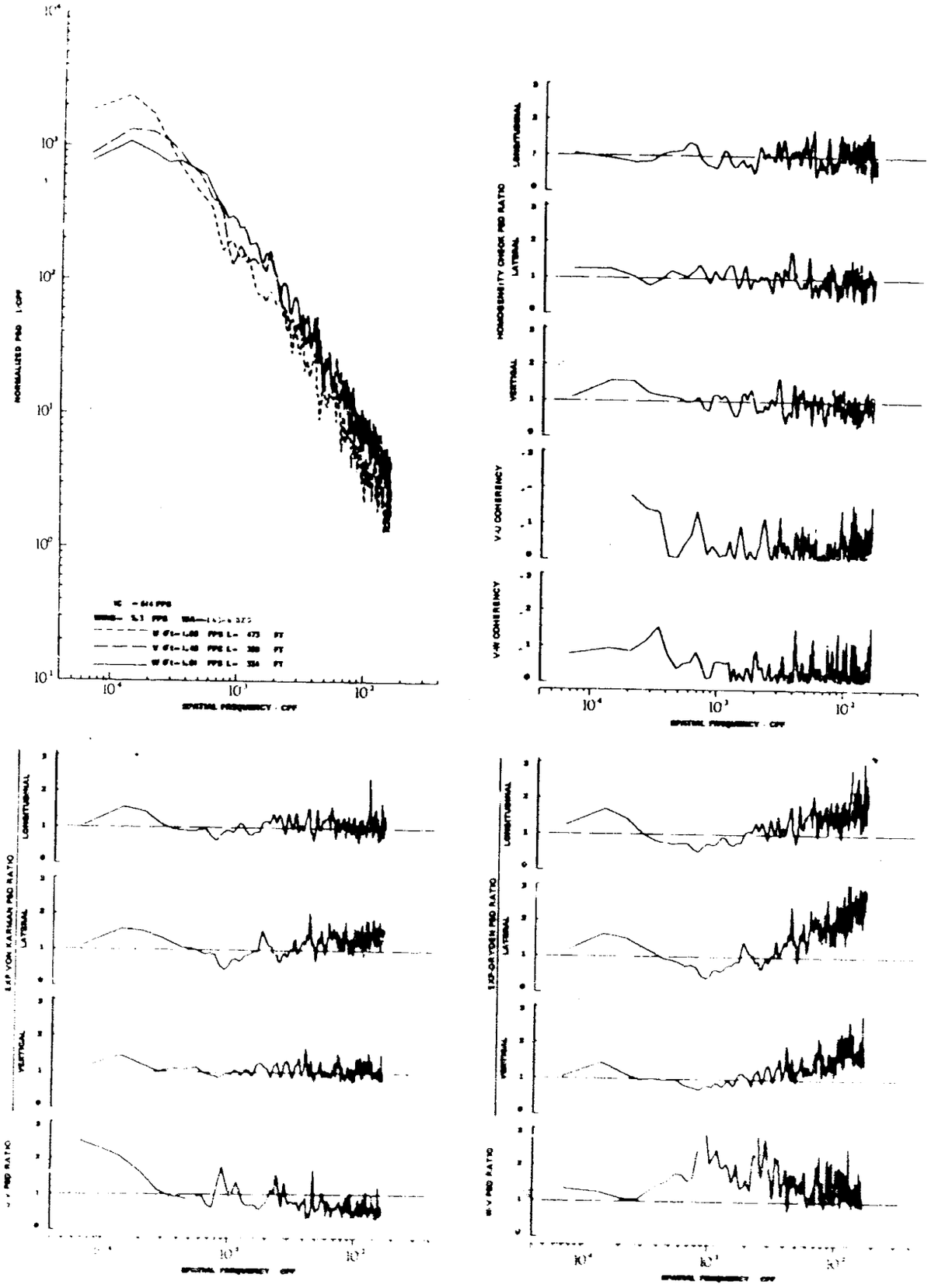
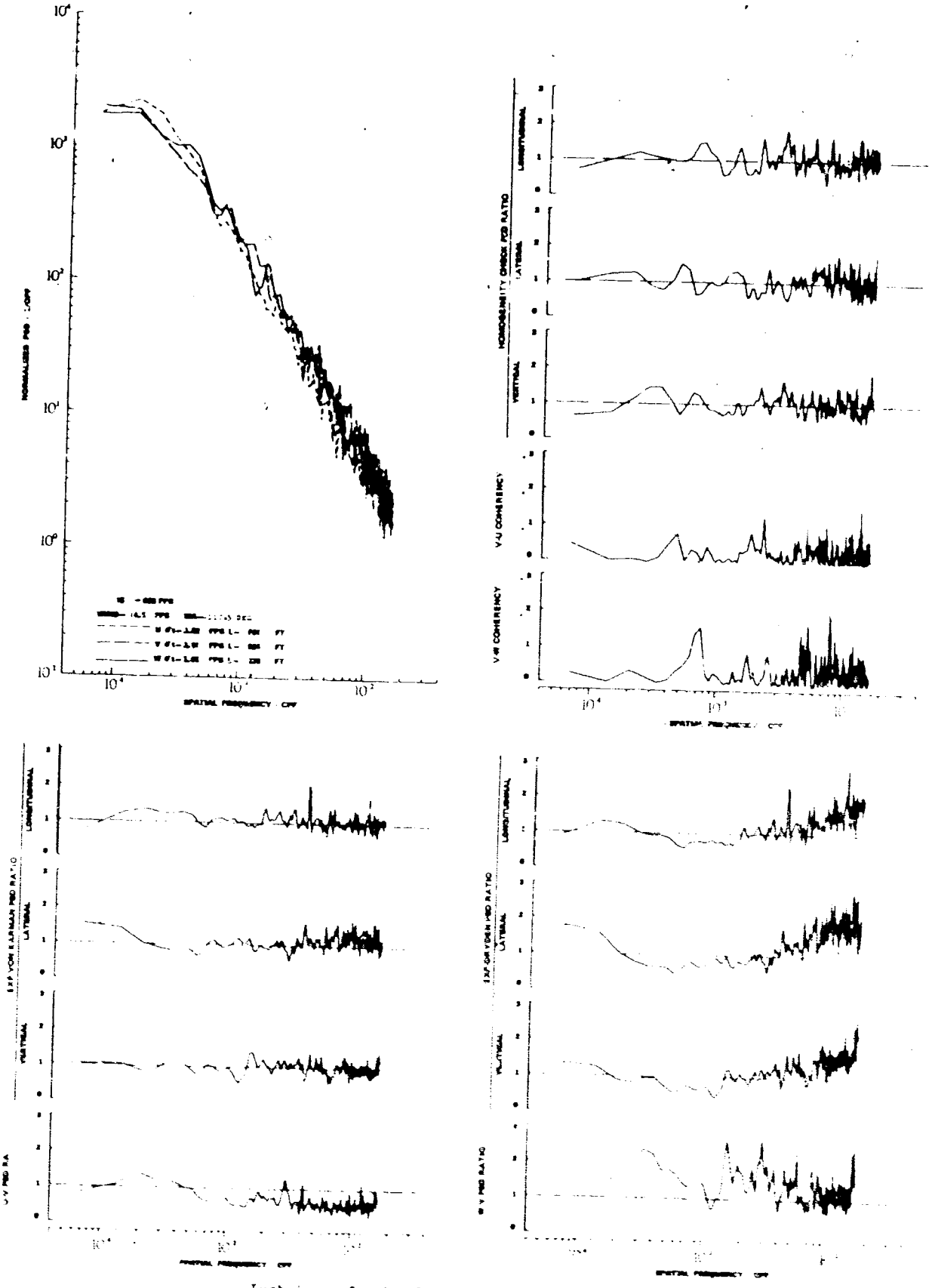


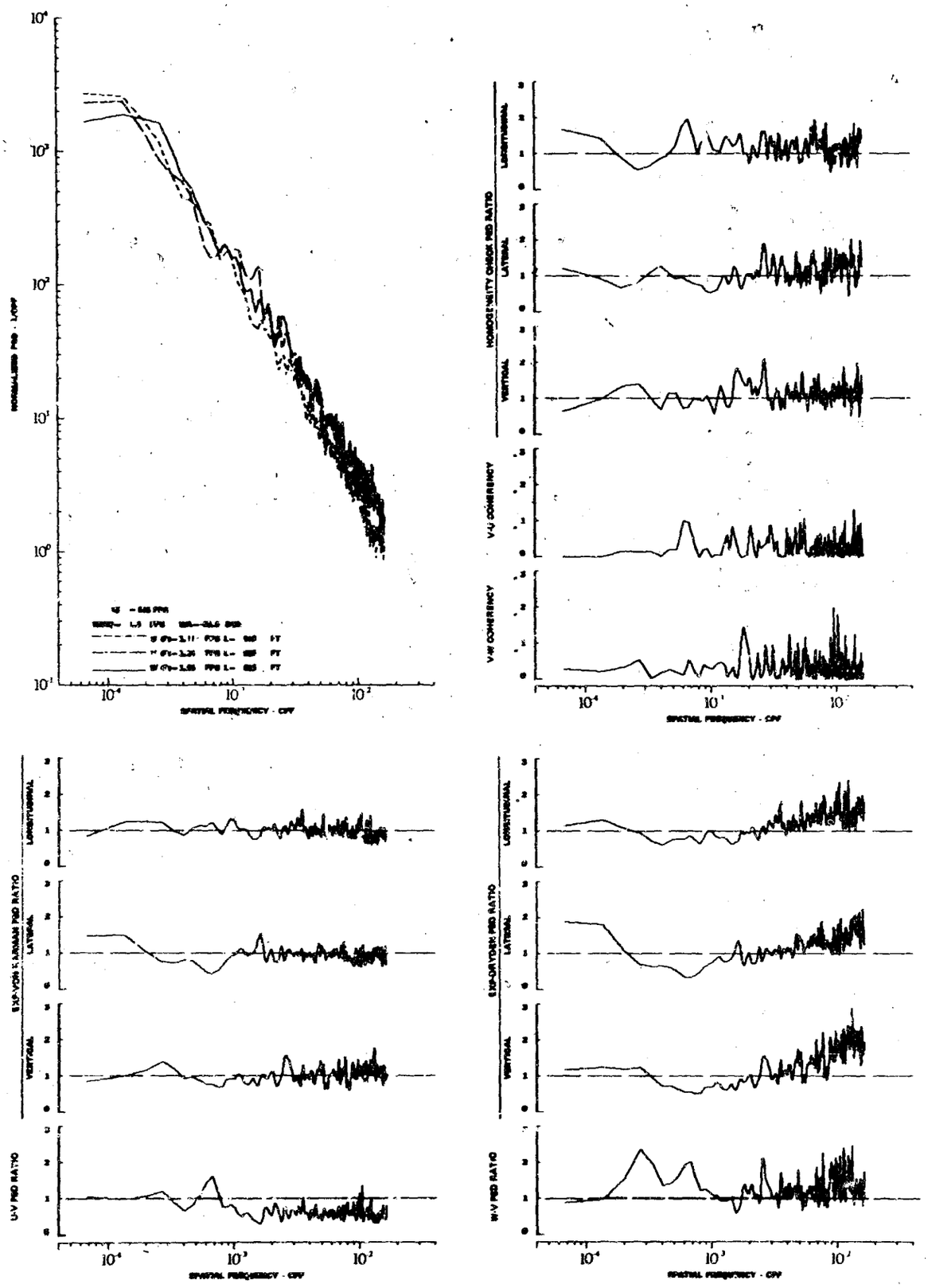
Turbulence Spectra Data For Test A7, Leg 7, Category 414334



Turbulence Spectra Data For Test 49, Leg 7, Category 421234



Turbulence Spectra Data For Test 50, Leg 2 Category 424334



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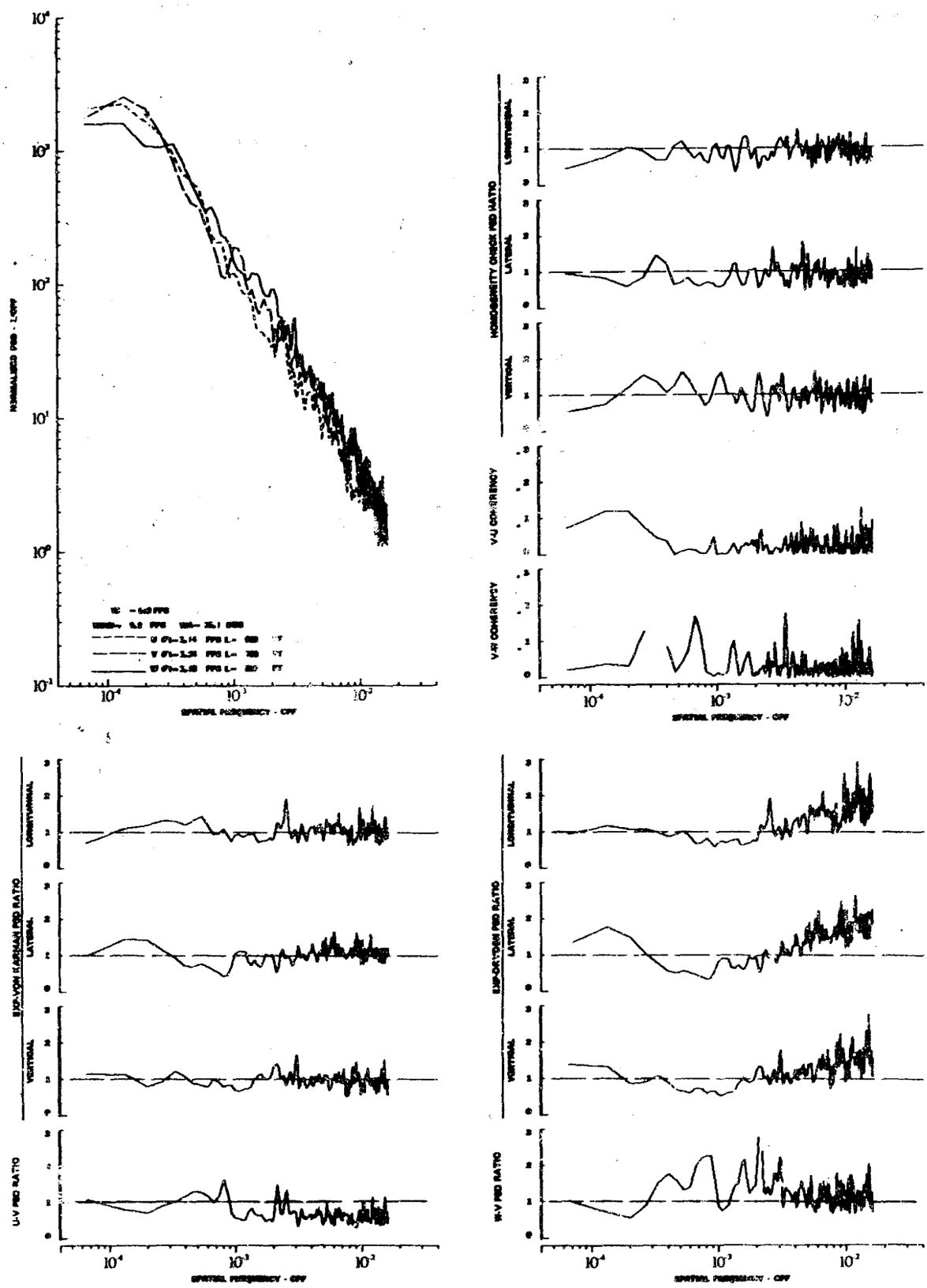

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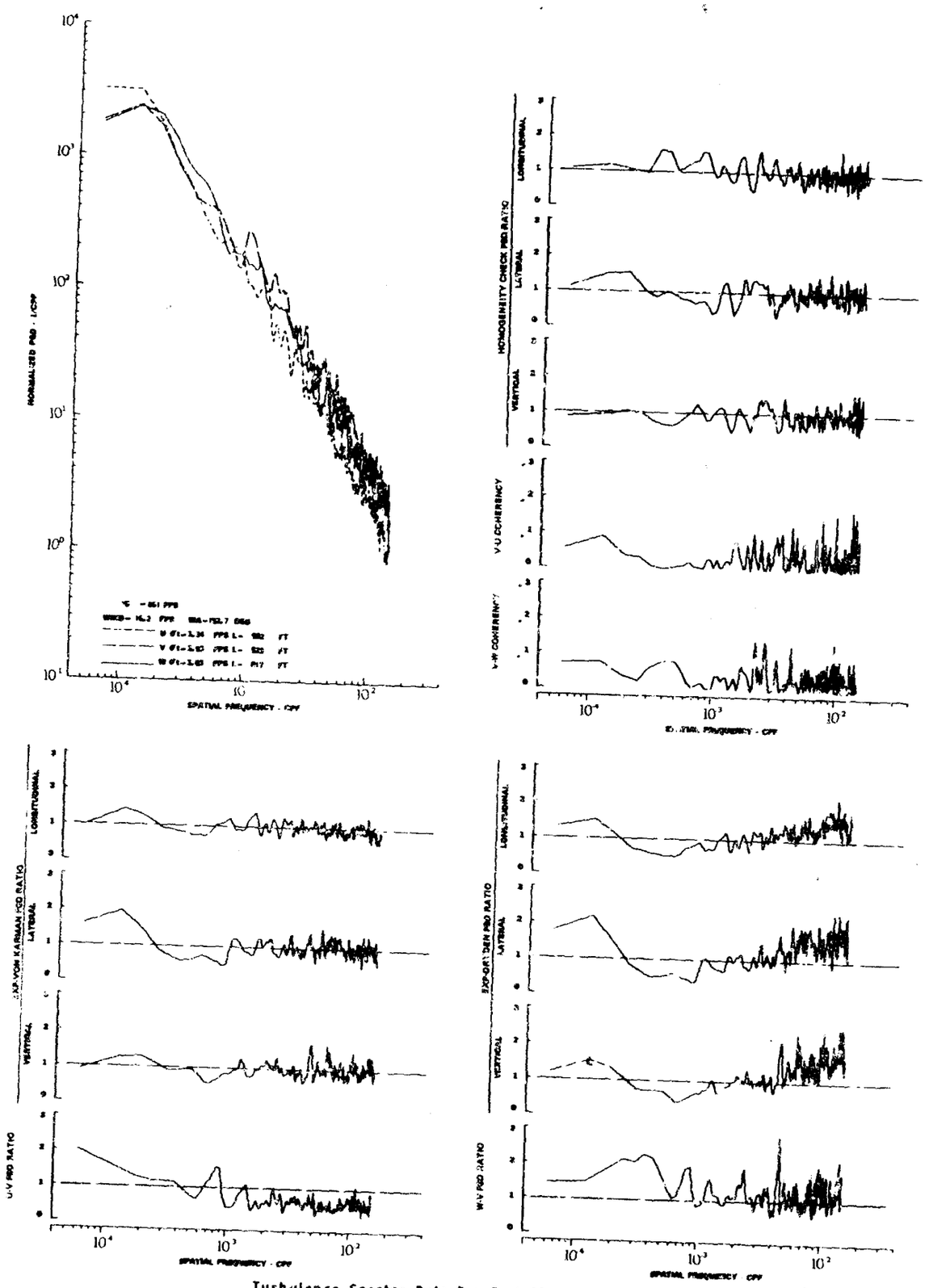

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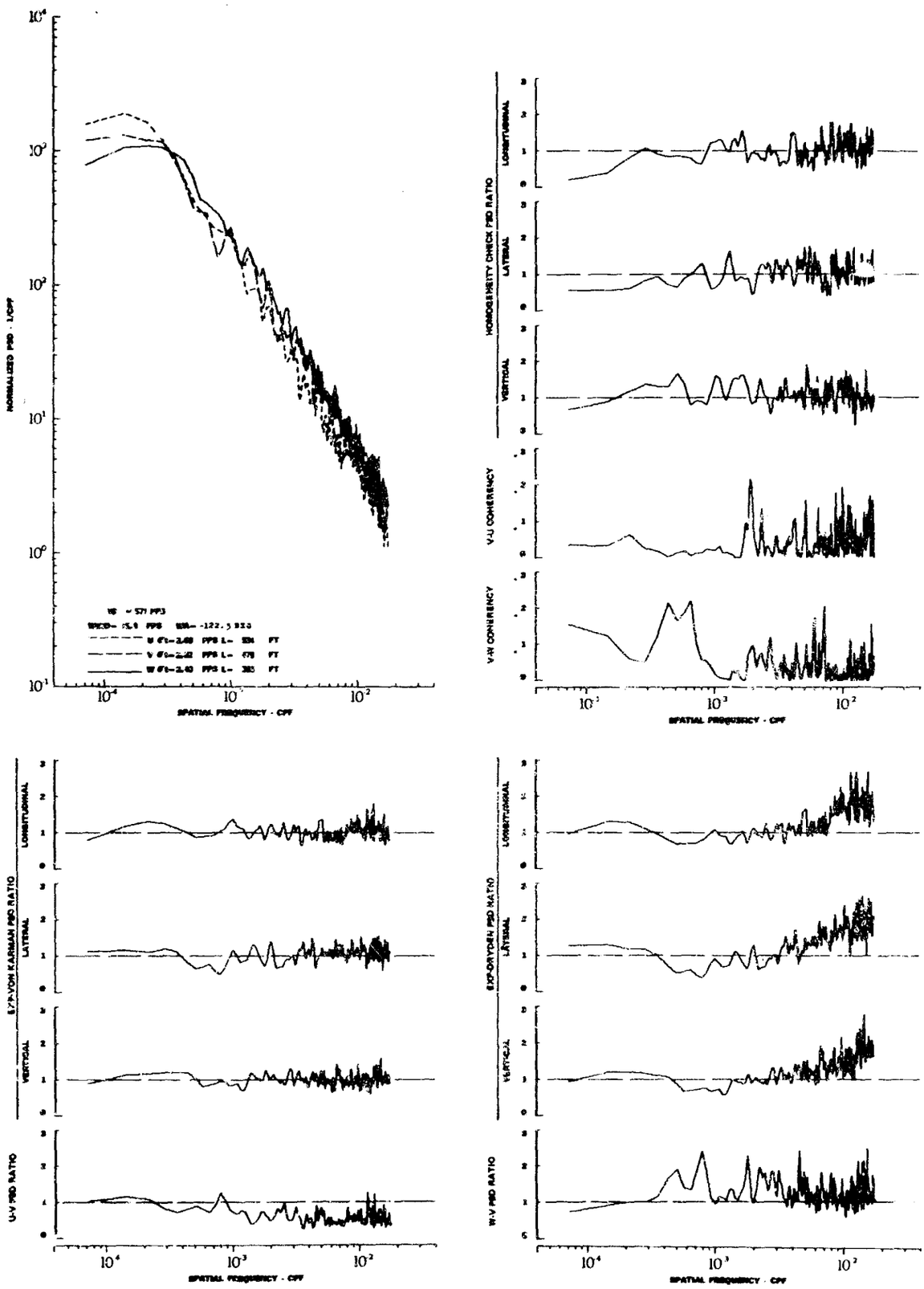
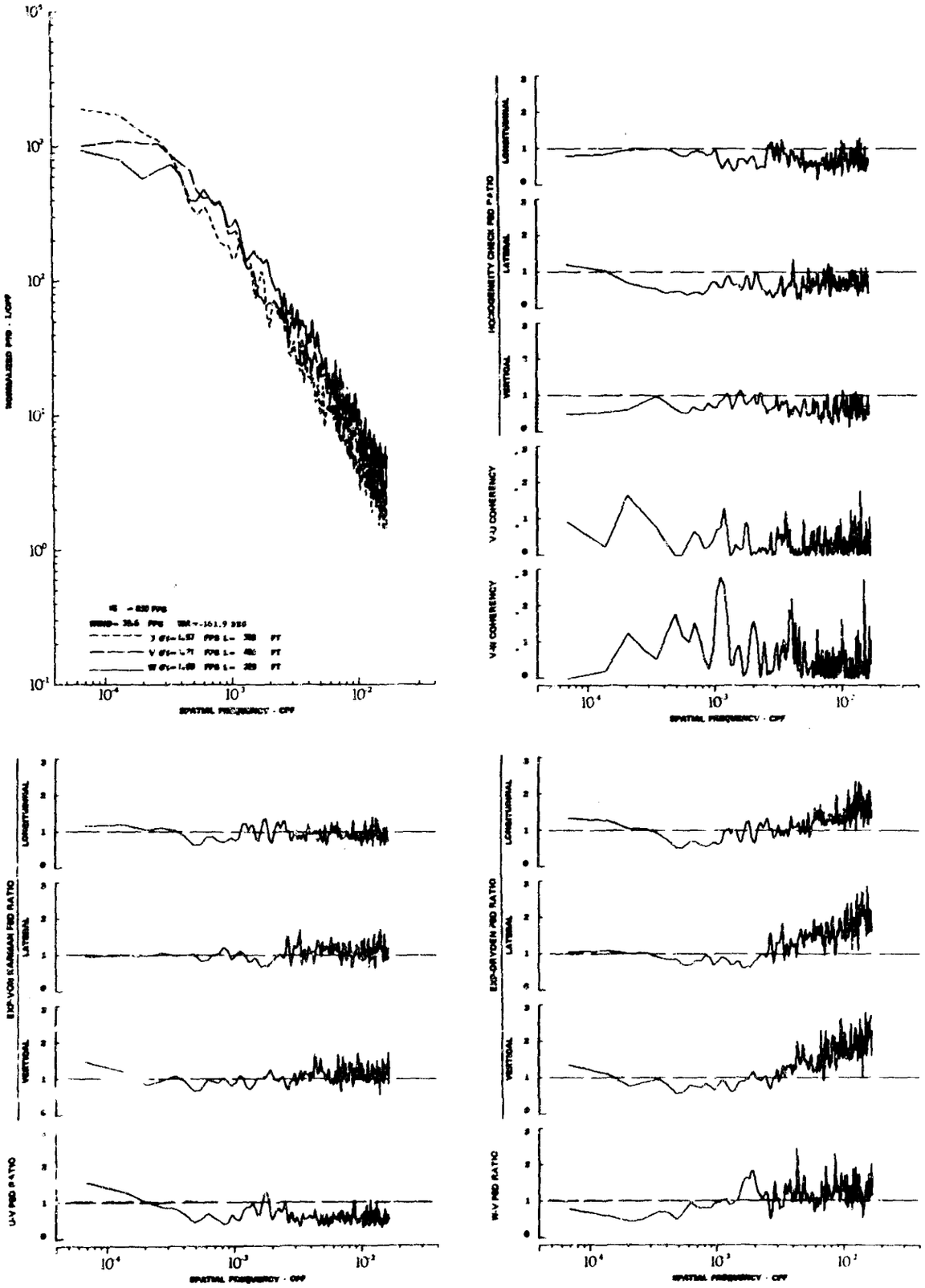
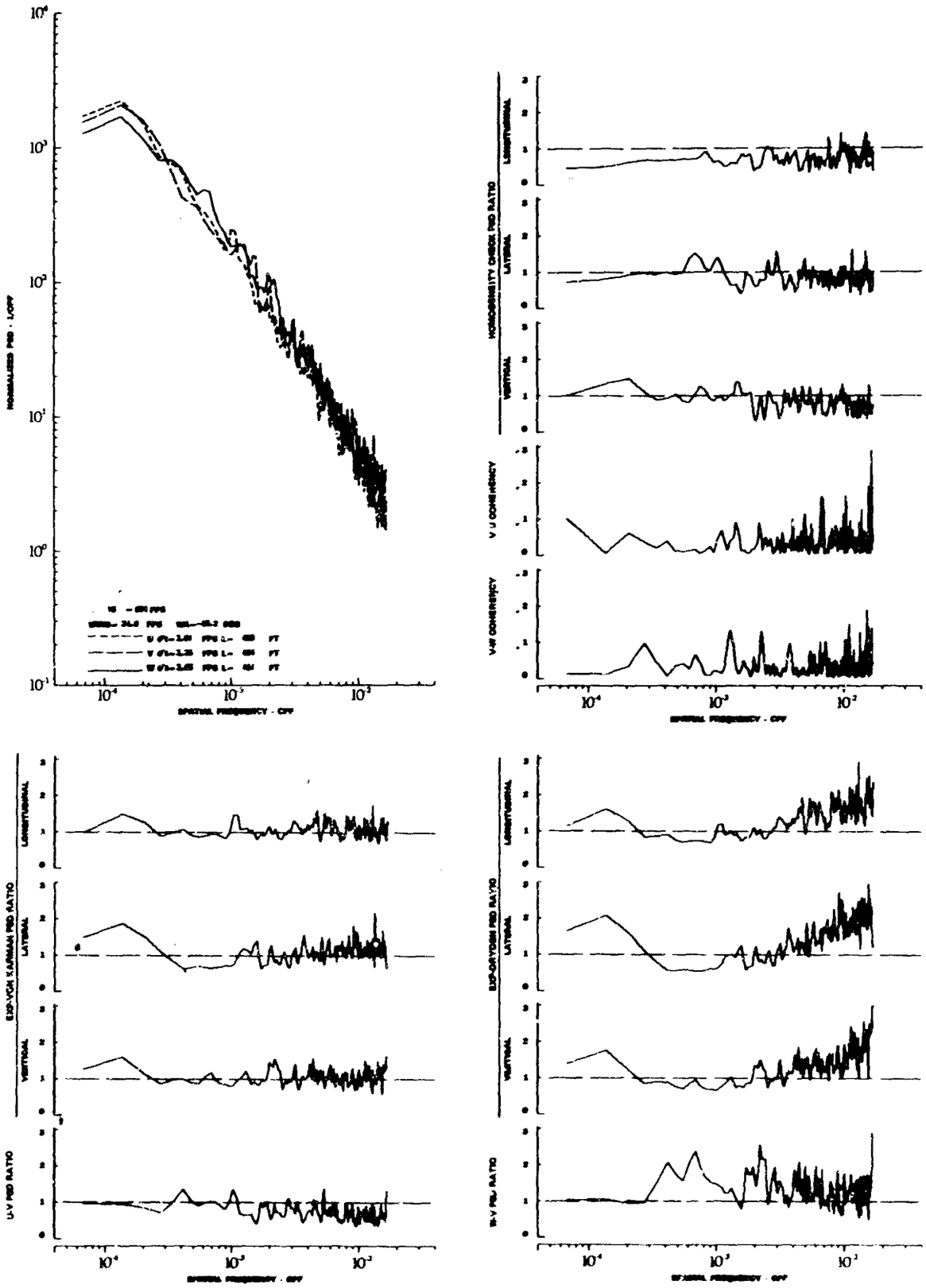


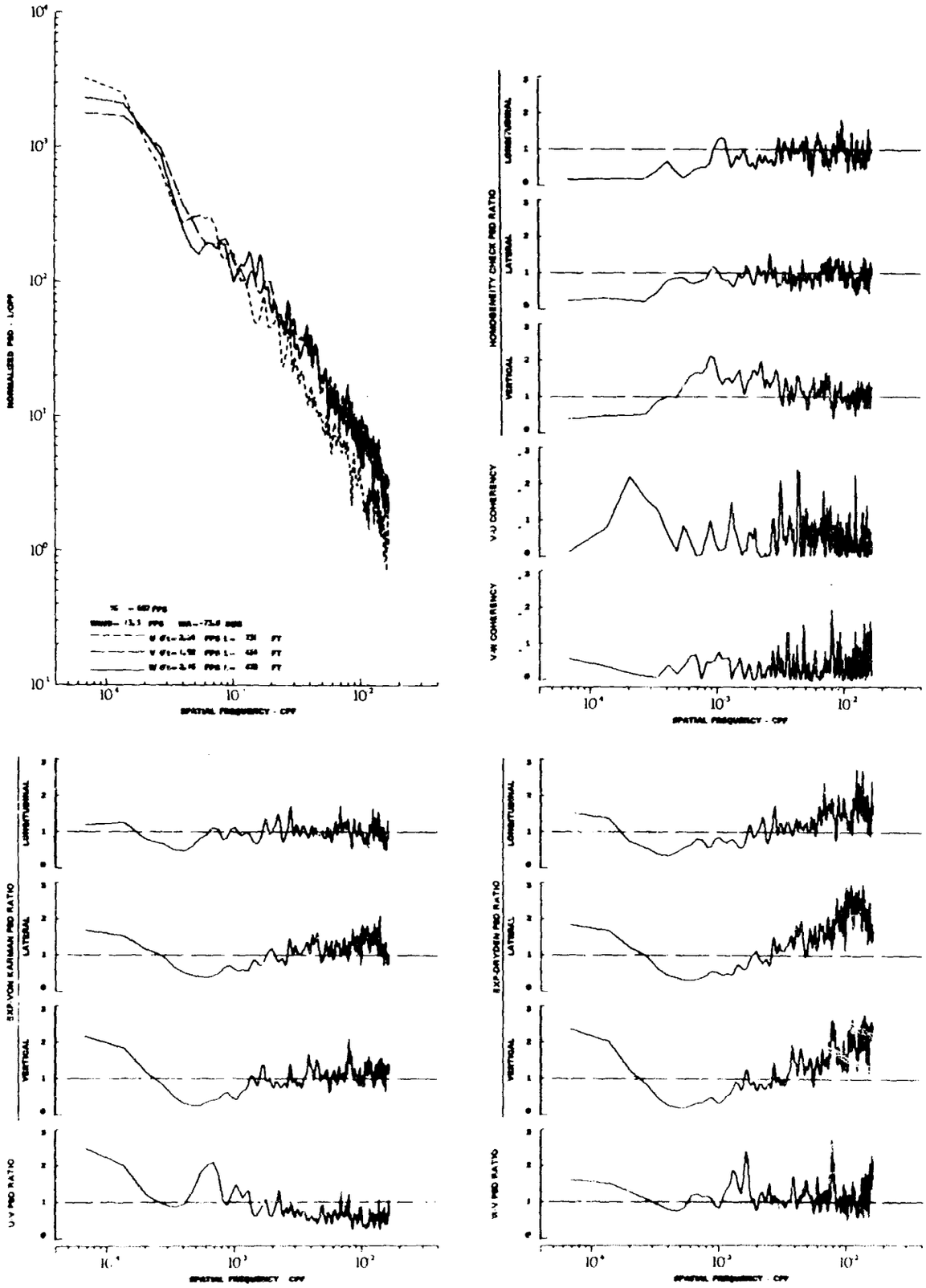
Turbulence Spectra Data For Test 51, Leg 3, Category 323231



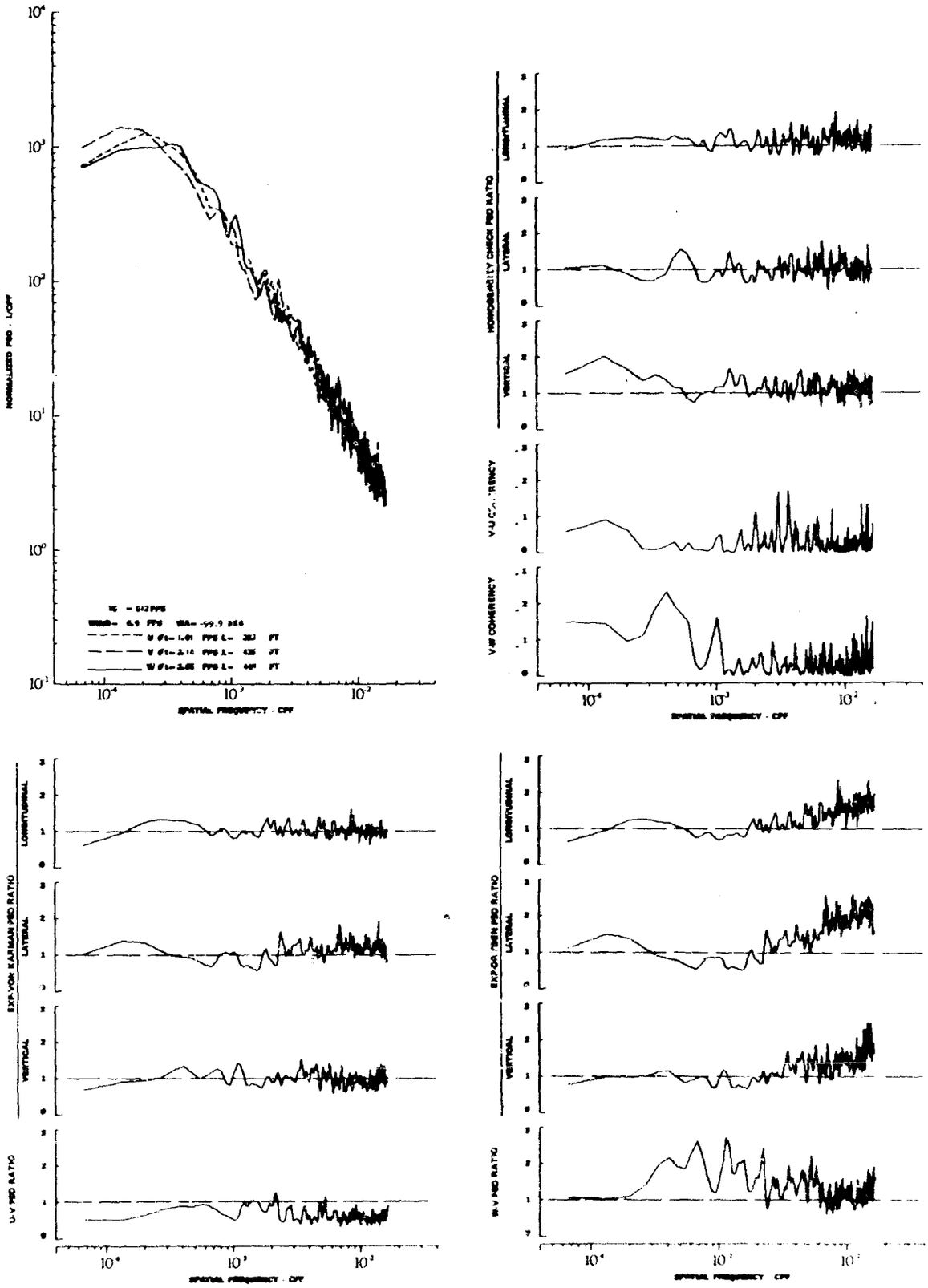
Turbulence Spectra Data For Test 53, Leg 3, Category 323231



Turbulence Spectra Data For Test 57, Leg 1, Category 224331



Turbulence Spectra Data For Test 59, Leg 1, Category 211231



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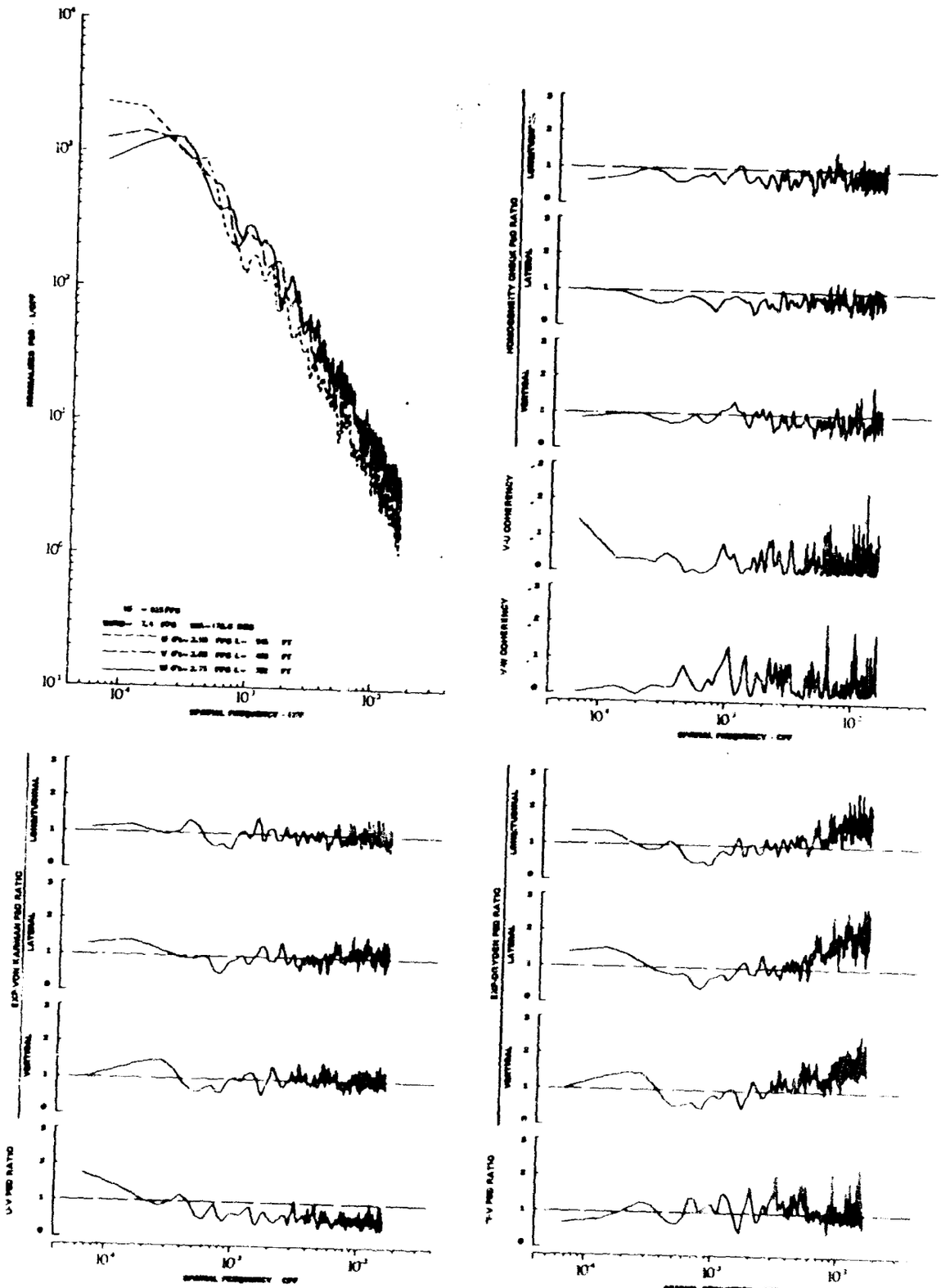

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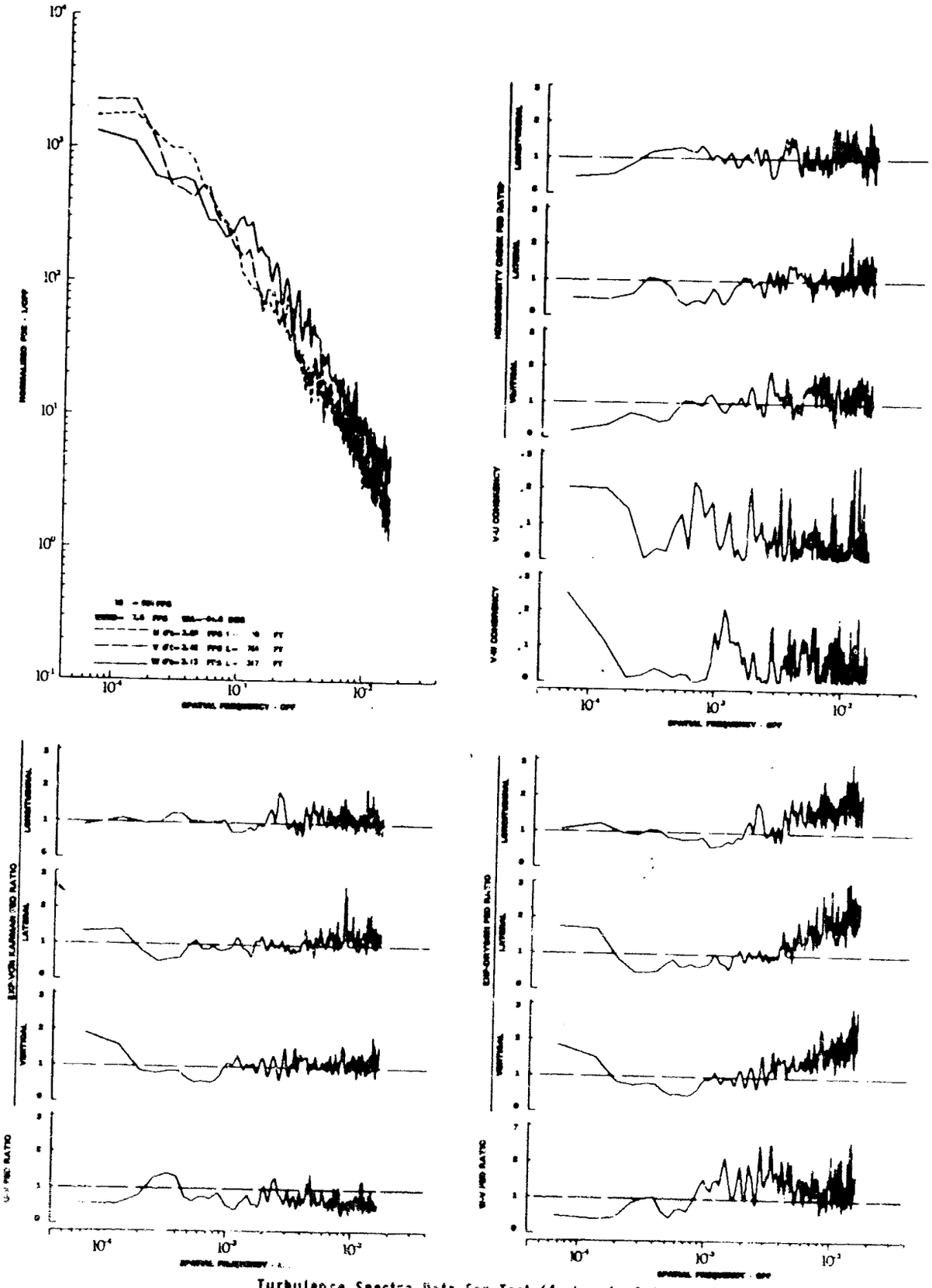

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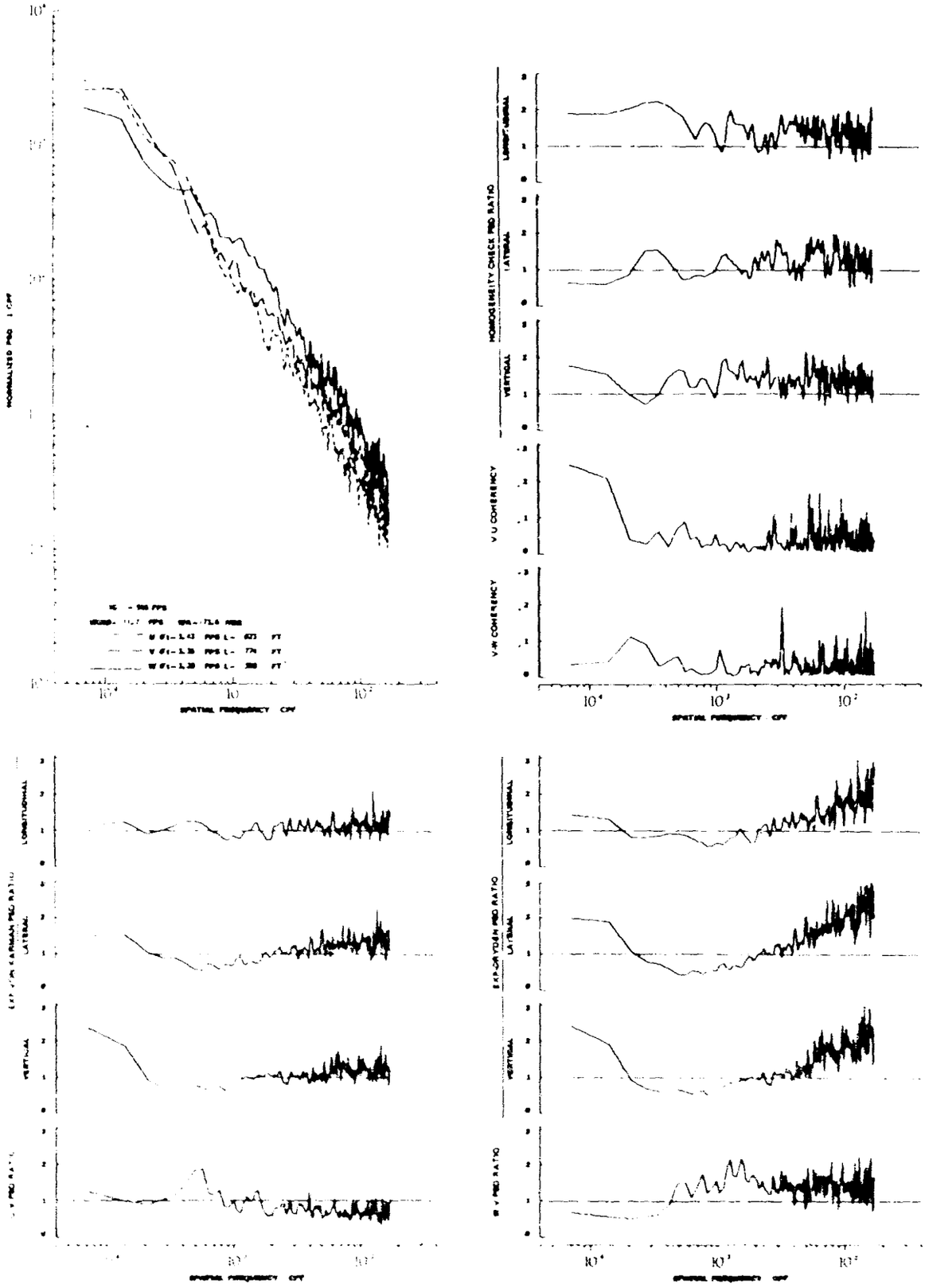
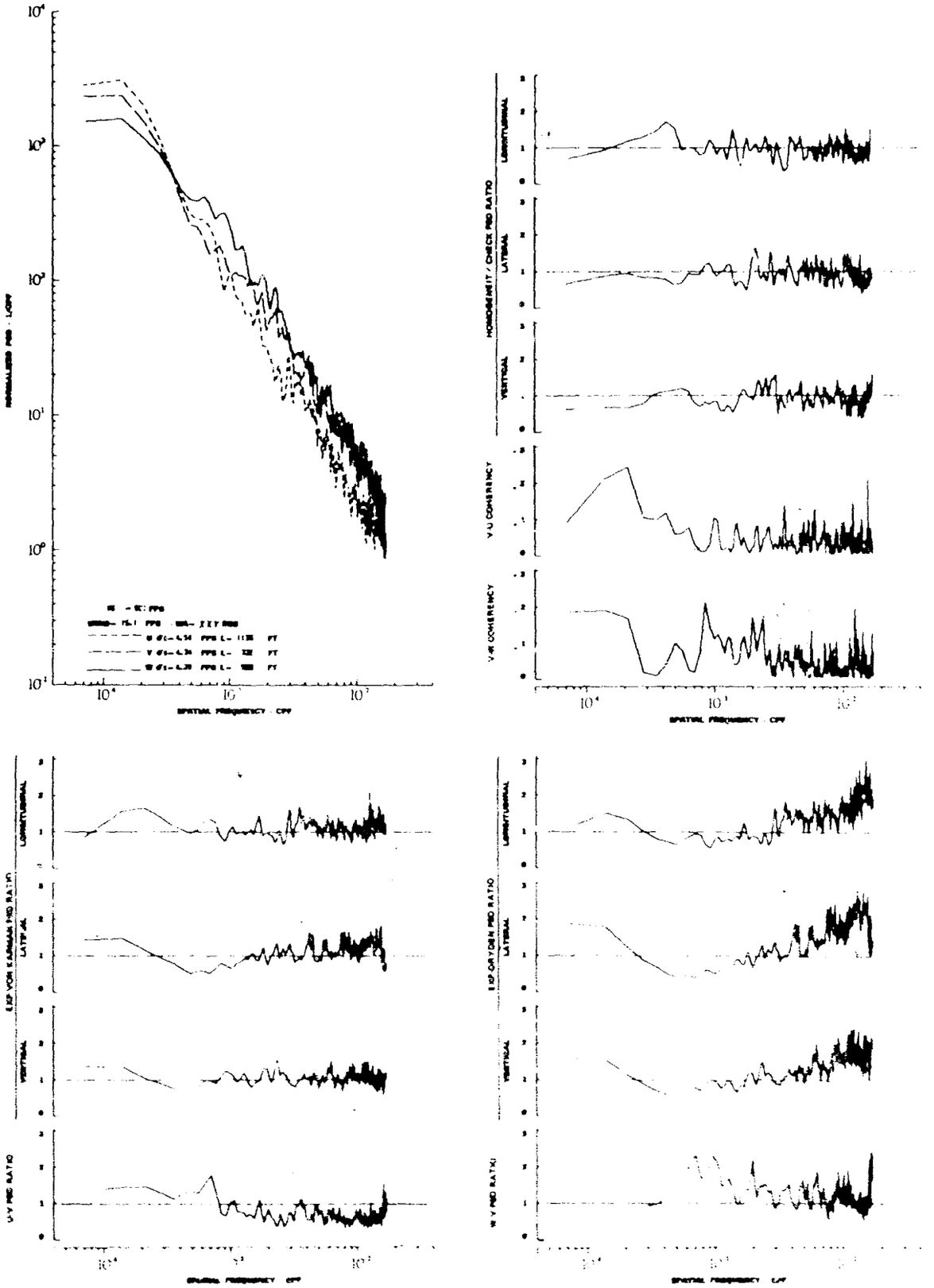
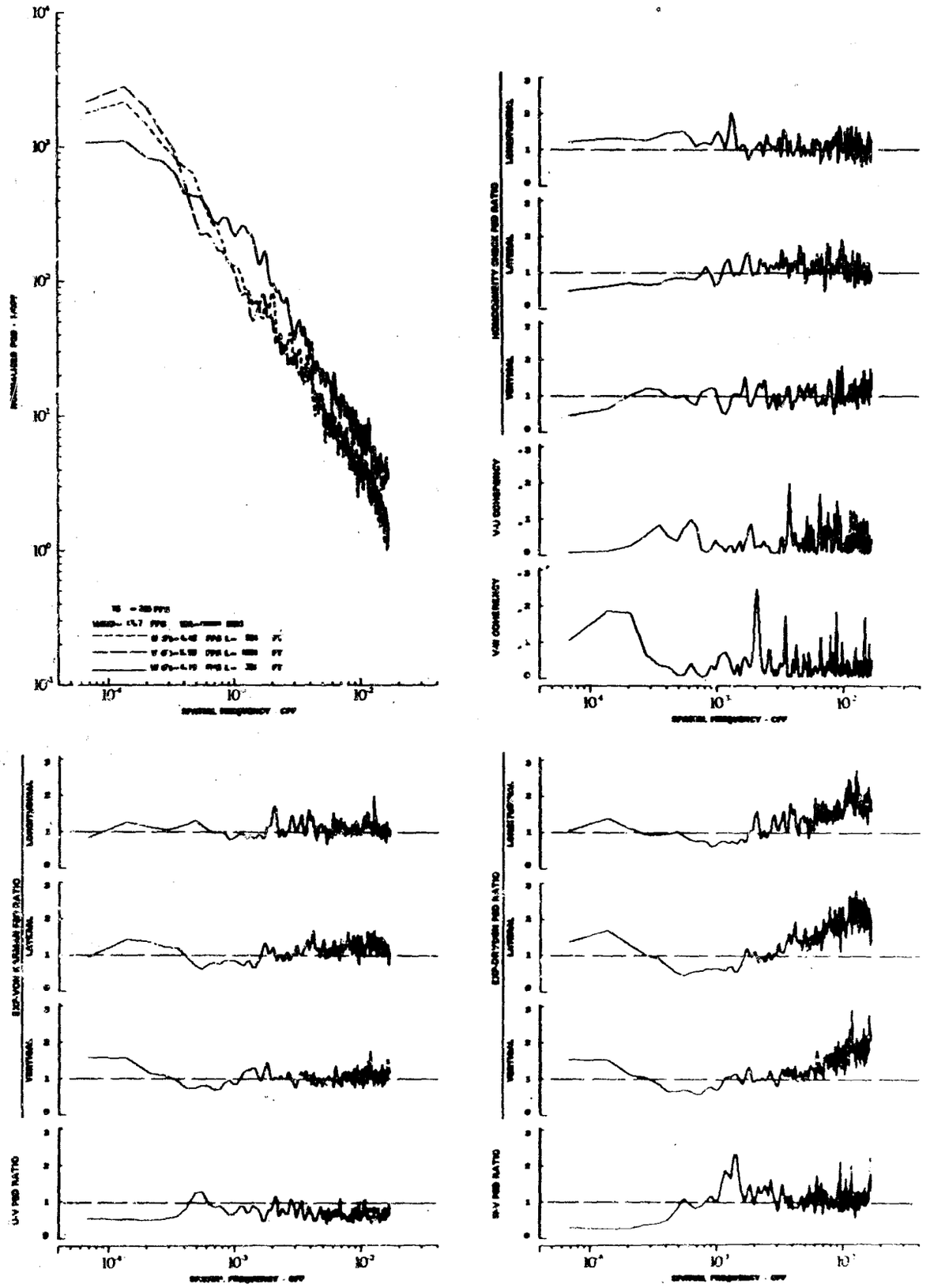


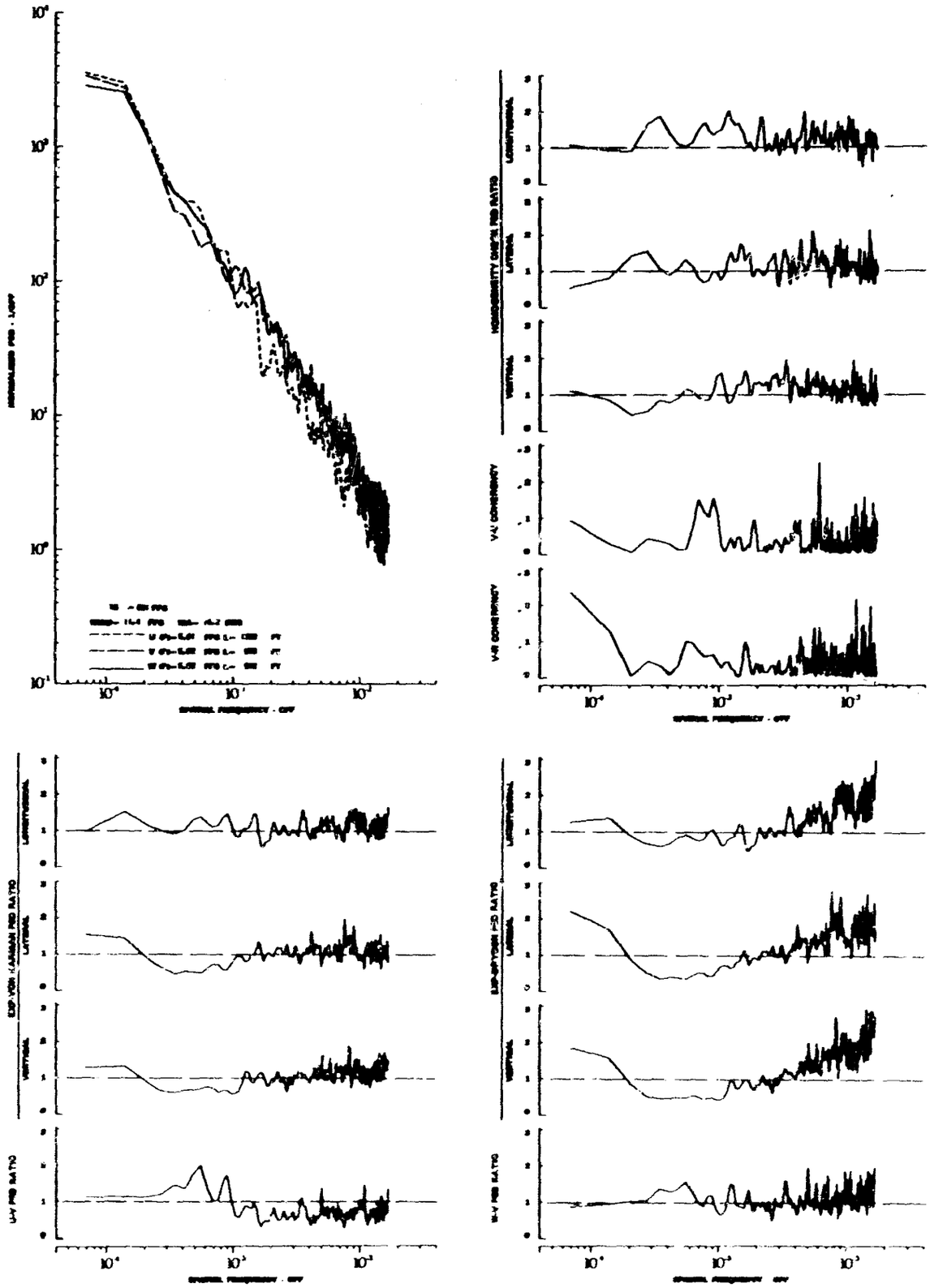
Turbulence Spectra Data For Test 64, Leg 8, Category 212231



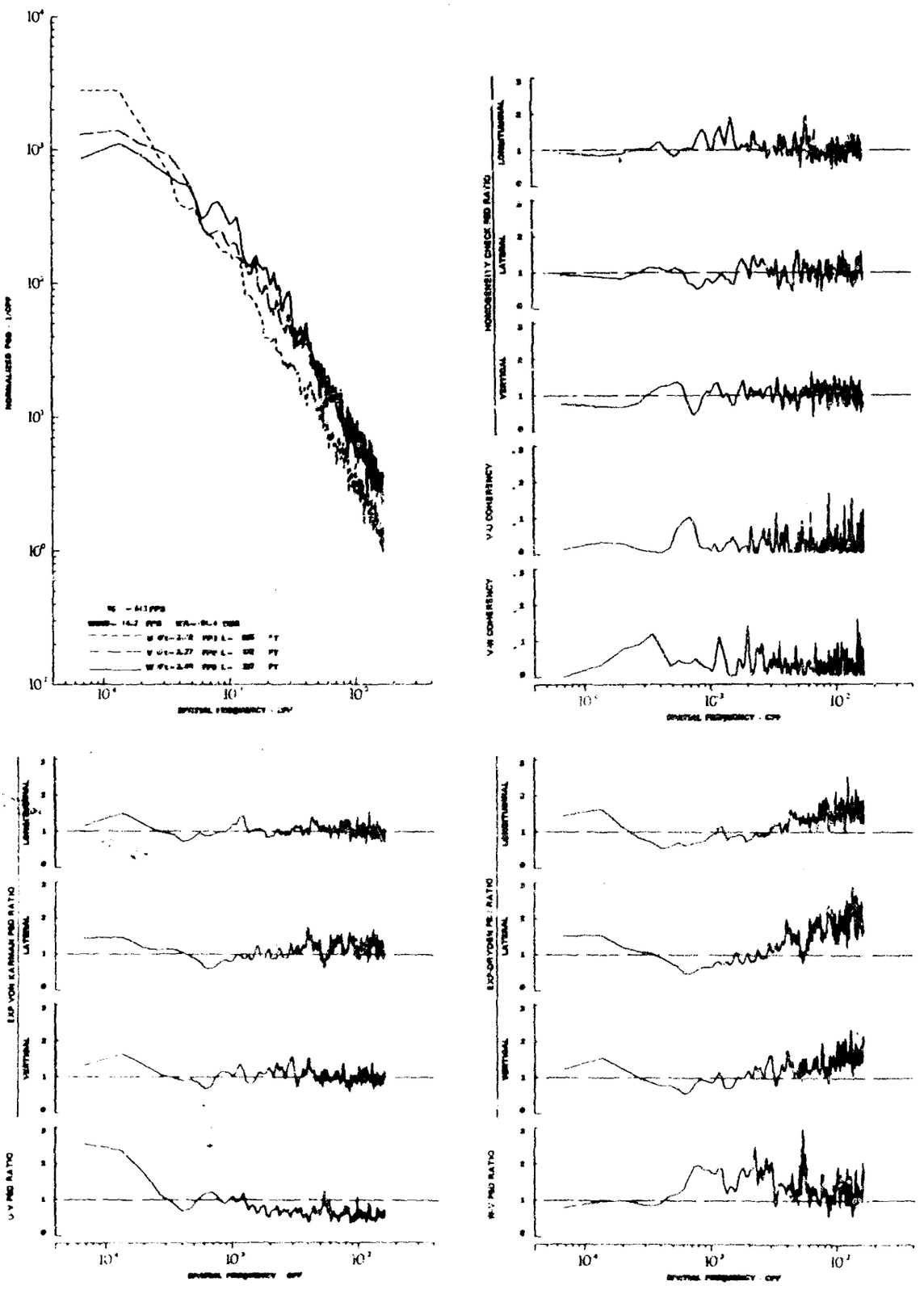
Turbulence Spectra Data For Test 65, Leg 1, Category 2[433]



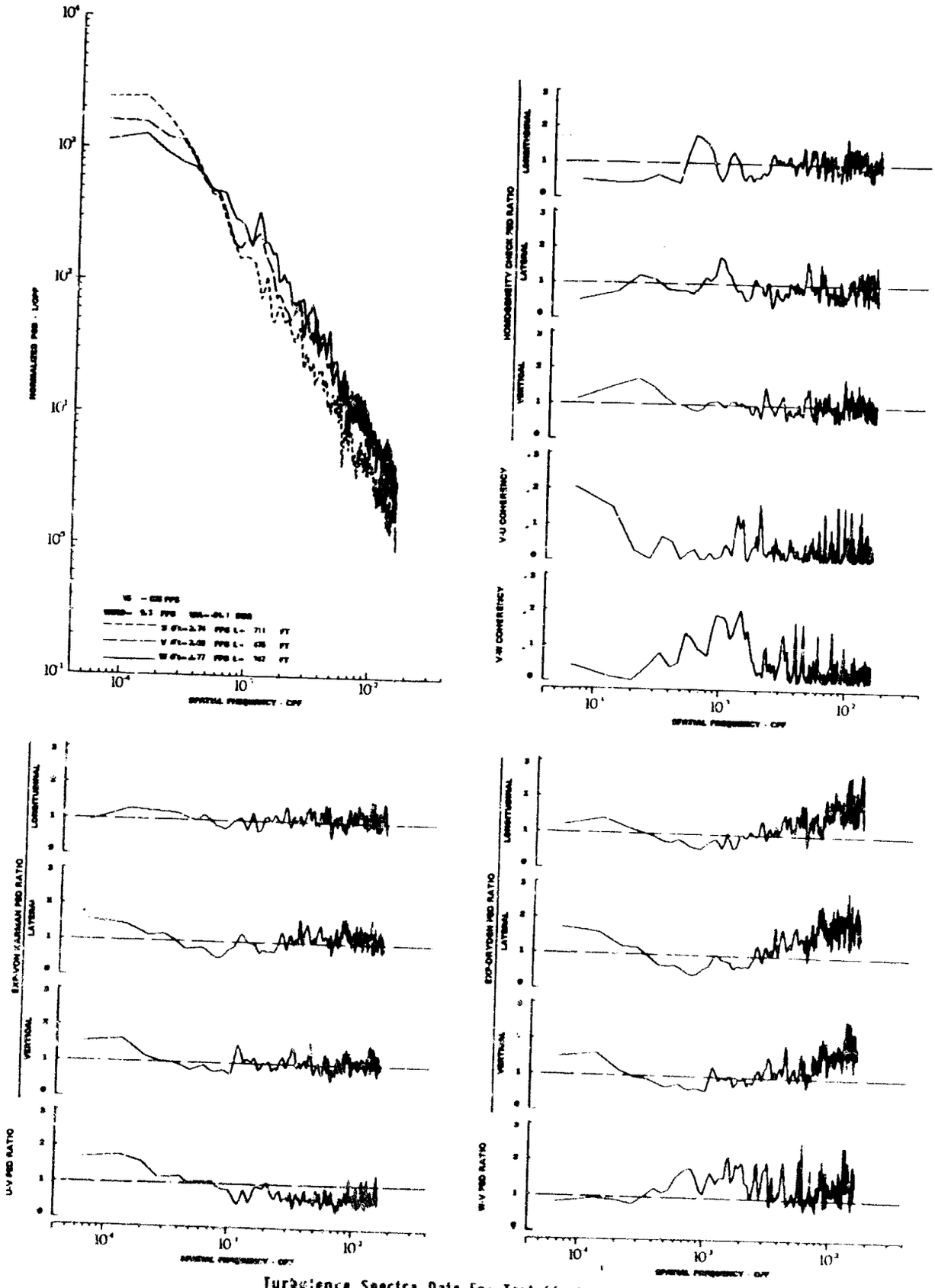
Turbulence Spectra Data For Test 65, Leg 3, Category 112331



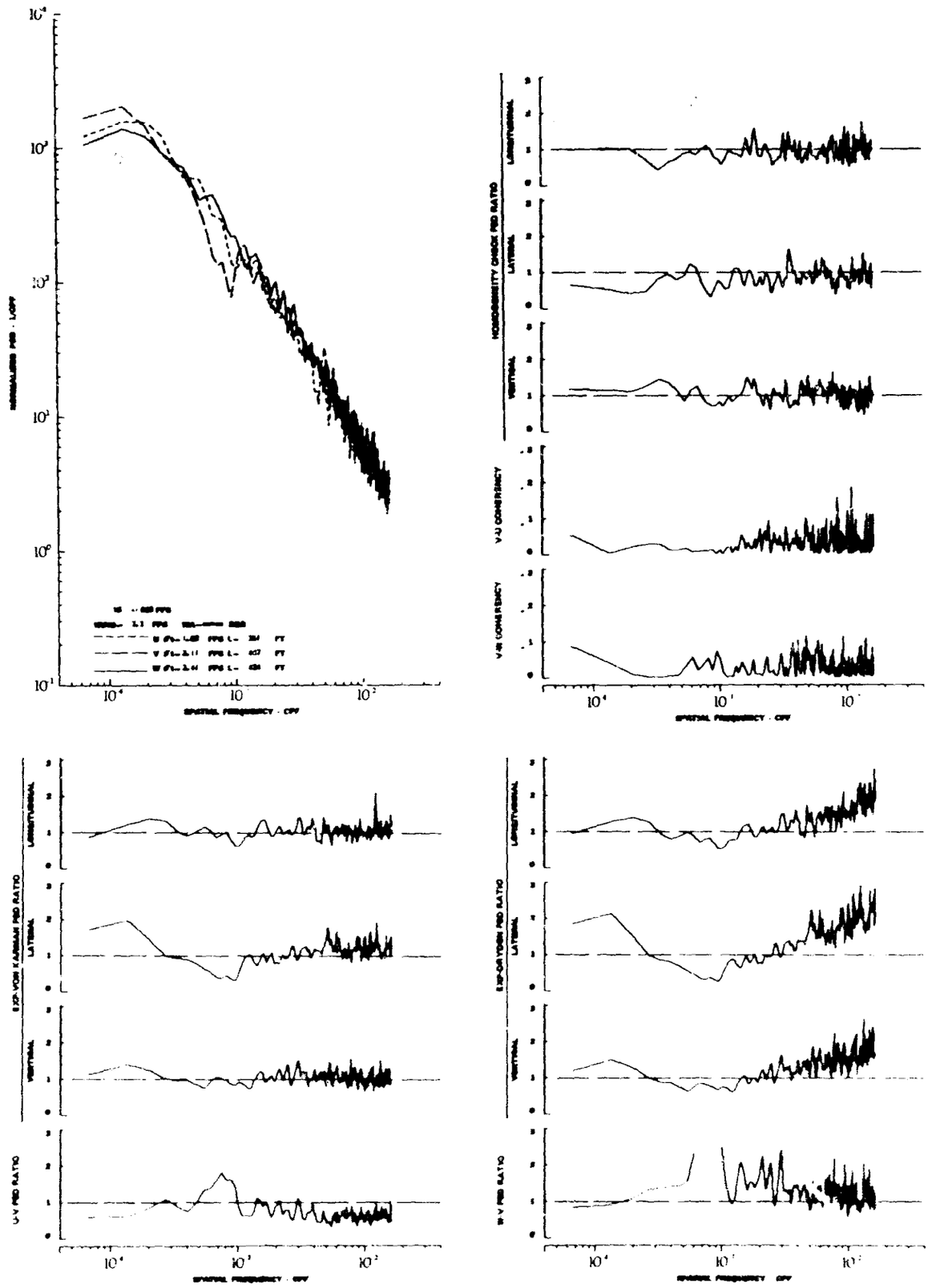
Turbulence Spectra Data For Test 65, Log 5, Category 114331



Turbulence Spectra Data For Test 66, Leg 2, Category 312331



Turbulence Spectra Data For Test 66, Leg 6, Category 113331



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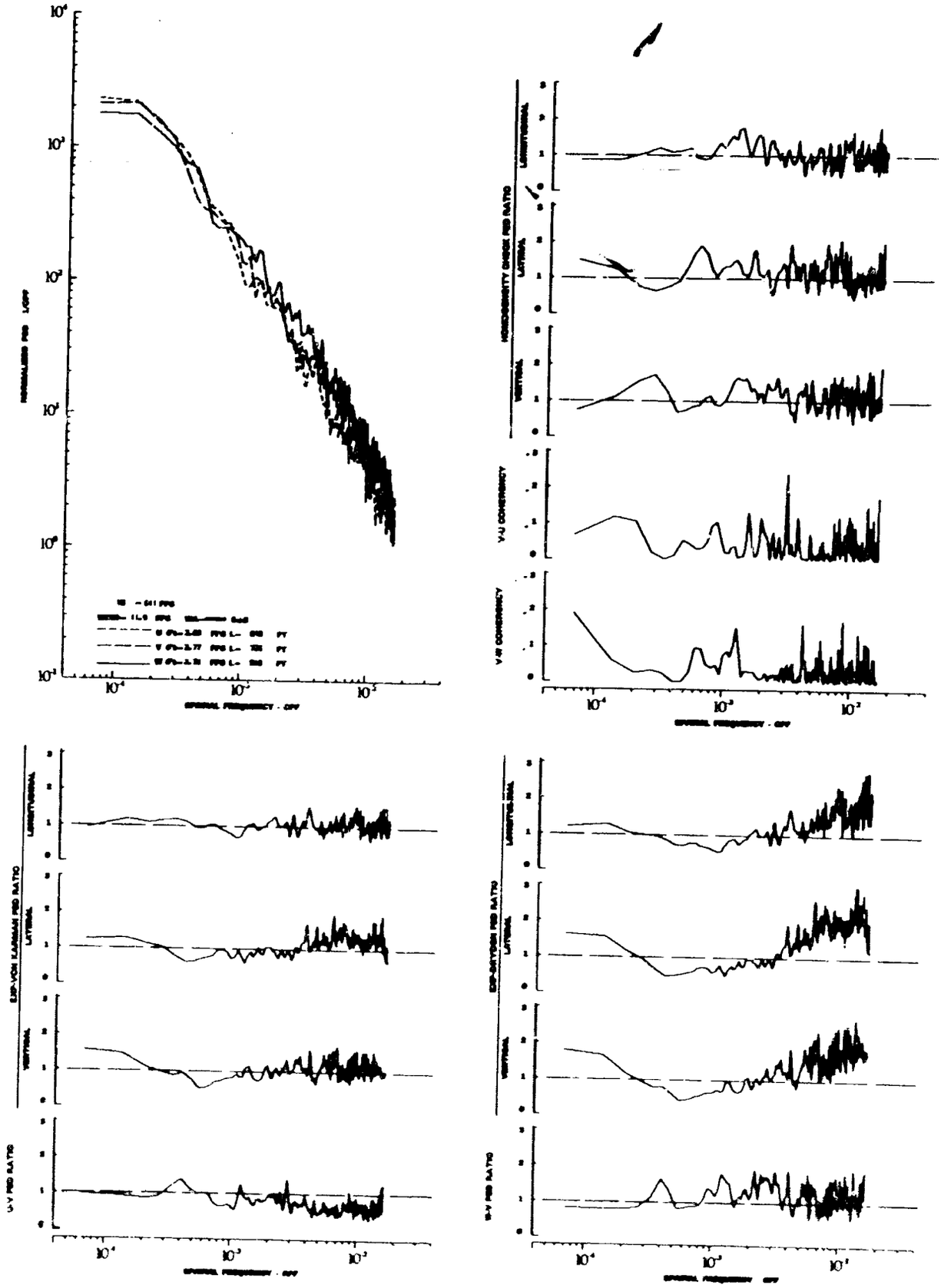
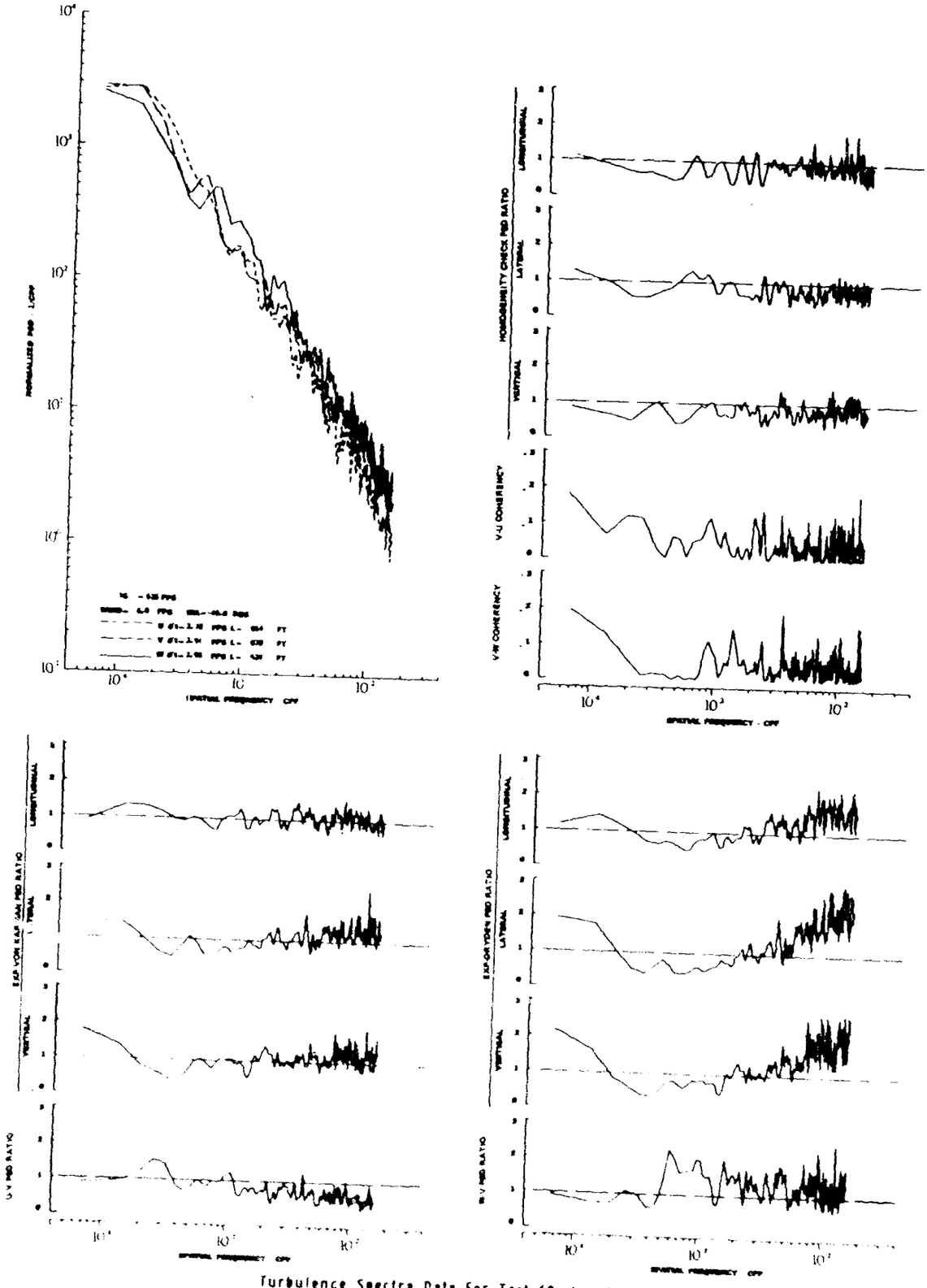
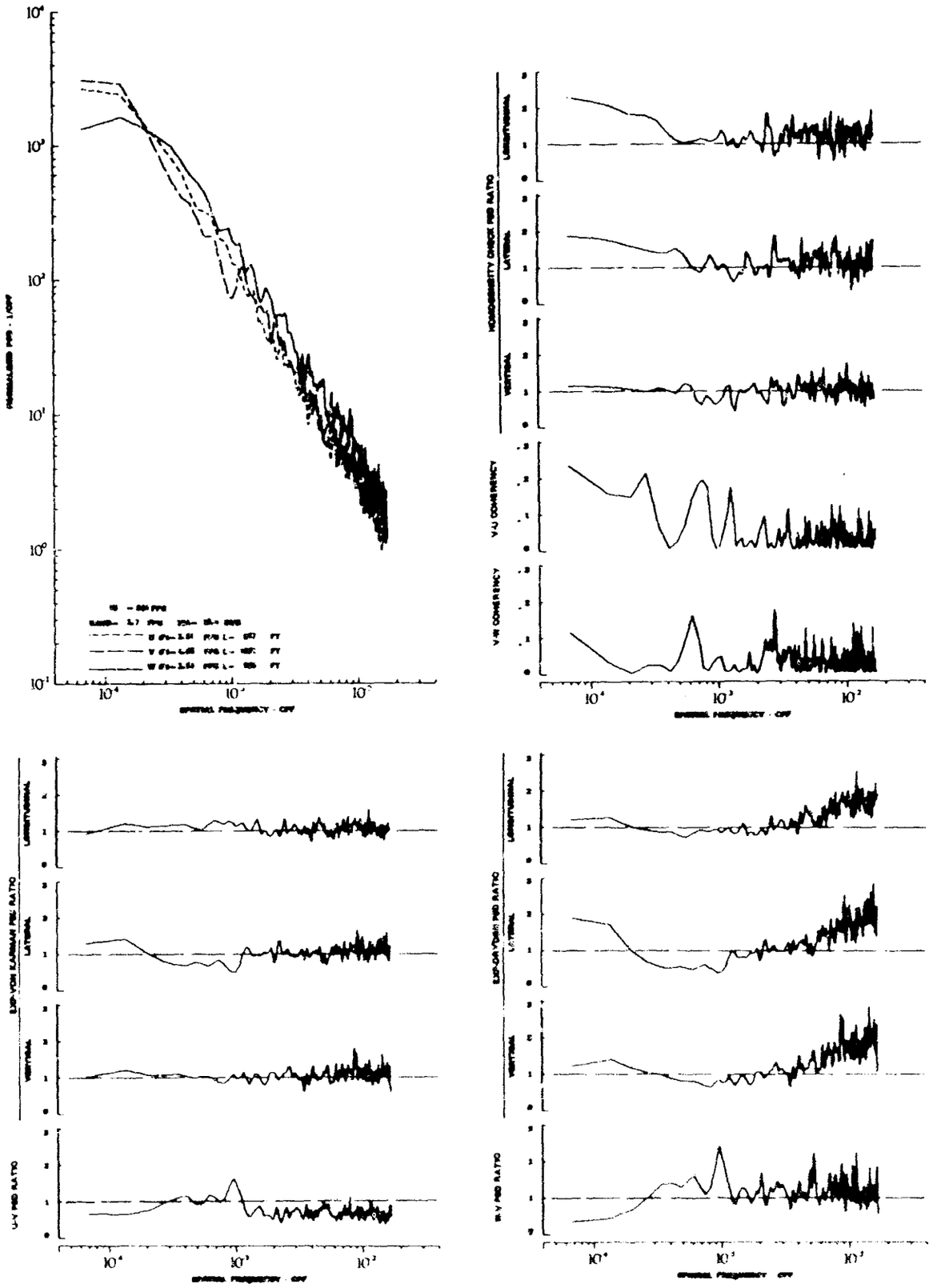


Turbulence Spectra Data For Test 69, Leg 1, Category 224331



Turbulence Spectra Data For Test 69, Leg 3, Category 122331



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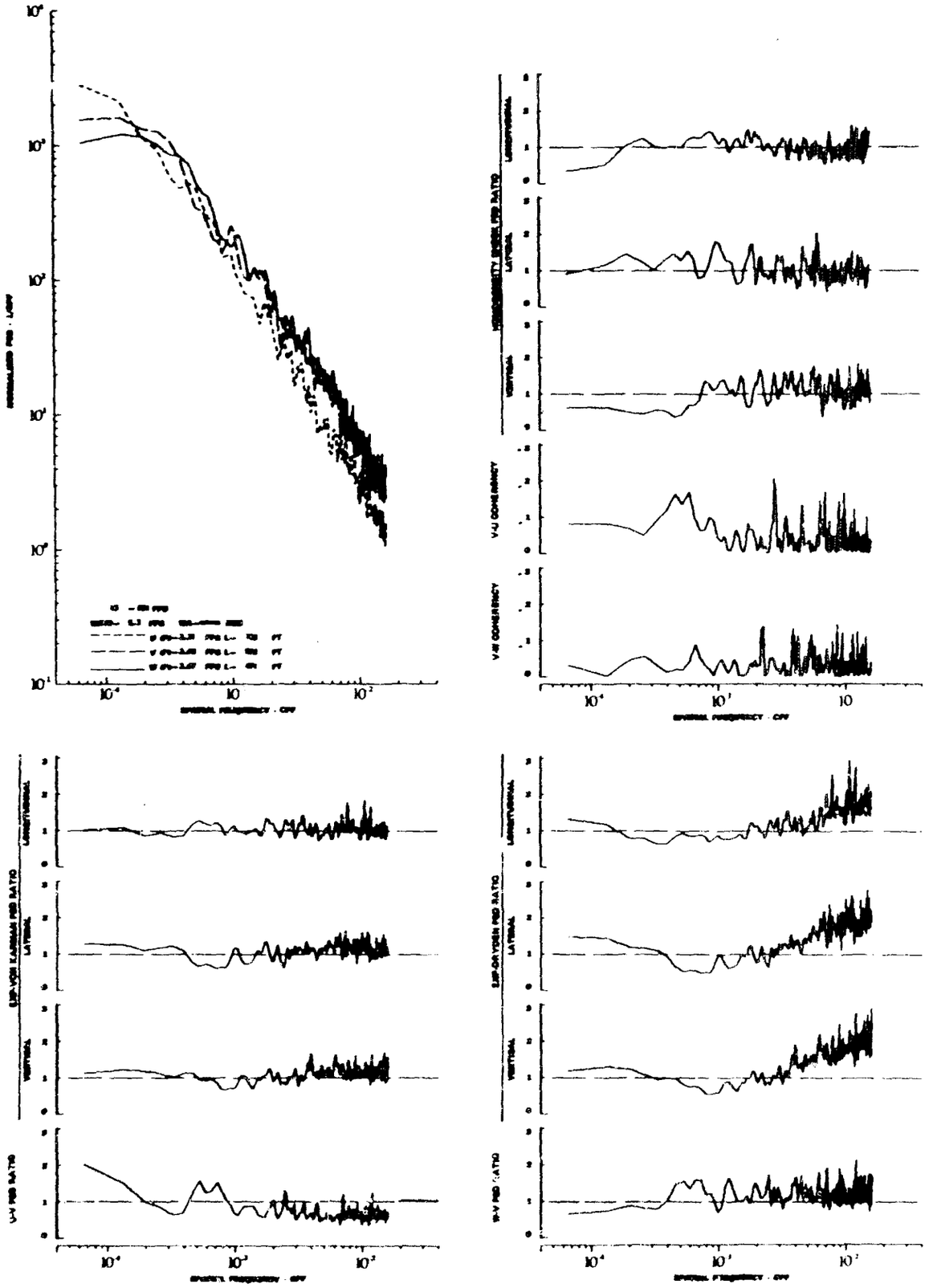
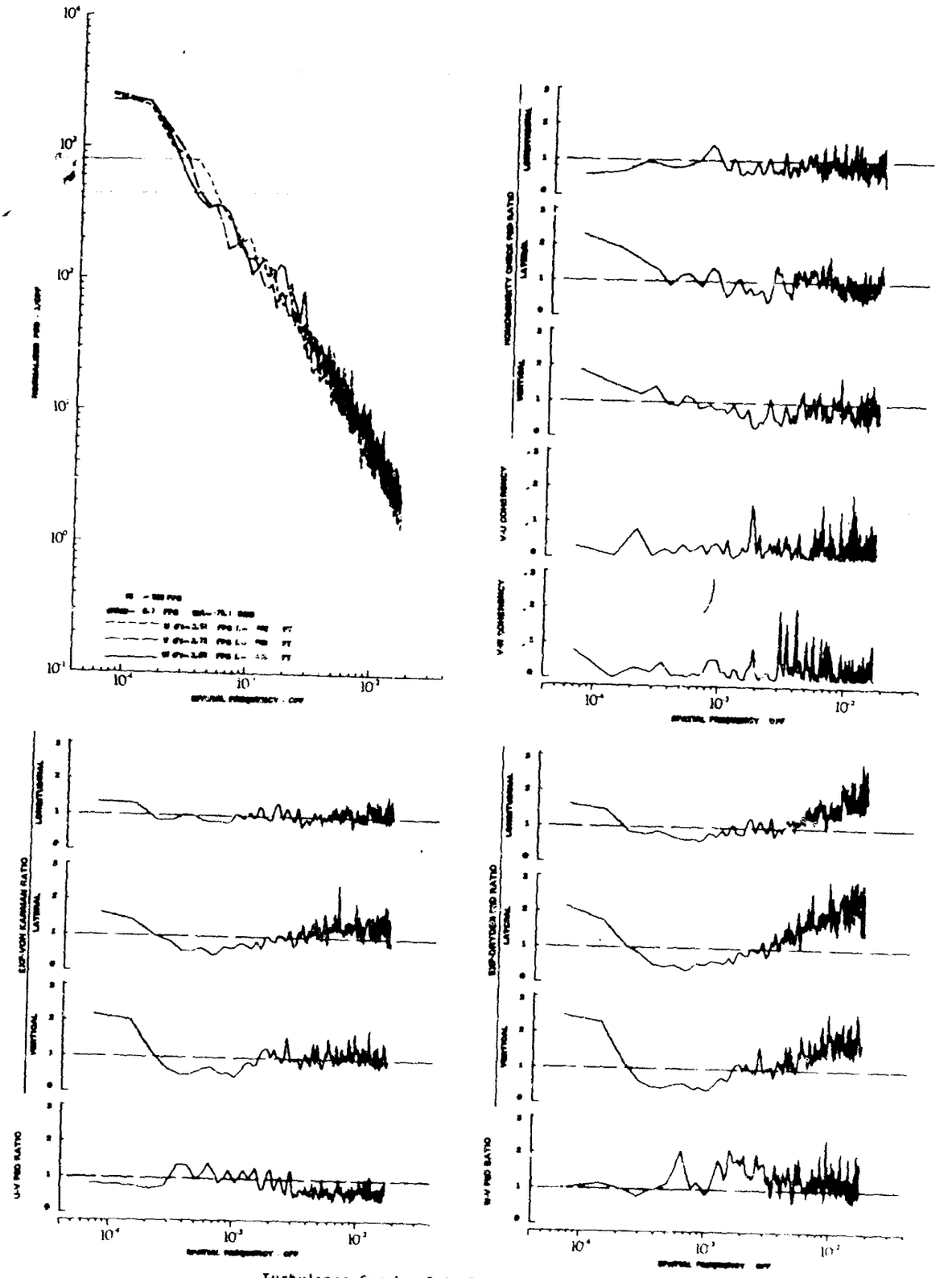


Turbulence Spectra Data For Test 69, Leg 7, Category 322331



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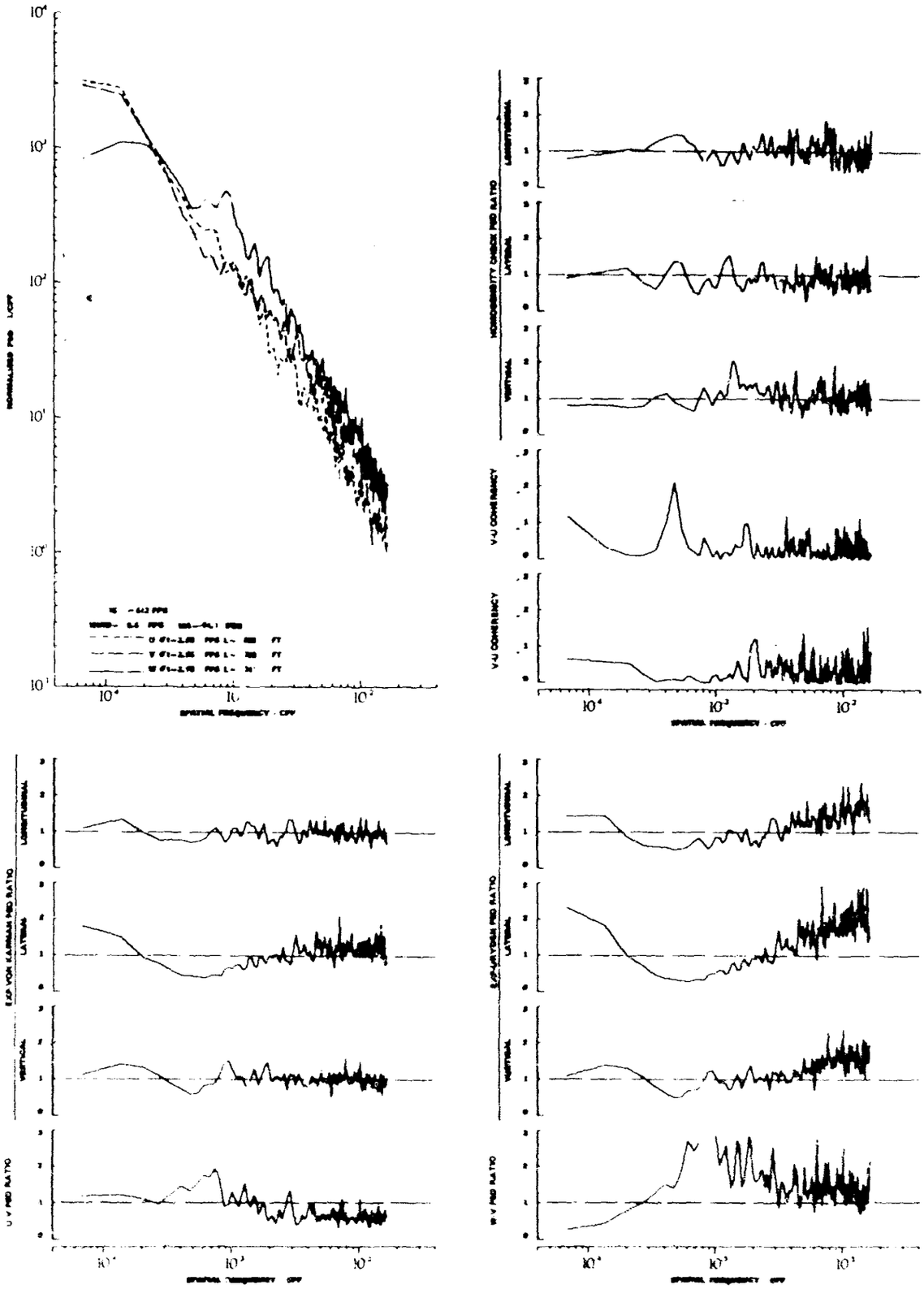

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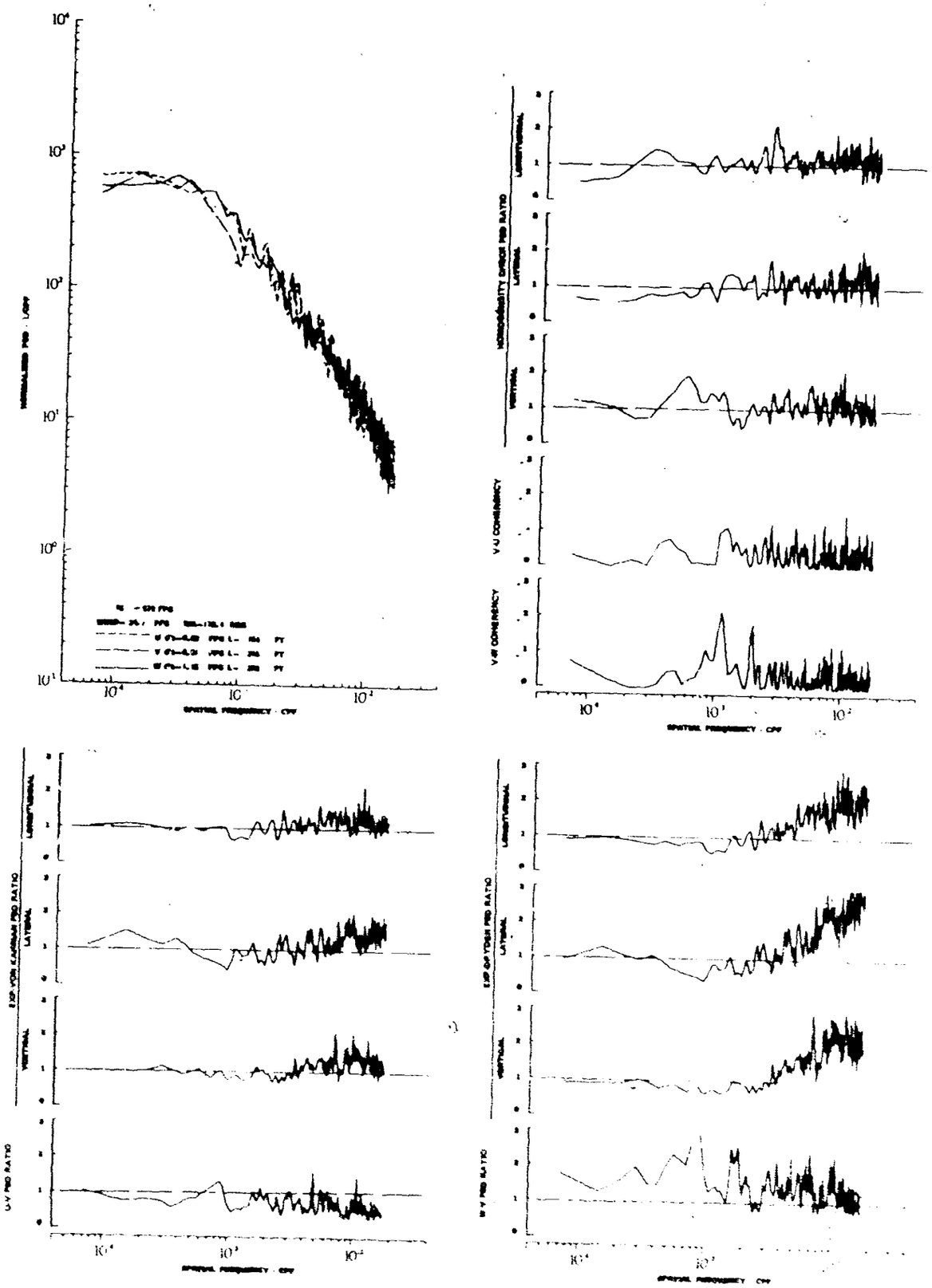
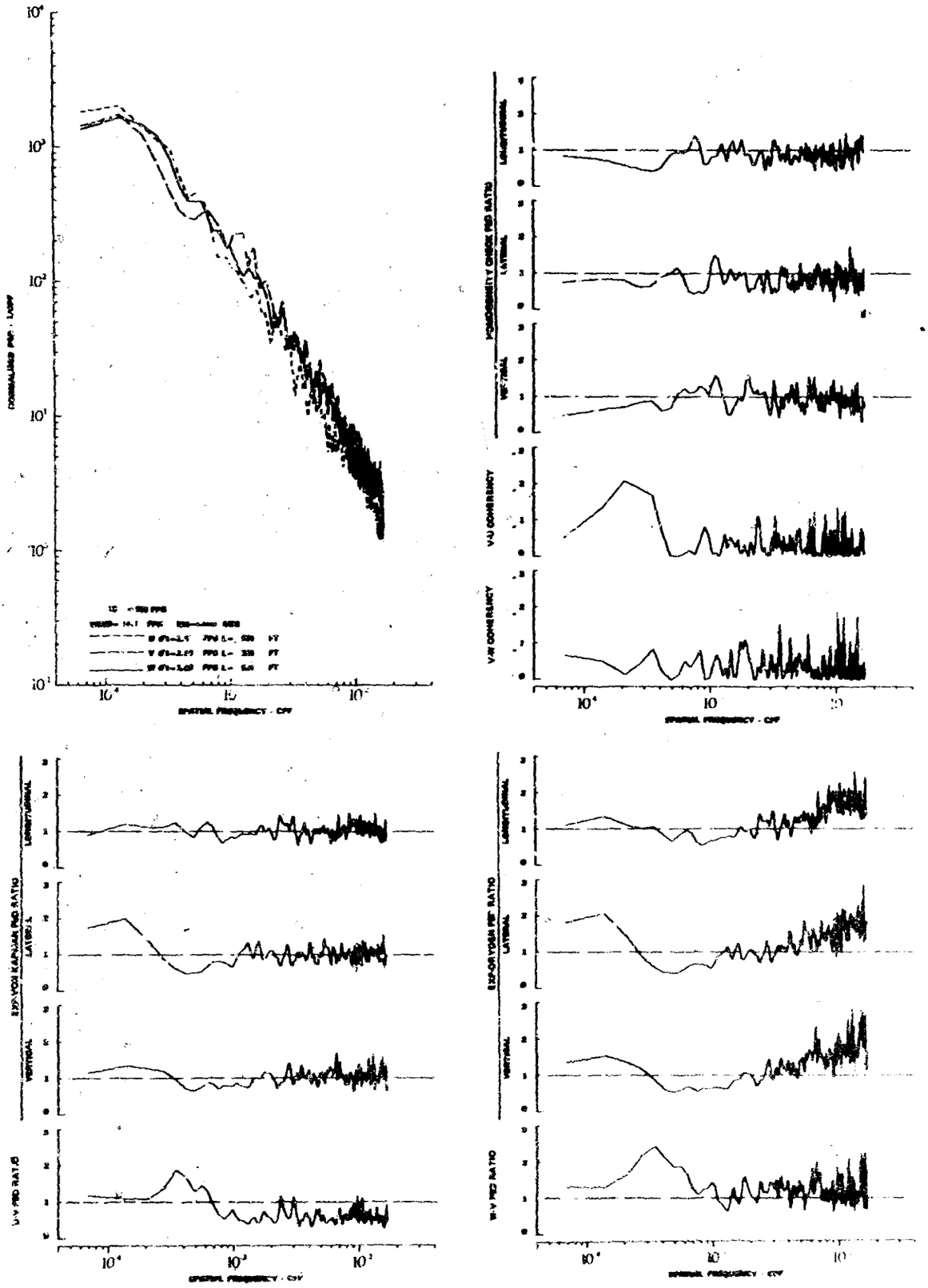
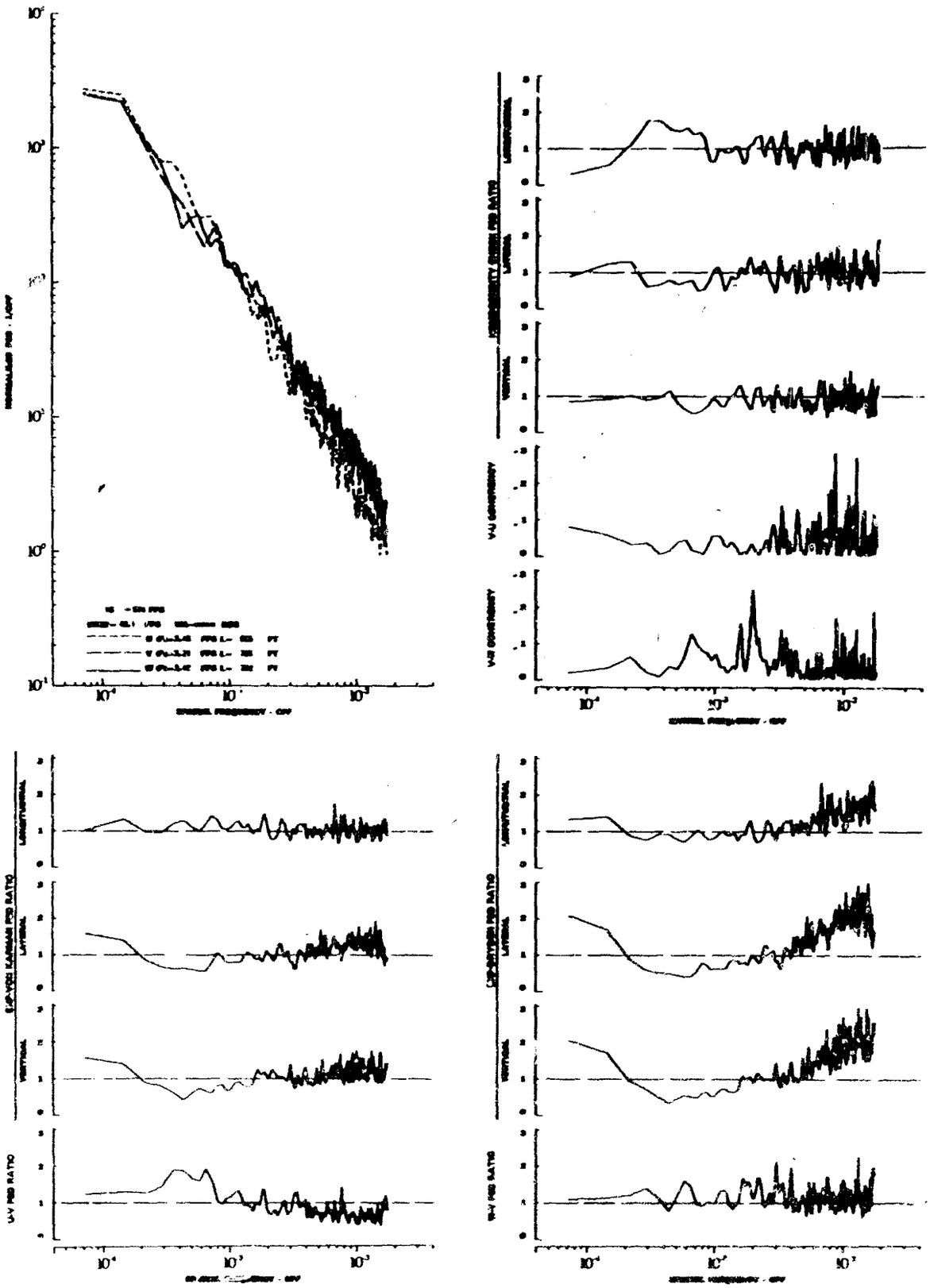


Turbulence Spectra Data For Test 72, Leg 4, Category 612331



Turbulence Spectra Data For Test 74, Leg 6, Category 123231



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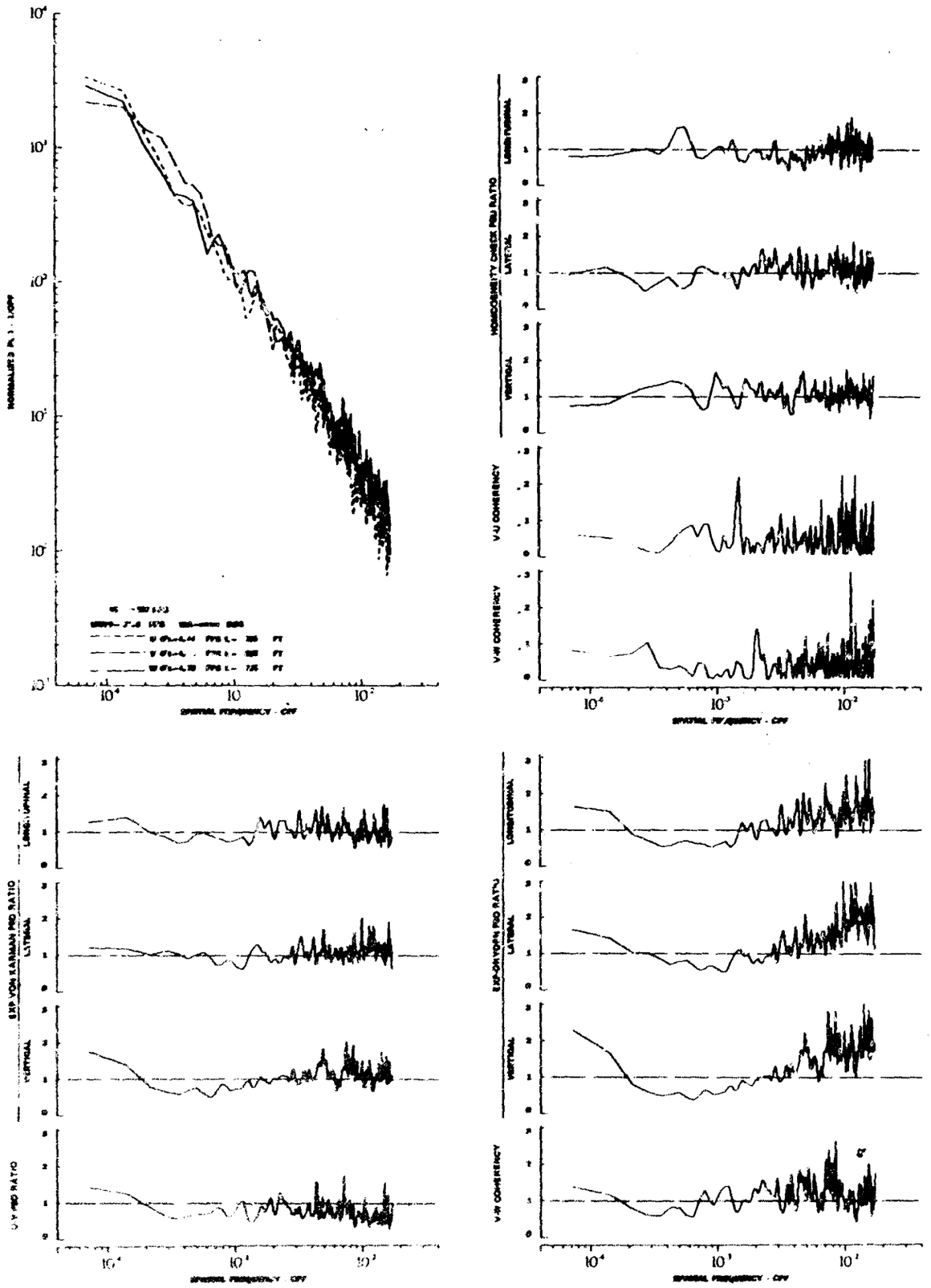
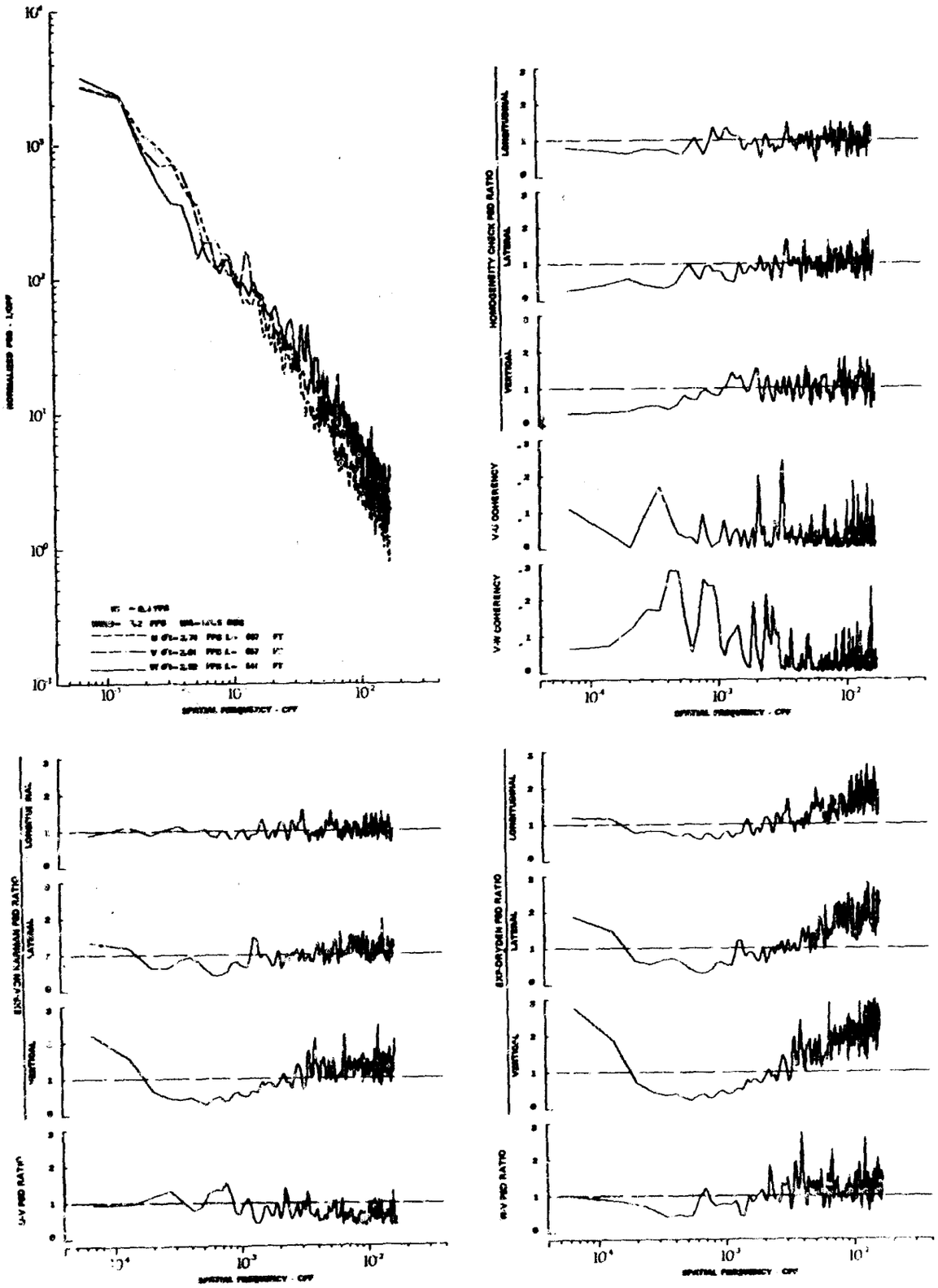
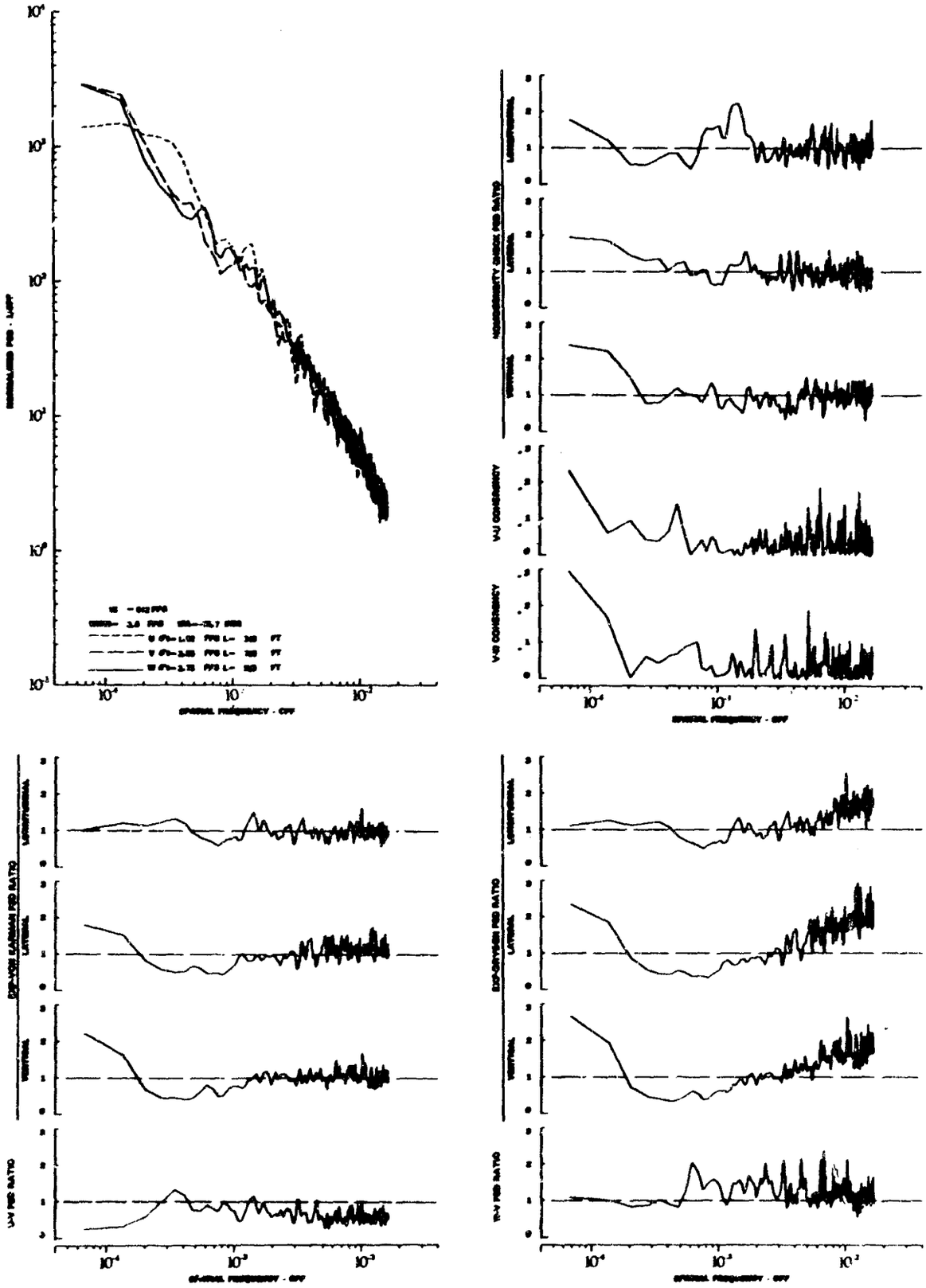


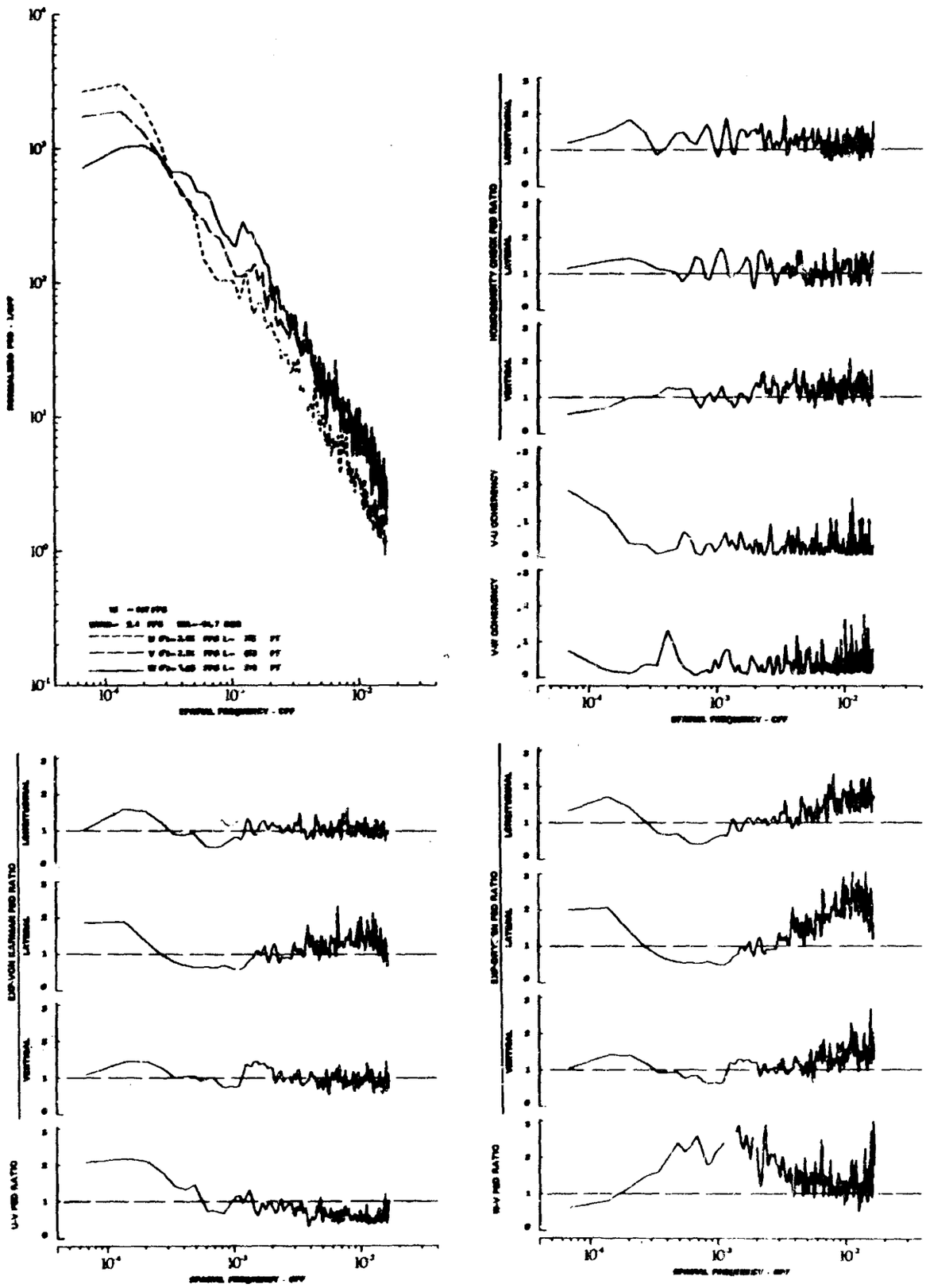
Turbulence Spectra Data For Test 75, Leg 5, Category 122331



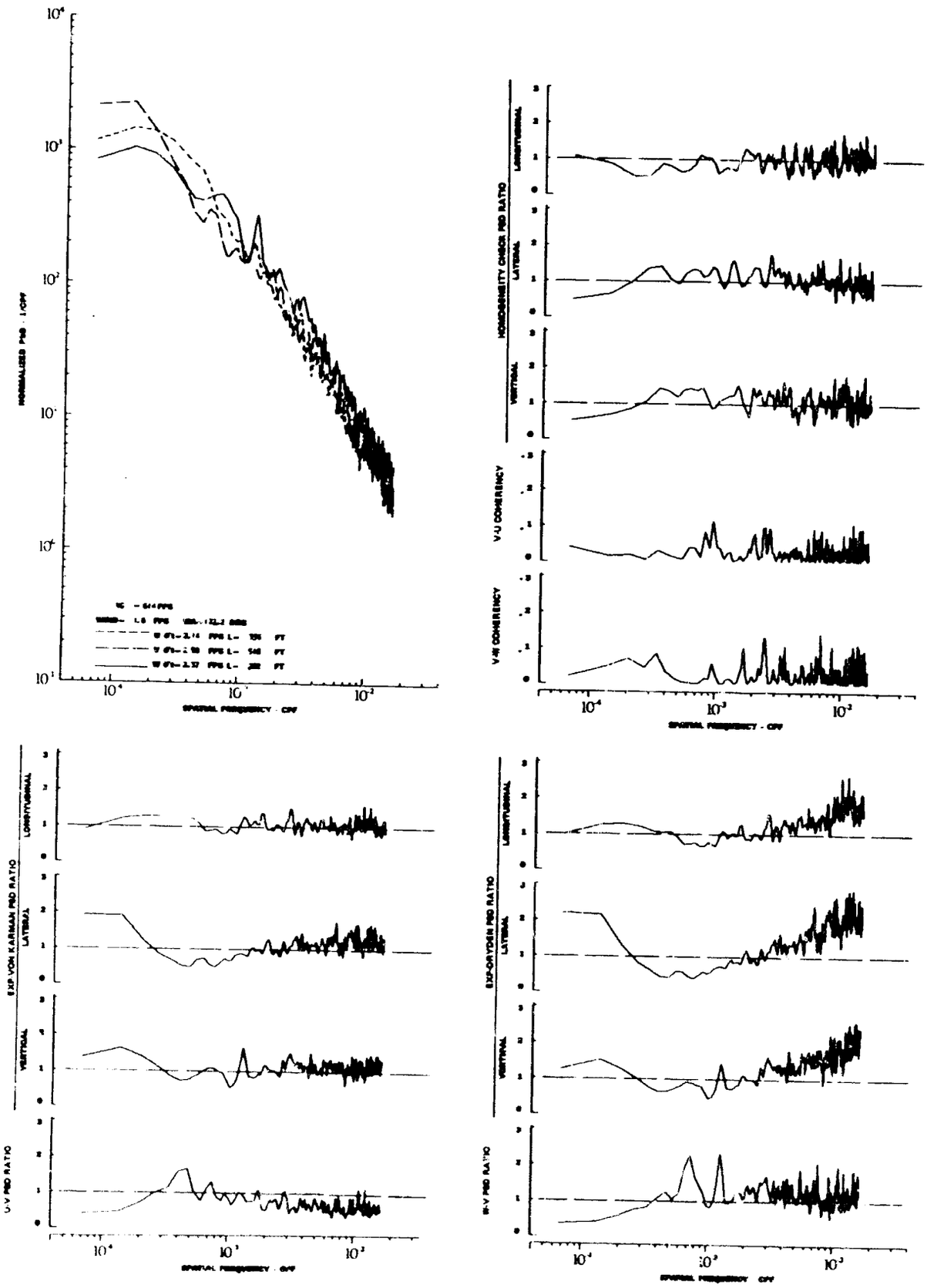
Turbulence Spectra Data For Test 77, Leg 3, Category 112231



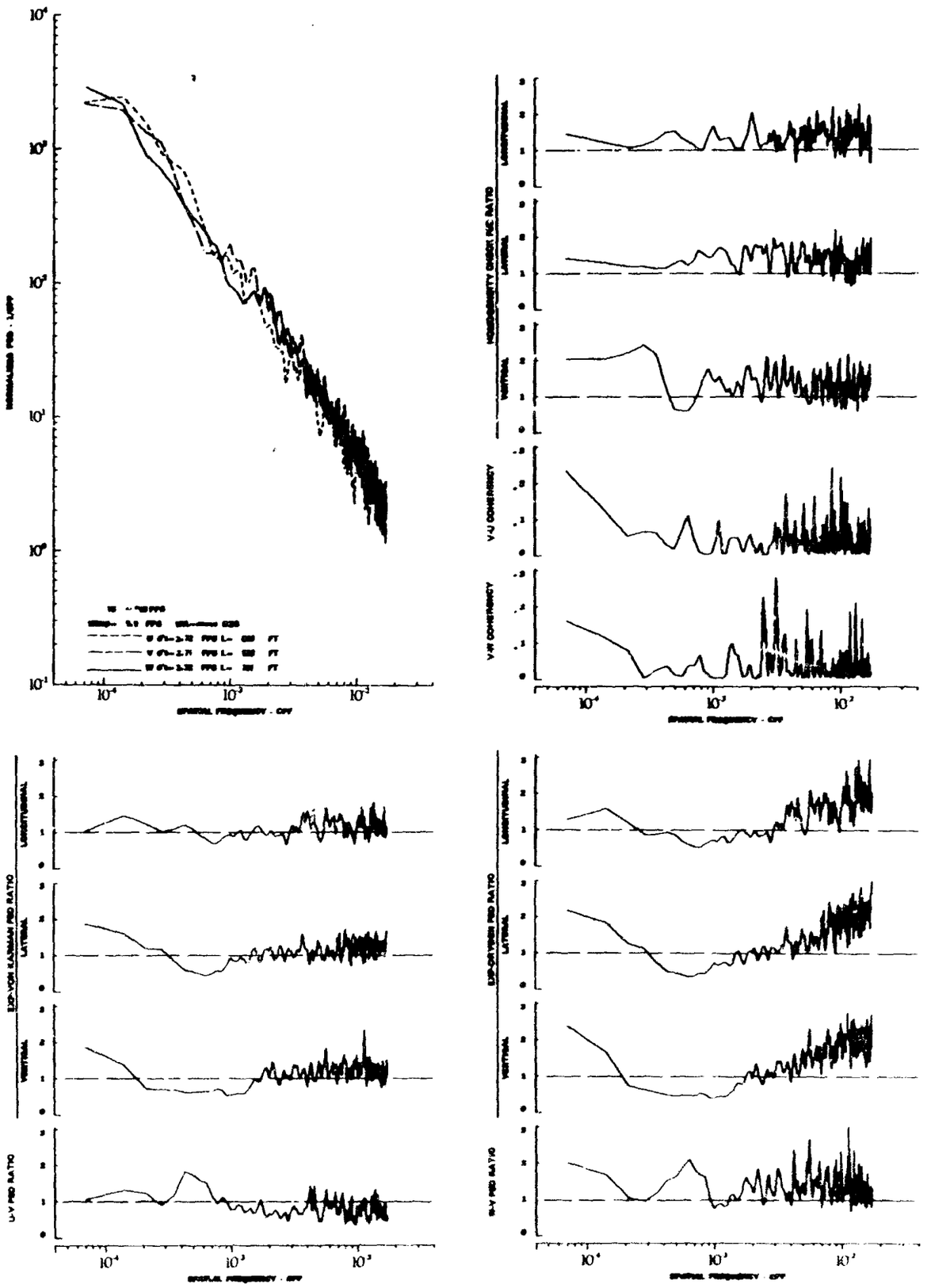
Turbulence Spectra Data For Test 77, Leg 7, Category 311231



Turbulence Spectra Data For Test 78, Leg 2, Category 312331



Turbulence Spectra Data For Test 78, Leg 6, Category 112331



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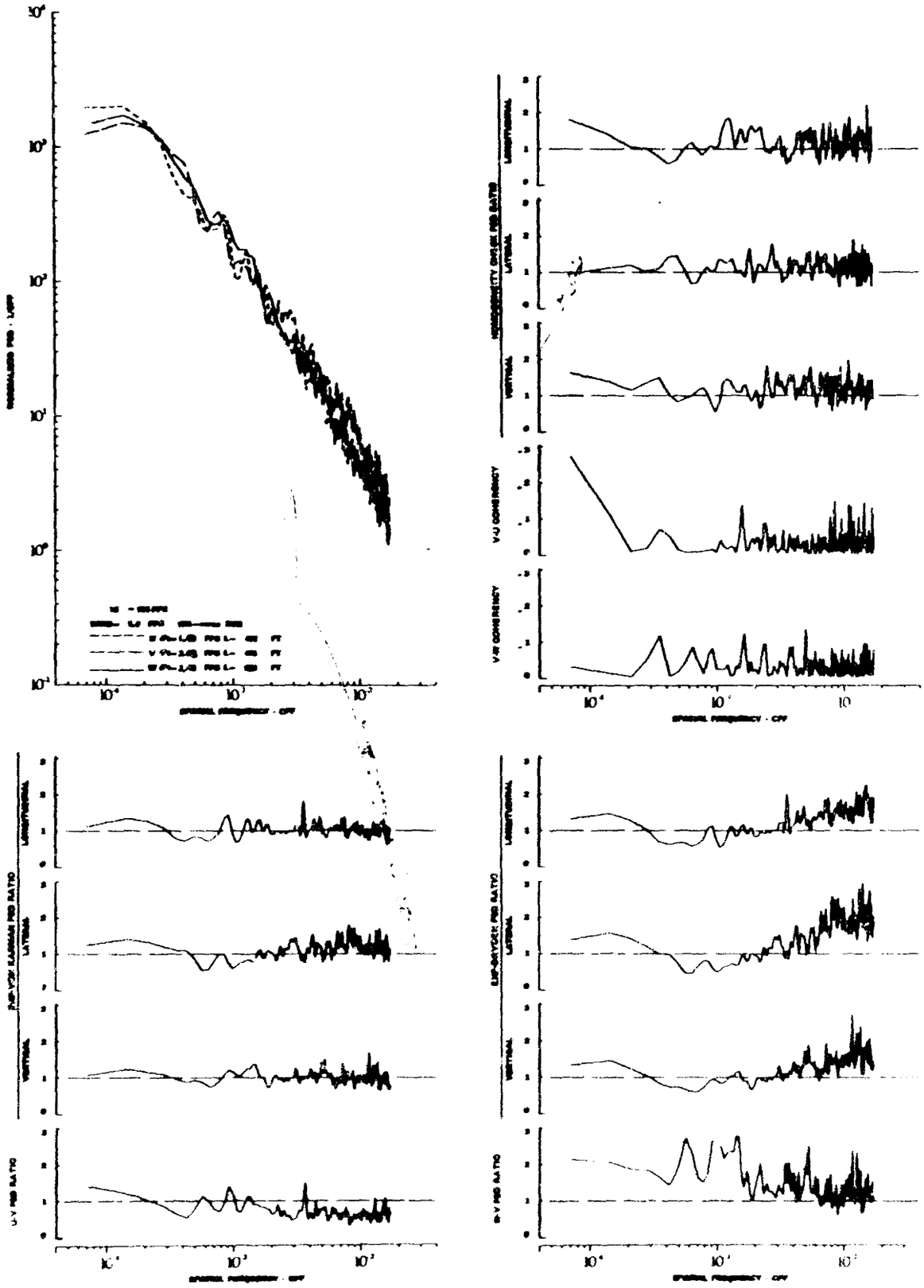
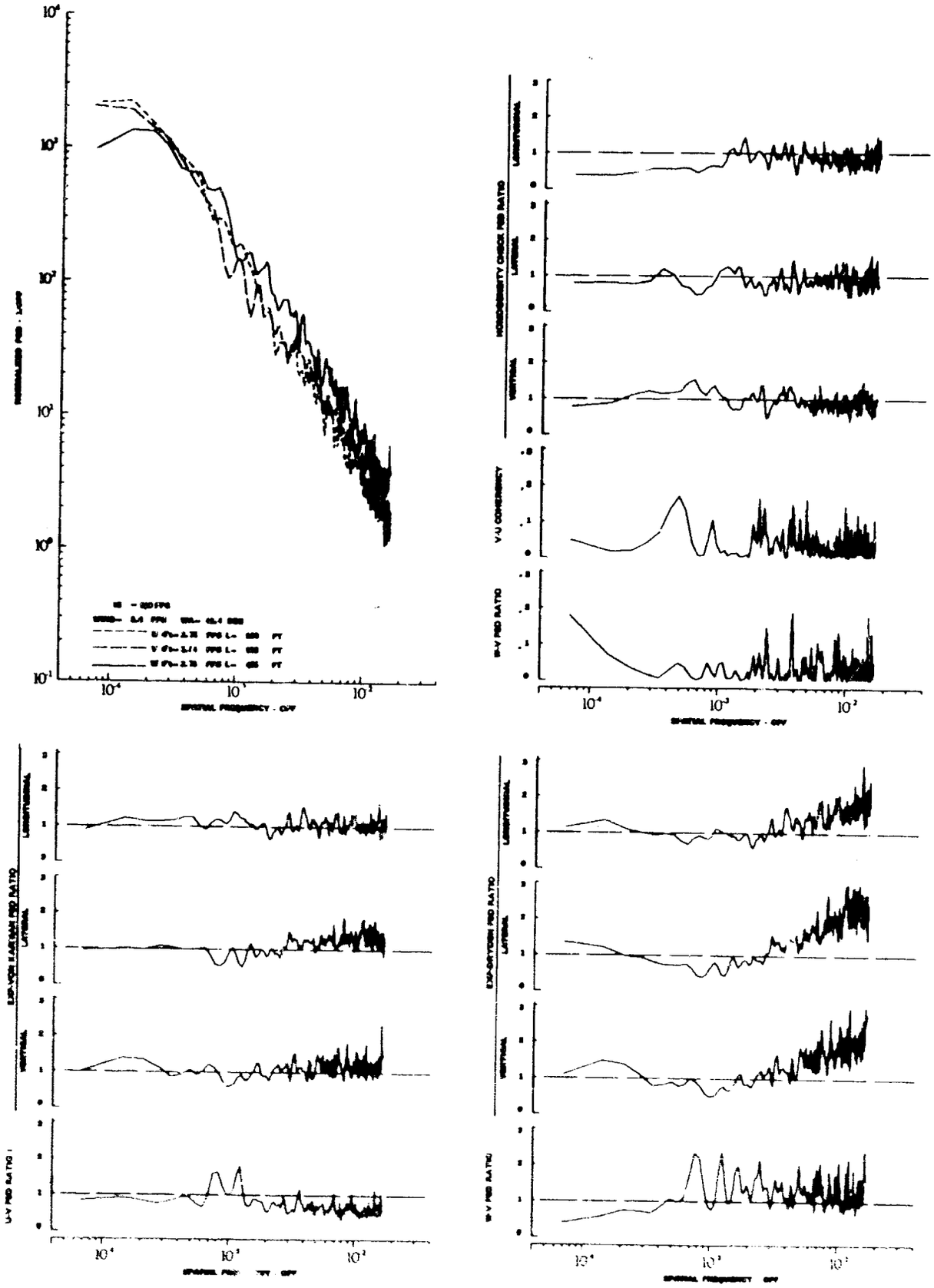
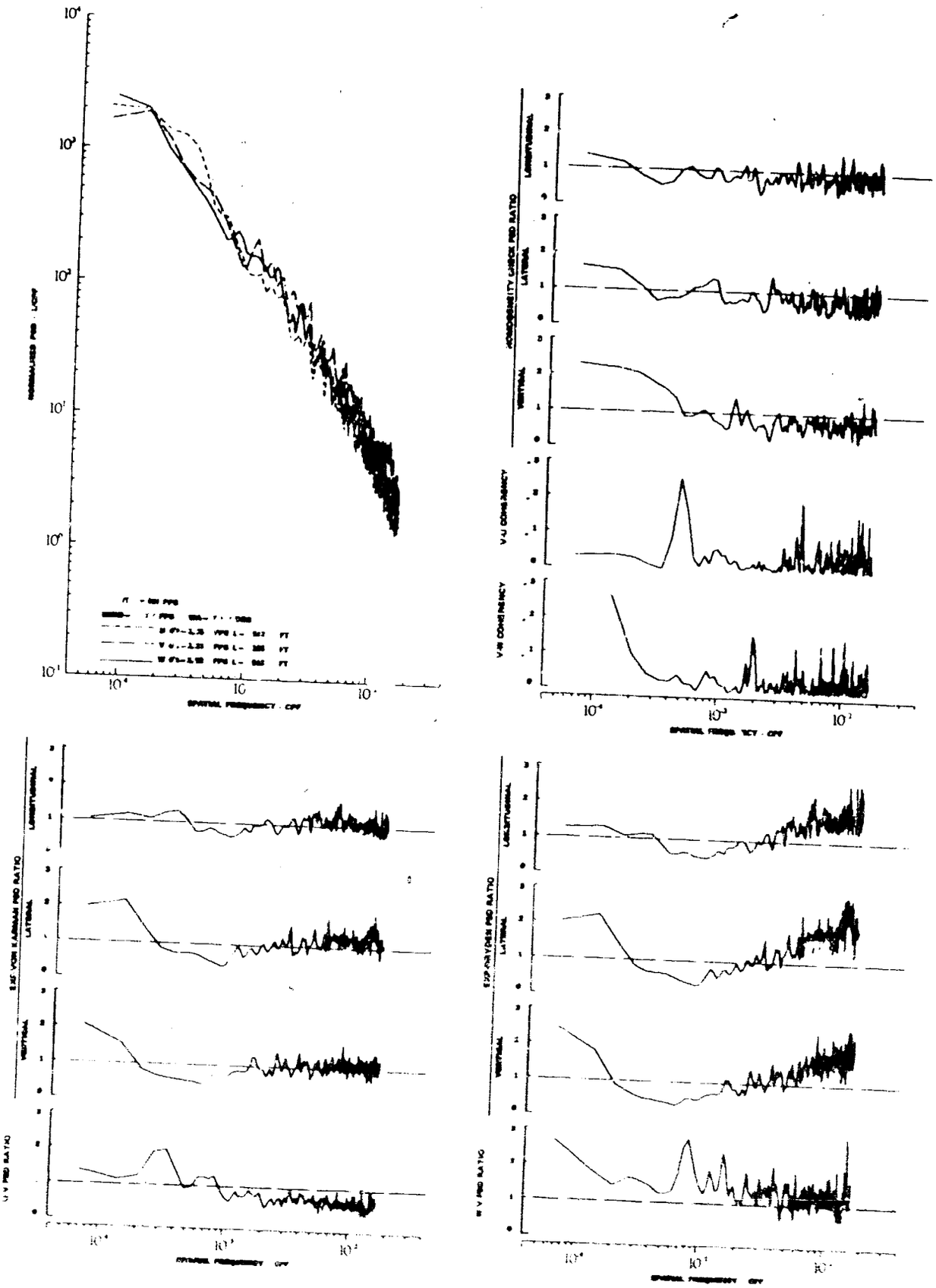


Turbulence Spectra Data For Test 88, Leg 2, Category 322331



Turbulence Spectra Data For Test 80, Leg 6, Category 122331



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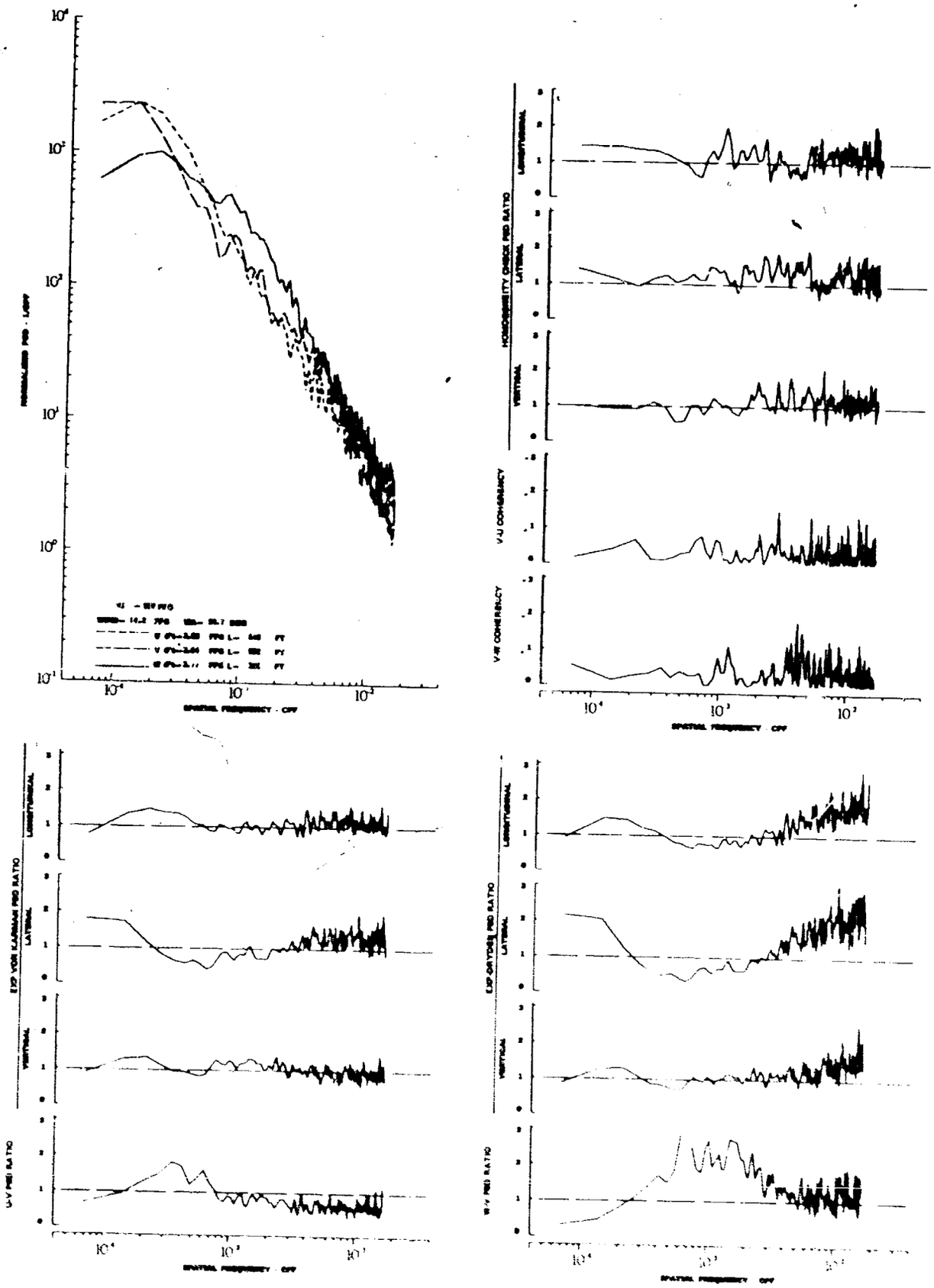
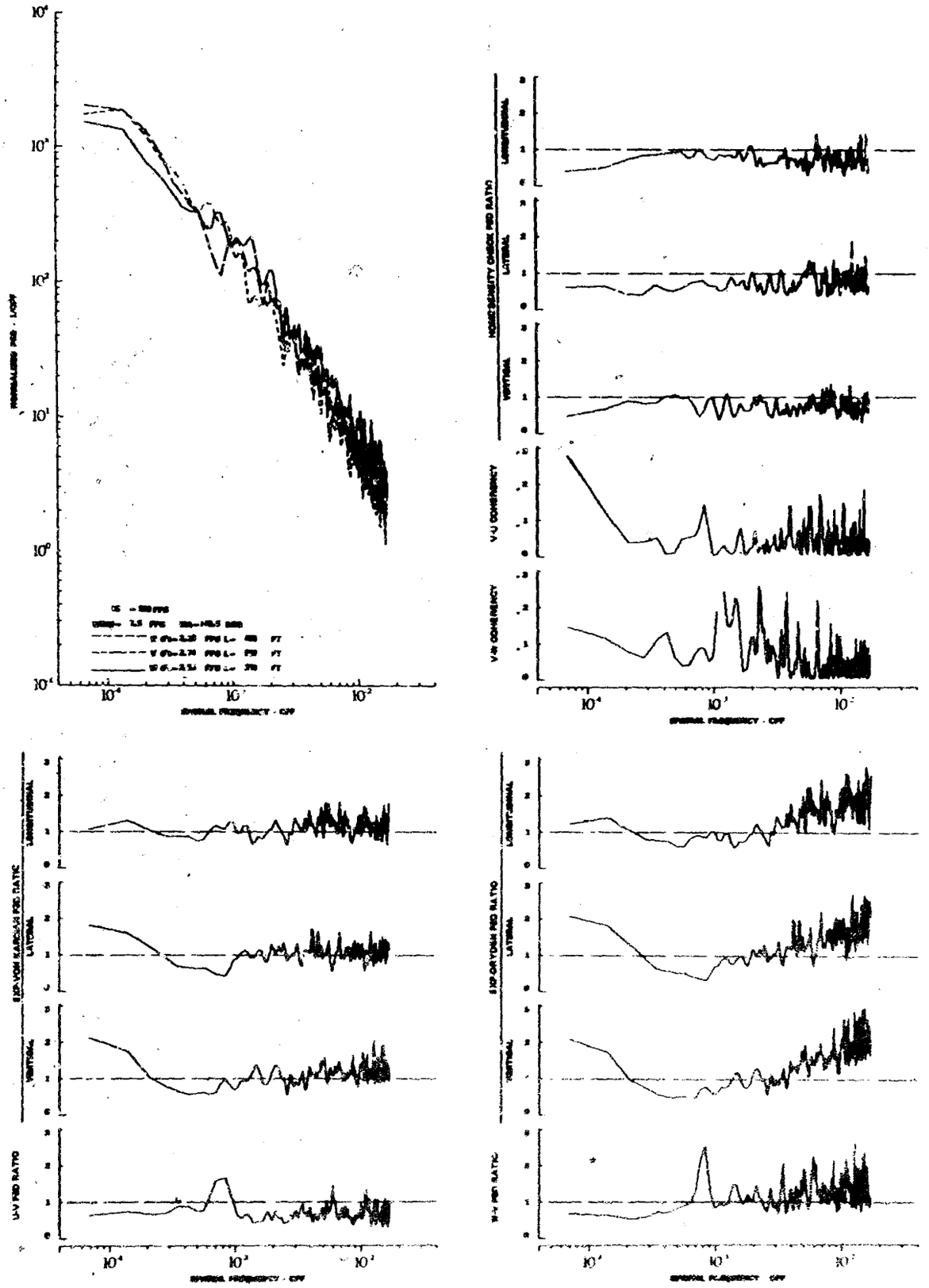


Turbulence Spectra Data For Test 82, Leg 2, Category 312331



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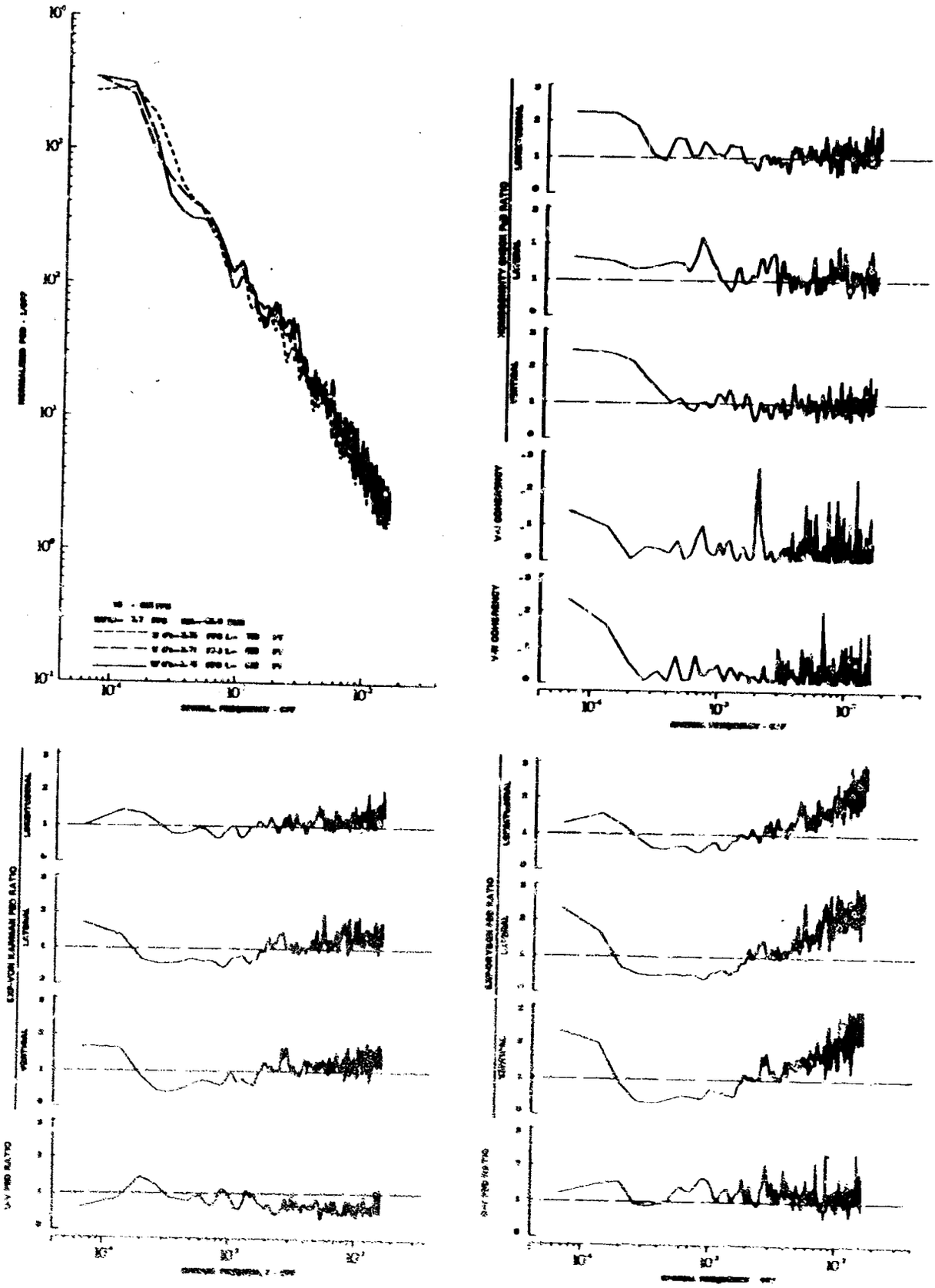
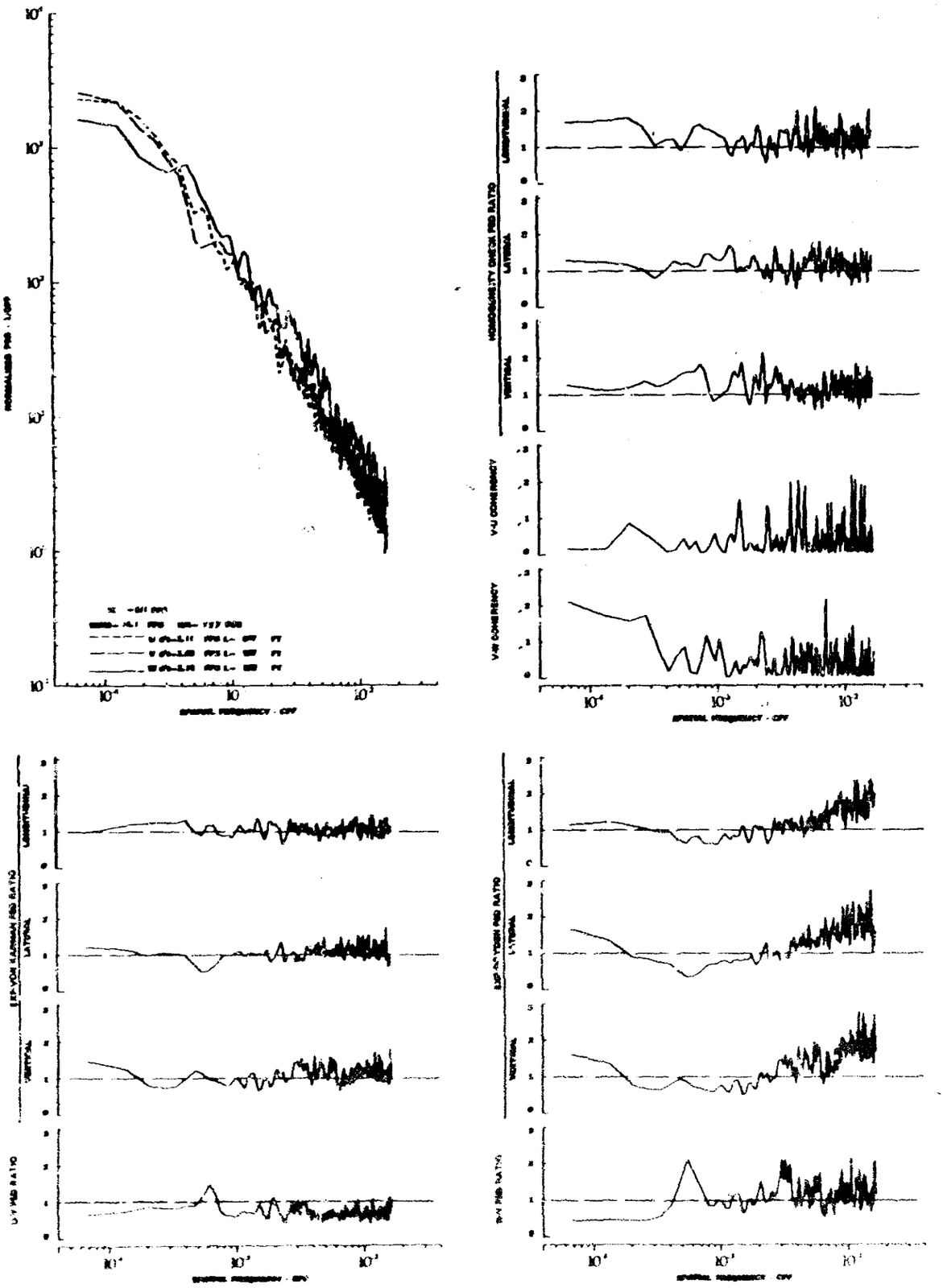
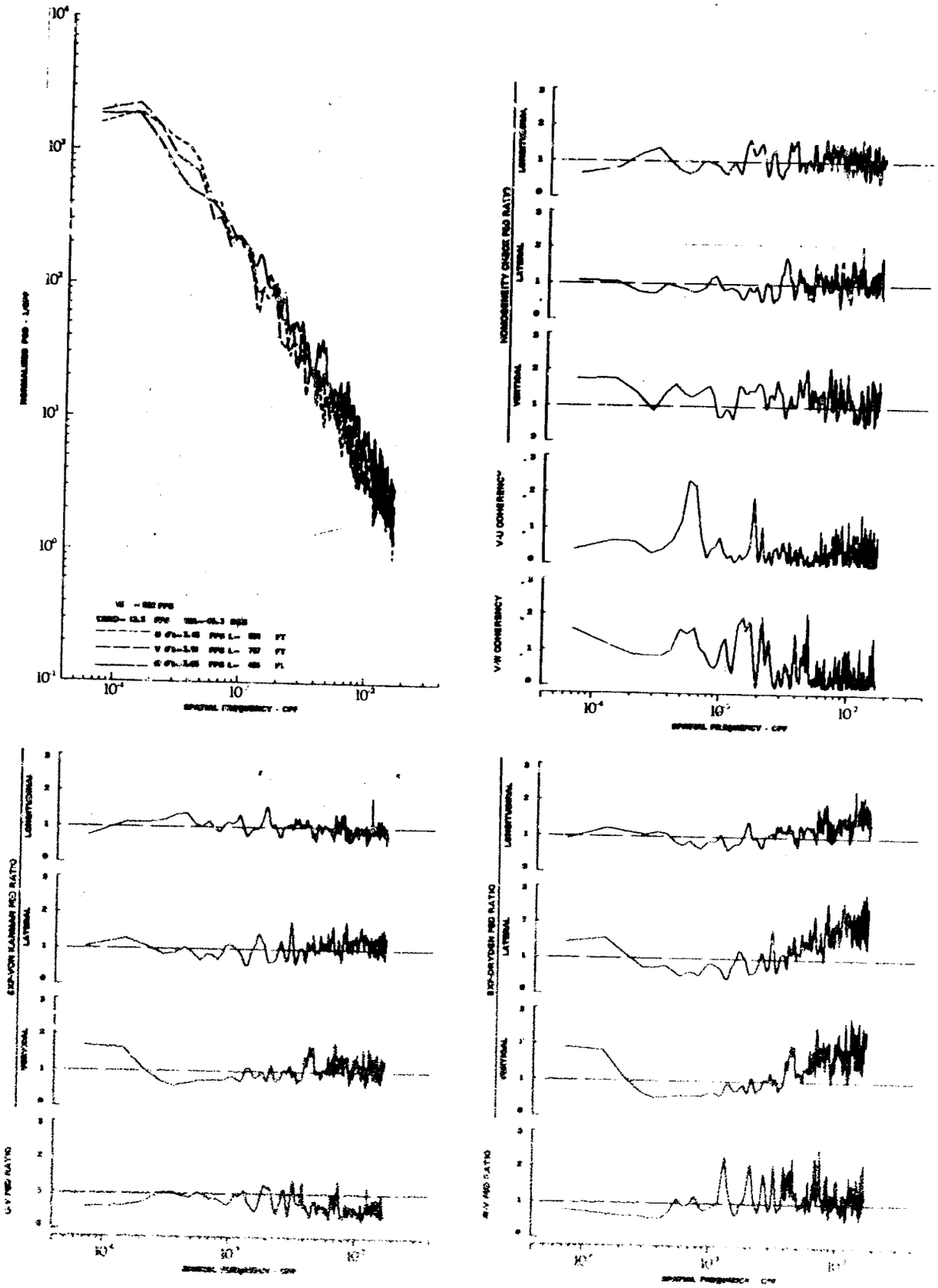


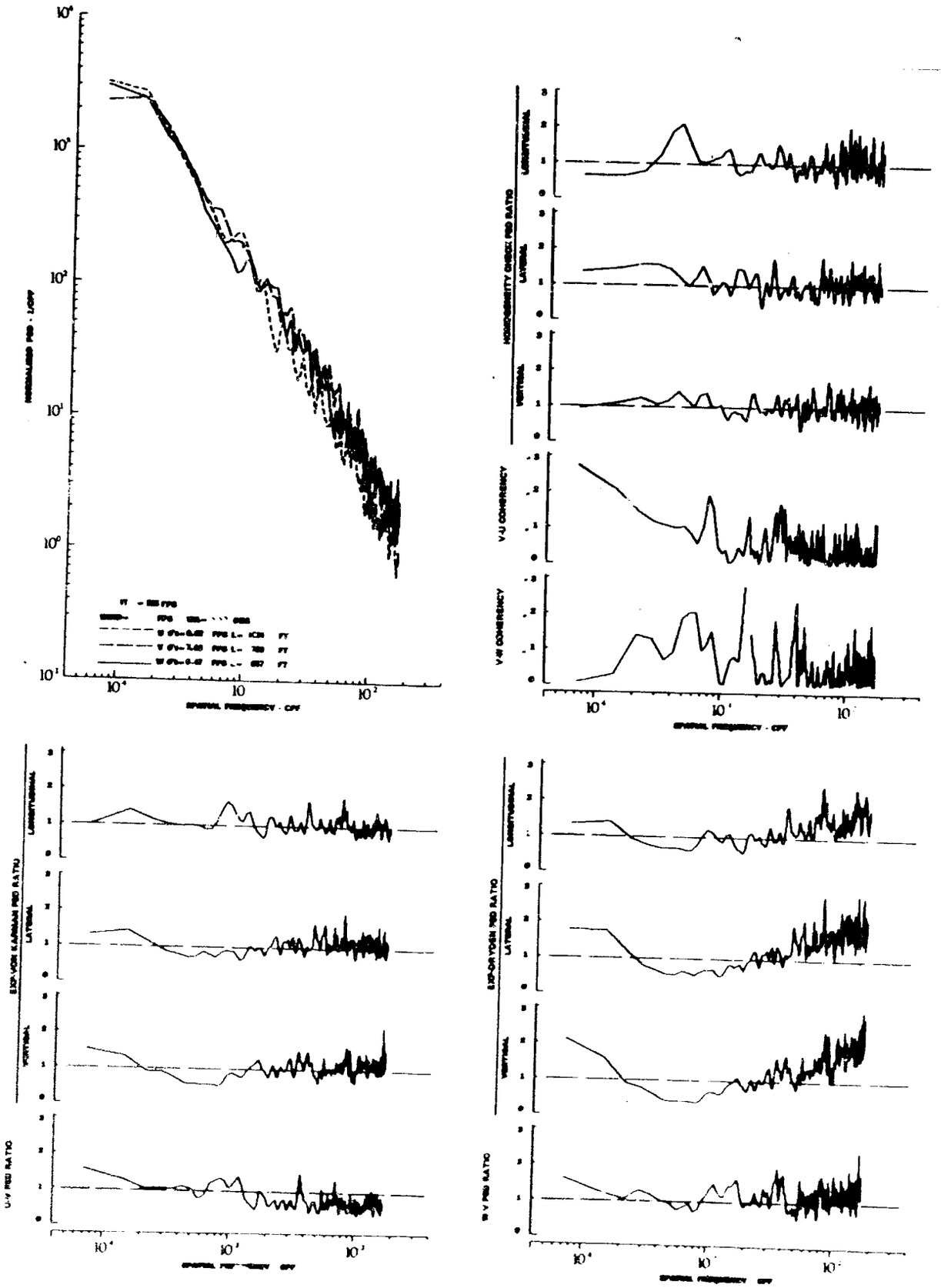
Turbulence Spectra Data For Test 82, Log 8, Category 213331



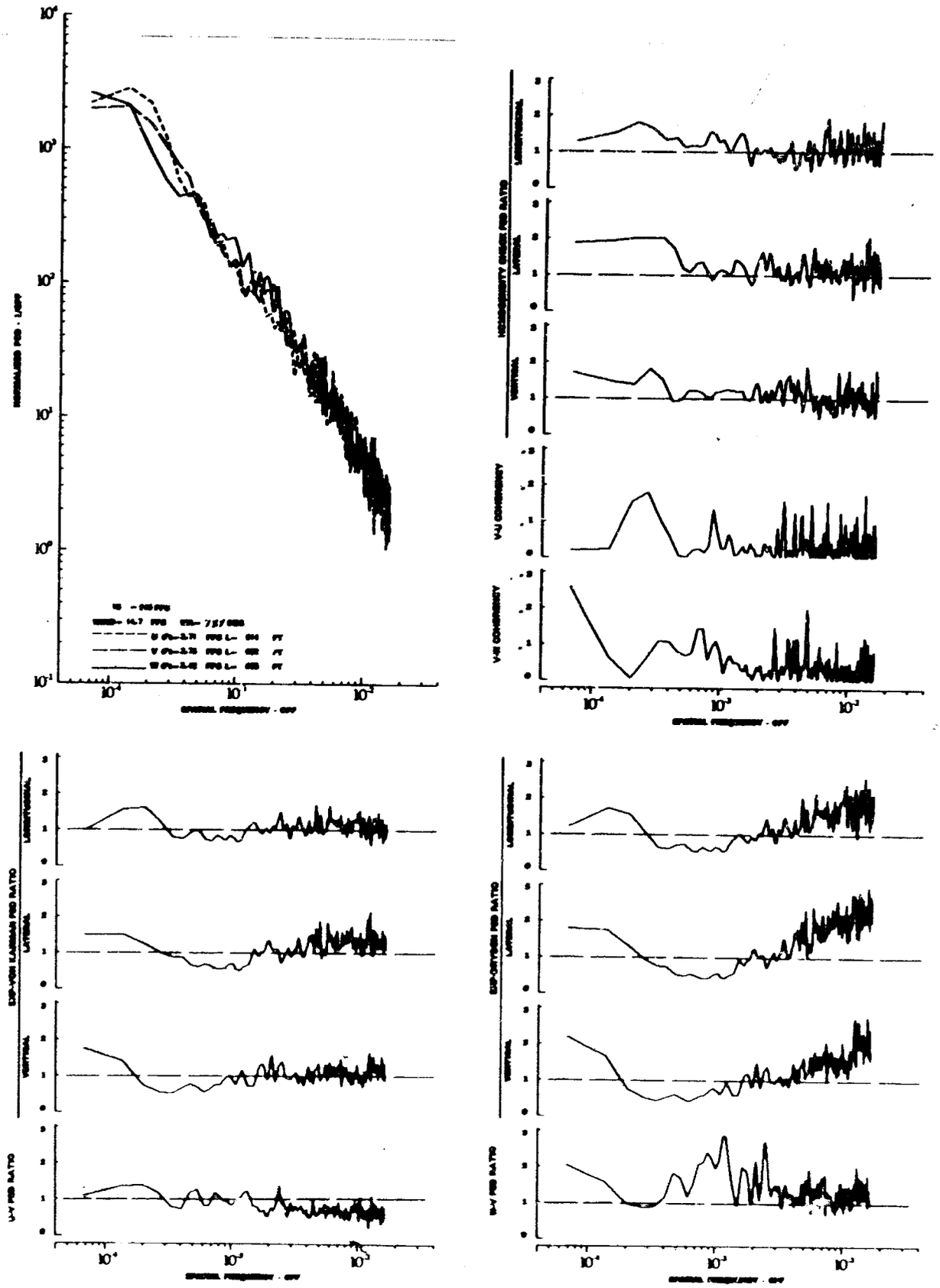
Turbulence Spectra Data for Test 35, Leg 1, Category 224331



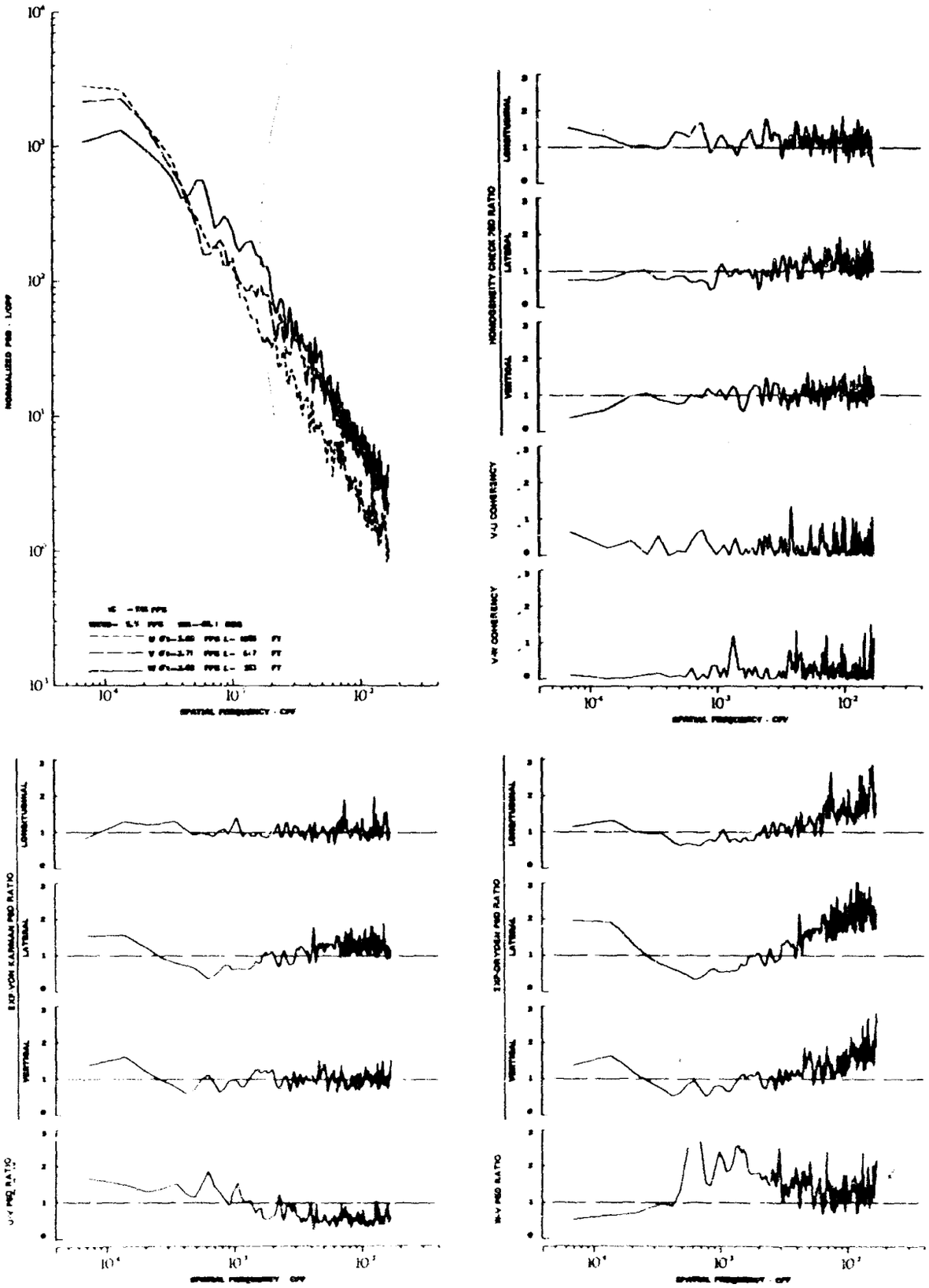
Turbulence Spectra Data For Test 85, Leg 5, Category 121331



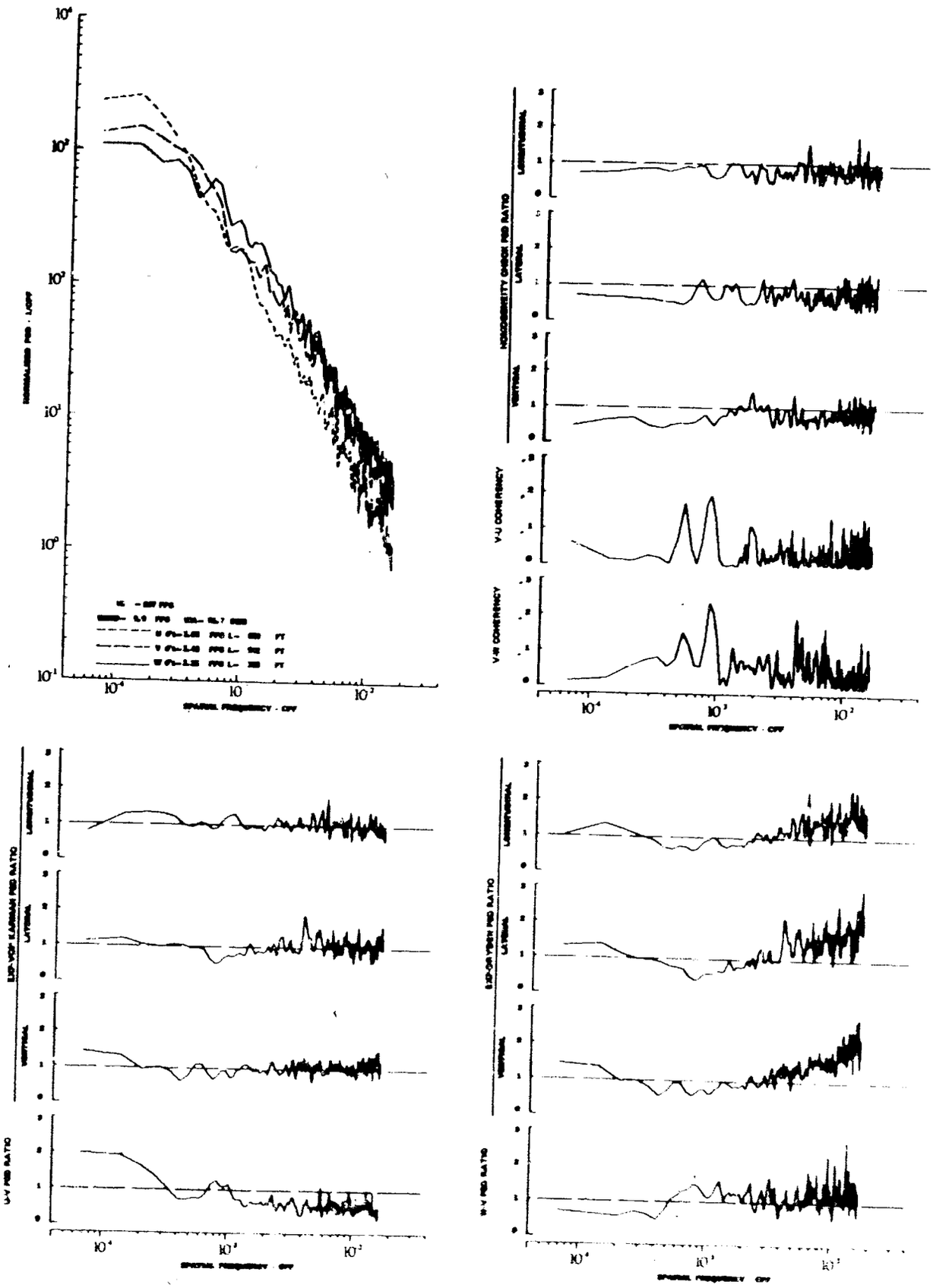
Turbulence Spectra Data For Test 87, Leg 5, Category 114231



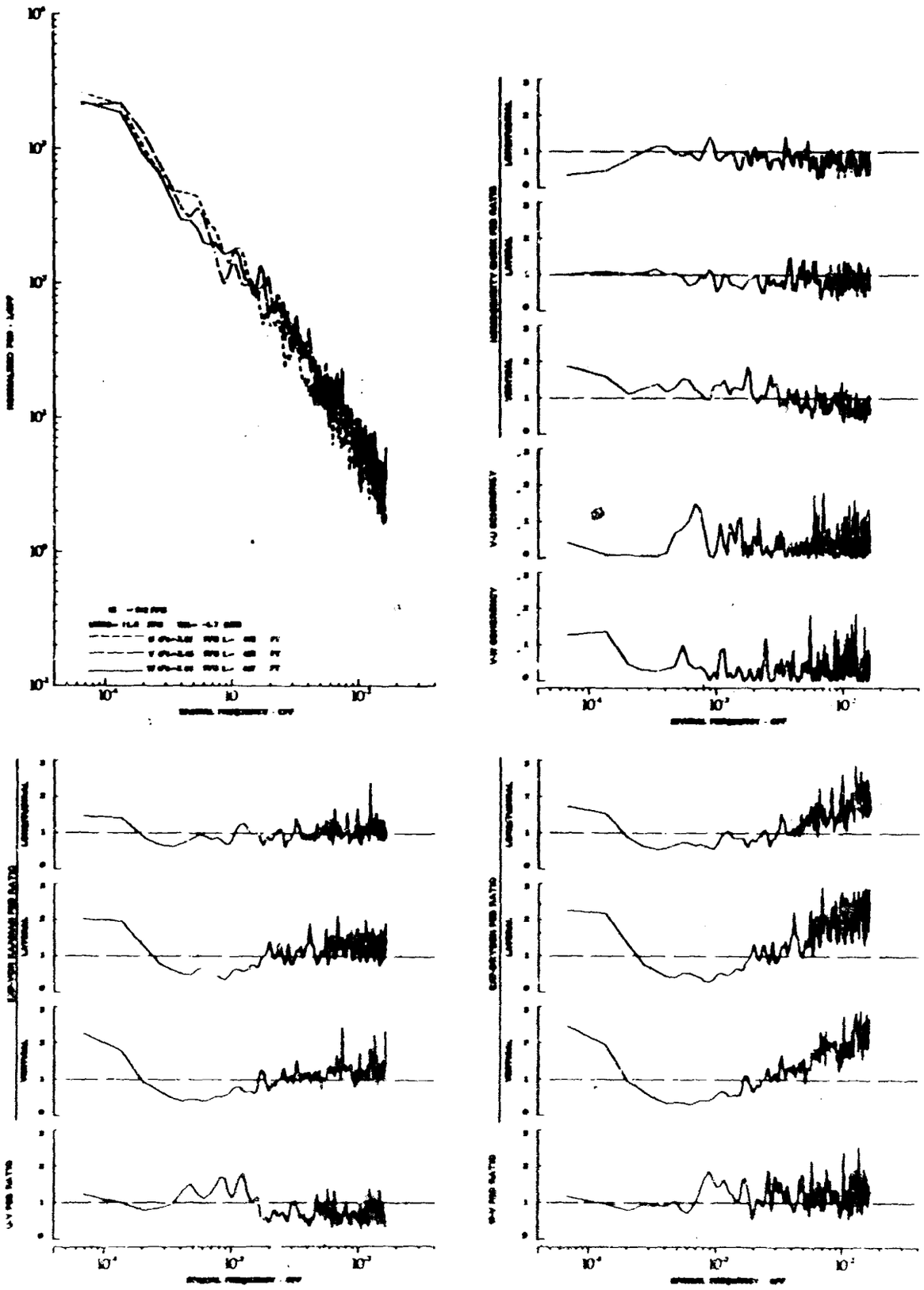
Turbulence Spectra Data For Test 87, Leg 7, Category 312231



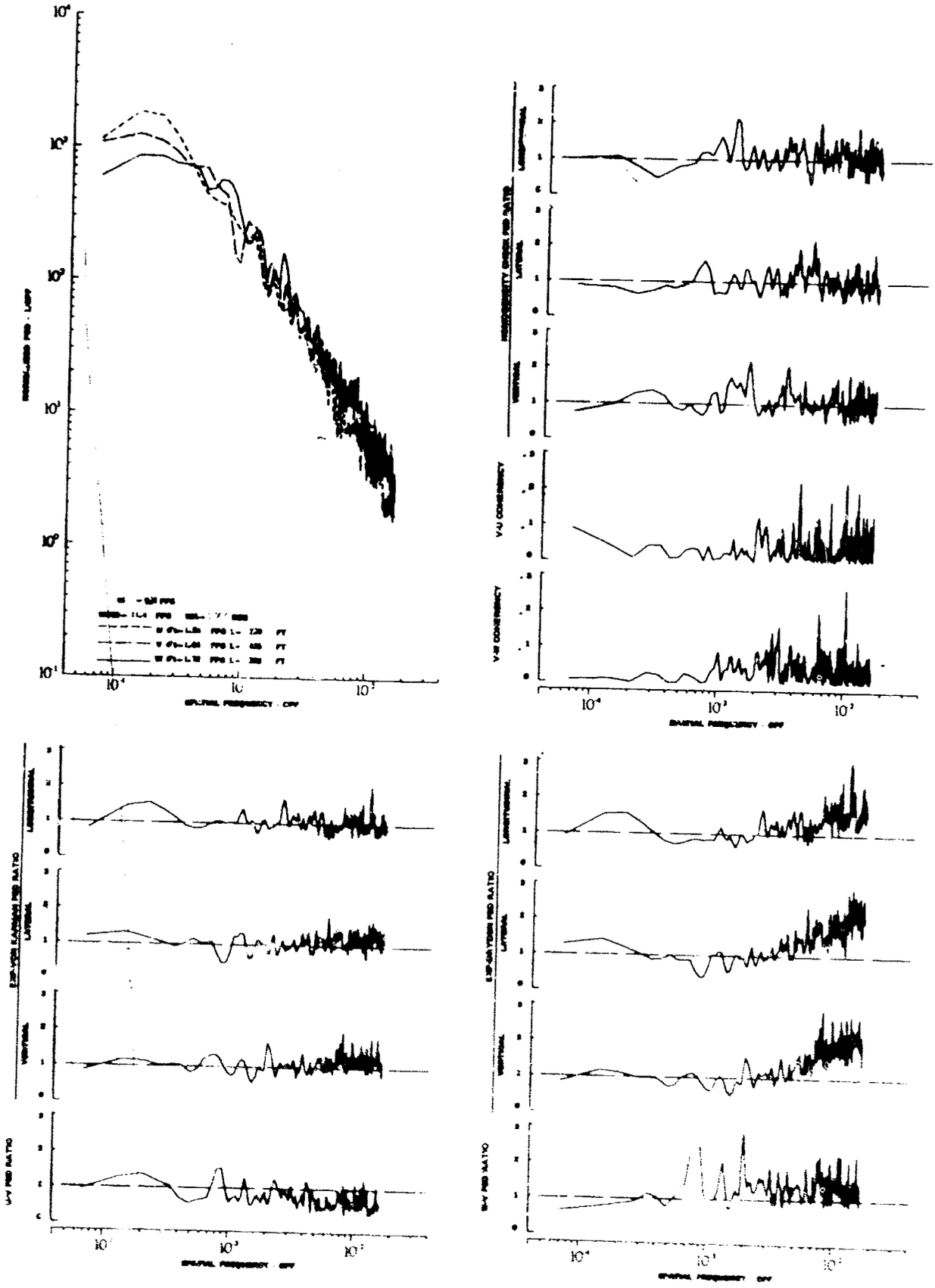
Turbulence Spectra Data For Test 88, Leg 2, Category 312331



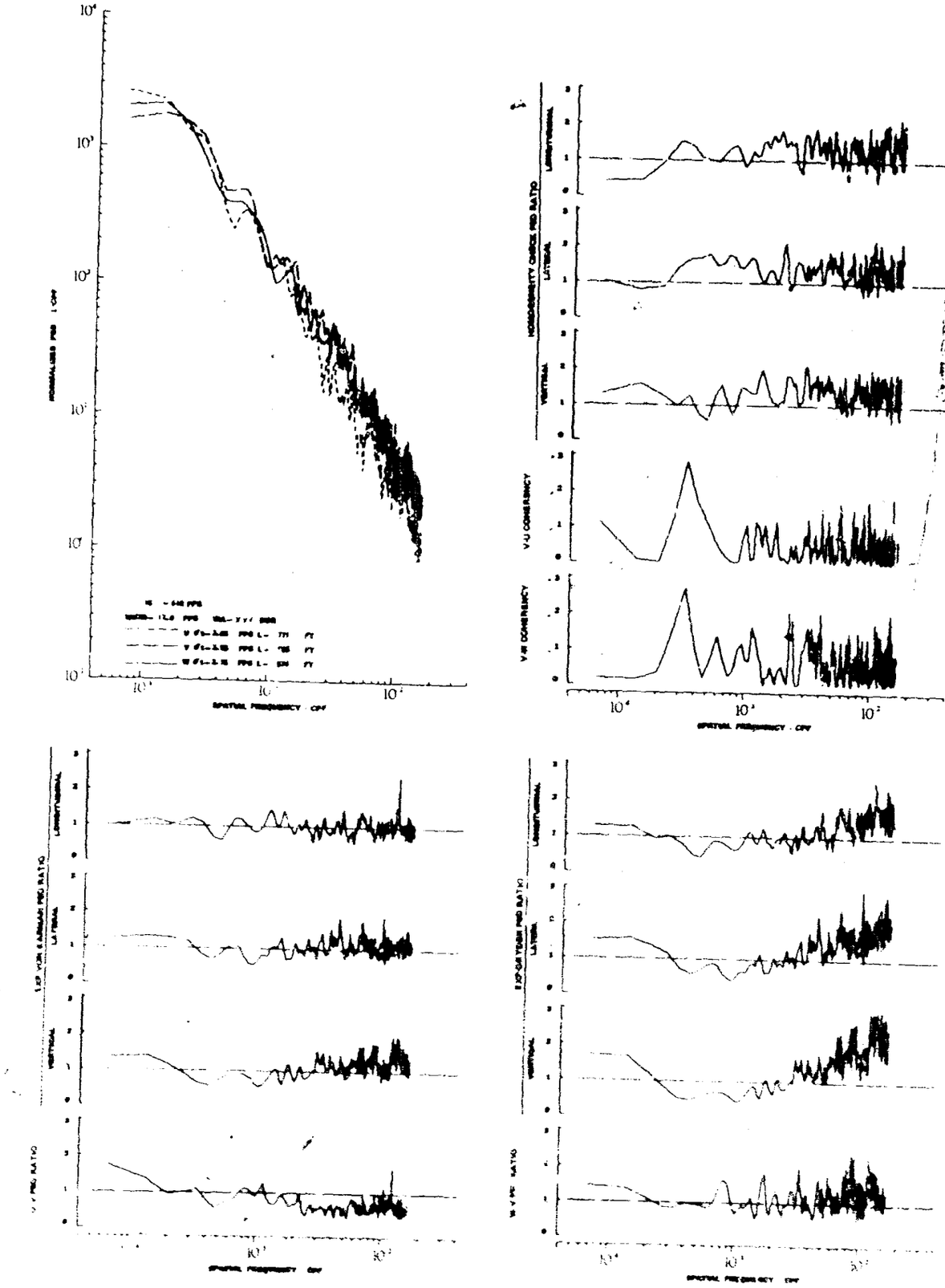
Turbulence Spectra Data For Test 88, Leg 6, Category 114331



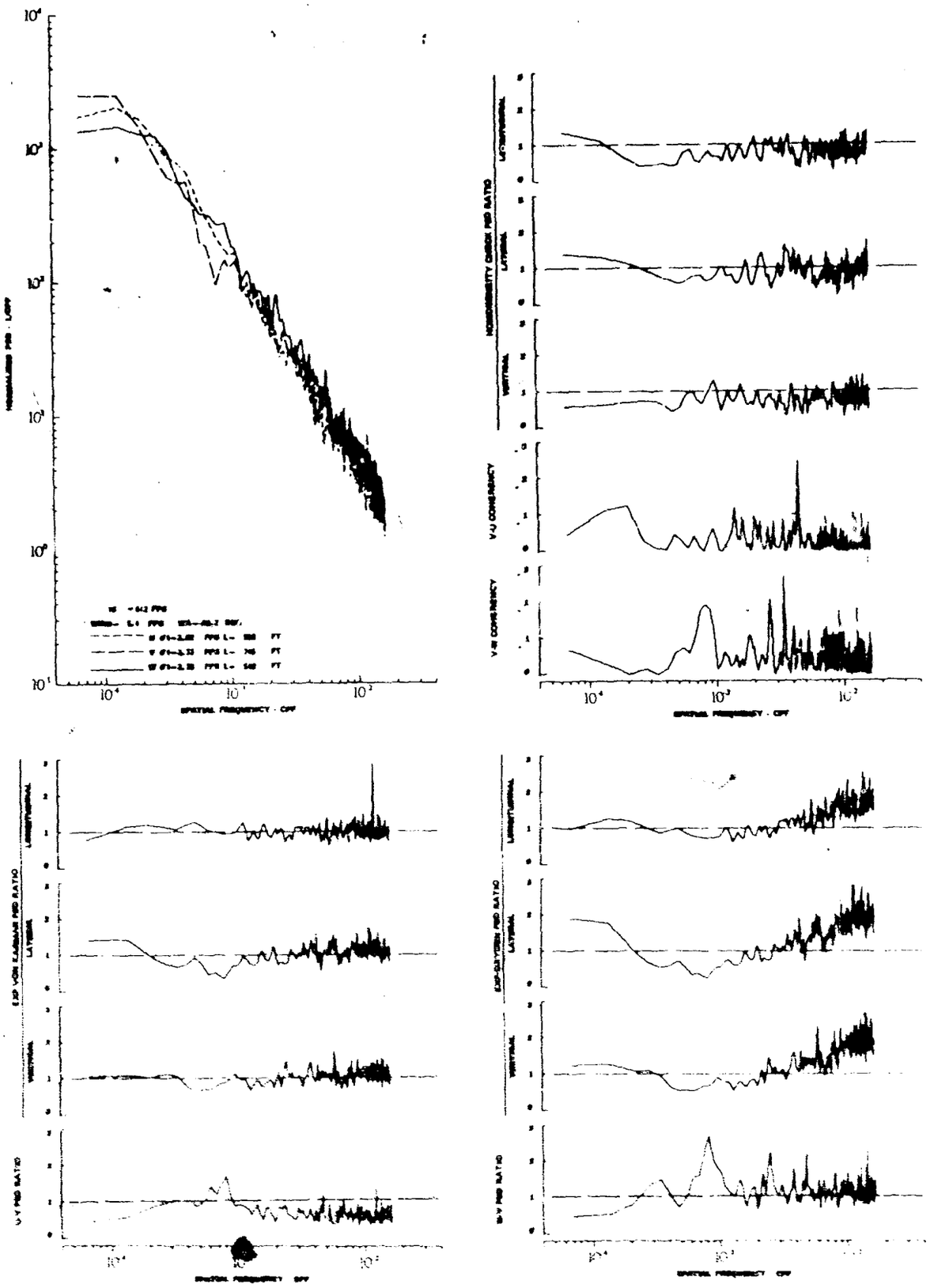
Turbulence Spectra Data For Test [illegible], Leg 8, Category 213331



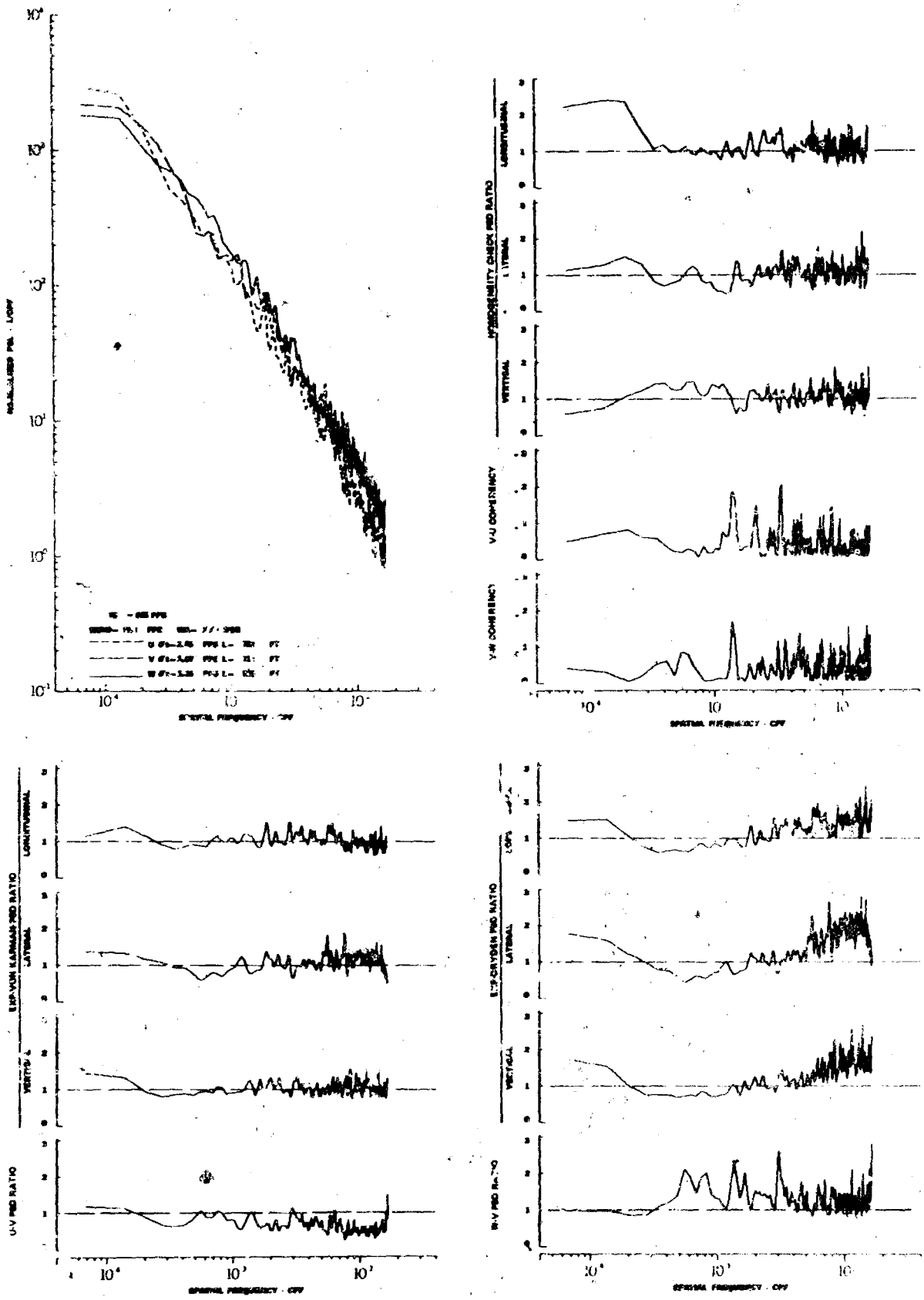
Turbulence Spectra Data For Test 00, Leg 6, Category 121231



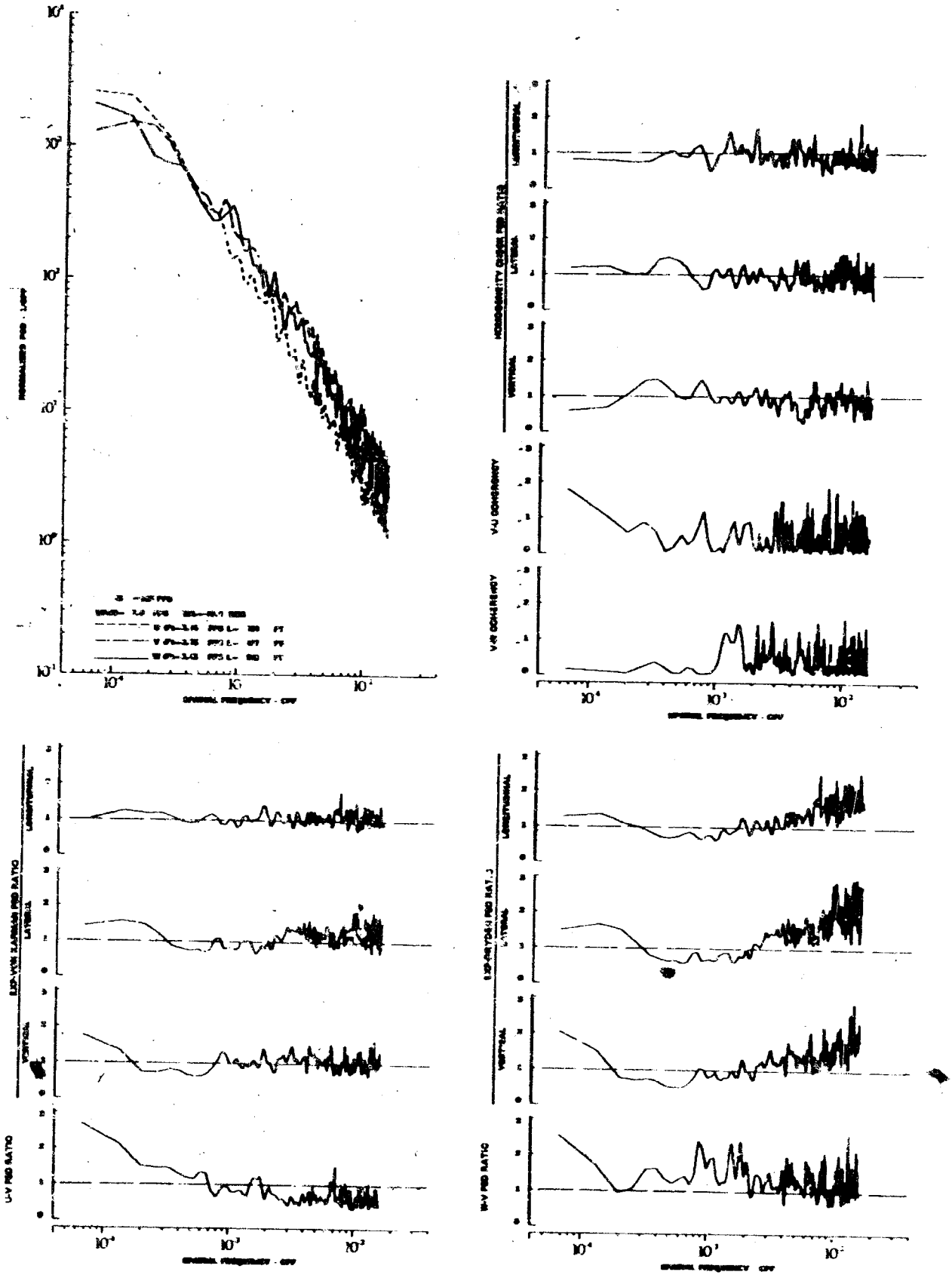
Turbulence Spectra Data For Test 90, Leg 8, Category 222231



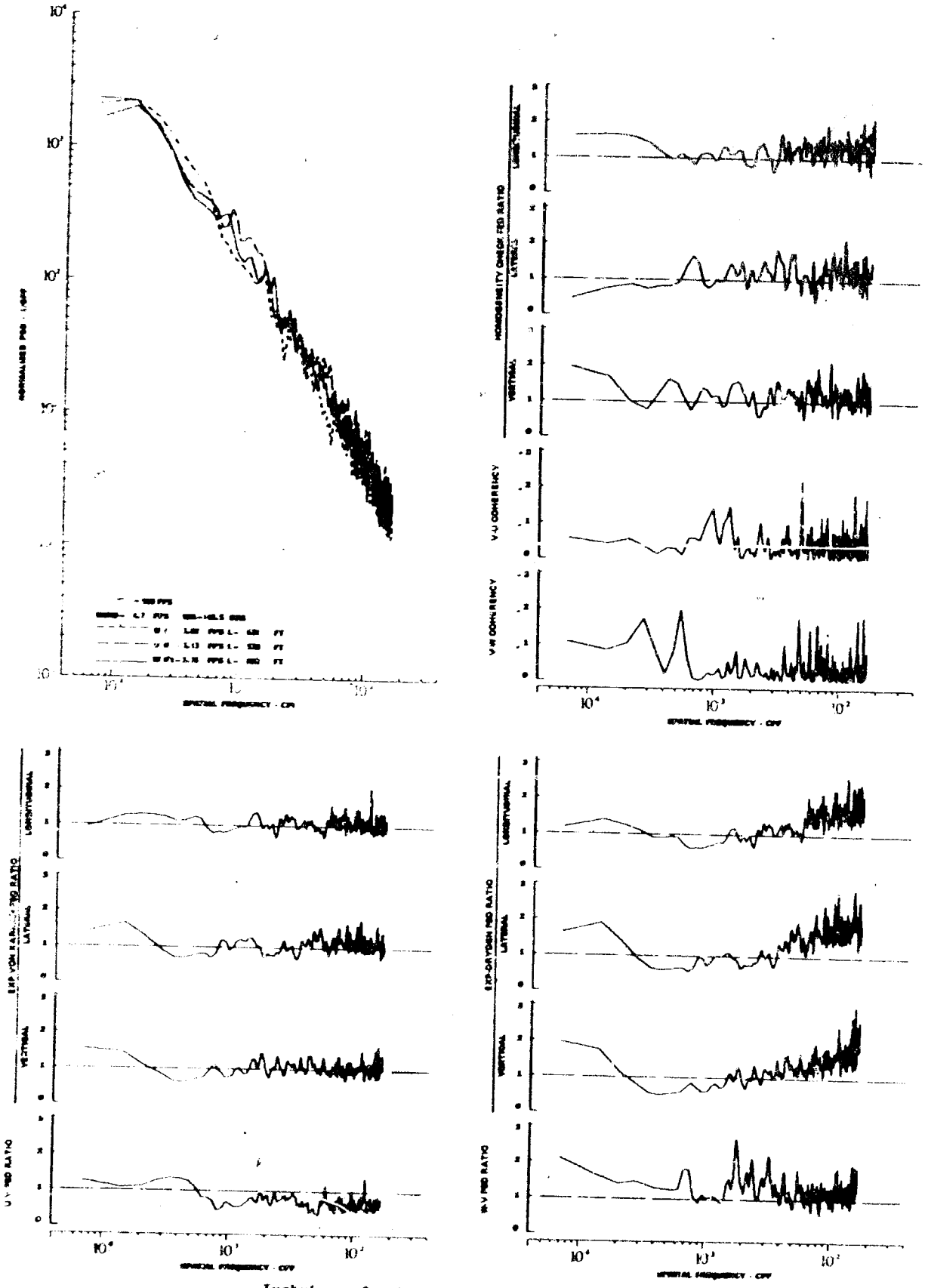
Turbulence Spectra Data For Test 94, Leg 8, Category 221231



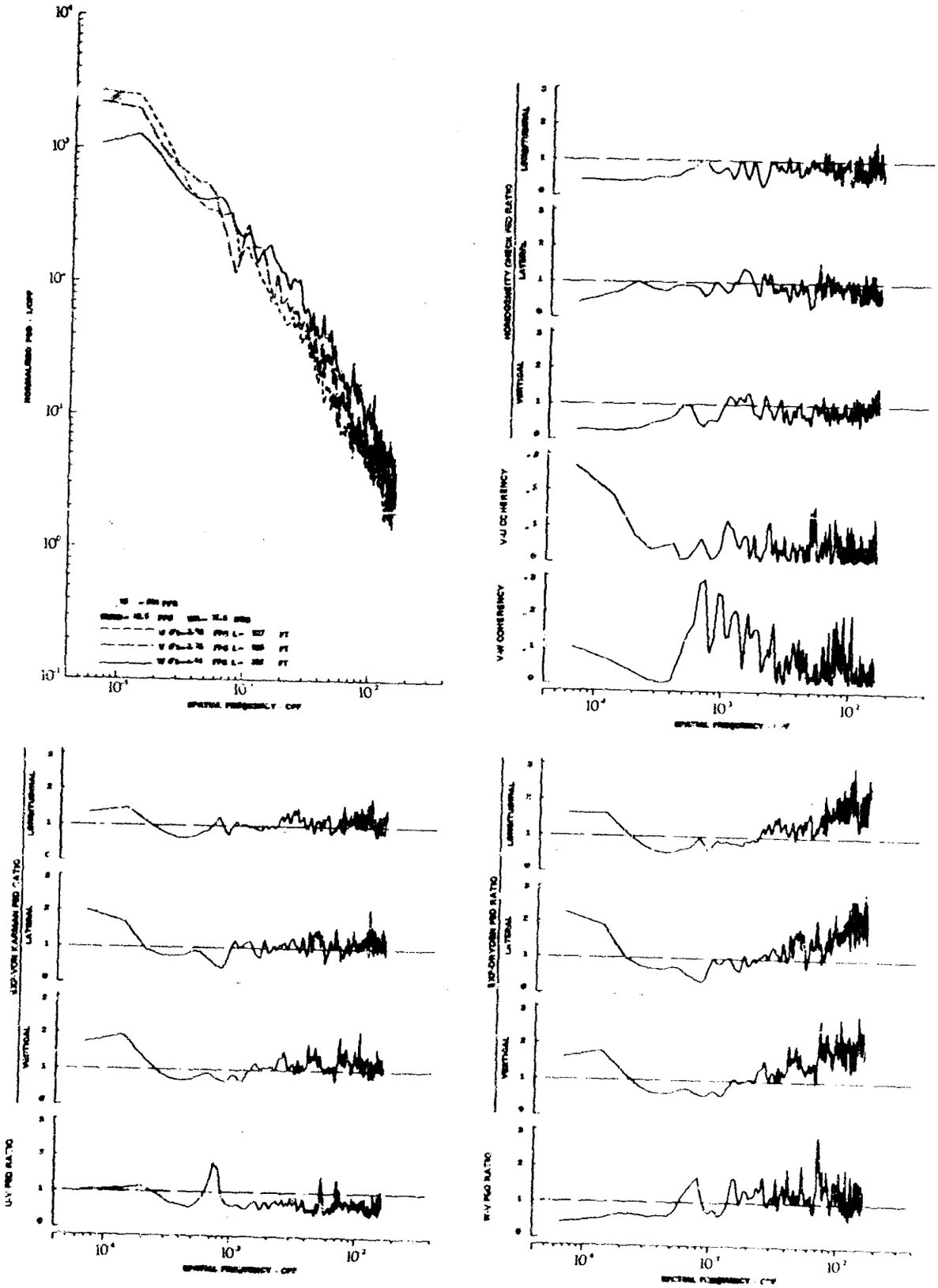
Turbulence Spectra Data For Test 55, Leg 1, Category 221331



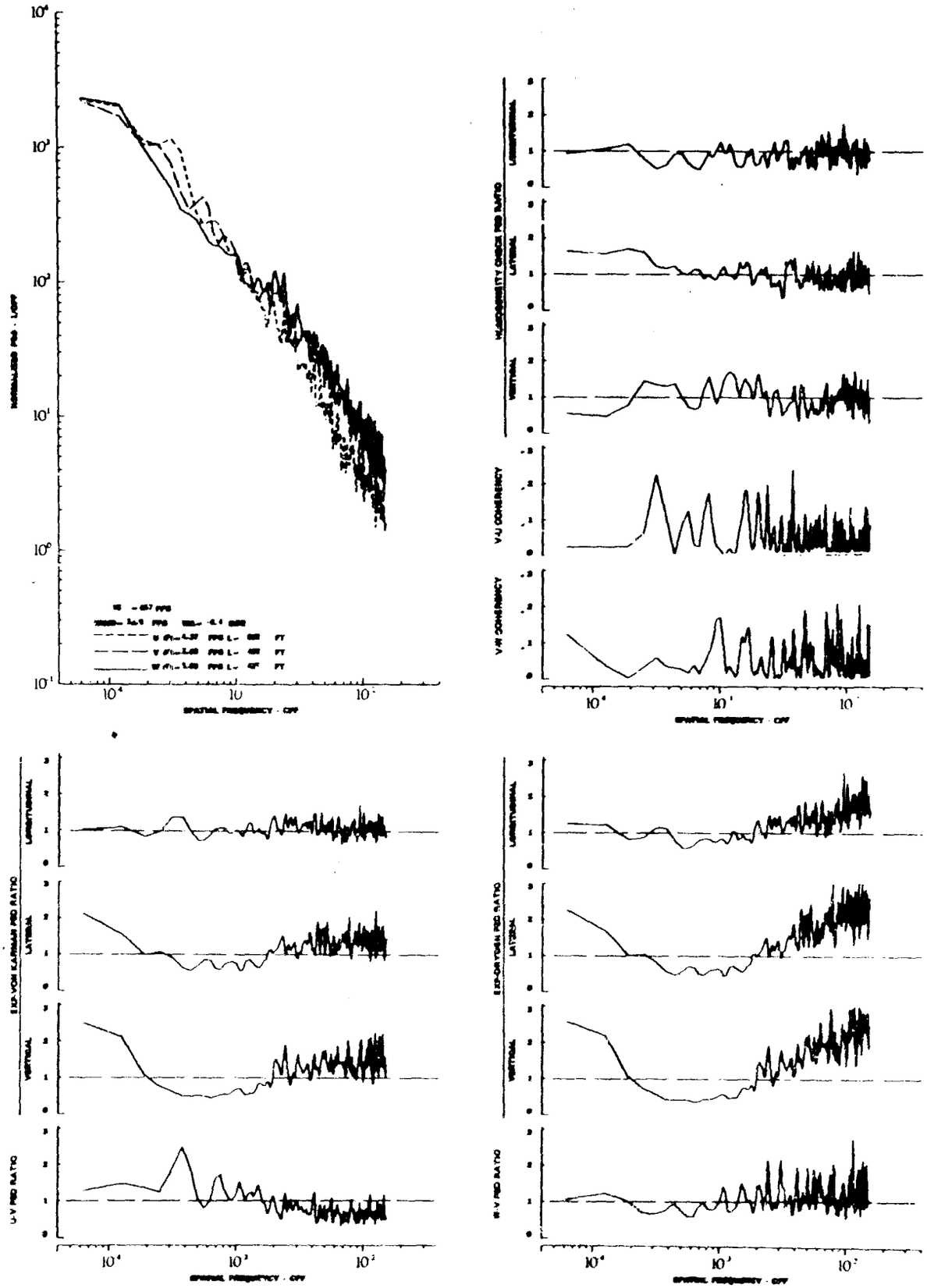
Turbulence Spectra Data For Test 95, Leg 3, Category 122331



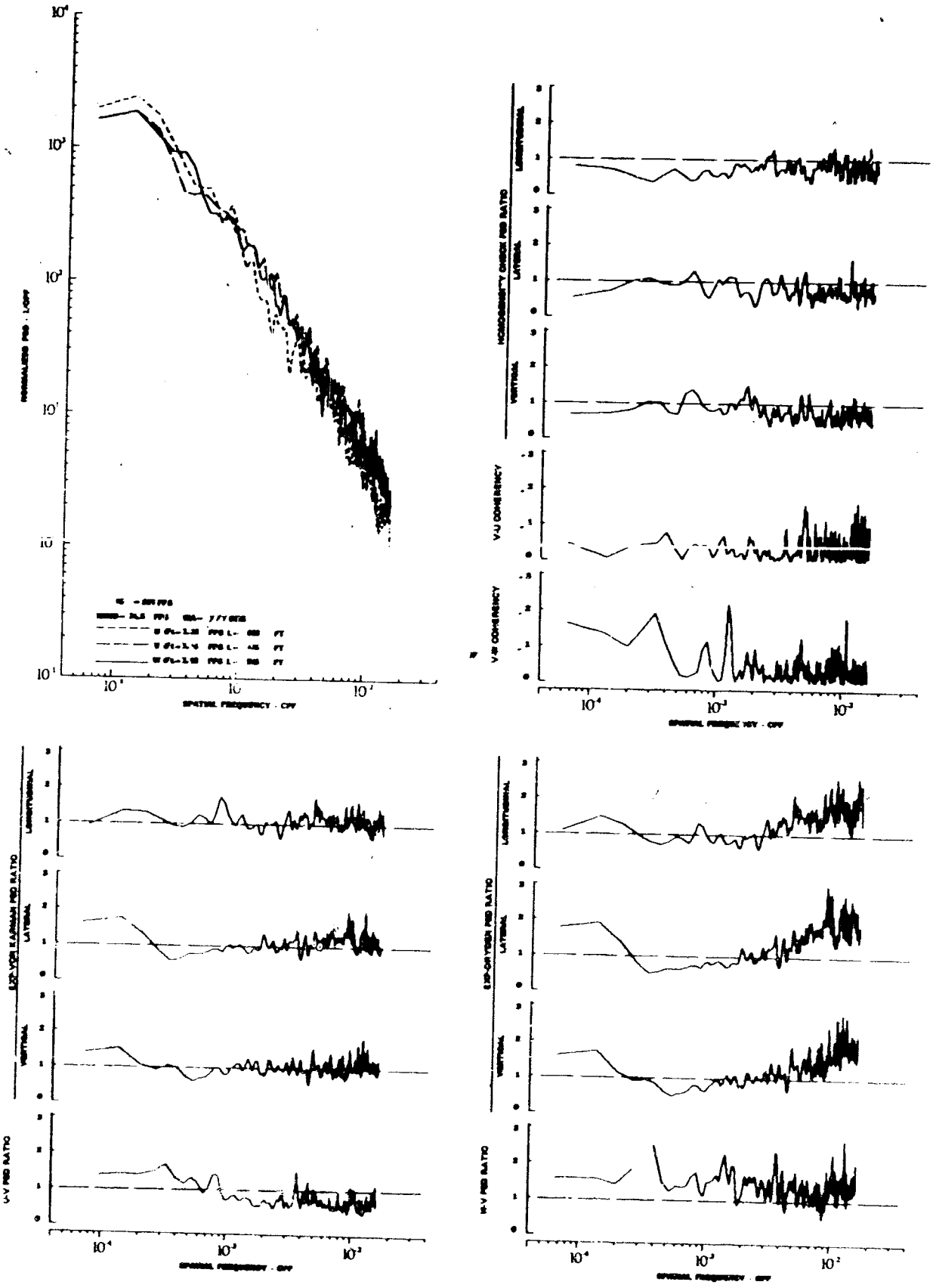
Turbulence Spectra Data For Test 95, Leg 5, Category 122331



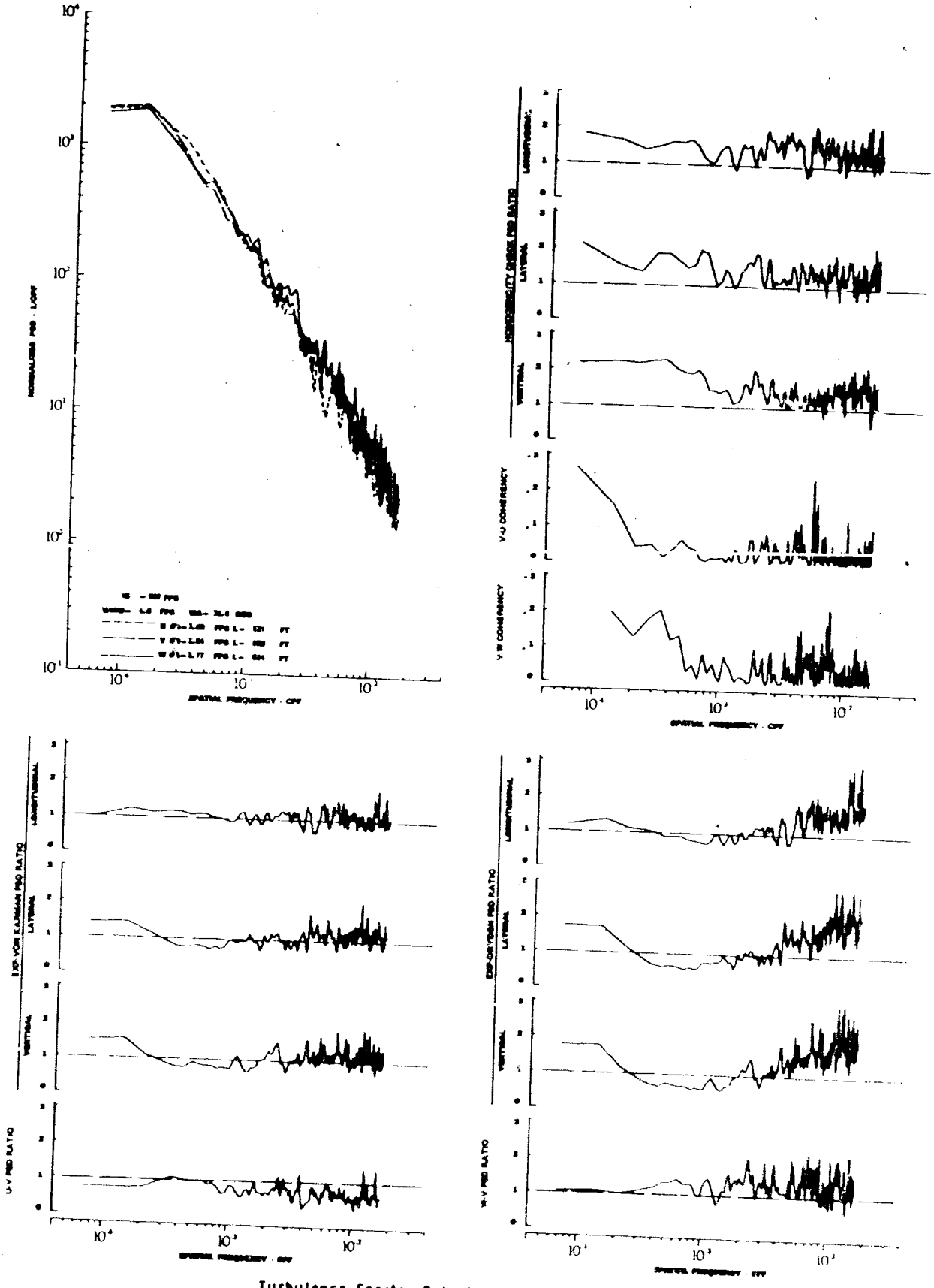
Turbulence Spectra Data For Test 98, Leg 6, Category 212331



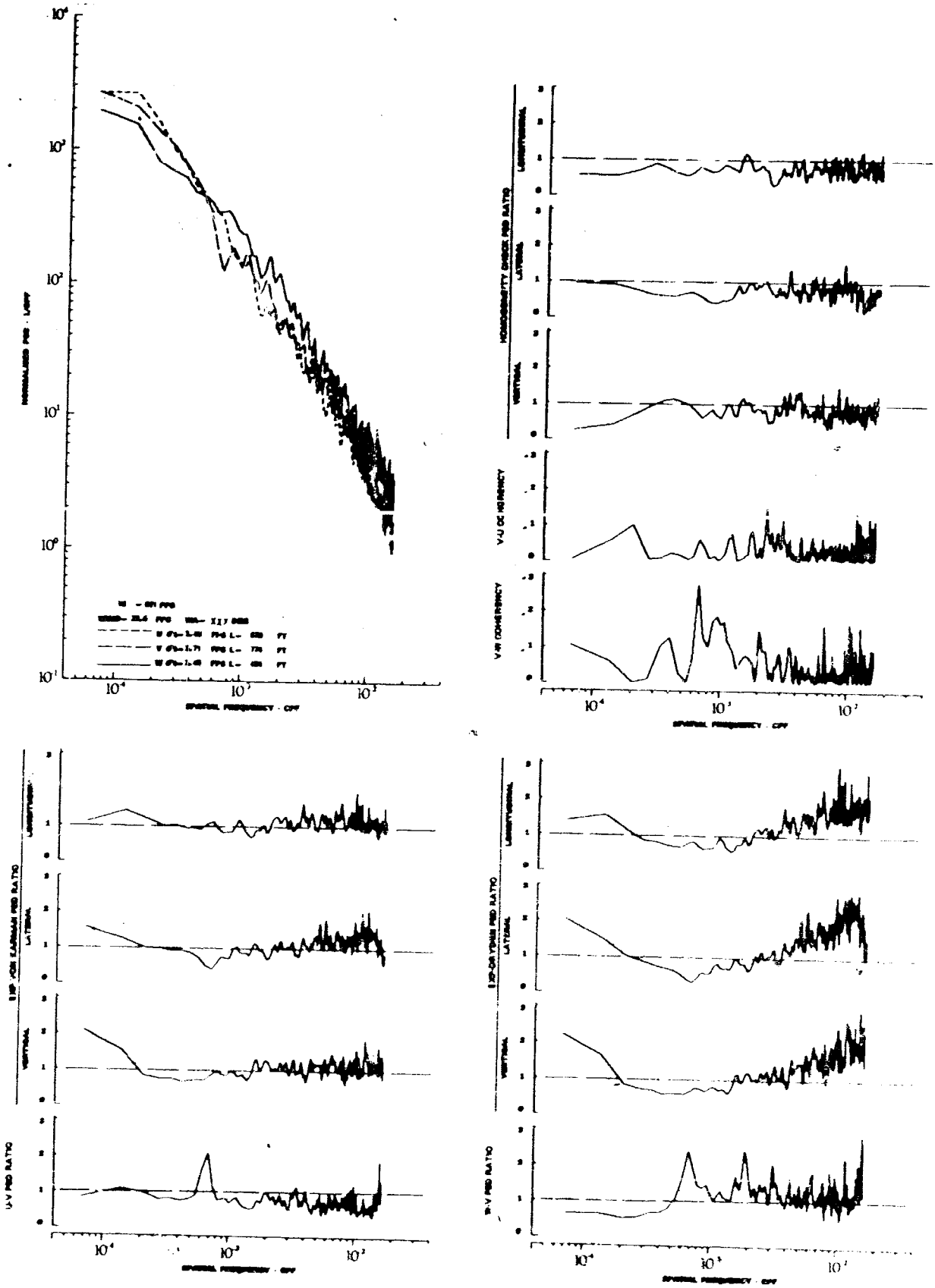
Turbulence Spectra Data For Test 98, Leg 8, Category 214331



Turbulence Spectra Data For Test 101, Leg I, Category 224331



Turbulence Spectra Data For Test 101, Leg 5, Category 122331



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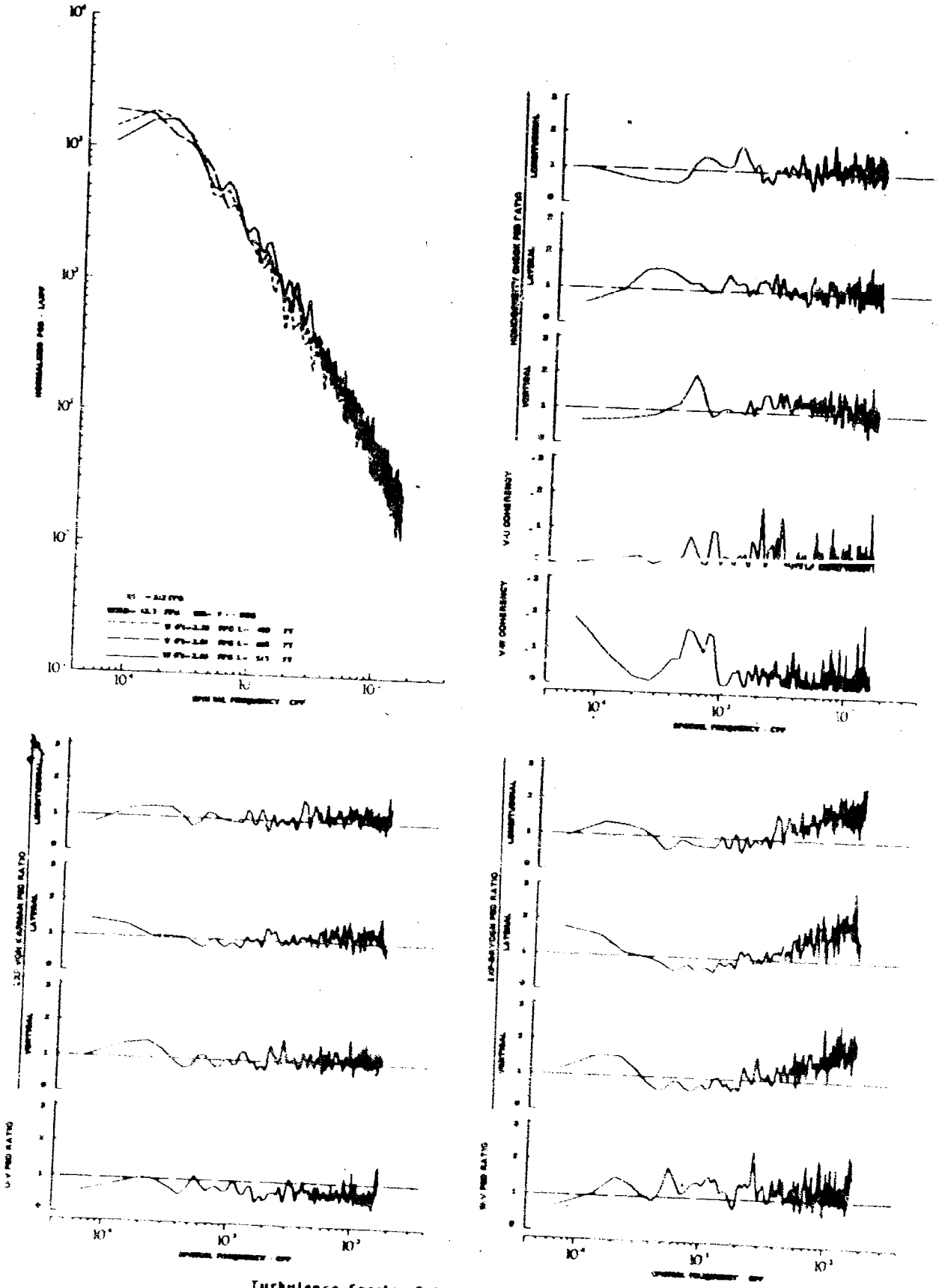
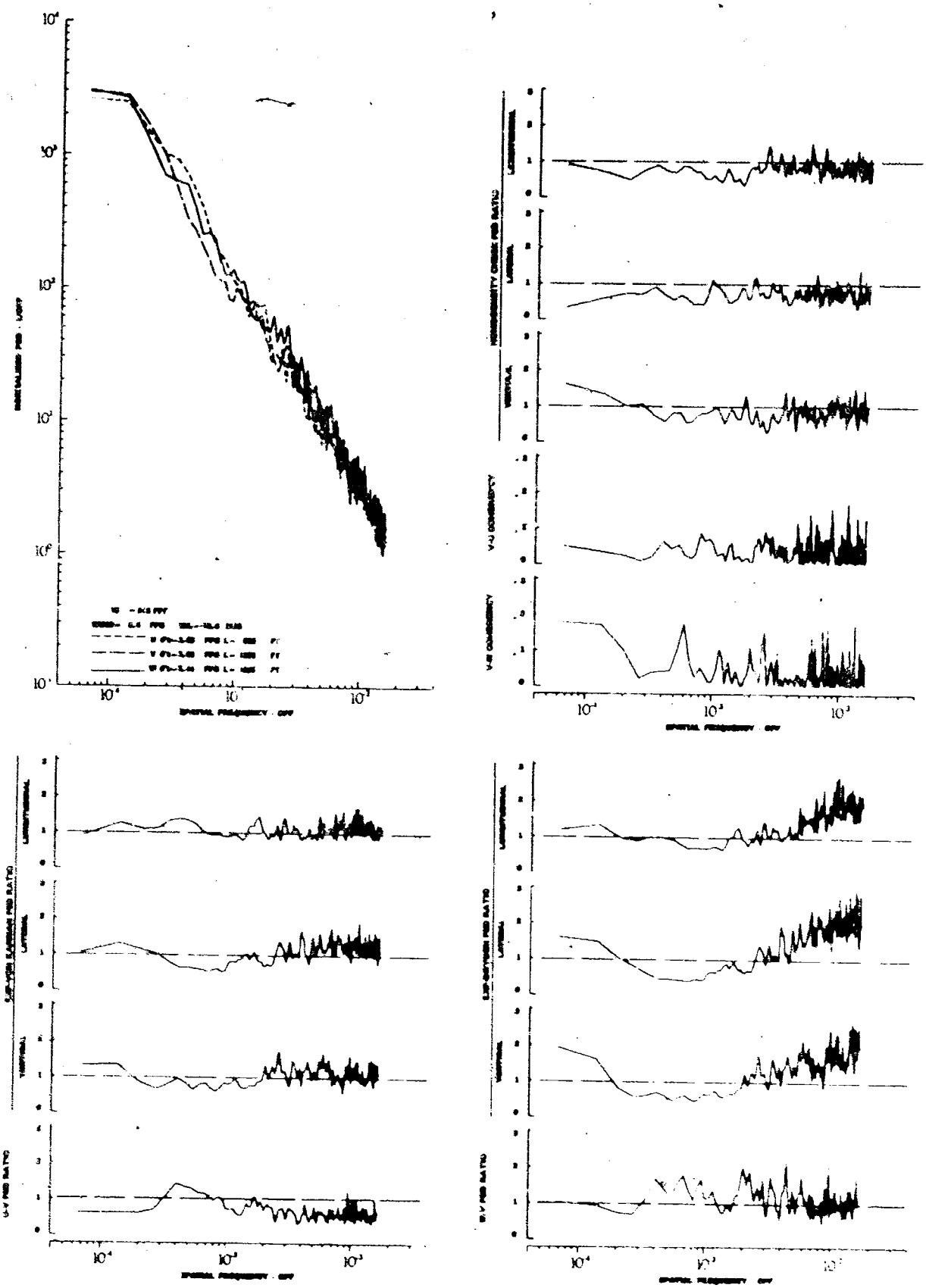
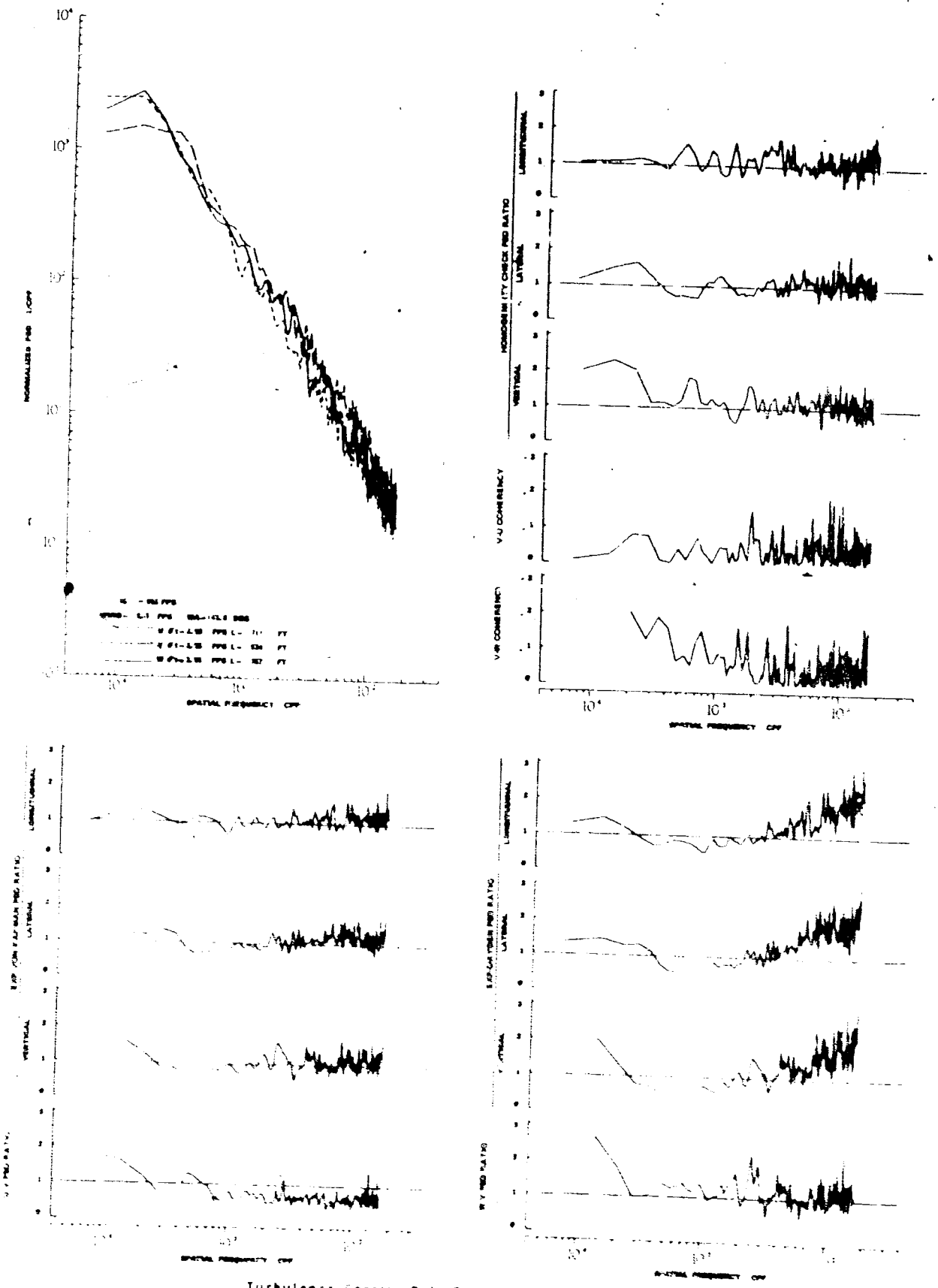


Turbulence Spectra Data For Test 187, Leg 1, Category 224331



Turbulence Spectra Data For Test 107, Leg 3, Category 121331



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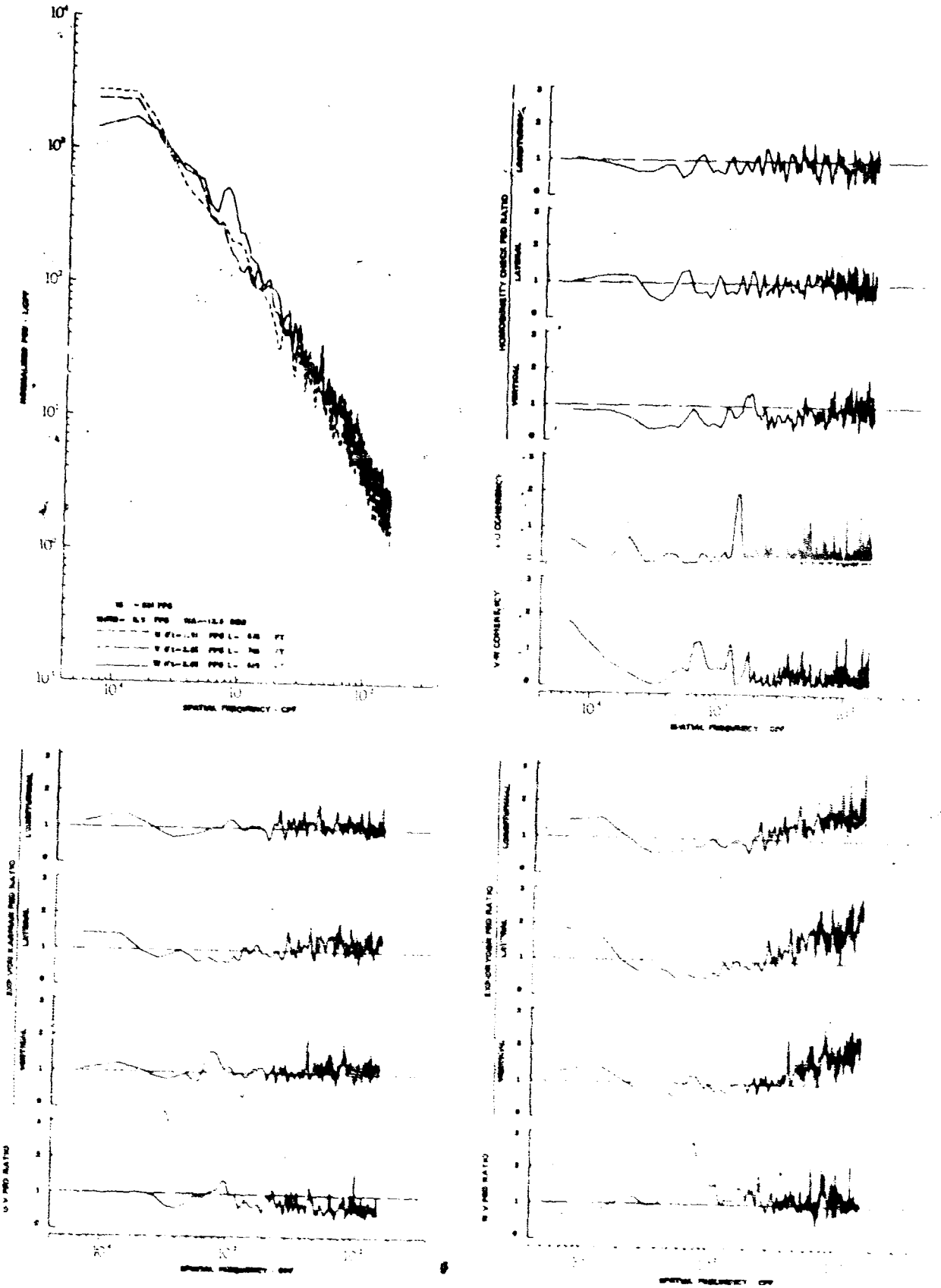
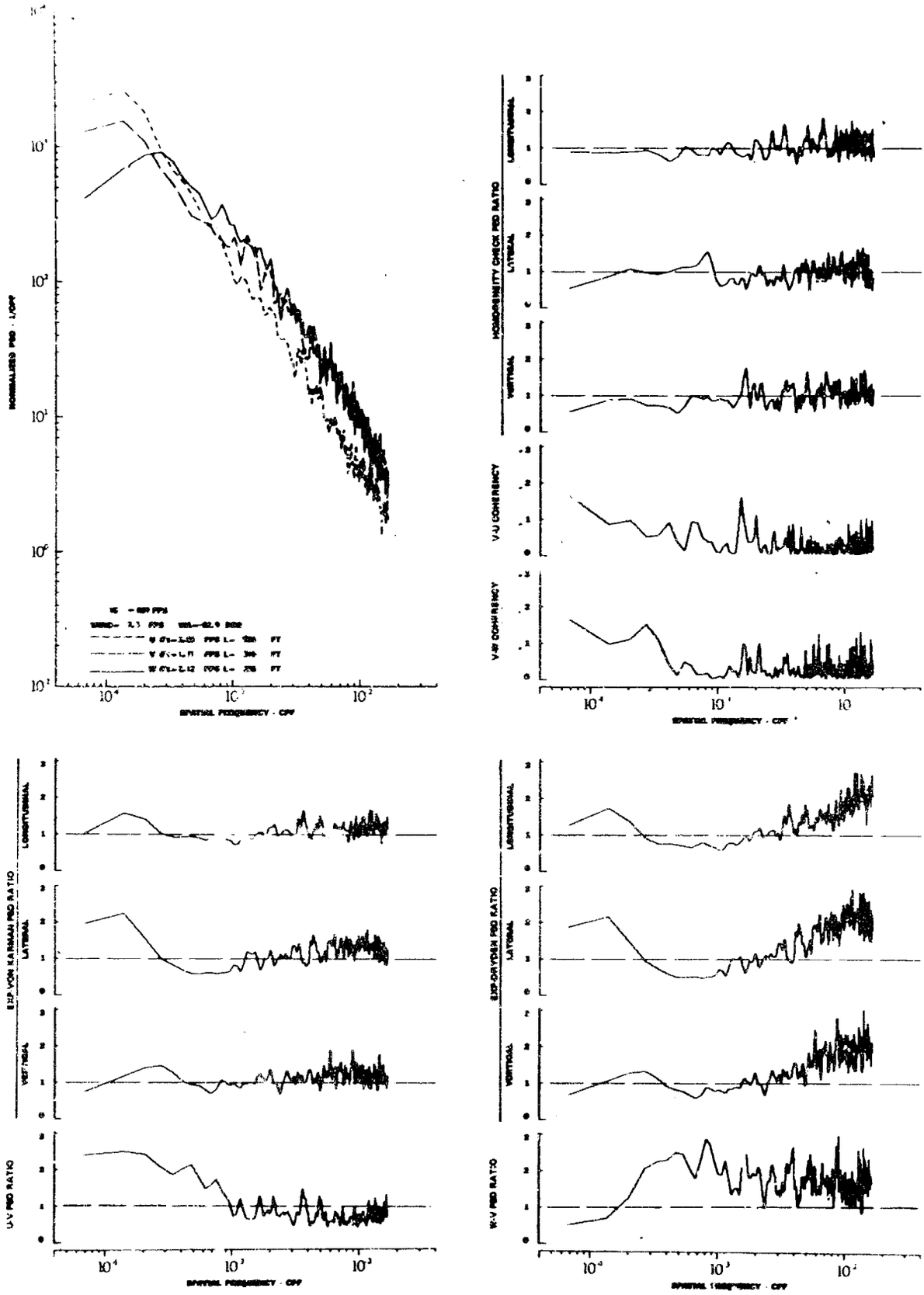
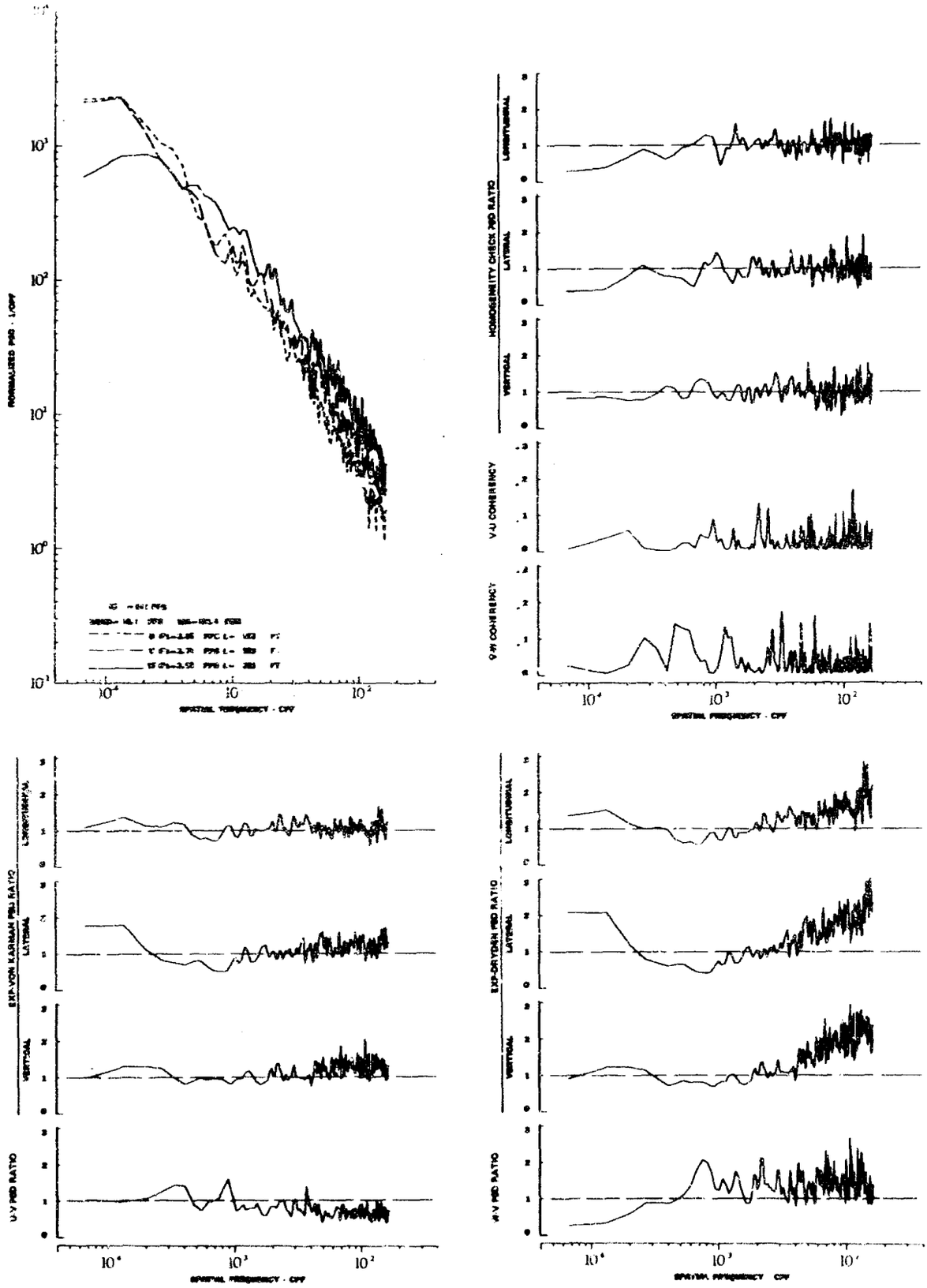


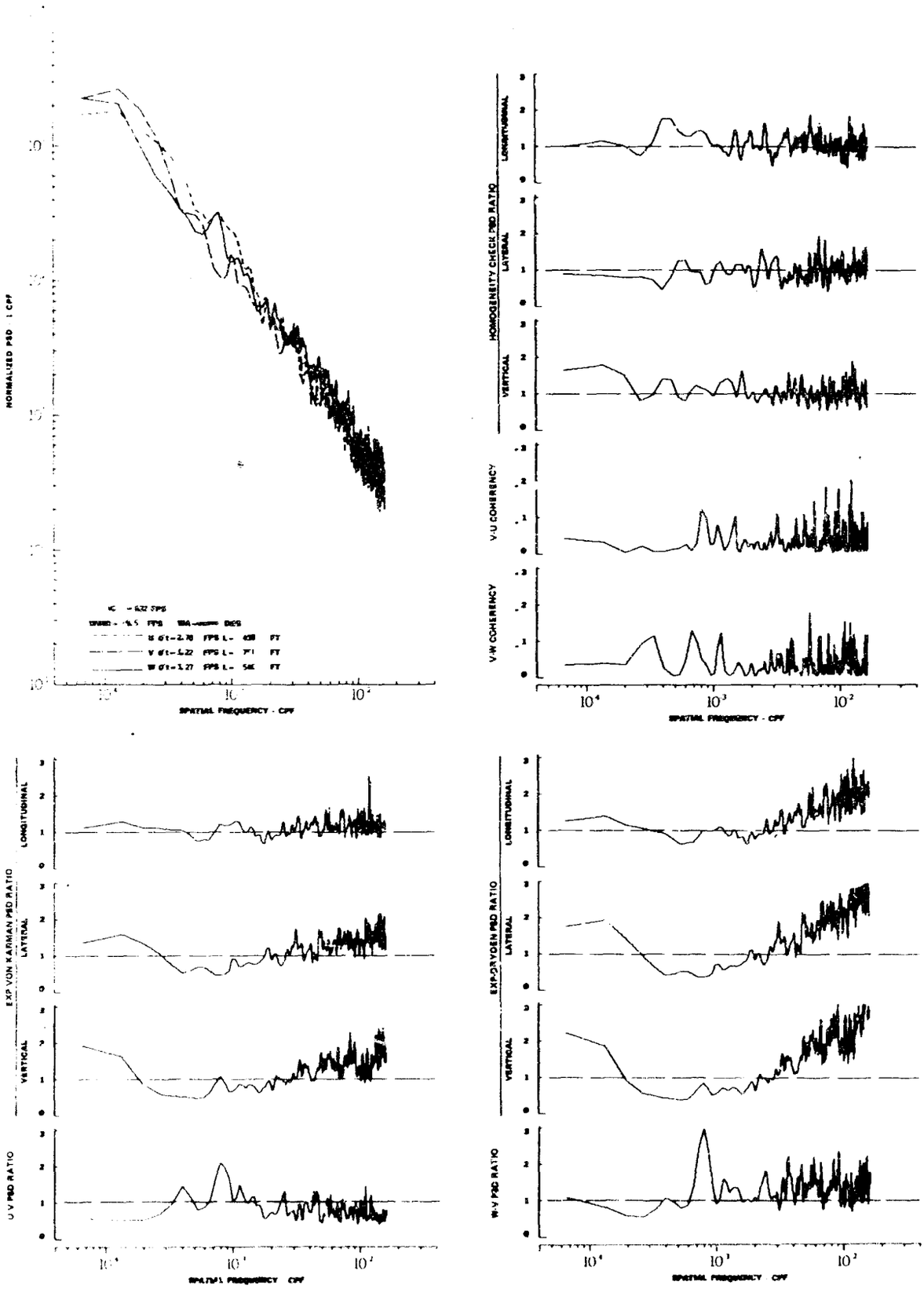
Turbulence Spectra Data For Test 107, Leg 7, Category 322331



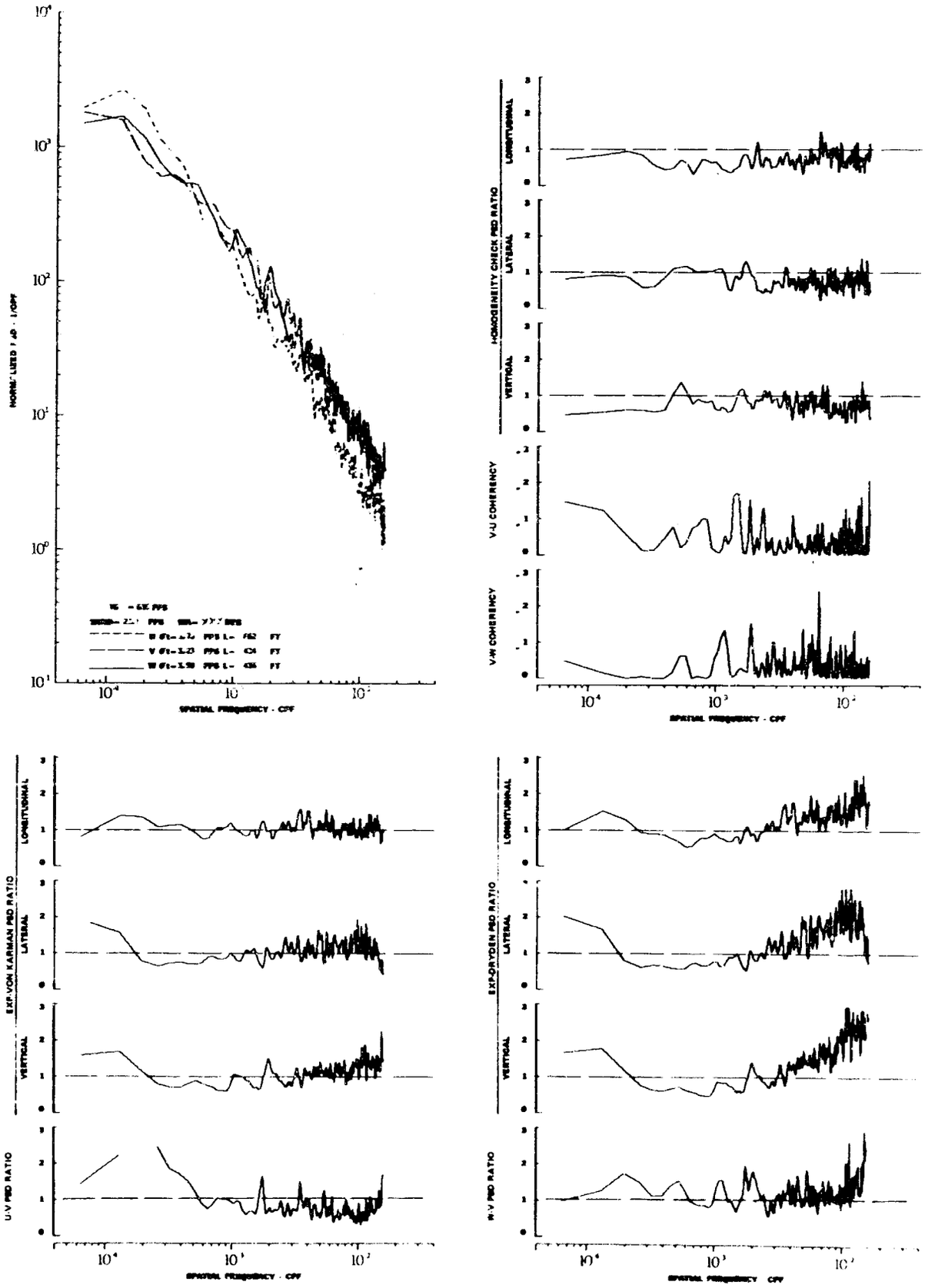
Turbulence Spectra Data For Test 108, Leg 2, Category 312231



Turbulence Spectra Data For Test 1Gb, Leg 6, Category 213231



Turbulence Spectra Data For Test 108, Leg 8, Category 212231



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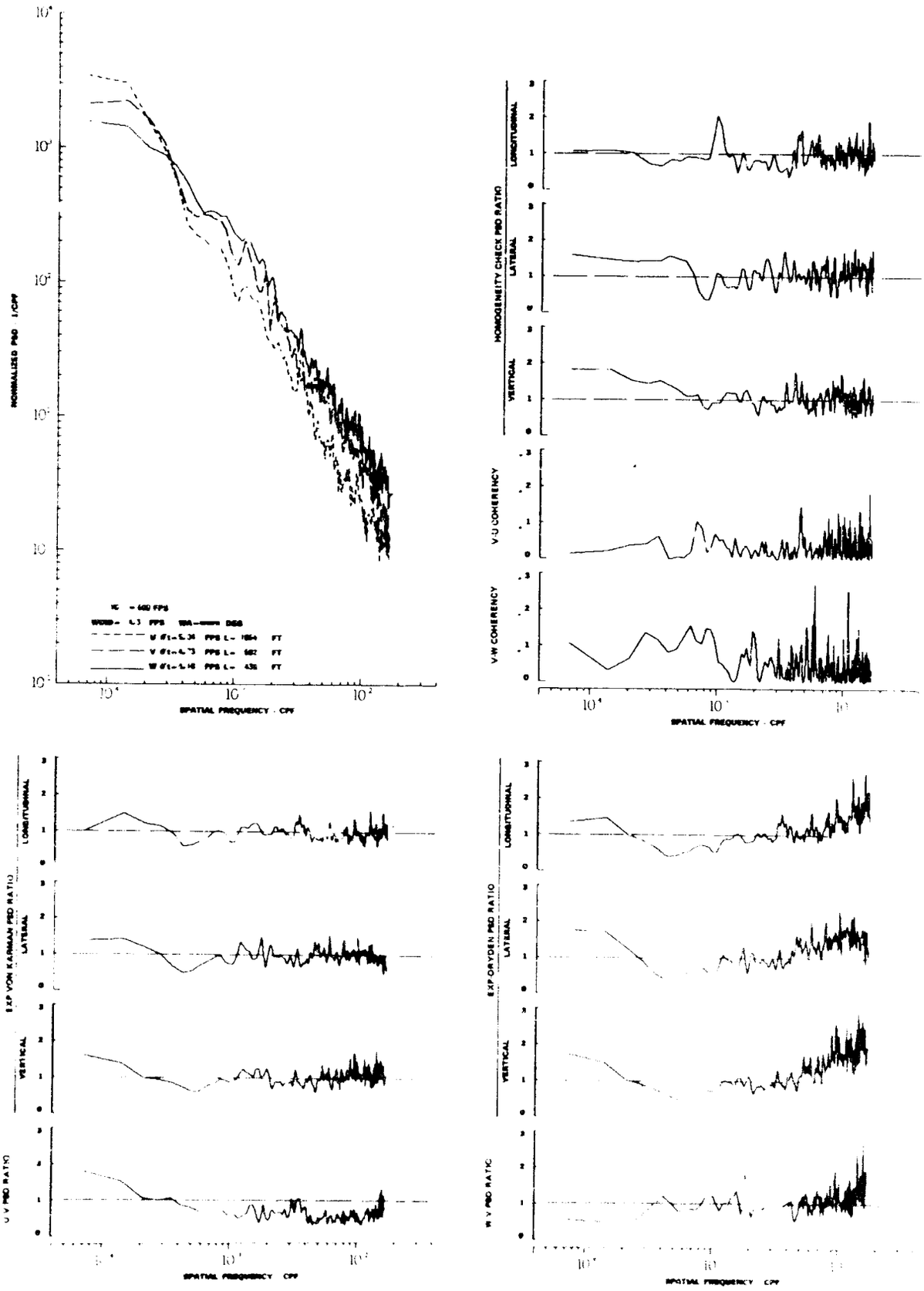

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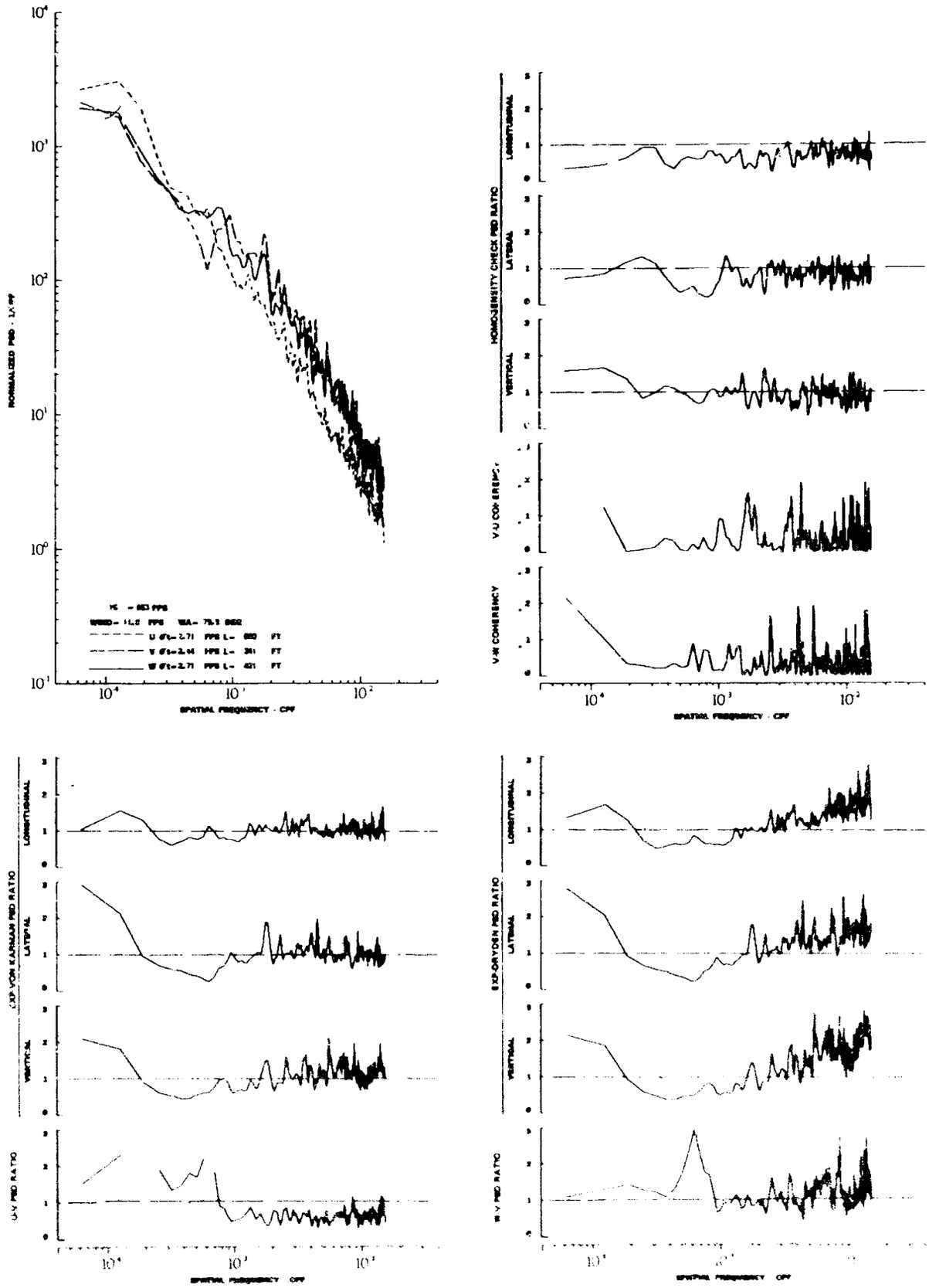
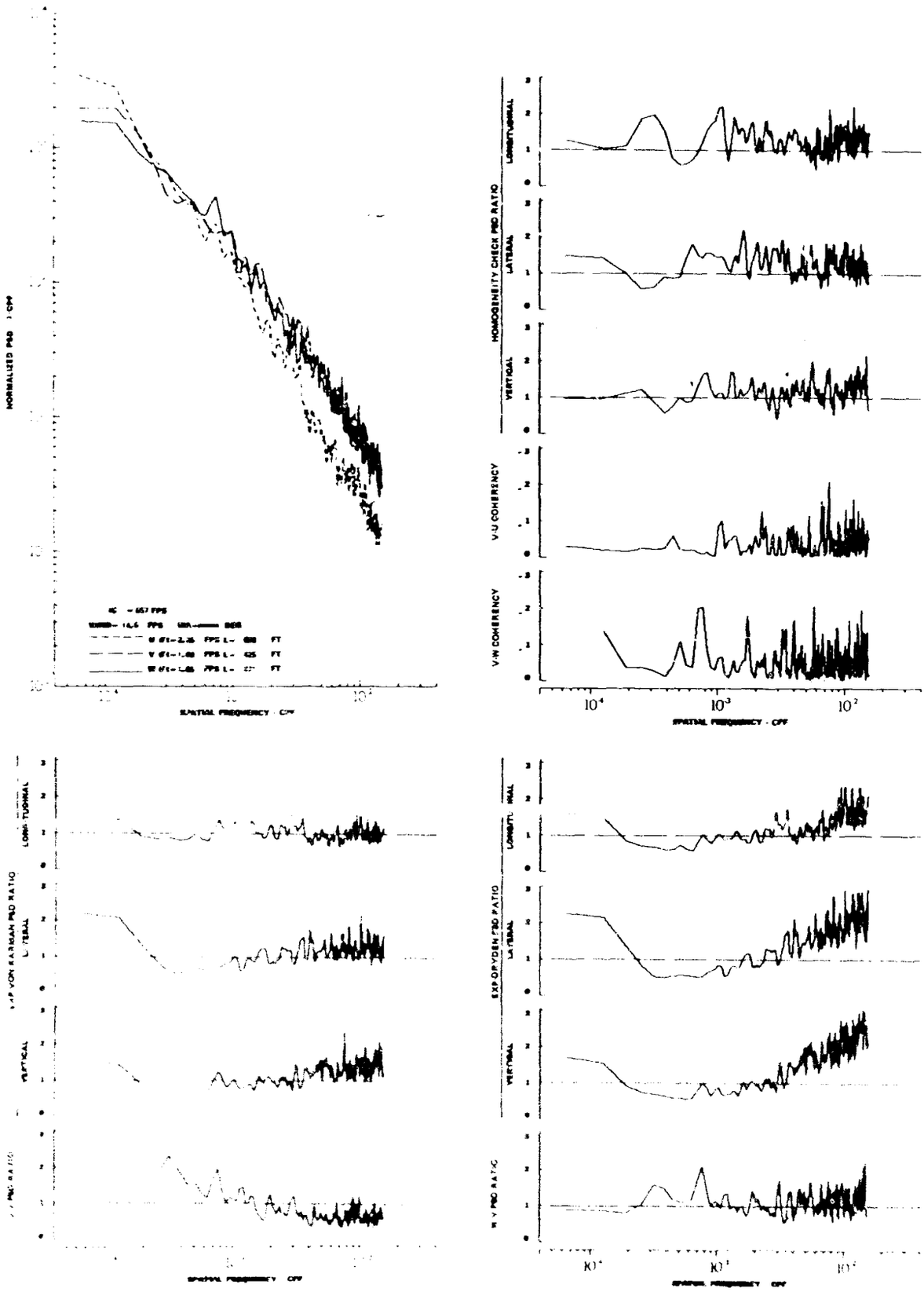
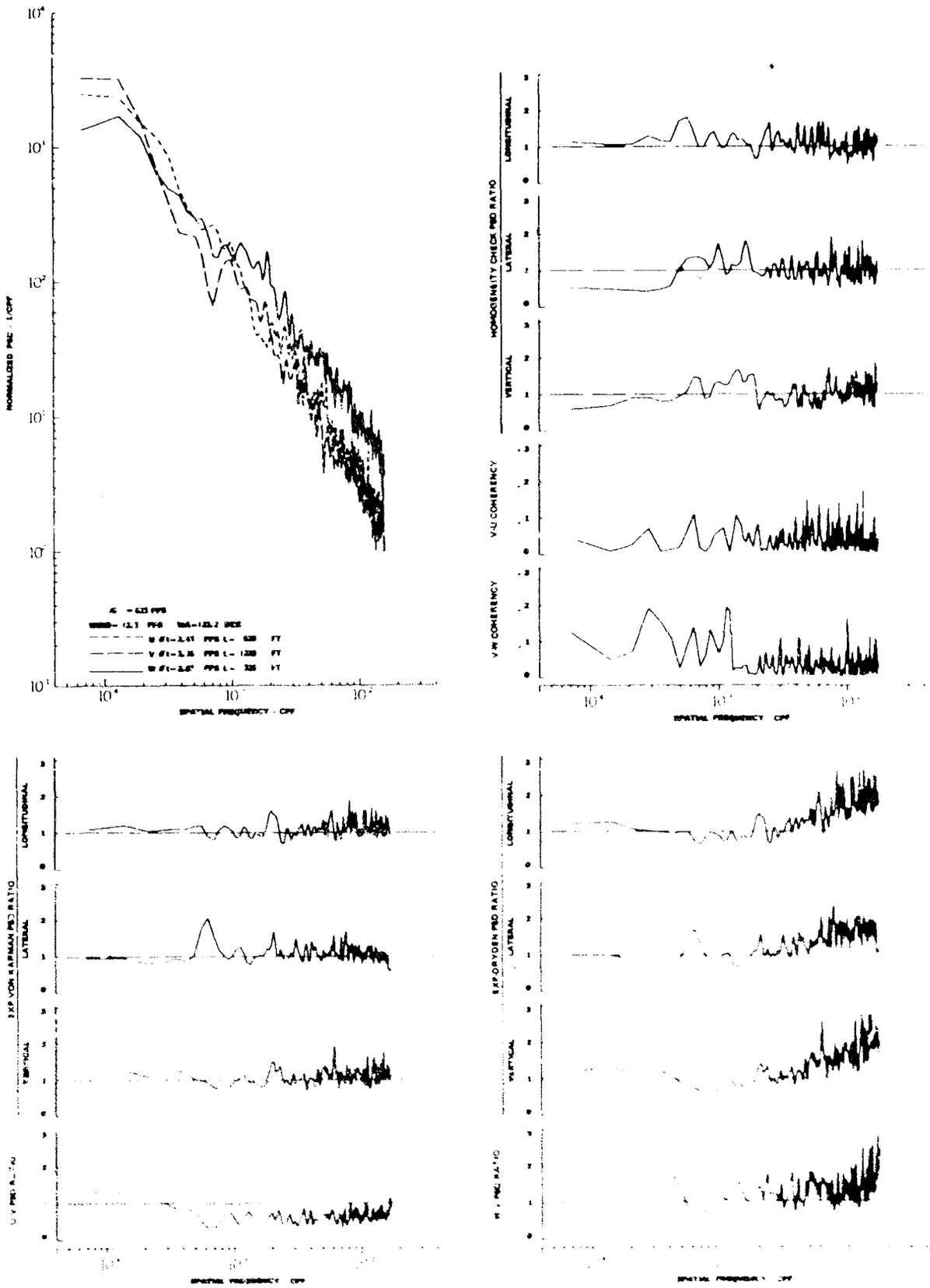


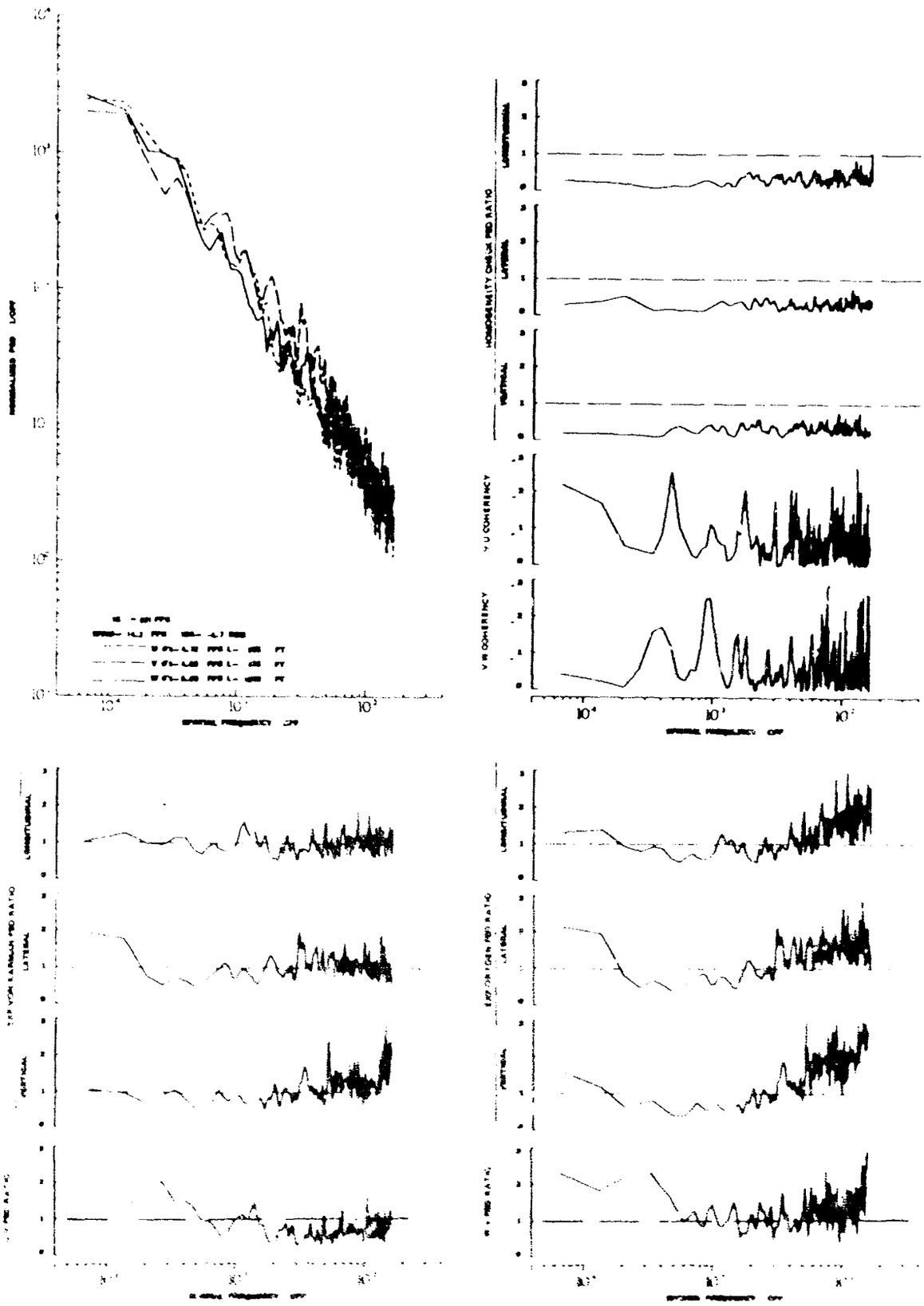
Turbulence Spectra Data For Test 109, Leg 7, Category 315331



Turbulence Spectra Data For Test 111, Leg 7, Category 321231



Turbulence Spectra Data For Test 112, Leg 6, Category 221331



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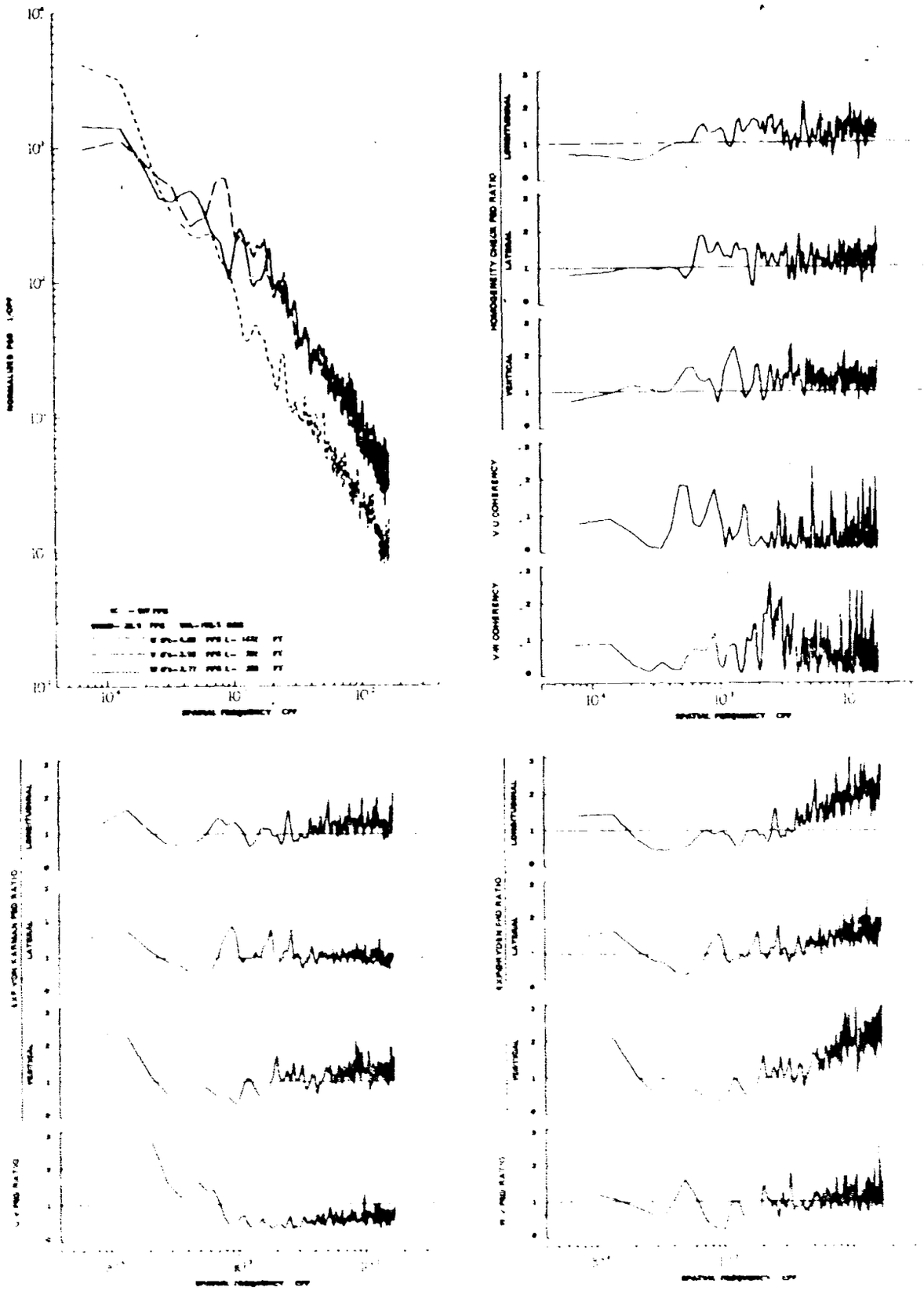
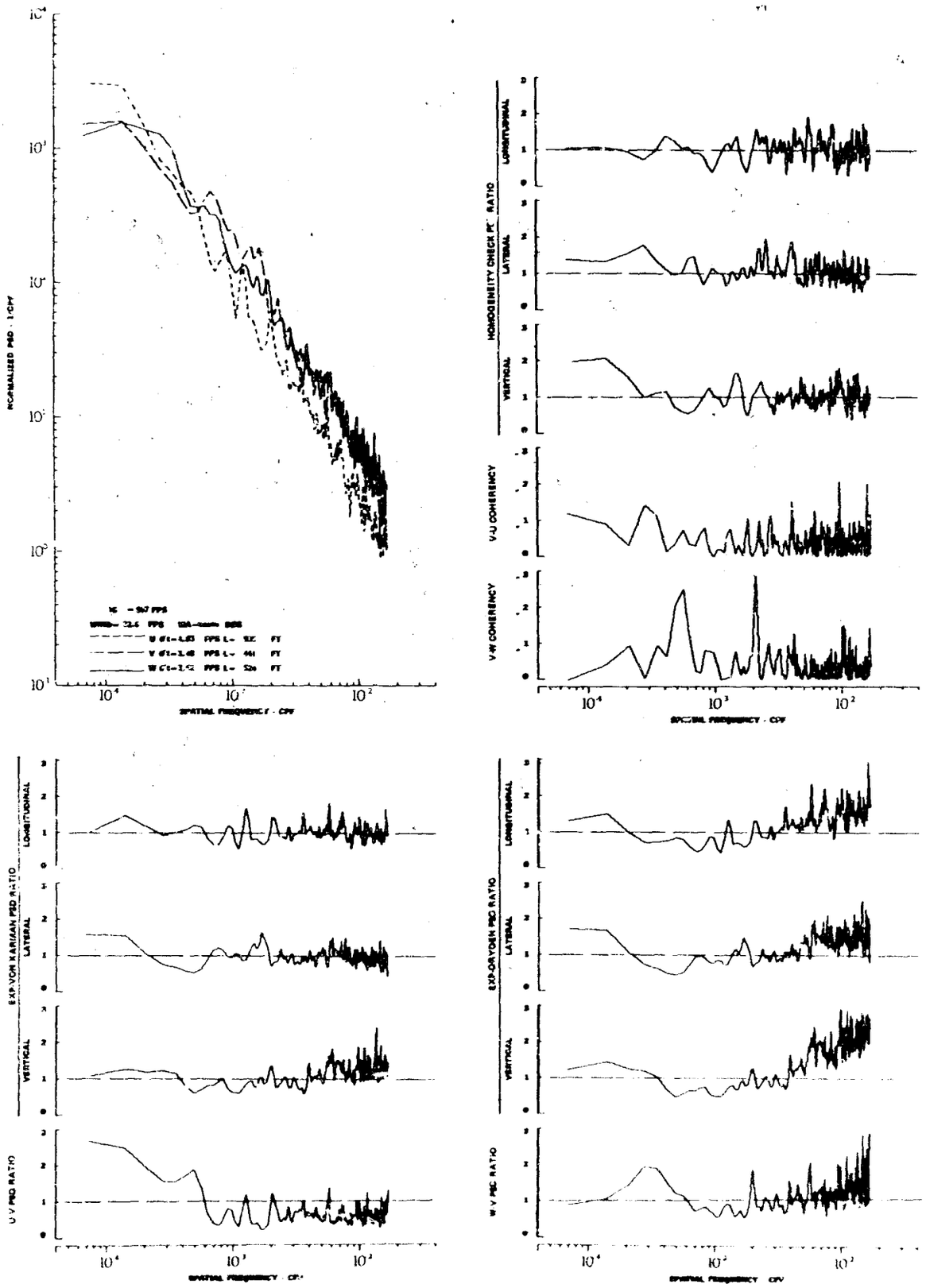
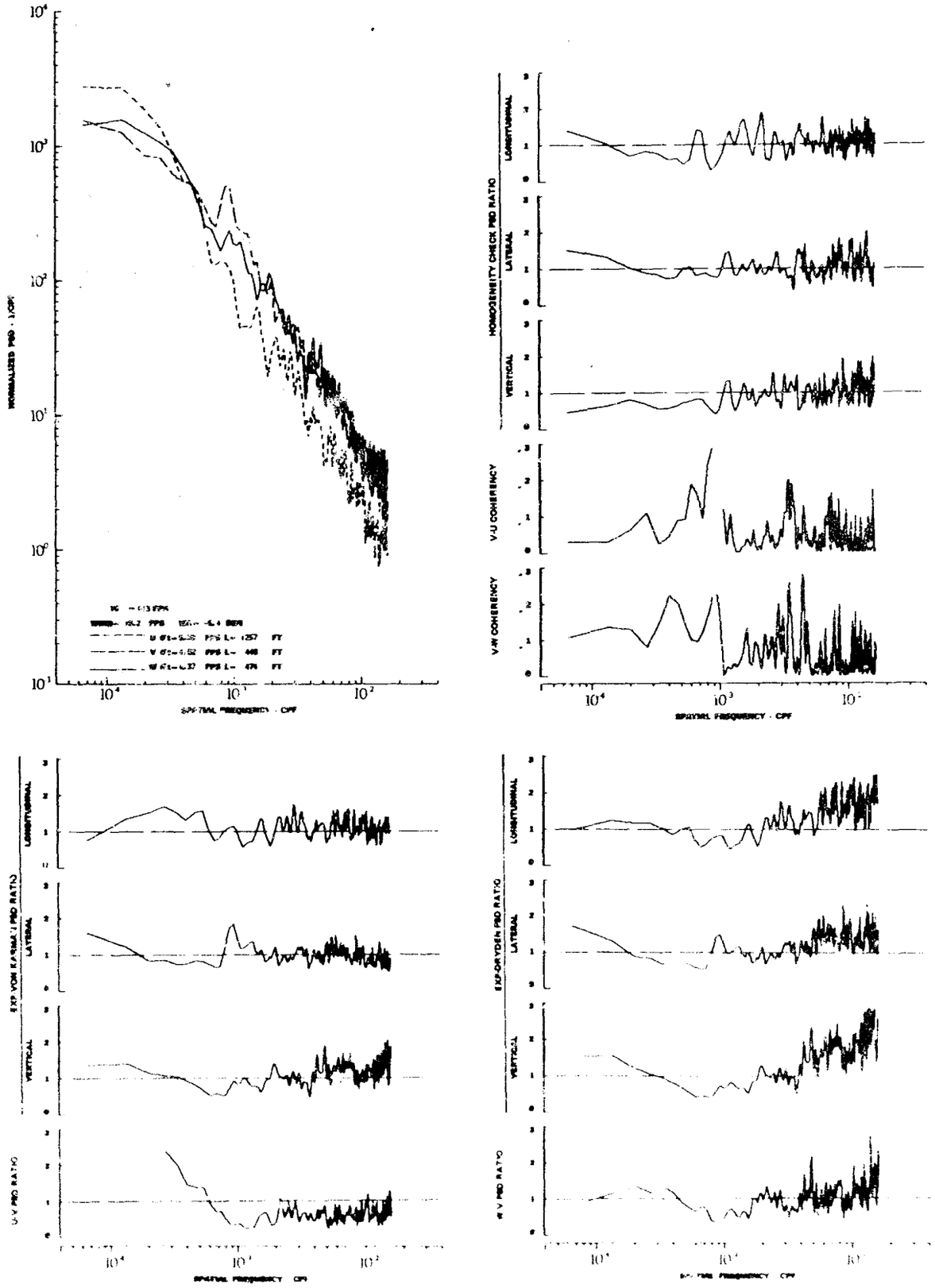


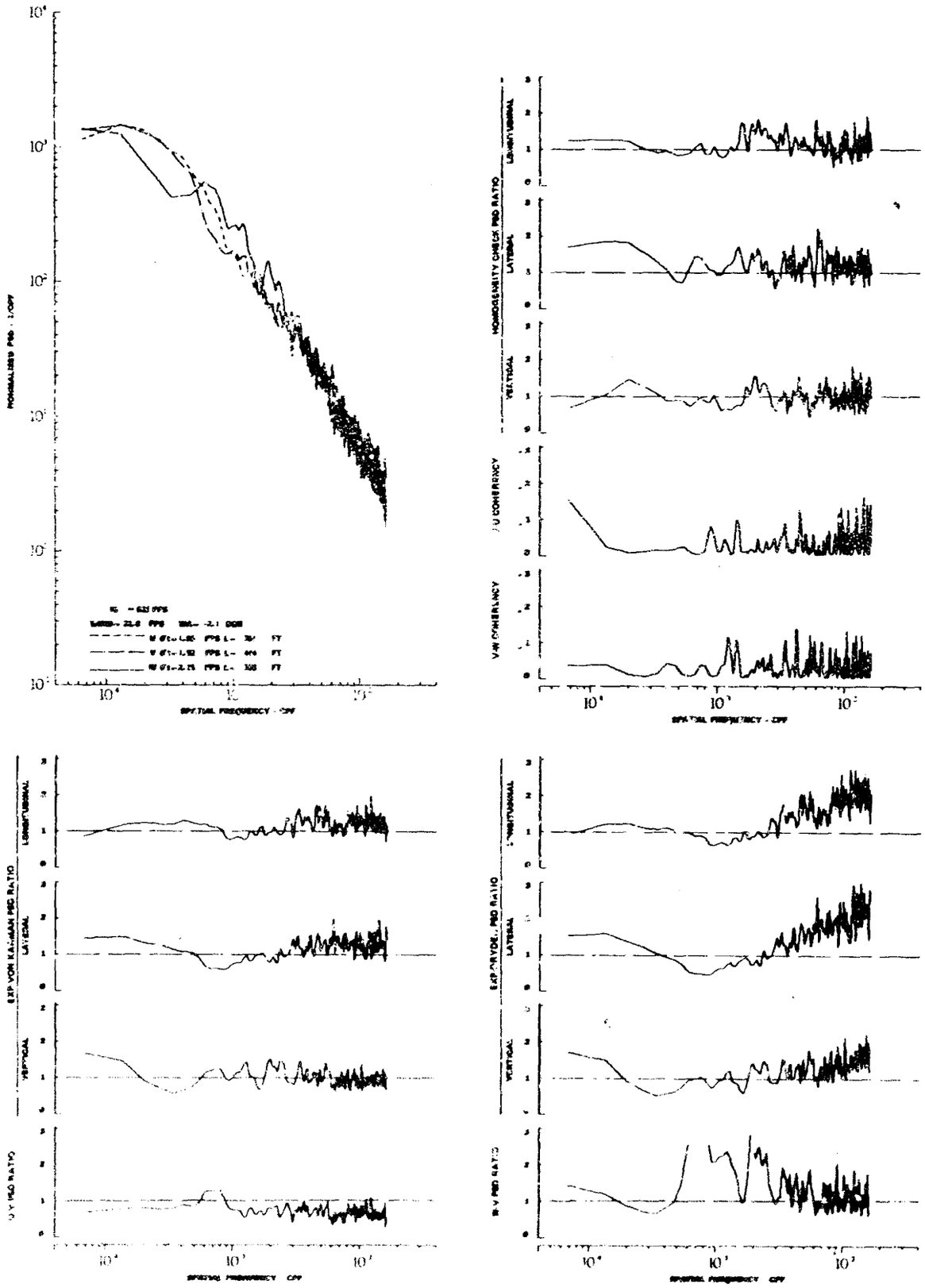
Turbulence Spectra Data for Test 112, Leg 8, Category 27333



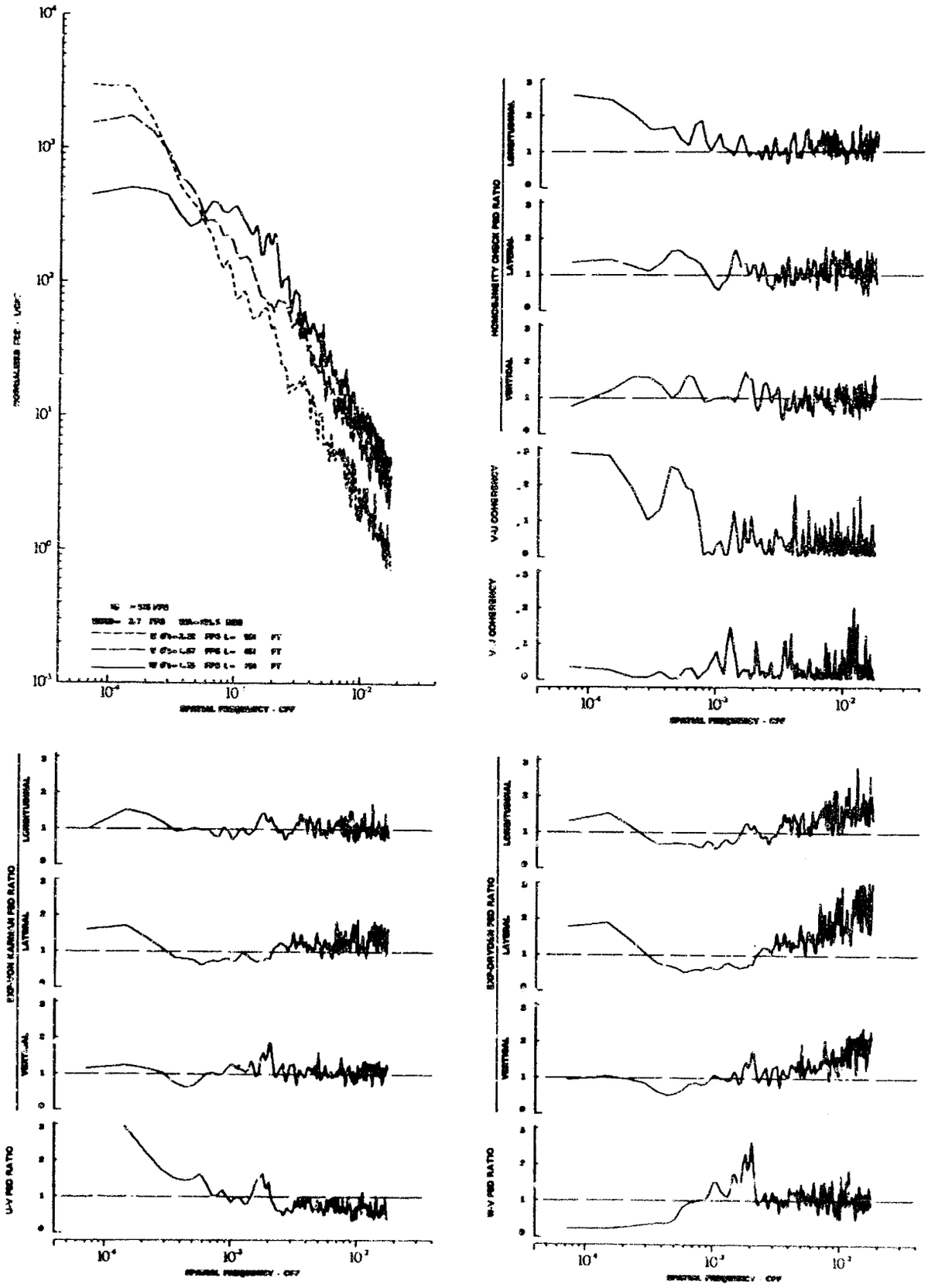
Turbulence Spectra Data For Test 123, Leg 3, Category 121331



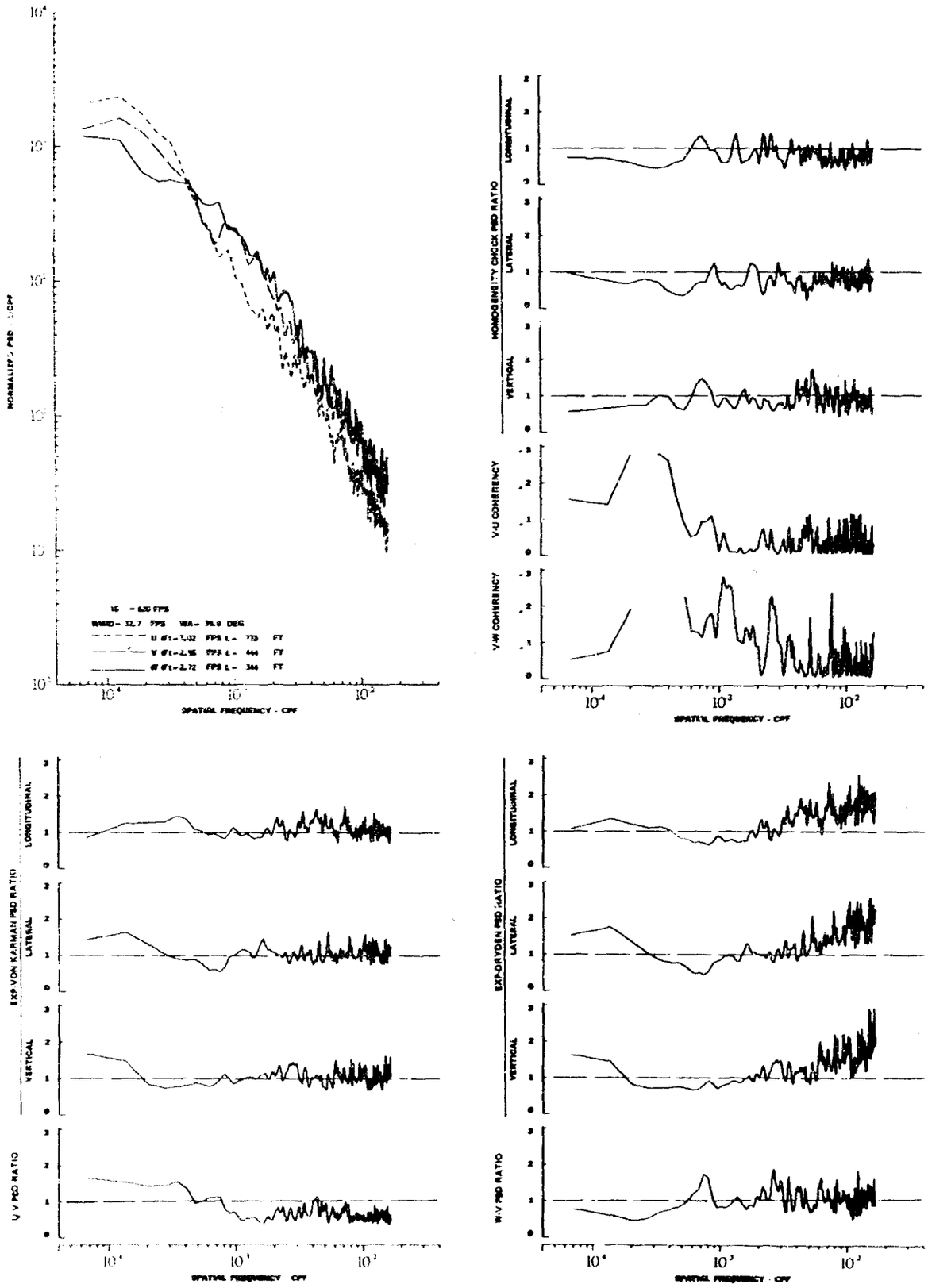
Turbulence Spectra Data For Test 123, Leg 5, Category 122331



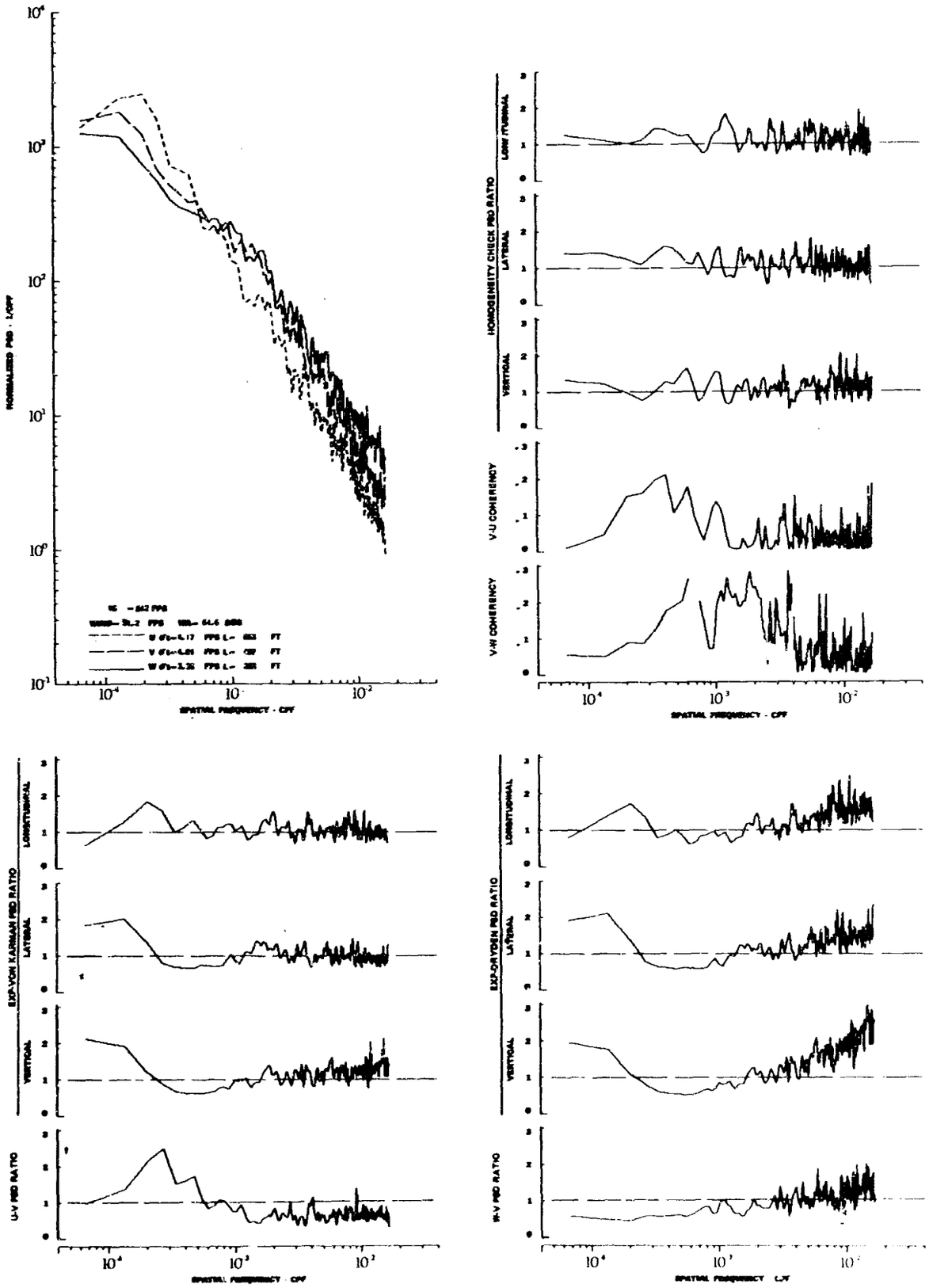
Turbulence Spectra Data For Test 124, Leg 2, Category 312231



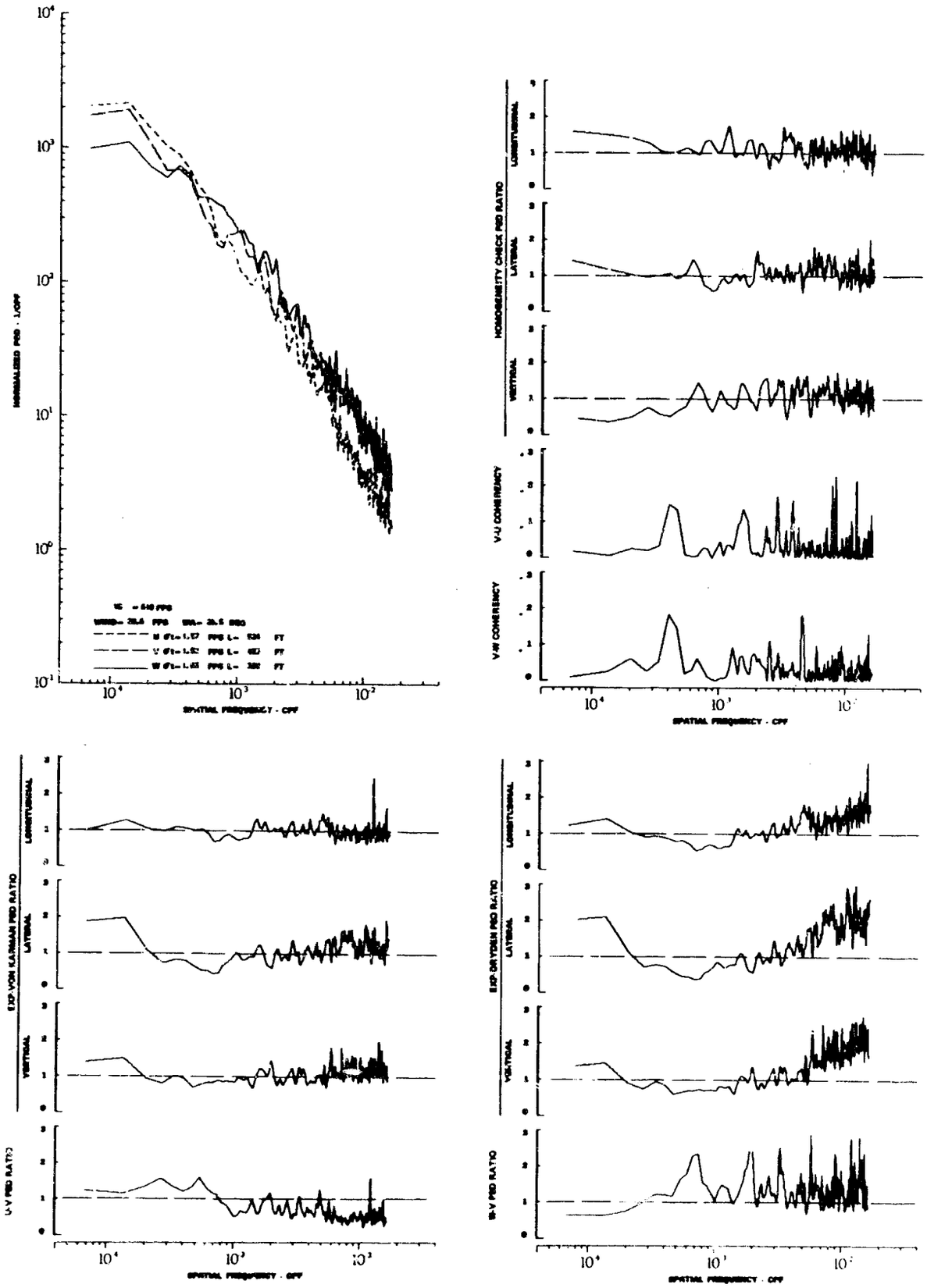
Turbulence Spectra Data For Test 124, Leg 4, Category 612231



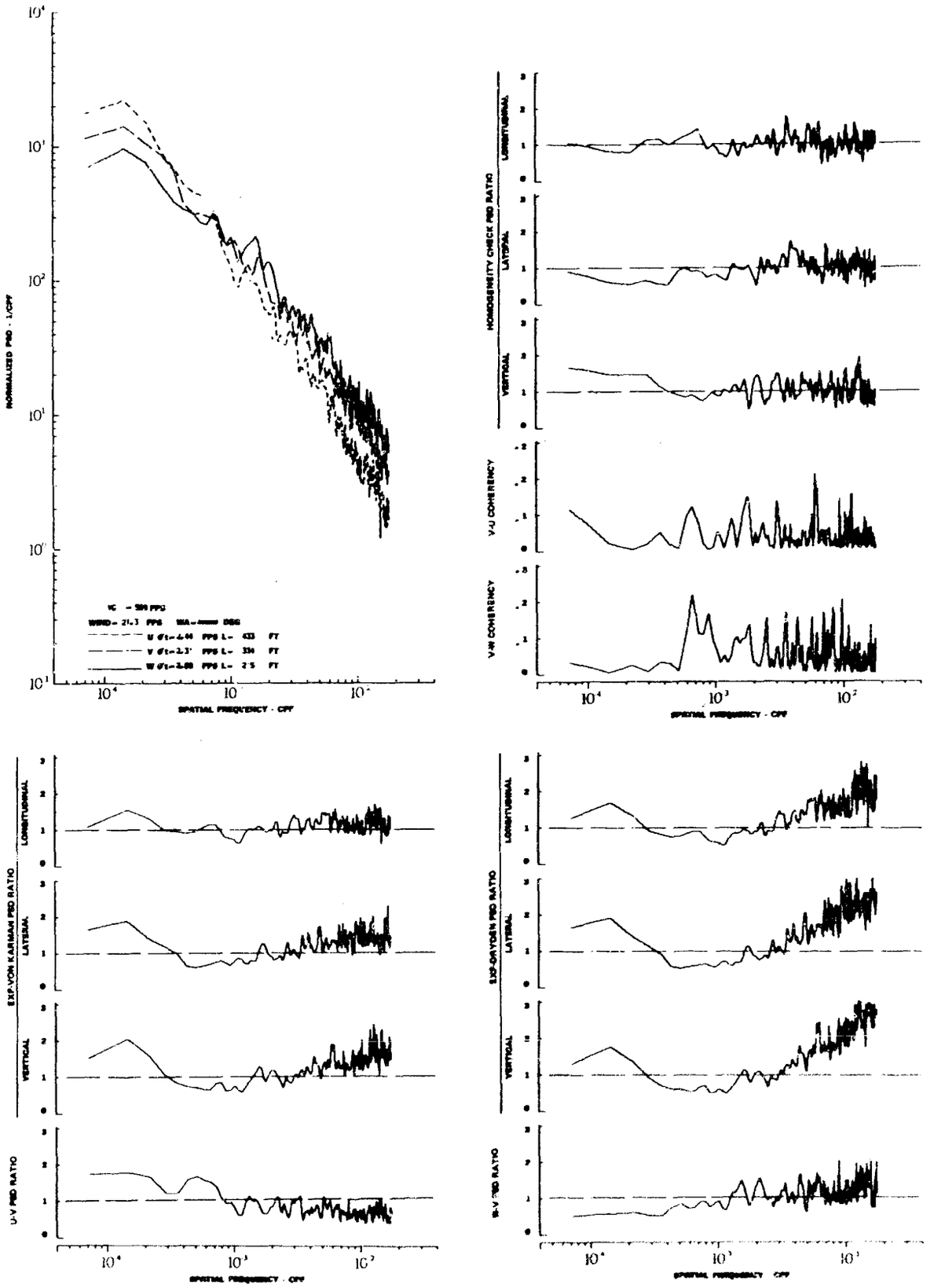
Turbulence Spectra Data For Test 124, Leg 6, Category 213231



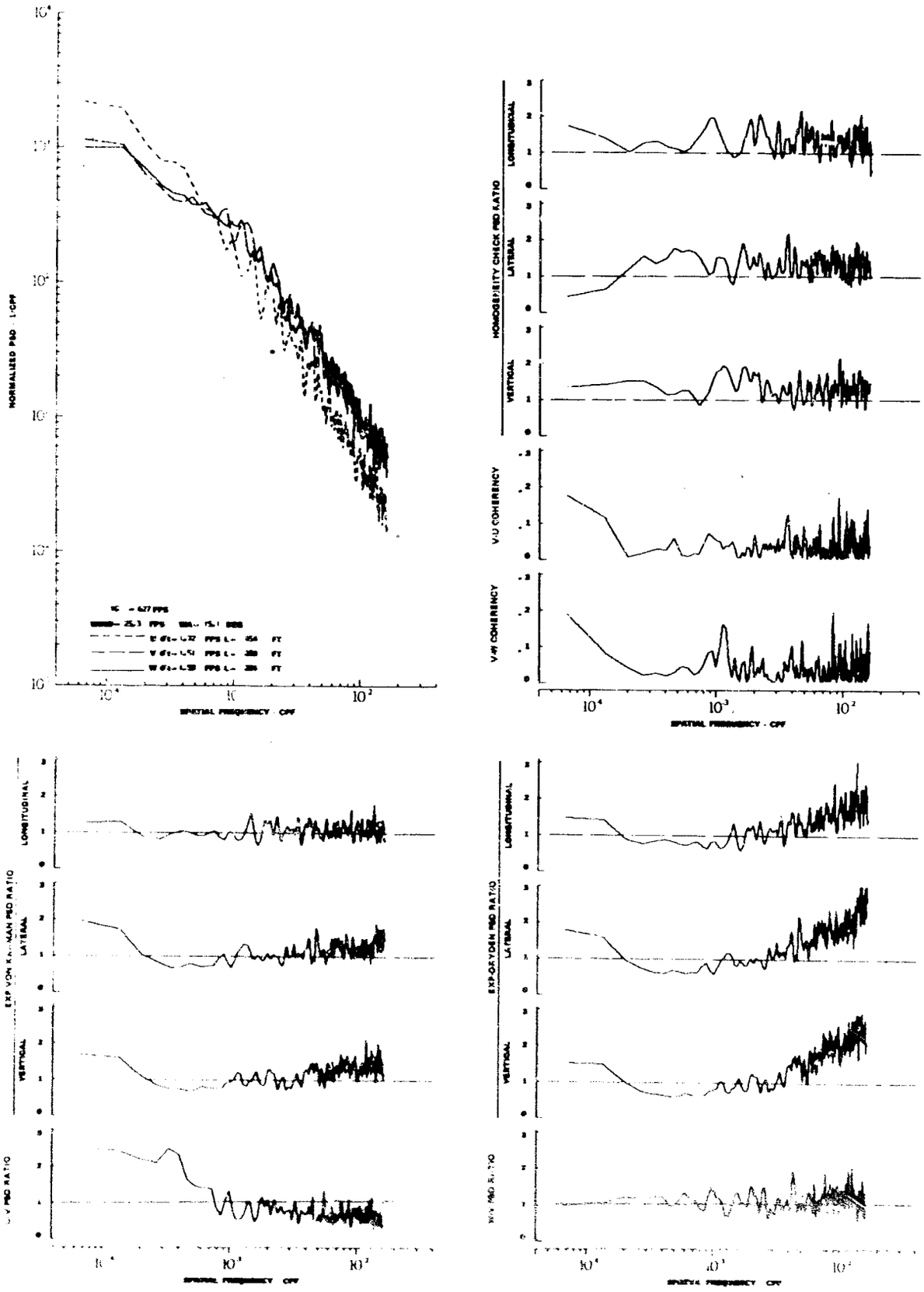
Turbulence Spectra Data For Test 124, Leg 8, Category 213231



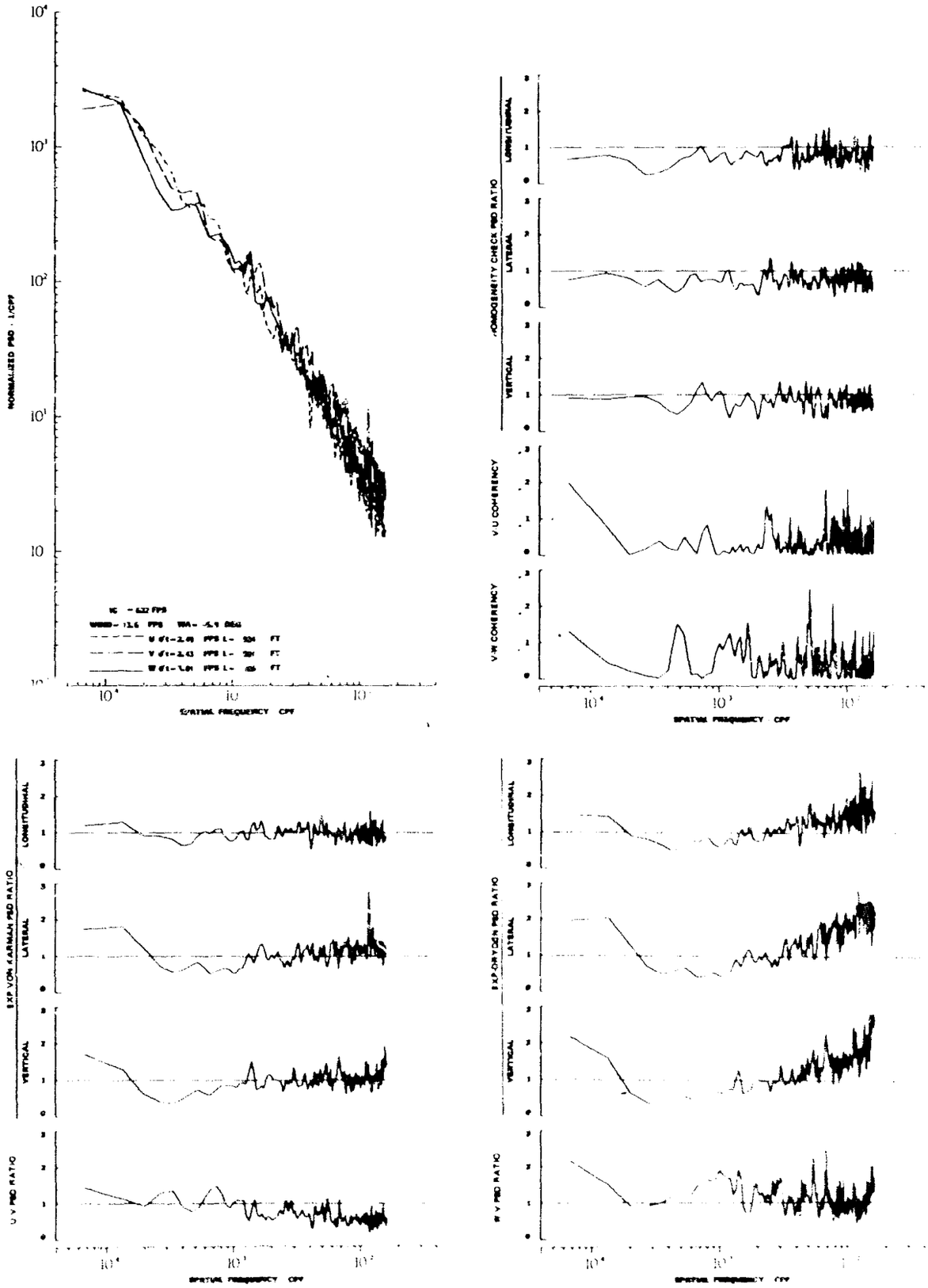
Turbulence Spectra Data for Test 125, Leg 7, Category 314331



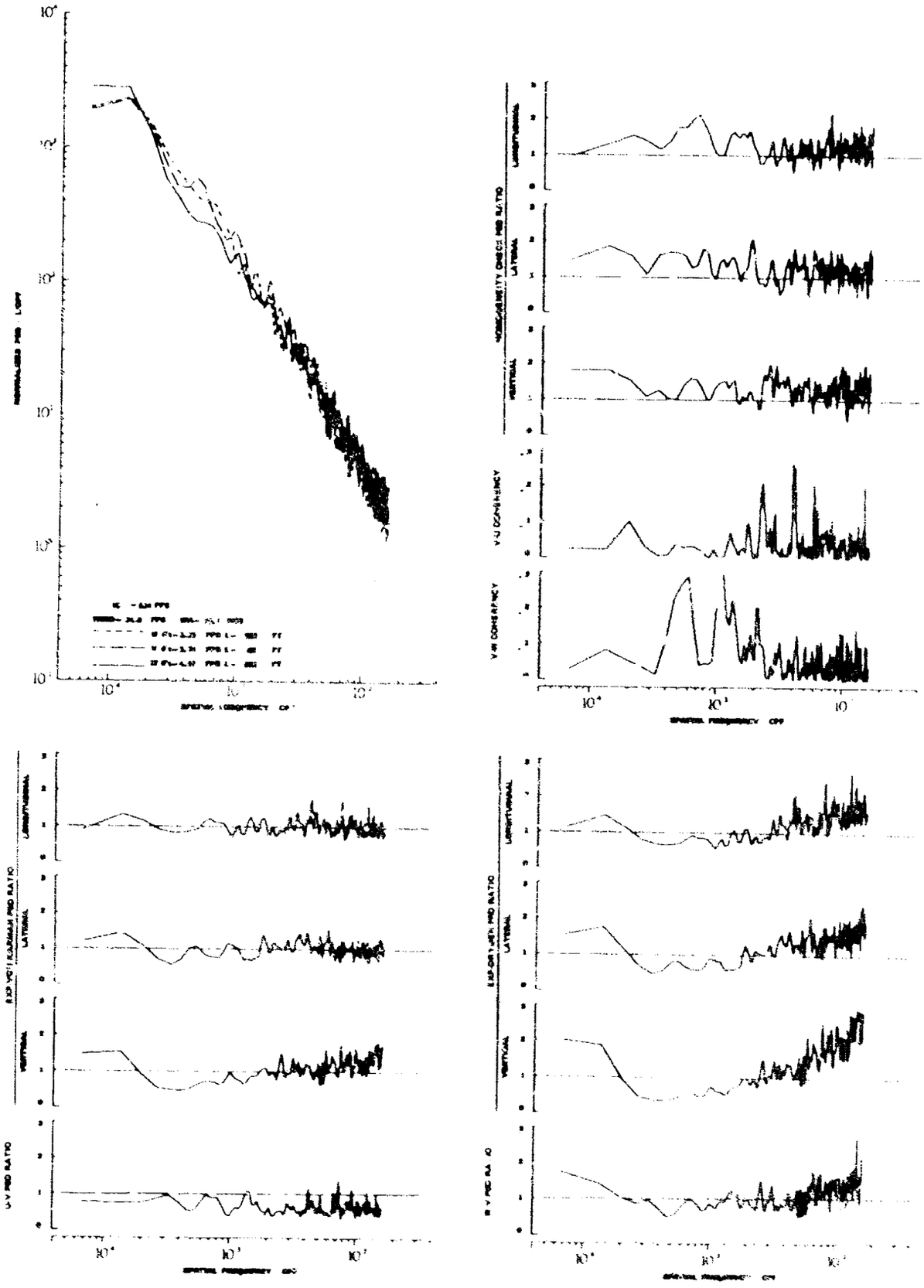
Turbulence Spectra Data For Test 130, Leg 4, Category 613231



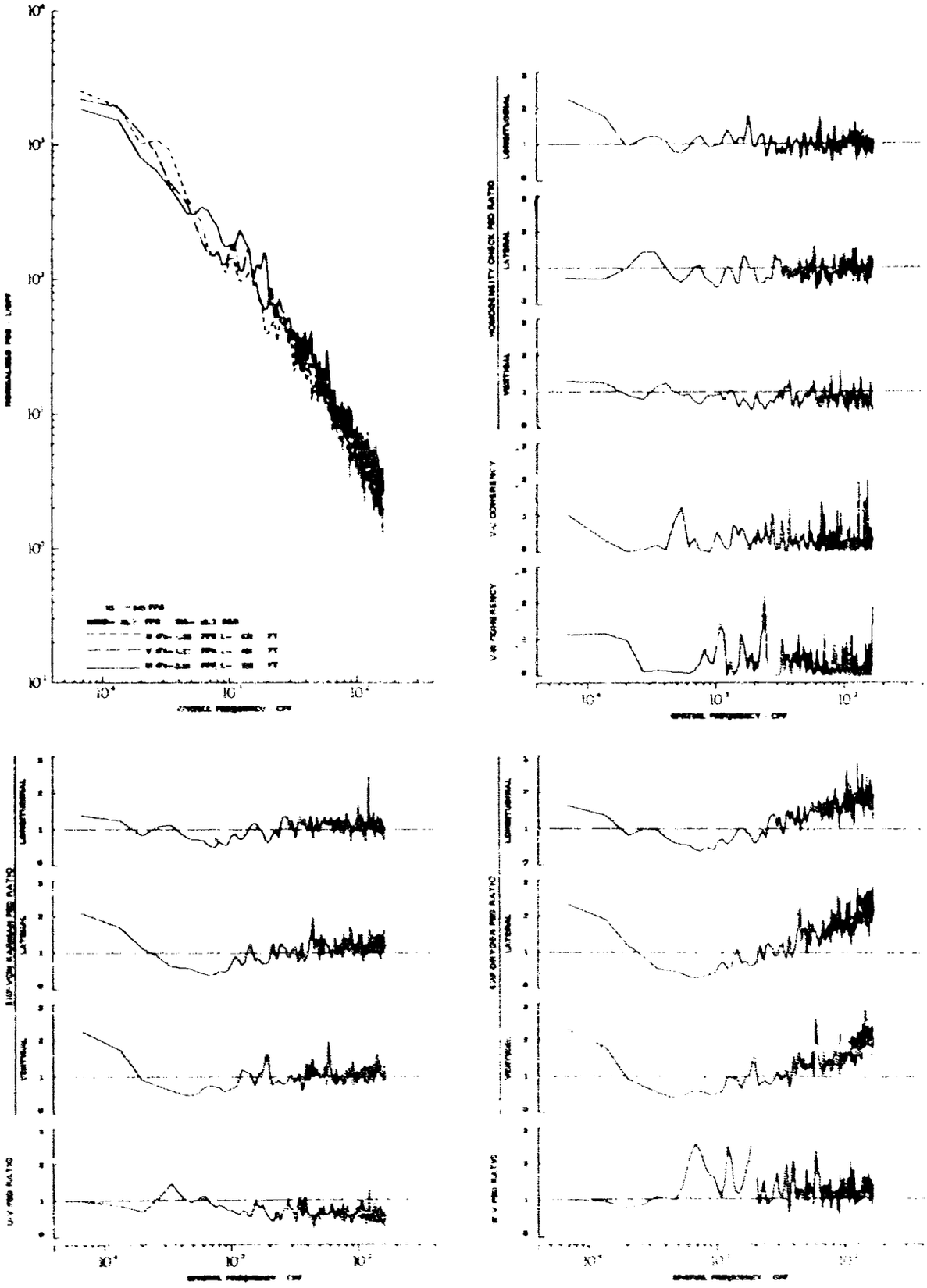
Turbulence Spectra Data For Test 130, Leg 6, Category 212231



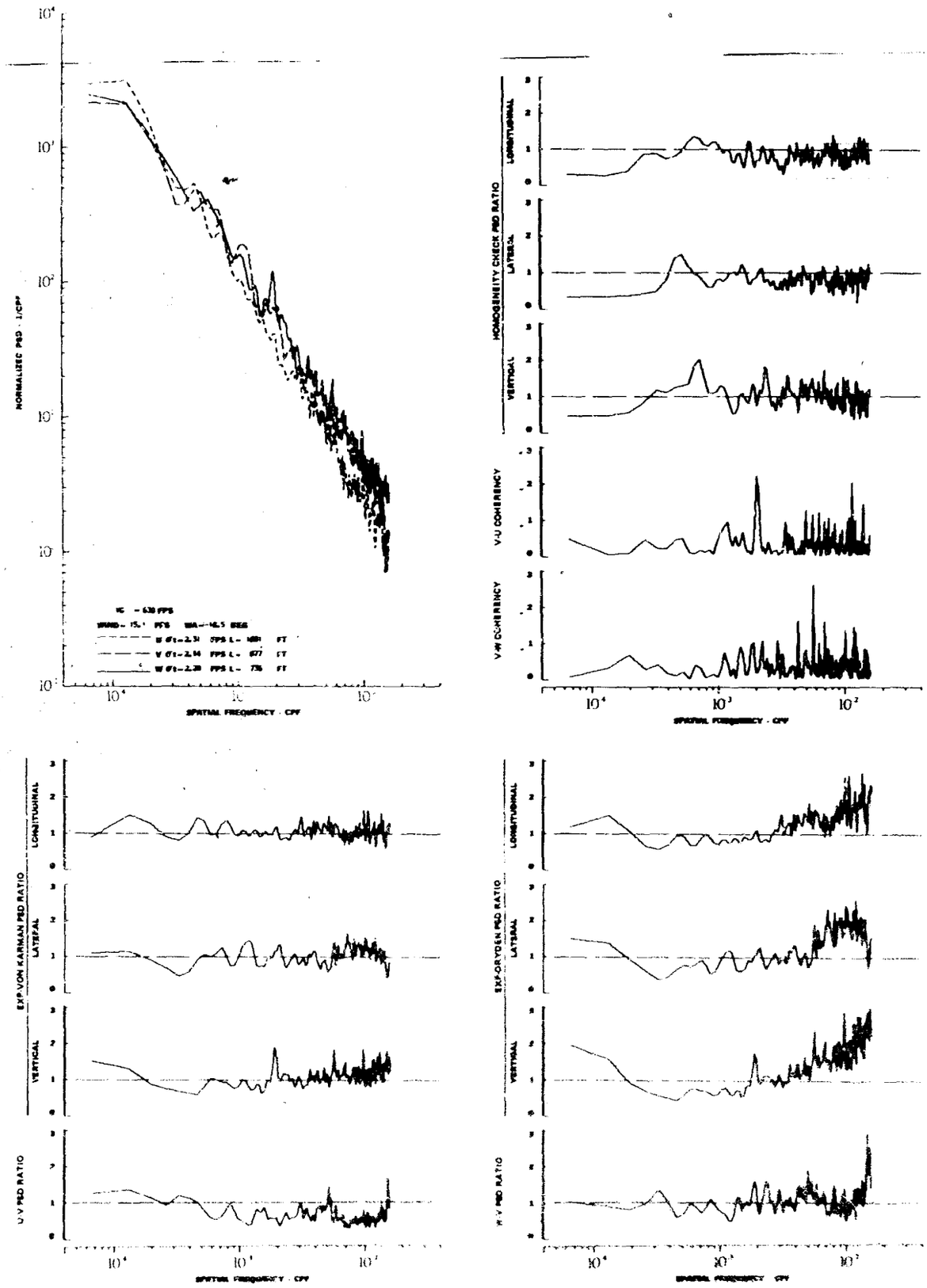
Turbulence Spectra Data For Test 135, Leg 3, Category 111341



Turbulence Spectra Data for Test 135, Leq Category 213341



Turbulence Spectra Data For Test 135, Leg 7, Category 312341



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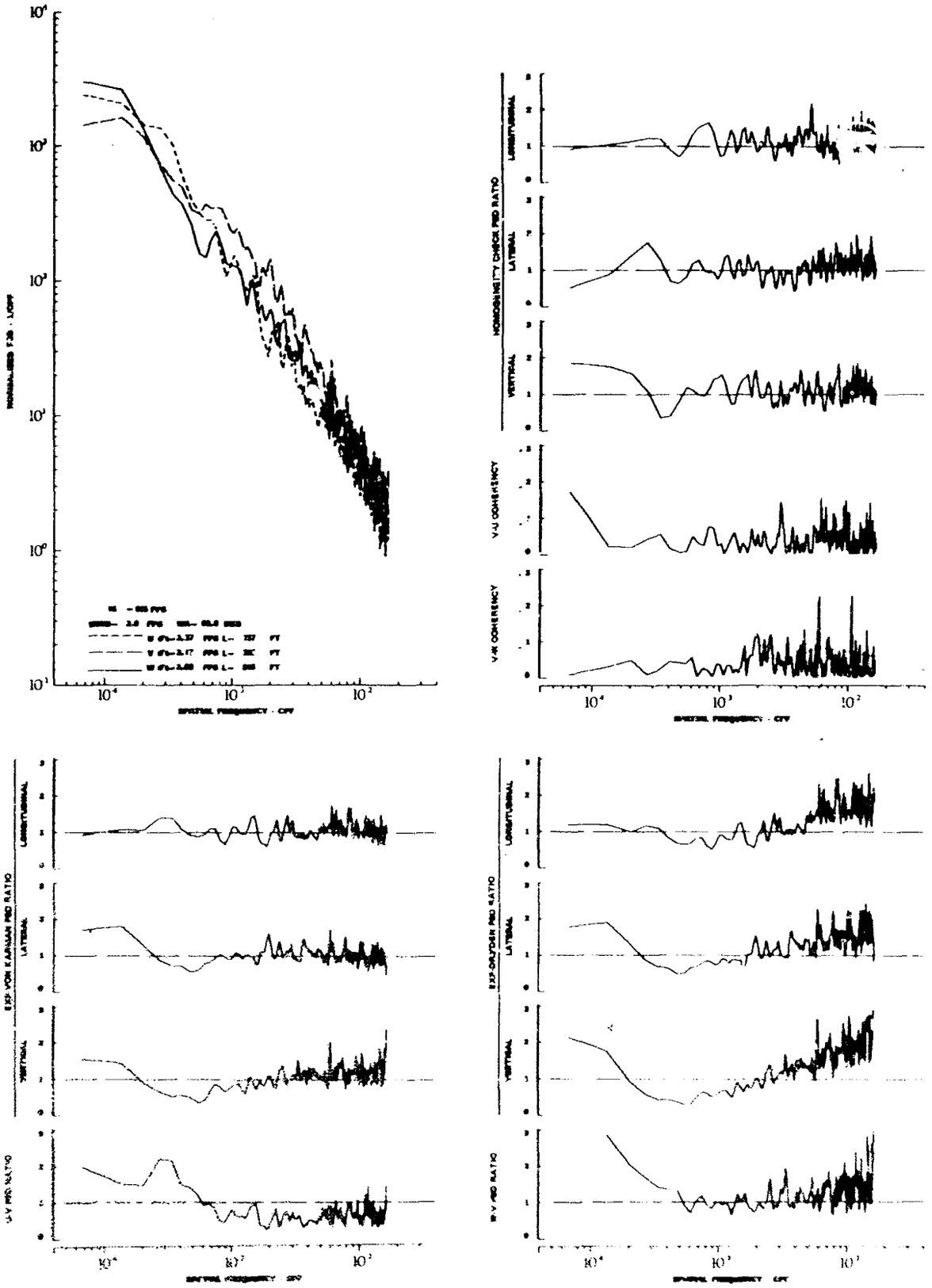

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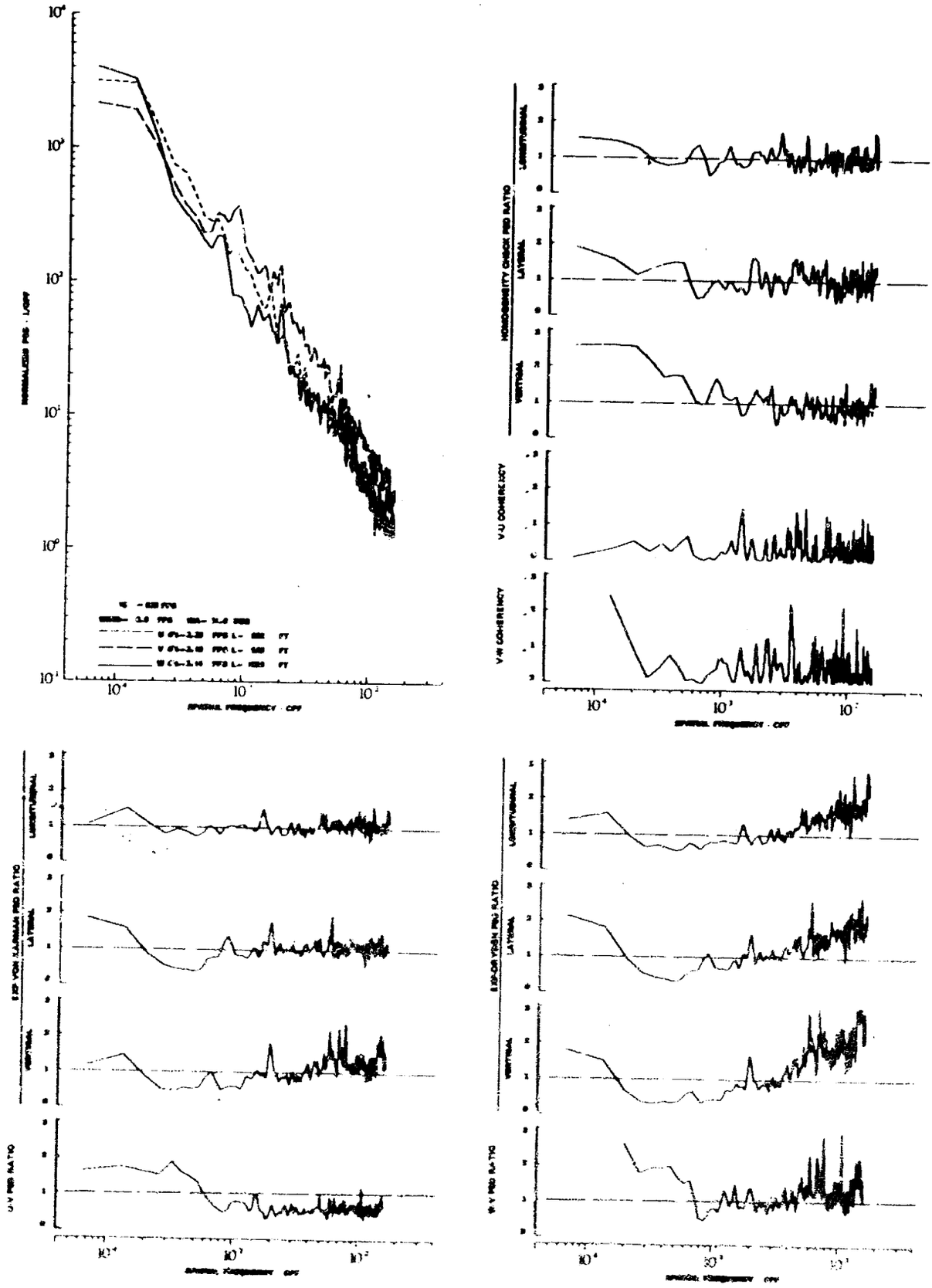

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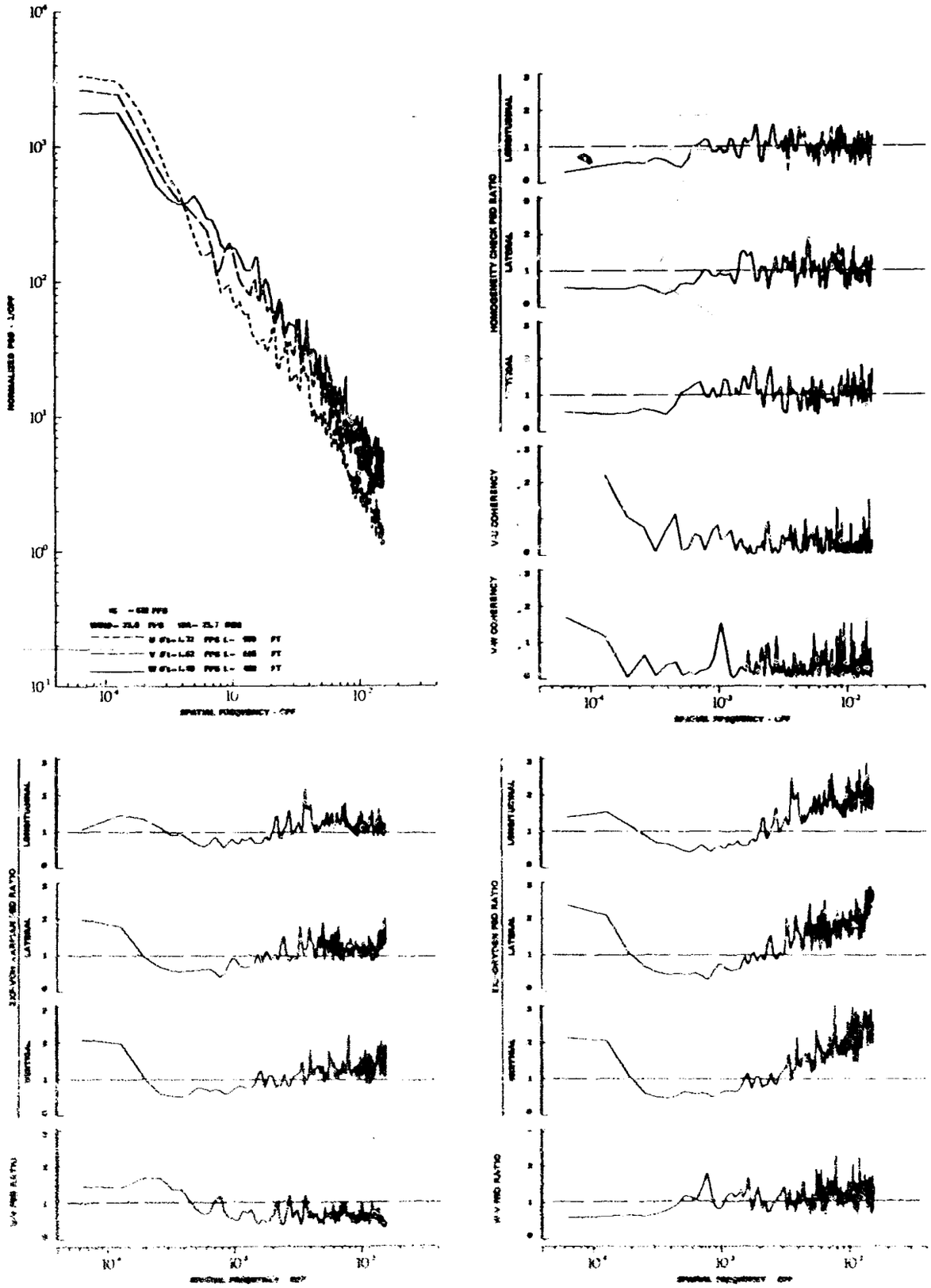

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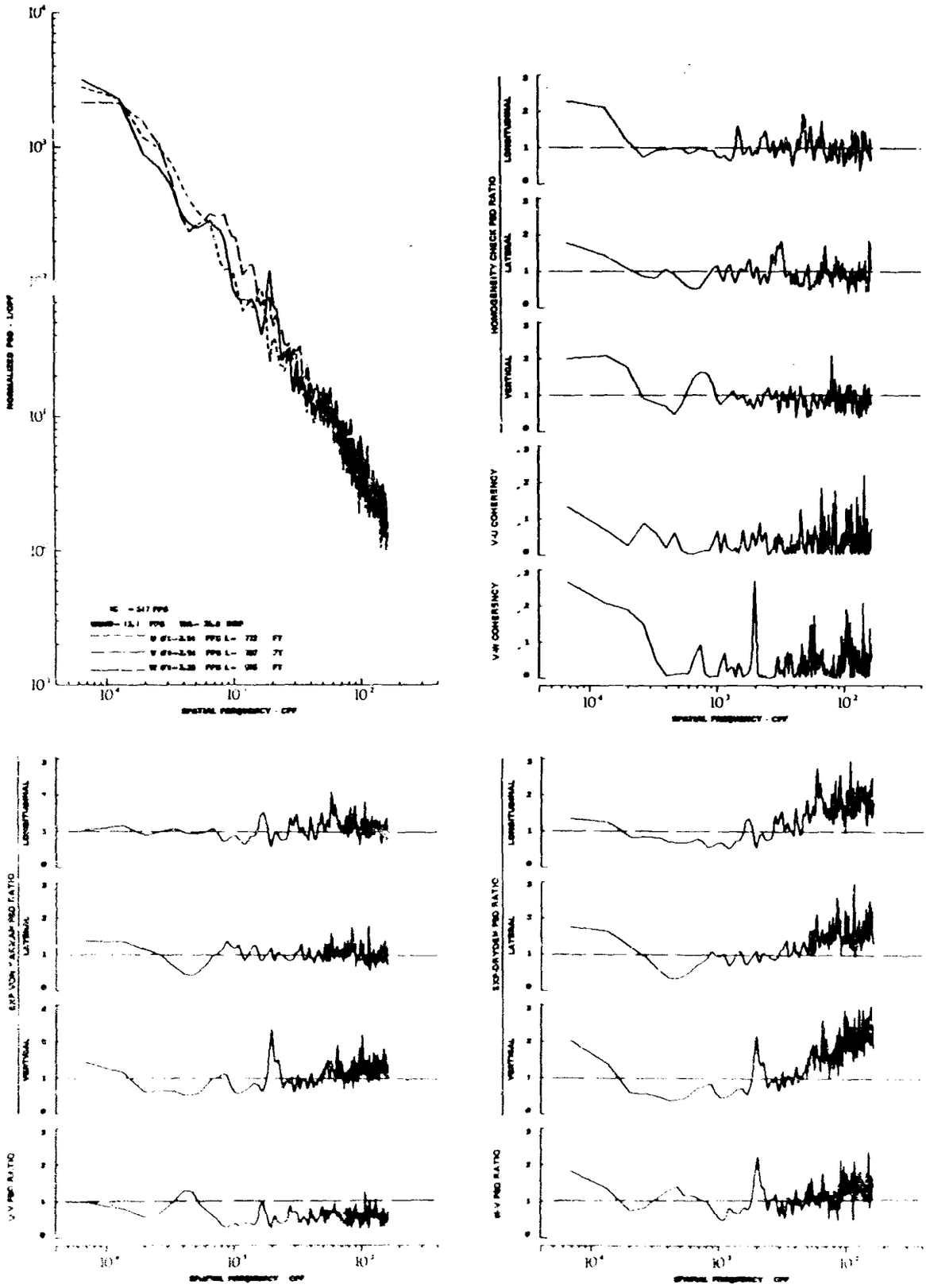

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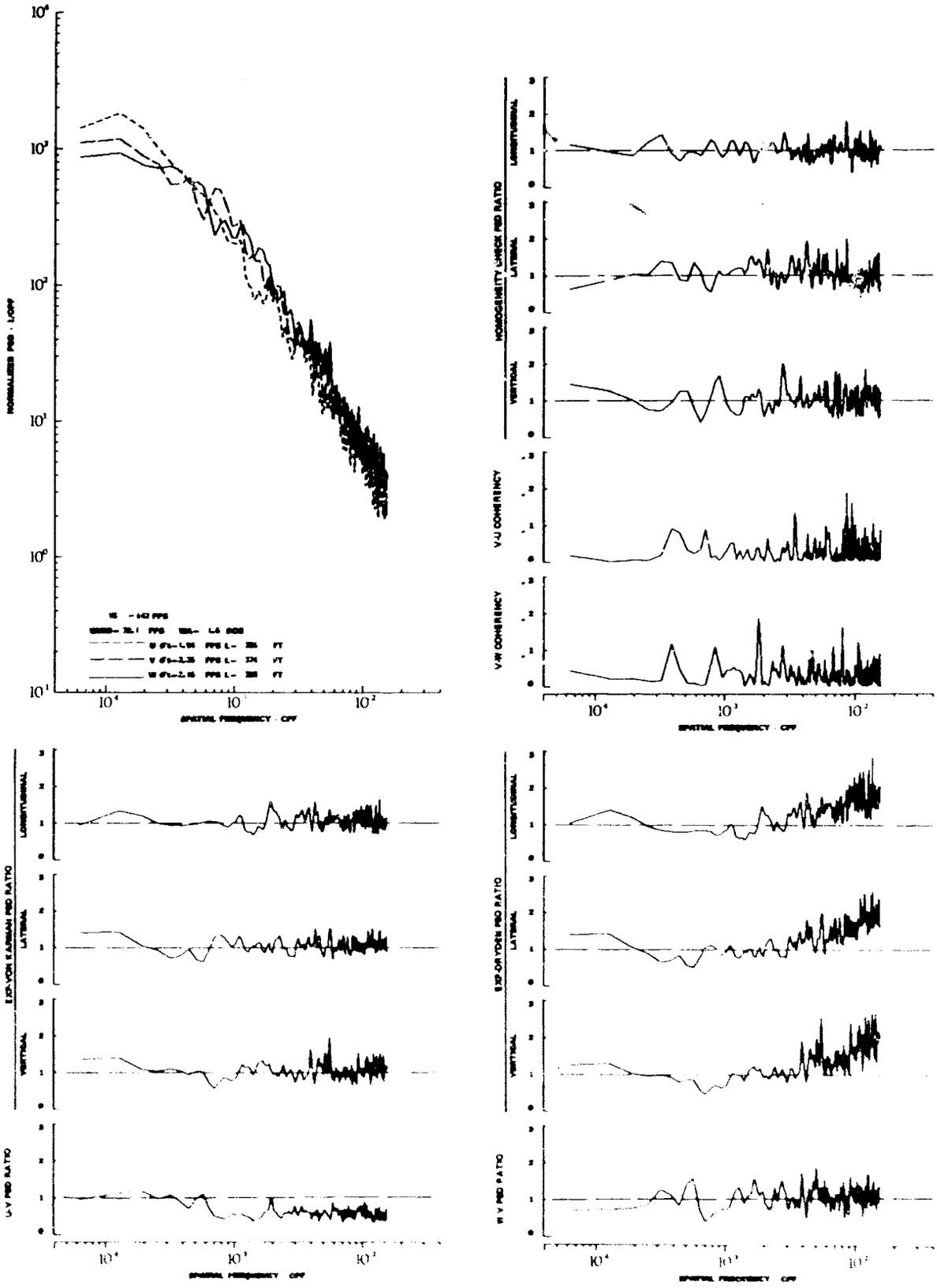

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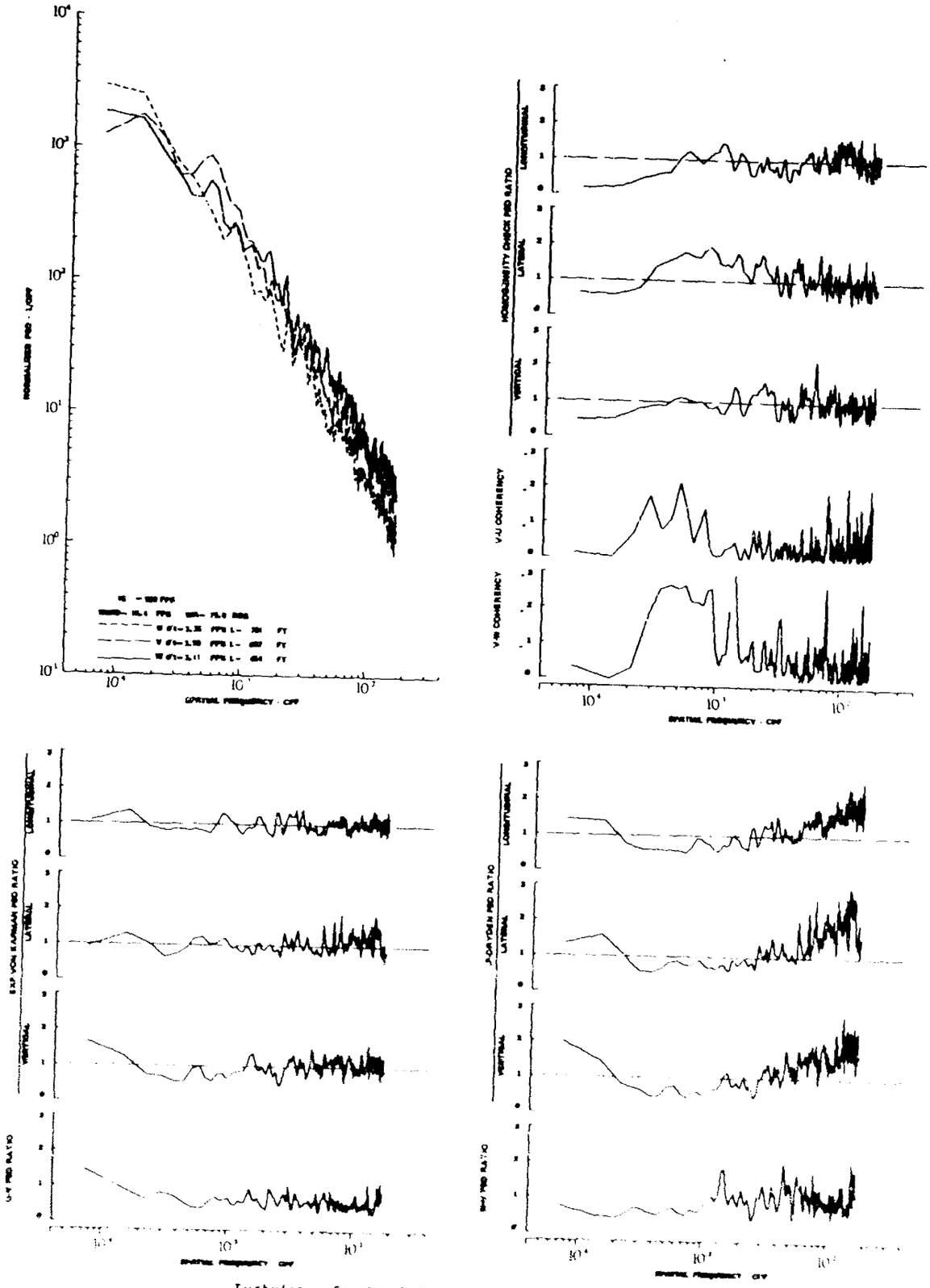

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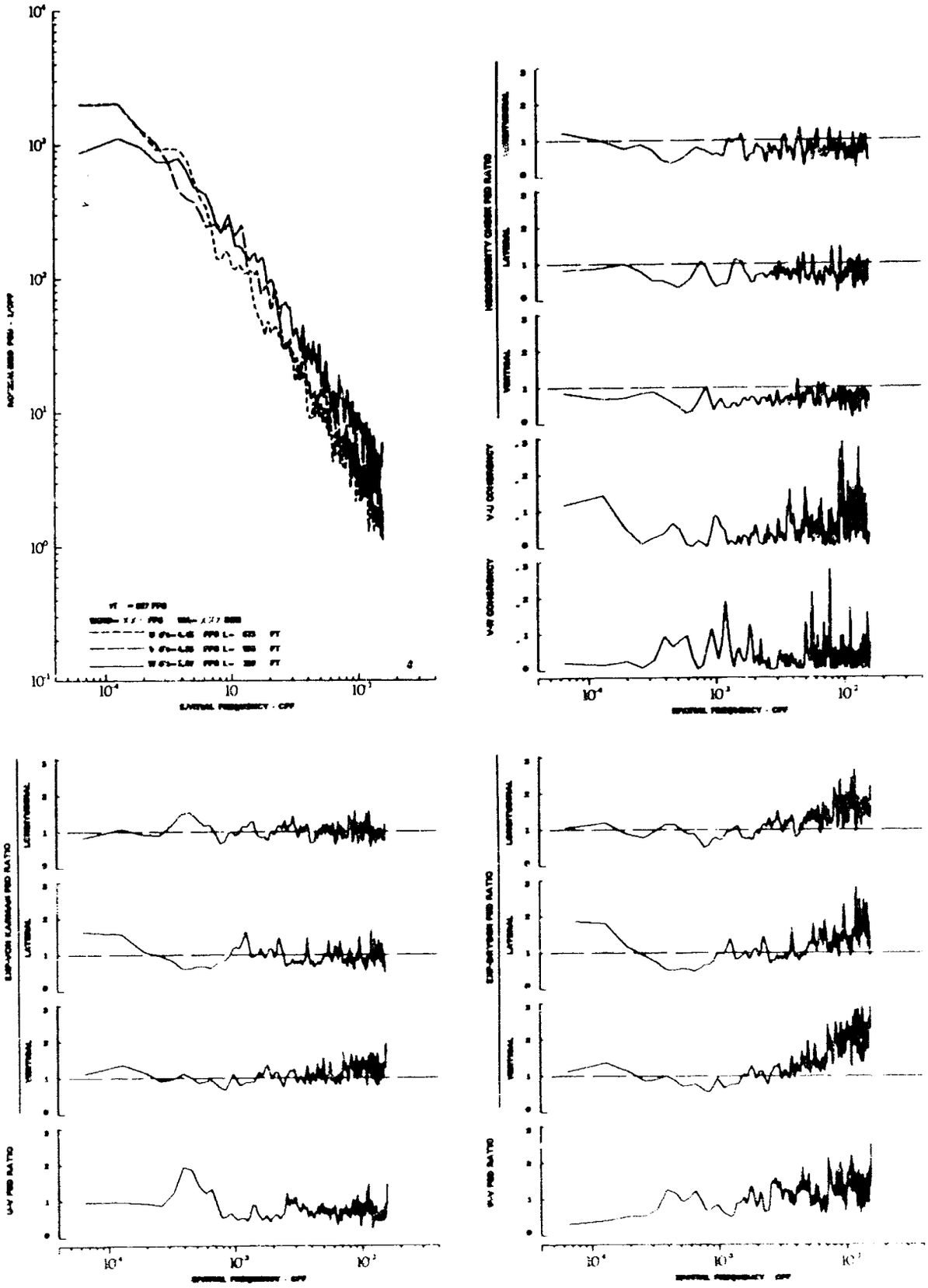

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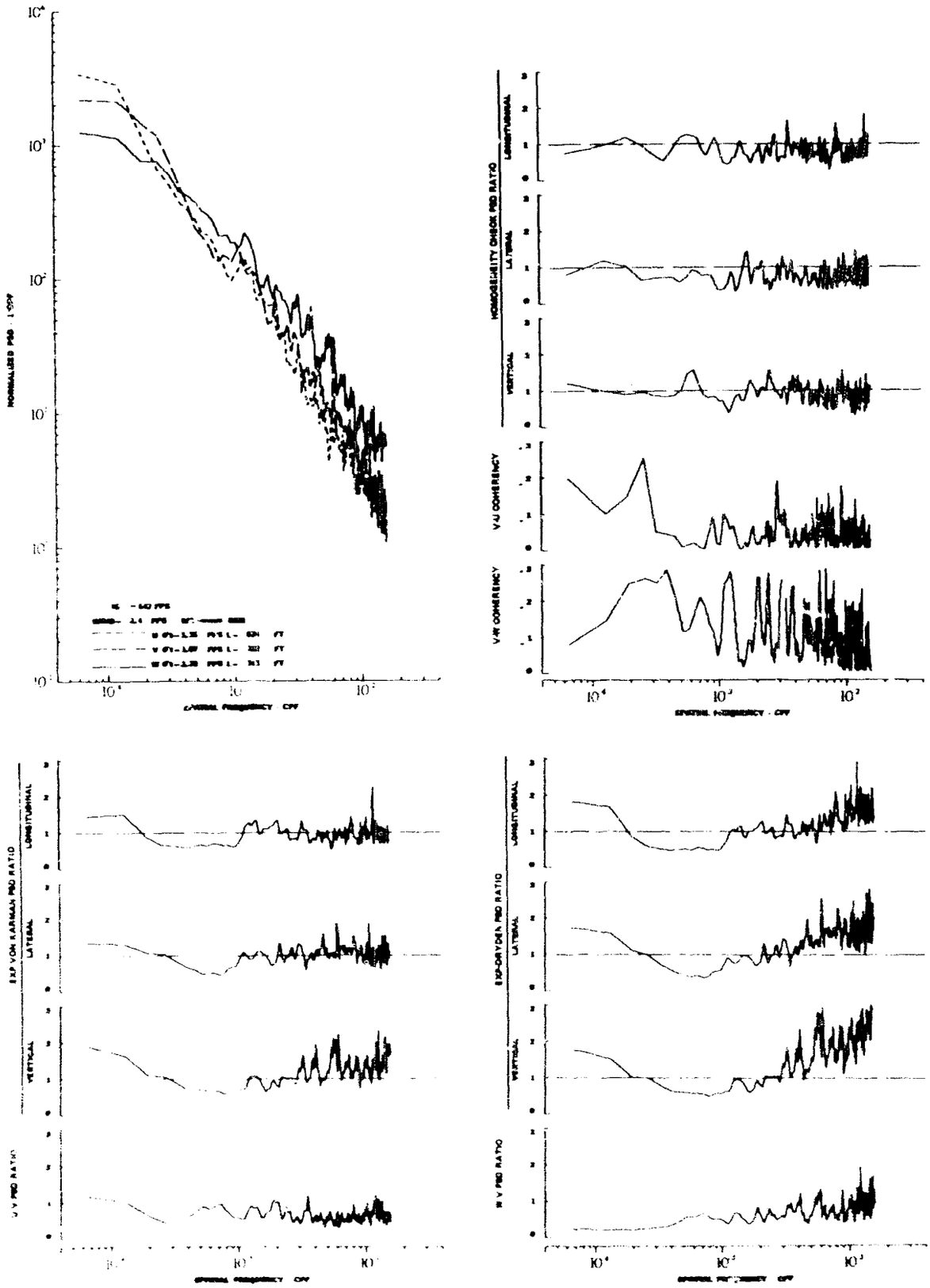
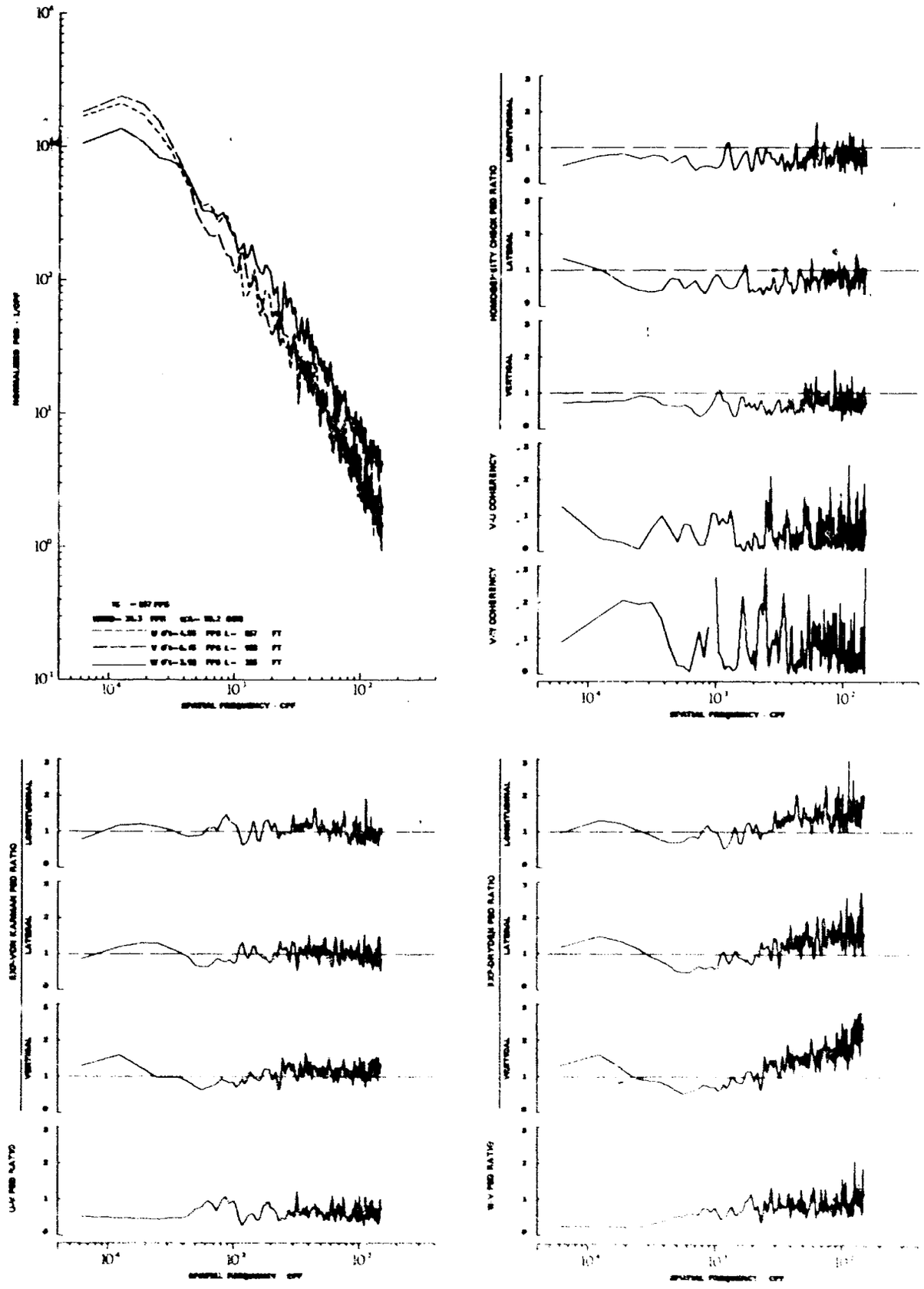


Turbulence Spectra Data For Test 154, Leg 4, Category 121143



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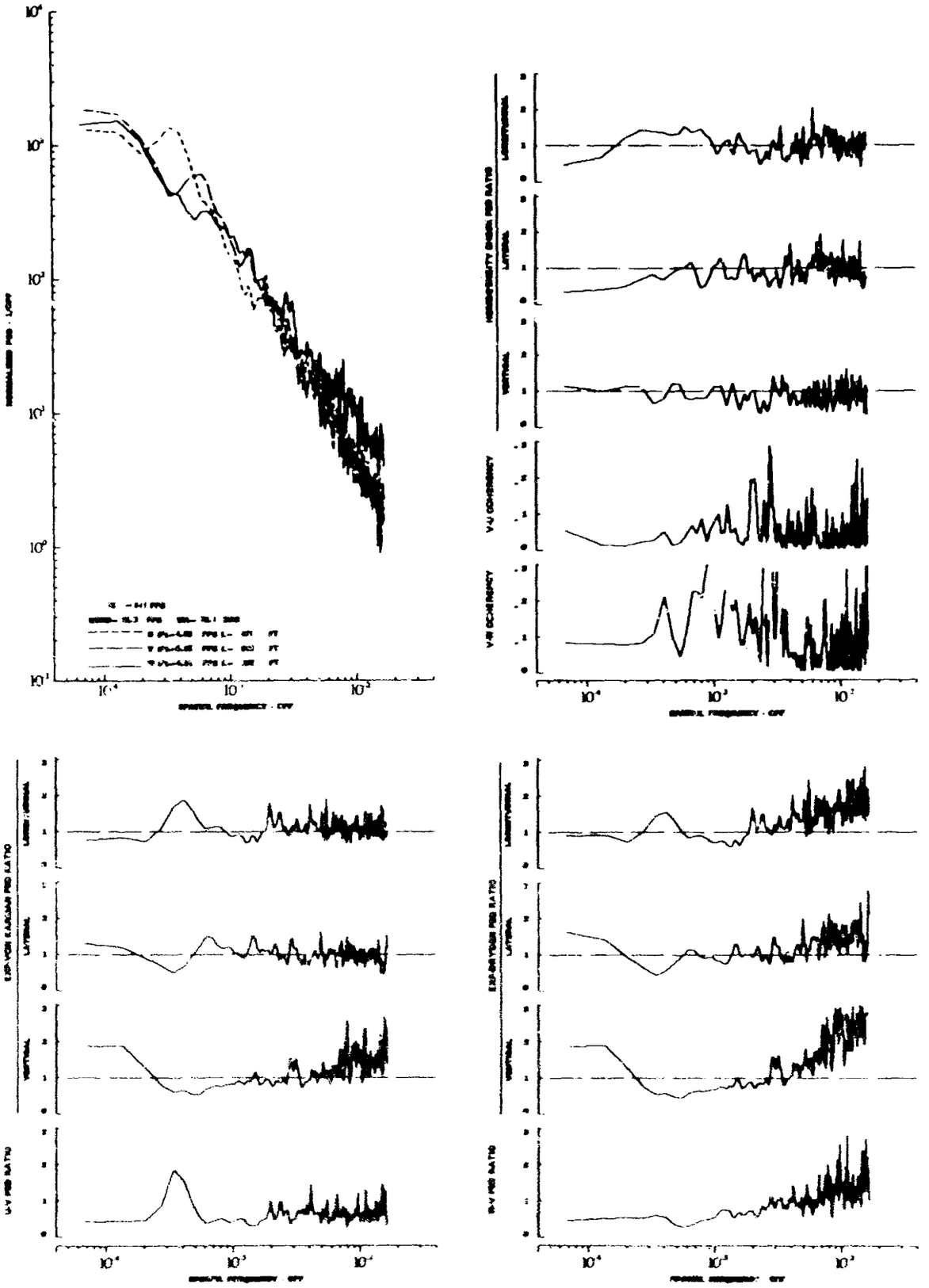
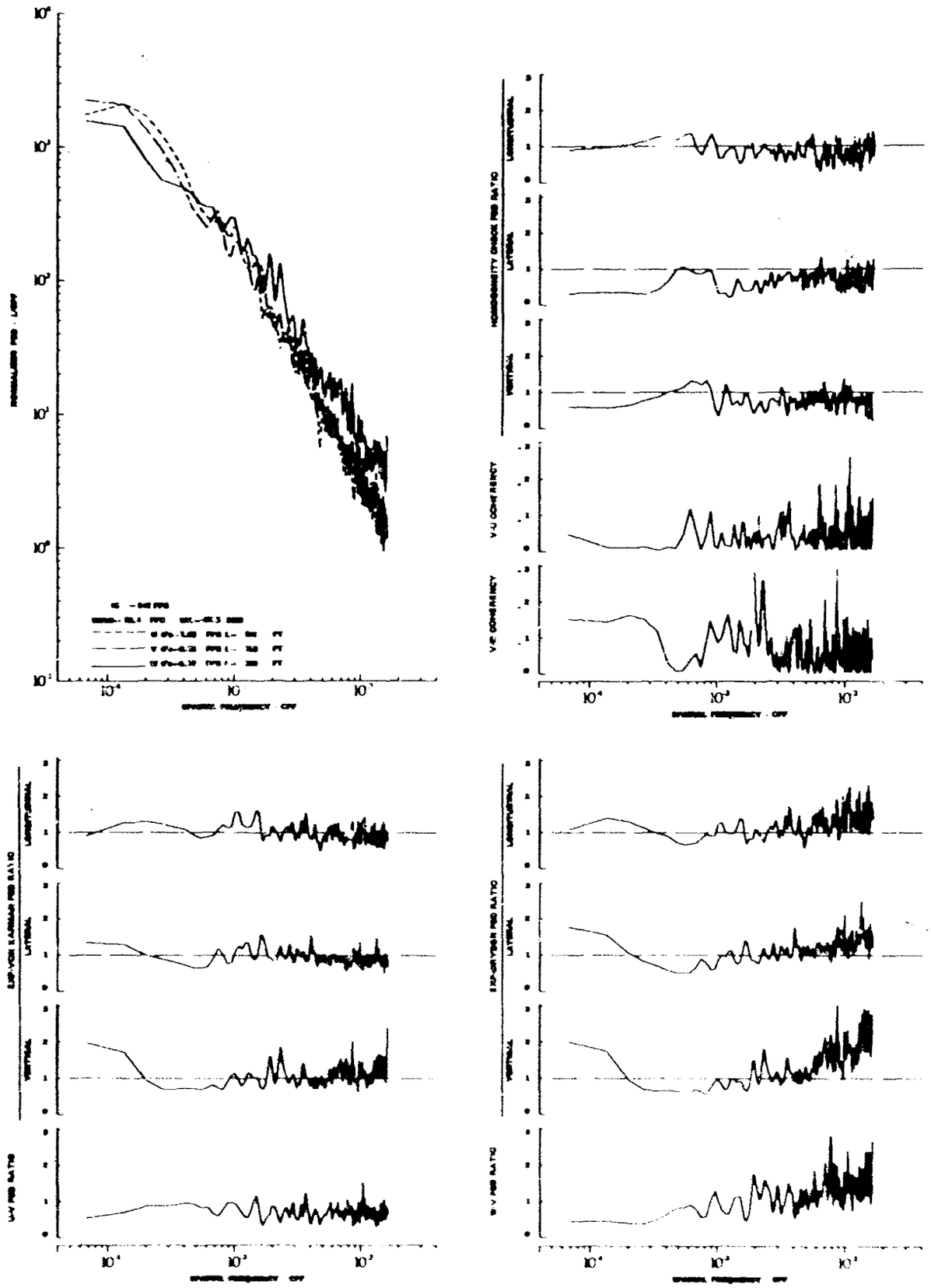


Turbulence Spectra Data for Test 155, Log 1, Category 122243



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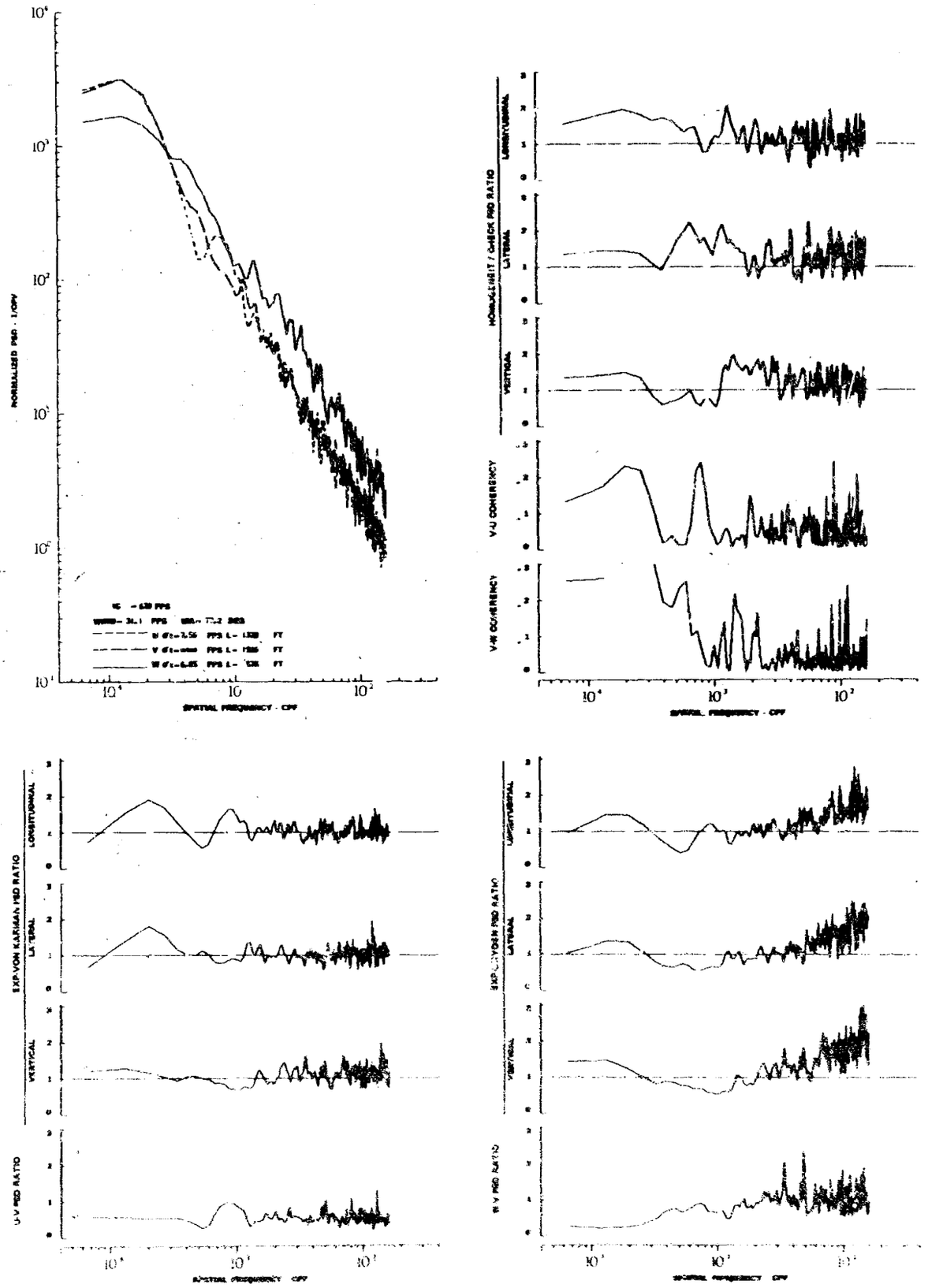

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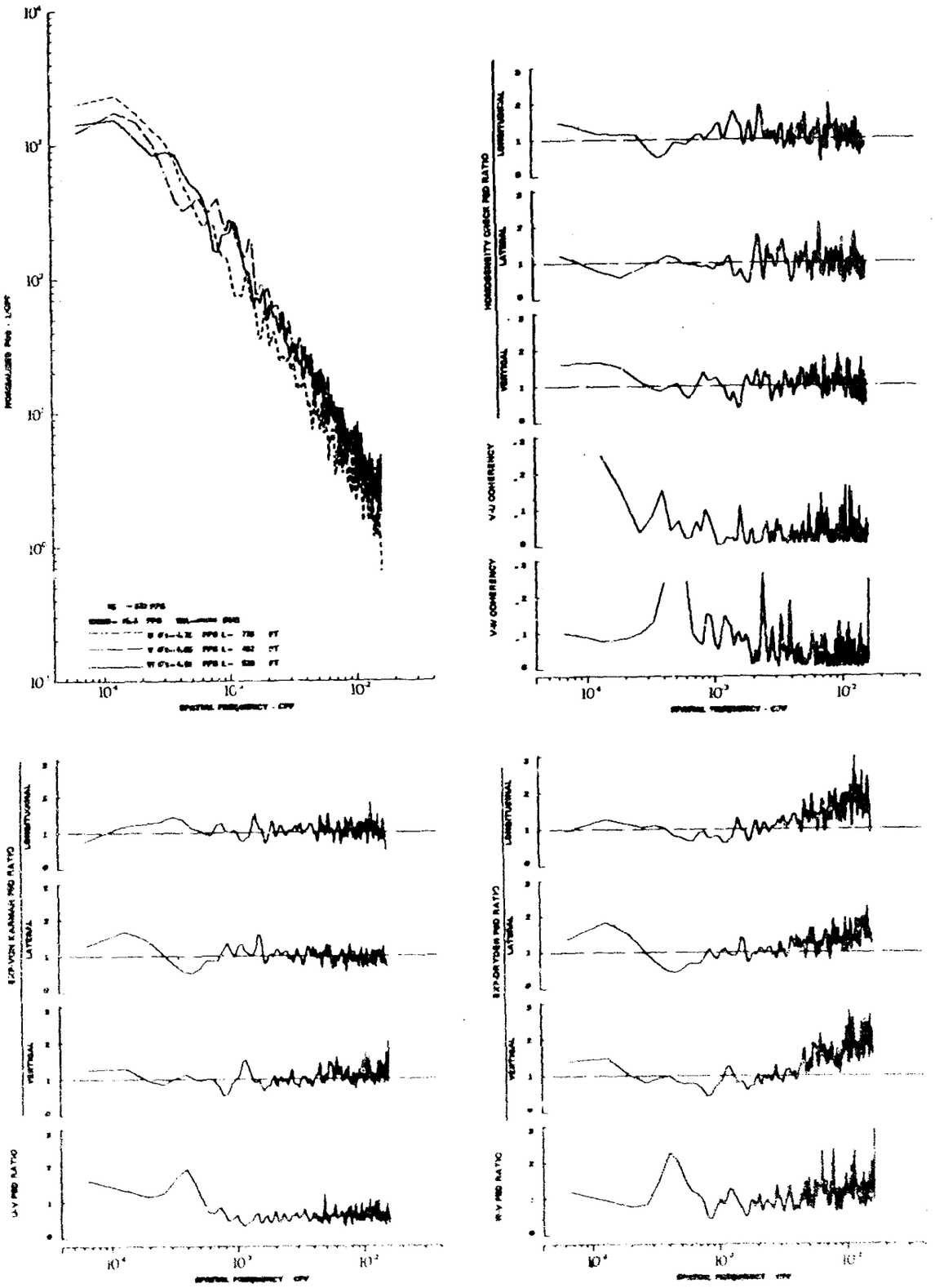

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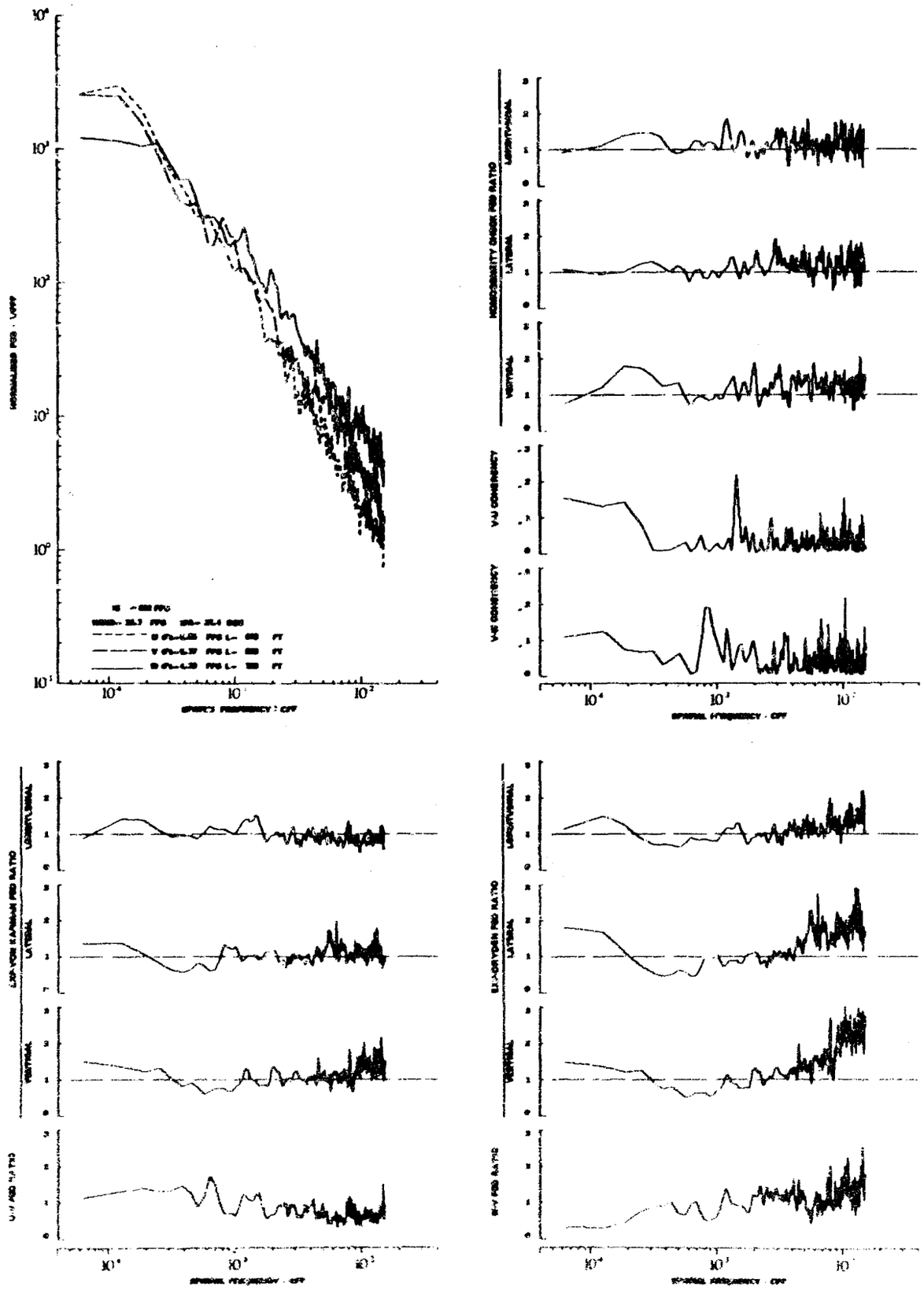
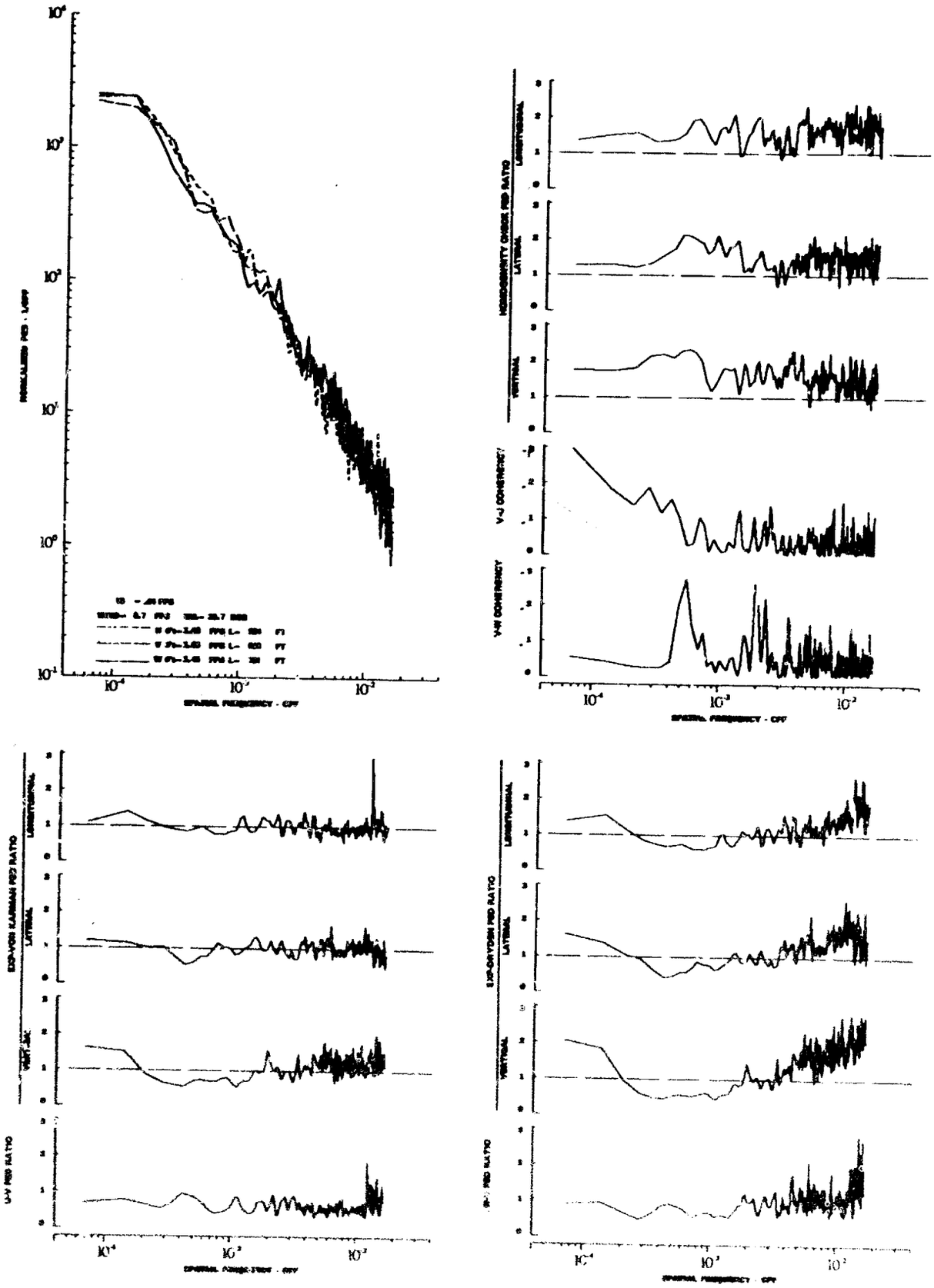
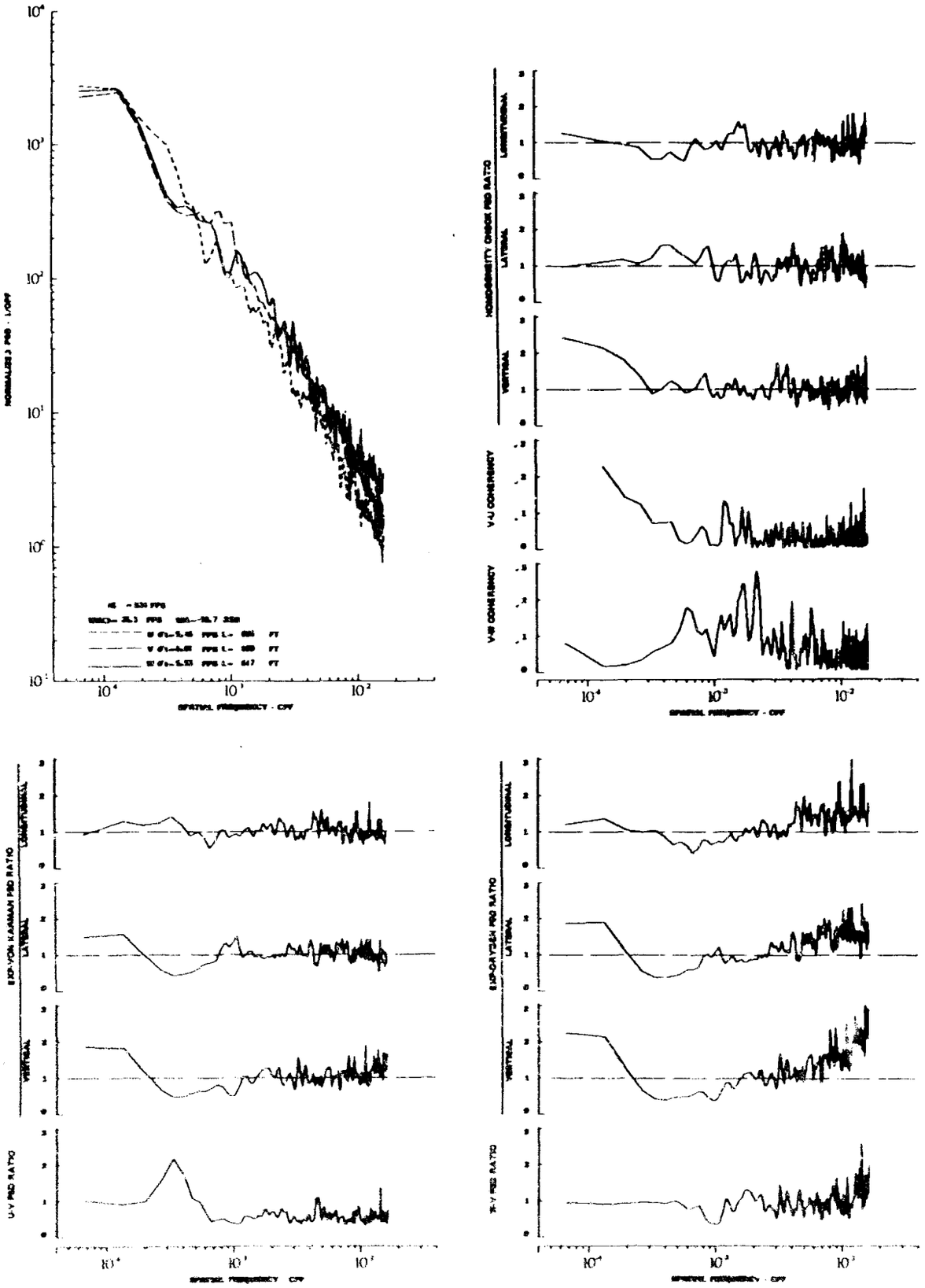


Turbulence Spectra Data For Test 156, Leg 6, Category 122343



Turbulence Spectra Data For Test 158, Leg 2, Category 11-243



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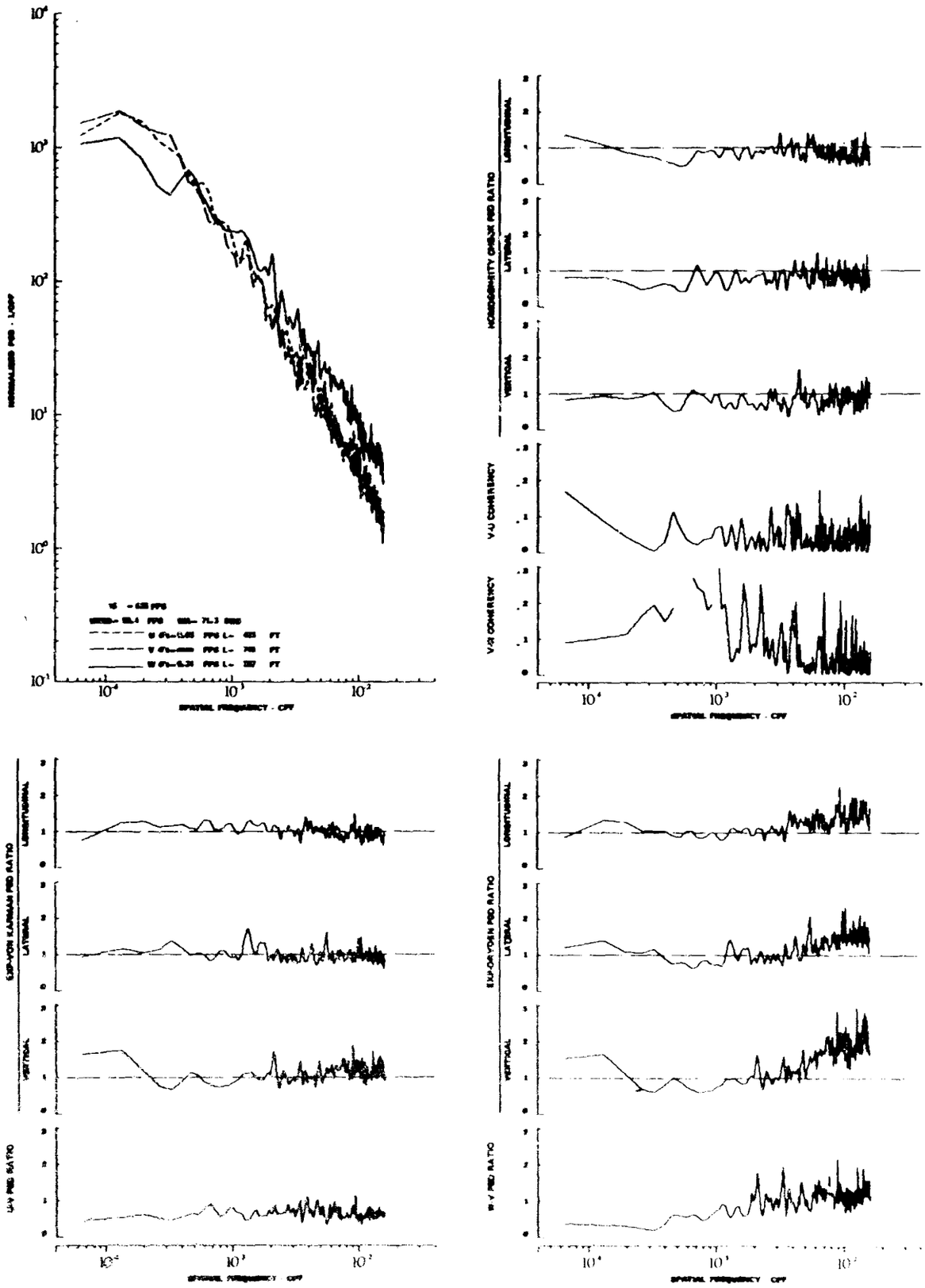

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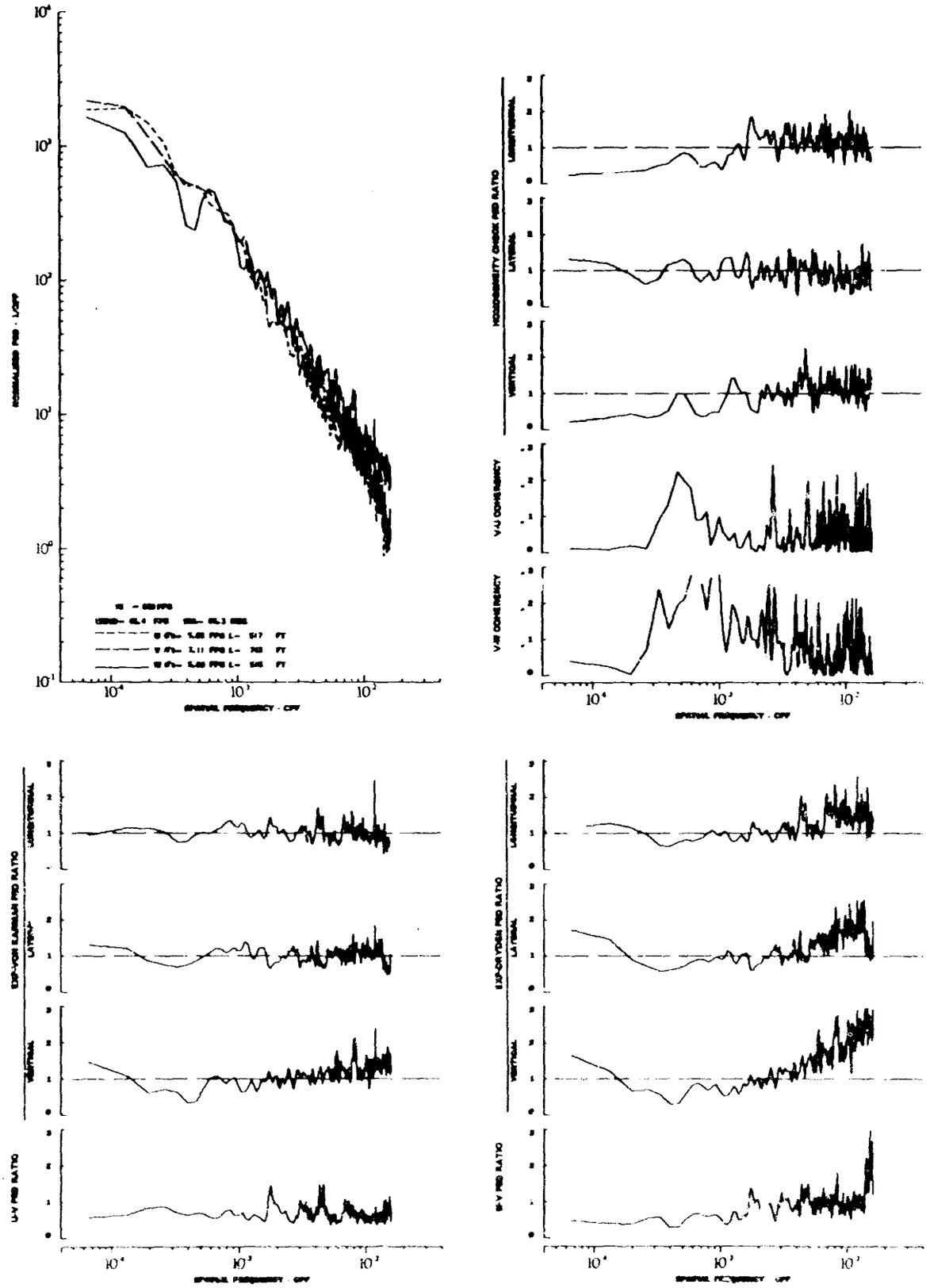

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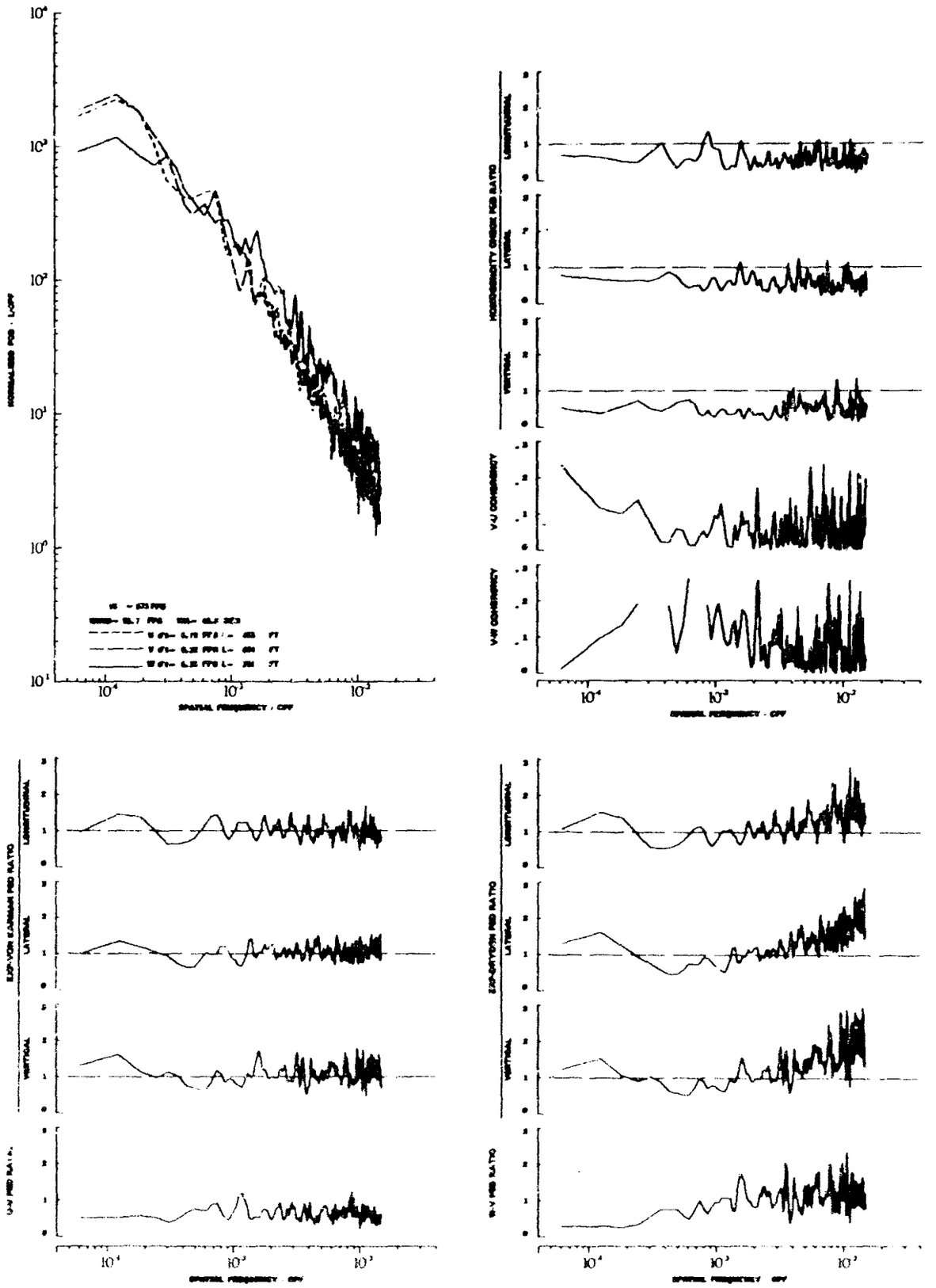

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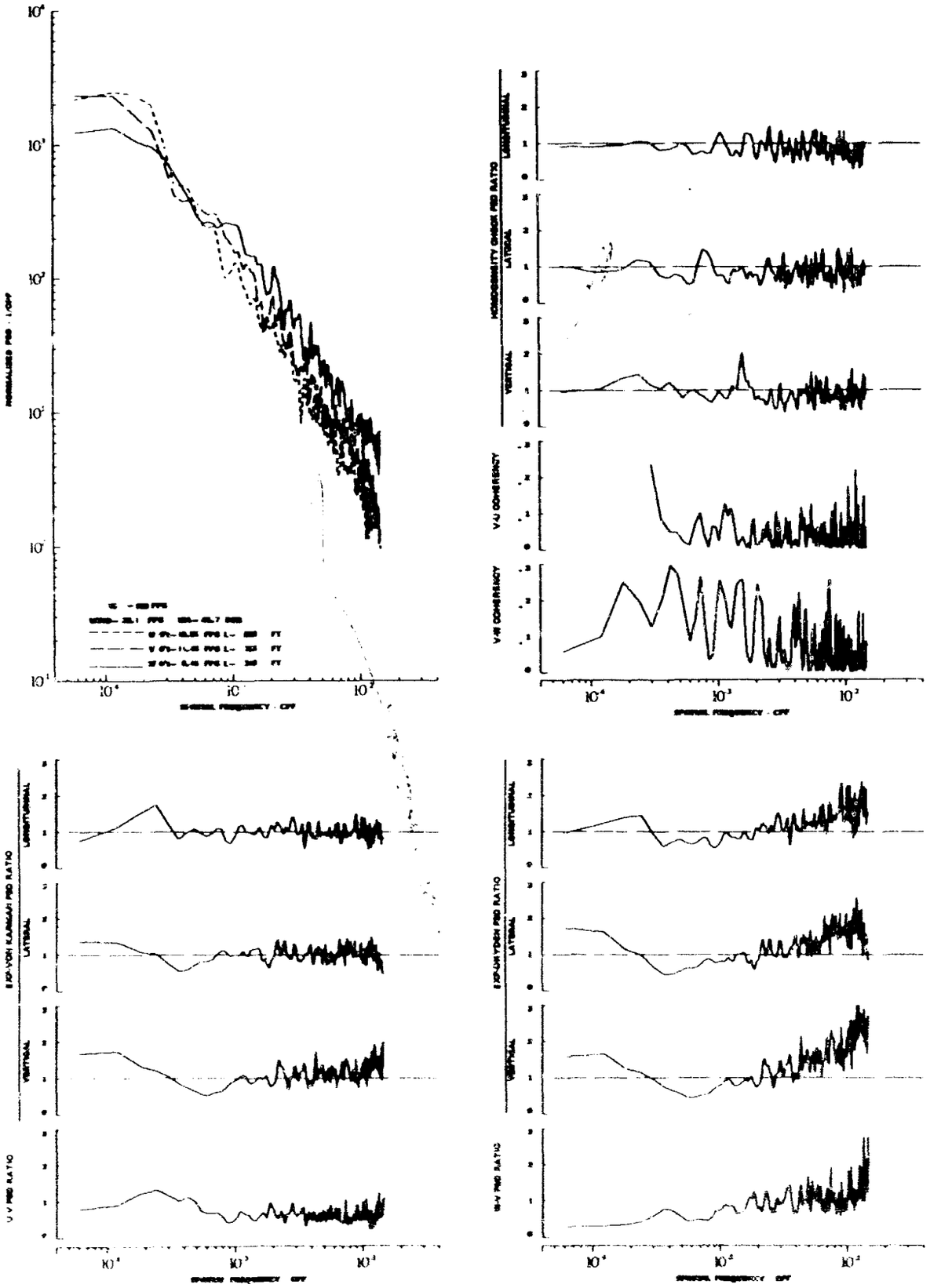

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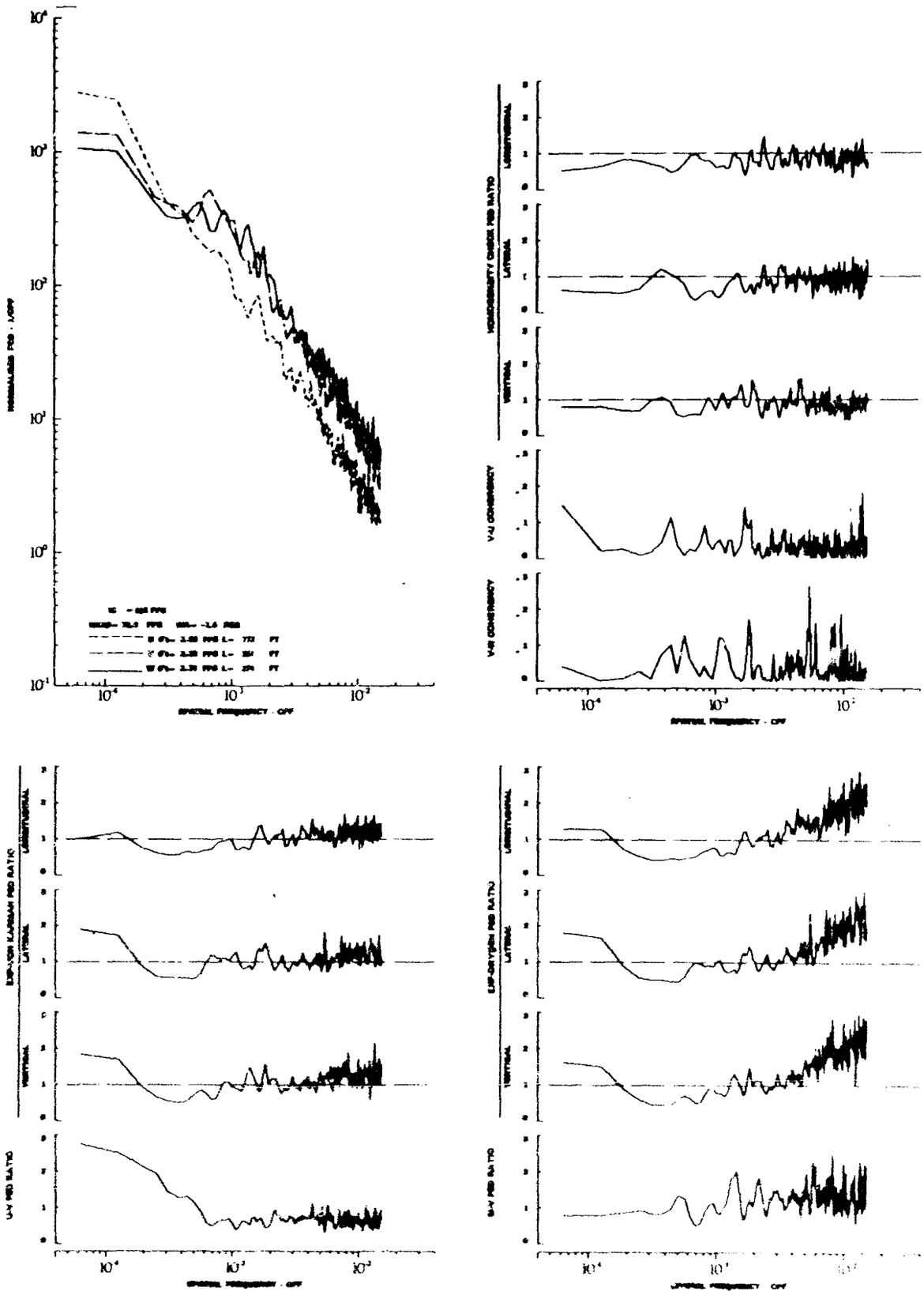

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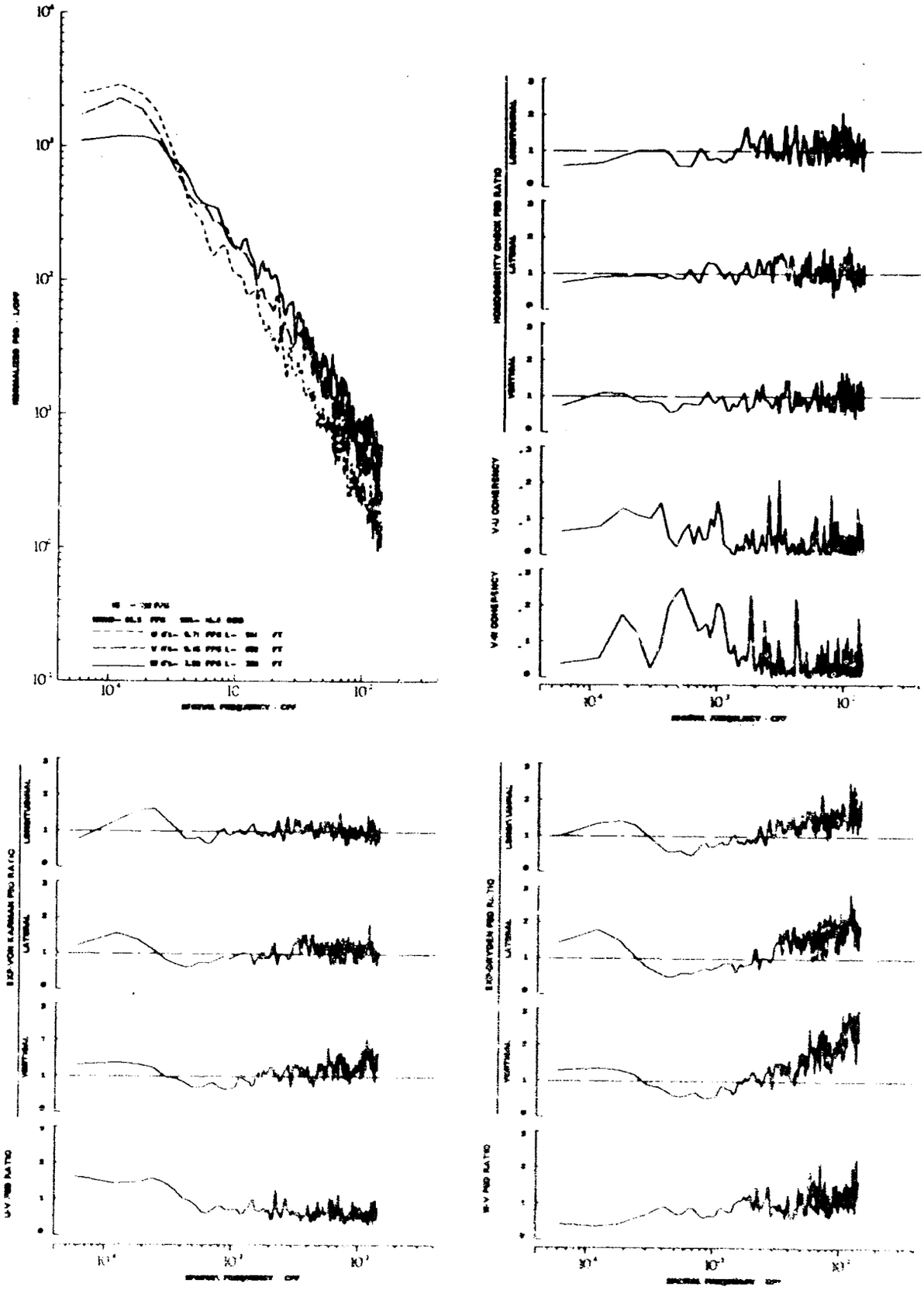
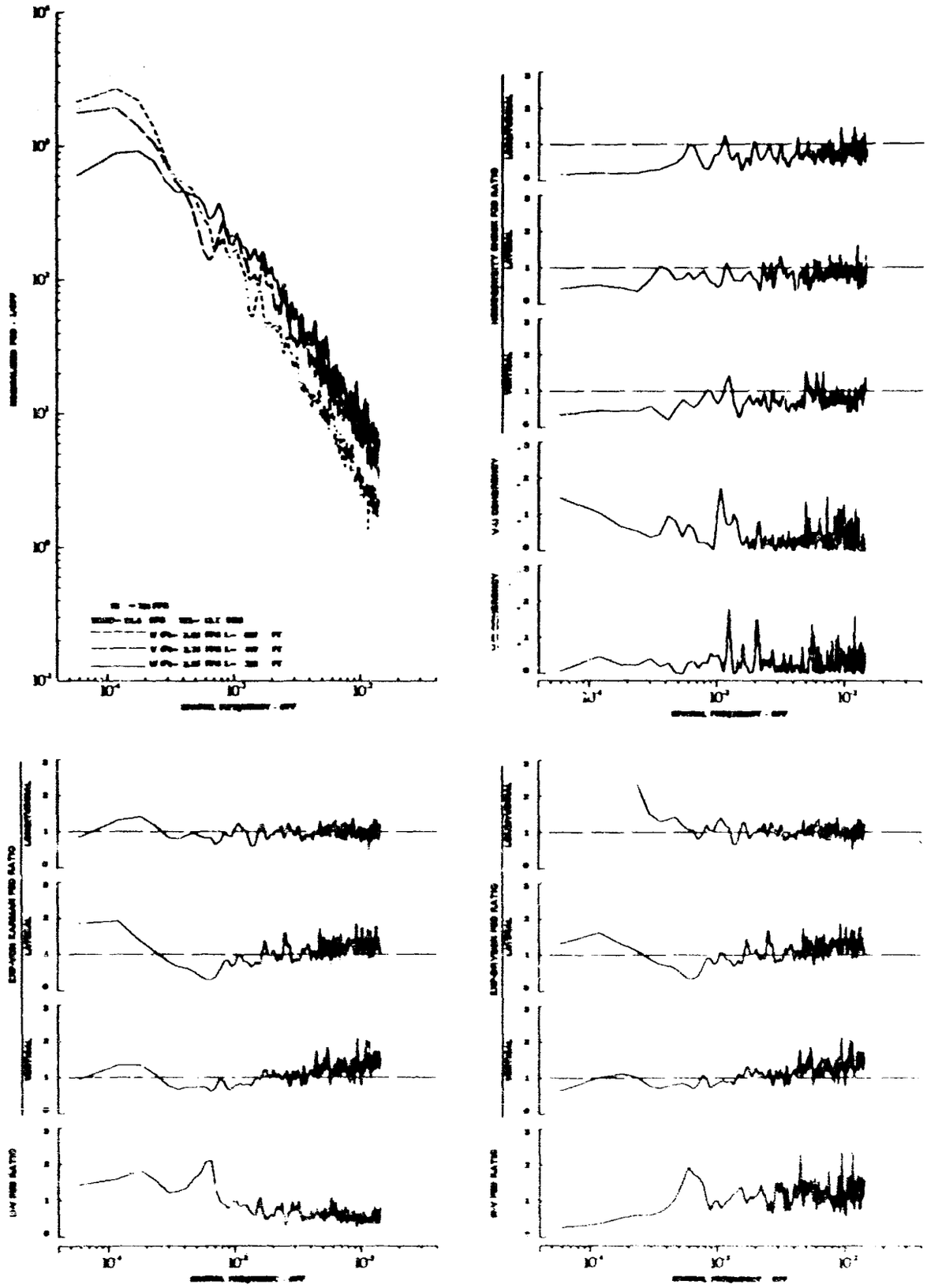


Turbulence Spectra Data For Test 161, Leg 5, Category 1 4343



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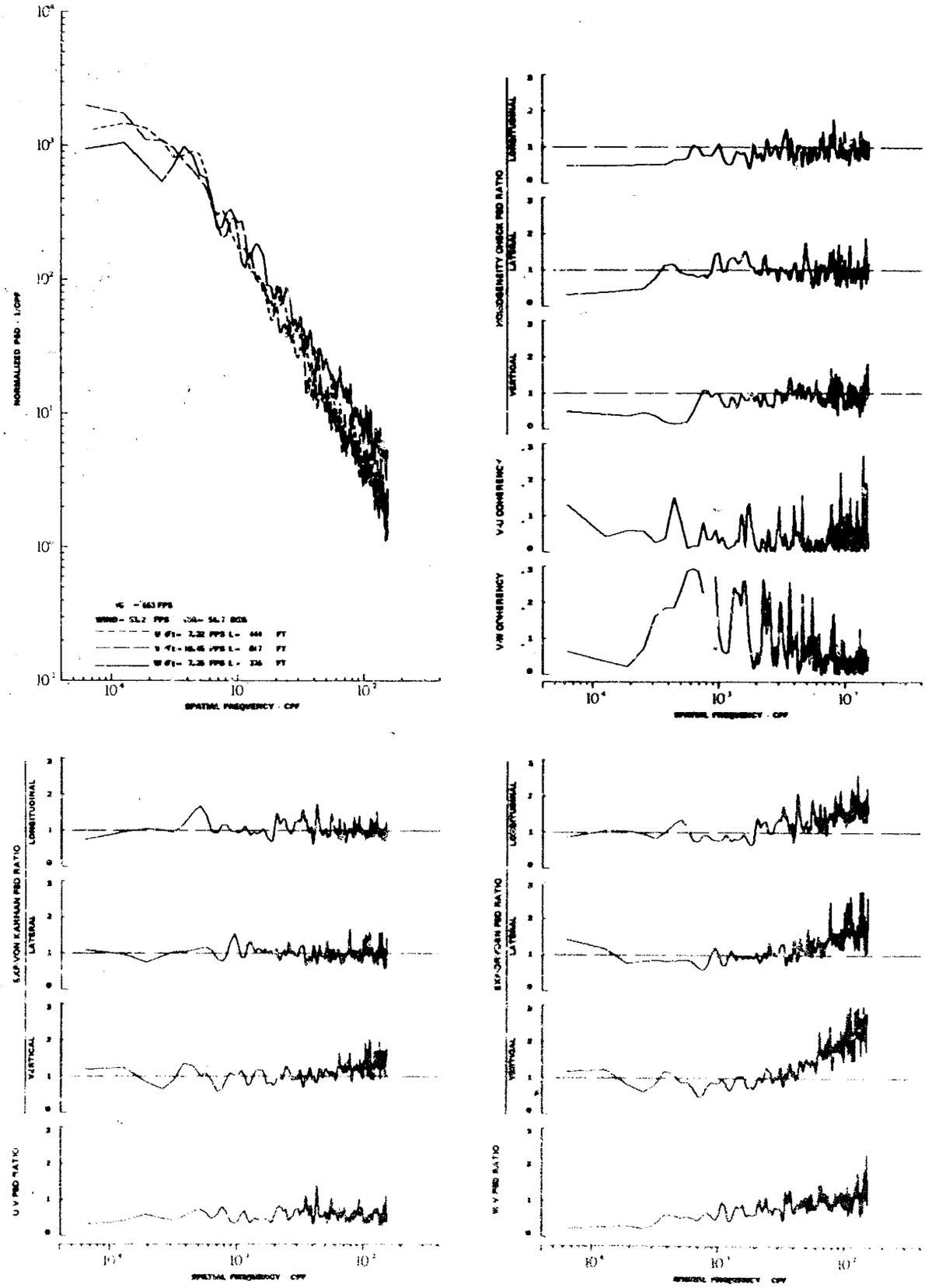

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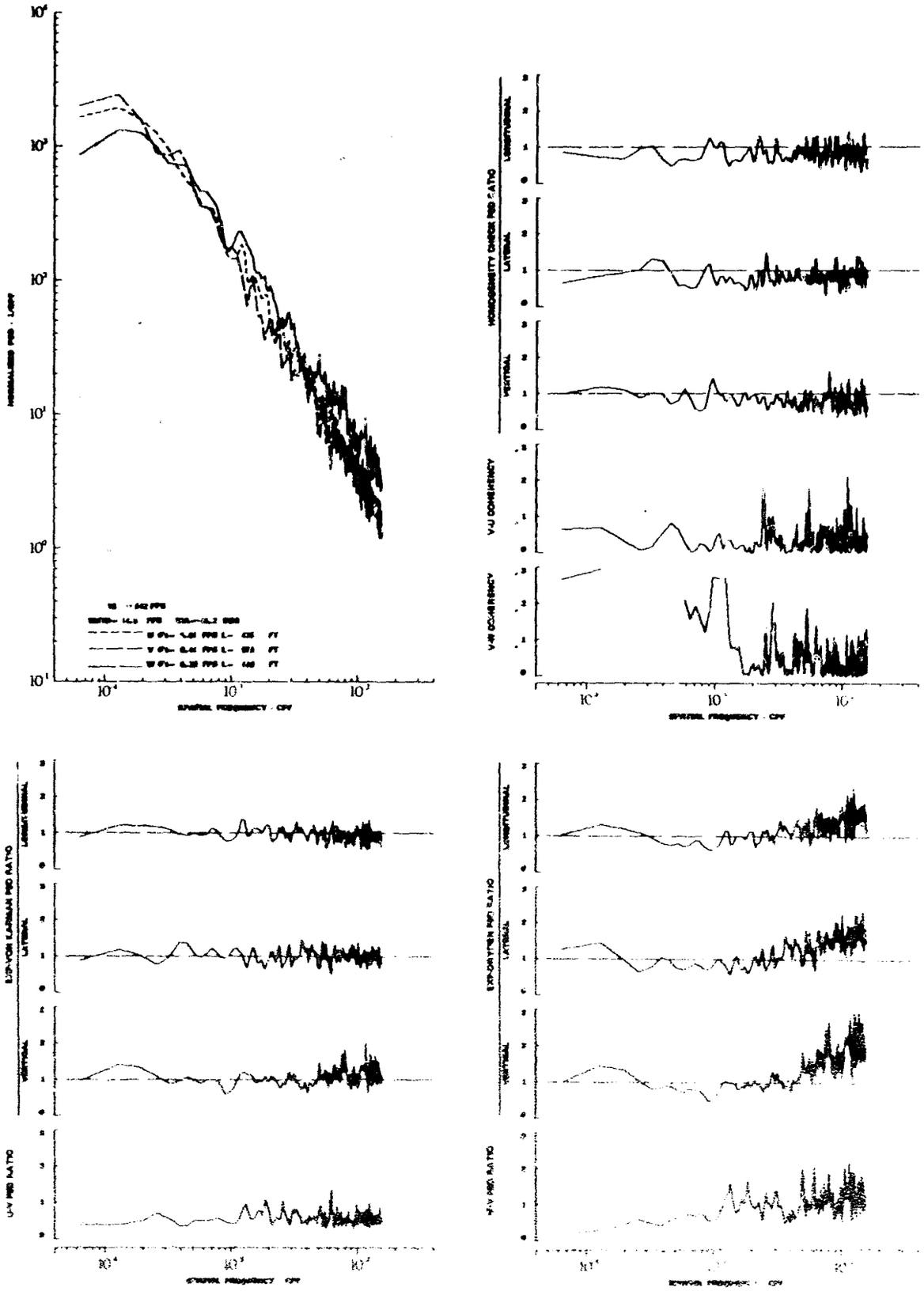

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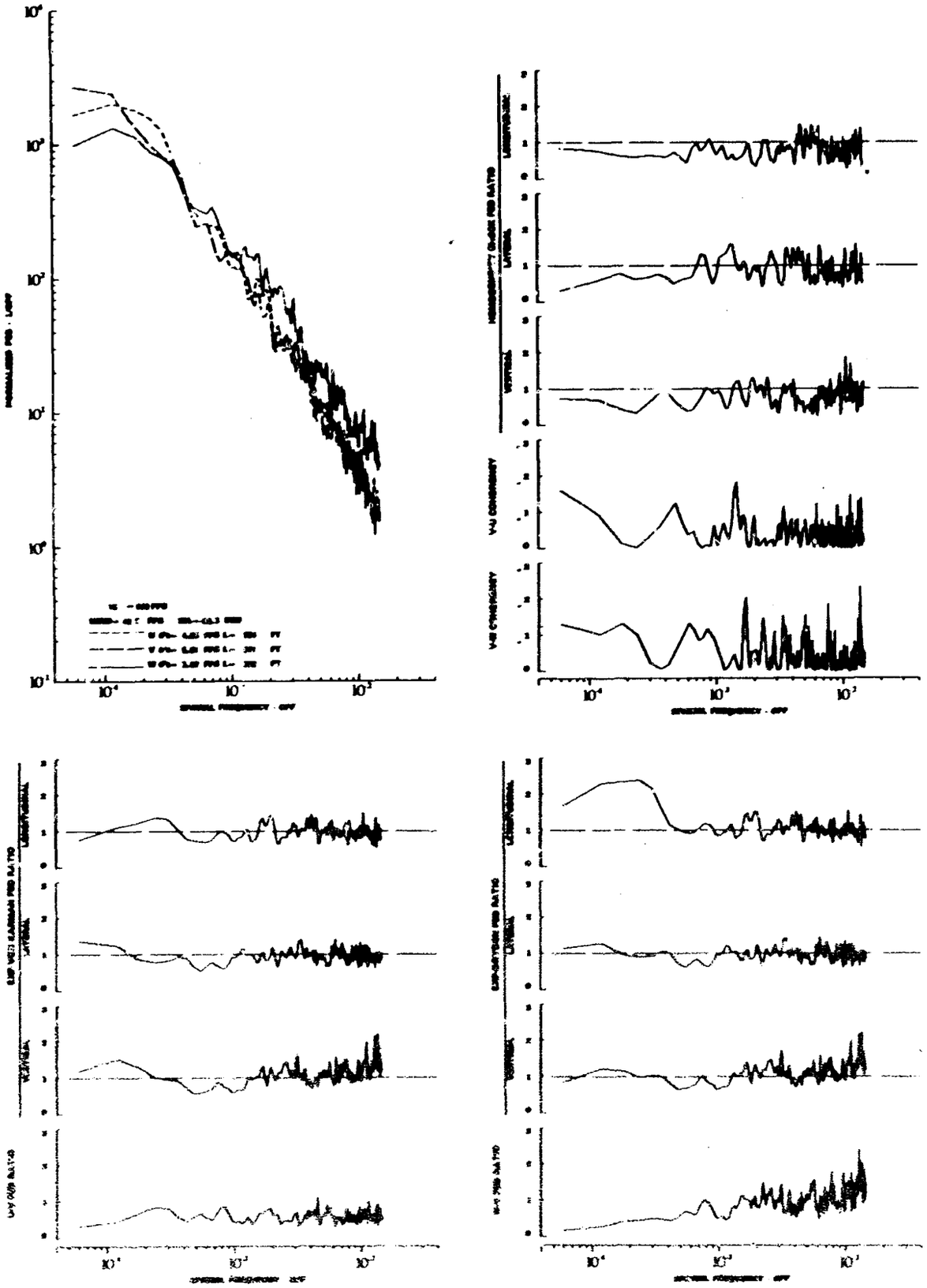

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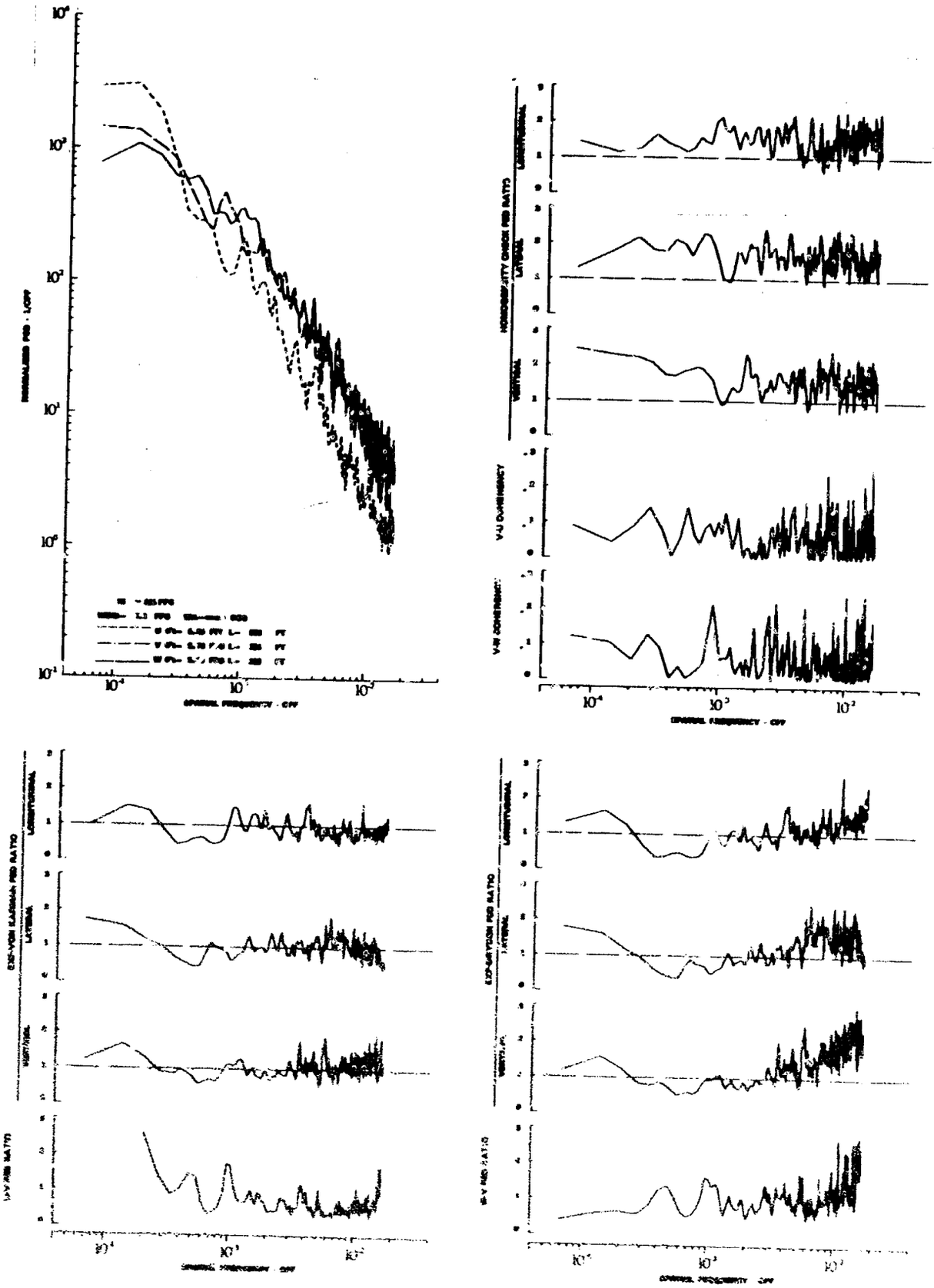

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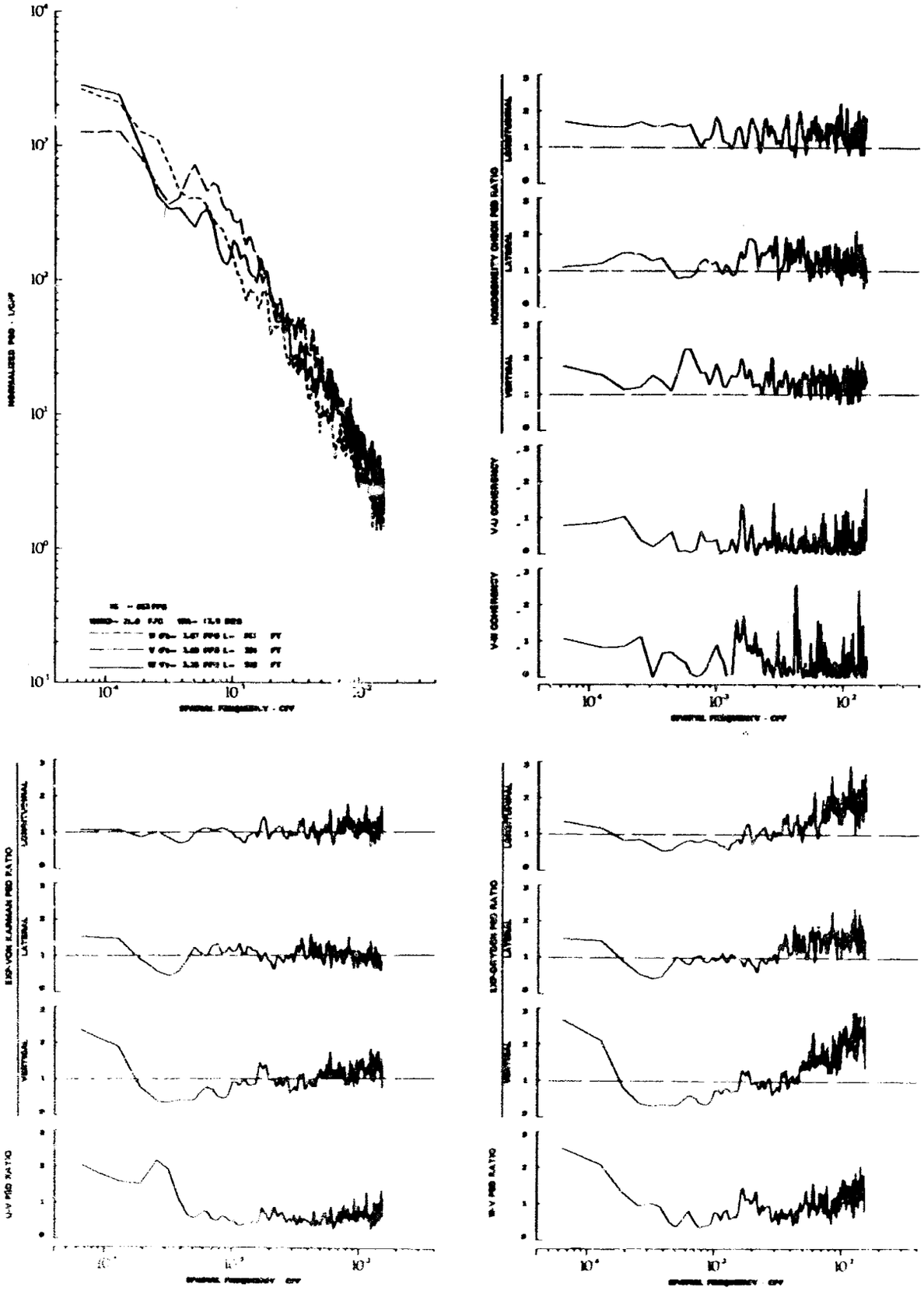

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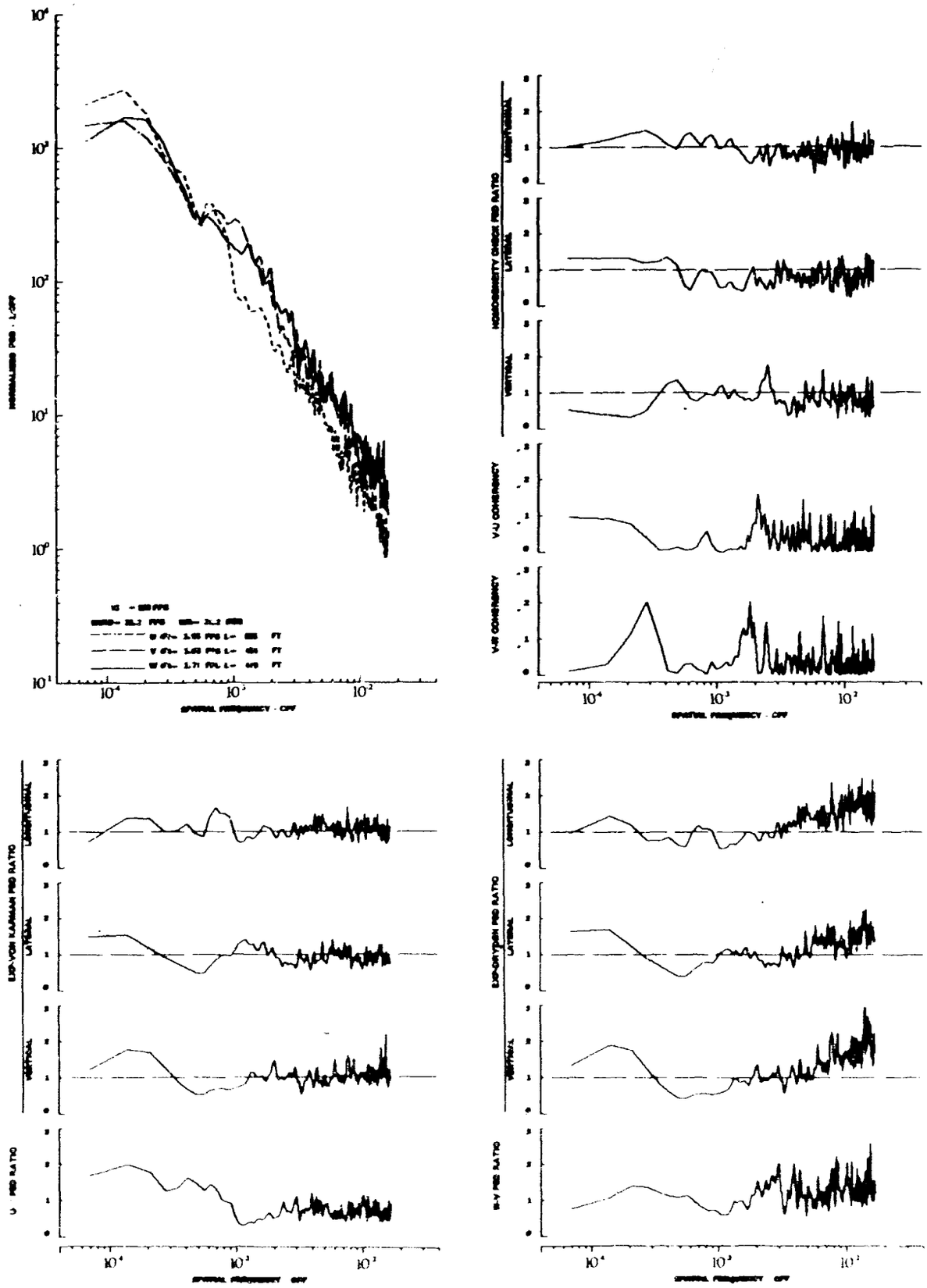
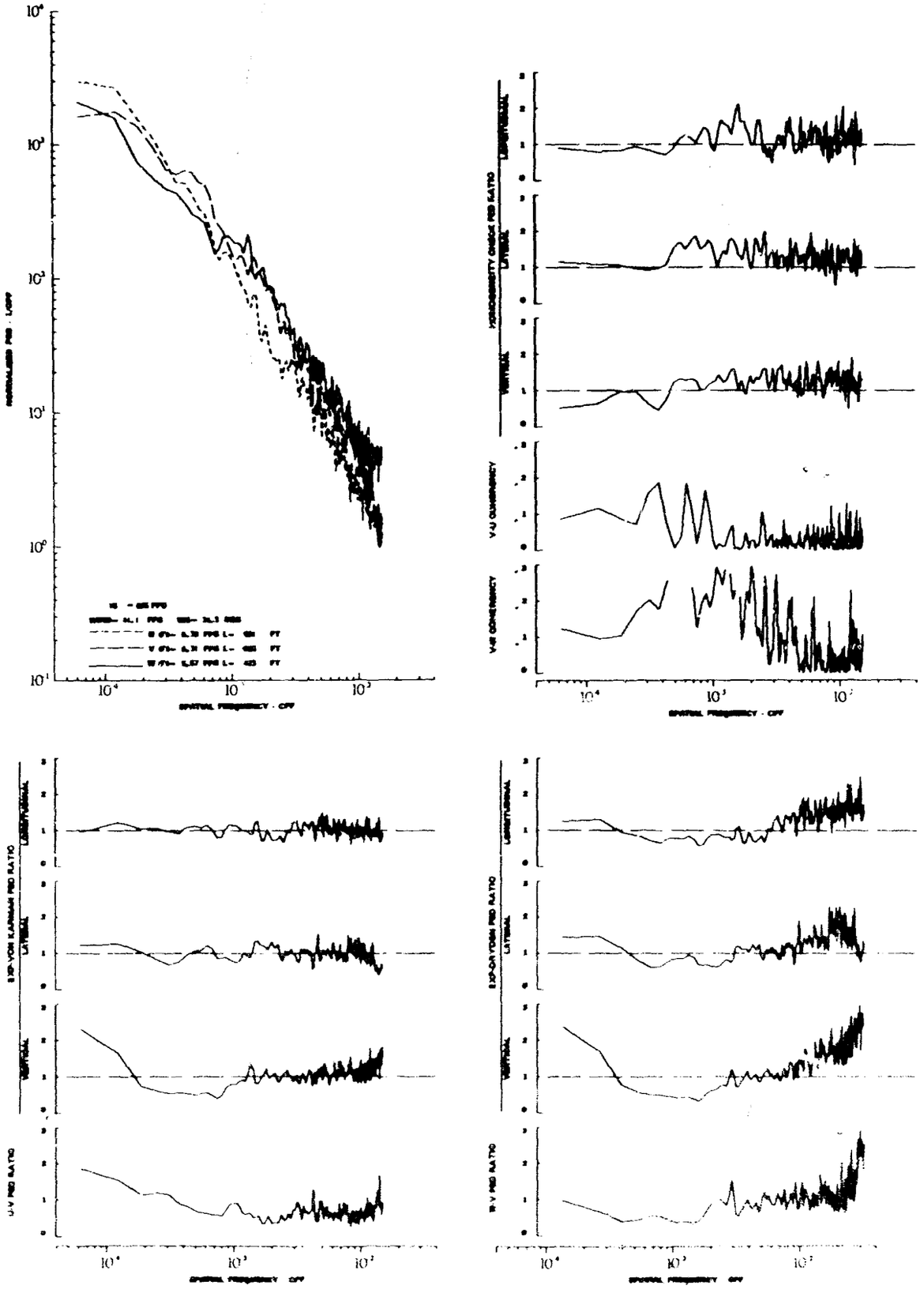
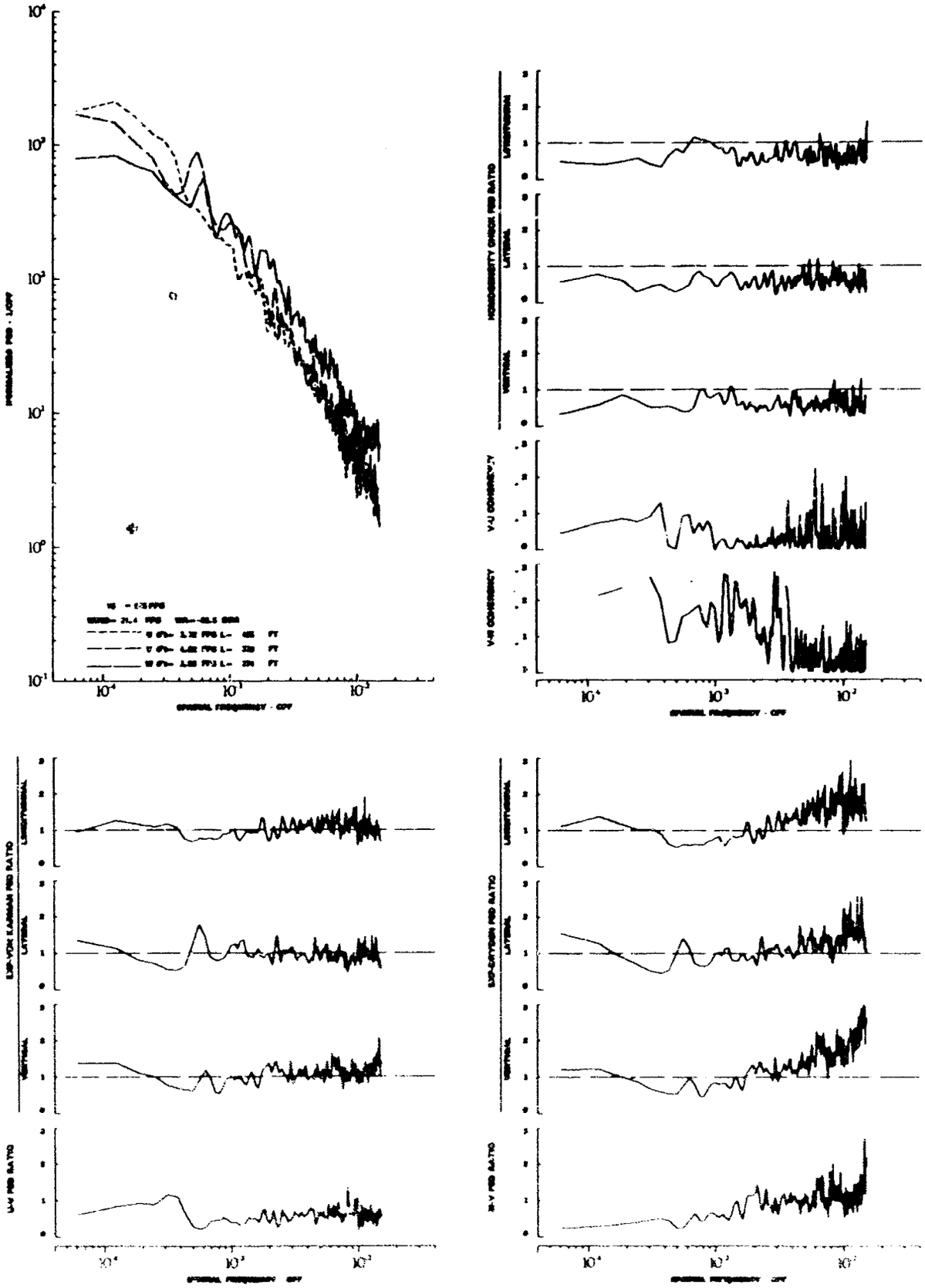


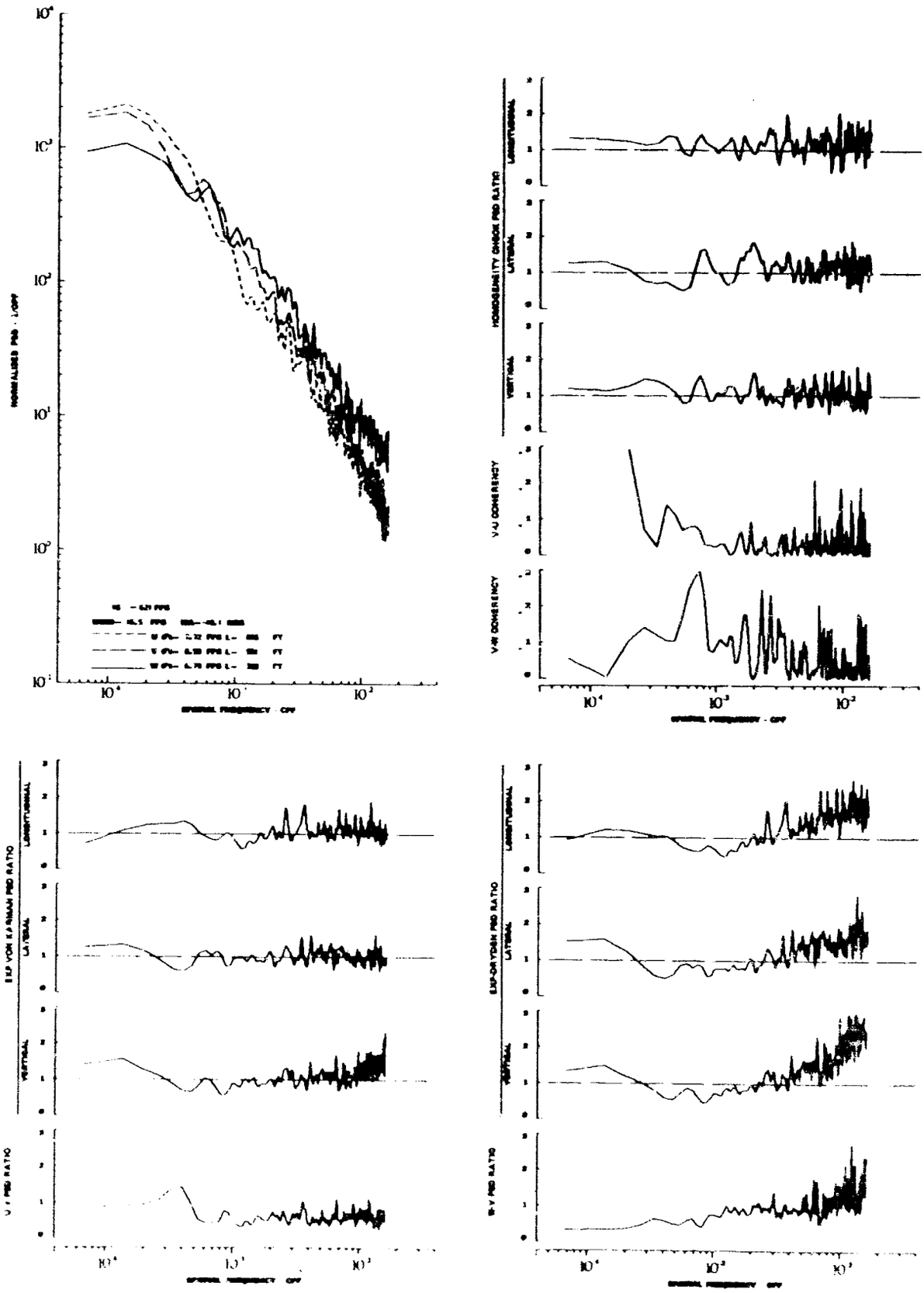
Turbulence Spectra Data For Test 166, Log 6, Category 114243



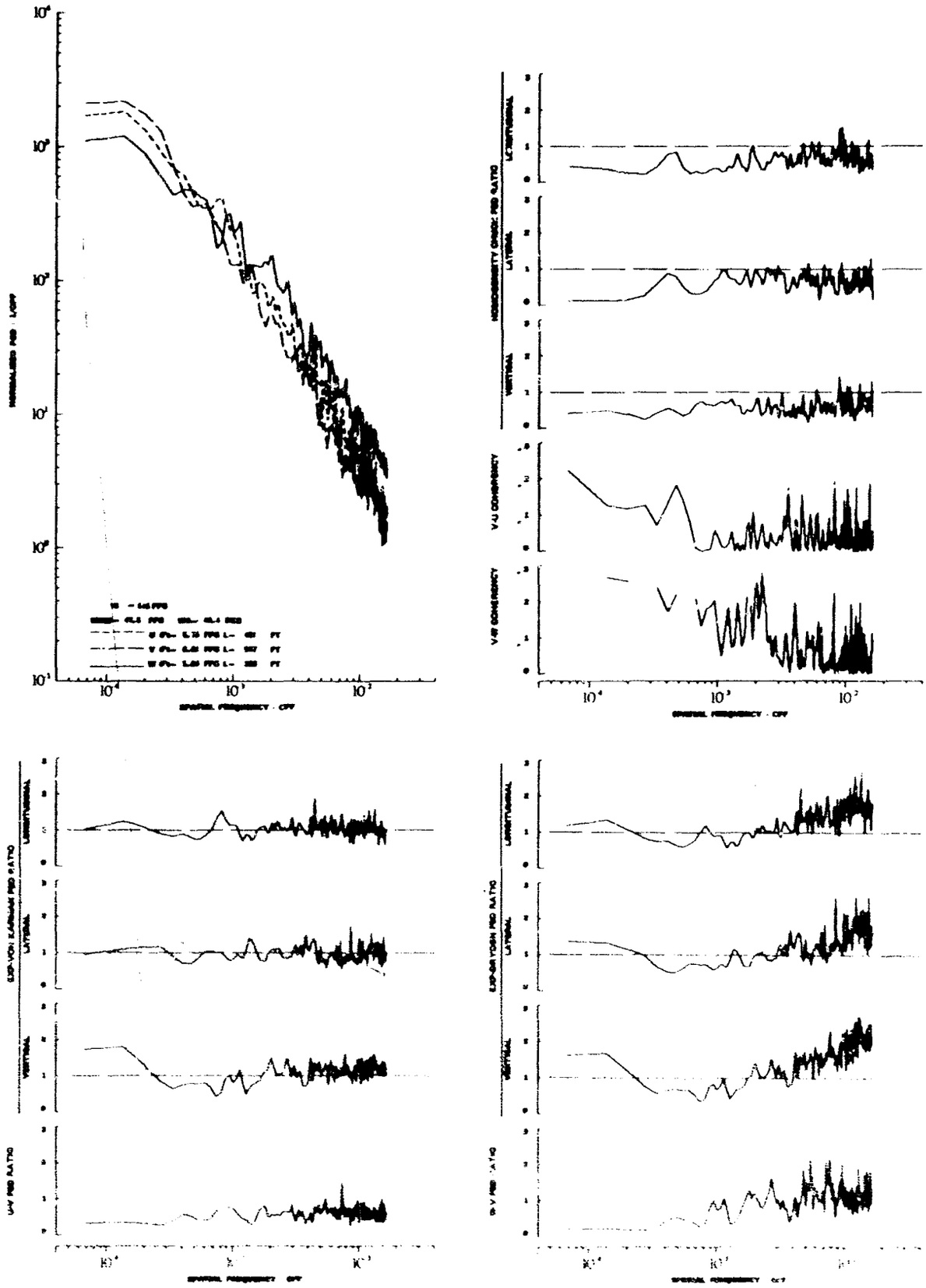
Turbulence Spectra Data For Test 167, Leg 1, Category 112343



Turbulence Spectra Data For Test 167, Leg 3, Category 111343



Turbulence Spectra Data For Test 167, Leg 5, Category 112343



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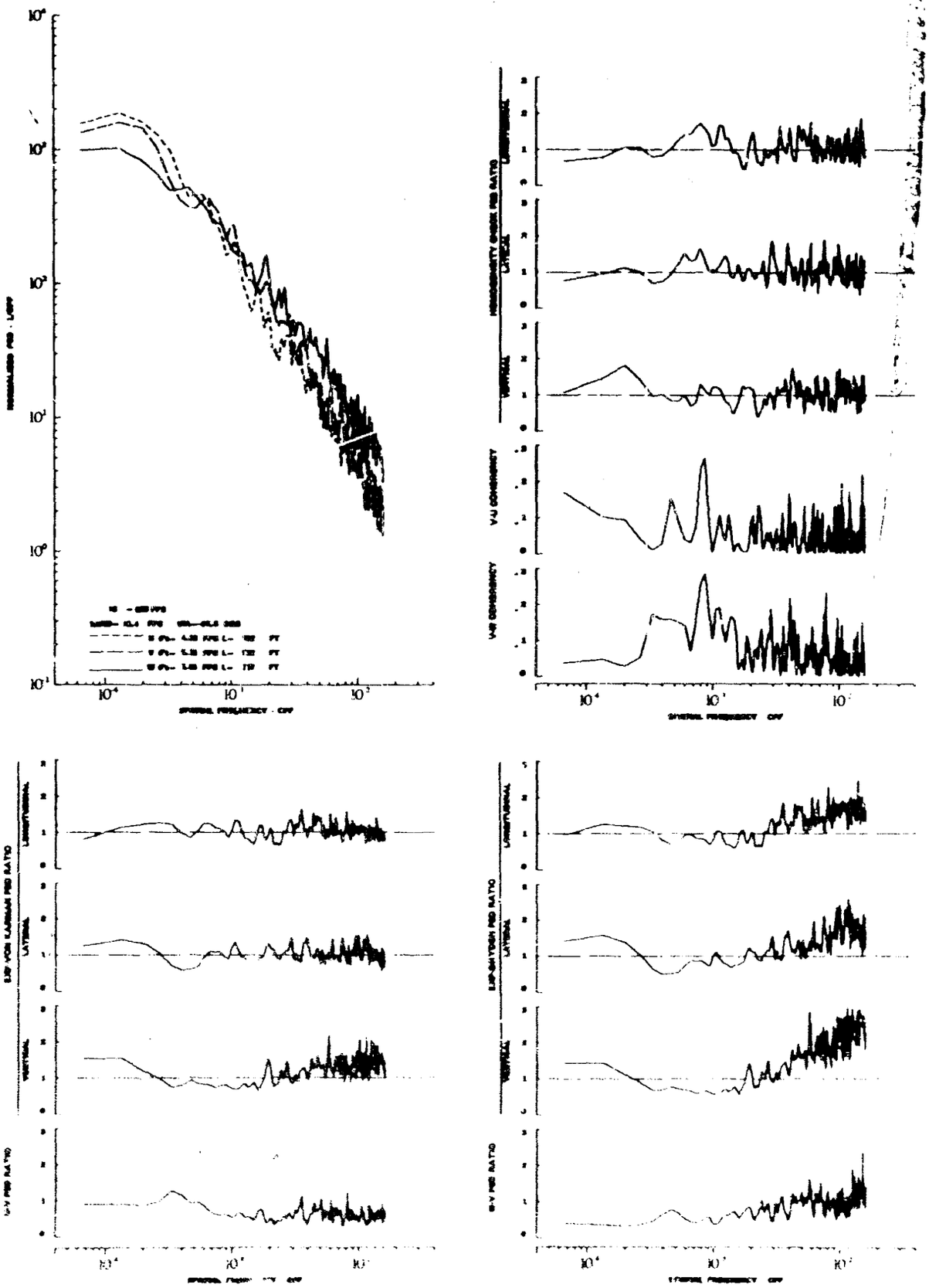
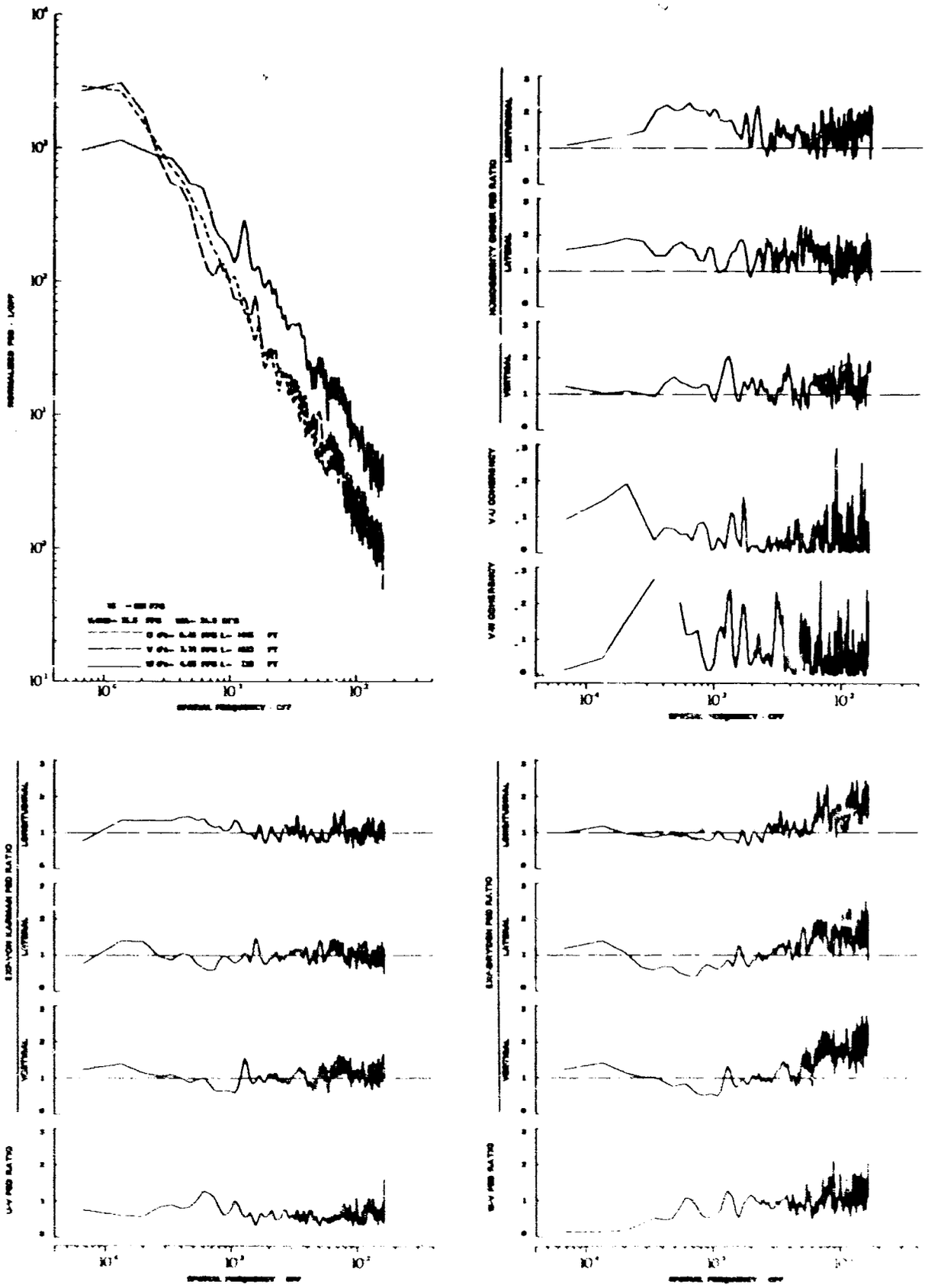


Turbulence Spectra Data For Test 168, Leg 4, Category 121143



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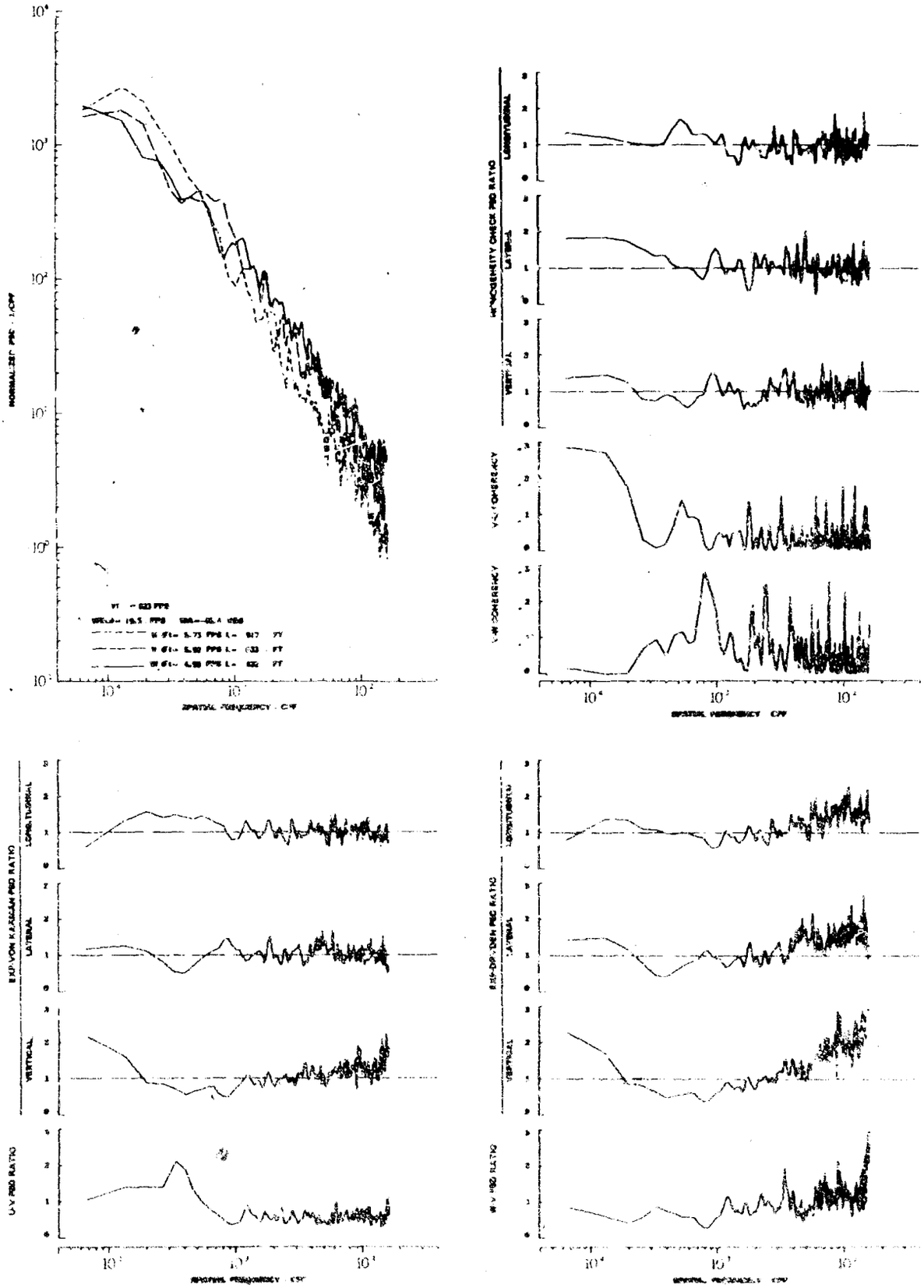

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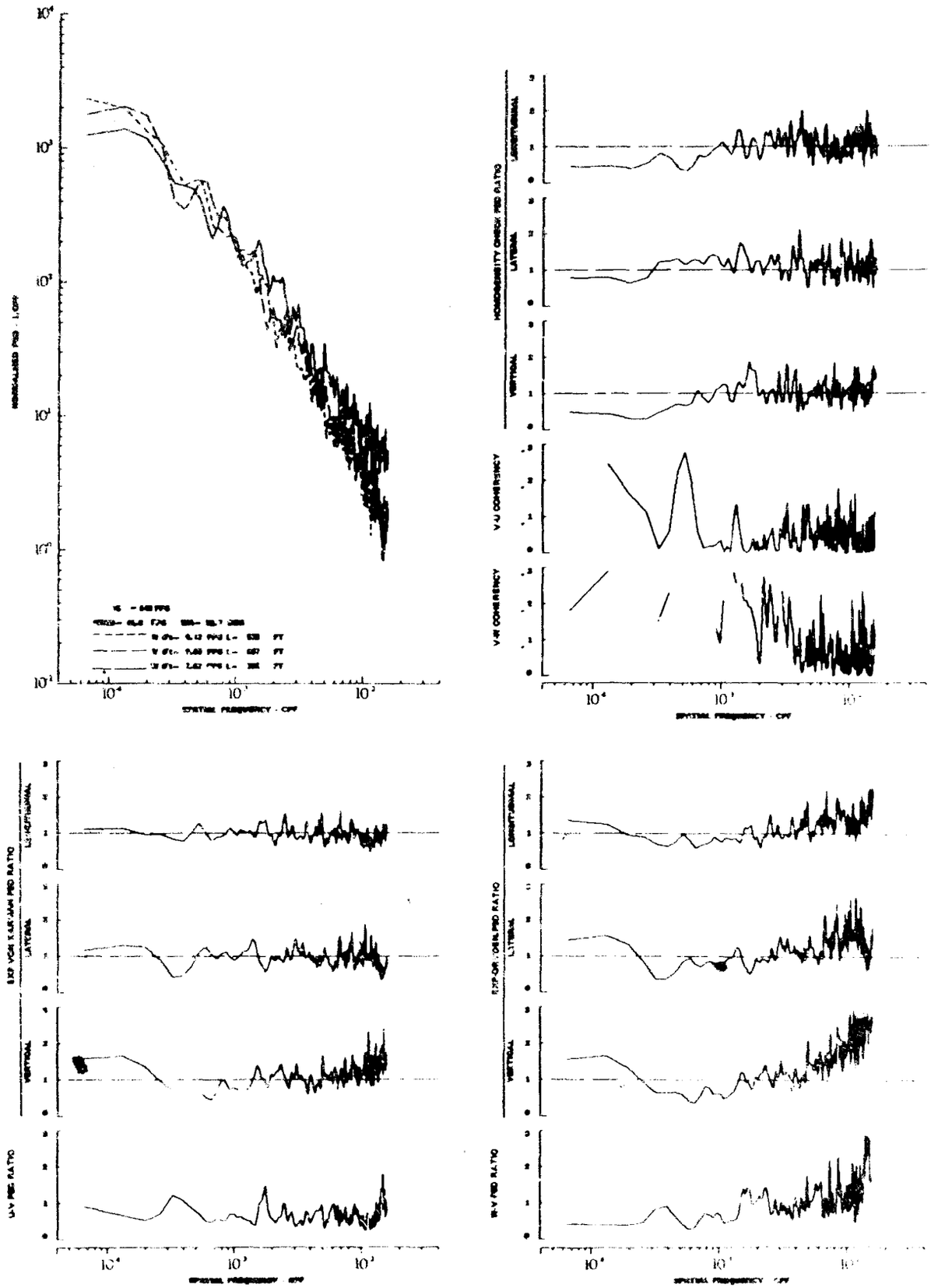
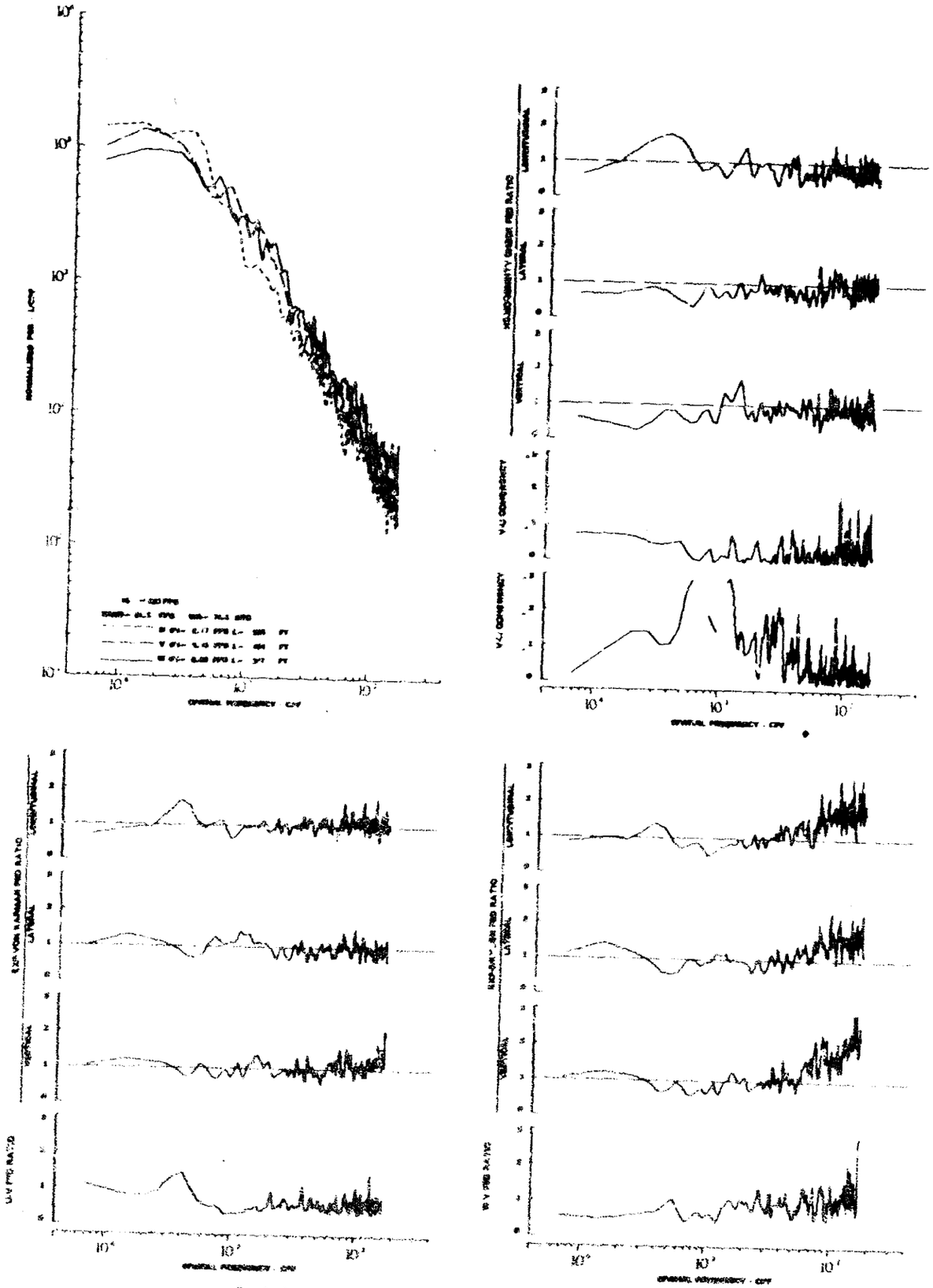


Turbulence Spectra Data For Test 171, Leg 1, Category 114243



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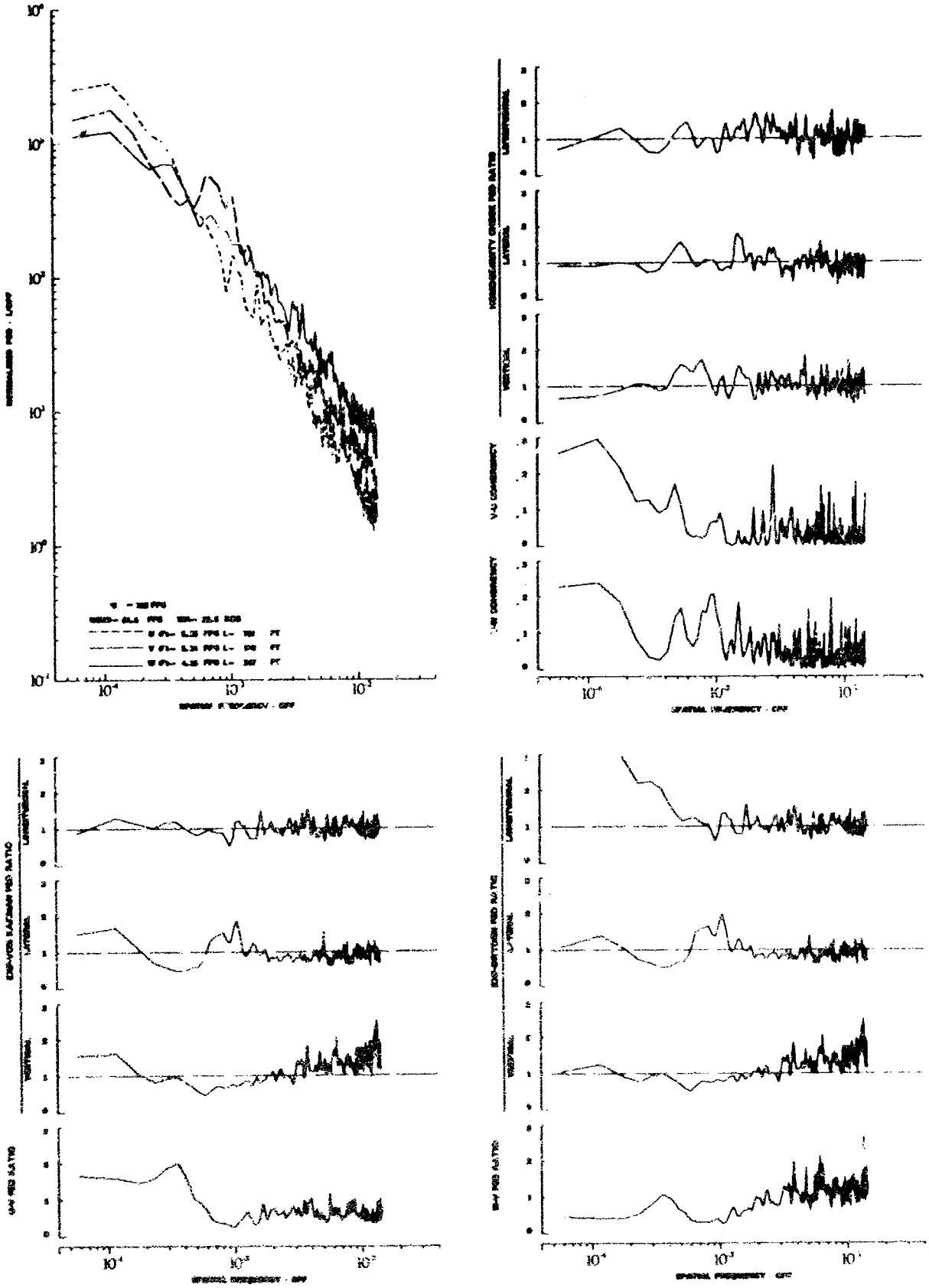

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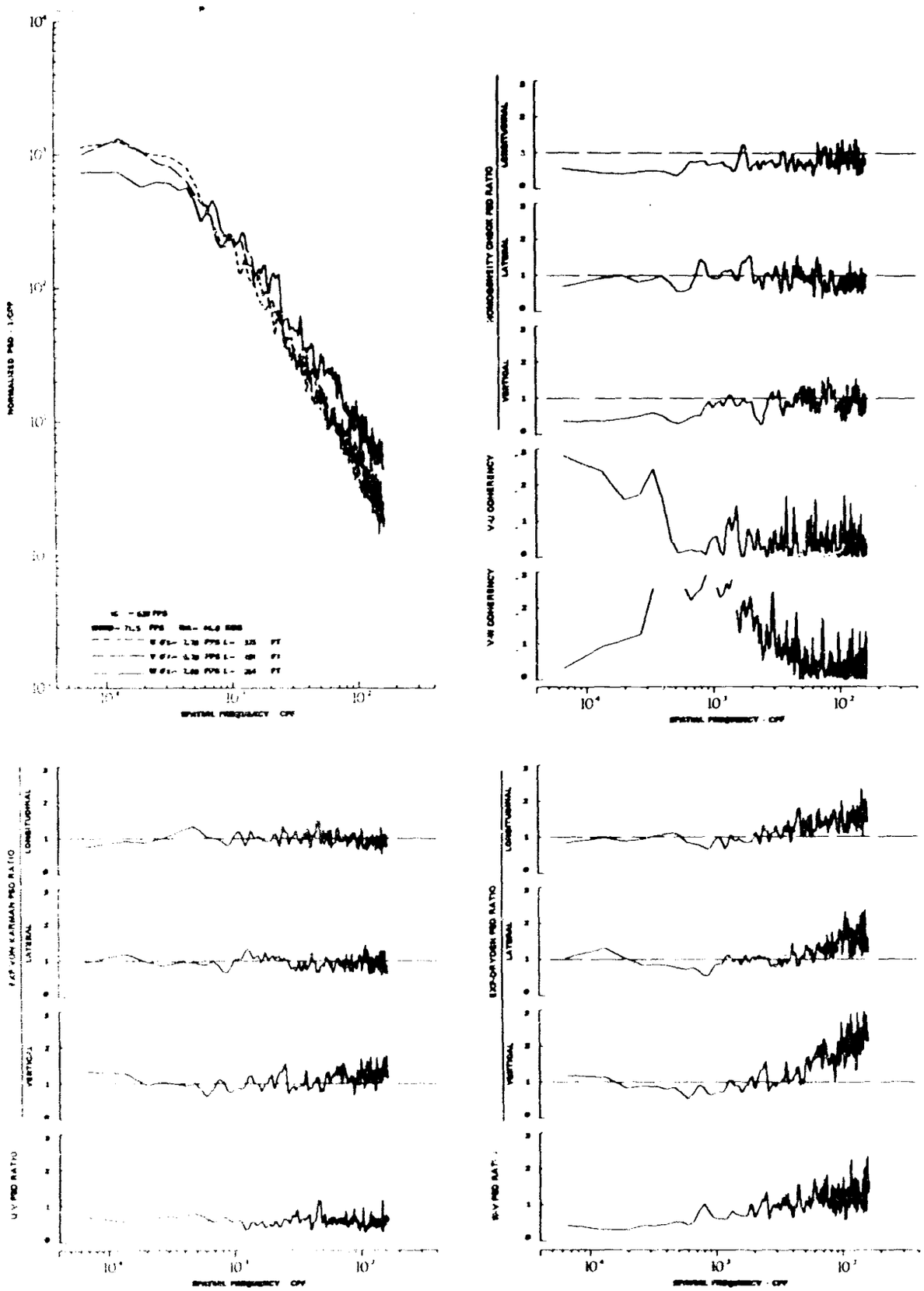
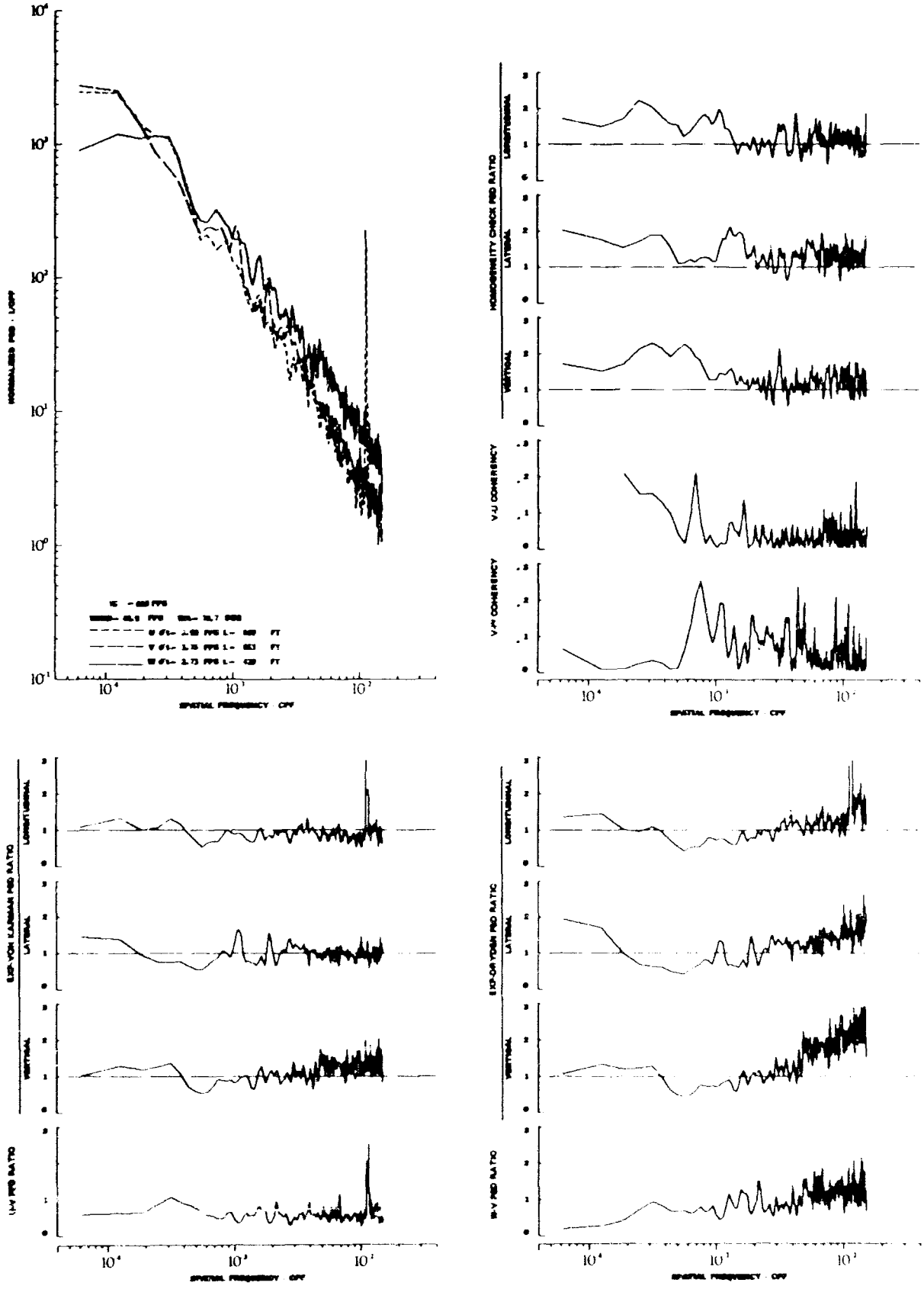


Turbulence Spectra Data For Test 172, Leg 6, Category 112343



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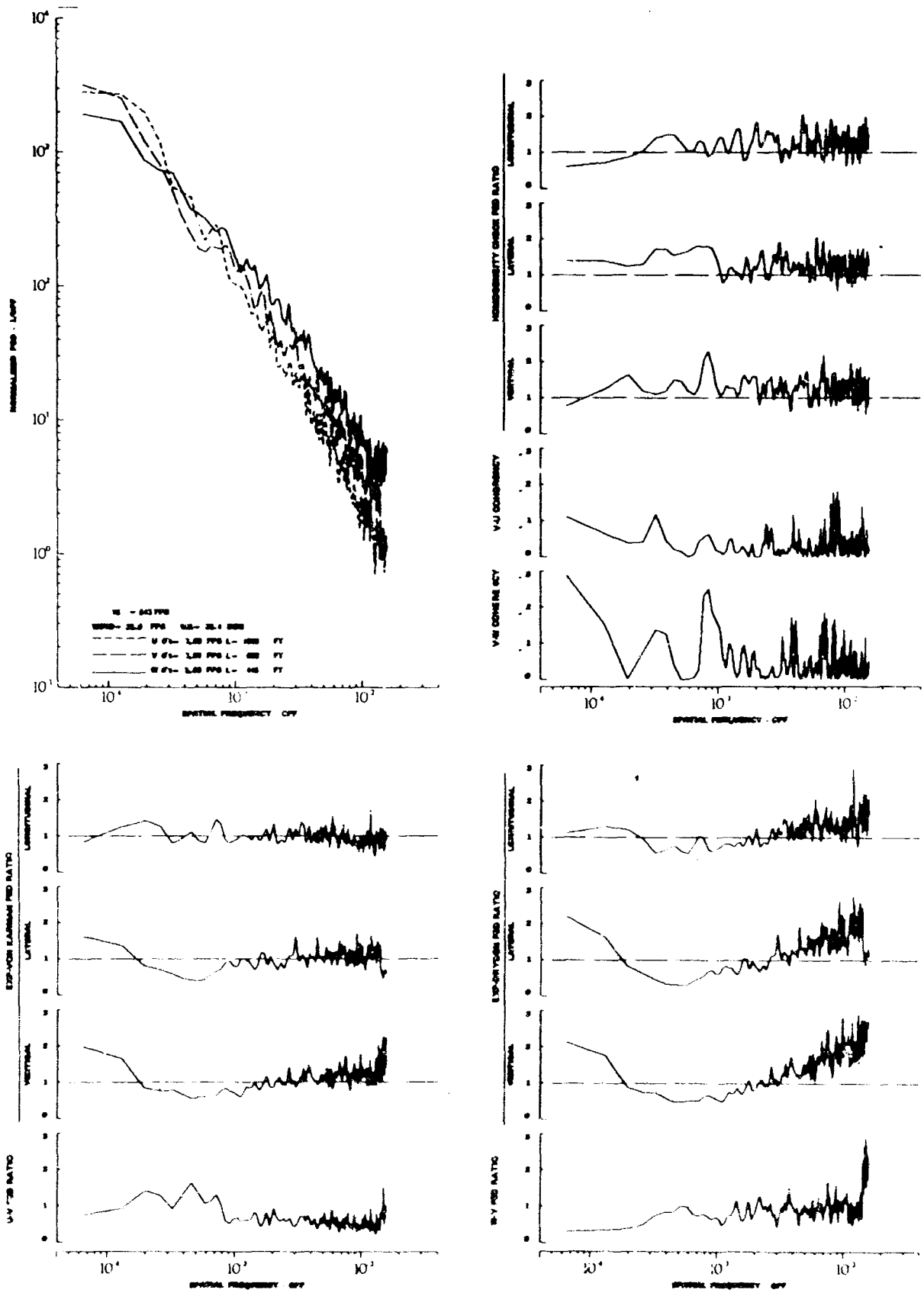

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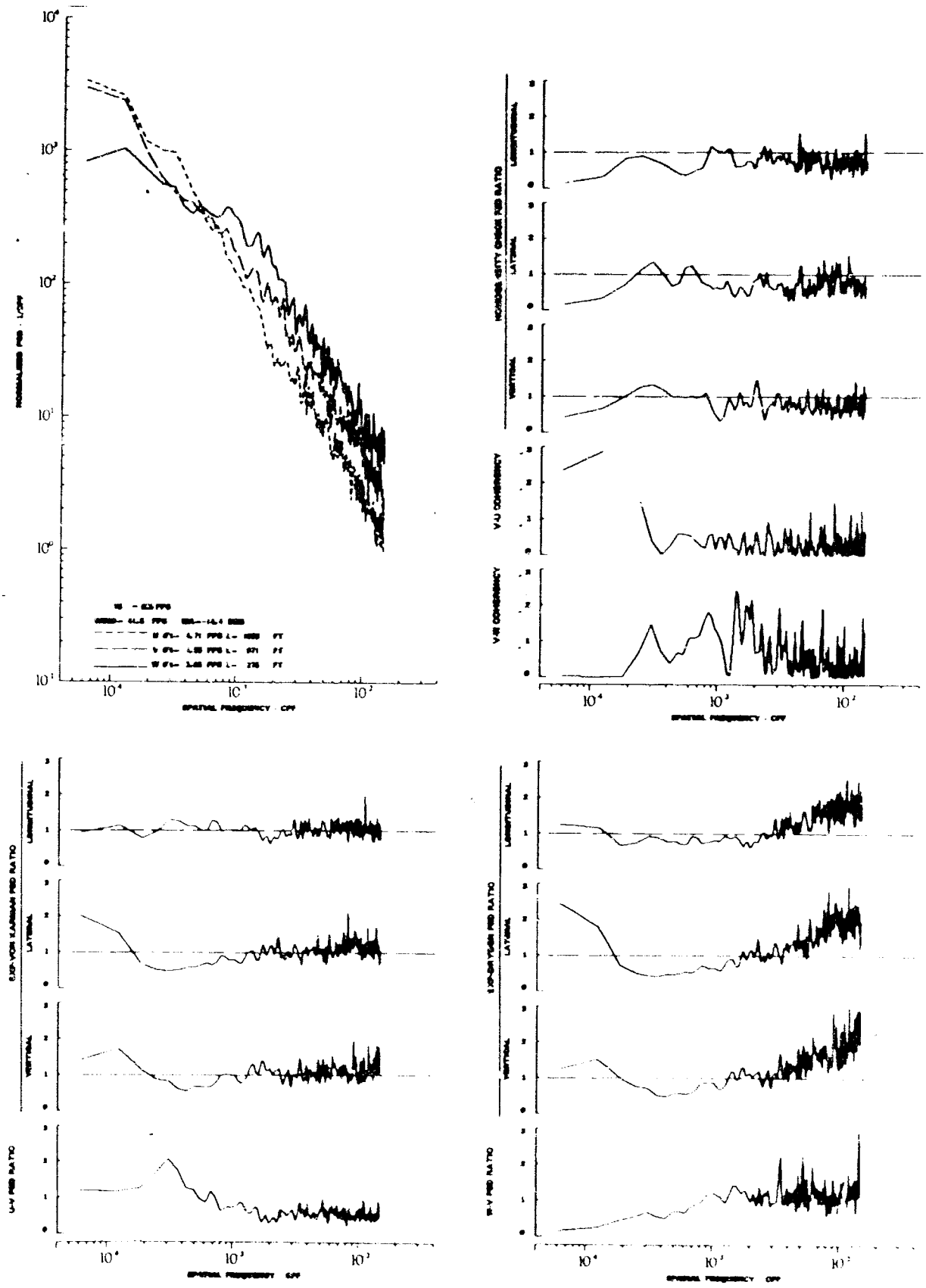

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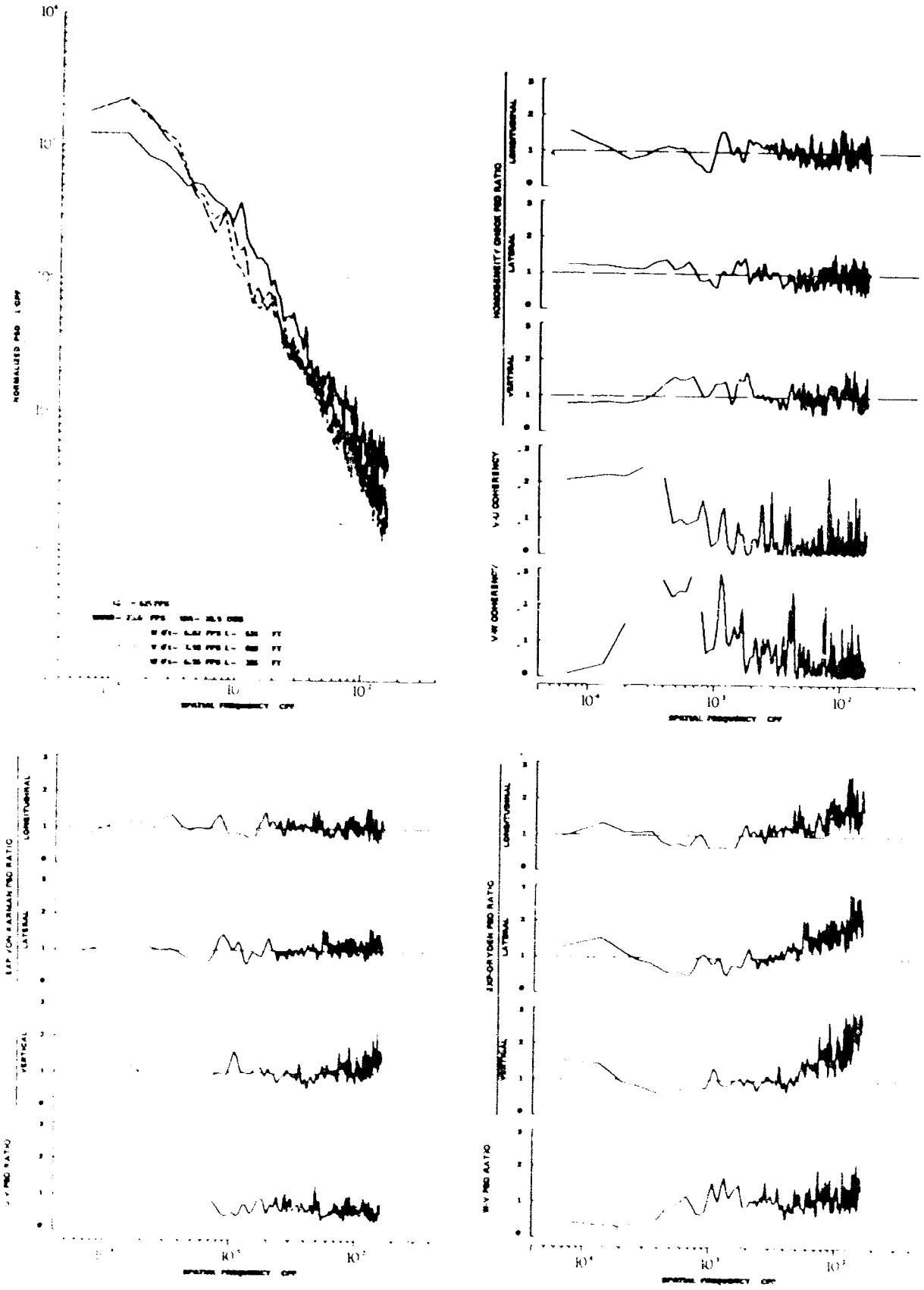
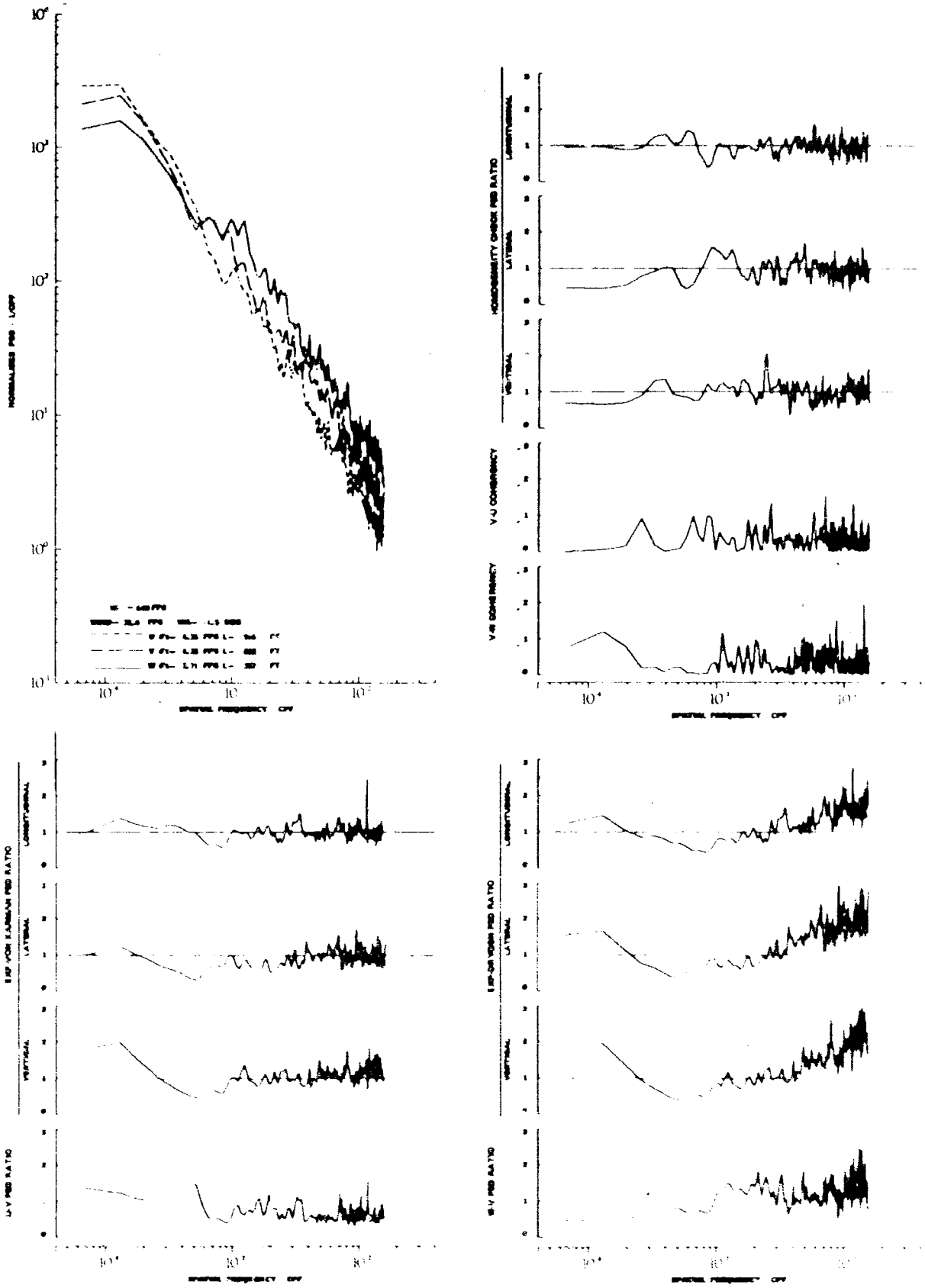


Turbulence Spectra Data For Test 177, Leg 5, Category 112343



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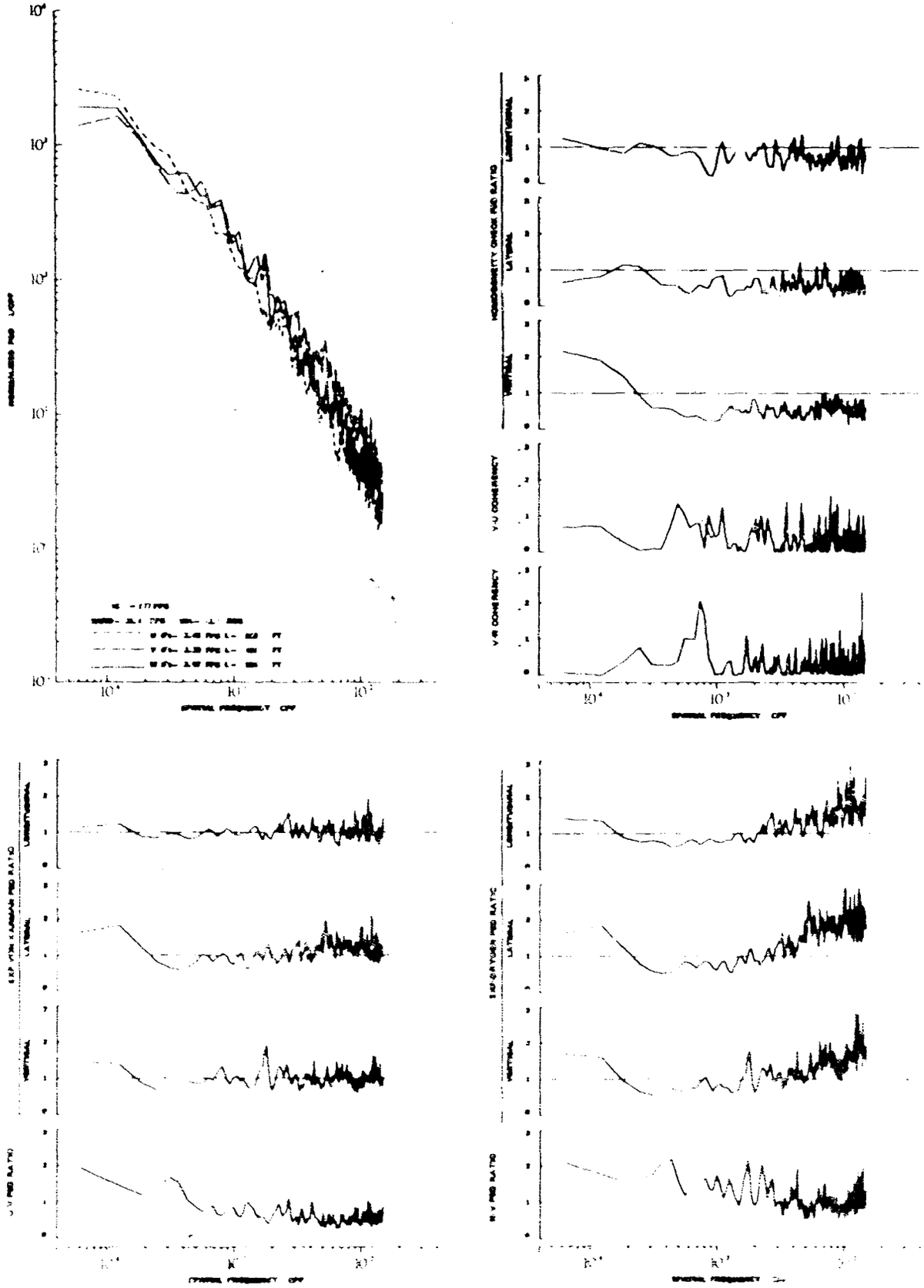

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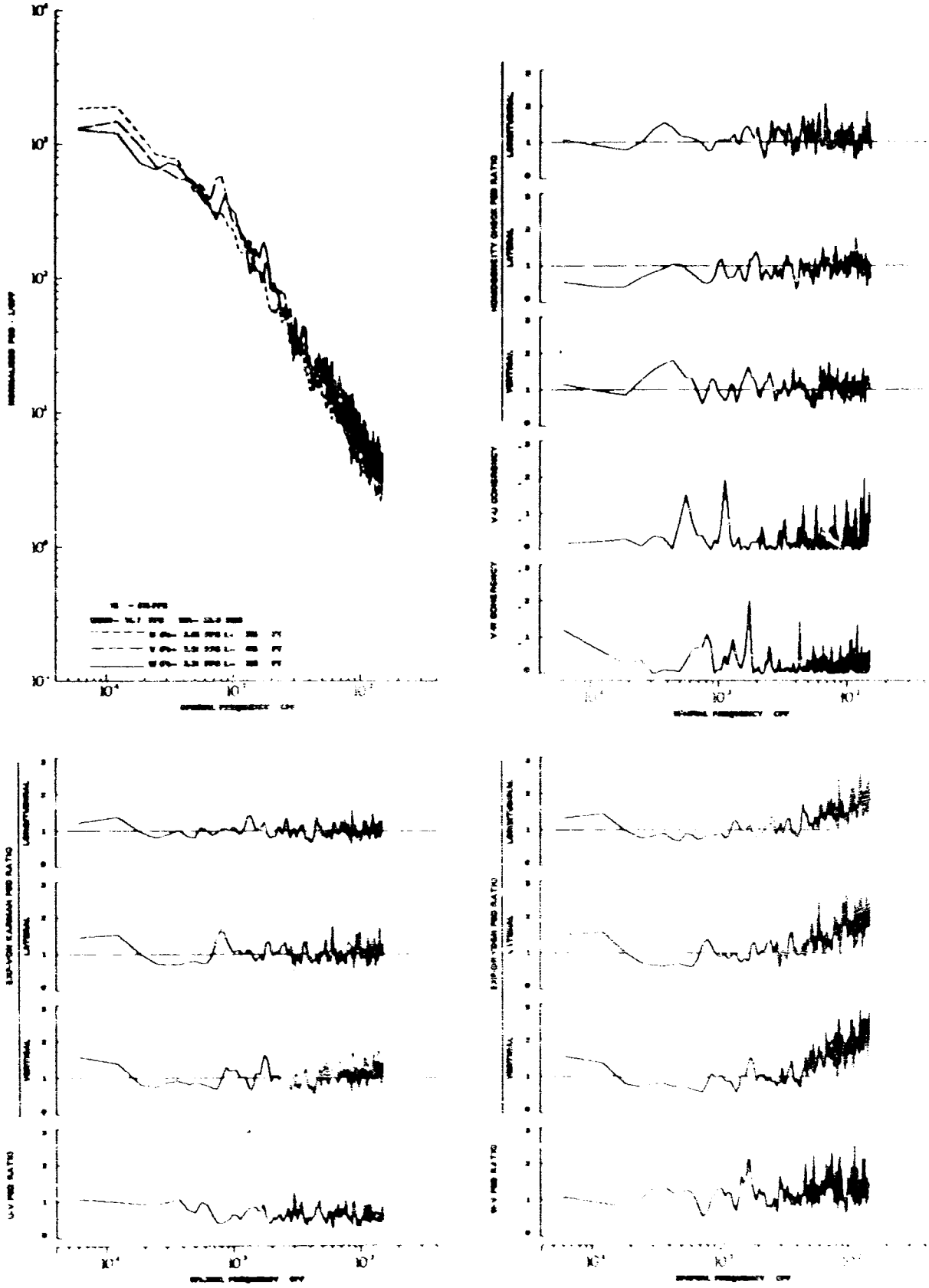

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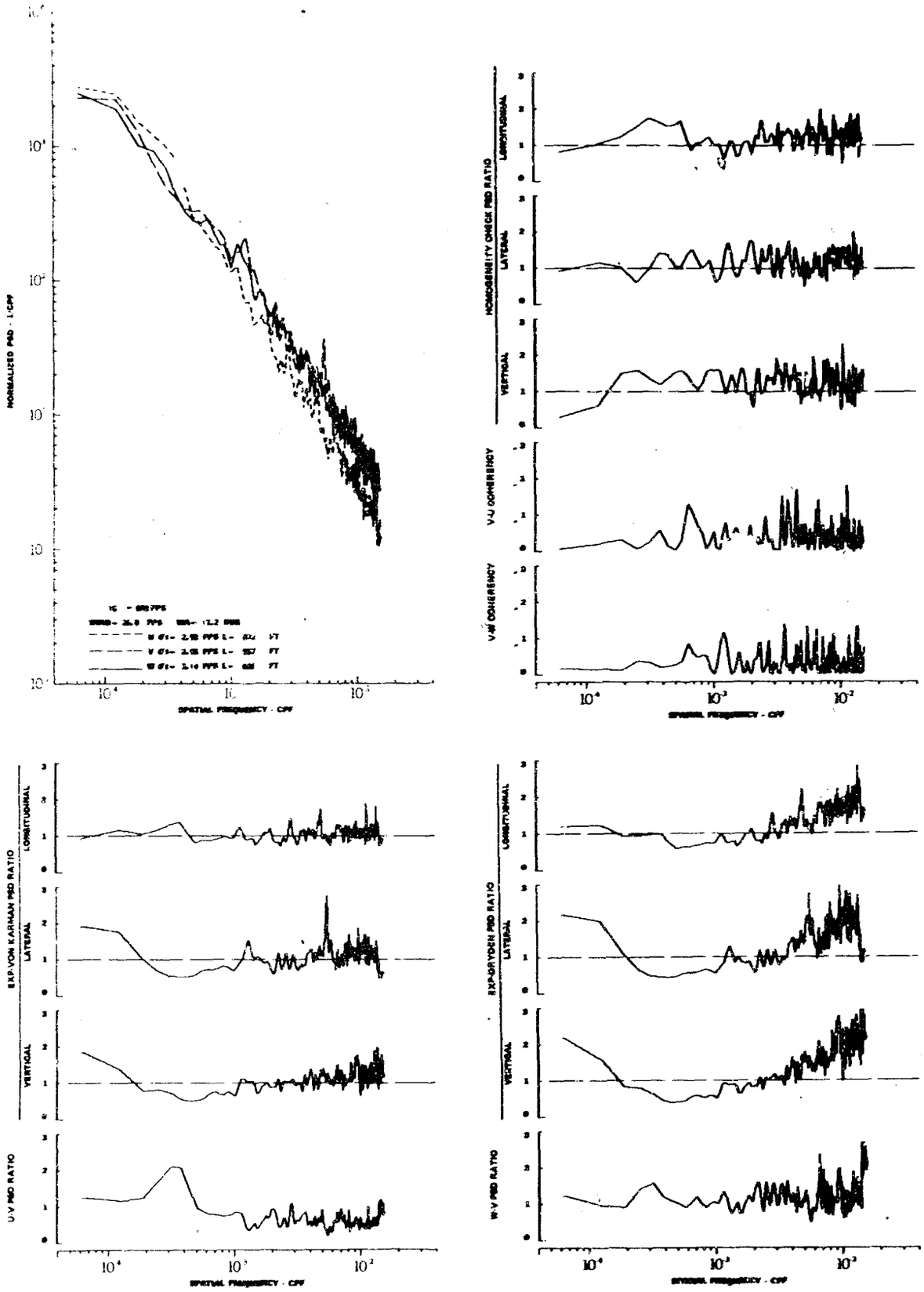

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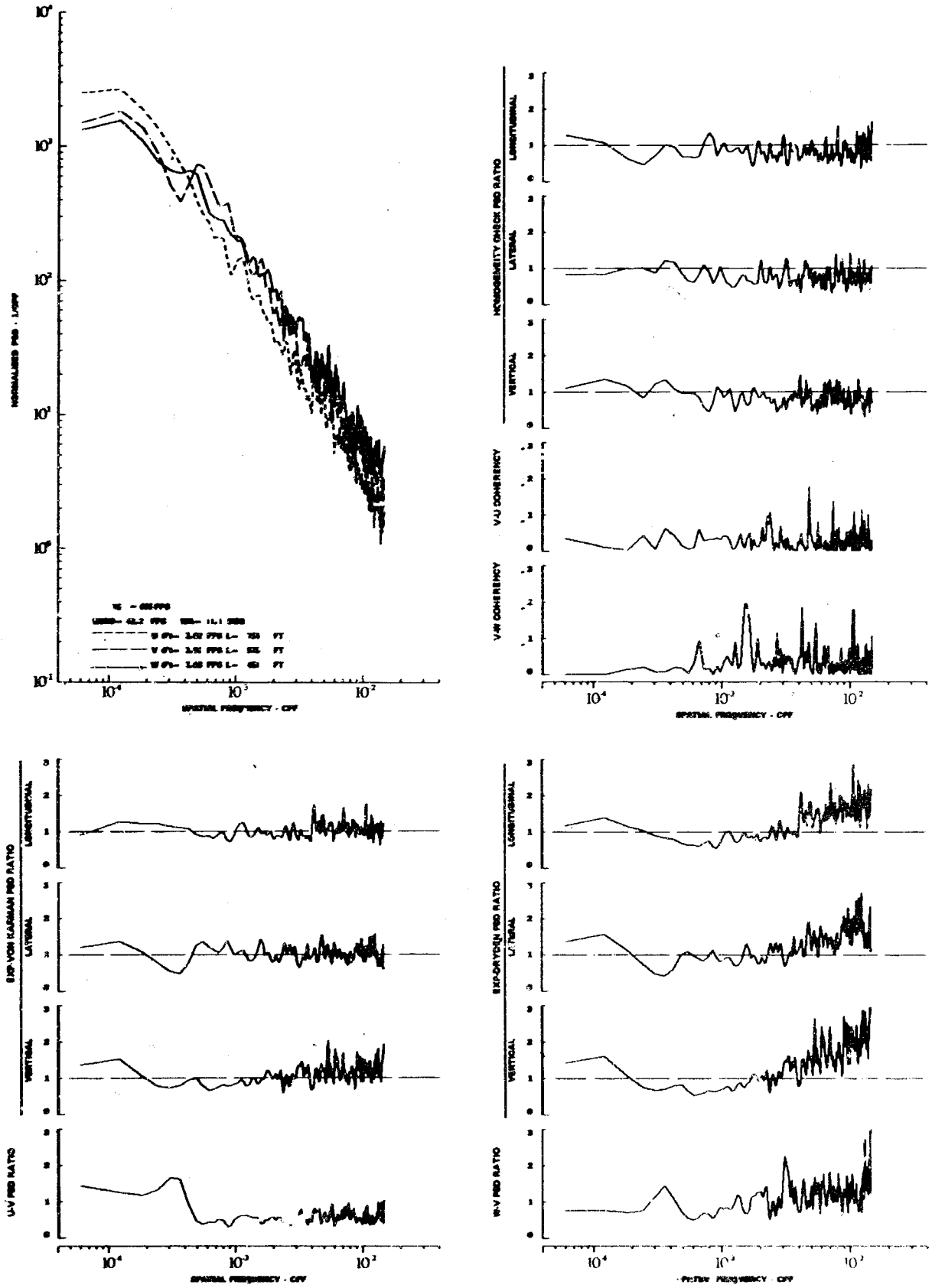

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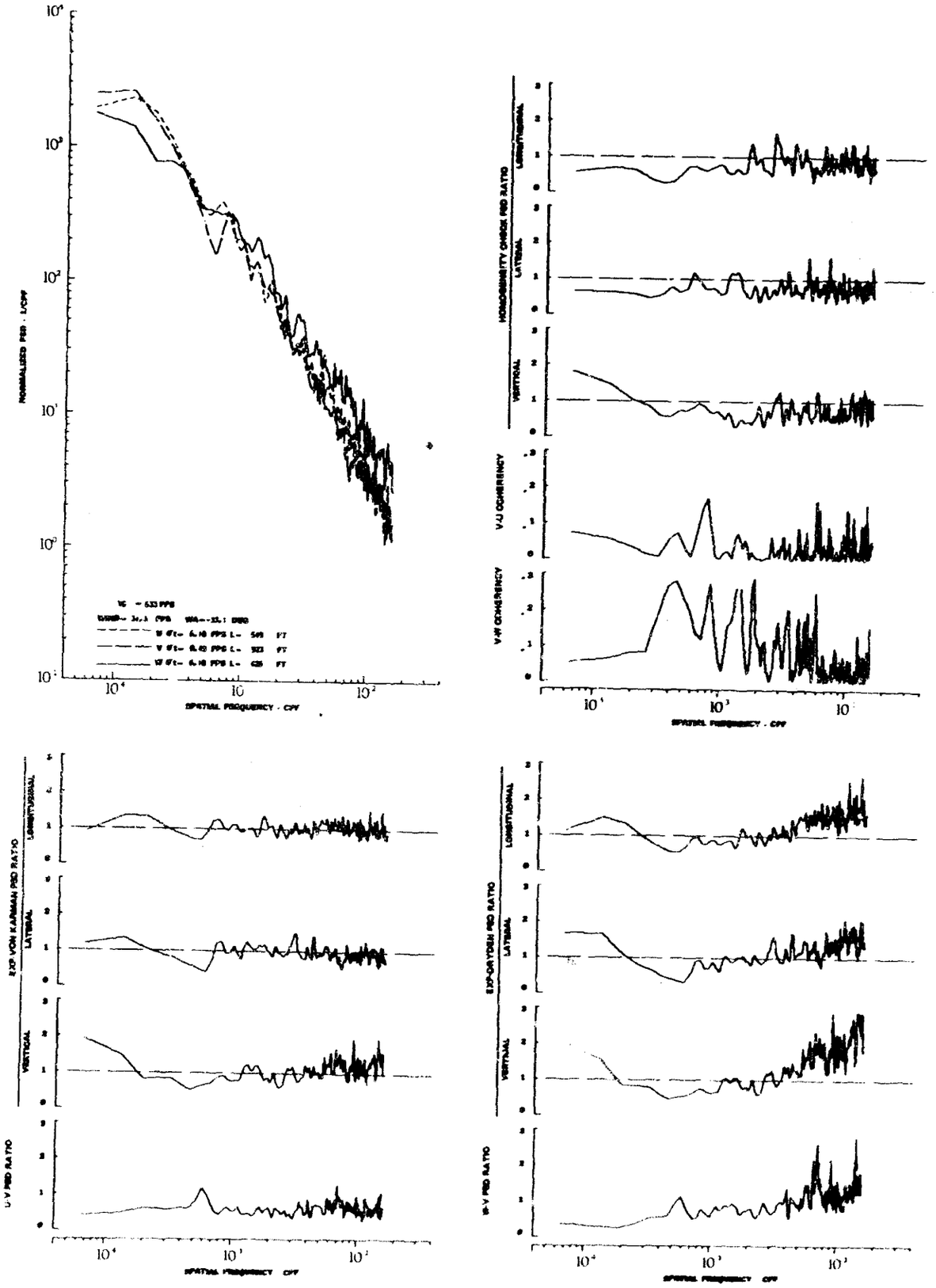

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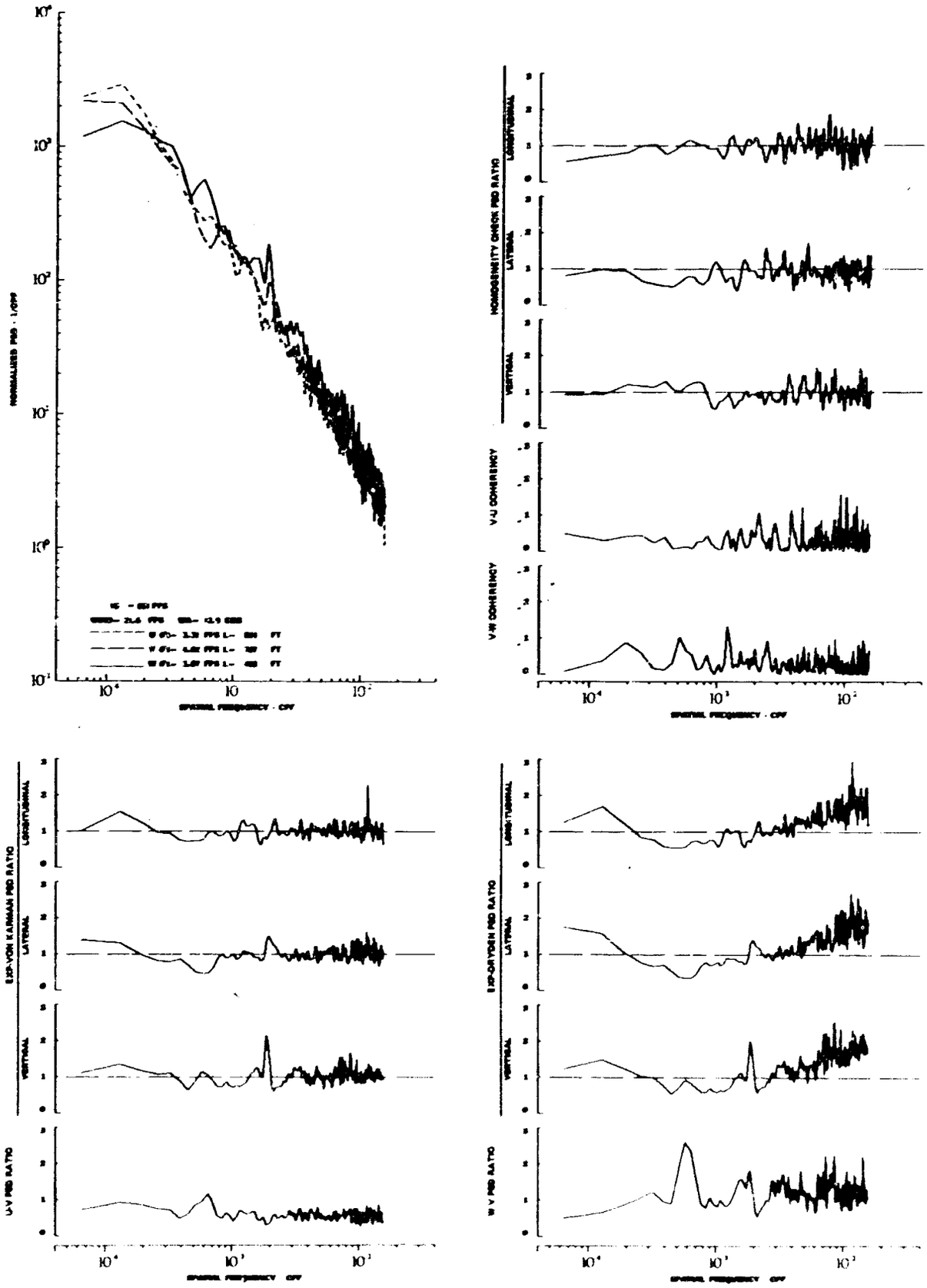

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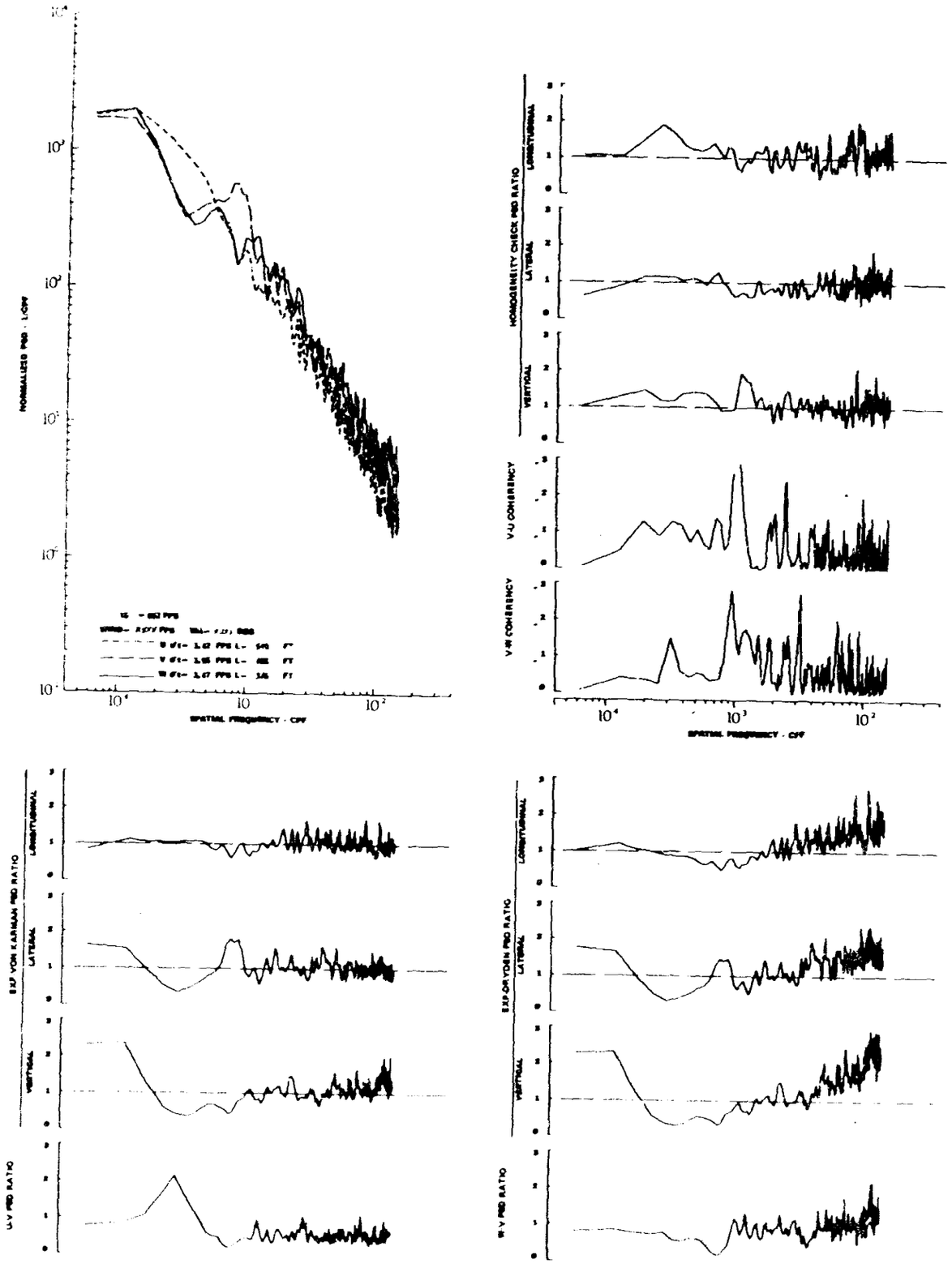
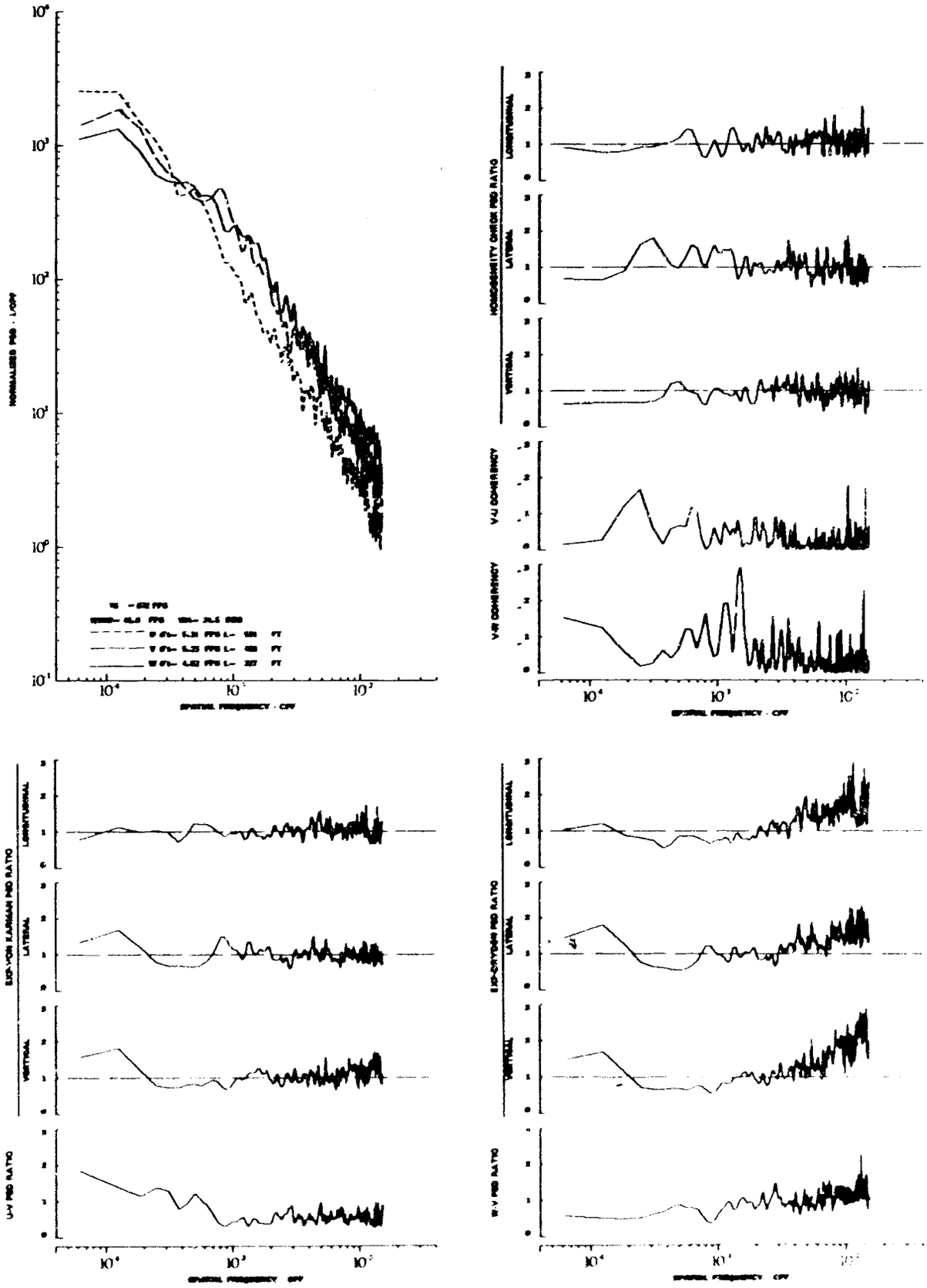
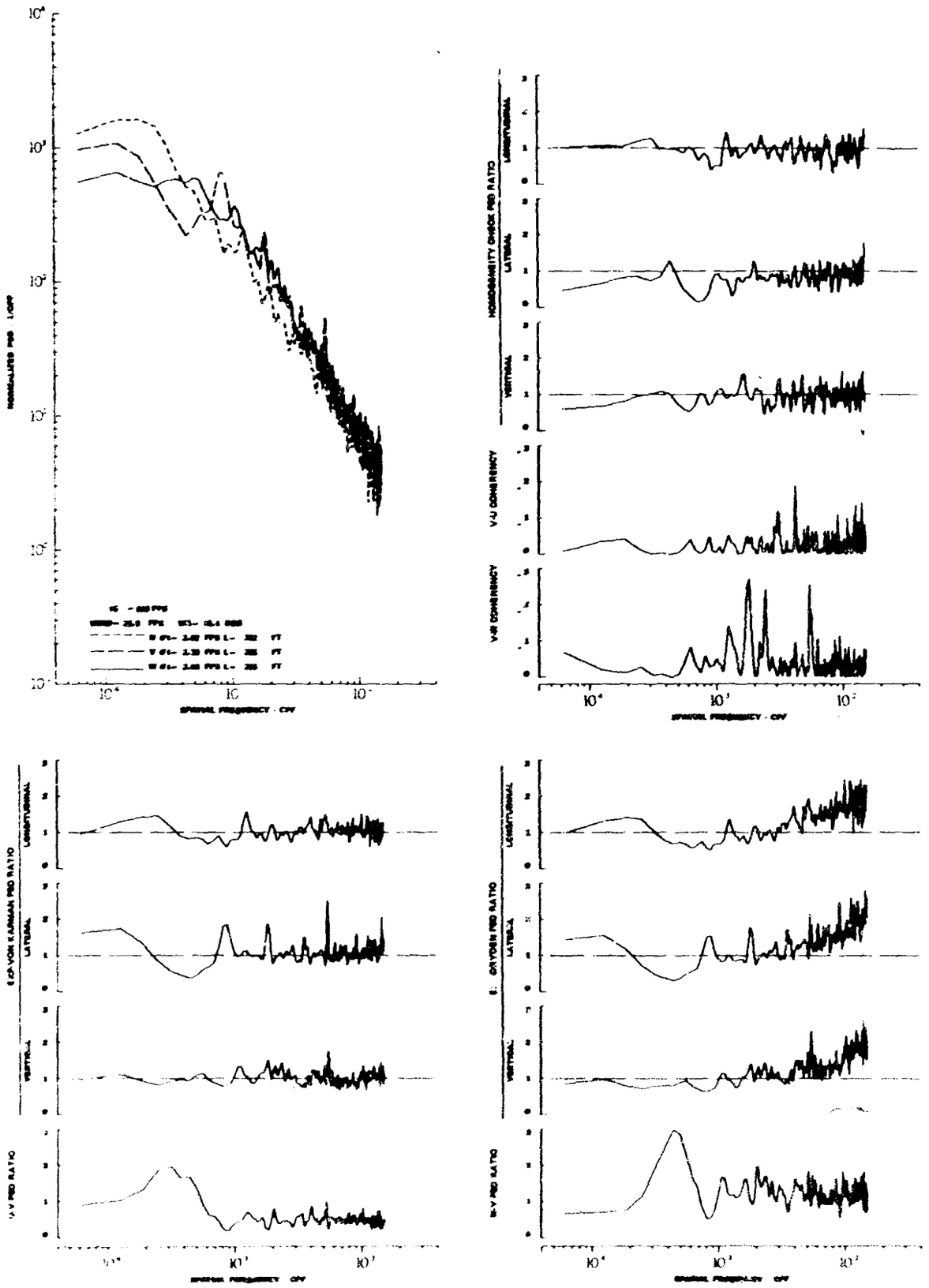


Turbulence Spectra Data For Test 180, Leg 4, Category 111243



Turbulance Spectra Data For Test [redacted], Leg 6, Category 112243



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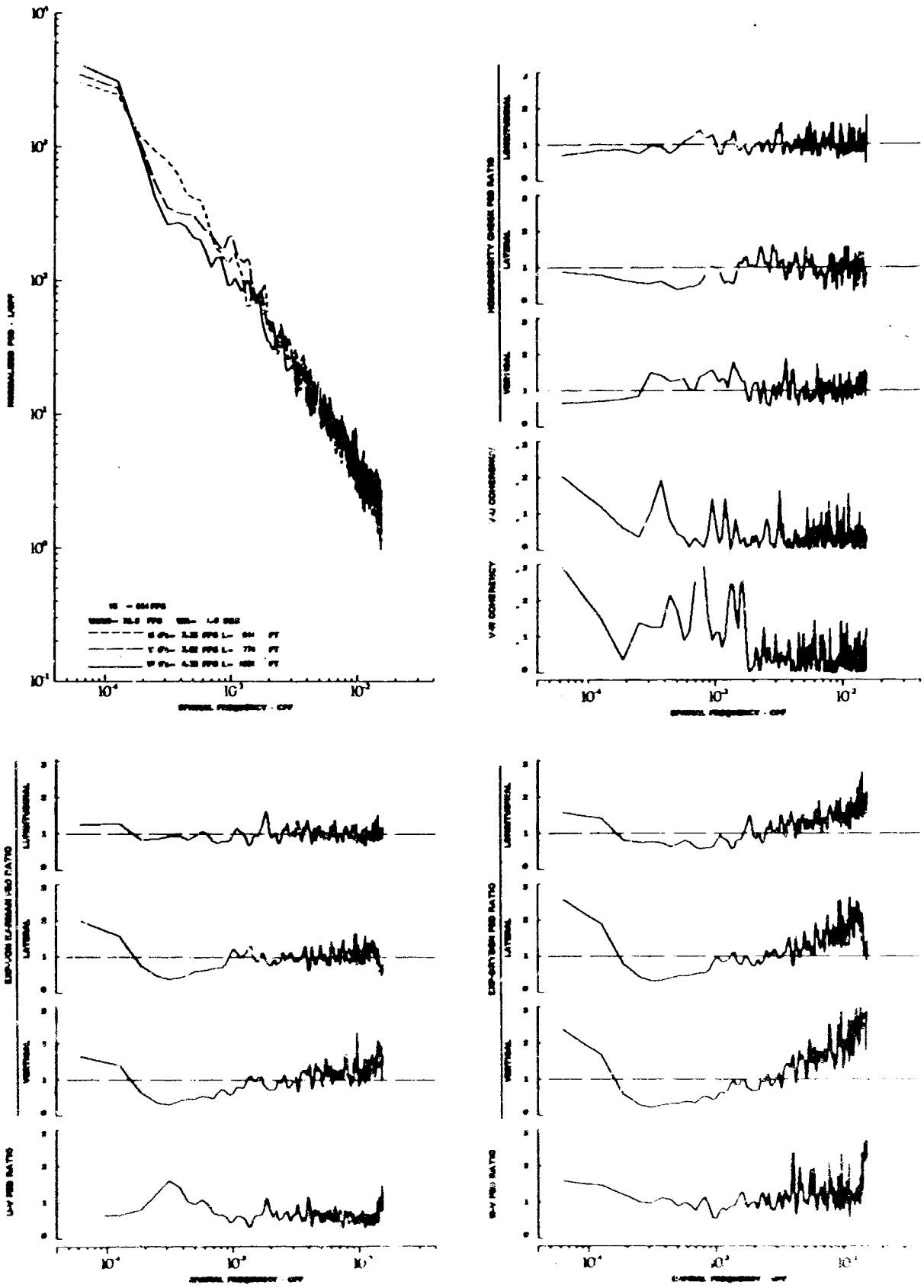
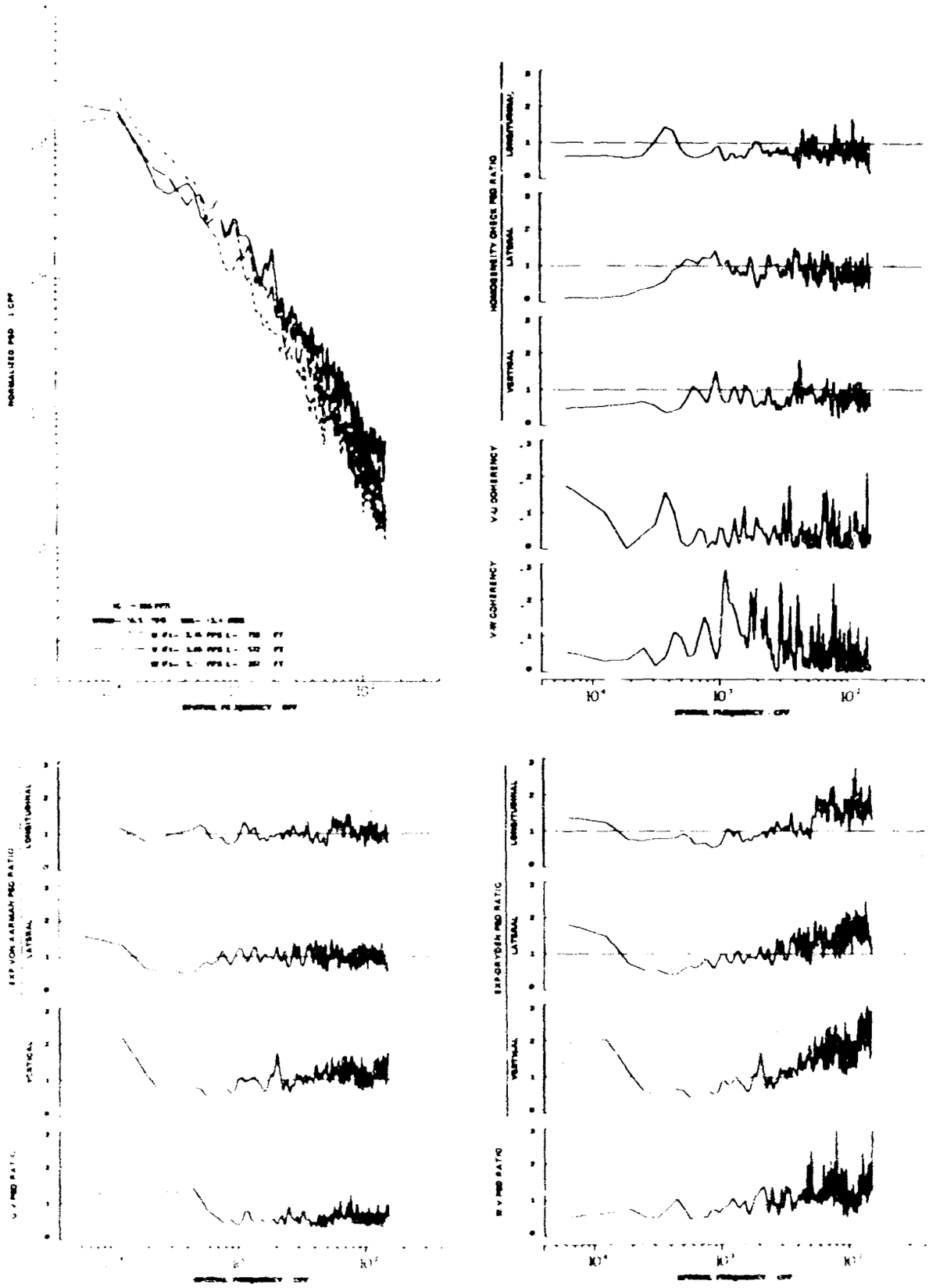
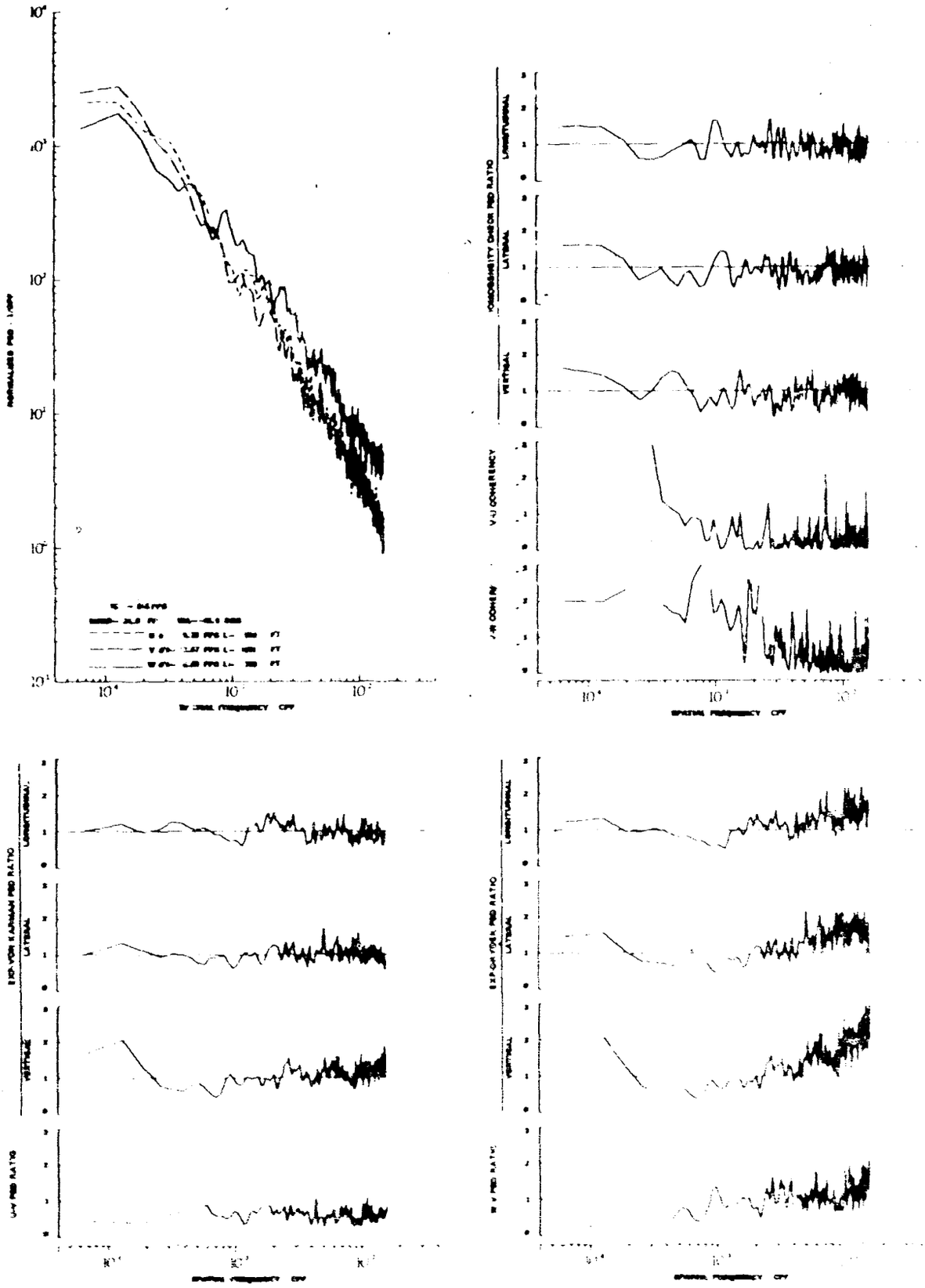


Turbulence Spectra Data For Test 181, Leg 1, Category 111343



Turbulence Spectra Data For Test 181, Leg 3, Category 112343



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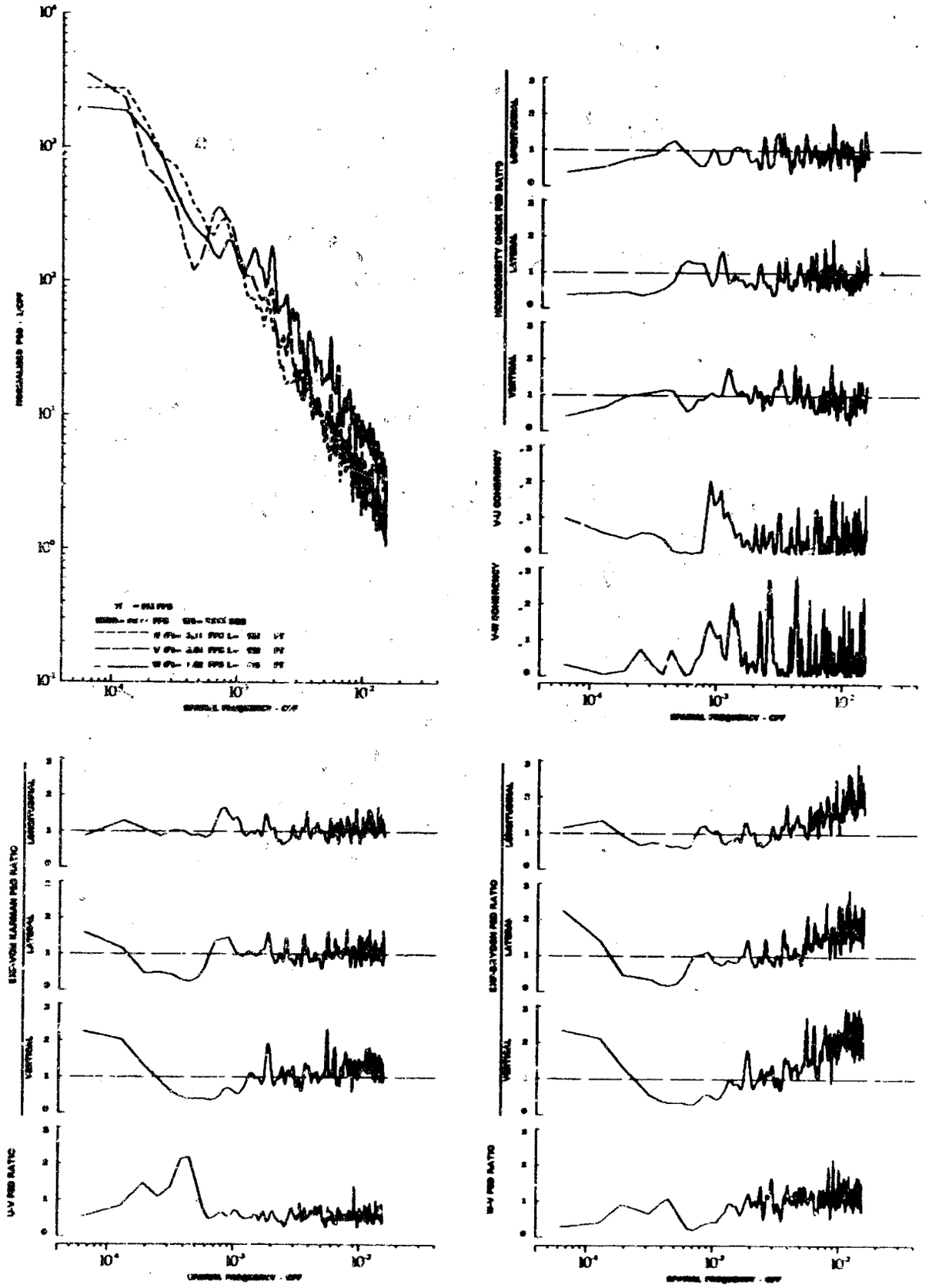

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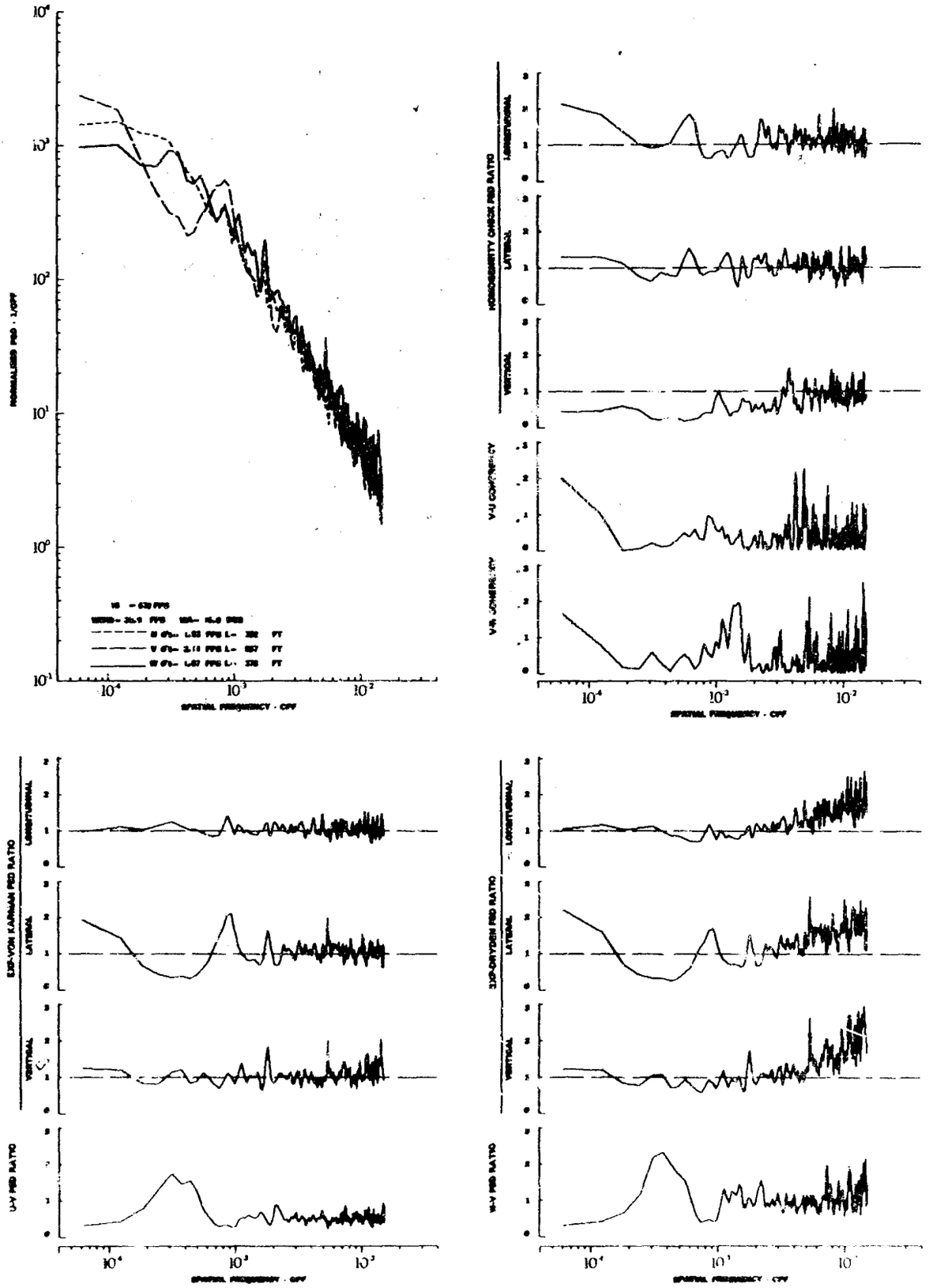

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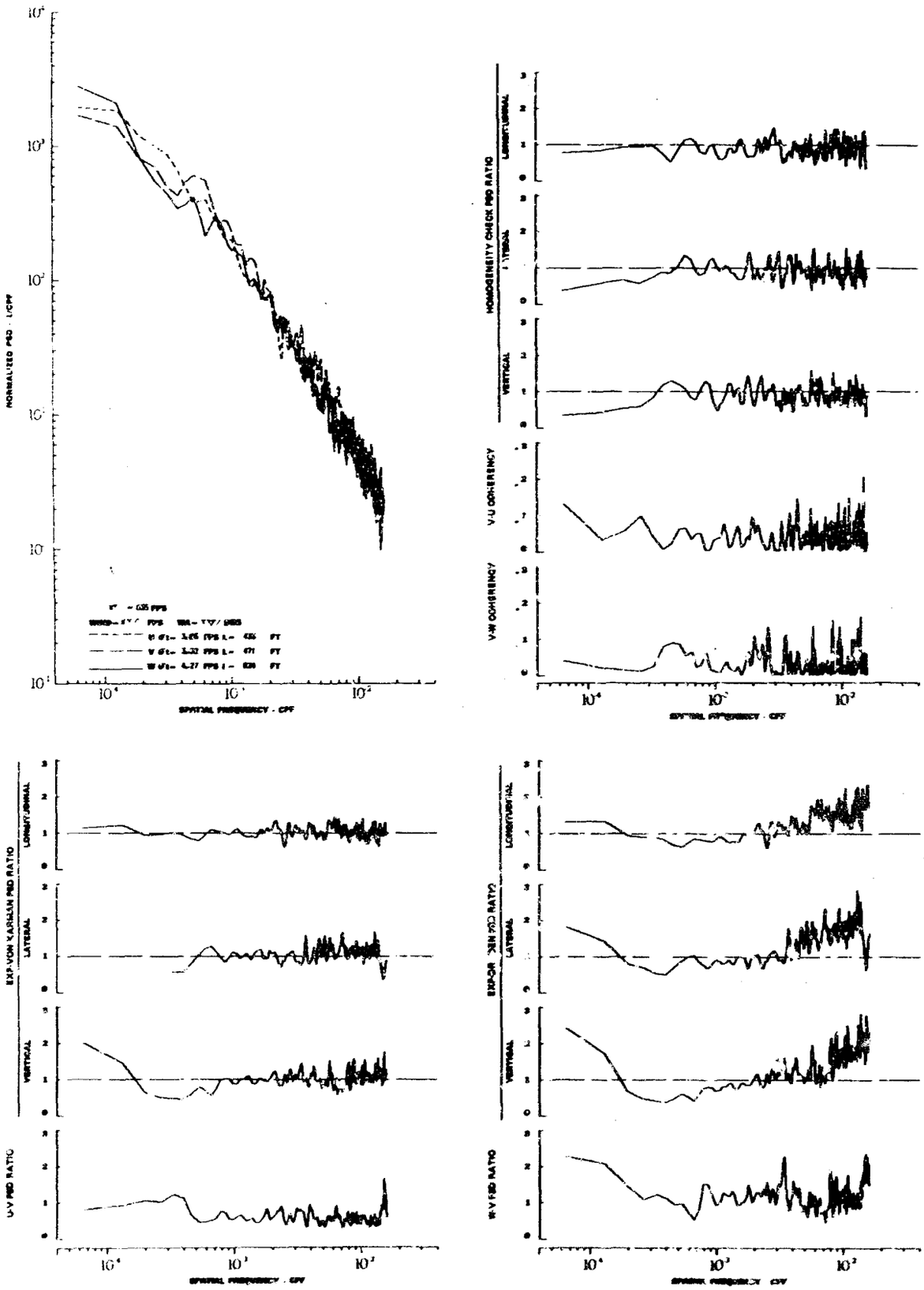

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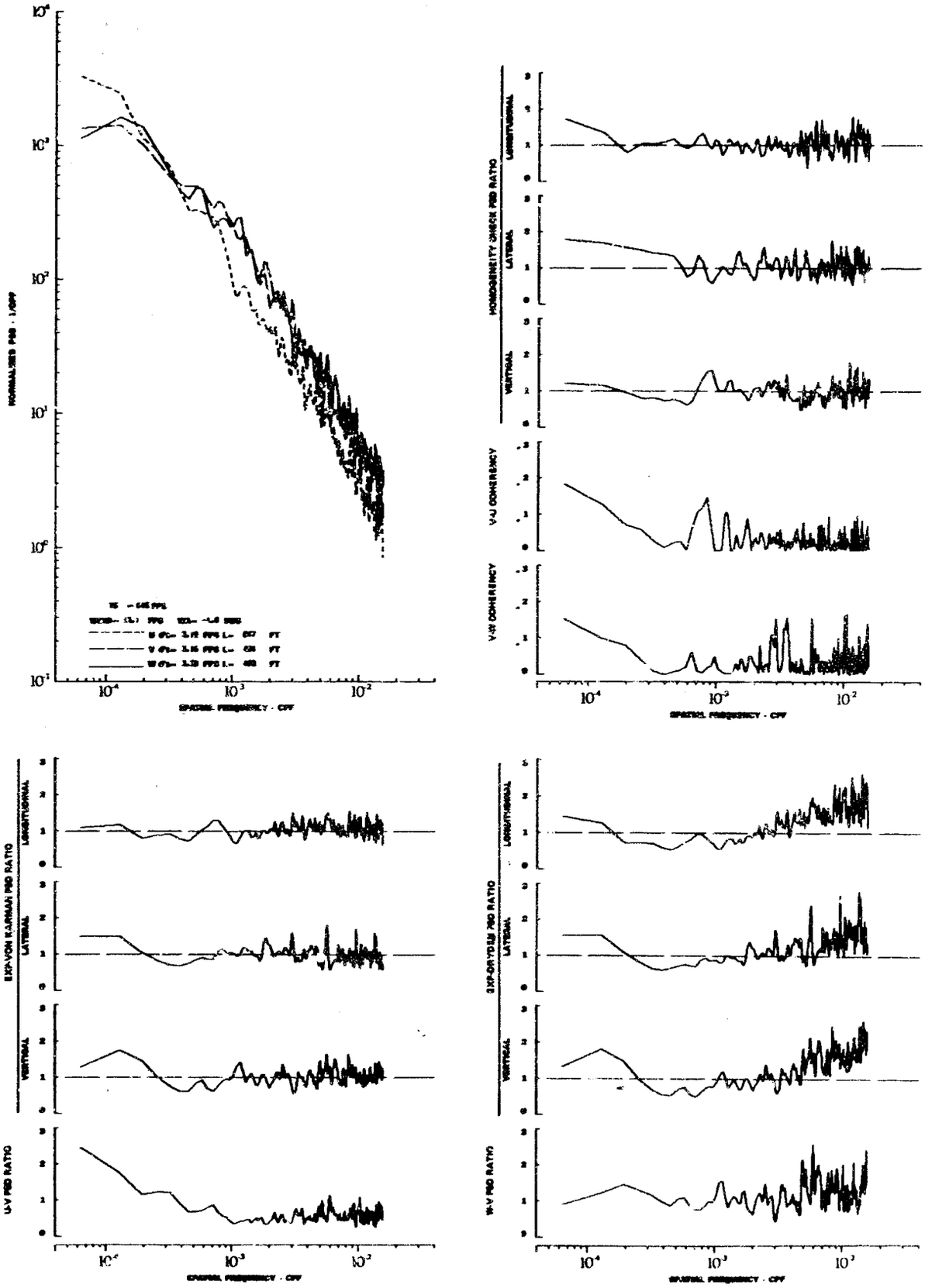

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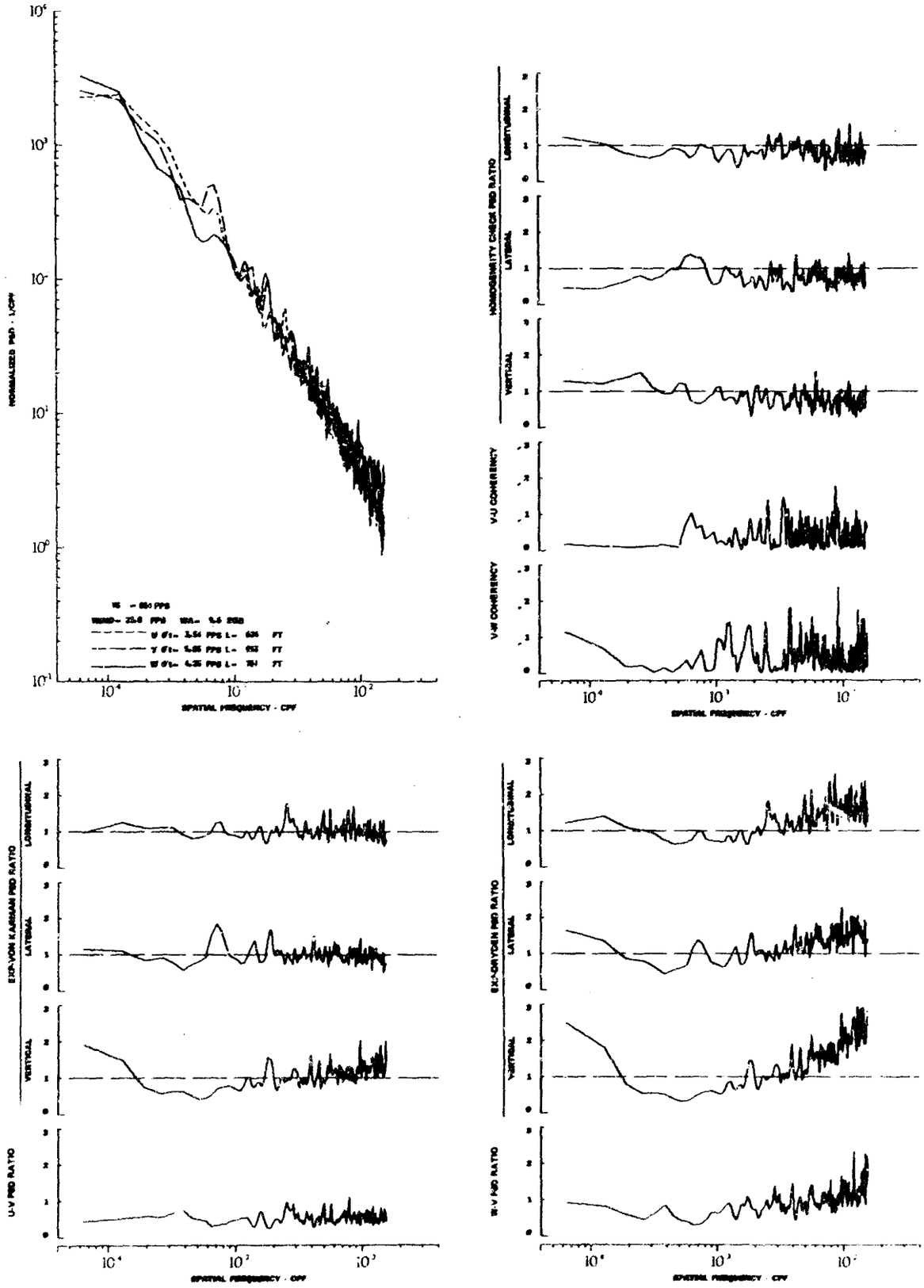

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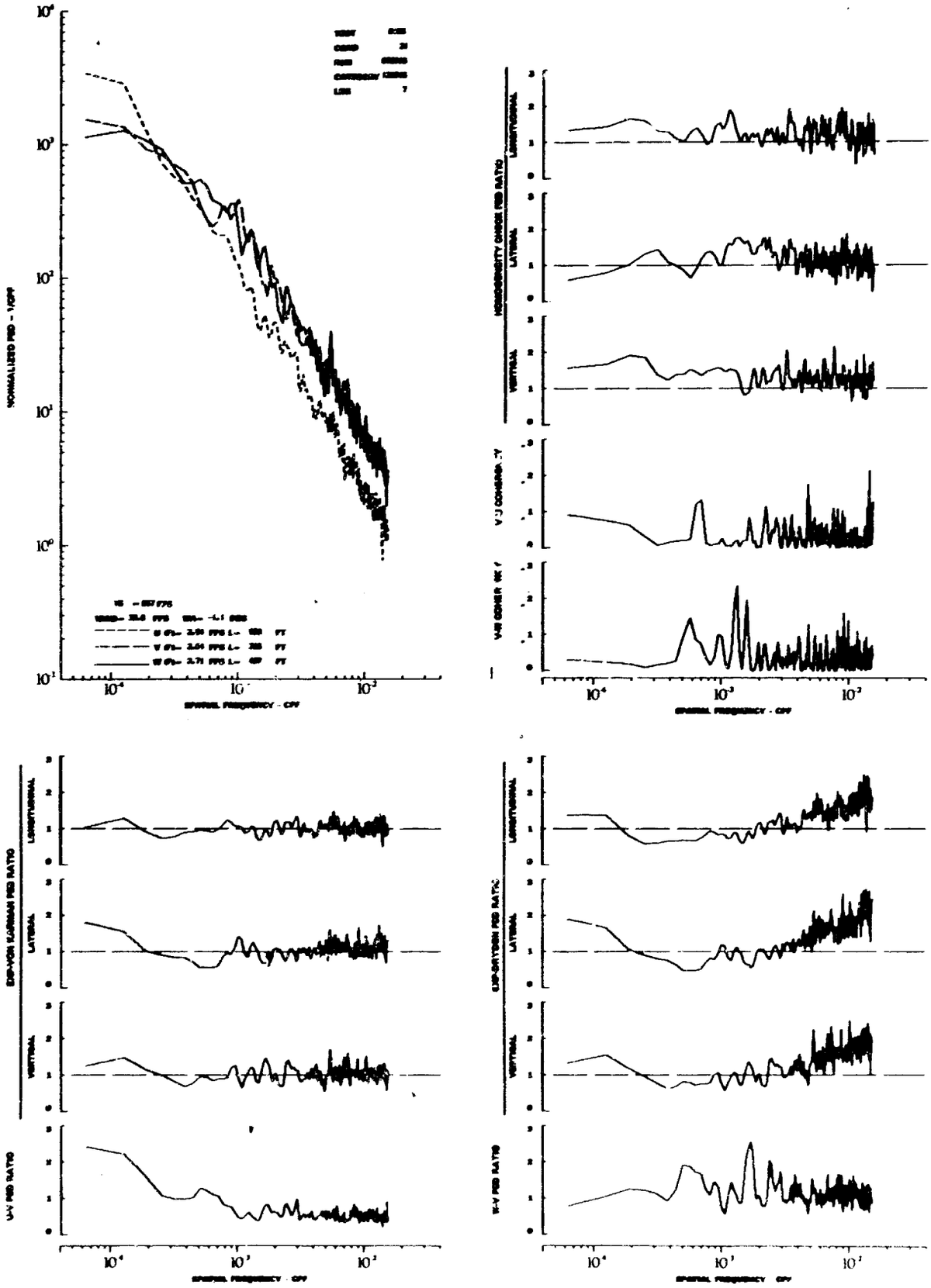
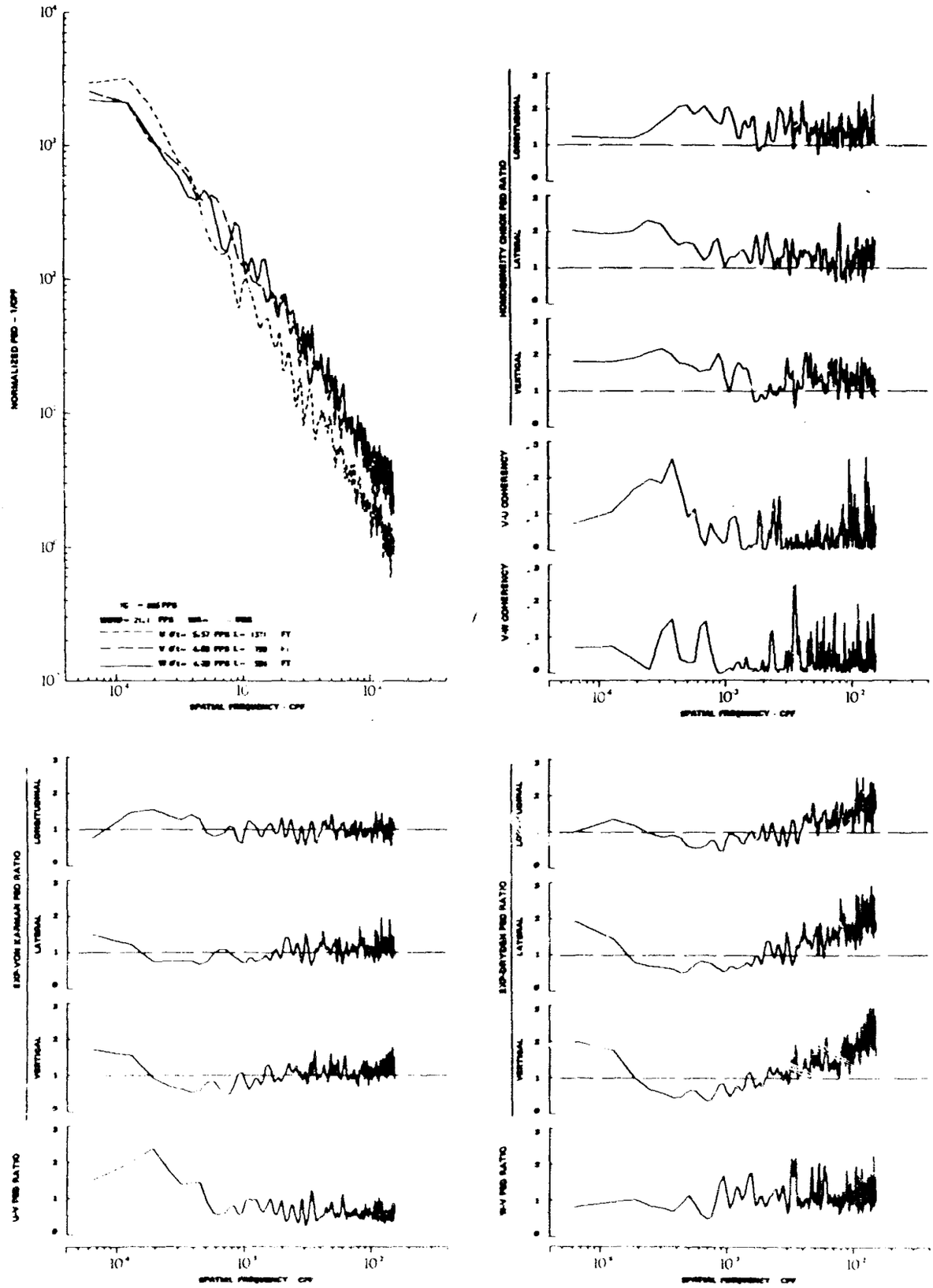
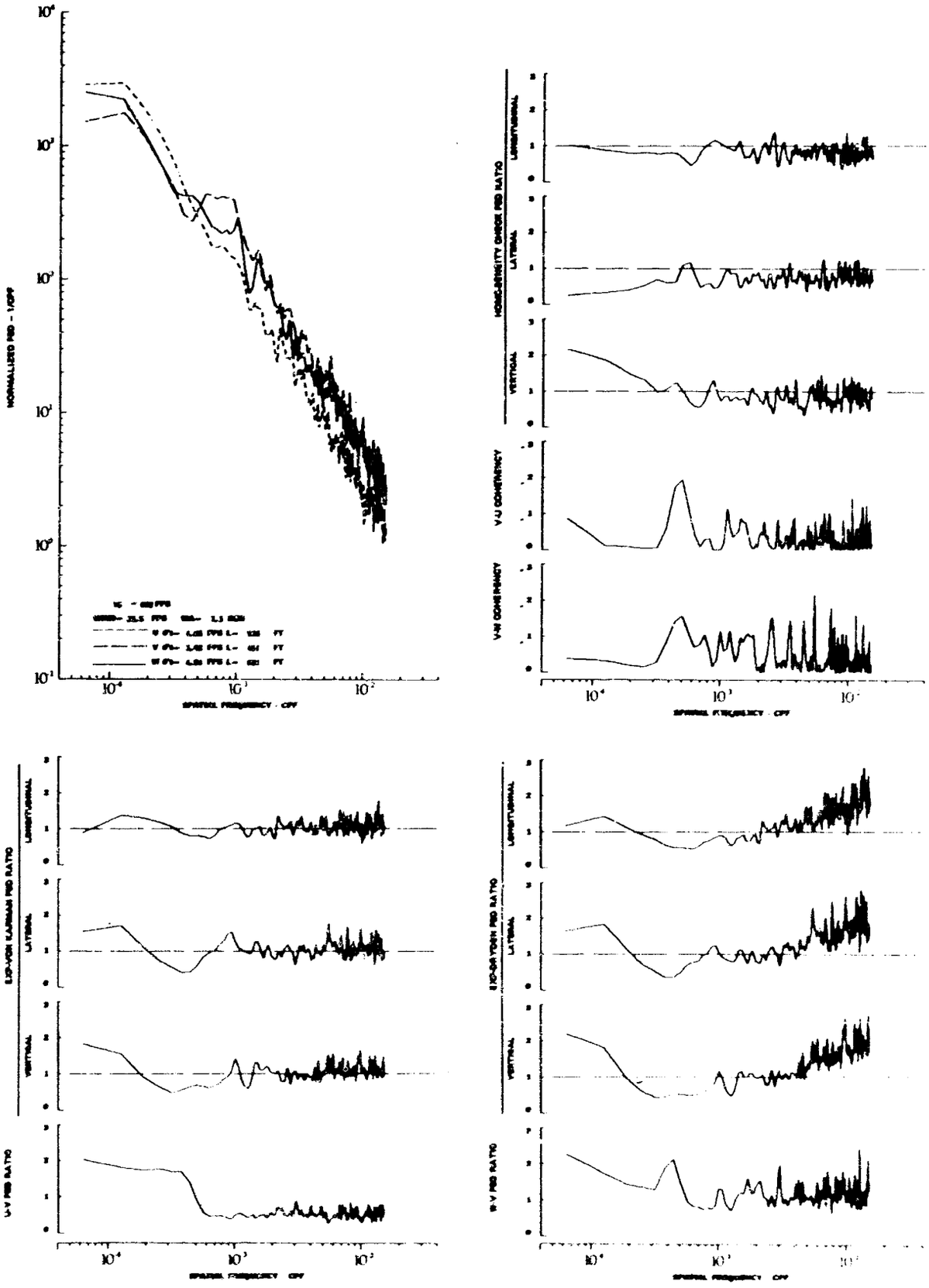


Turbulence Spectra Data For Test 183, Leg 7, Category 122343



Turbulence Spectra Data For Test 184, Leg 2, Category 112243



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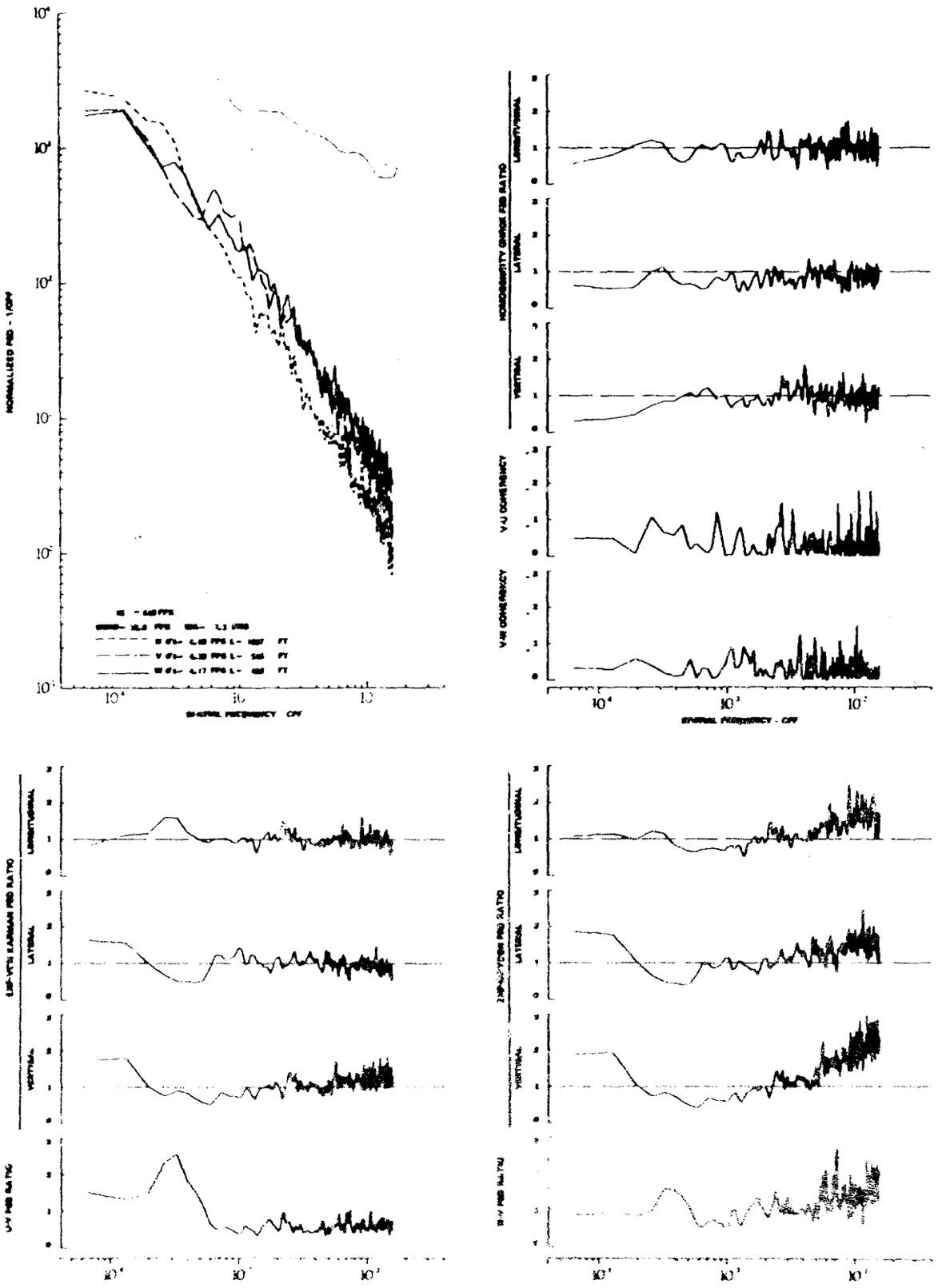
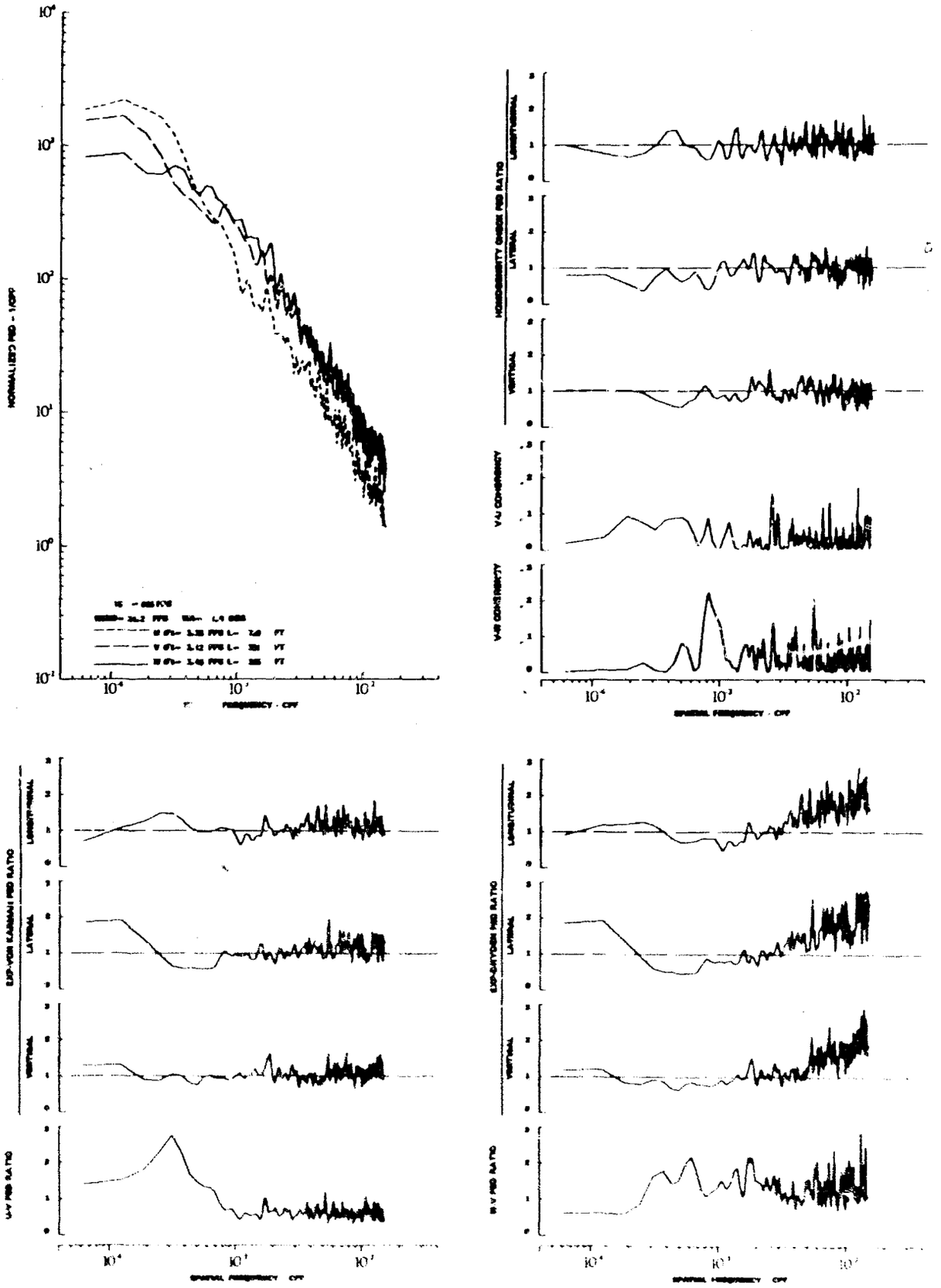


Turbulence Spectra Data For Test 194, Leg 6, Category 112243



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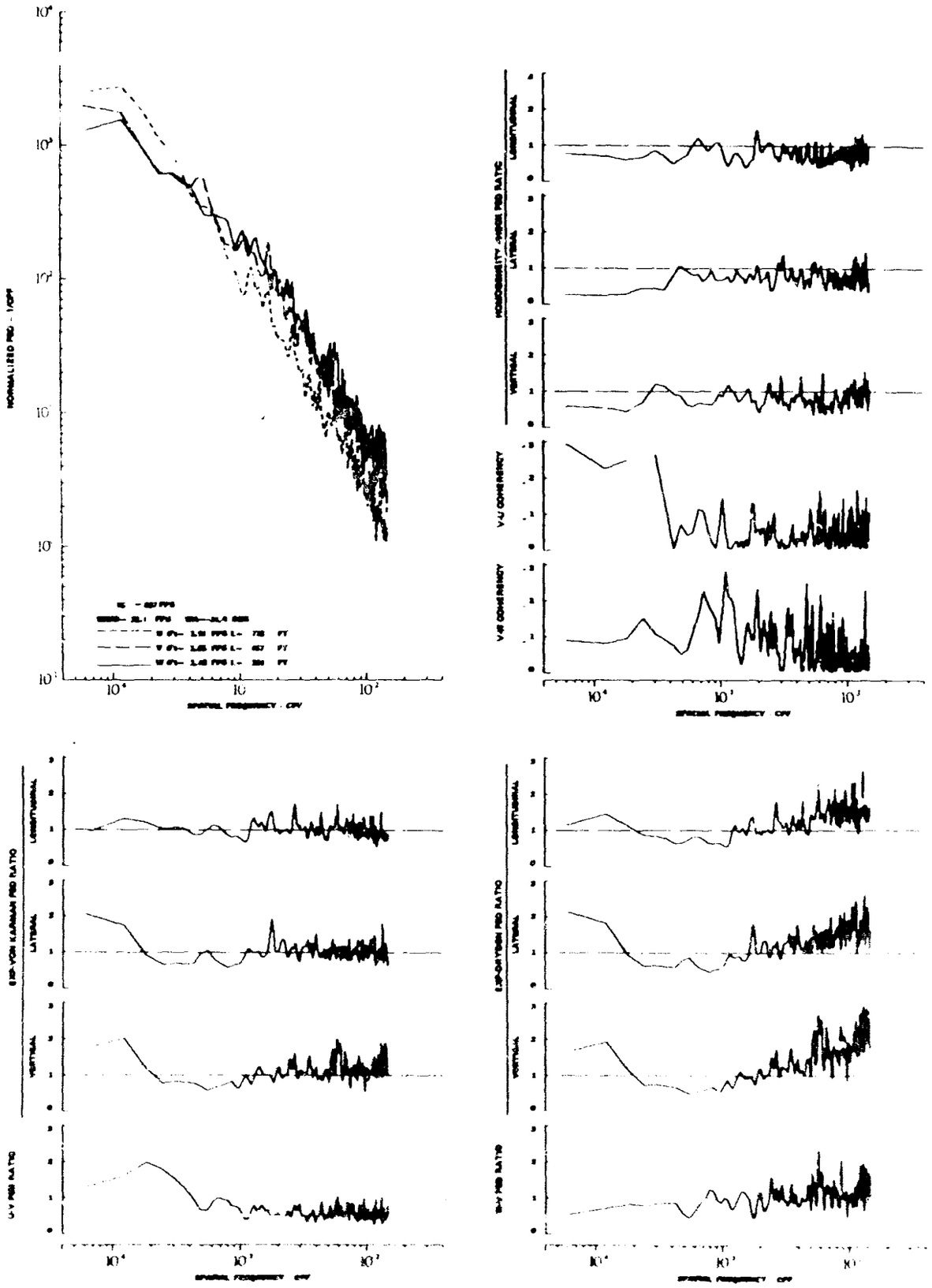
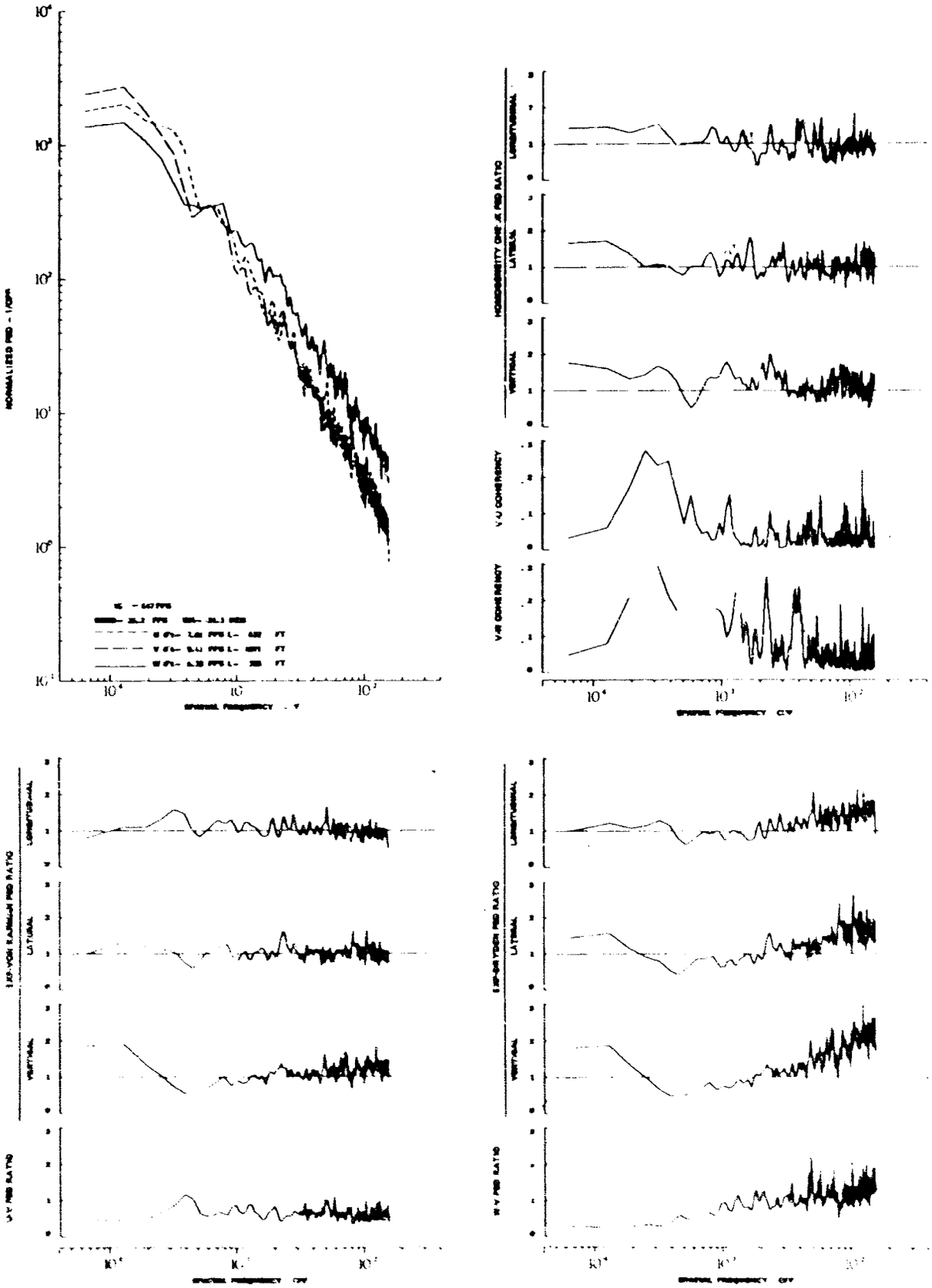
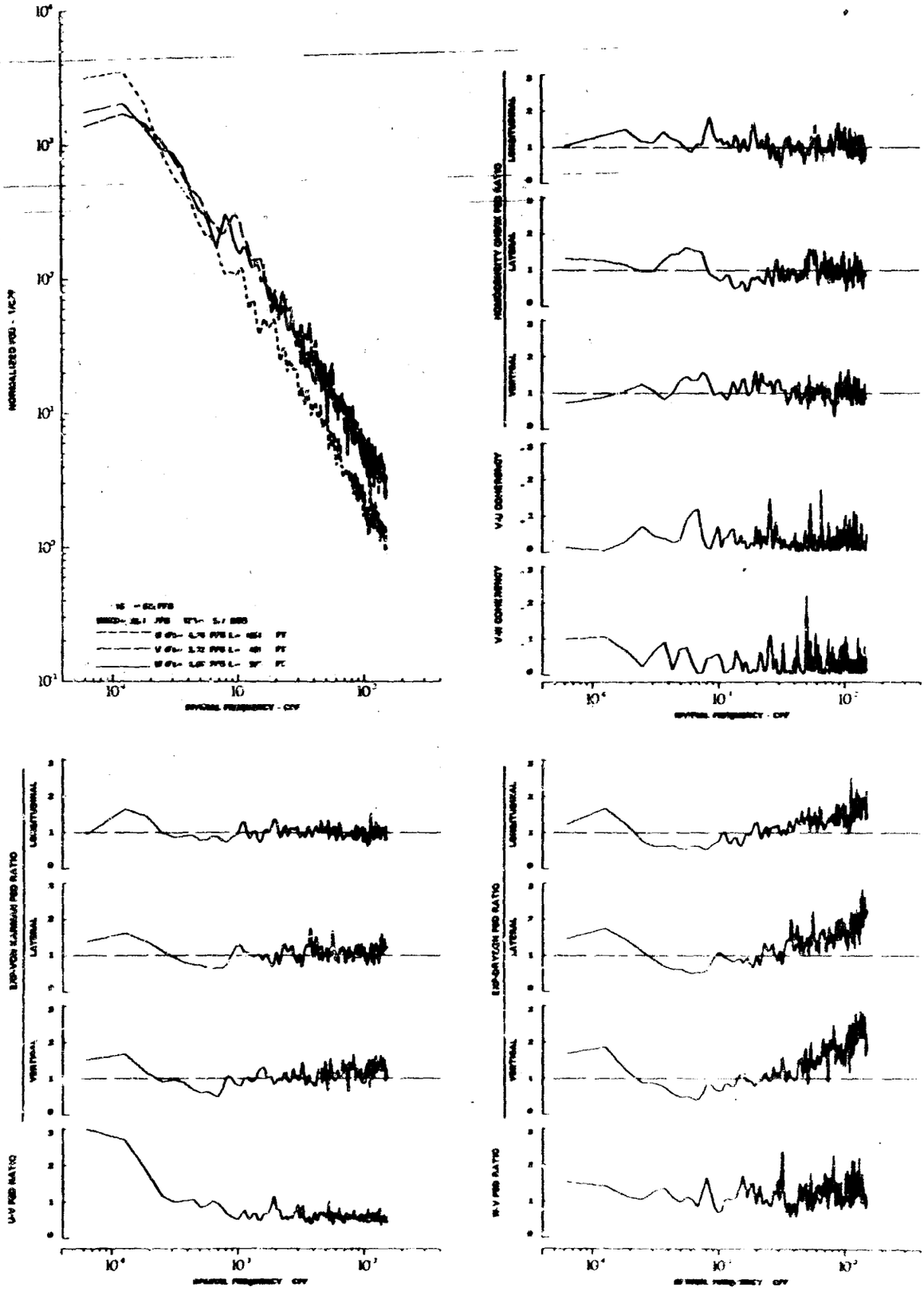


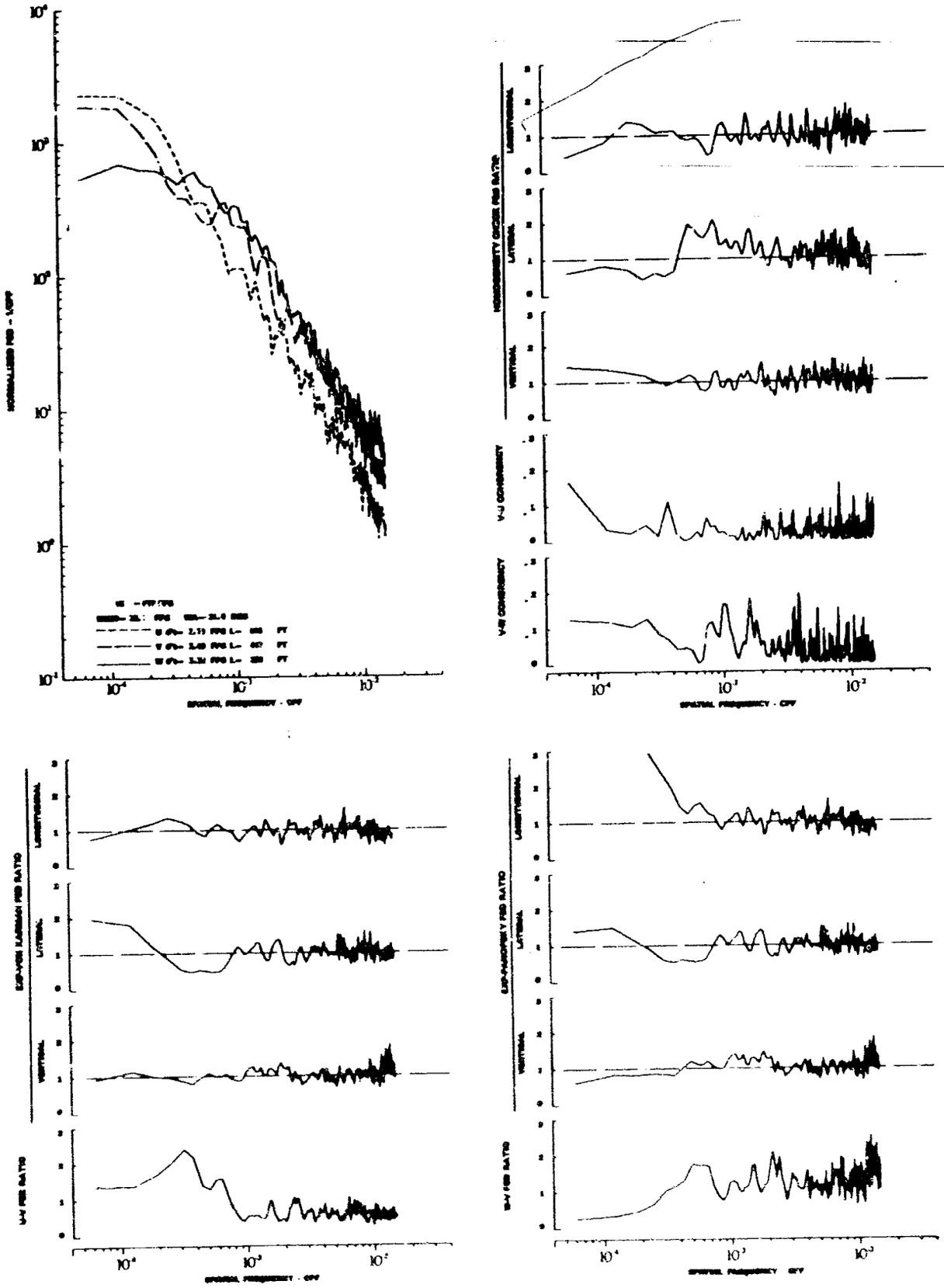
Turbulence Spectra Data For Test 185, Leg 3, Category 113543



Turbulence Spectra Data For Test 185, Leg 5, Category 112343



Turbulence Spectra Data For Test 185, Leg 7, Category 112343



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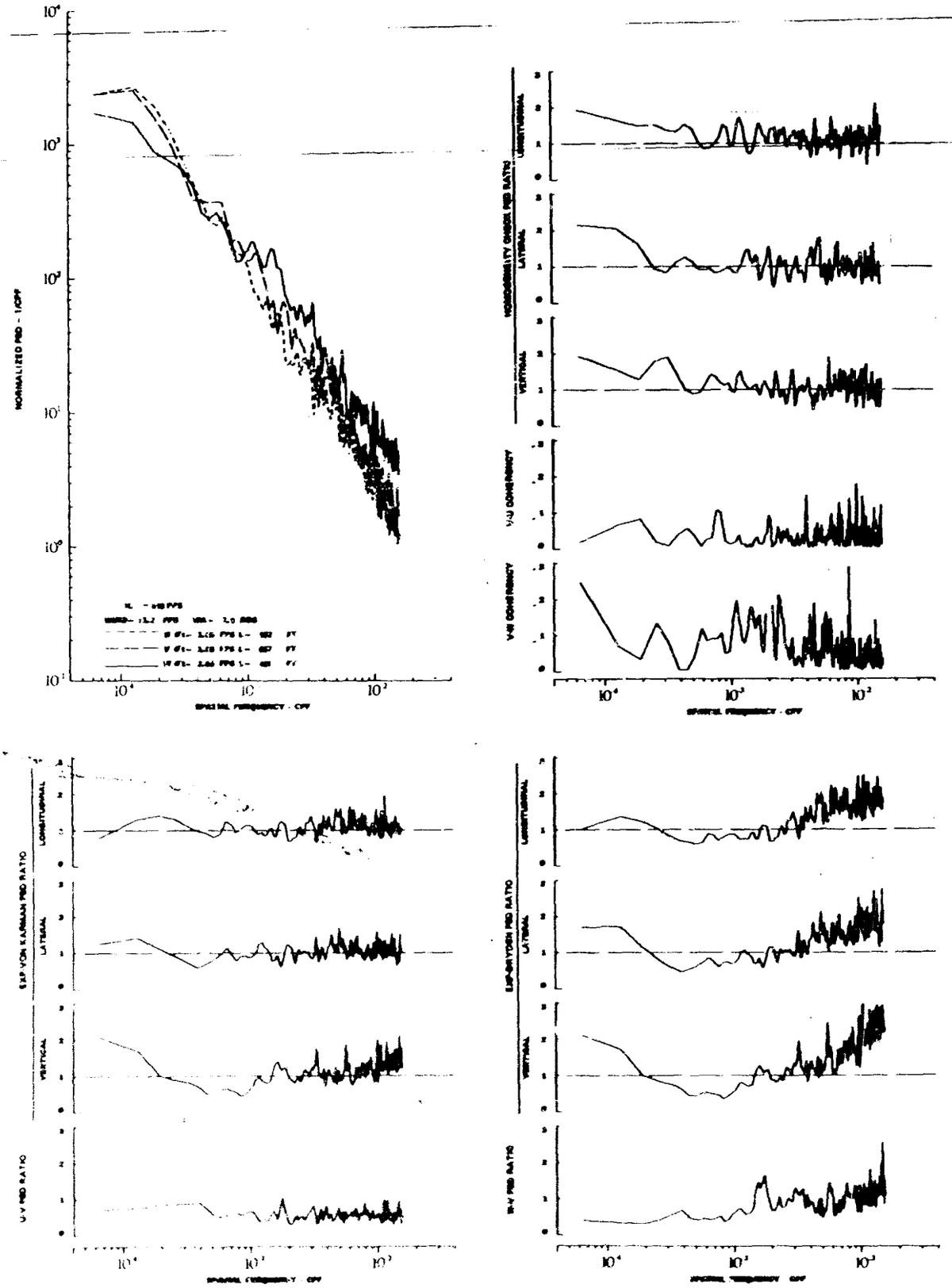
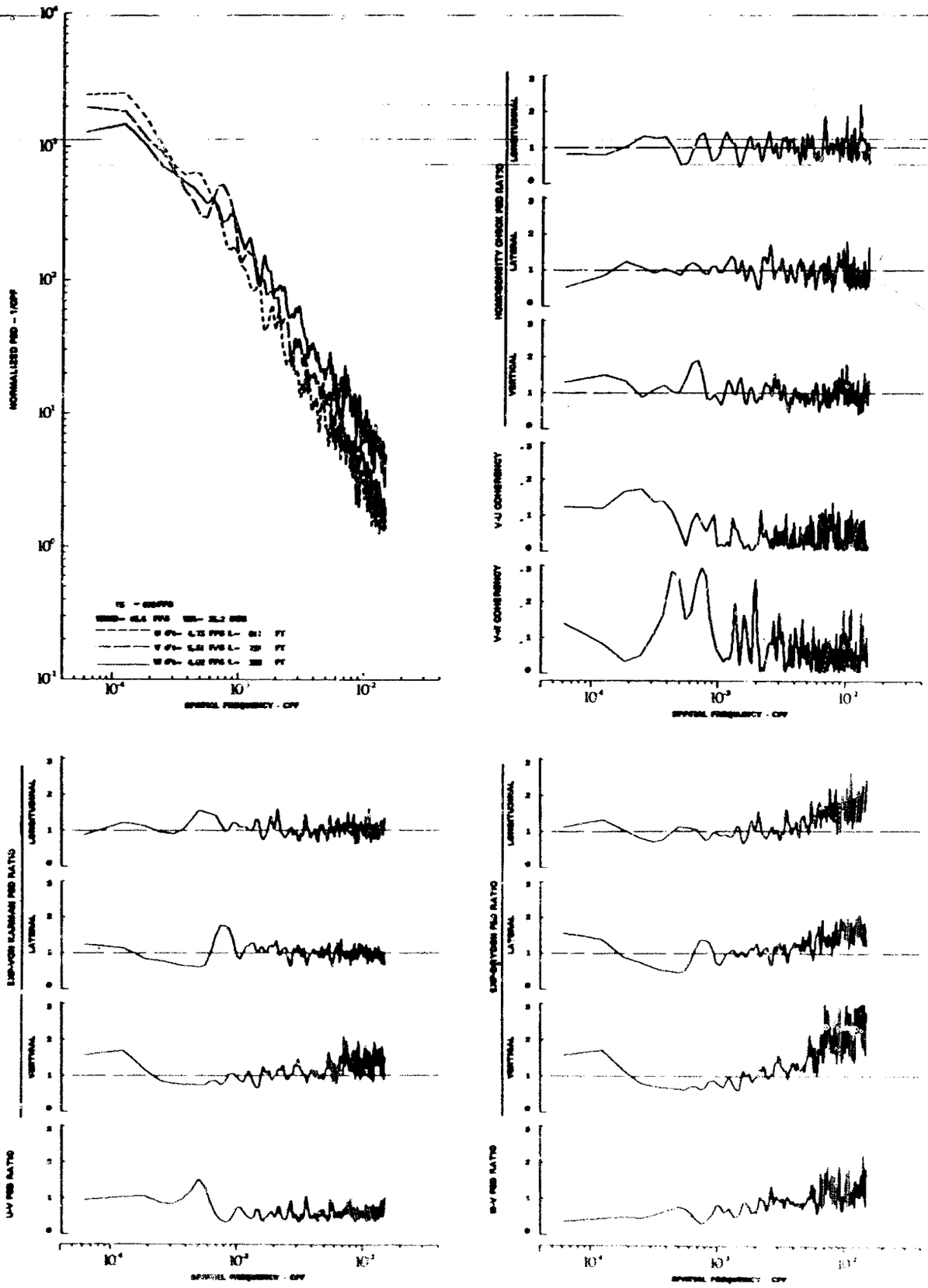
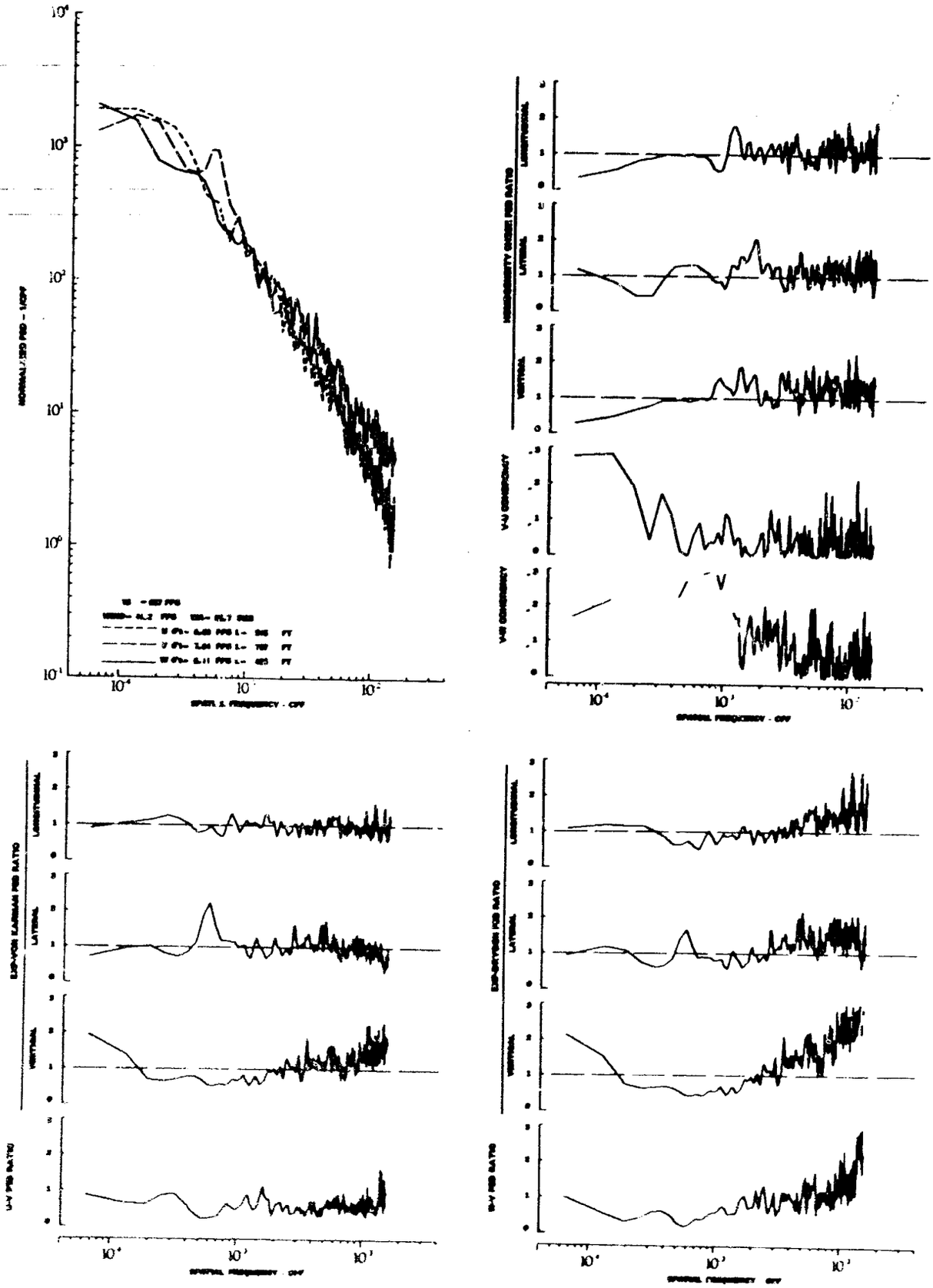


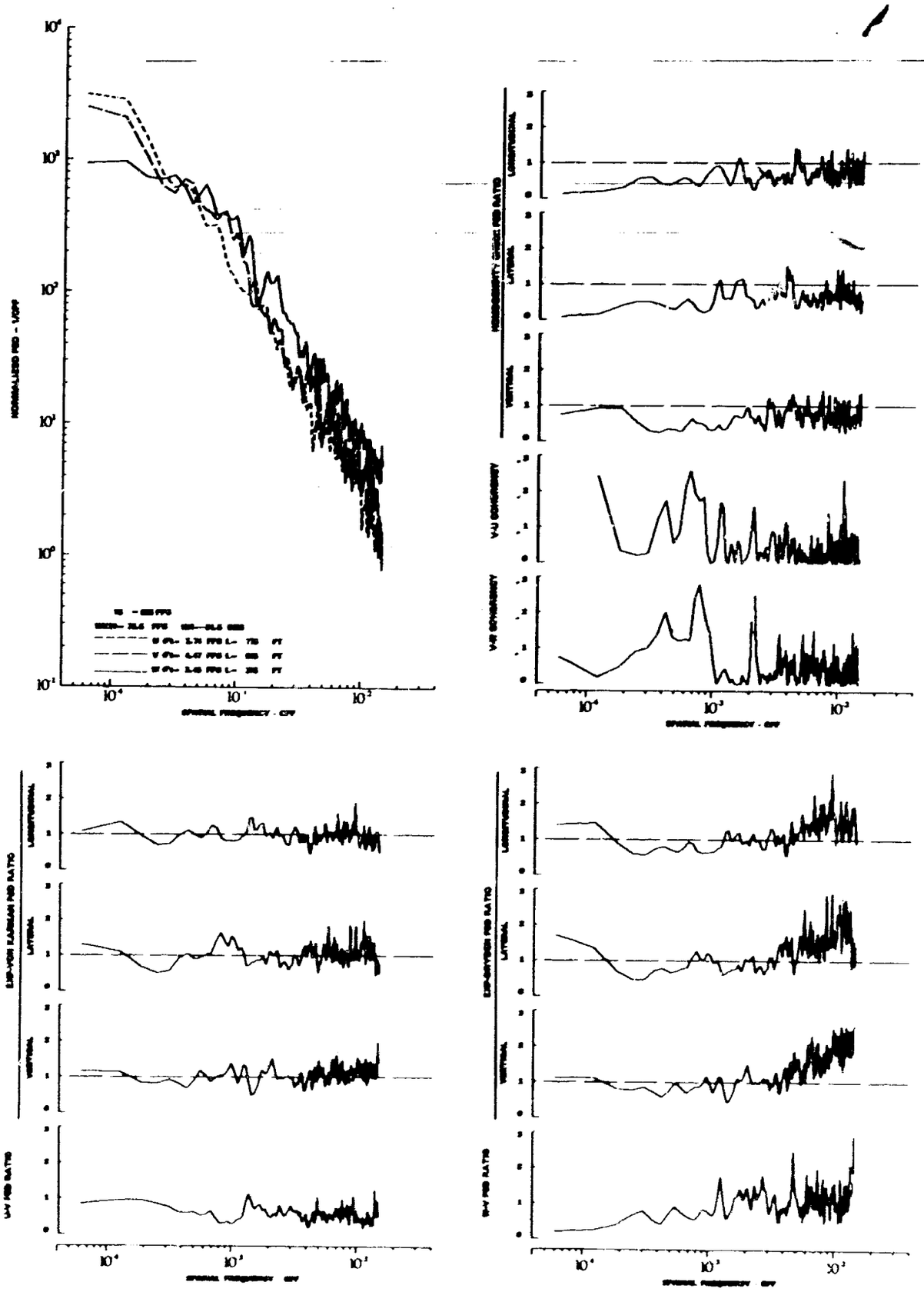
Turbulence Spectra Data For Test 186, Log 4, Category 122143



Turbulence Spectra Data For Test 186, Leg 6, Category 123143



Turbulence Spectra Data For Test 187, Leg 1, Category 123243



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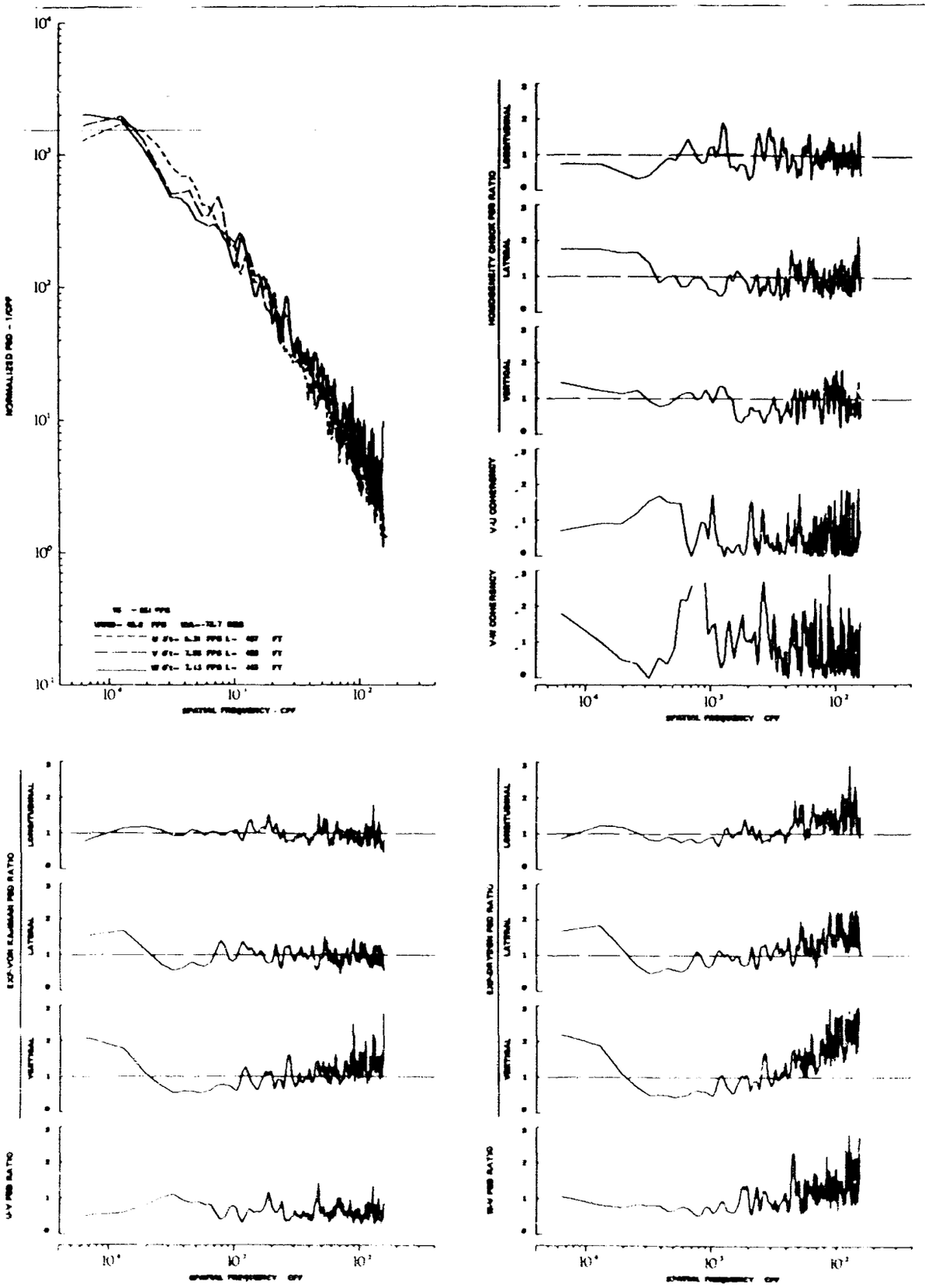

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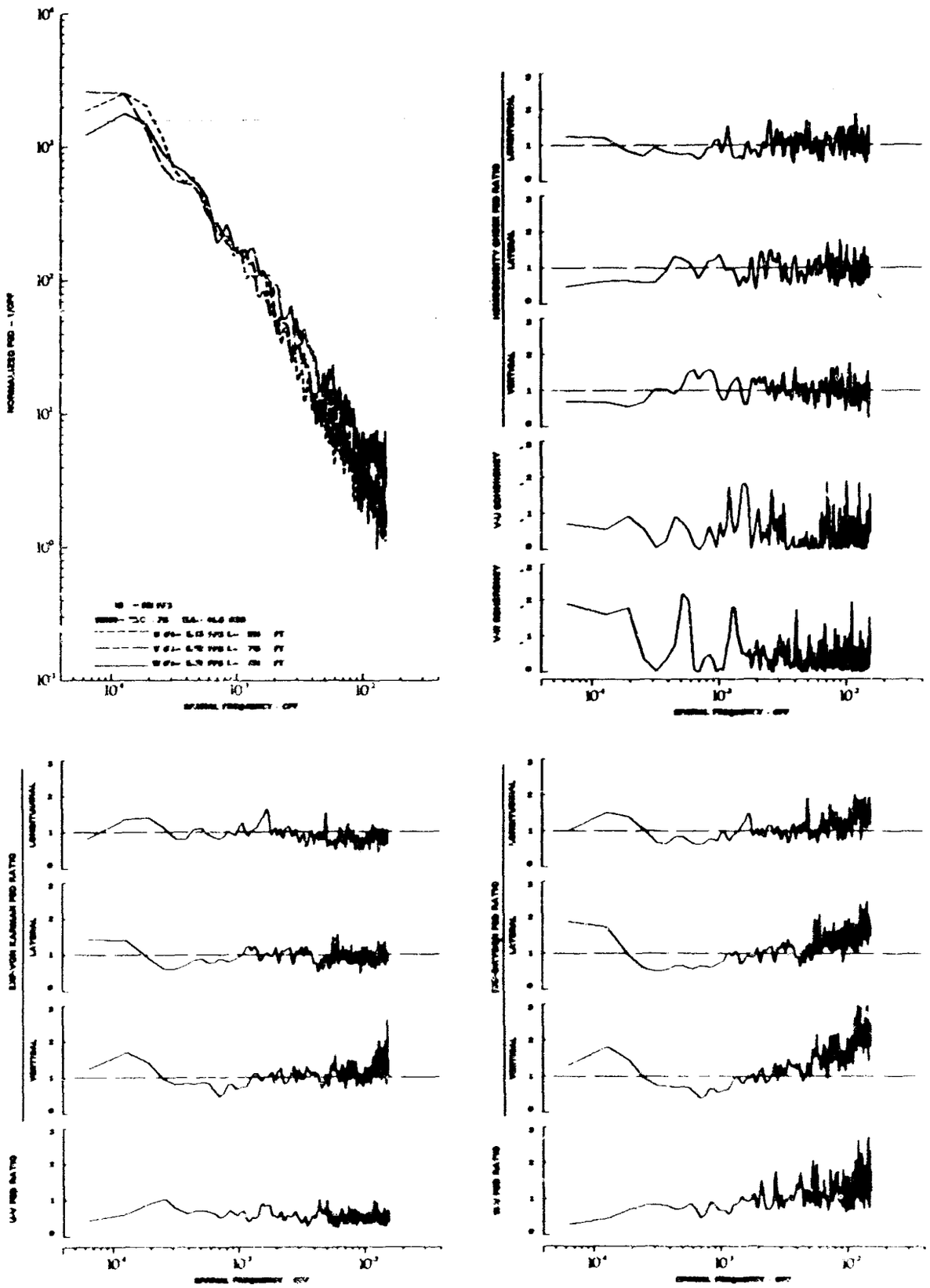

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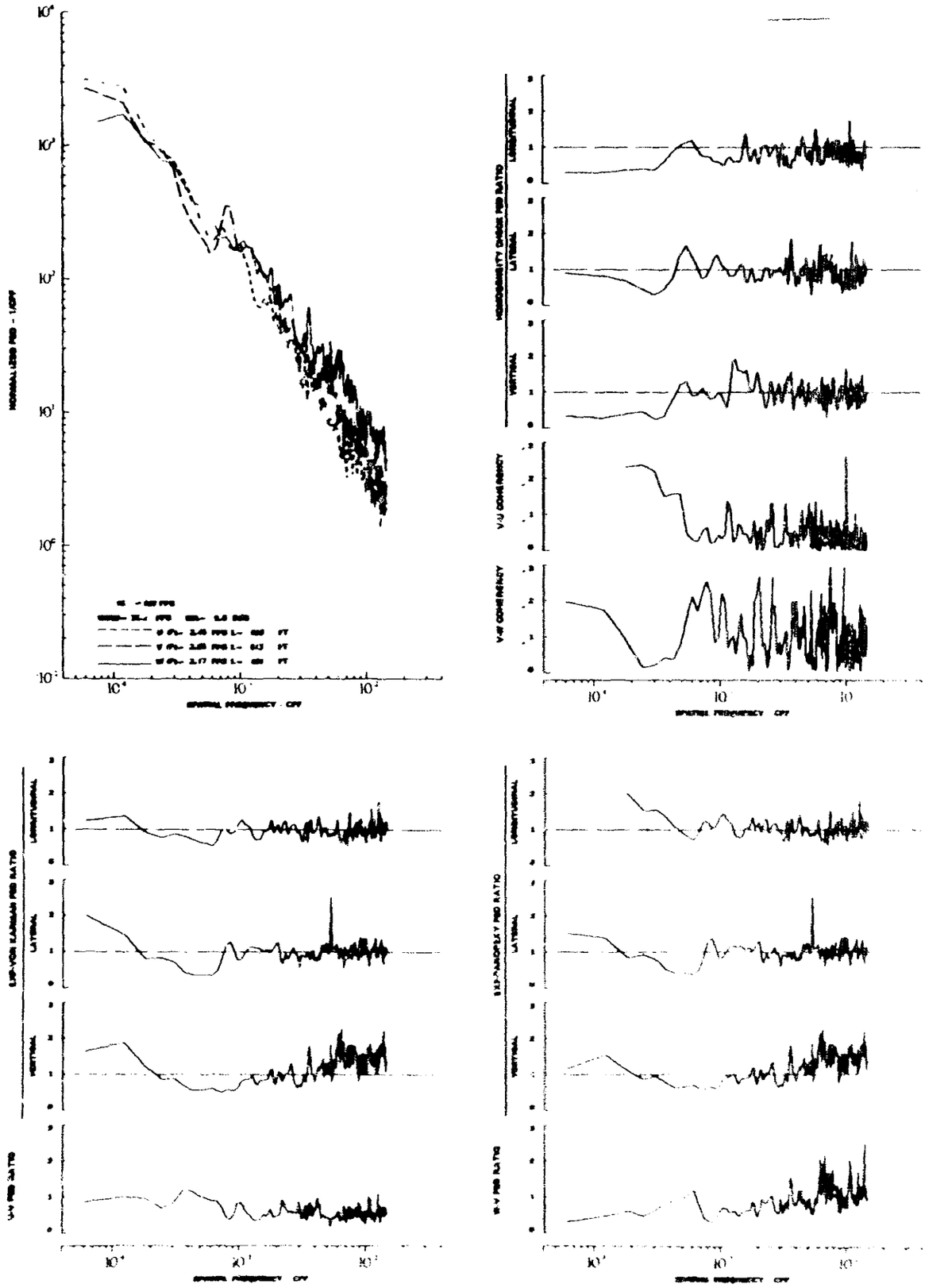

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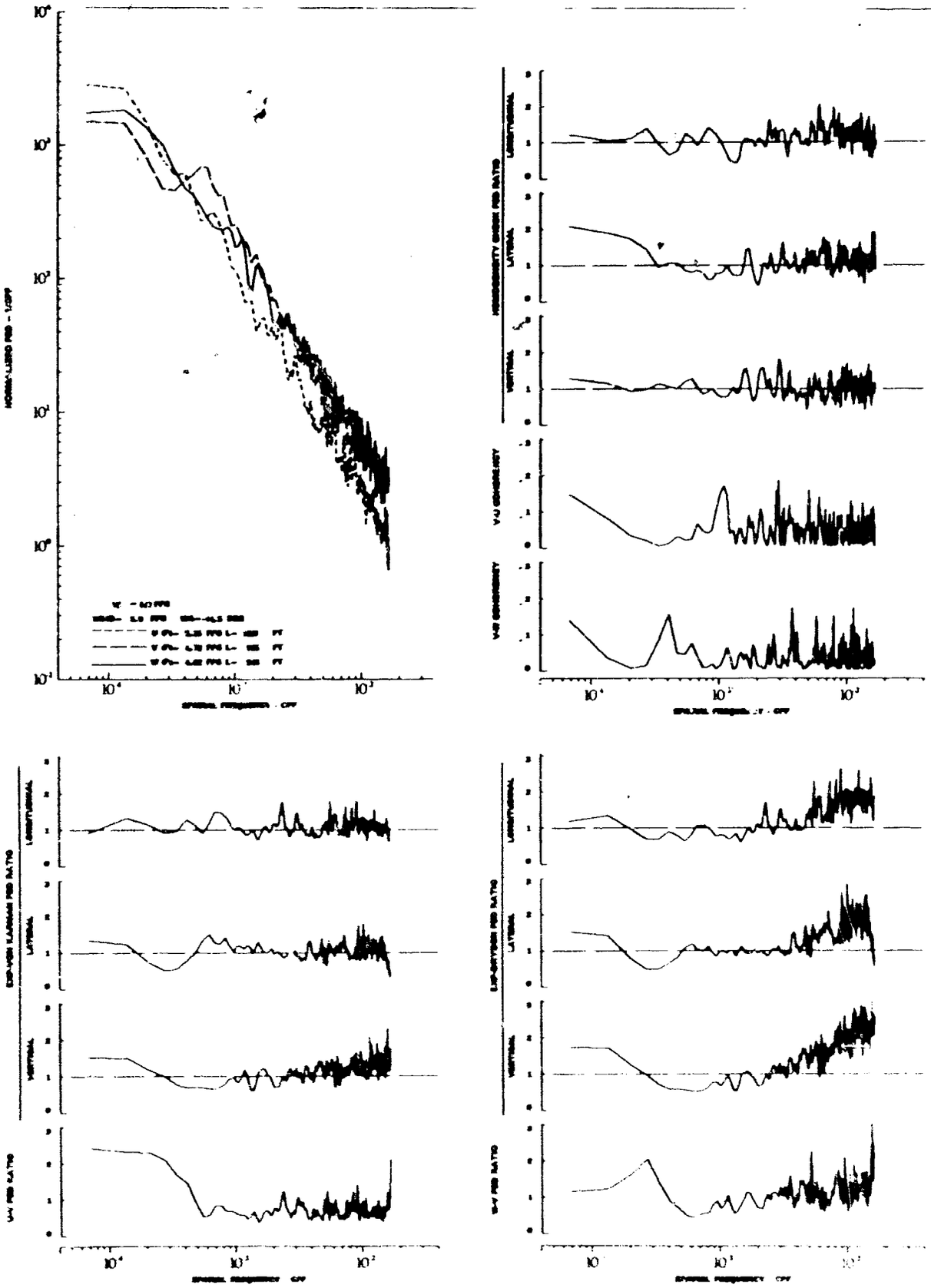

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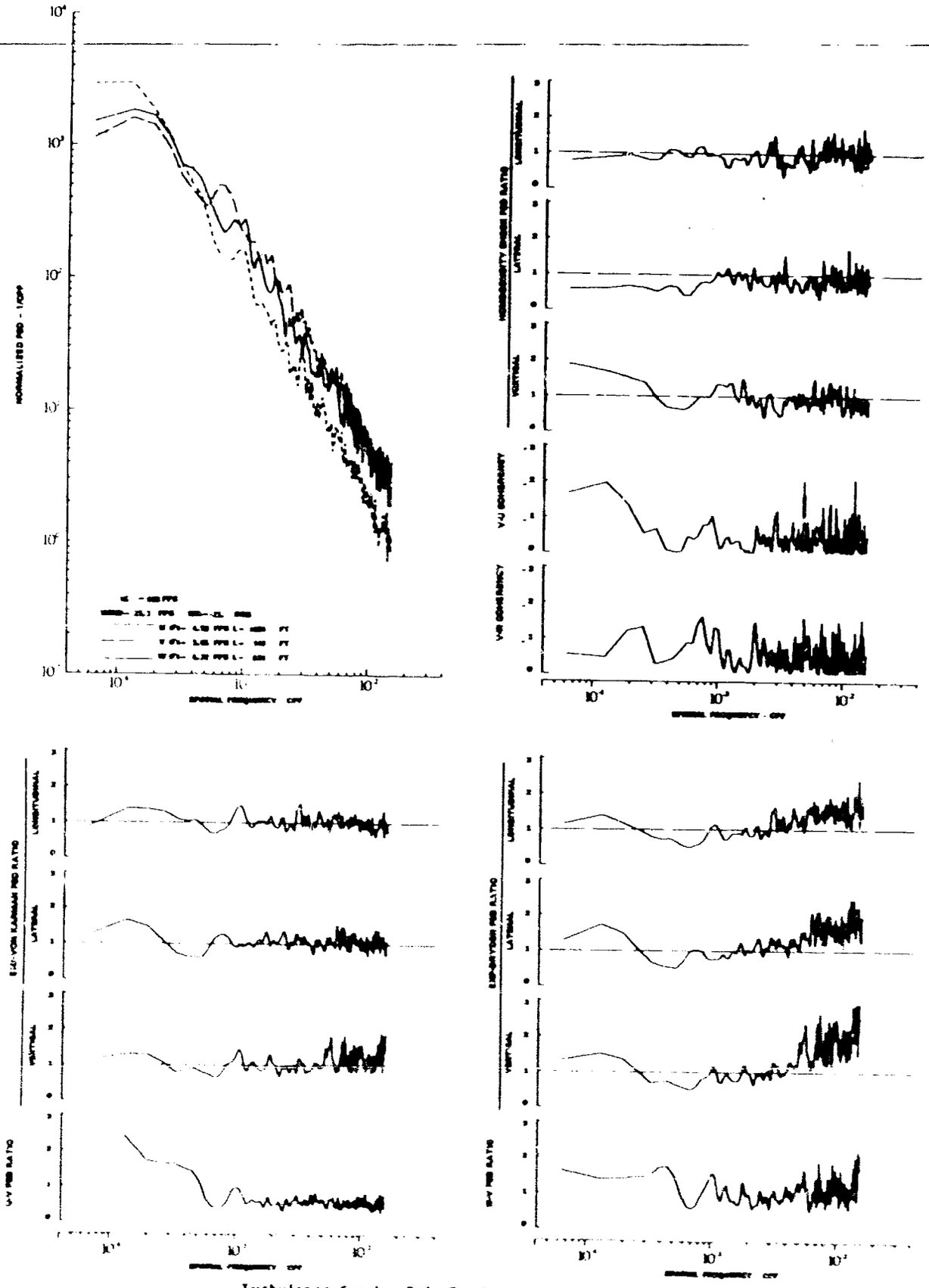

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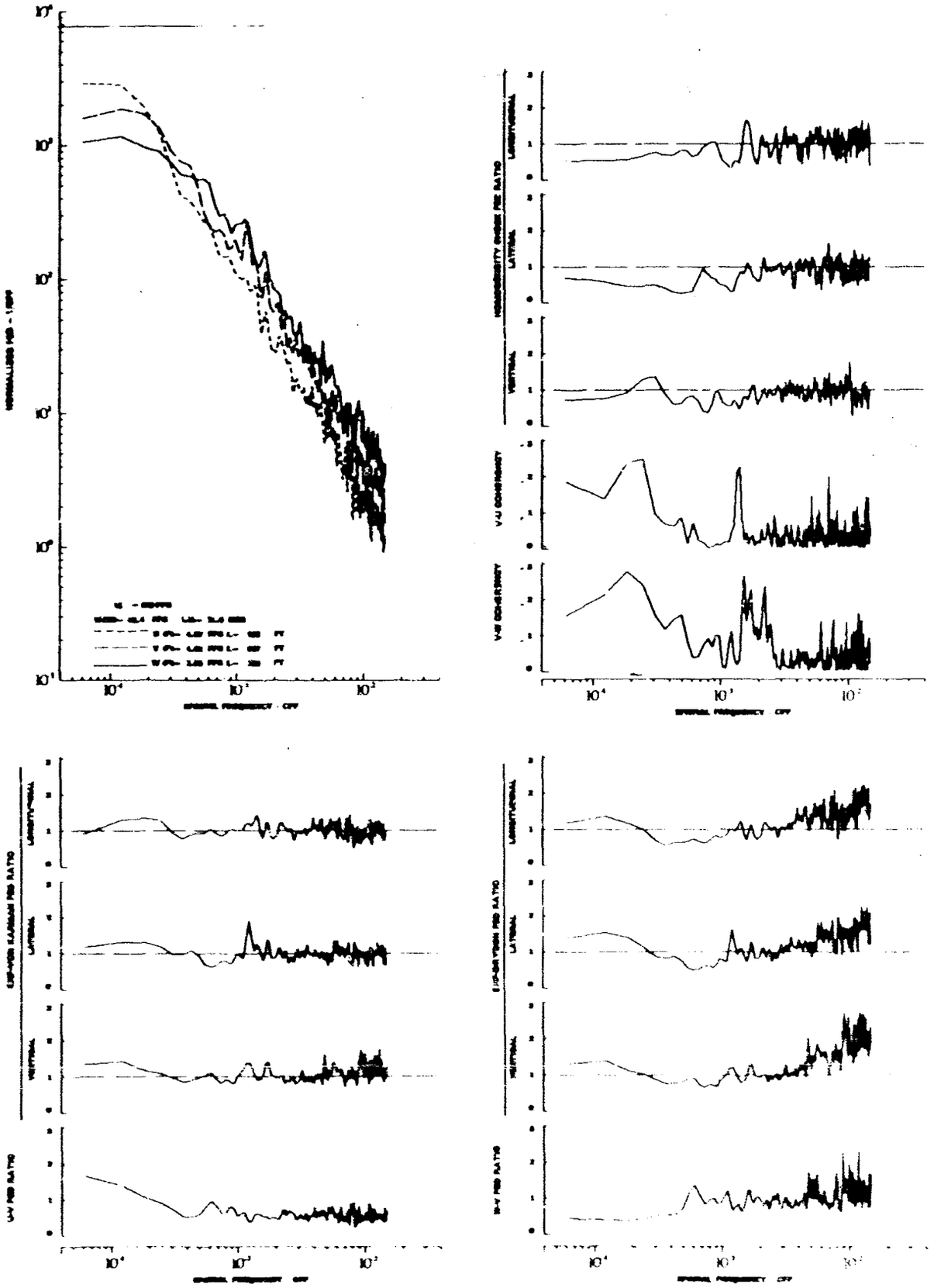

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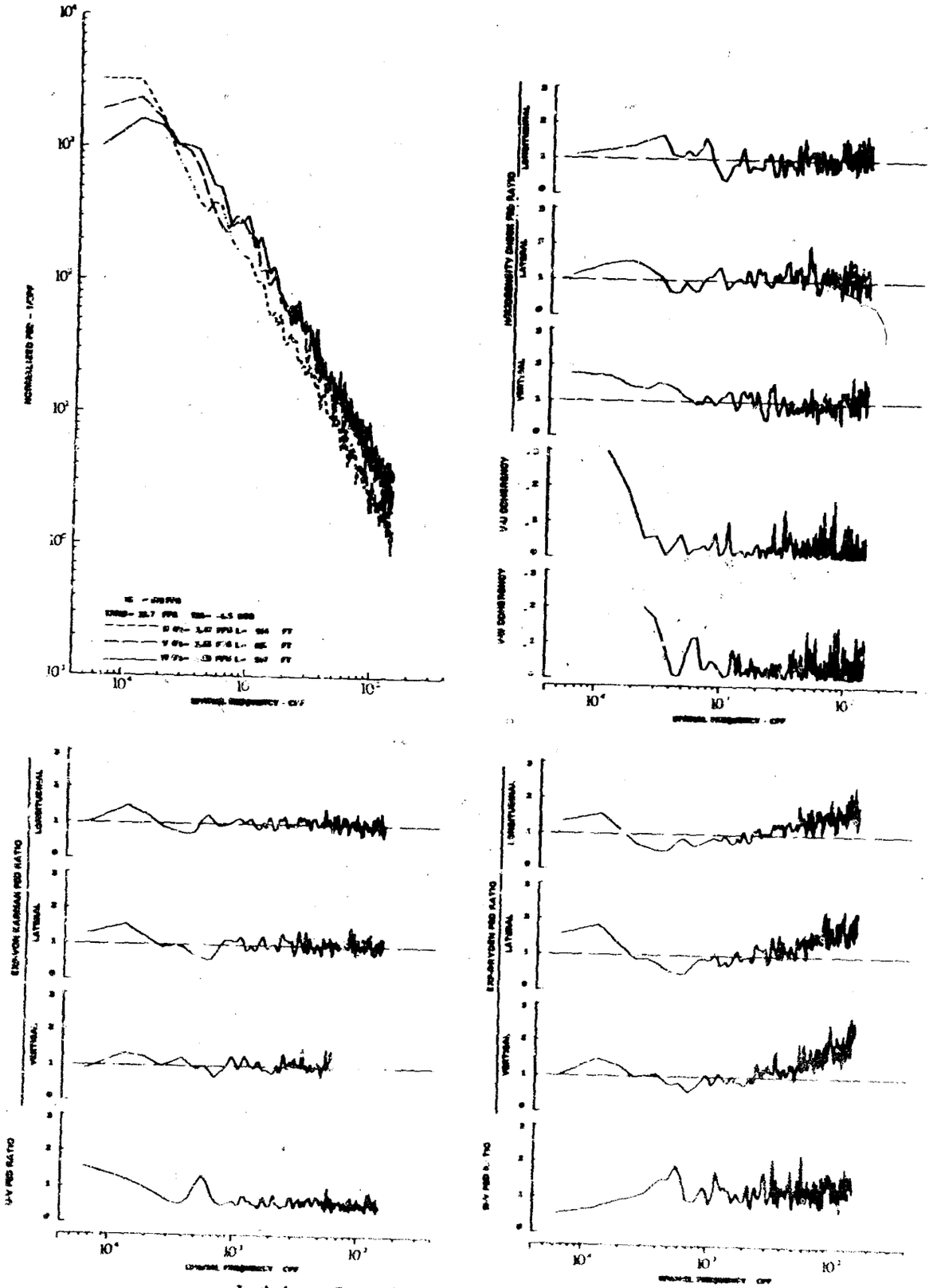

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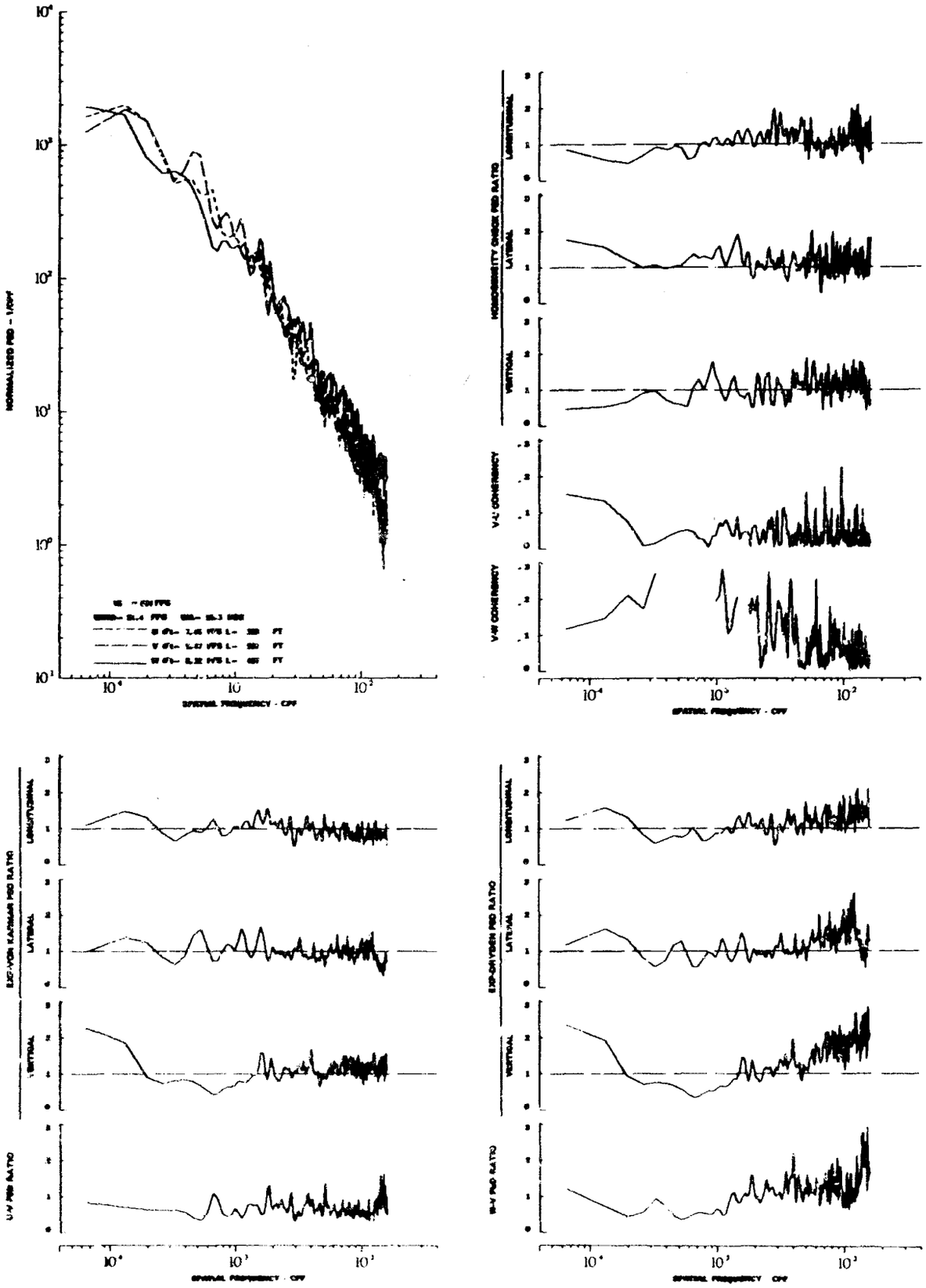
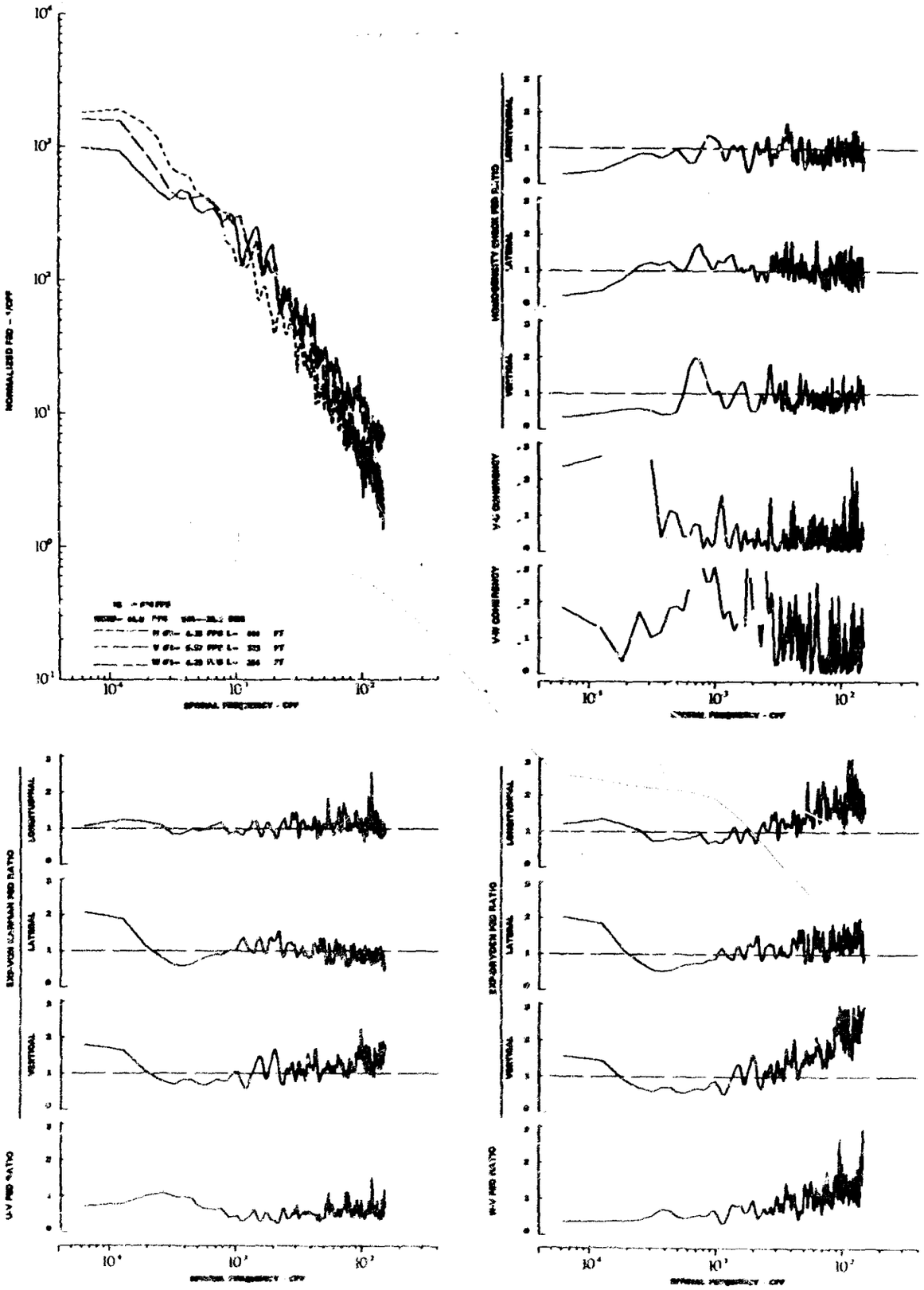
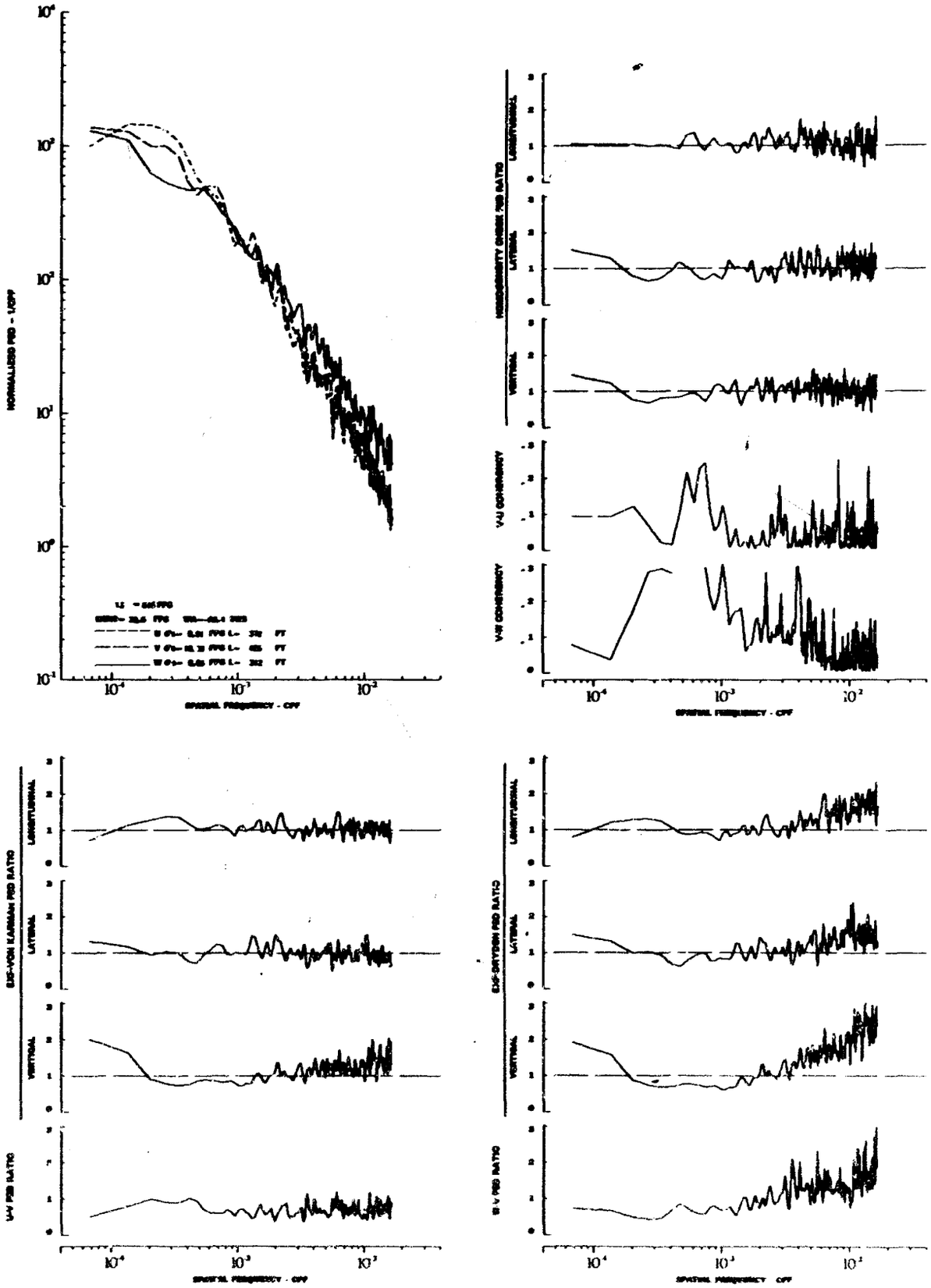


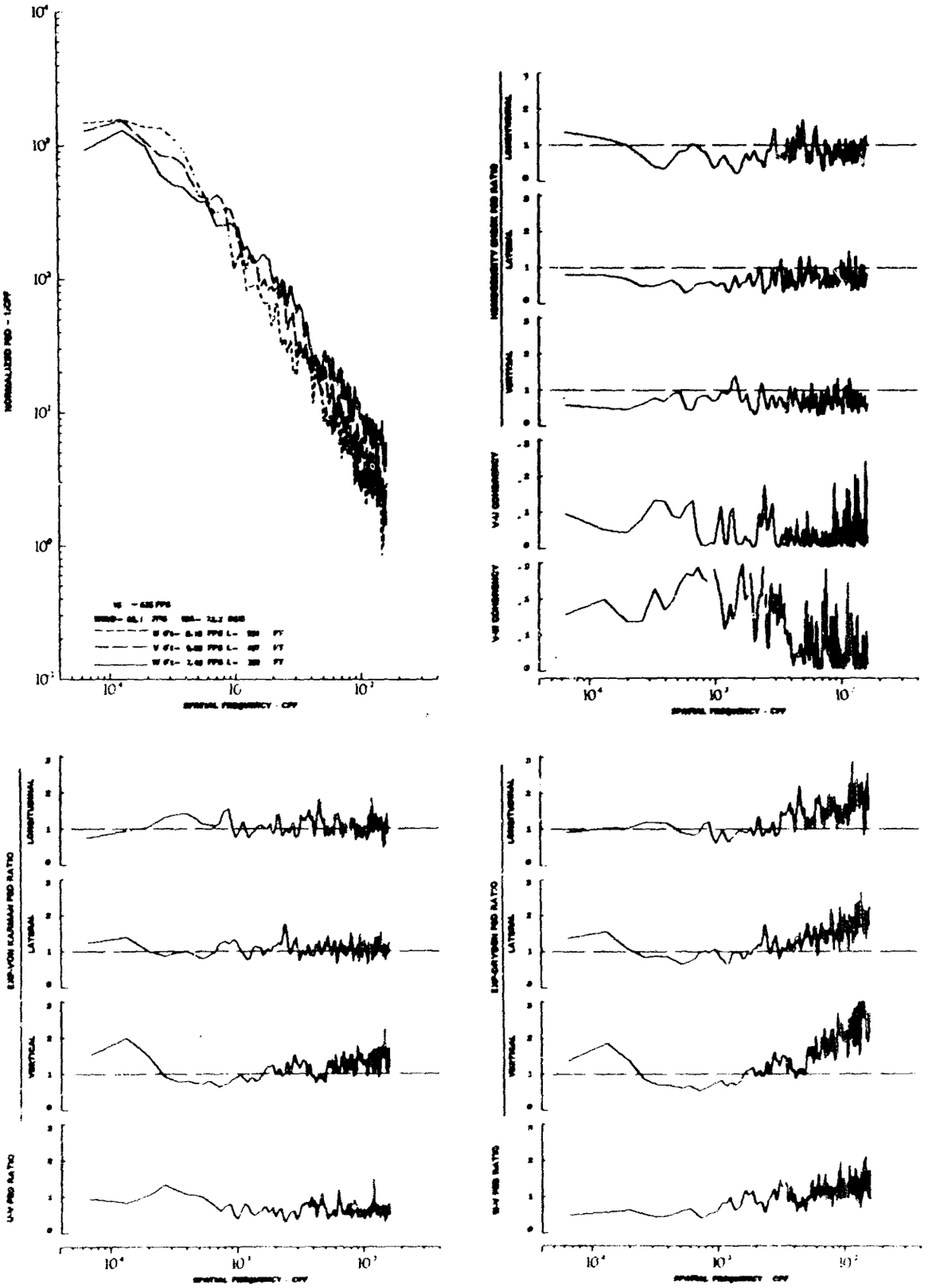
Turbulence Spectra Data For Test 189, Leg 1, Category 112243



Turbulence Spectra Data For Test 189, Leg 3, Category 113243



Turbulence Spectra Data For Test 189, Leg 5, Category 113243



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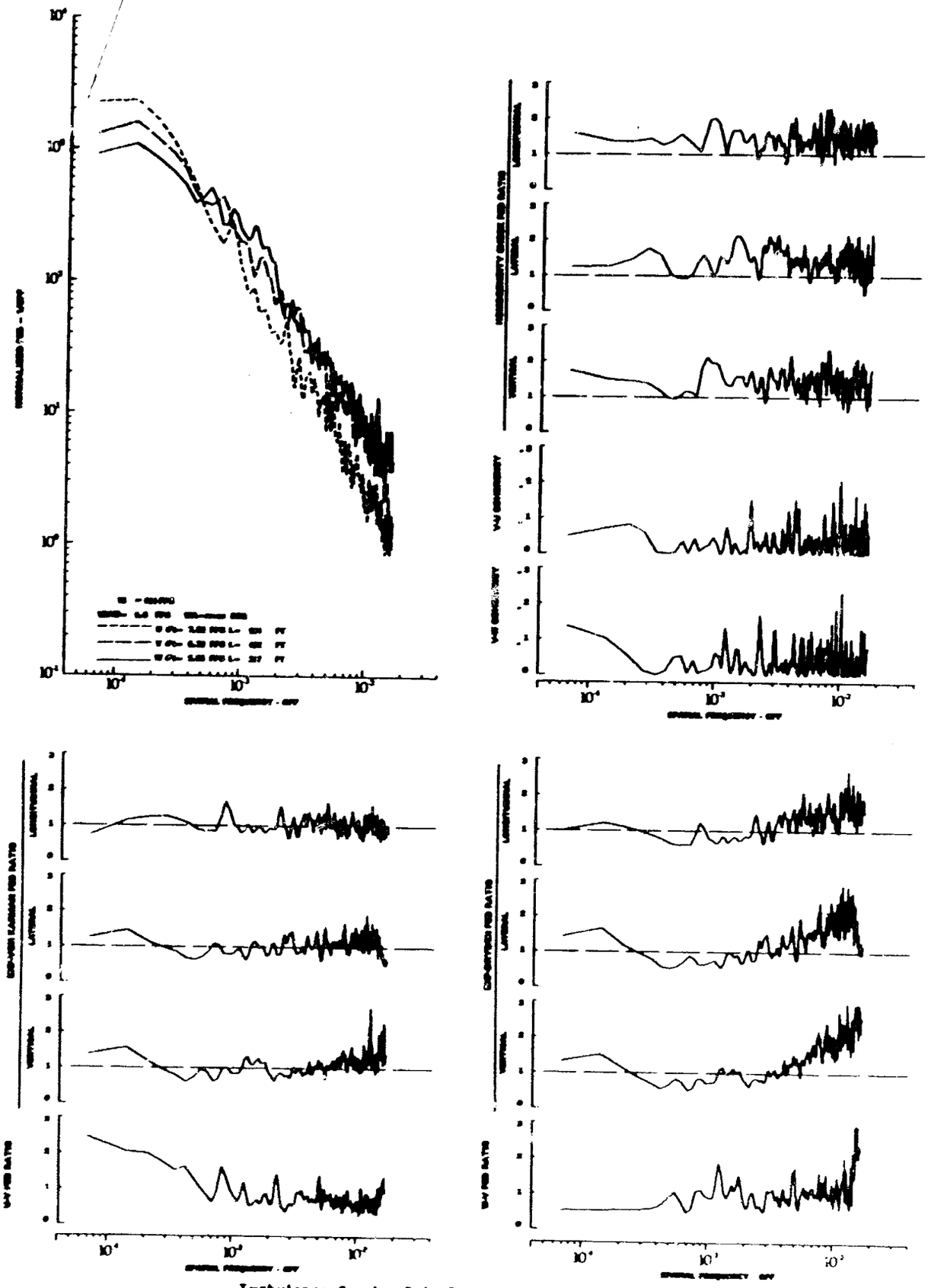
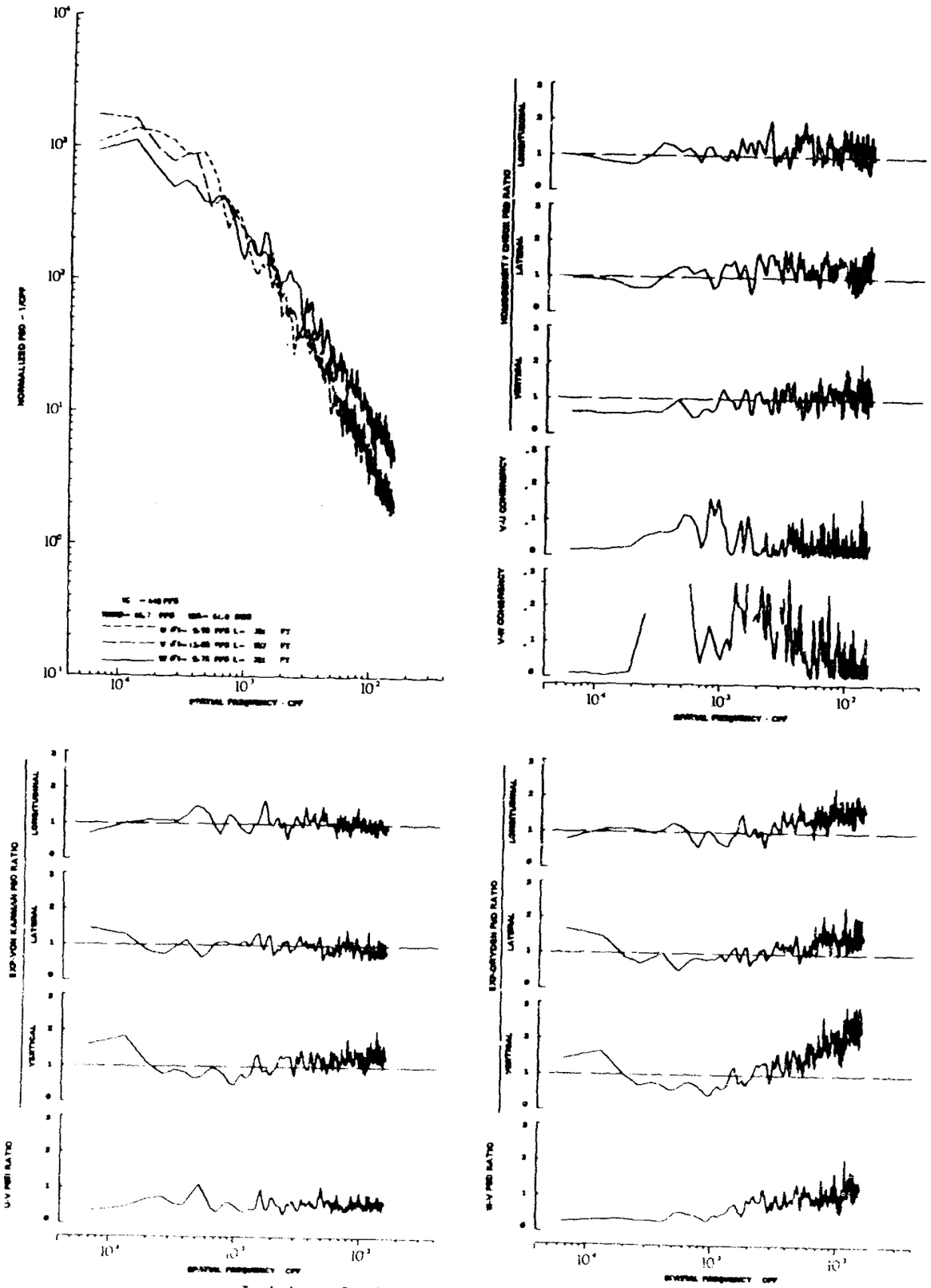
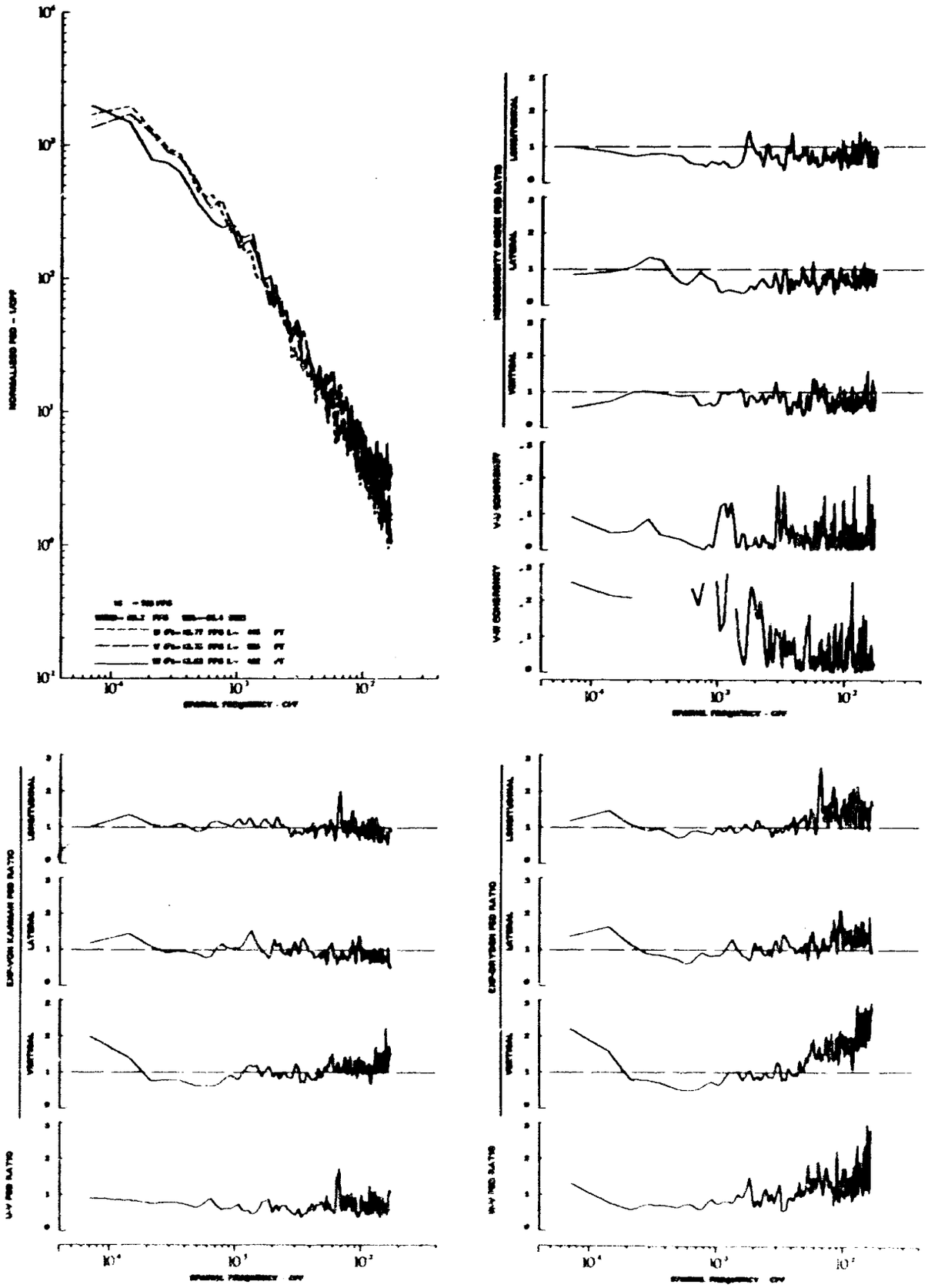


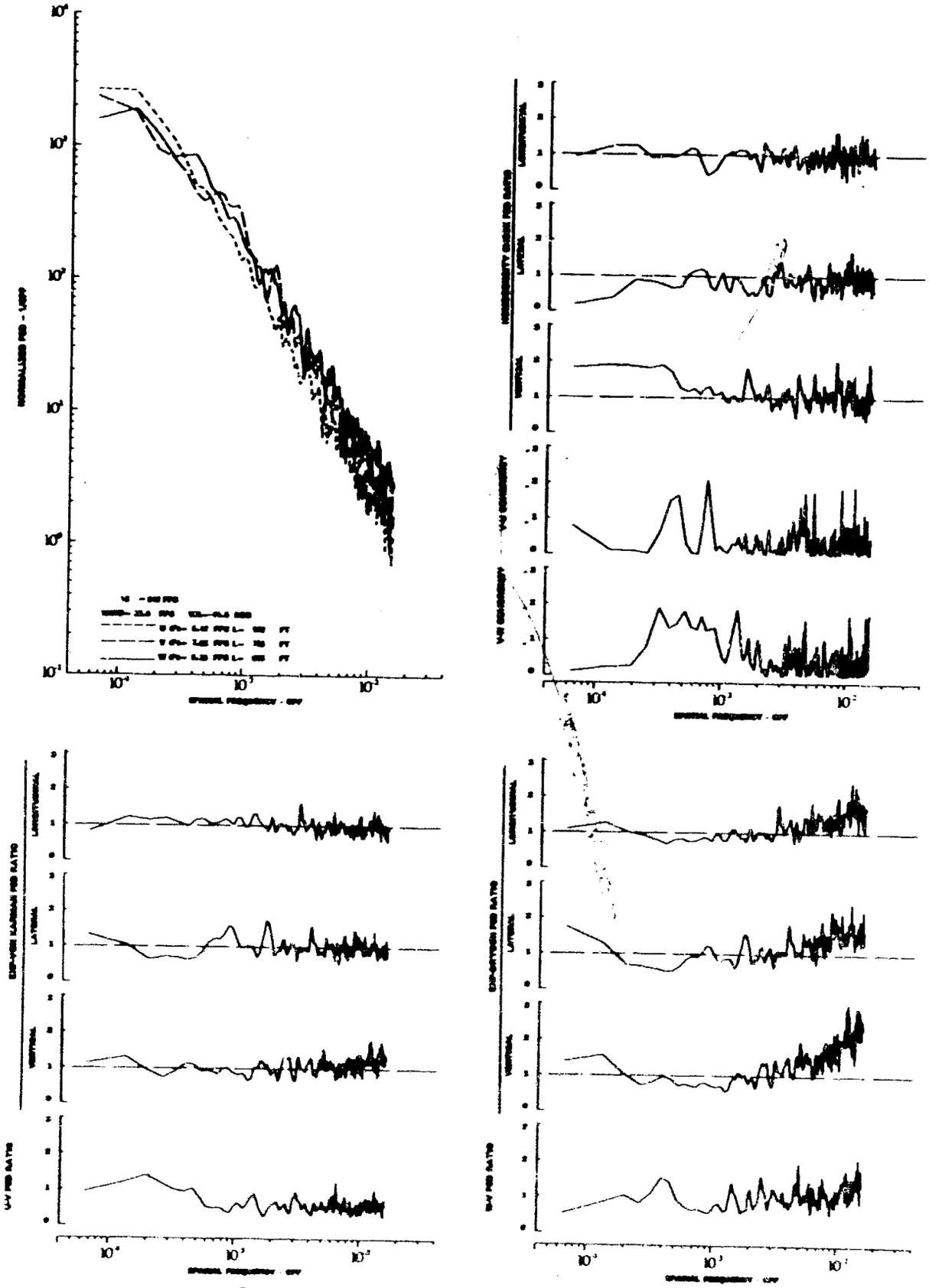
Turbulence Spectra Data For Test 190, Log 2, Category 114343



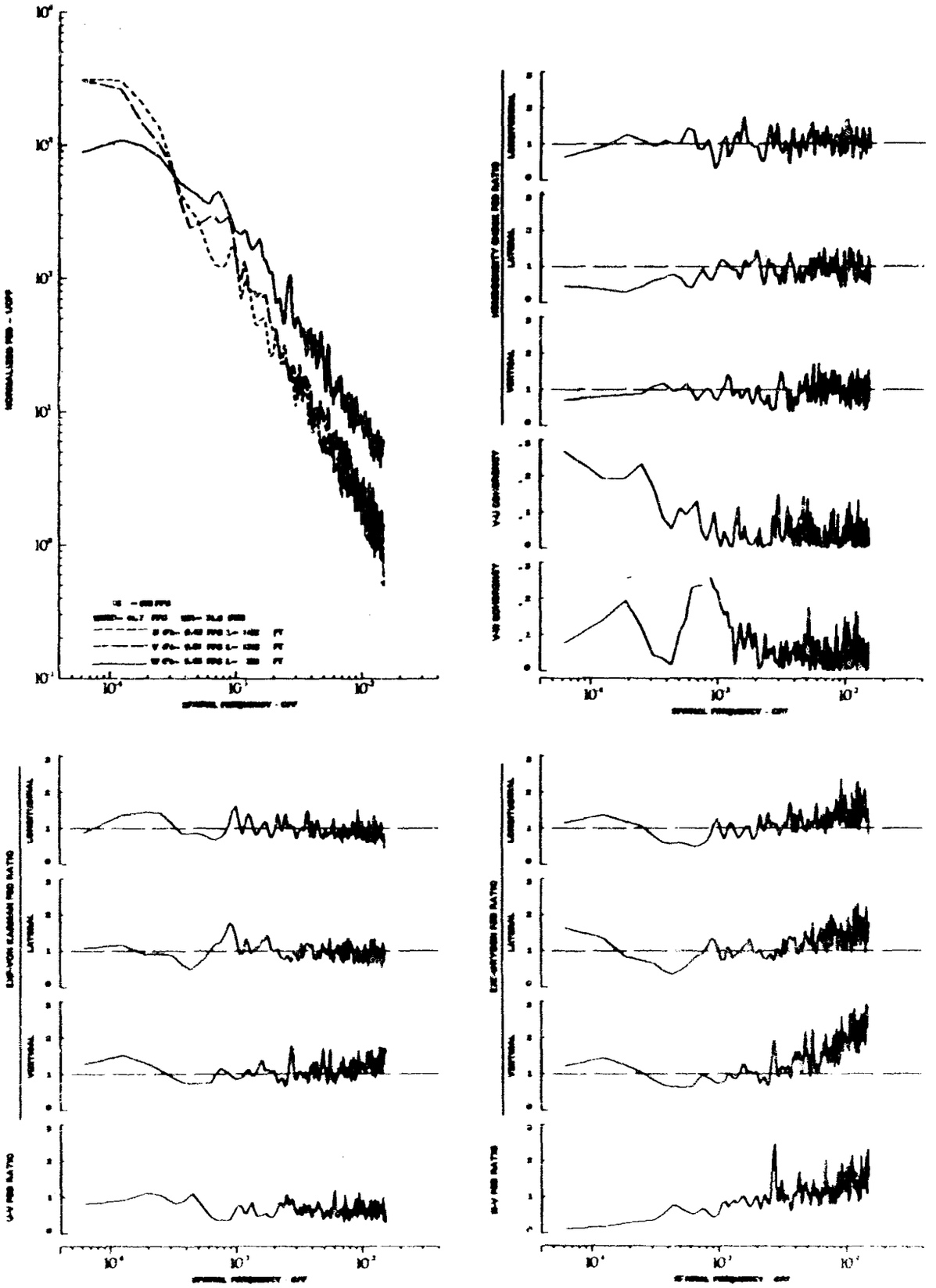
Turbulence Spectra Data For Test 190, Leg 6, Category 112343



Turbulence Spectra Data For Test 191, Leg 5, Category 122143



Turbulence Spectra Data For Test 192, Leg 4, Category 124243



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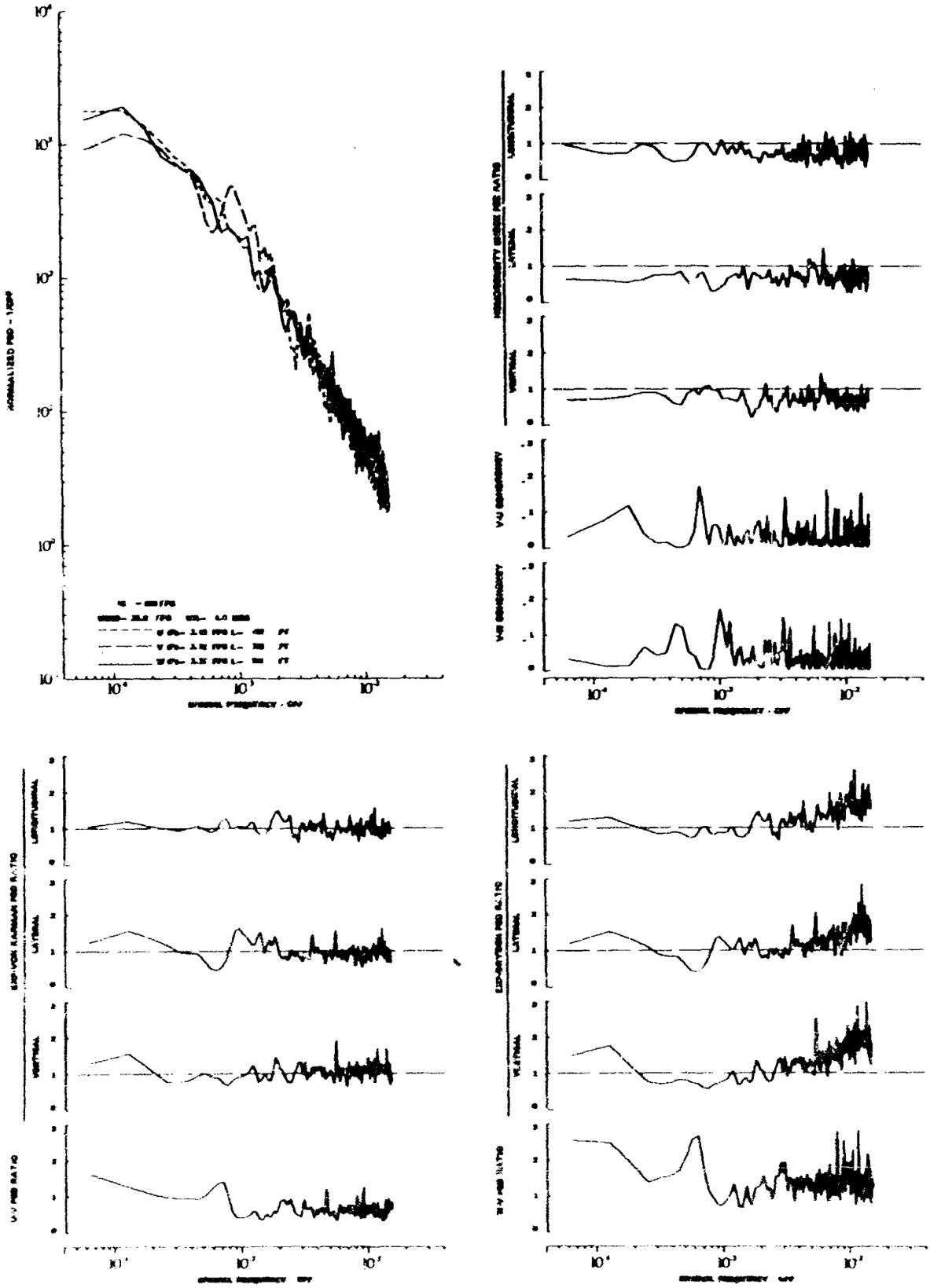
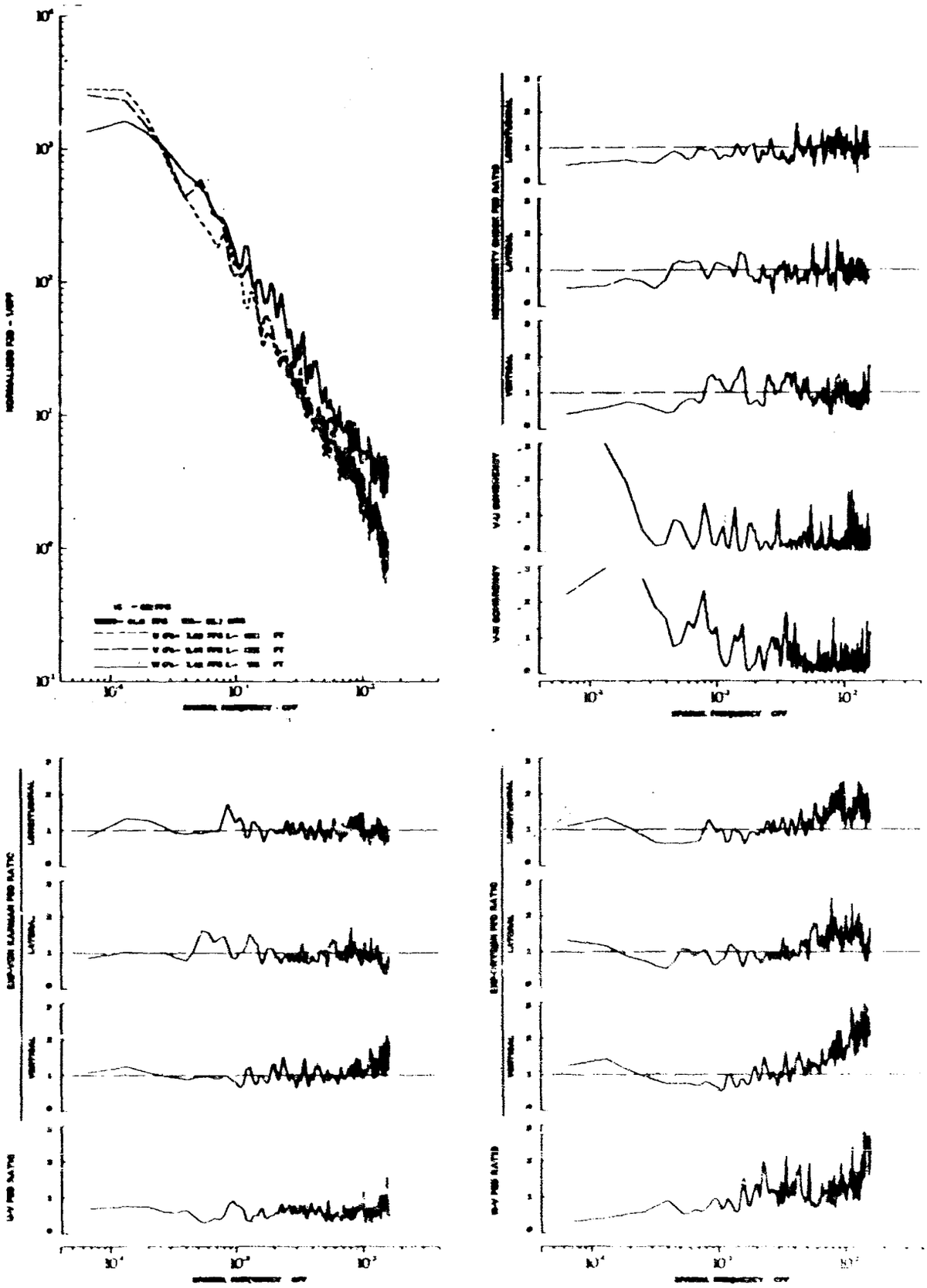


Turbulence Spectra Data For Test 192, Leg 8, Category 423243



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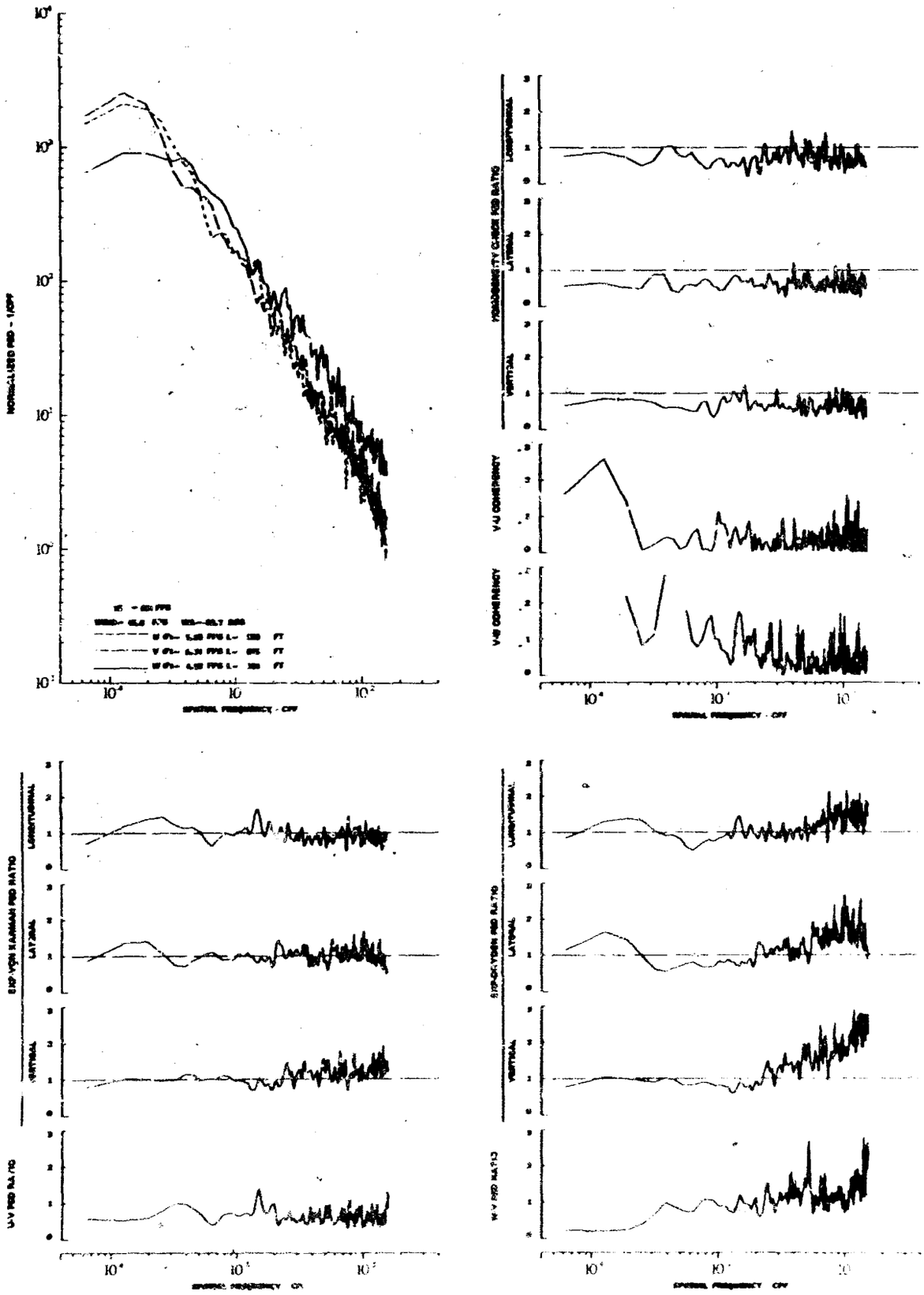

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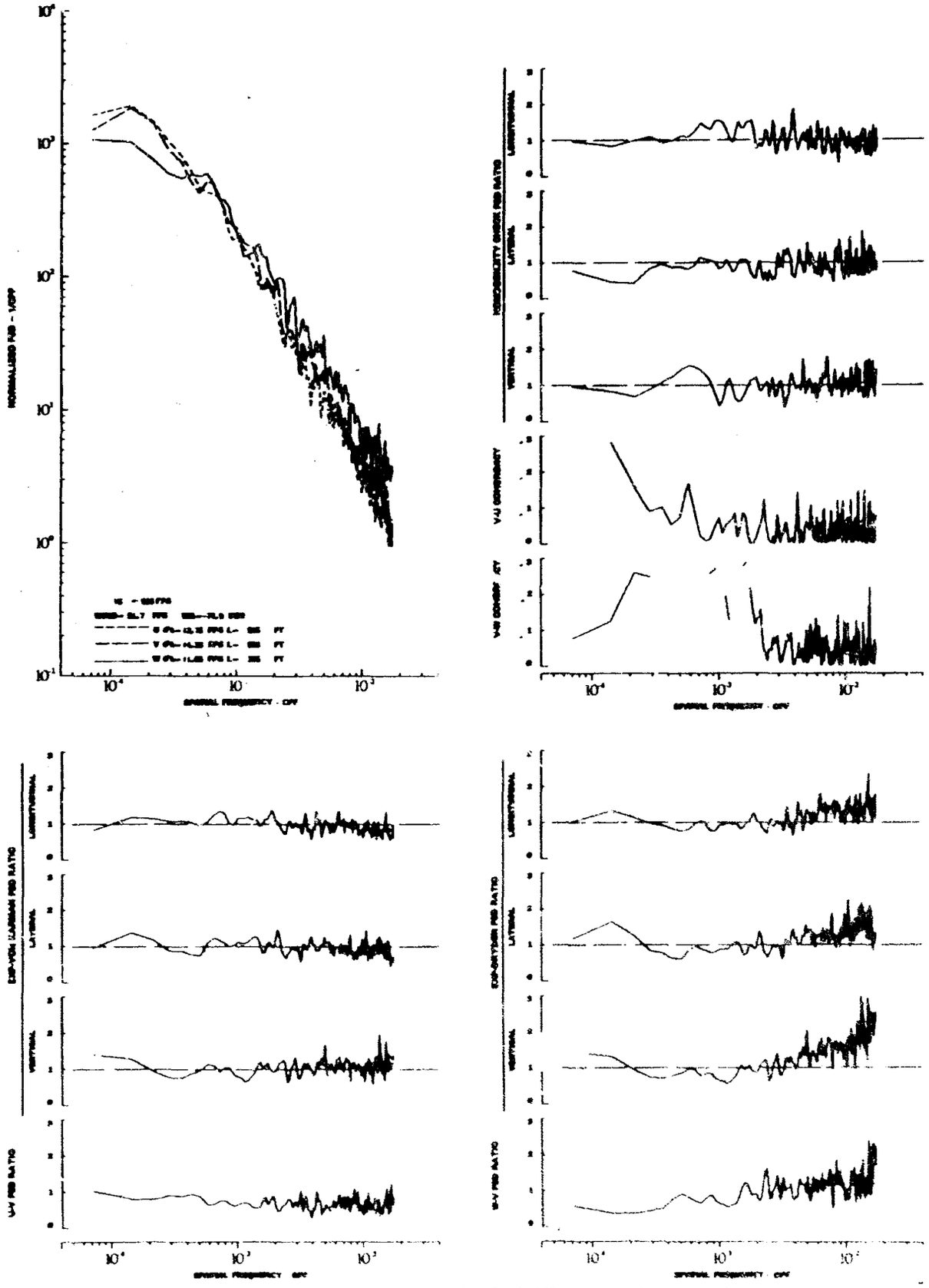

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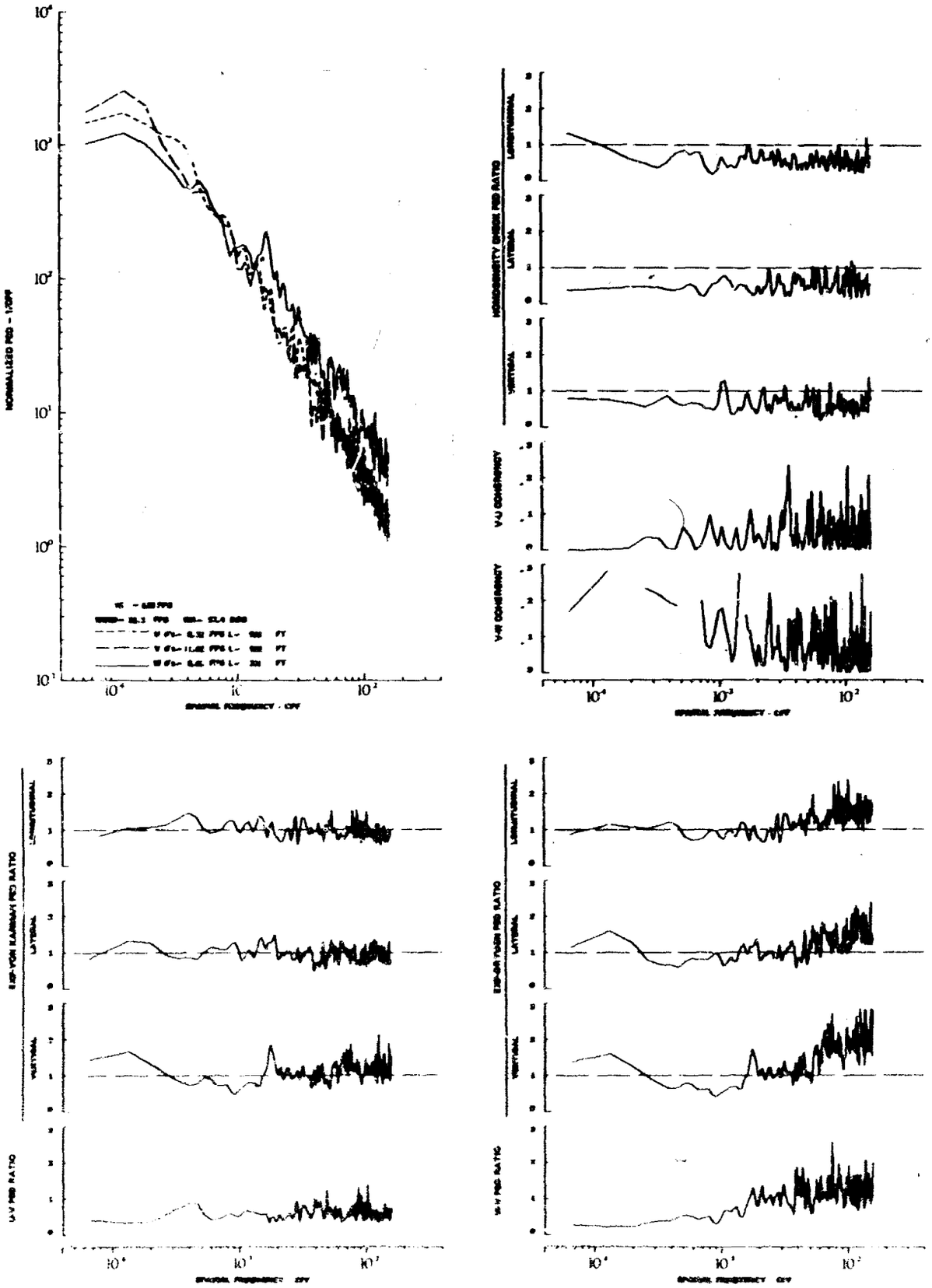

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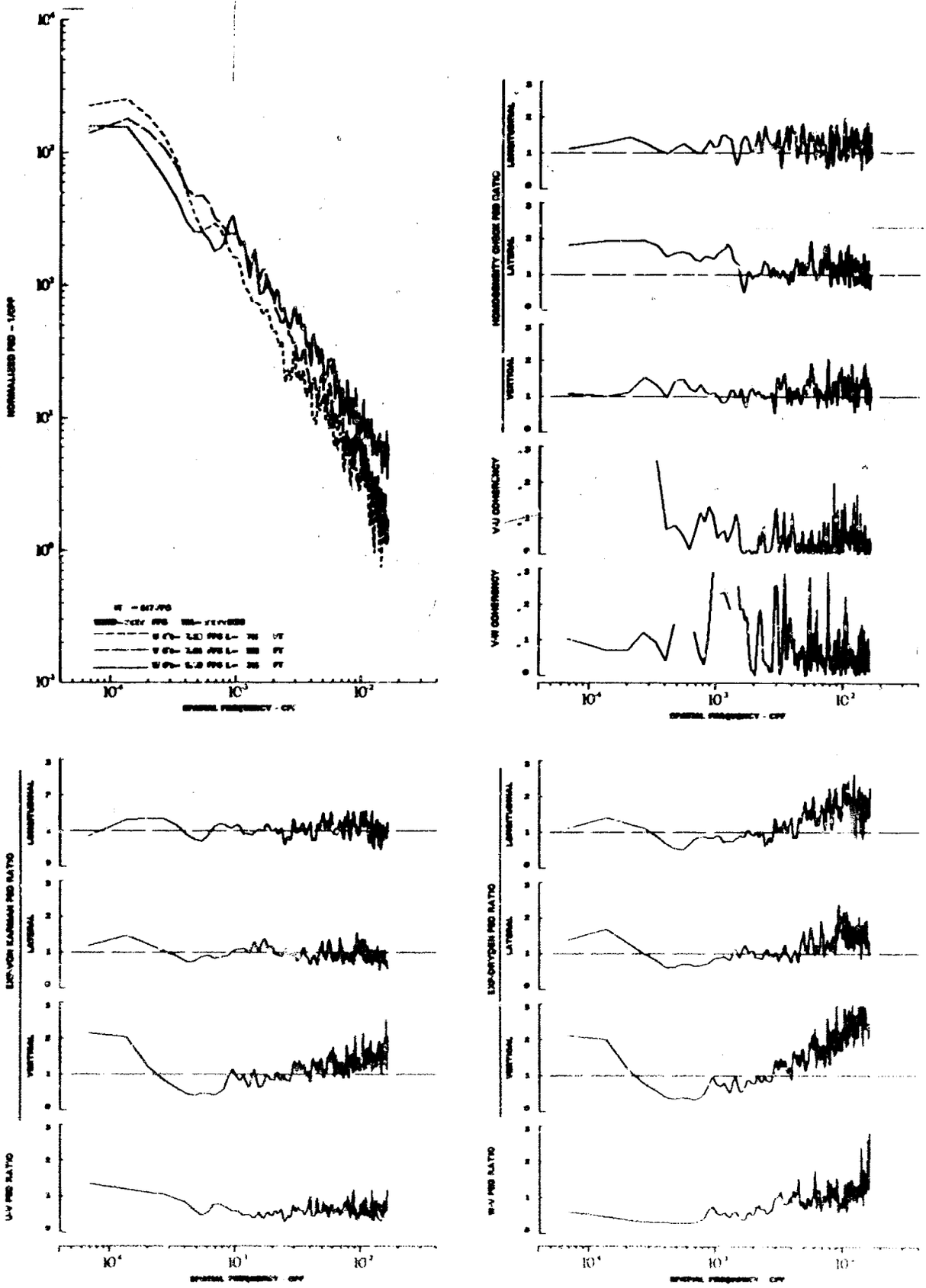

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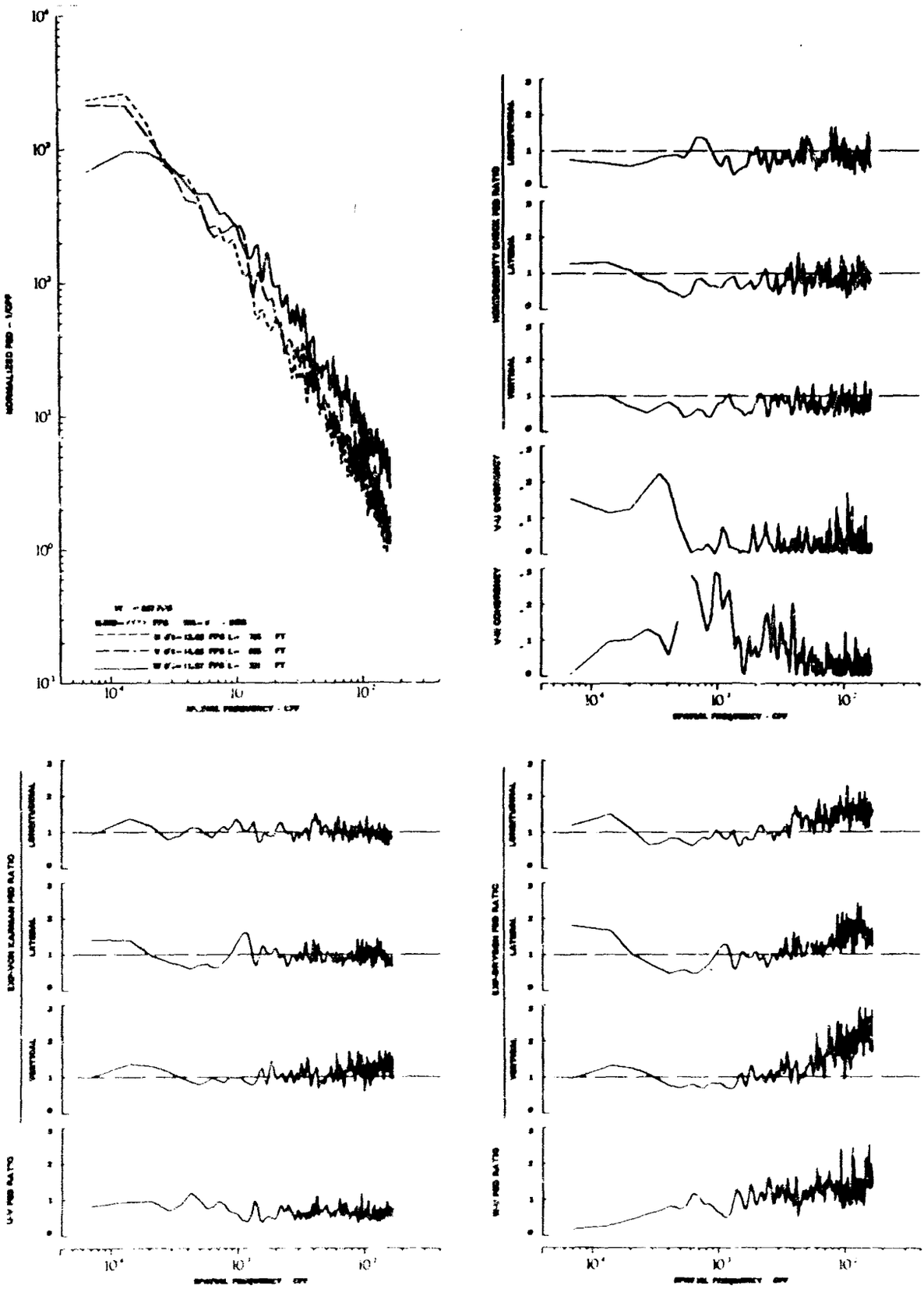
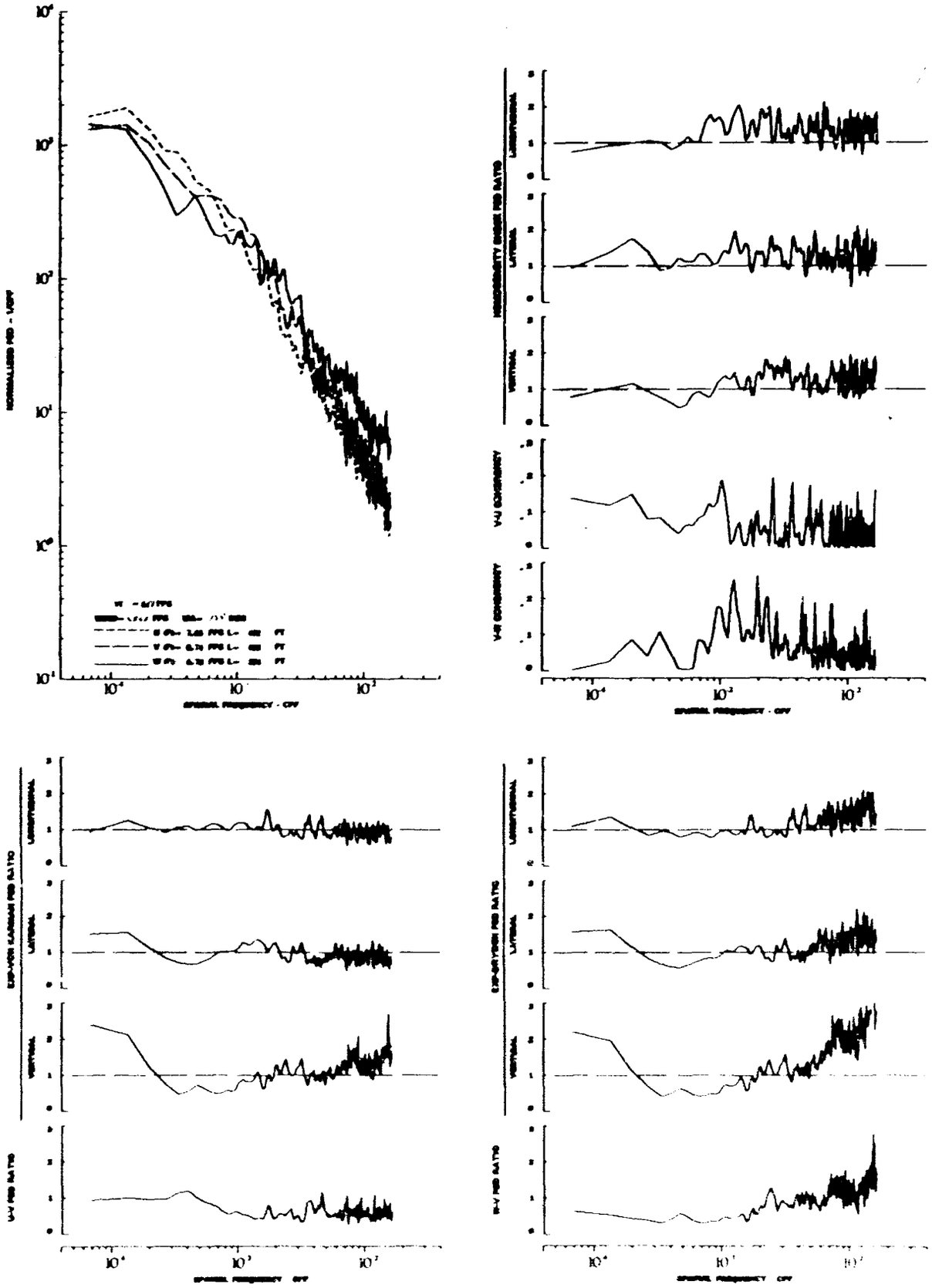


Turbulence Spectra Data For Test 194, Leg 5, Category 112143



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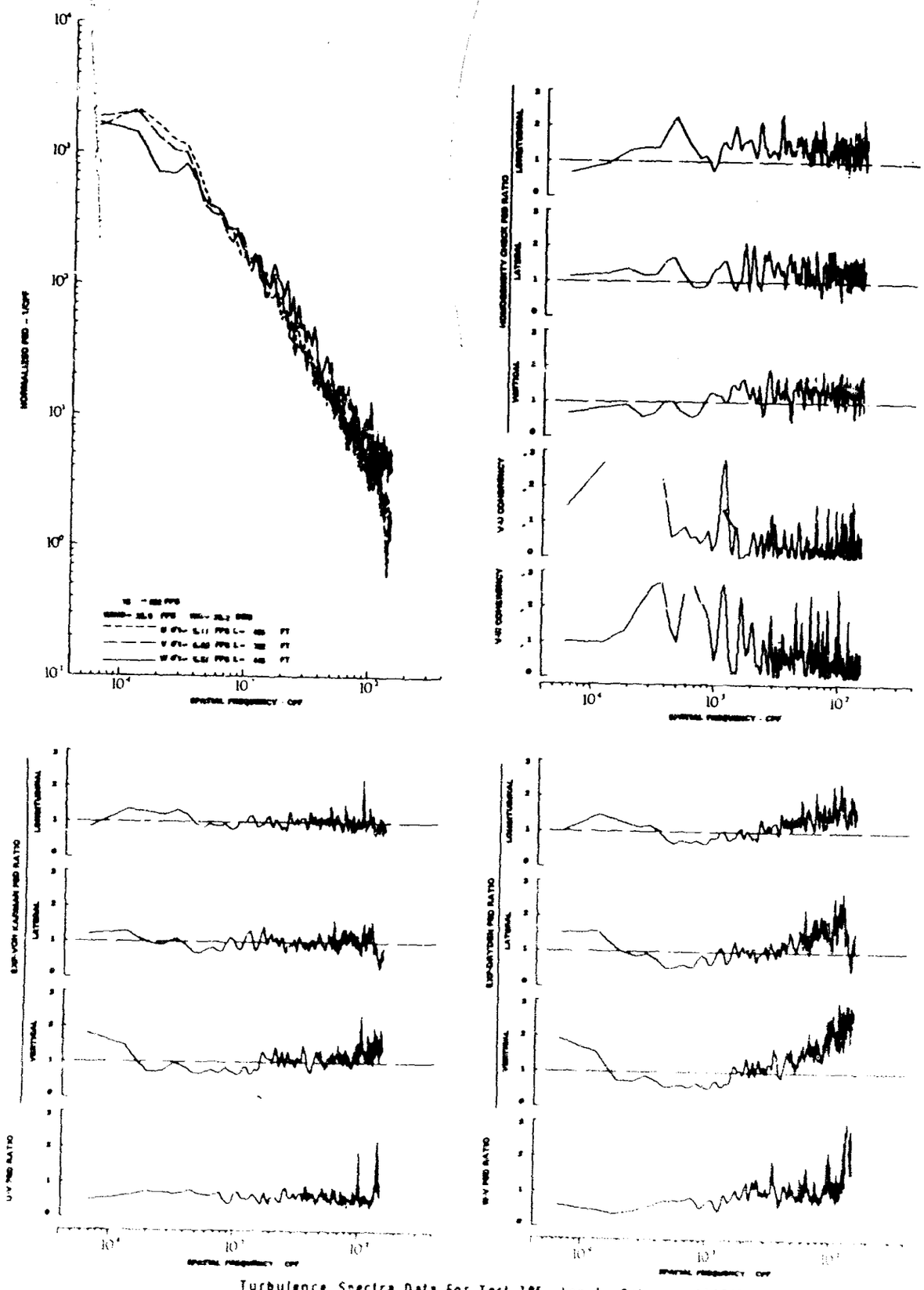
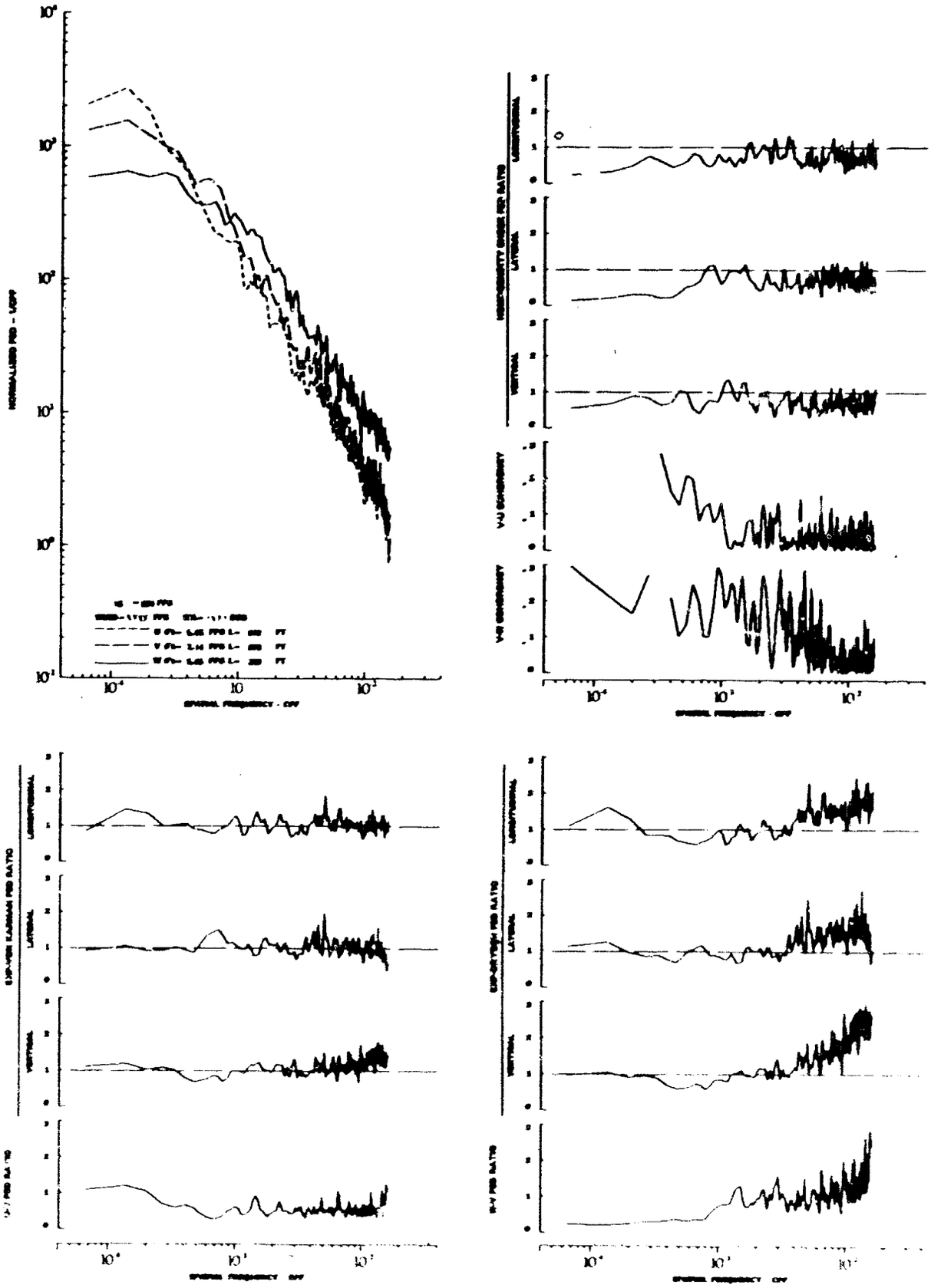
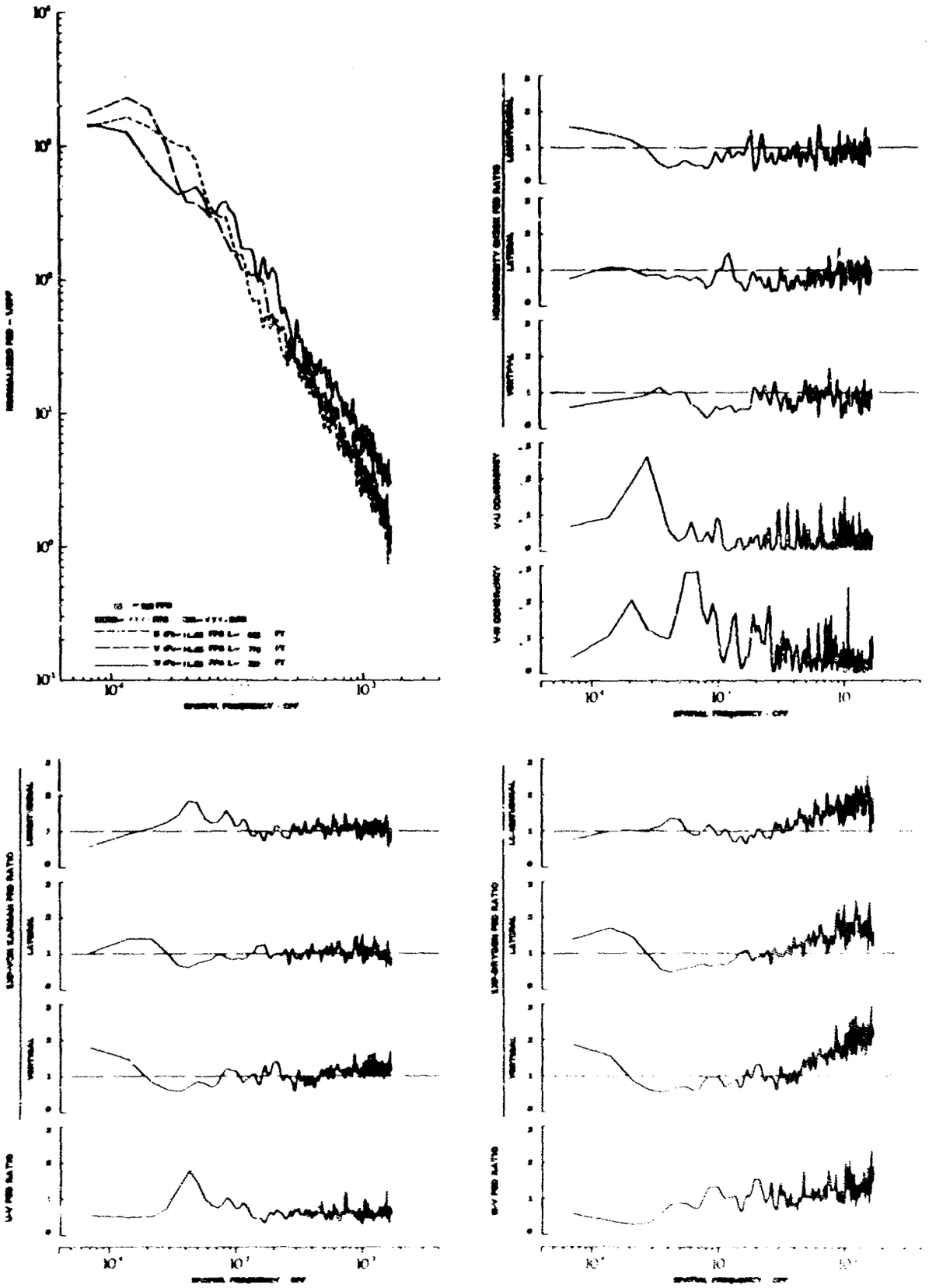


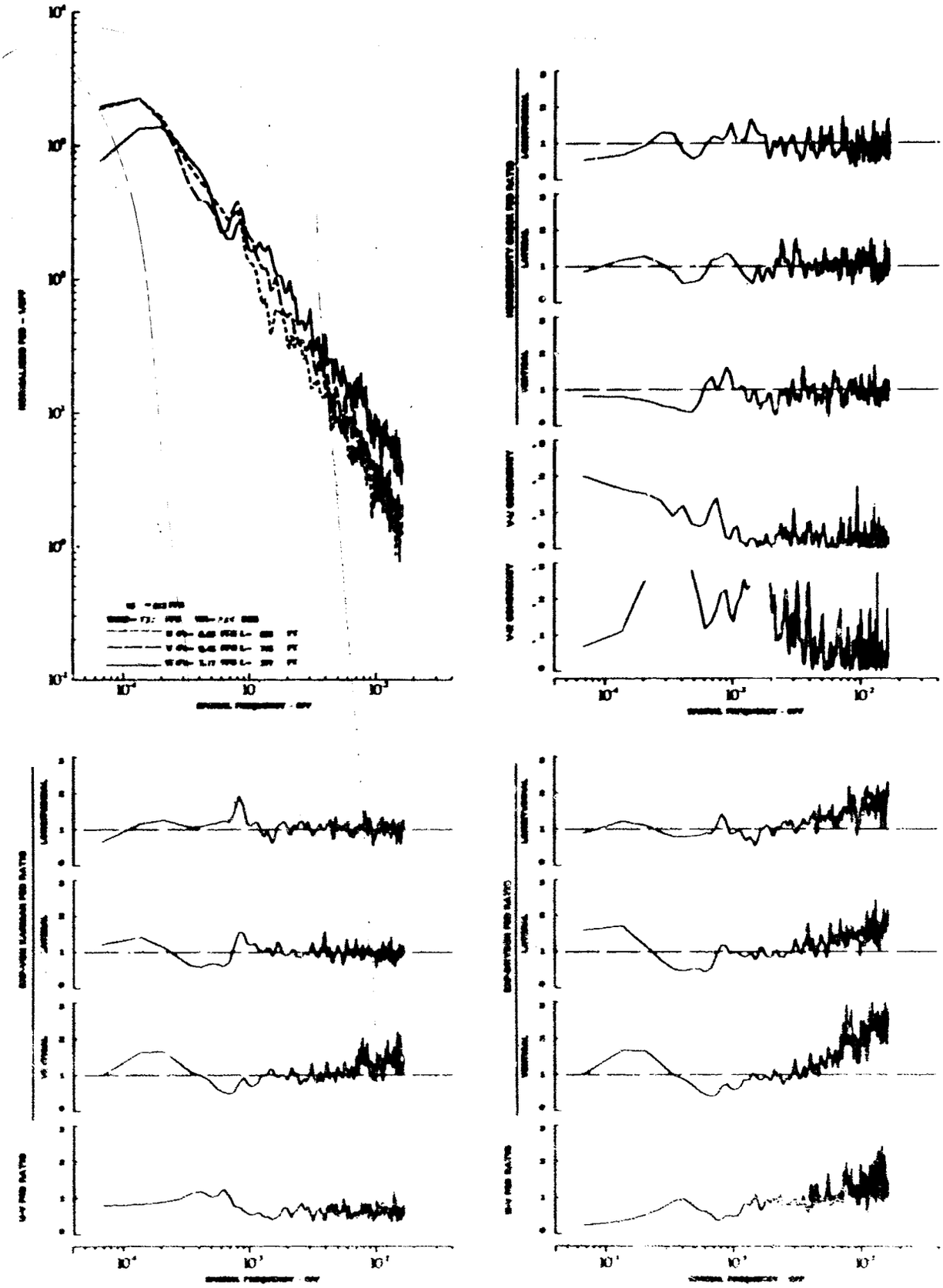
Turbulence Spectra Data For Test 195, Leg 1, Category 114243



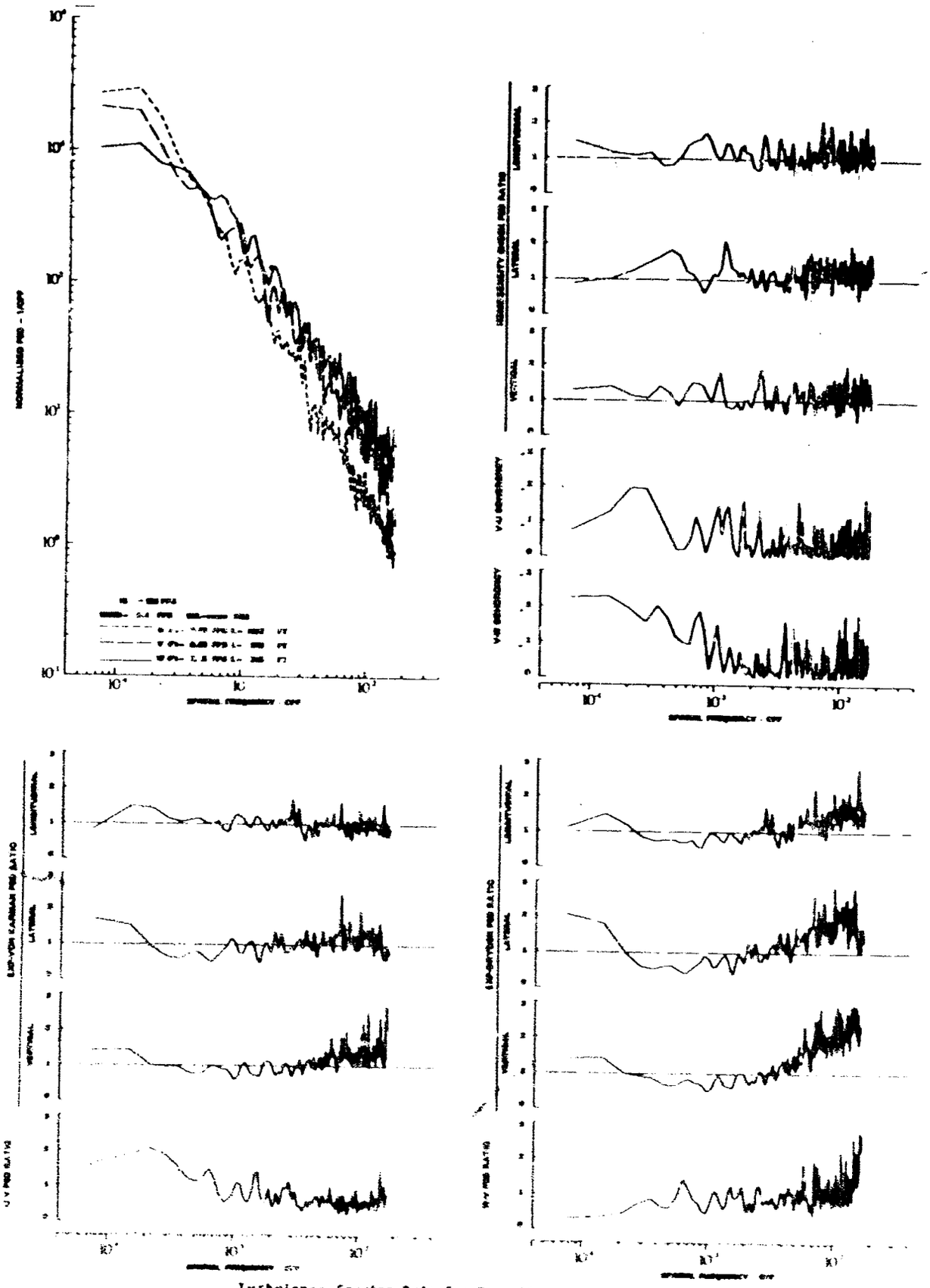
Turbulence Spectra Data For Test 195, Leg 3, Category 113243



Turbulence Spectra Data For Test 195, Leg 5, Category 133243



Turbulence Spectra Data For Test 195, Log 7, Category 114243



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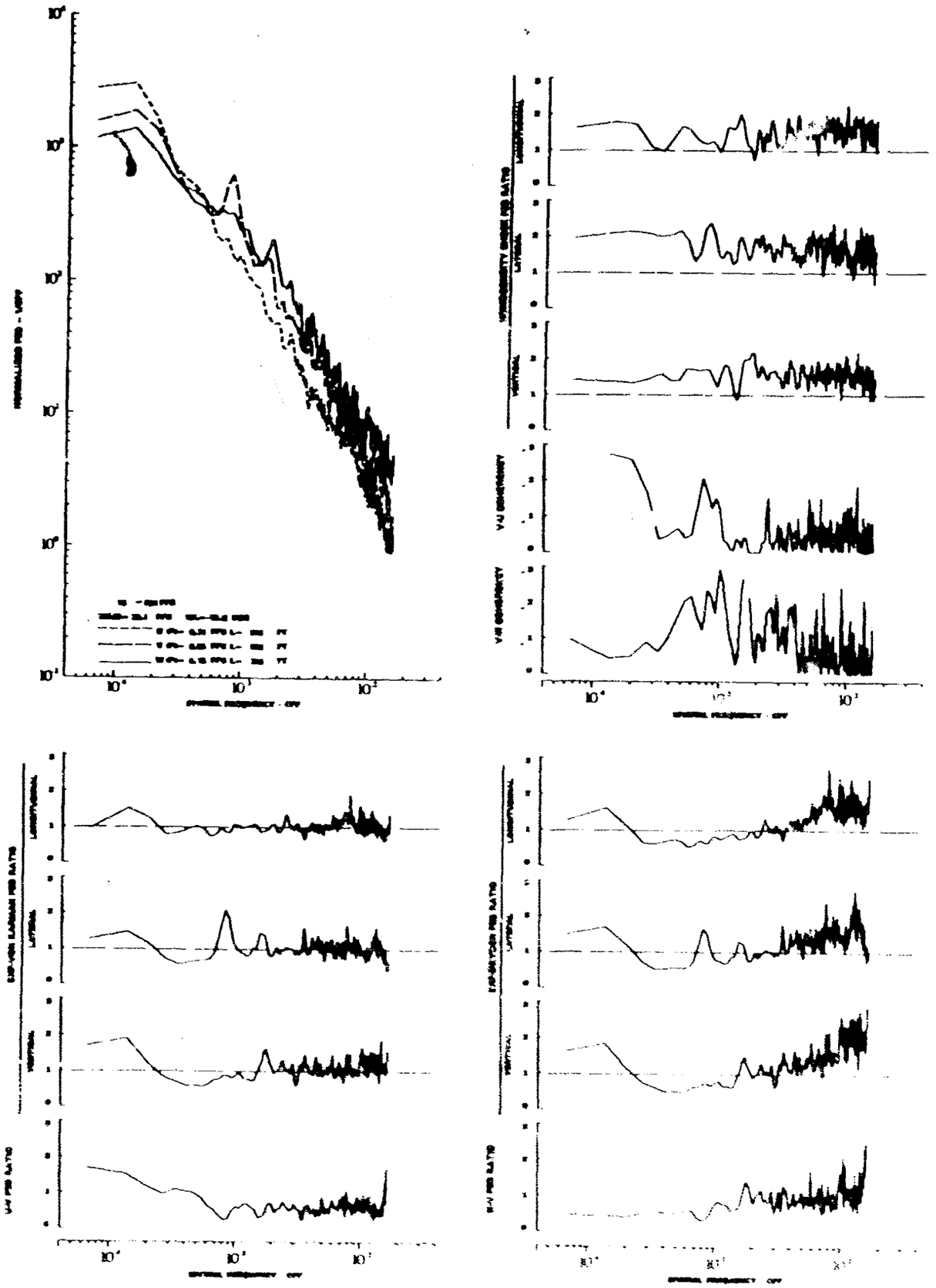
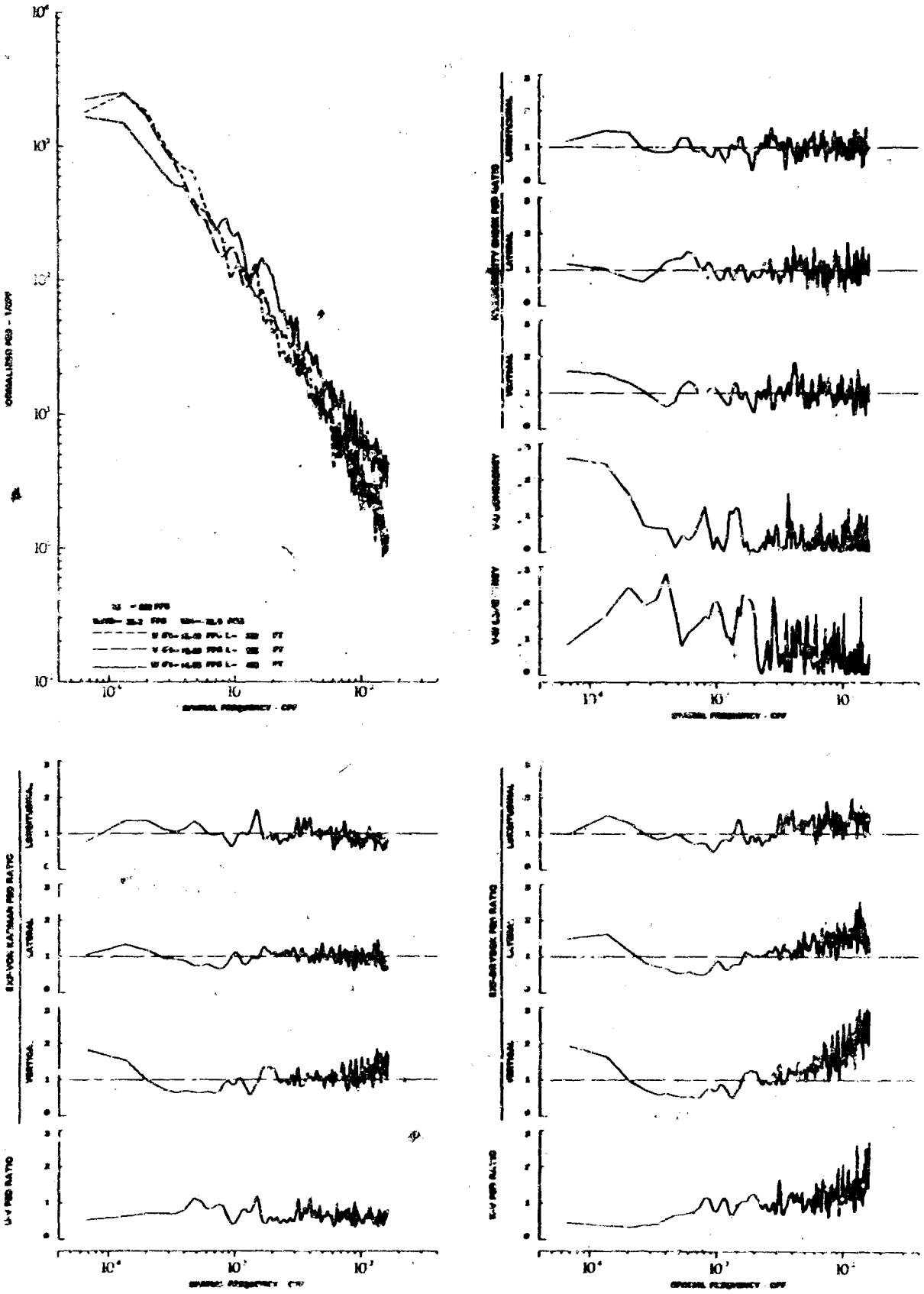
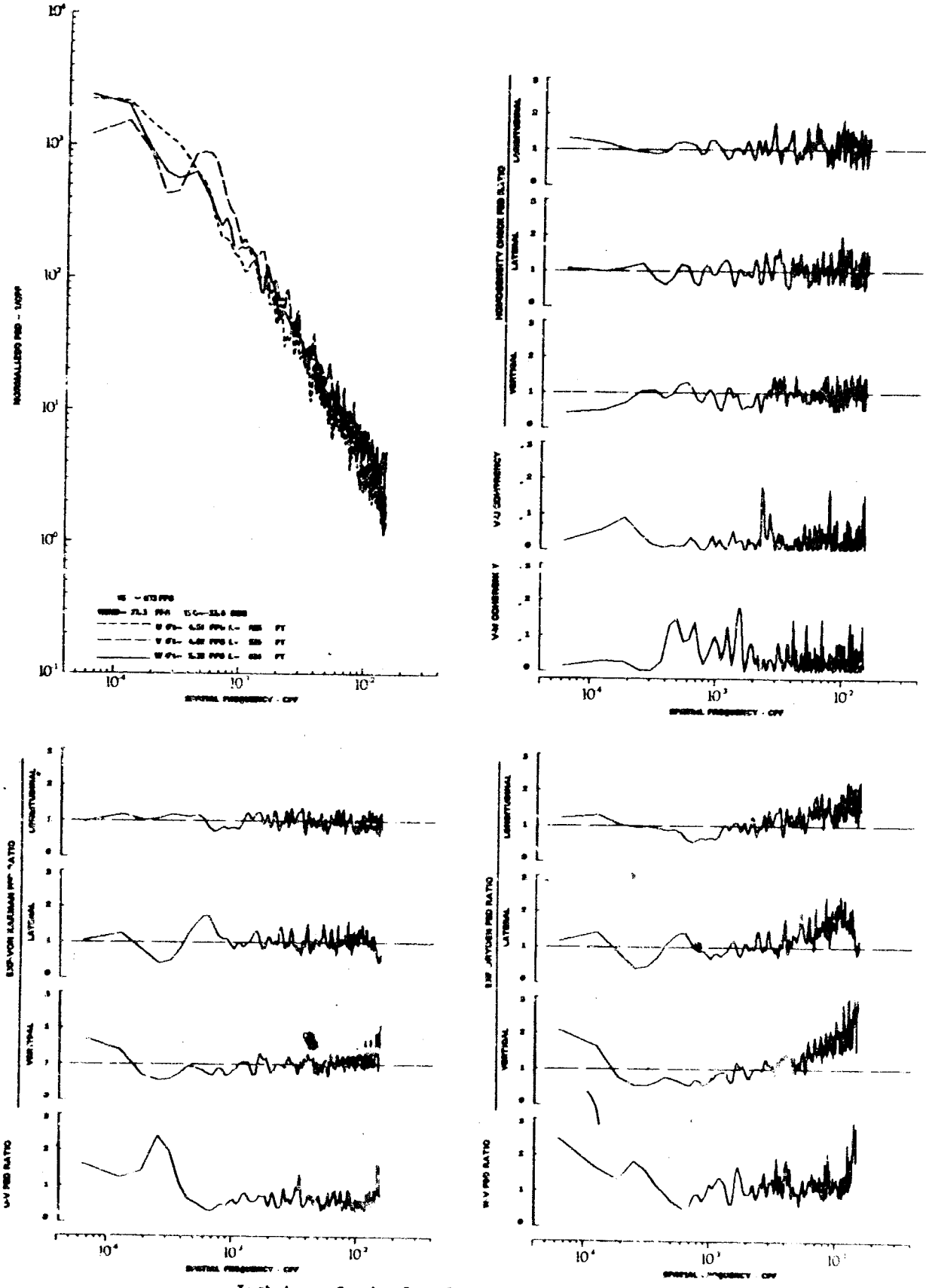


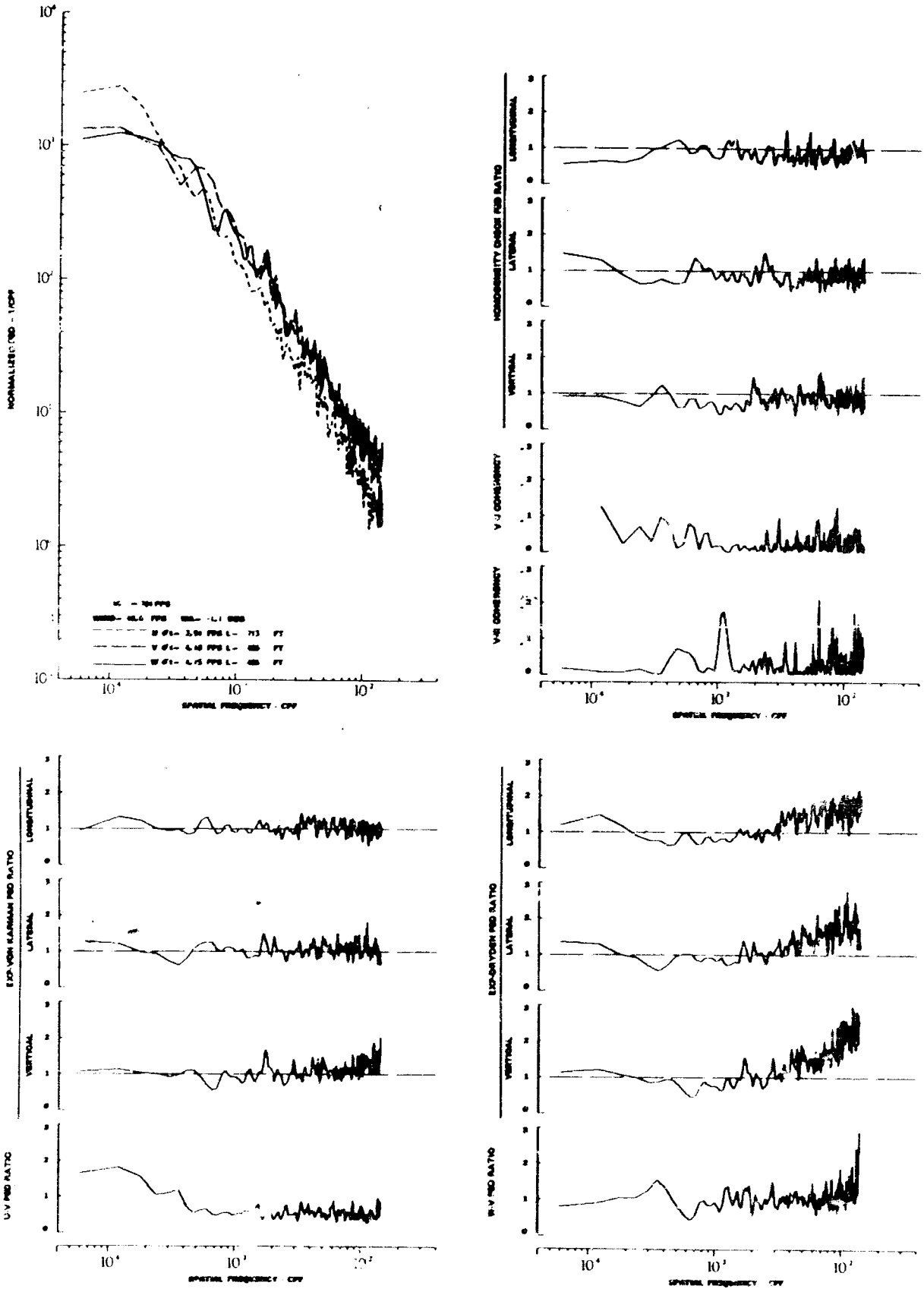
Turbulence Spectra Data For Test 196, Leg 4, Category 114343



Turbulence Spectra Data for Test 196, Leg 5, Category 114343



Turbulence Spectra Data For Test 197, Leg 1, Category 122343



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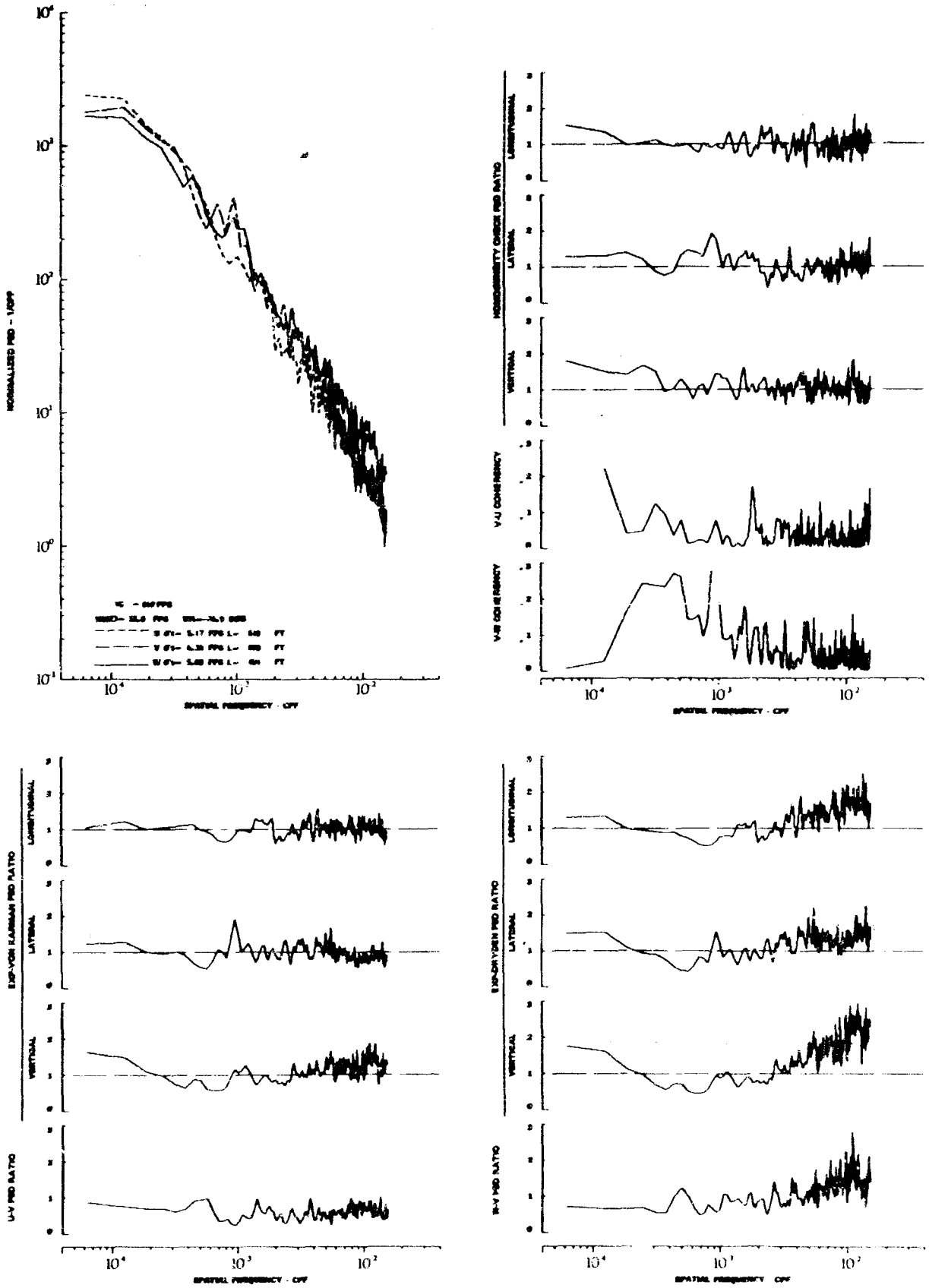

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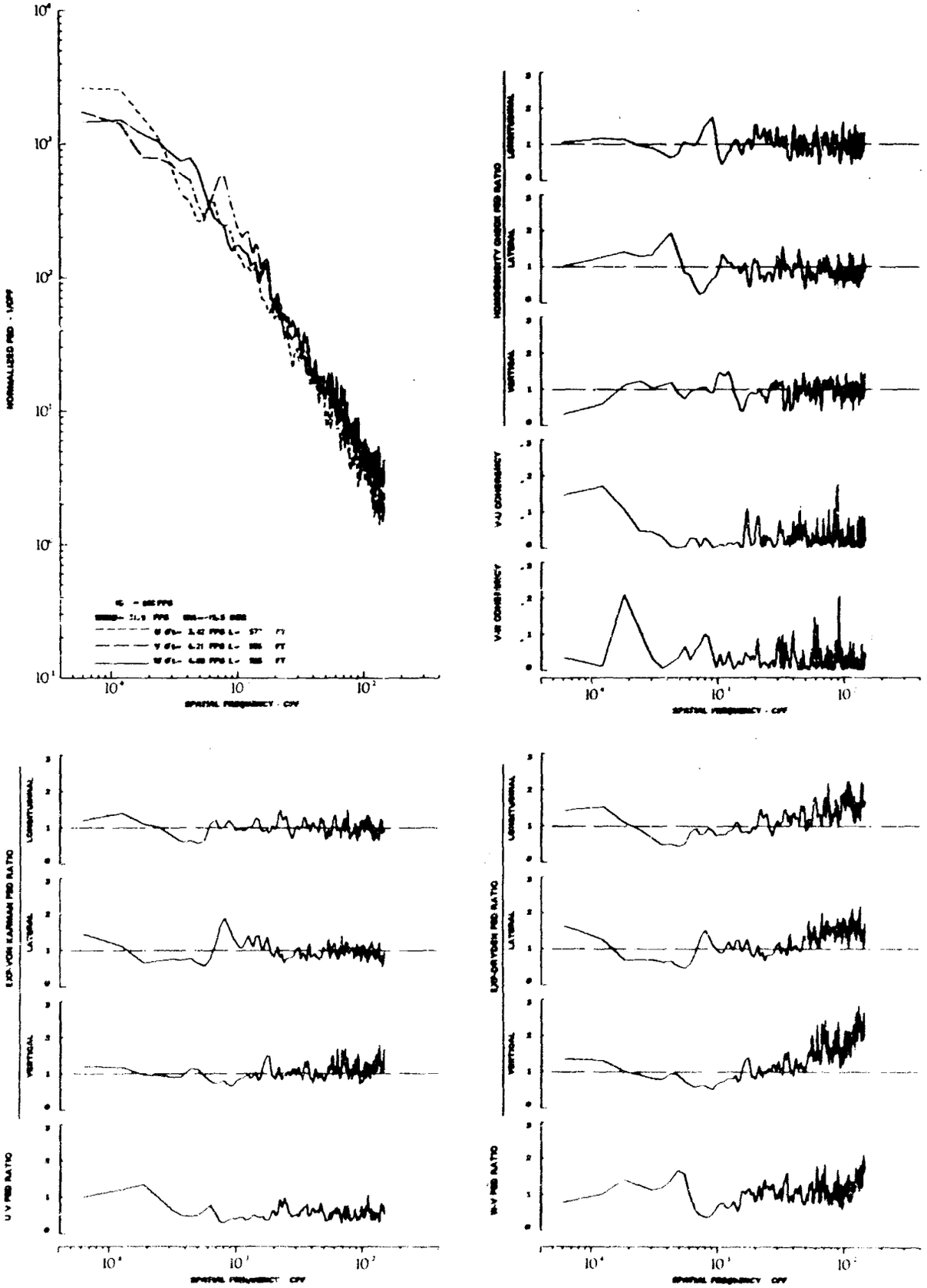
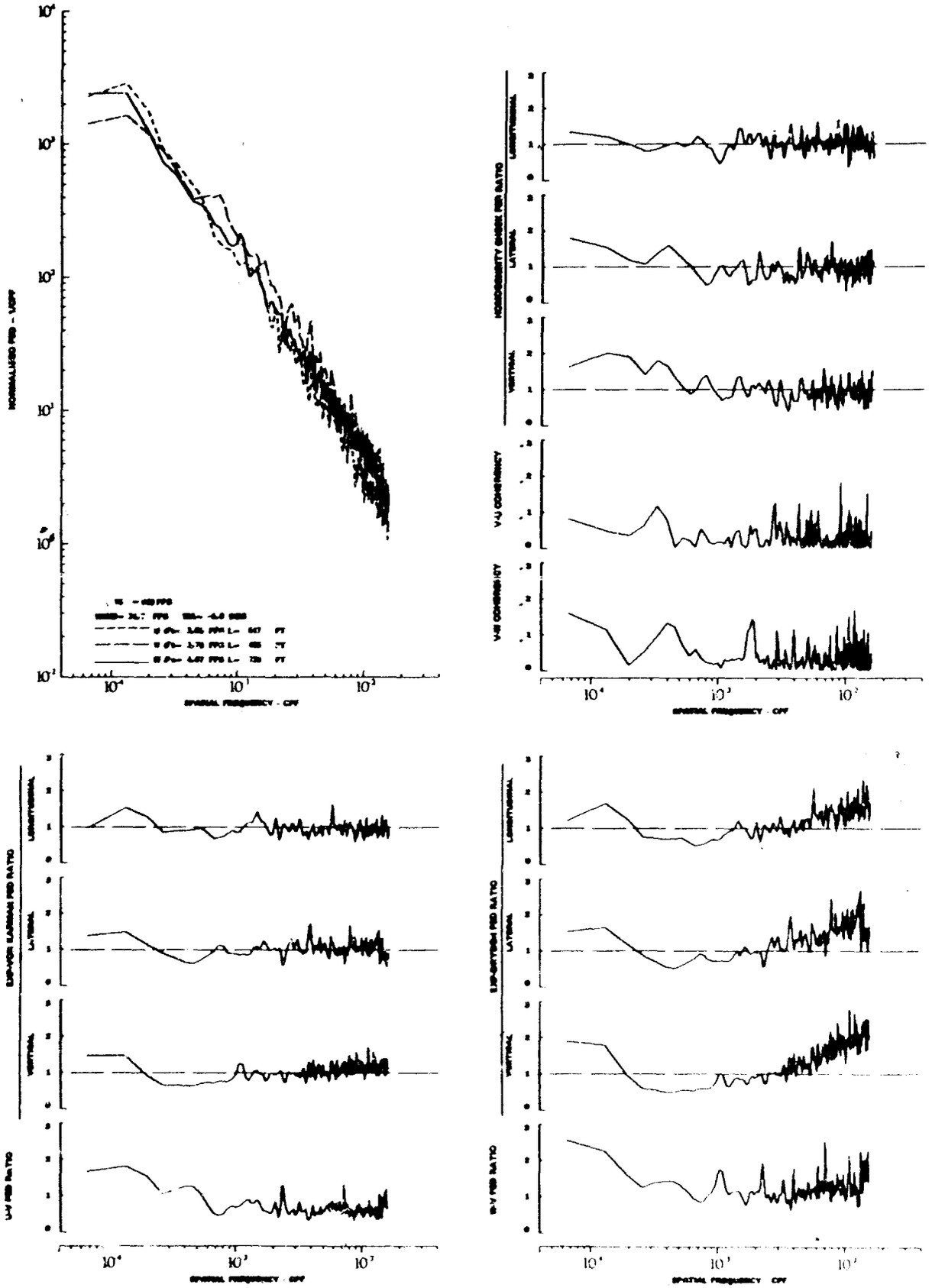


Turbulence Spectra Data For Test 197, Leg 7, Category 124343



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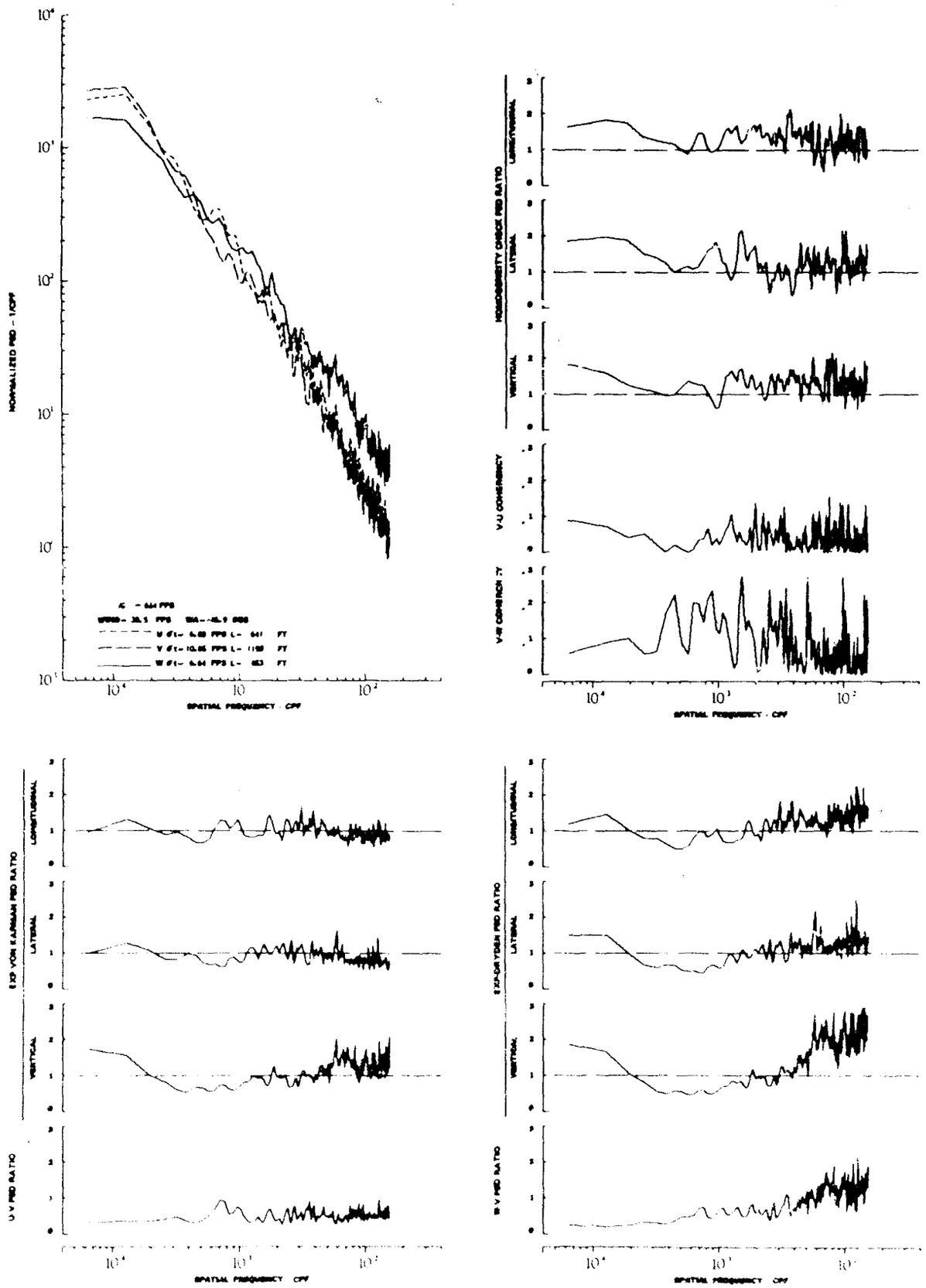
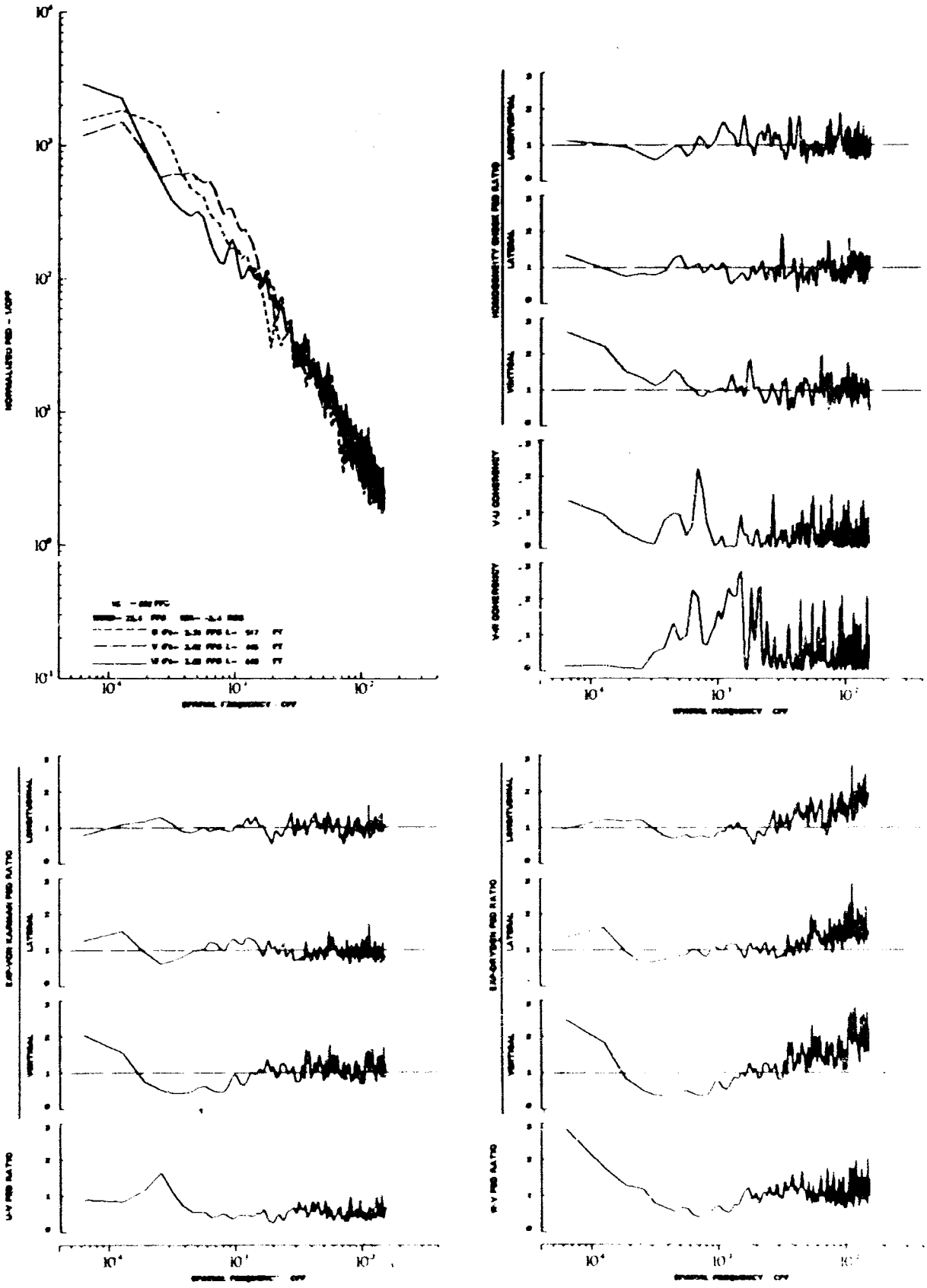
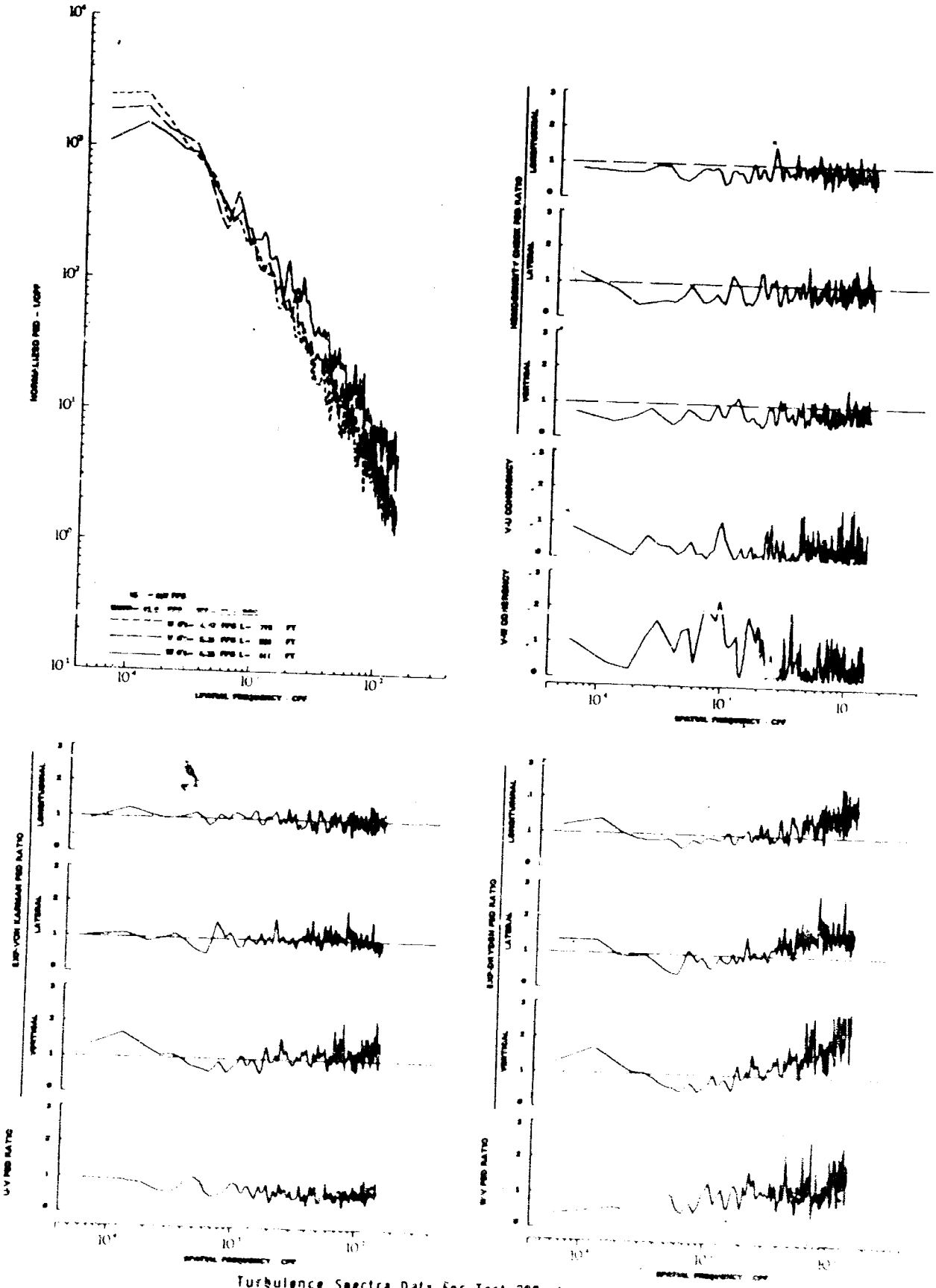


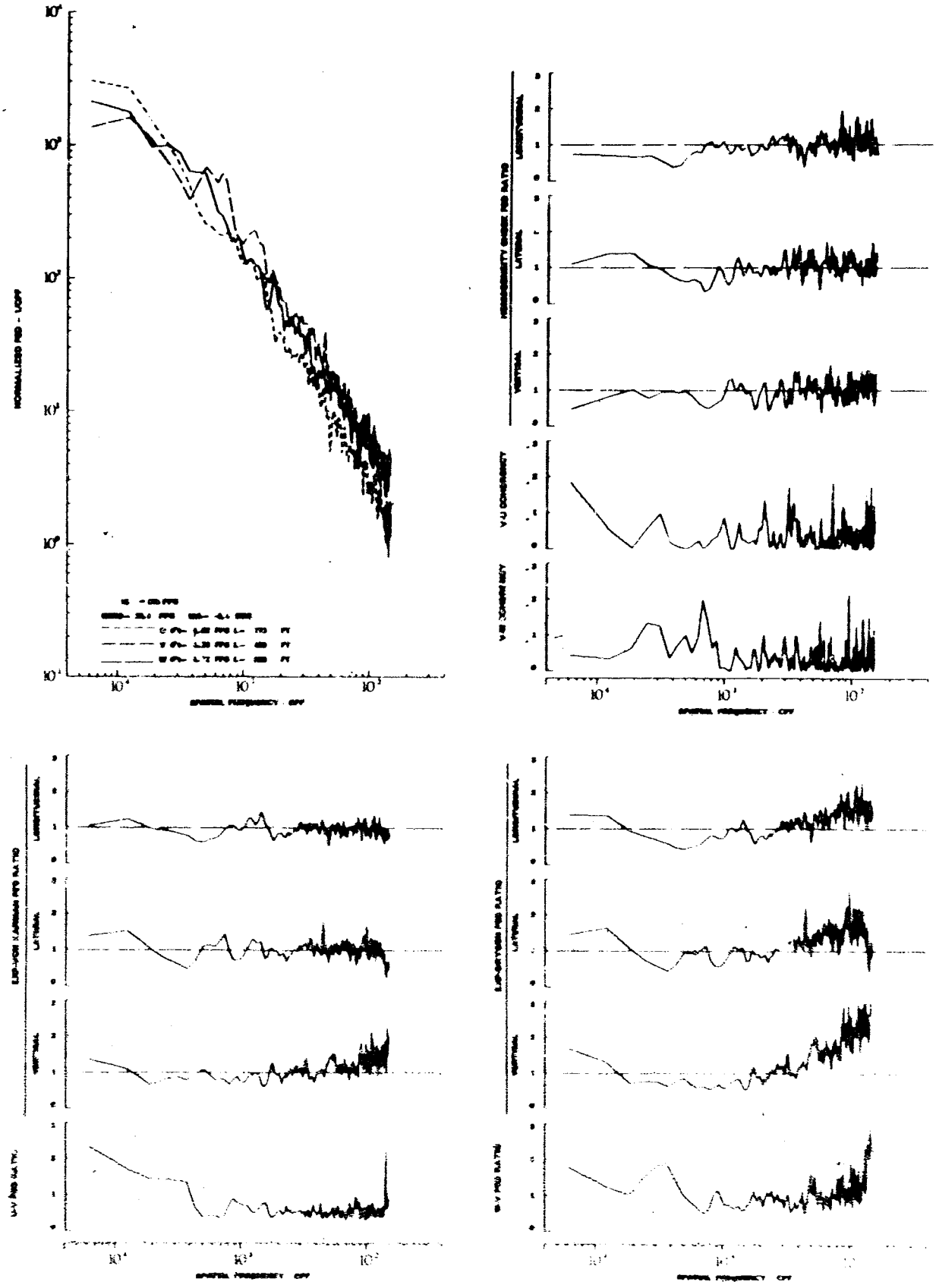
Turbulence Spectra Data For Test 199, Leg 5, Category 122143



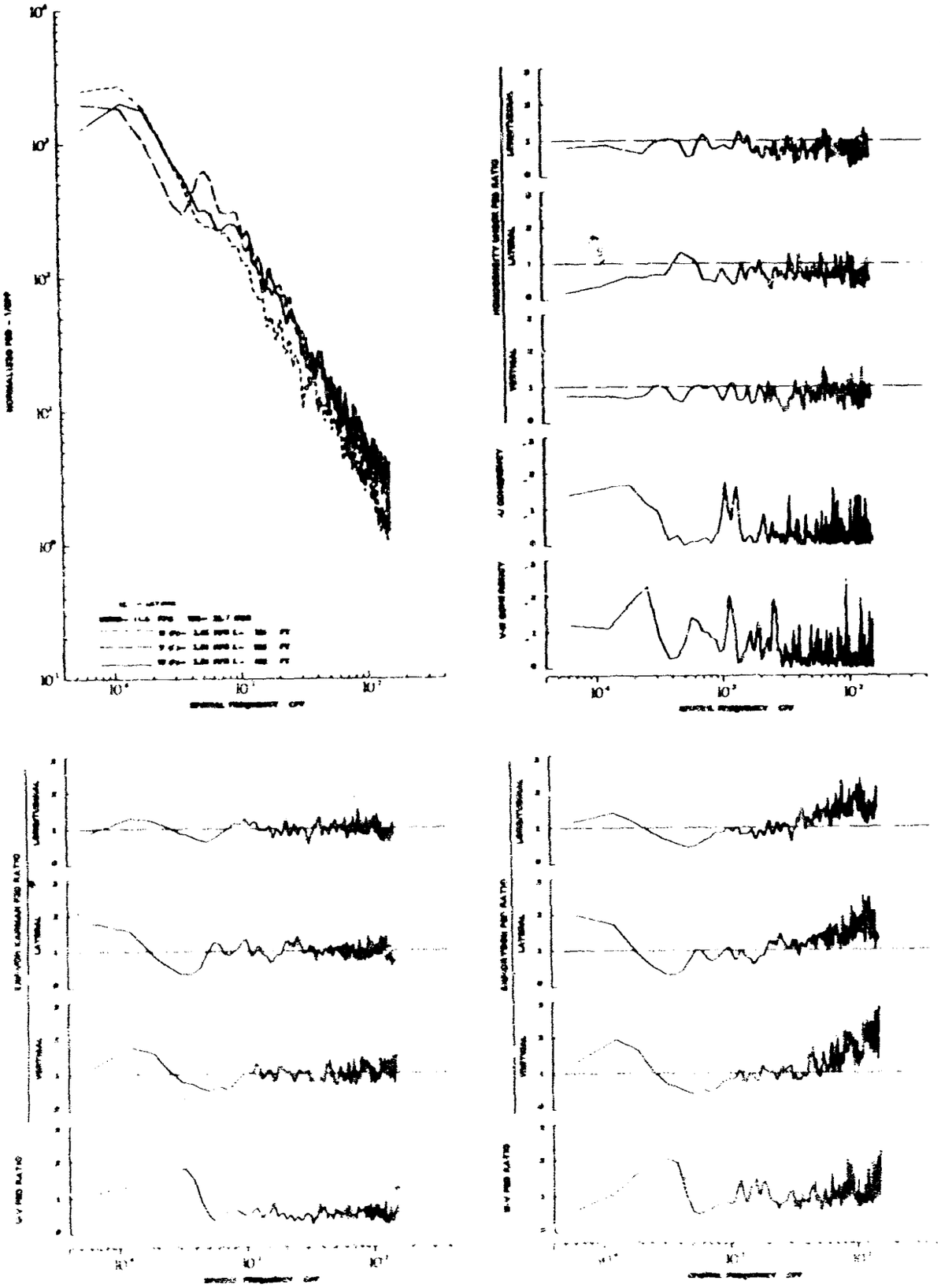
Turbulence Spectra Data For Test 200, Leg 4, Category 122243



Turbulence Spectra Data For Test 200, Leg 6, Category 122243



Turbulence Spectra Data For Test 291, Leg 1, Category 121343



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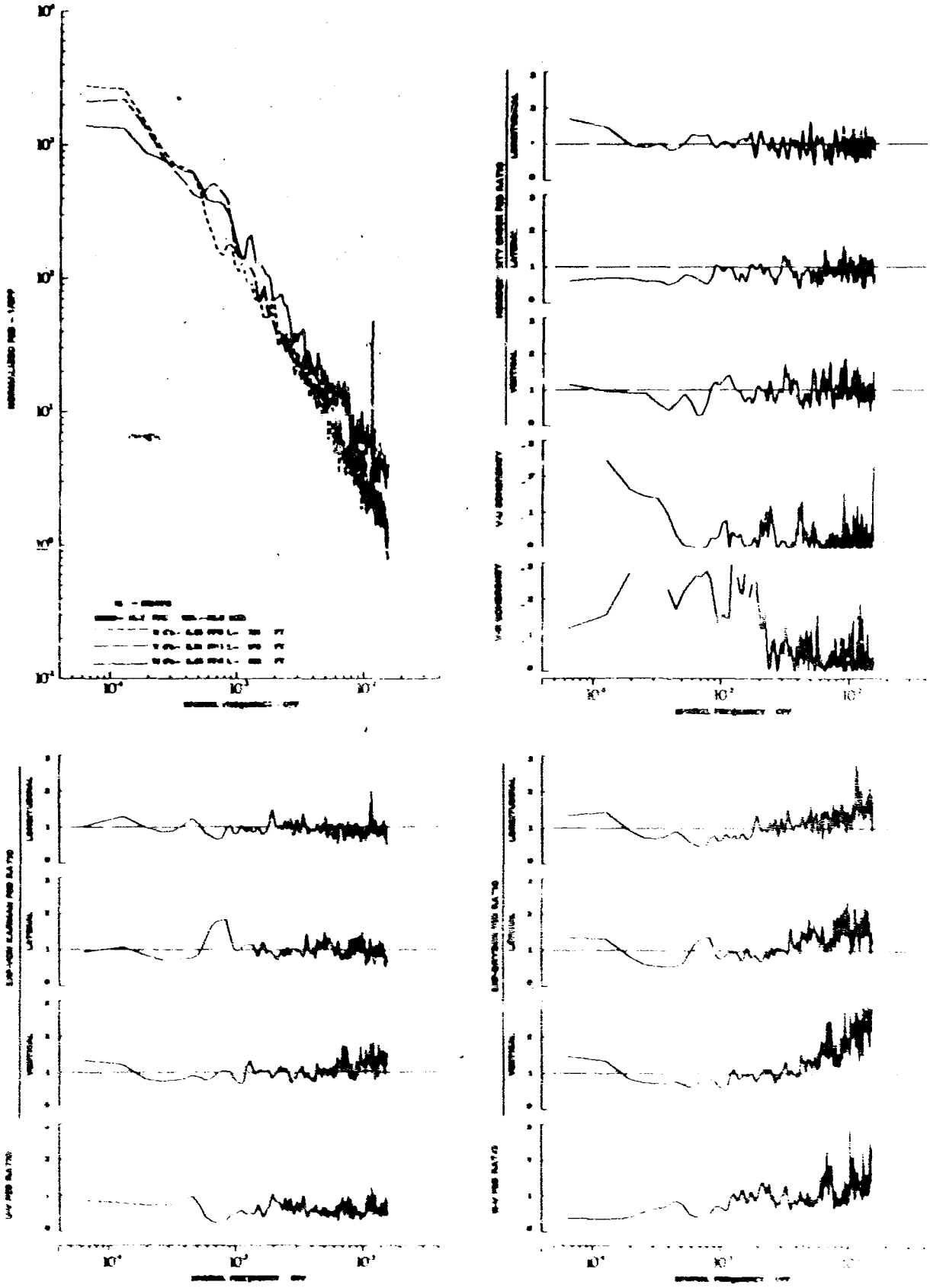

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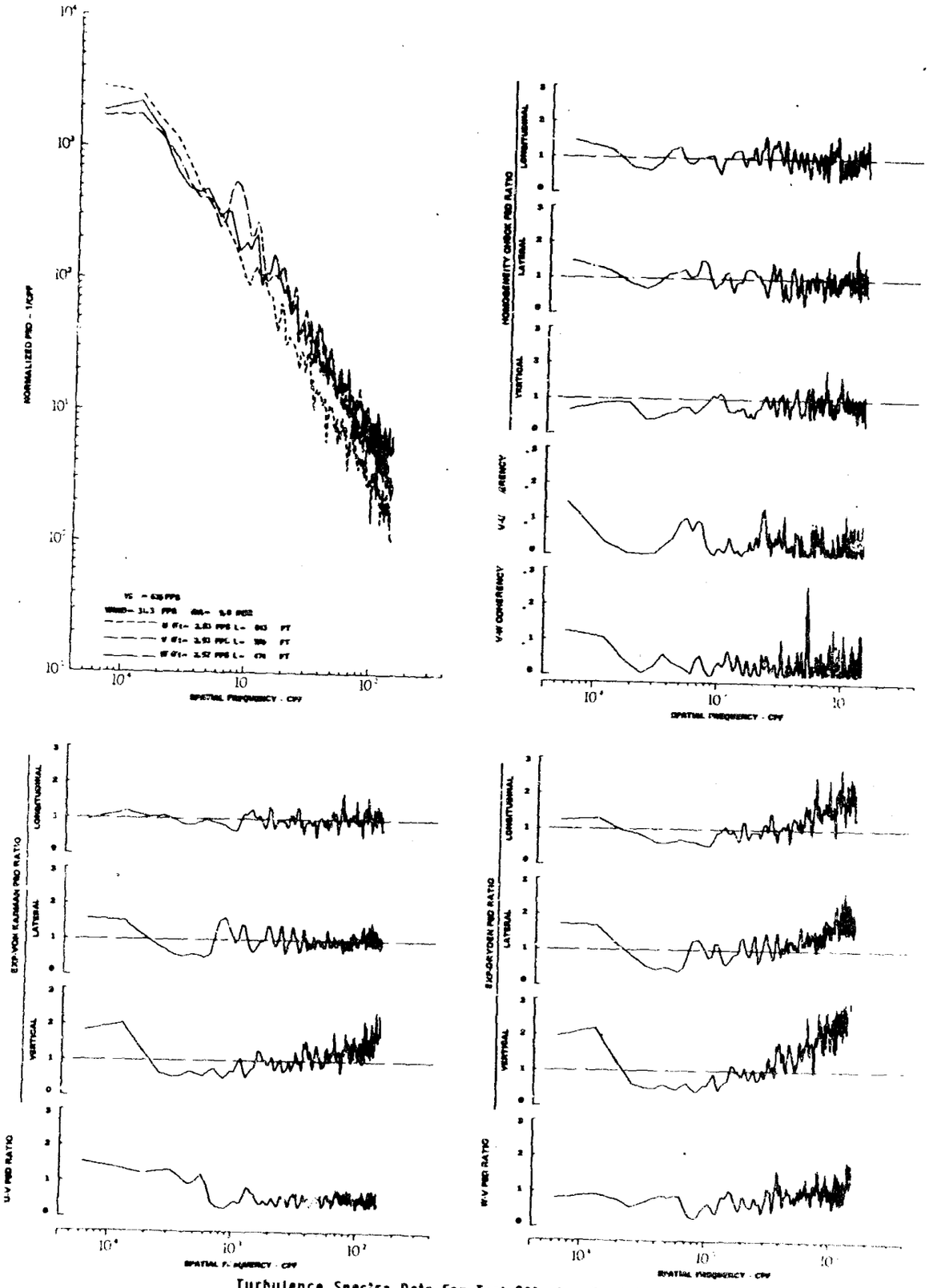

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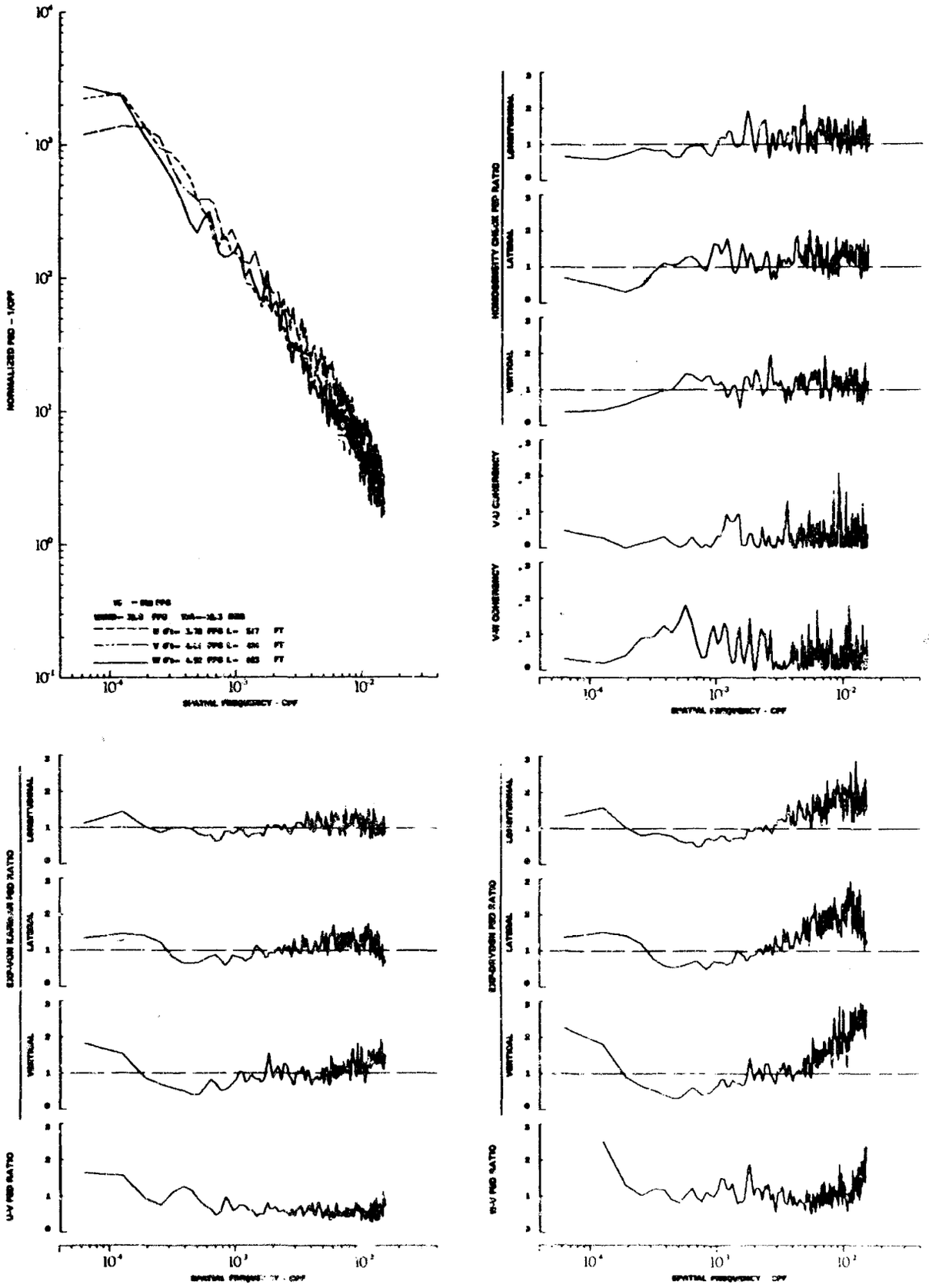

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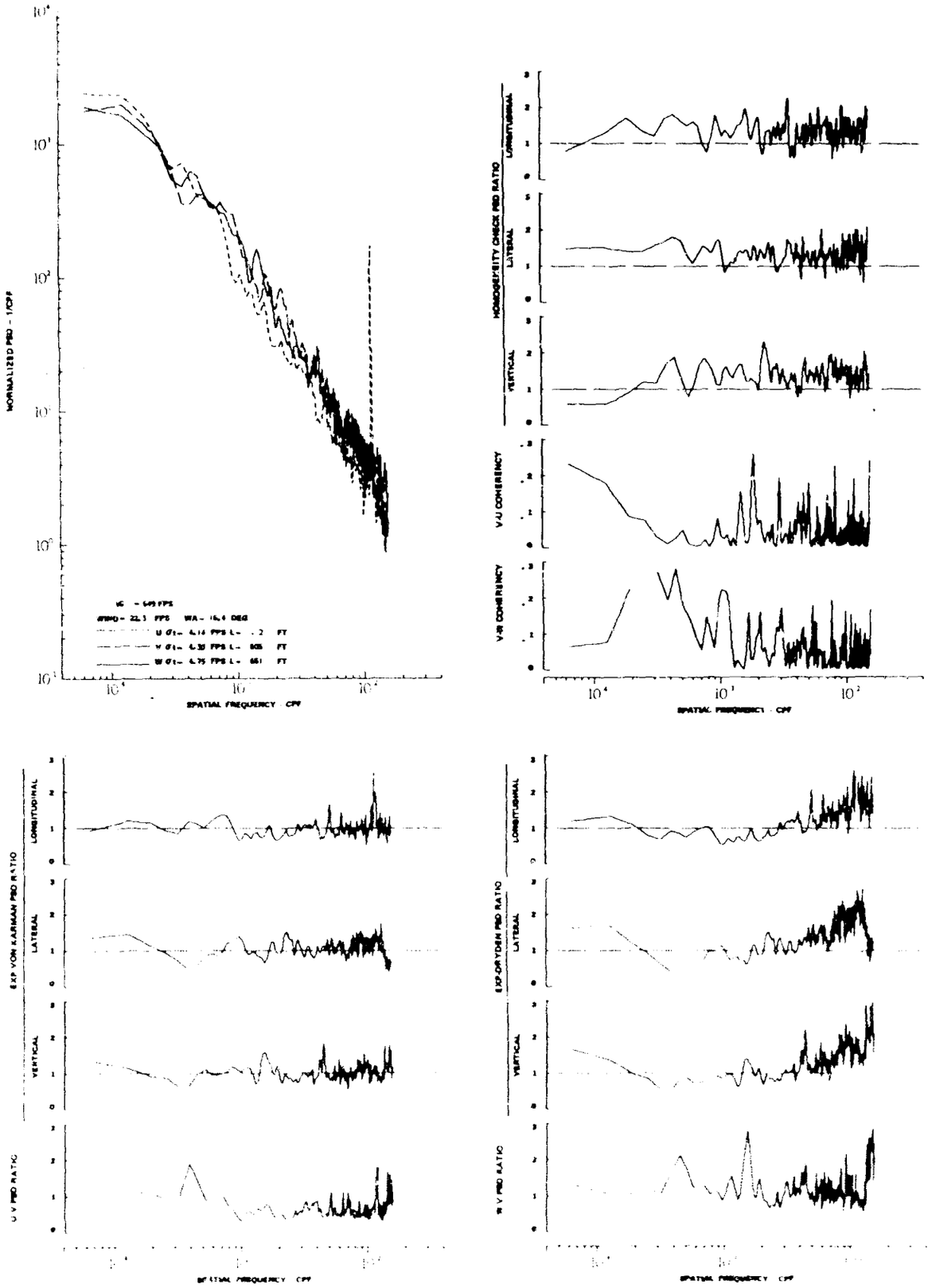
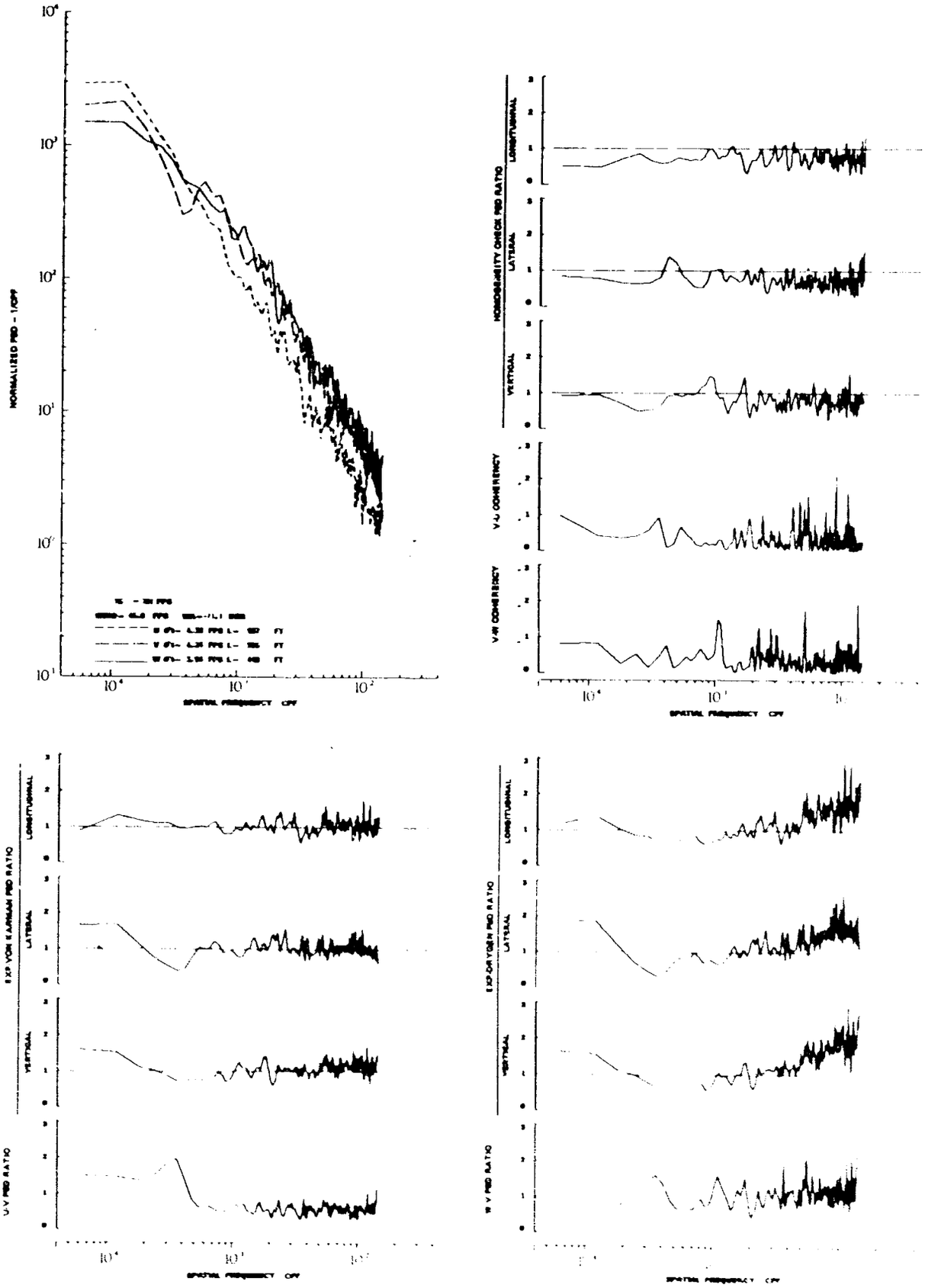
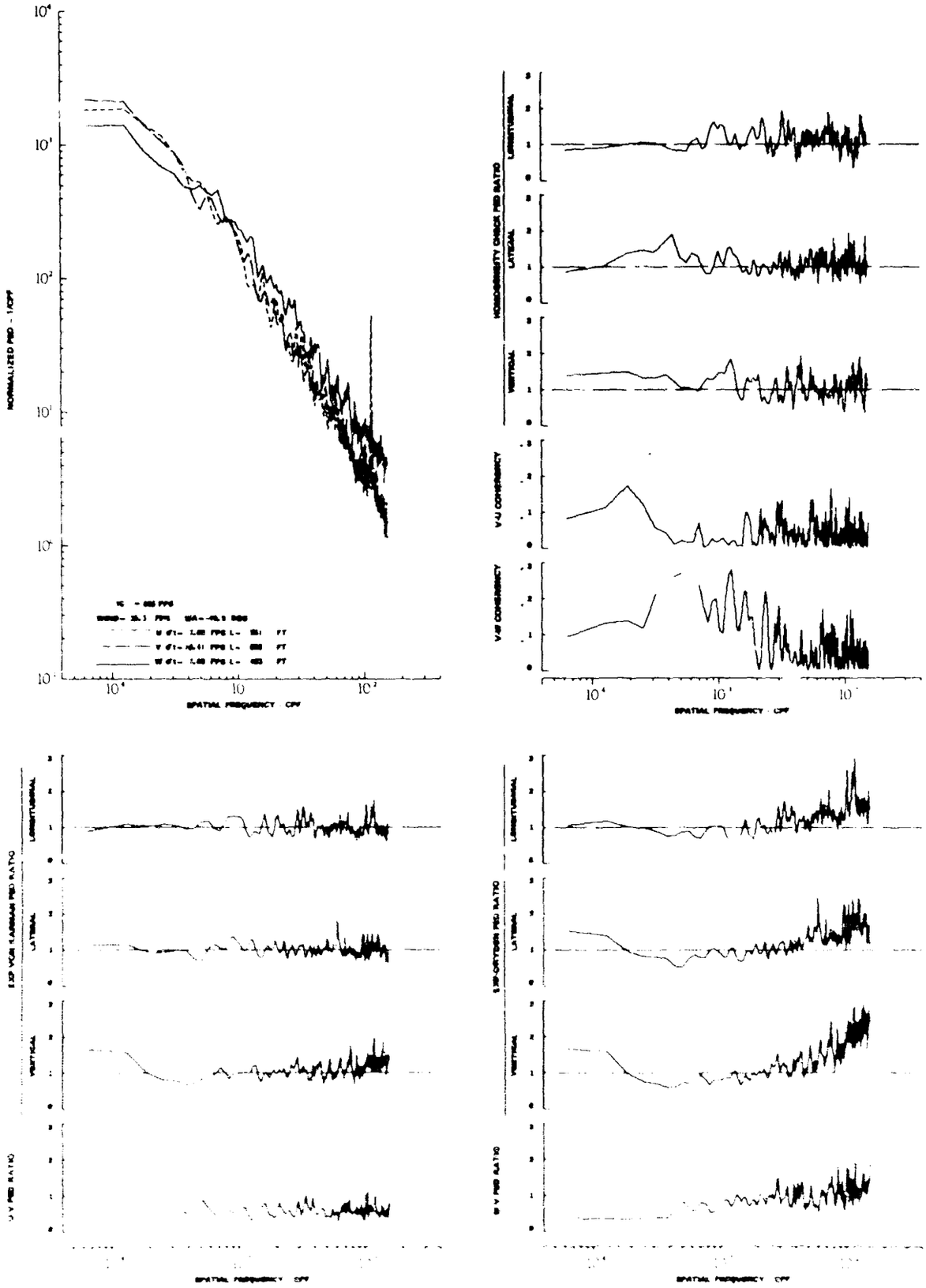


Turbulence Spectra Data For Test 209, Leg 1, Category 122243



Turbulence Spectra Data For Test 209, Leg 3, Category 123243



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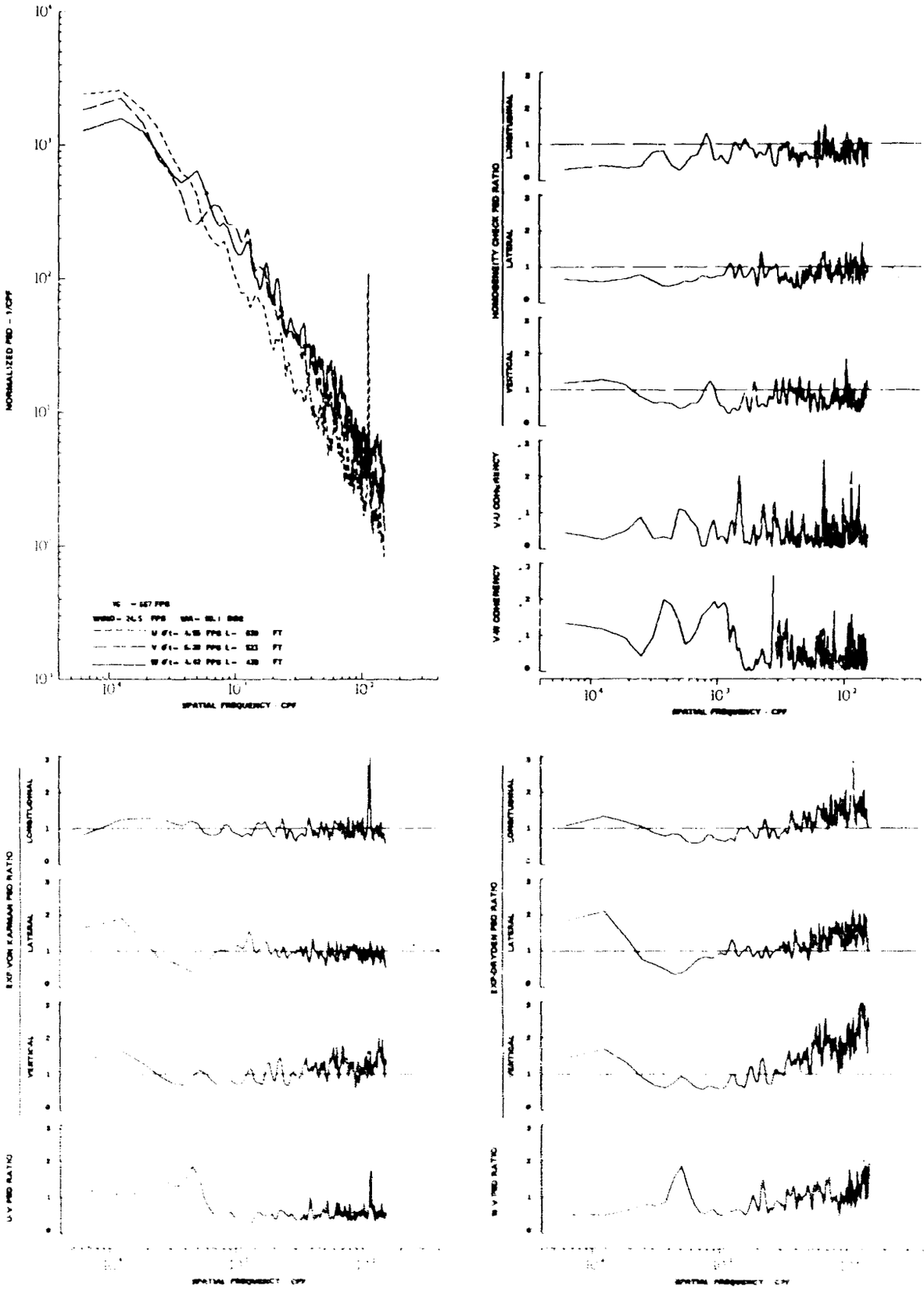

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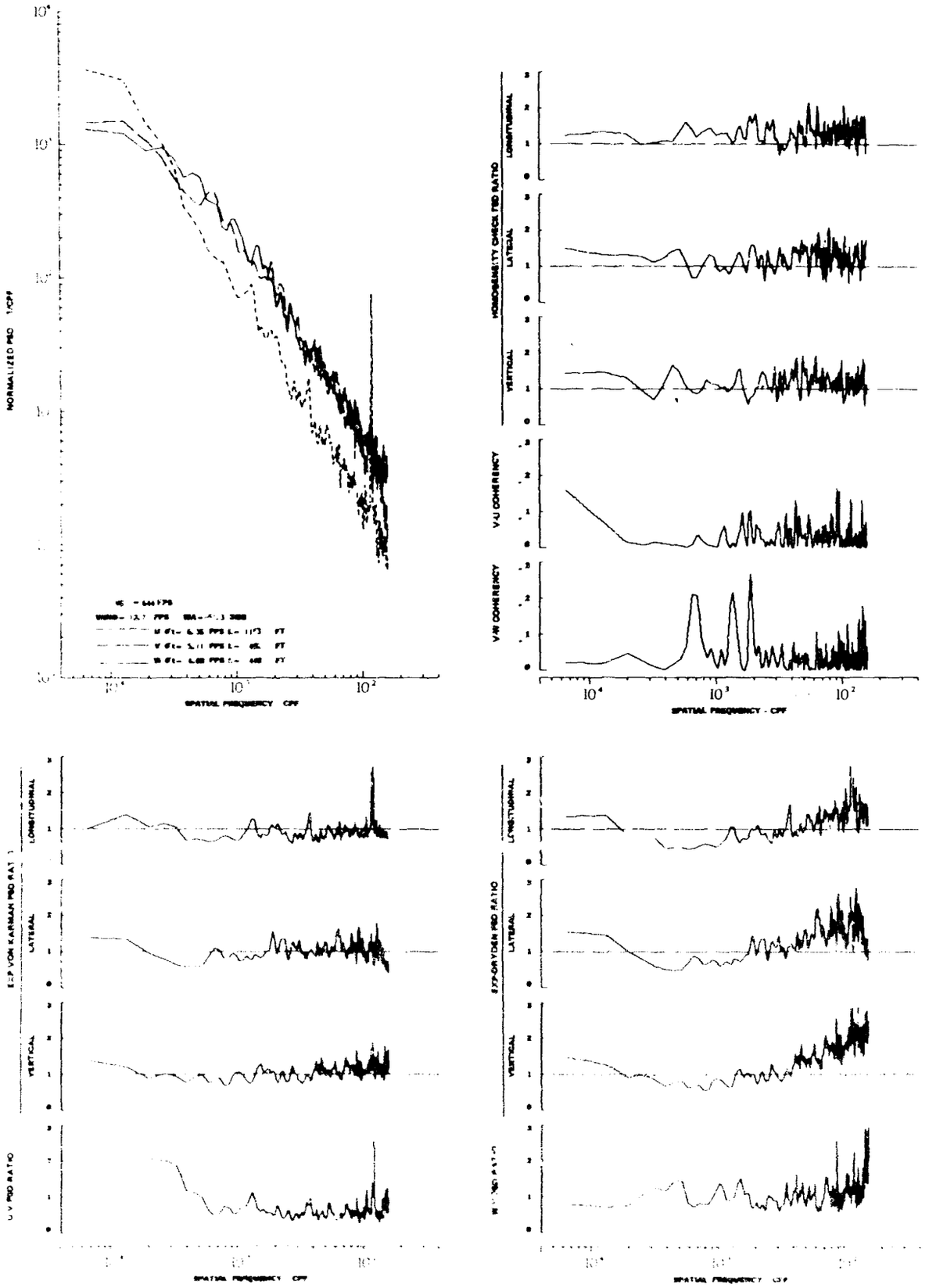
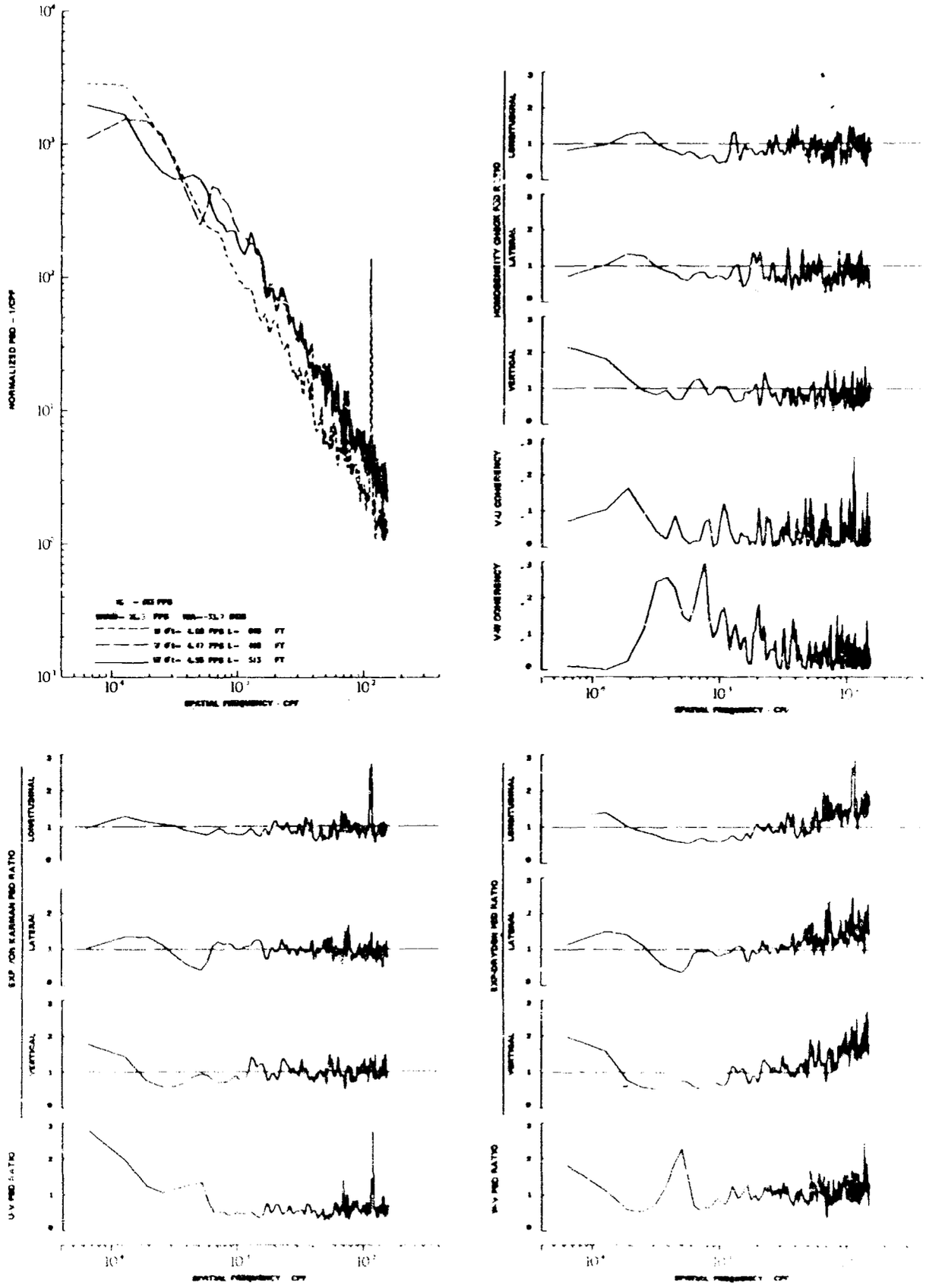
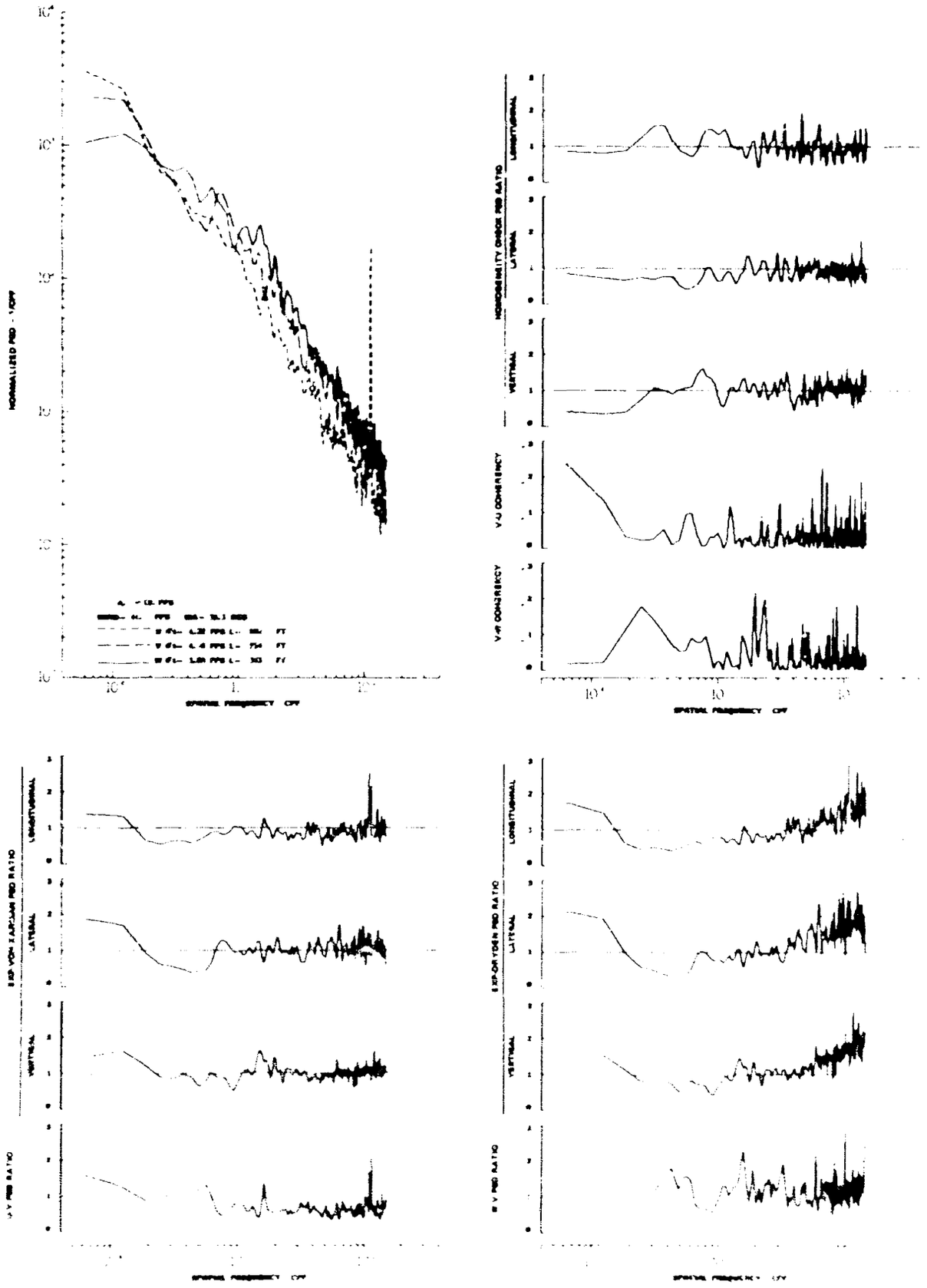


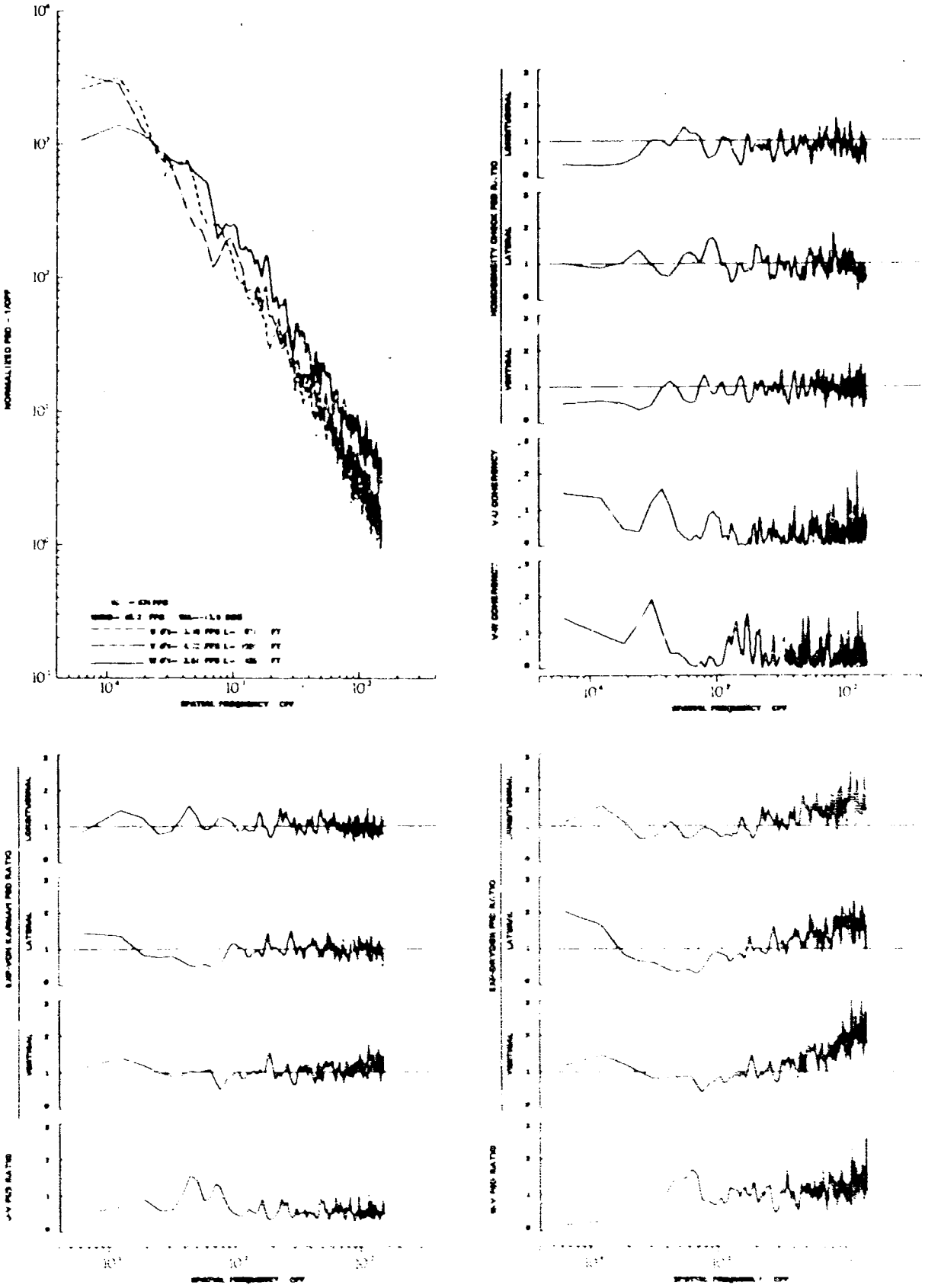
Turbulence Spectra Data For Test 210, Leg 2, Category 123343



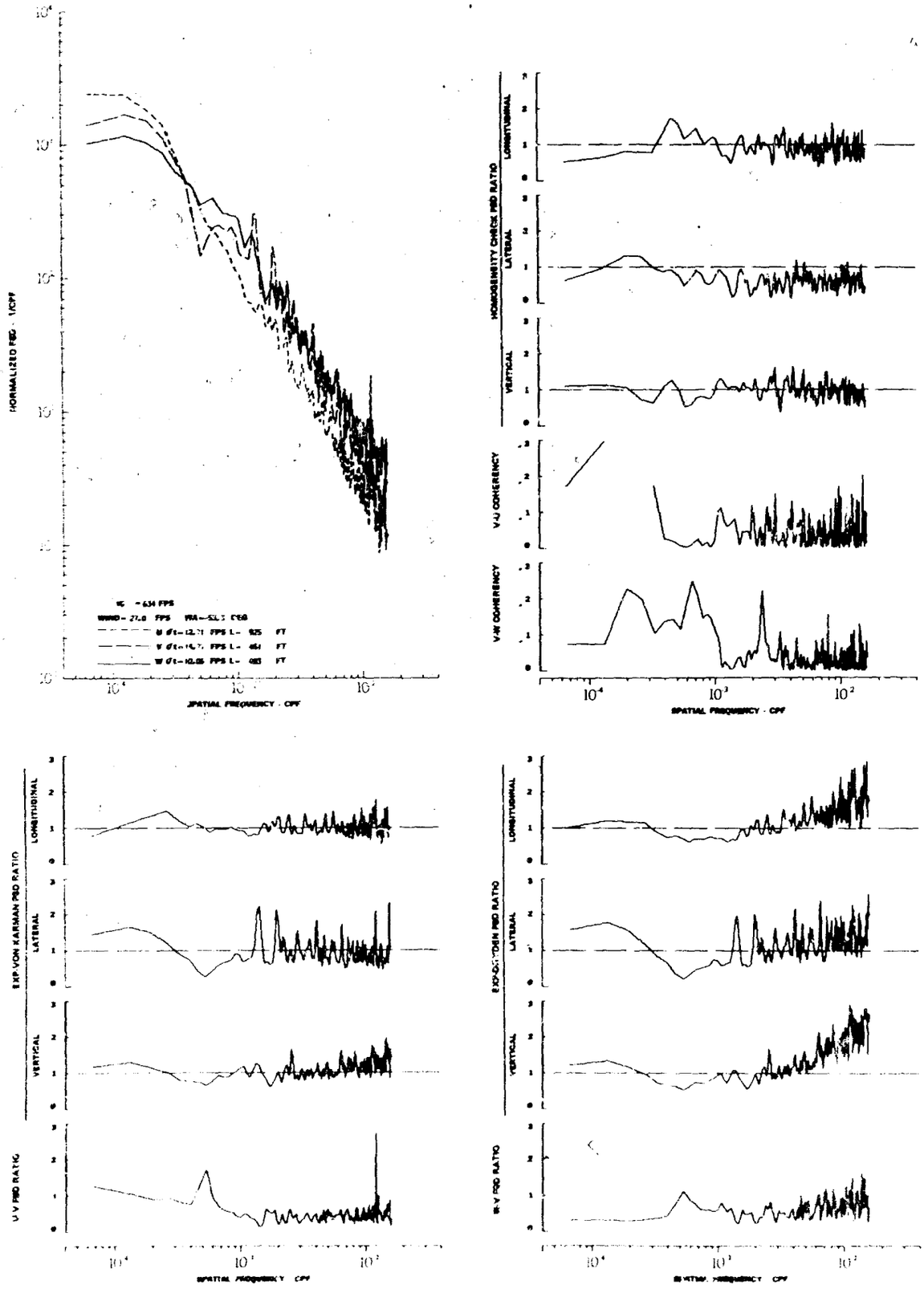
Turbulence Spectra Data For Test 210, Leg 4, Category 124343



Turbulence Spectra Data for Test 210, Leg 6, Category 124343



Turbulence Spectra Data For Test 210, Leg 8, Category 423/43



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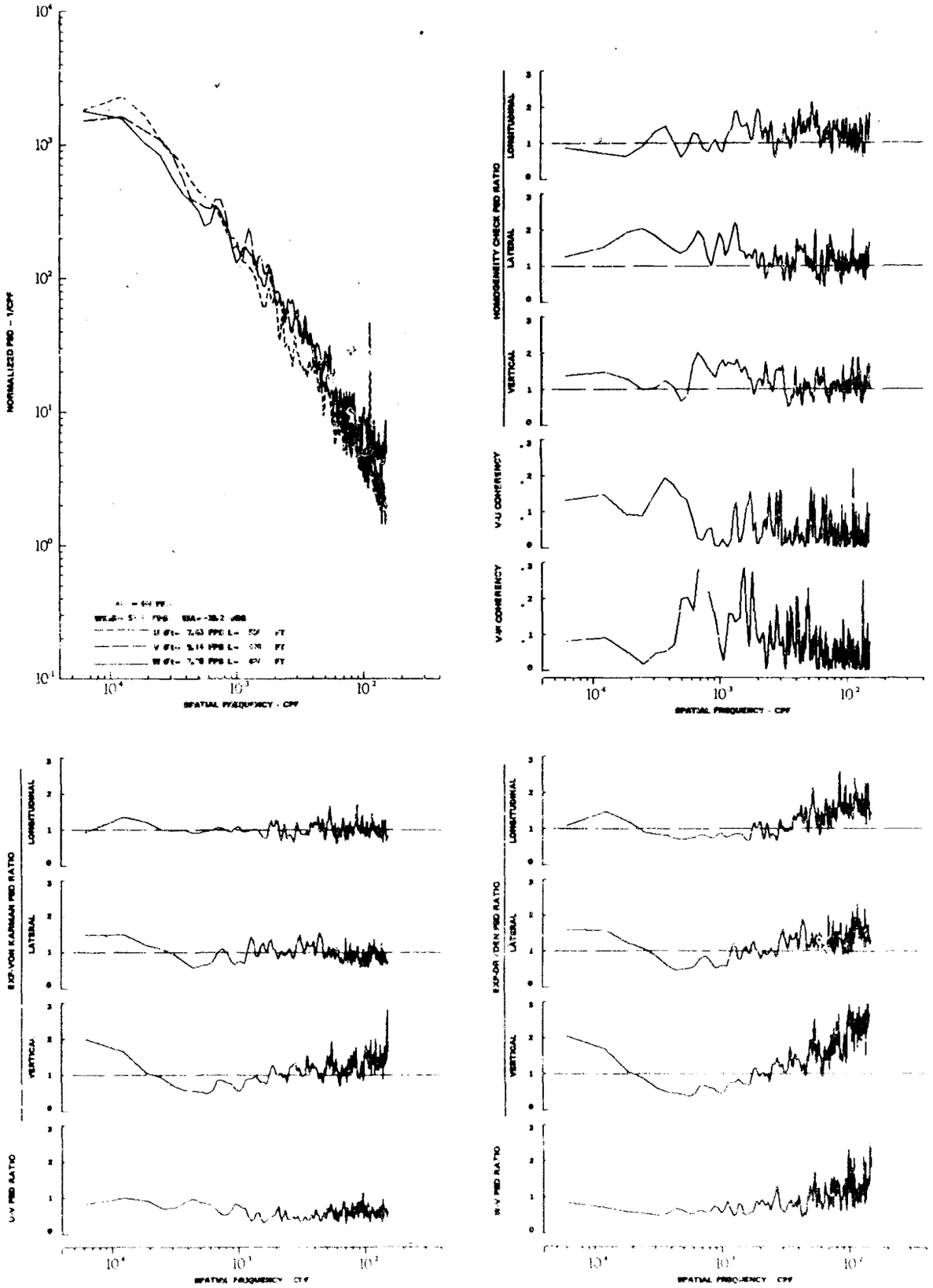

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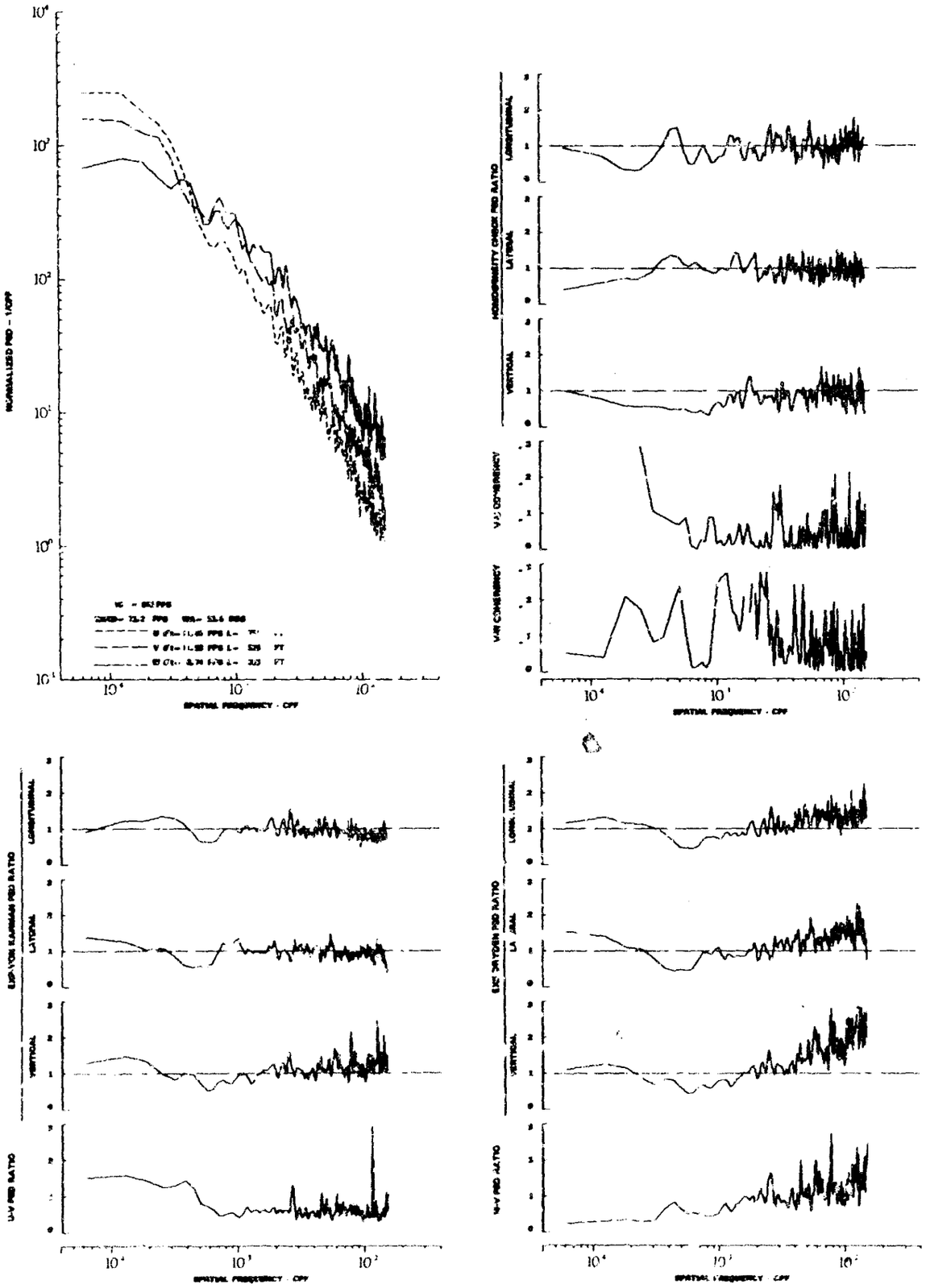

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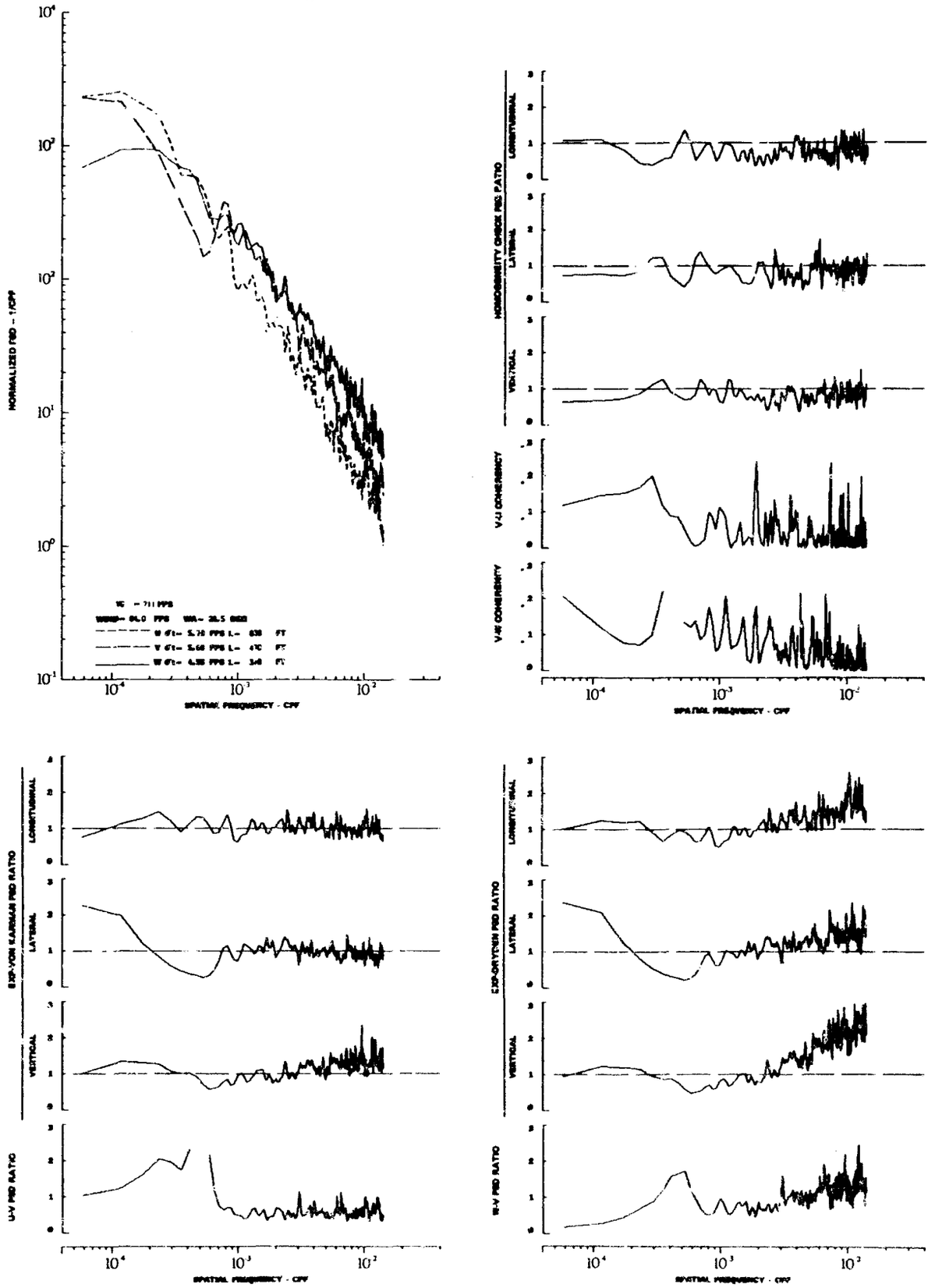

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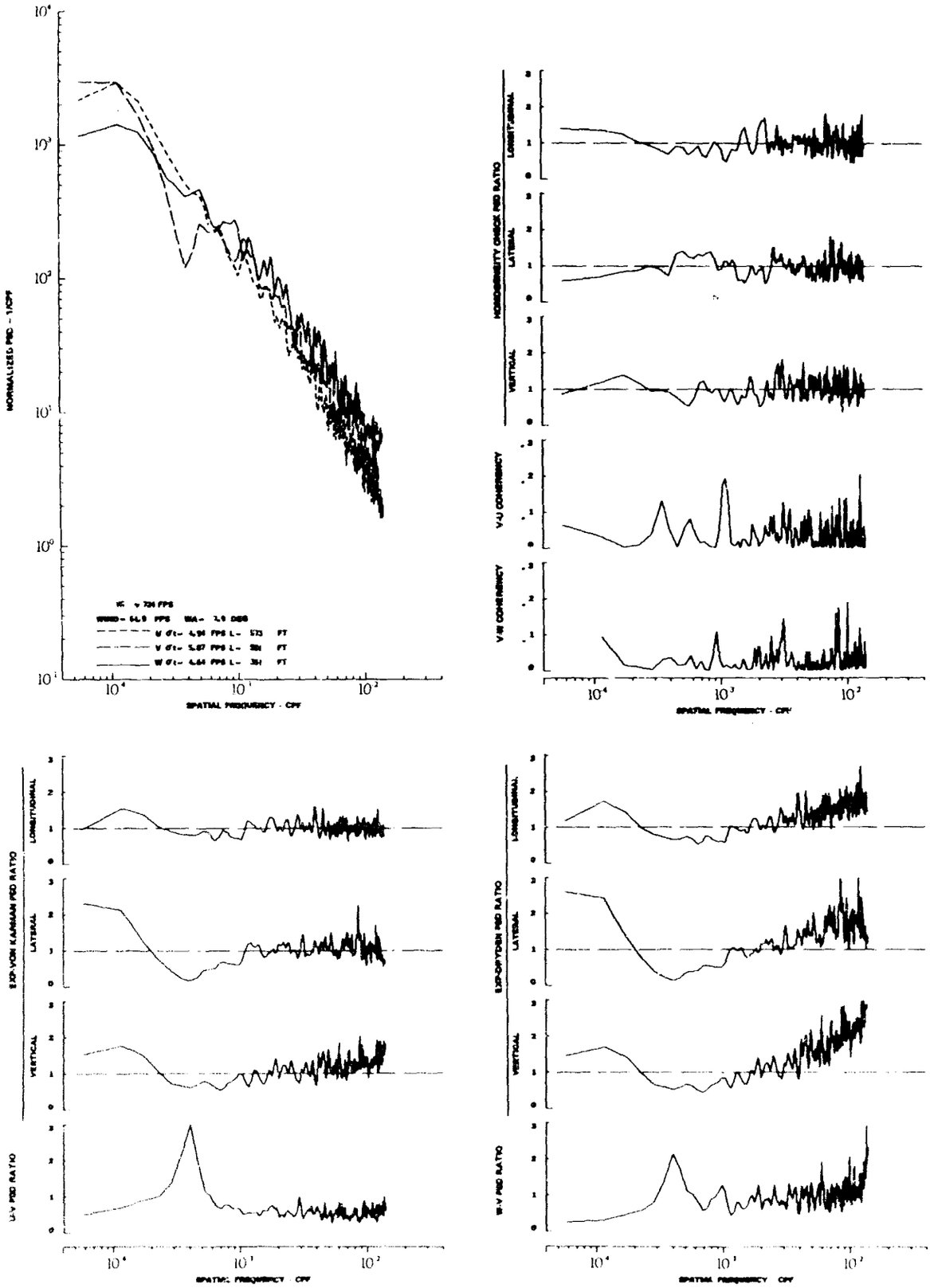

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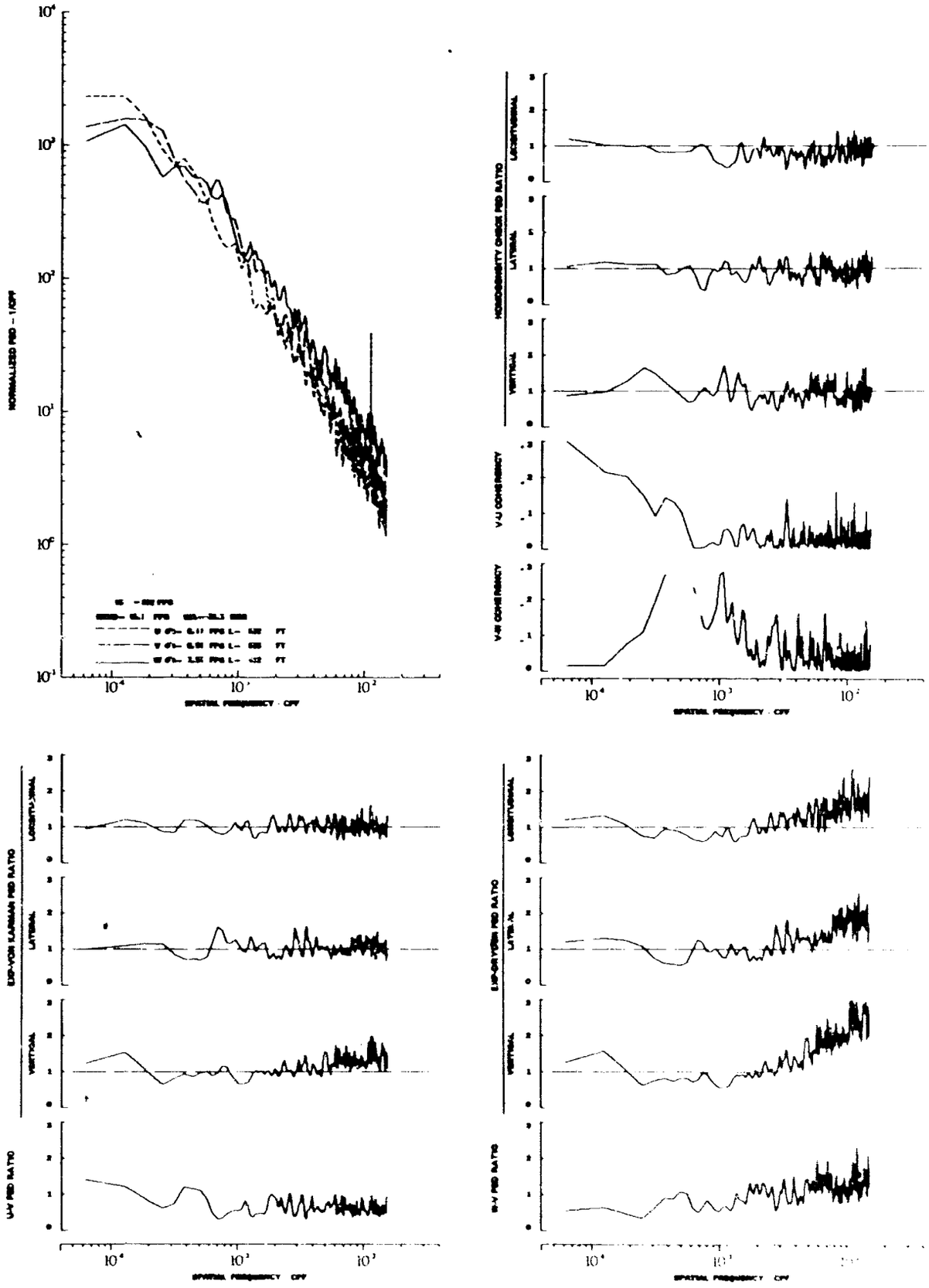

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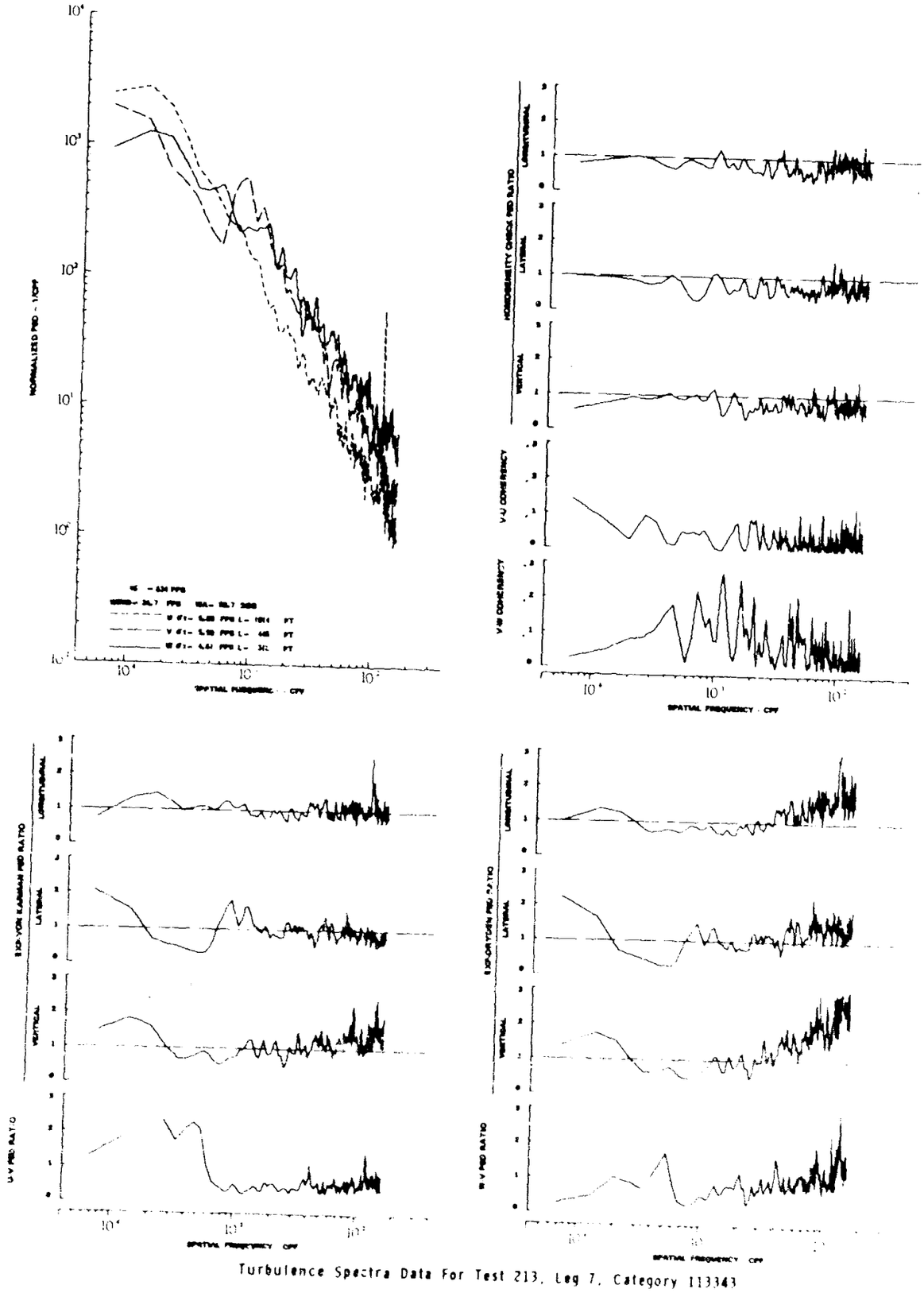

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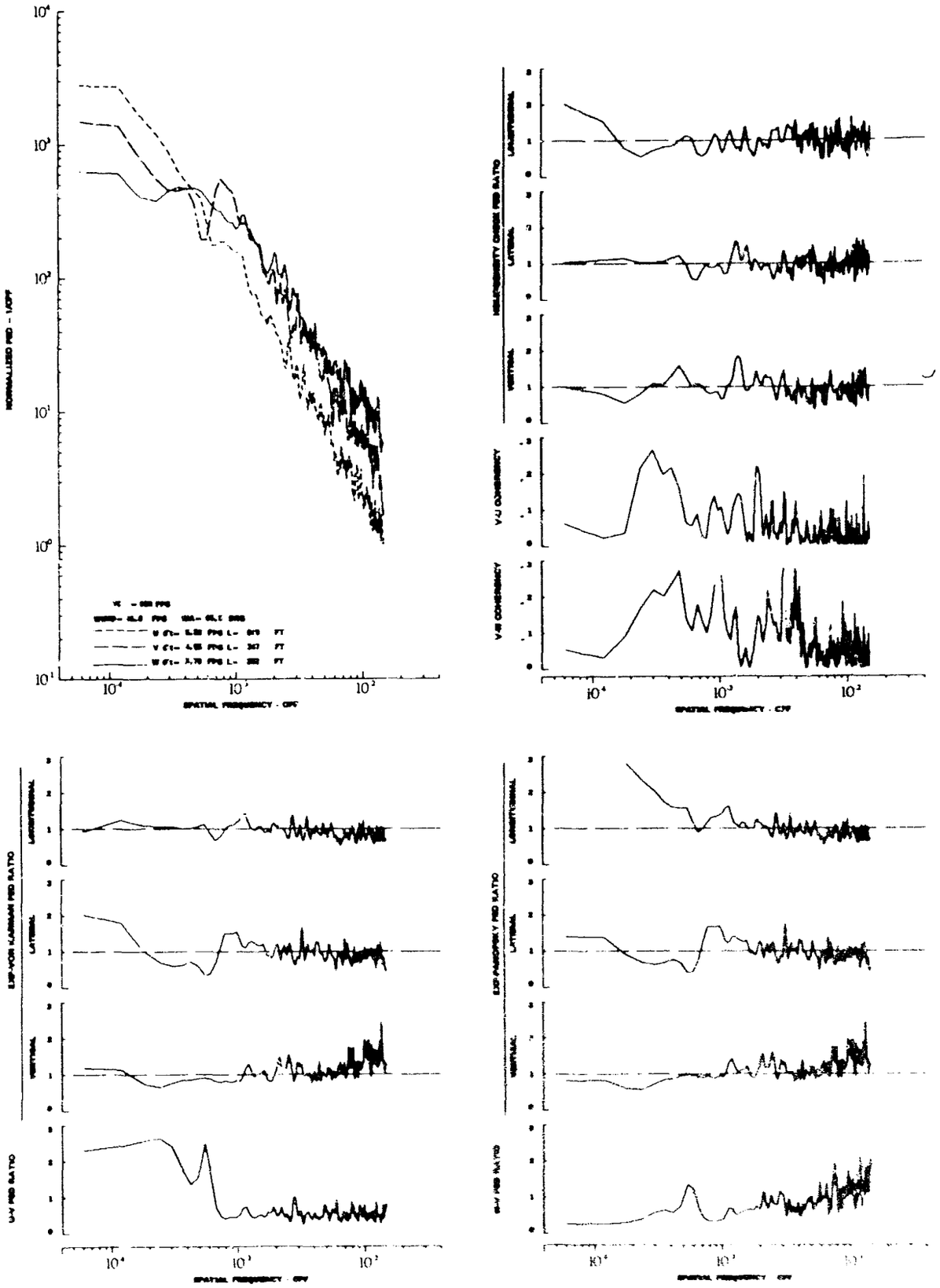

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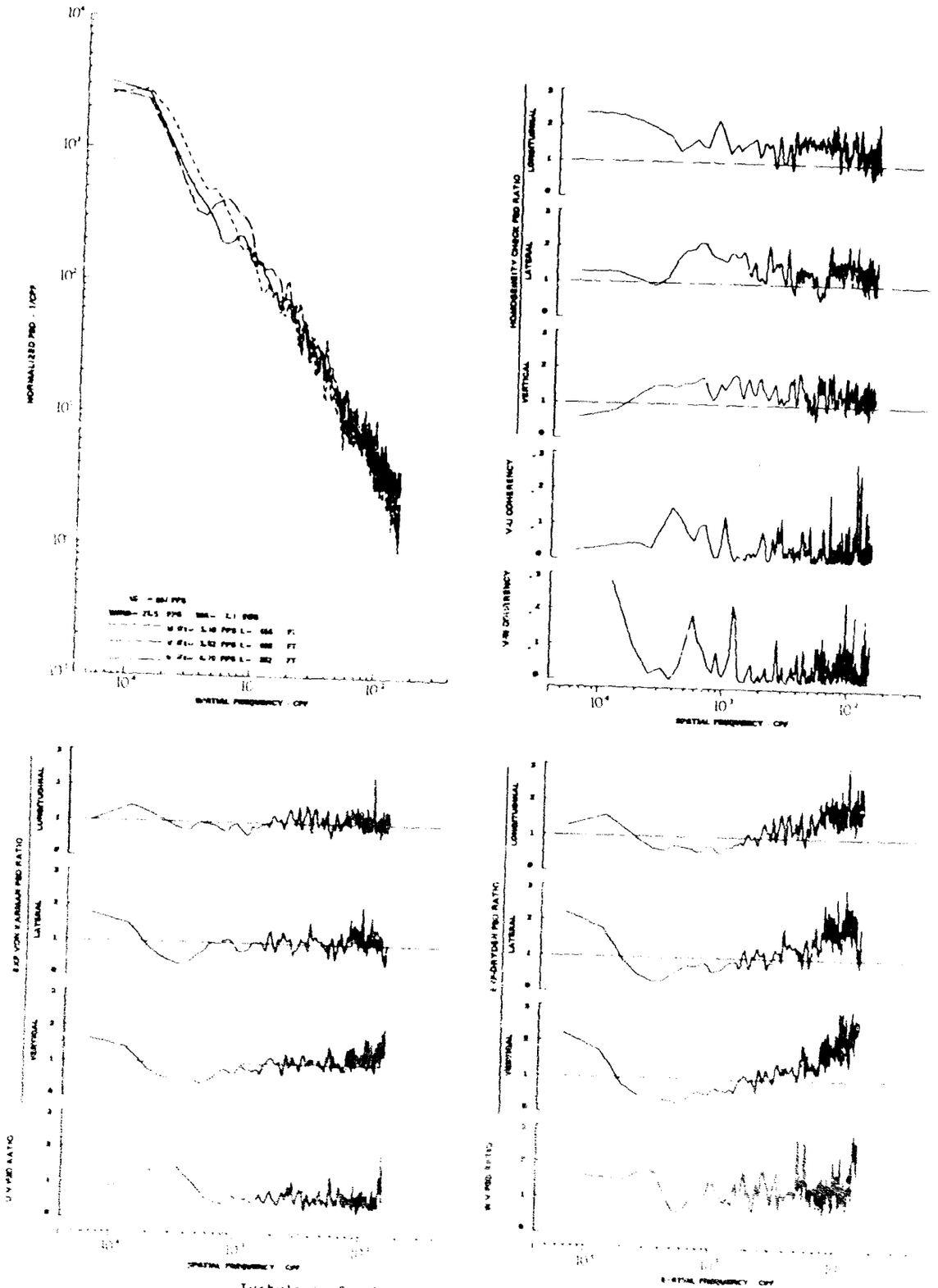

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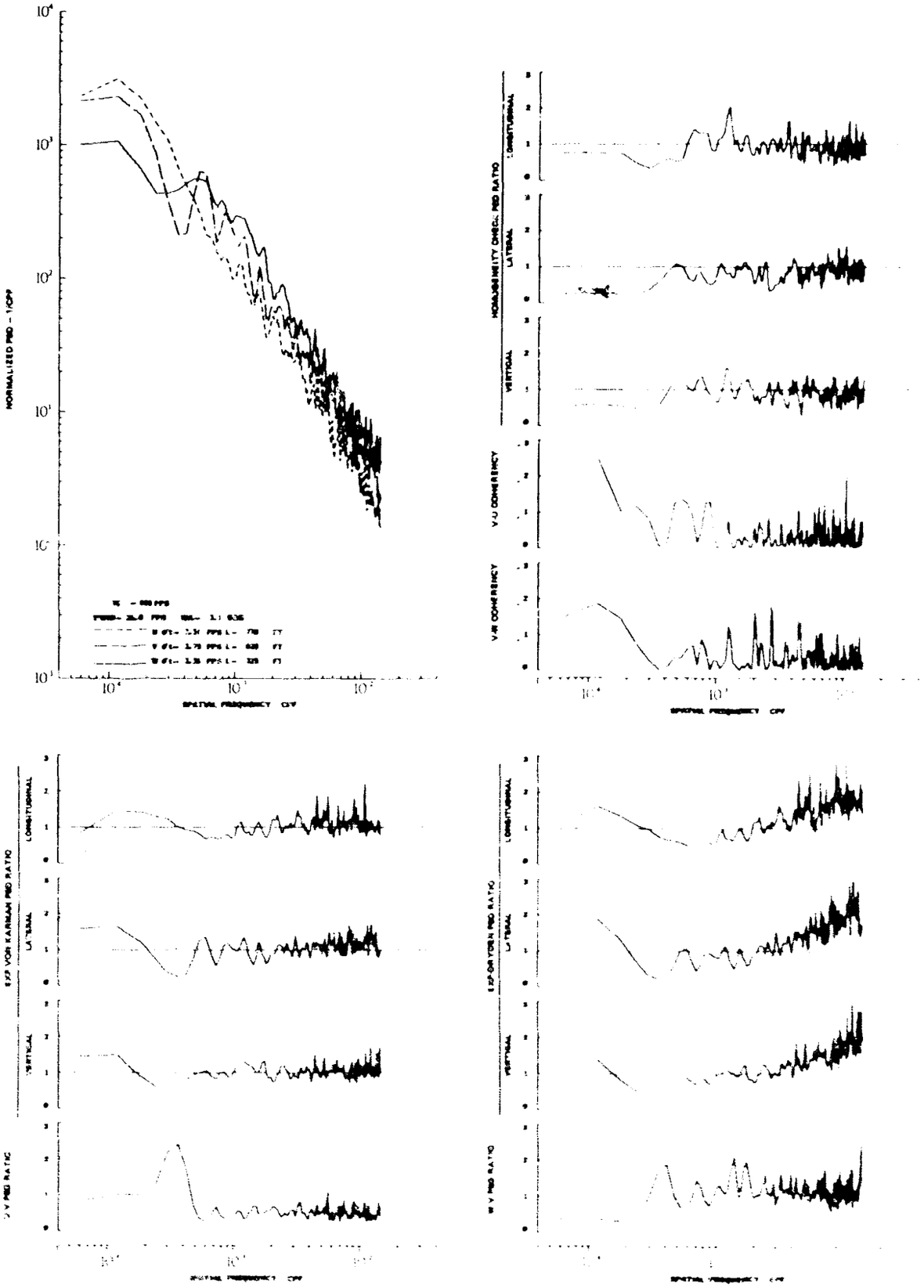

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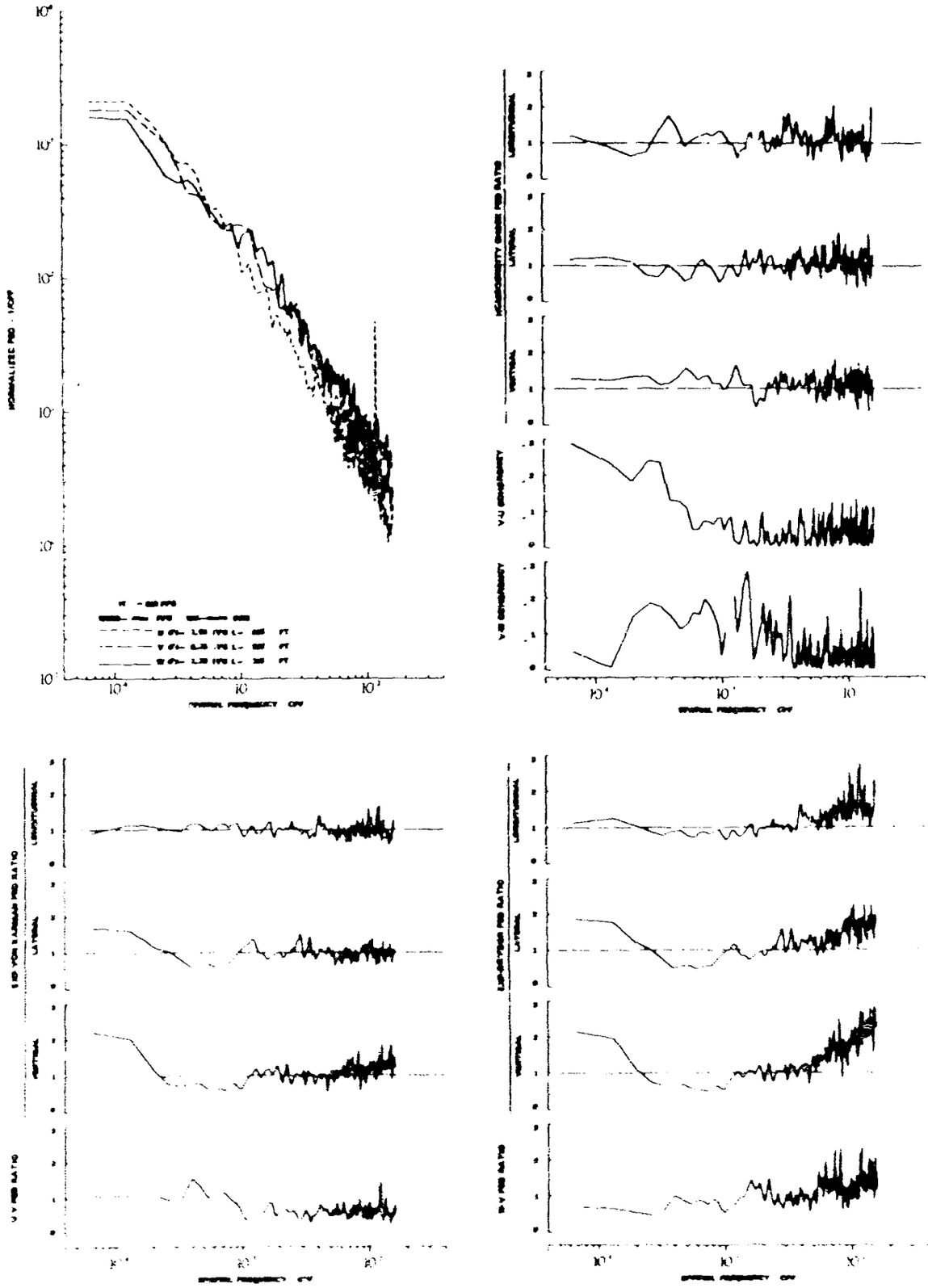

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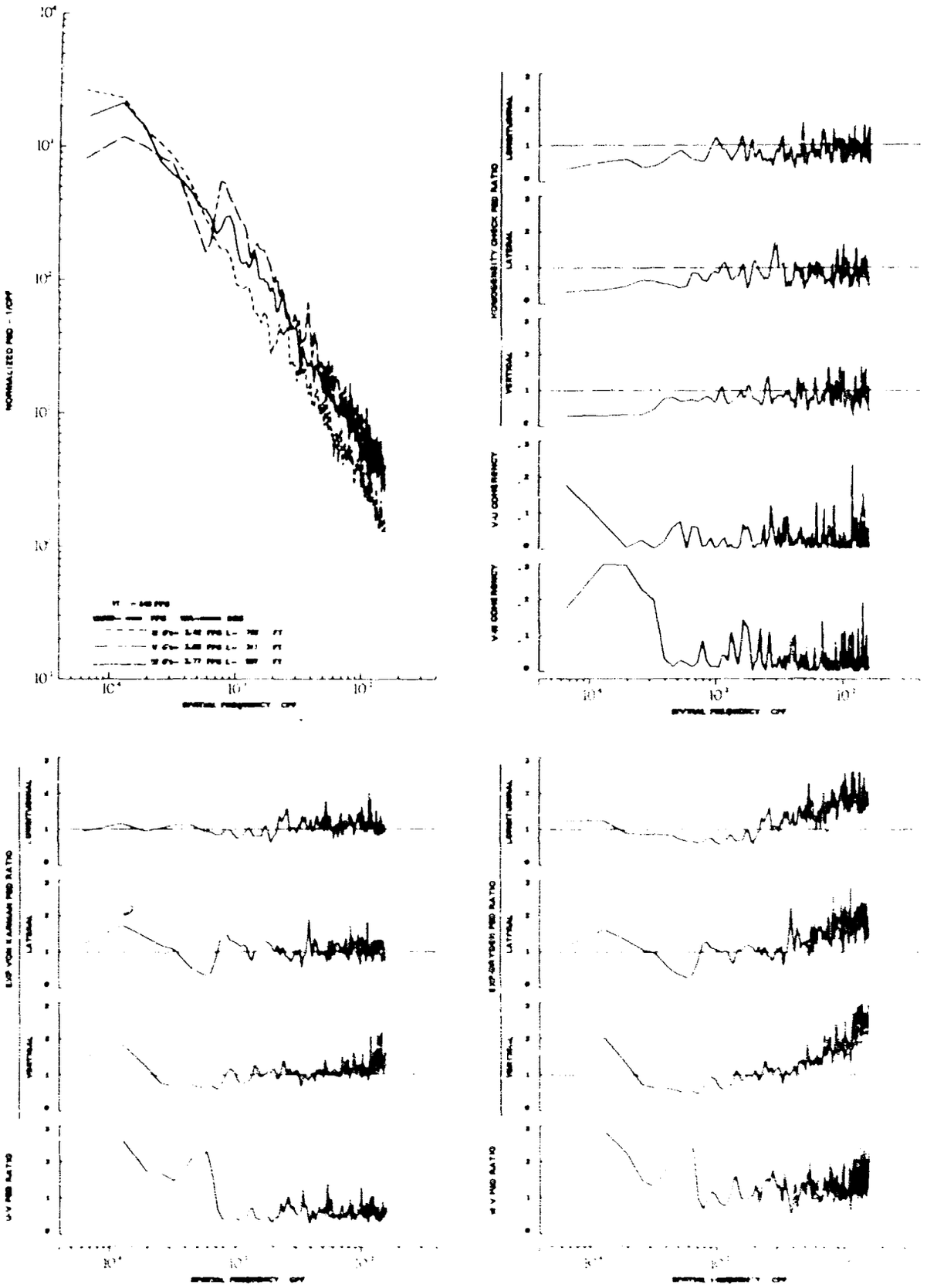

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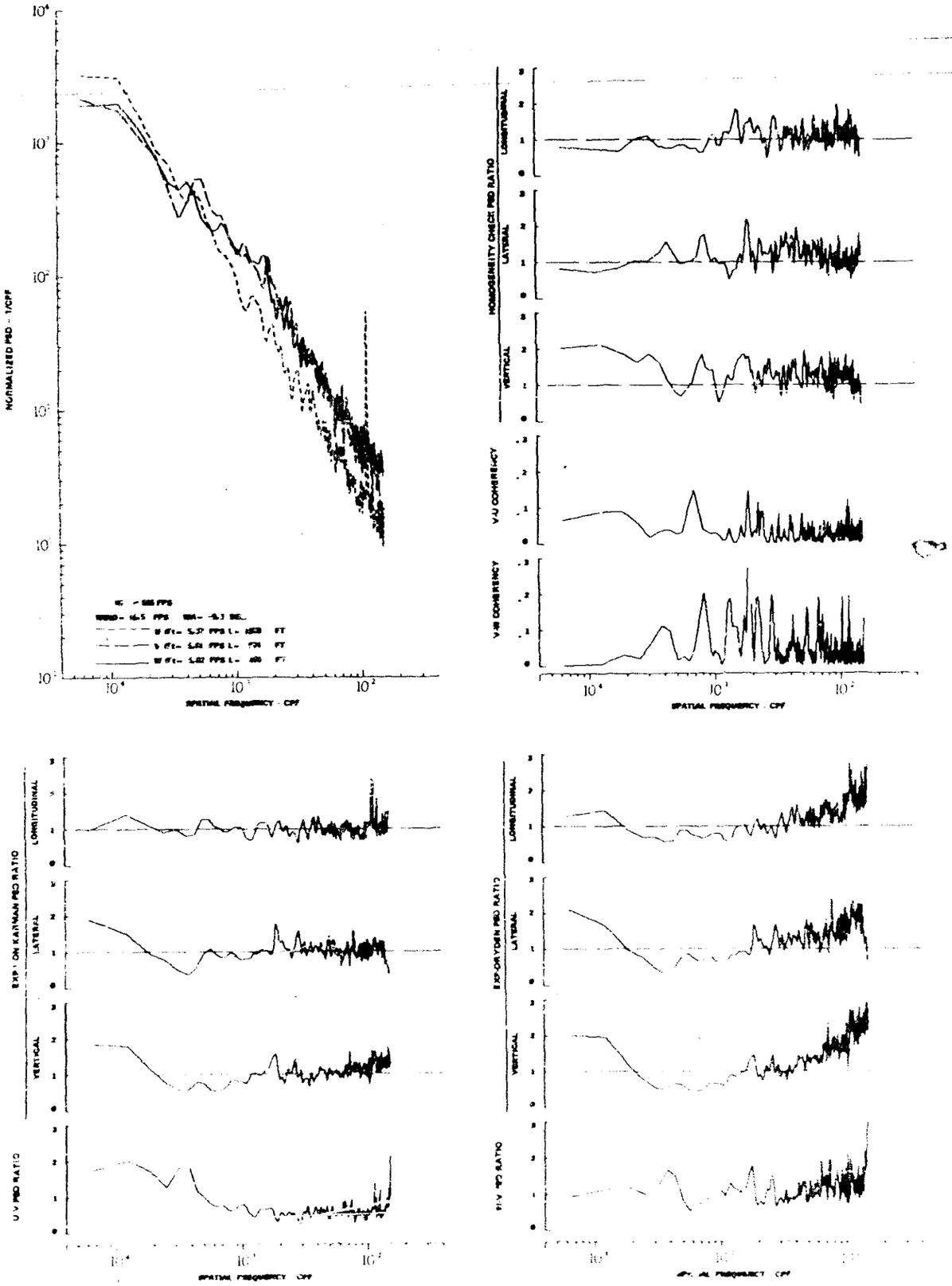

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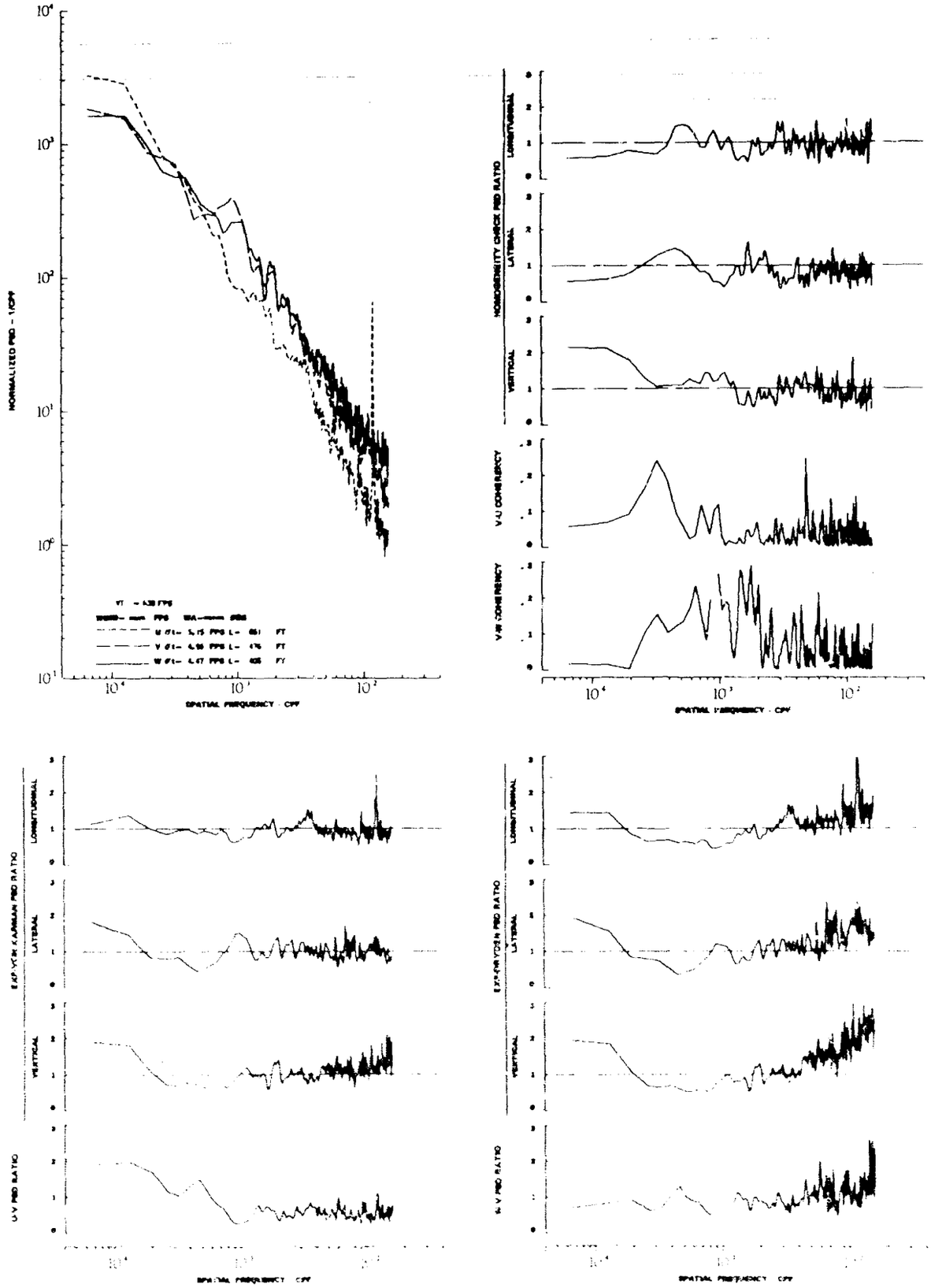
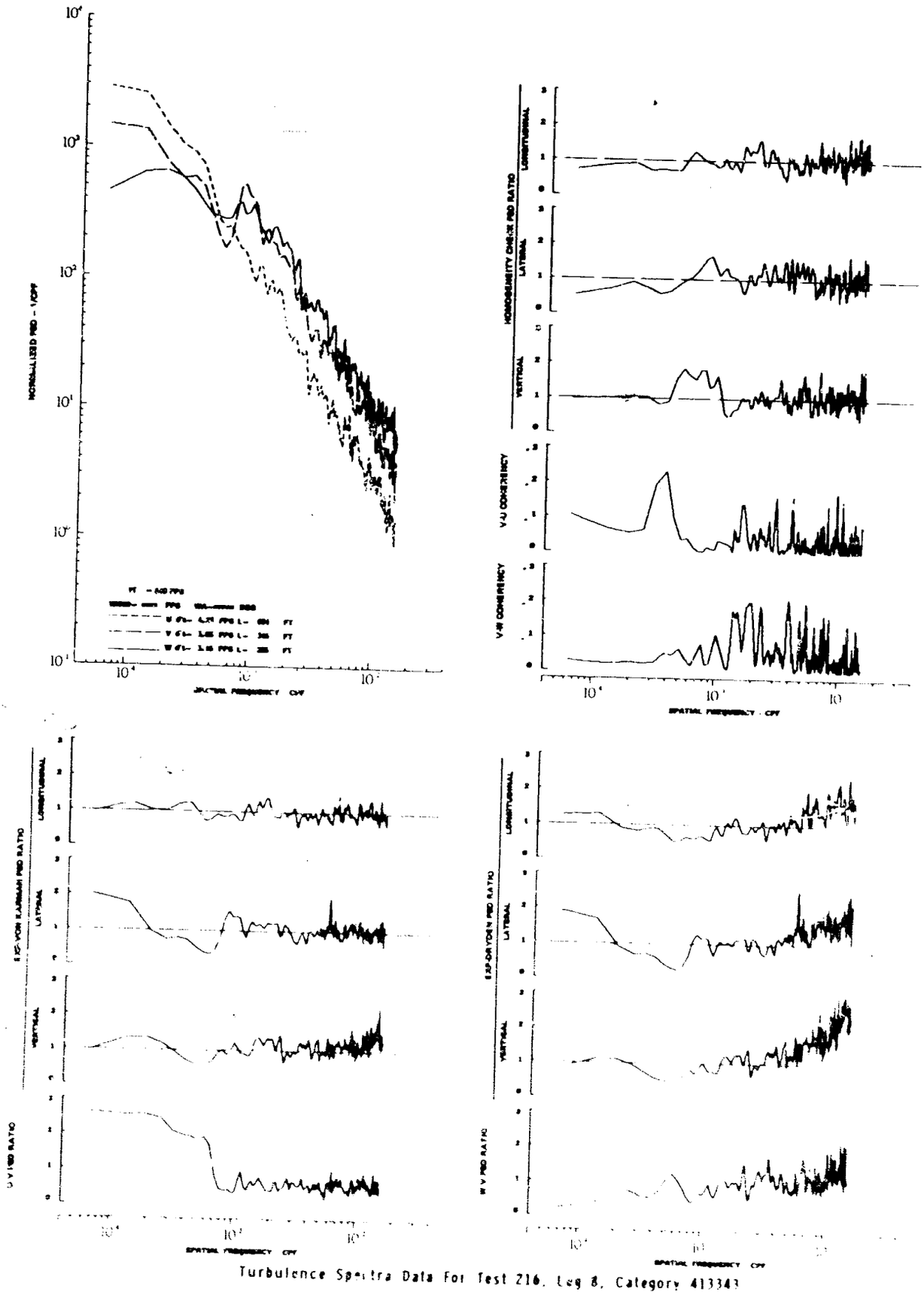
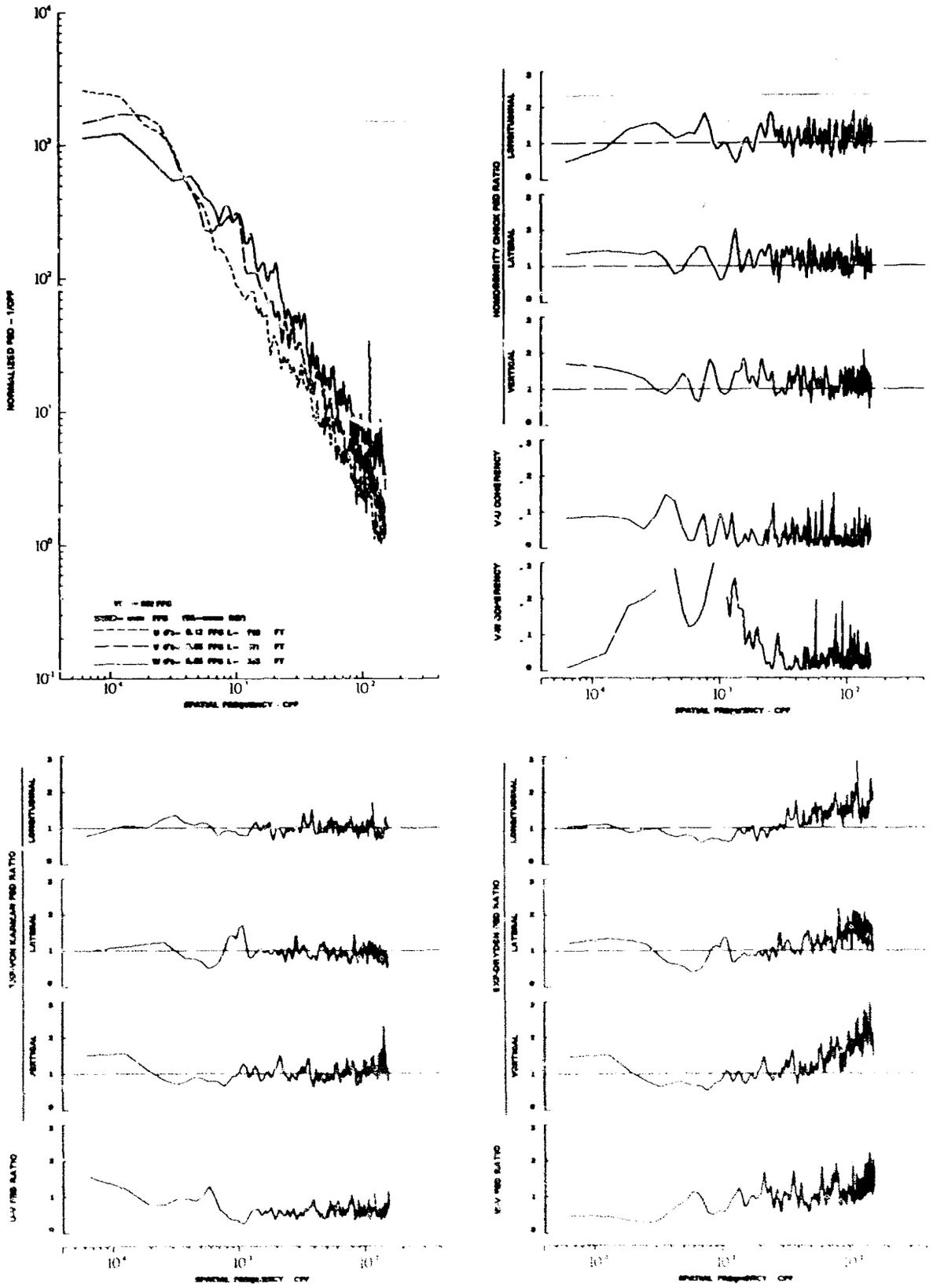


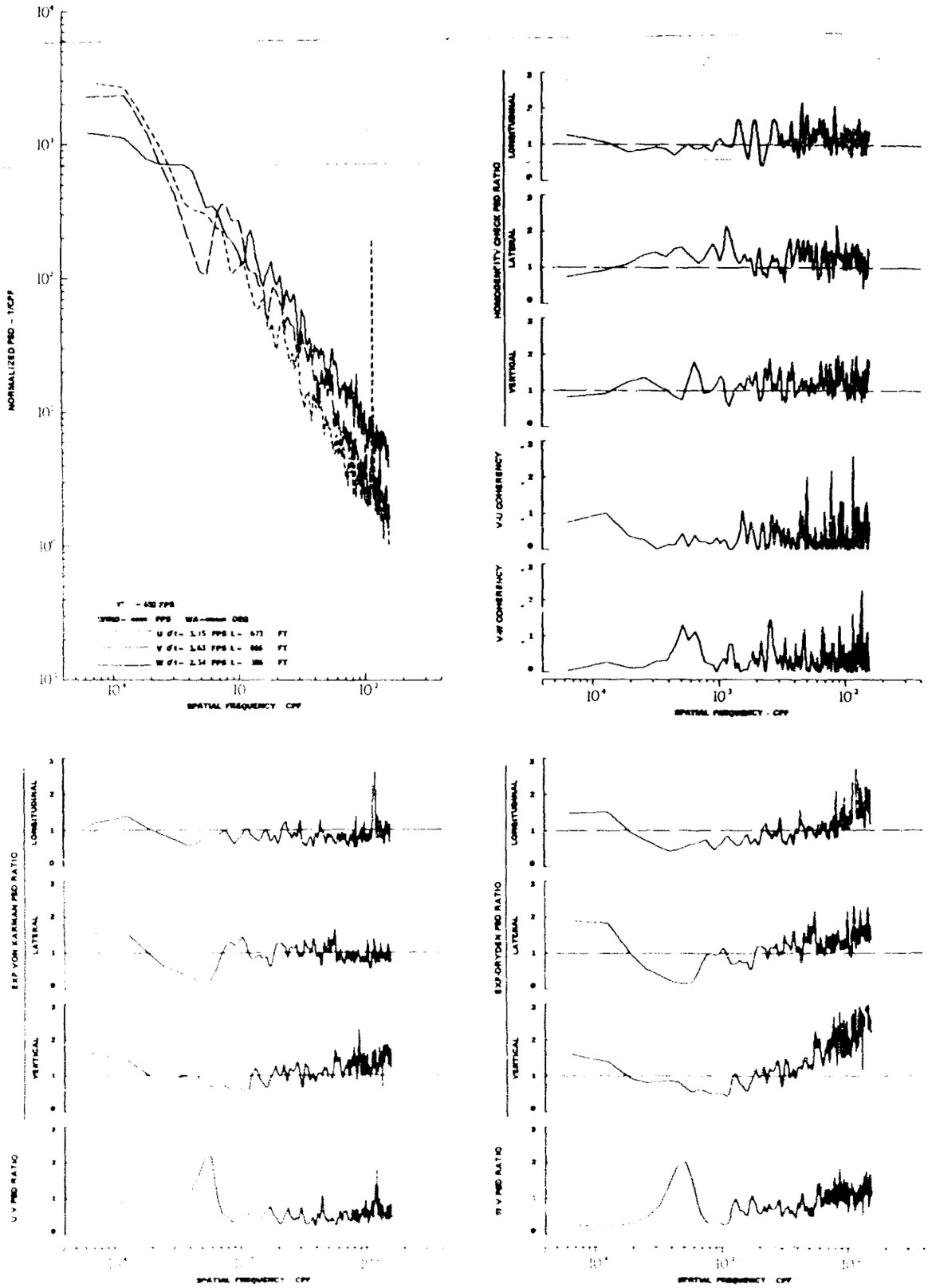
Turbulence Spectra Data For Test 216, Leg 4, Category 114343



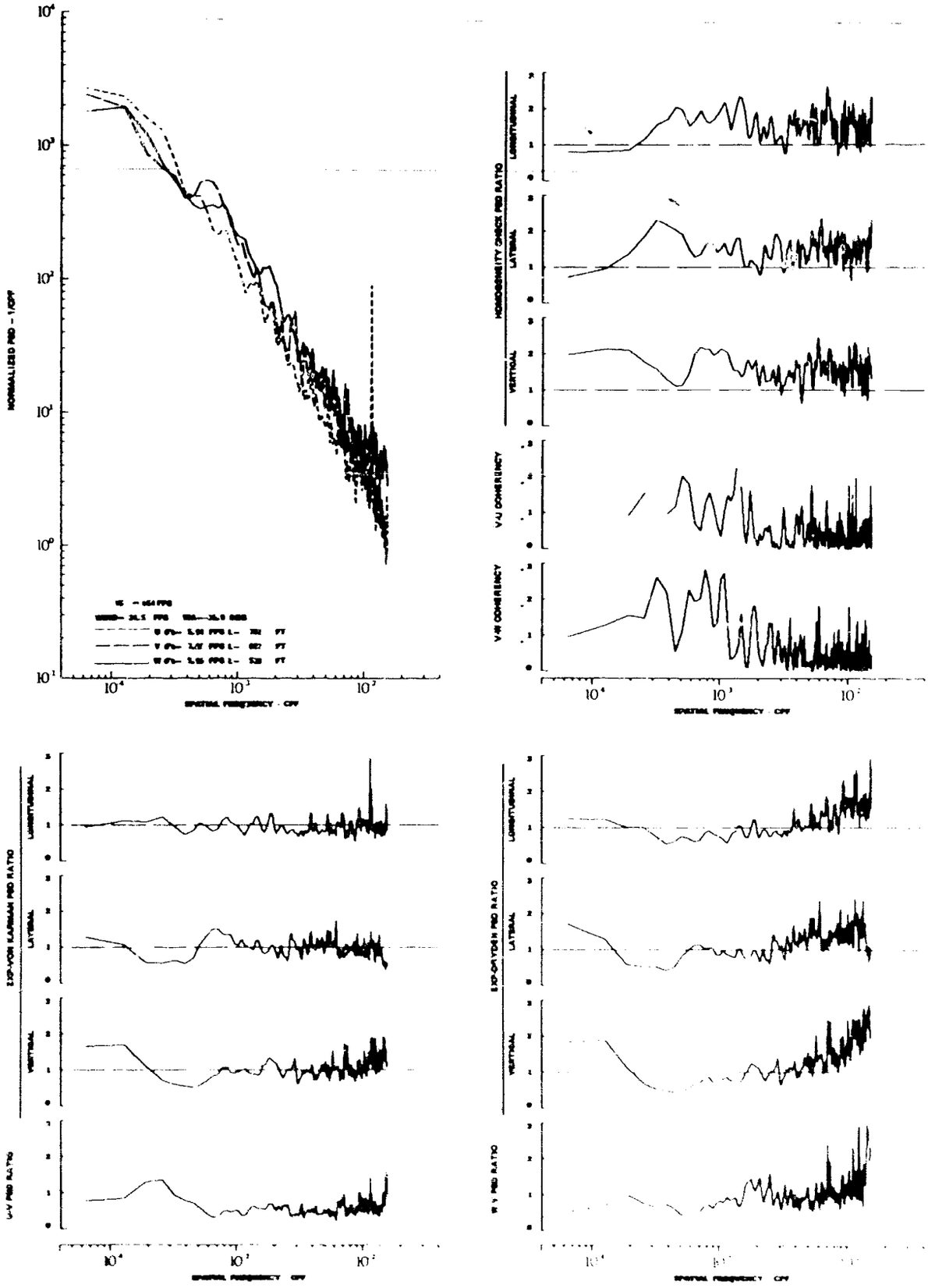
Turbulence Spectra Data For Test 216, Leg 8, Category 413343



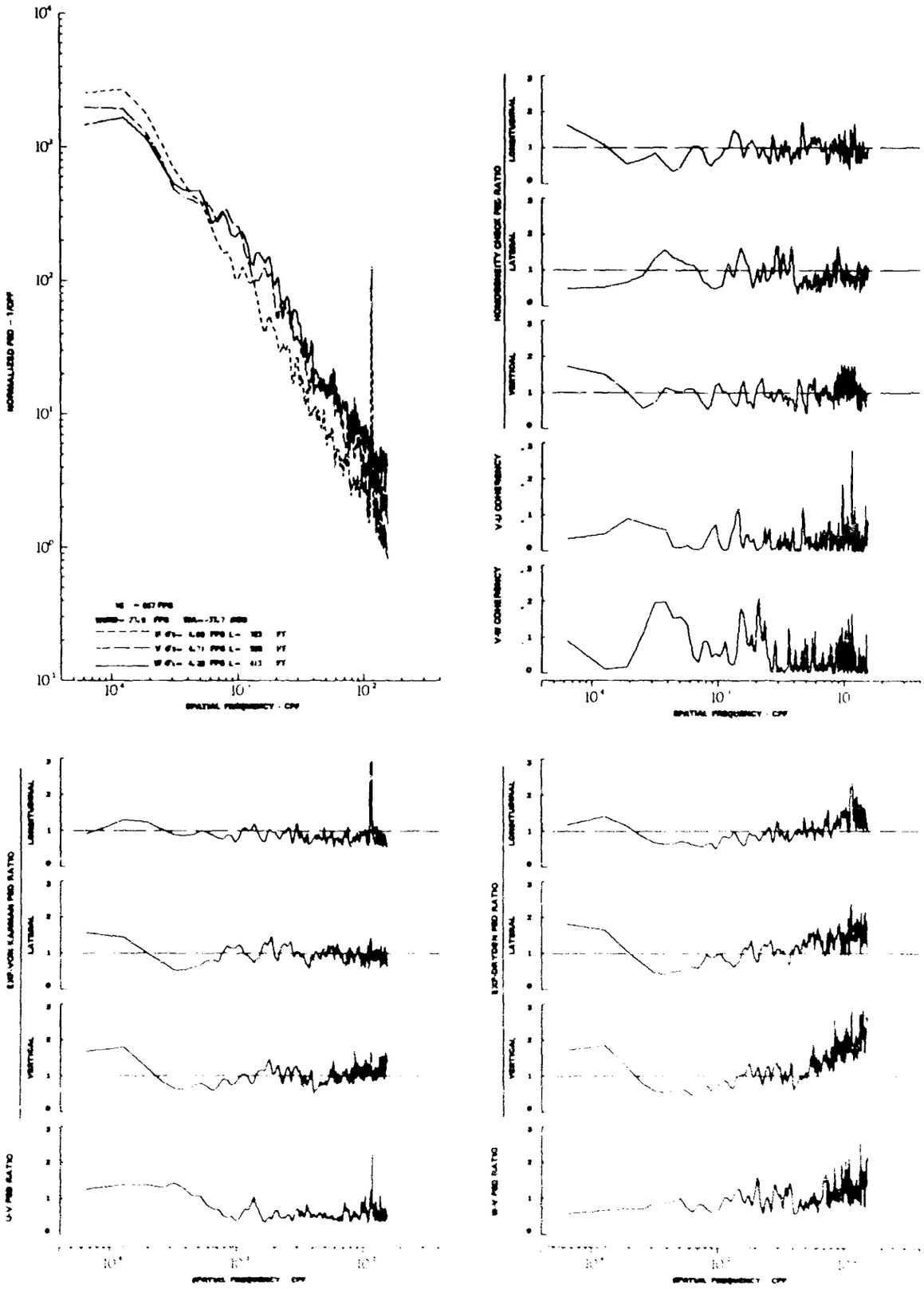
Turbulence Spectra Data For Test 217, Leg 5, Category 123113



Turbulence Spectra Data For Test 217, Leg 7, Category 121113



Turbulence Spectra Data For Test 218, Leg 2, Category 122213



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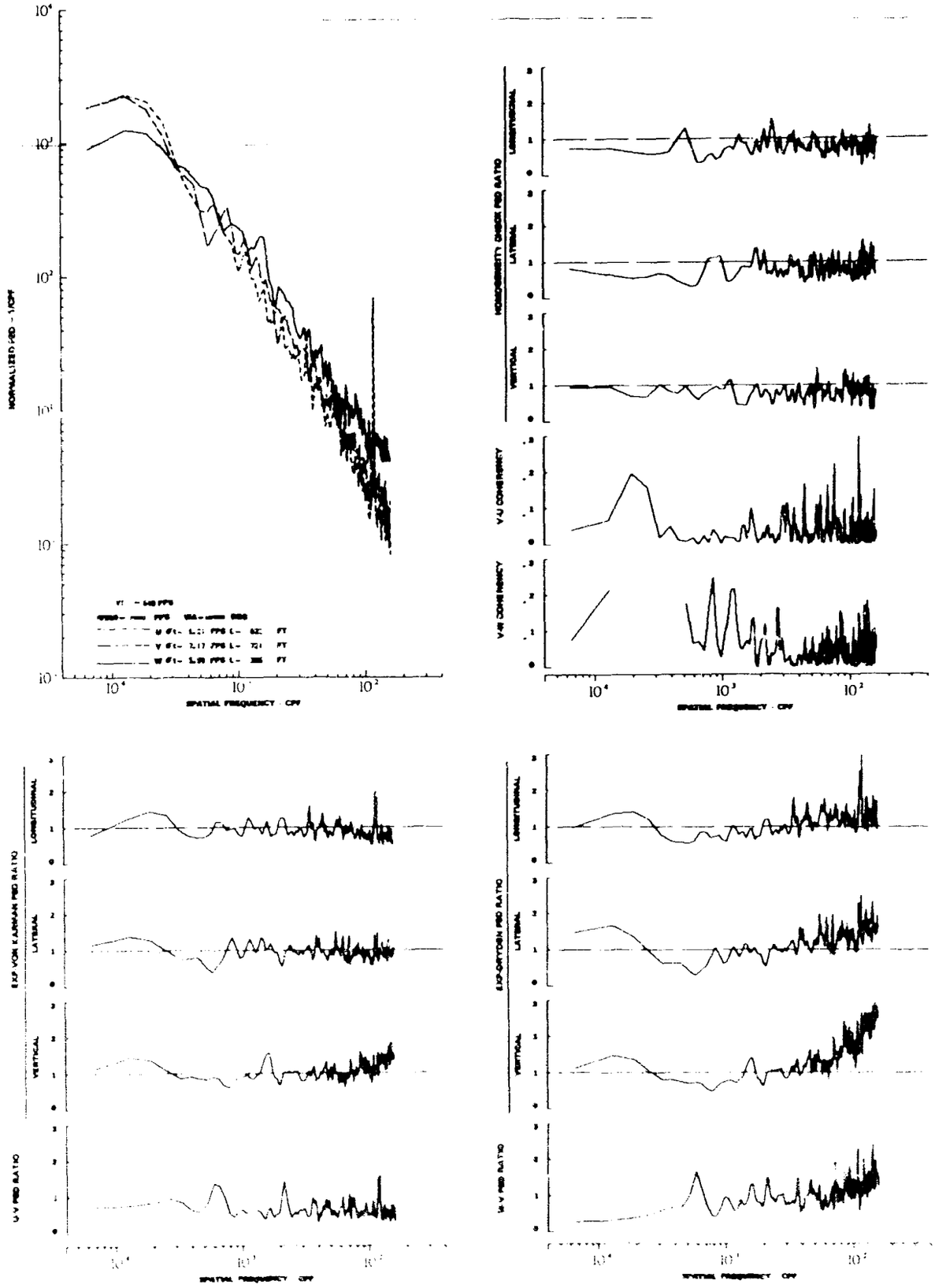

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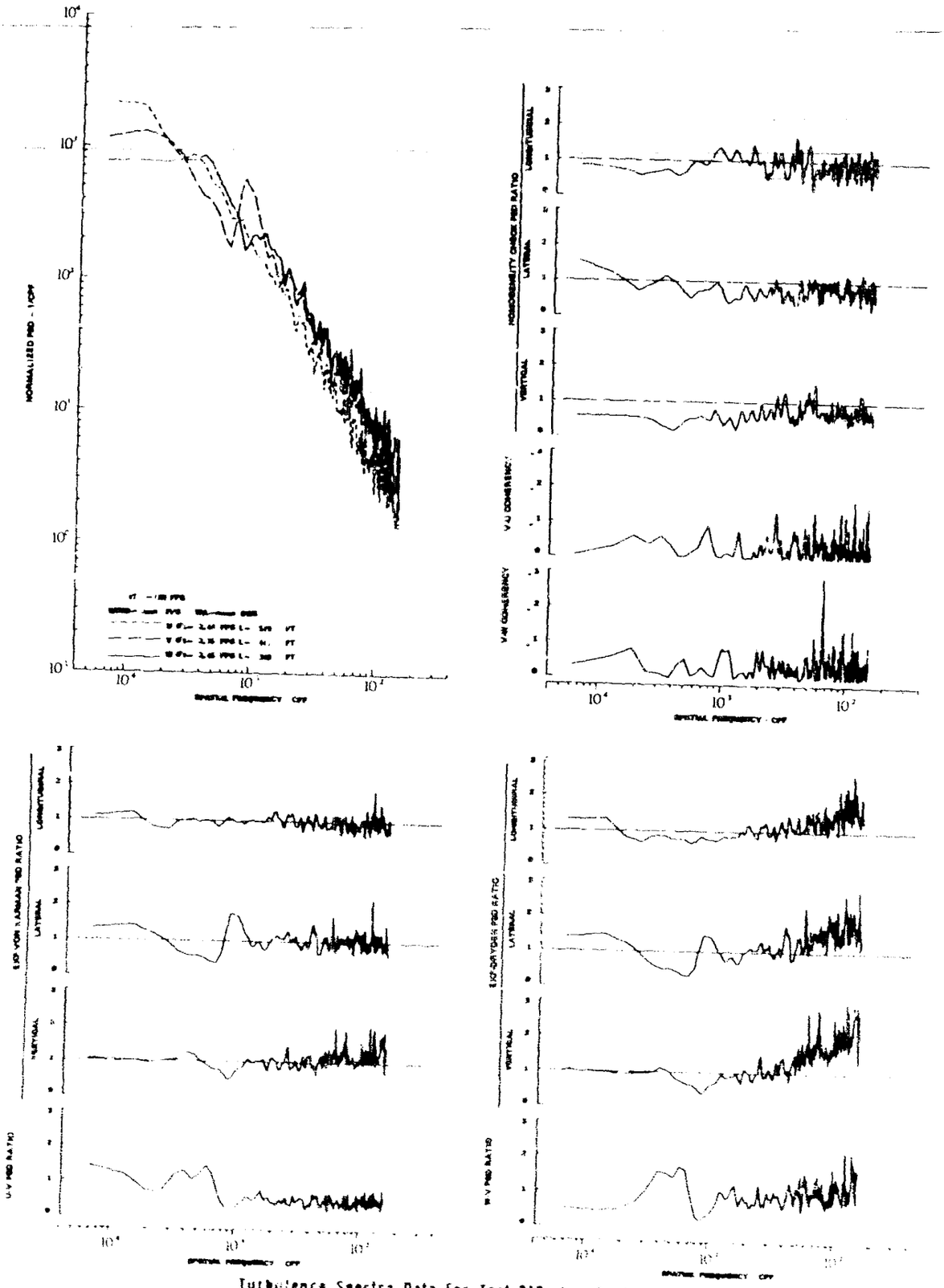
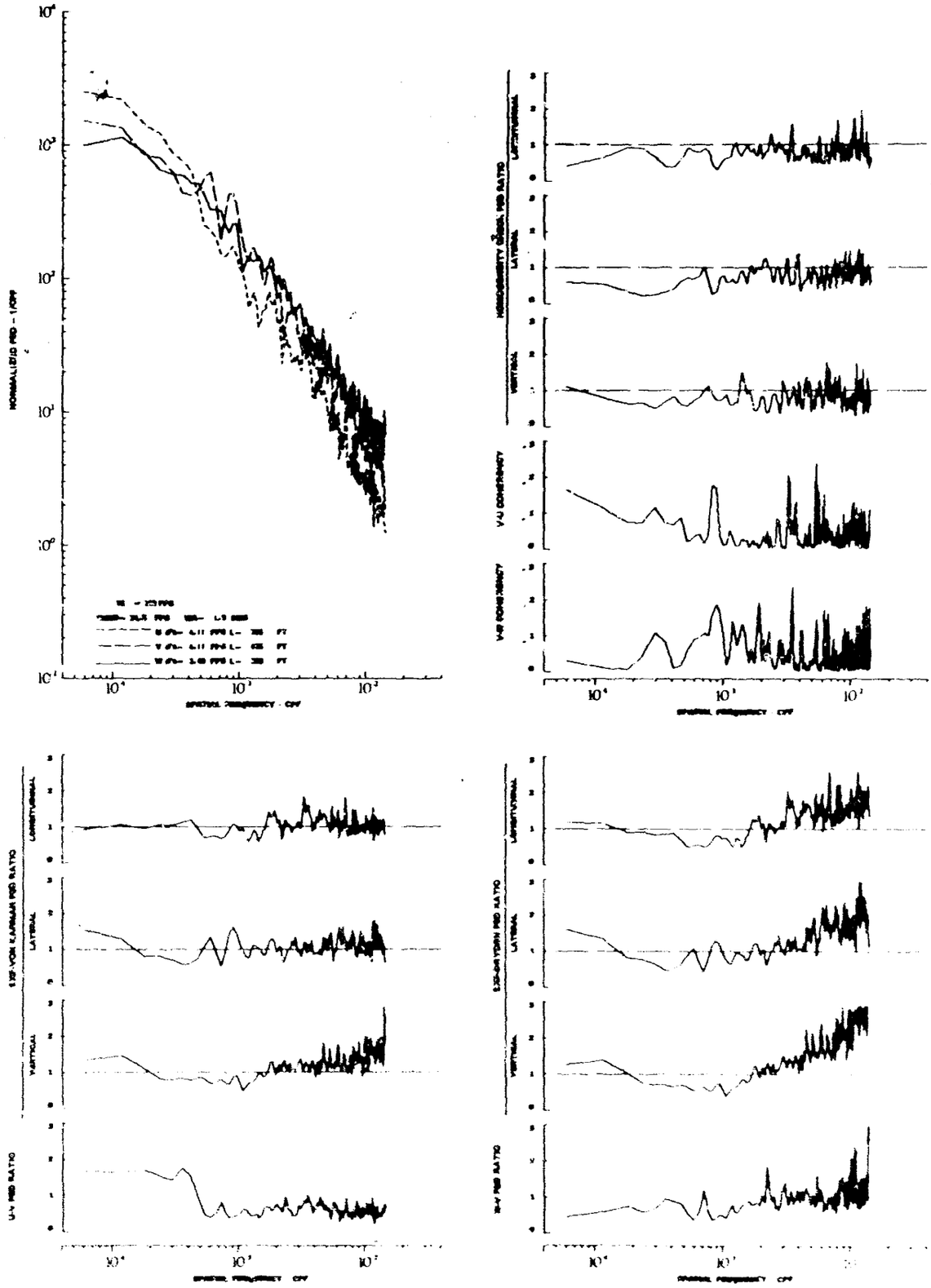
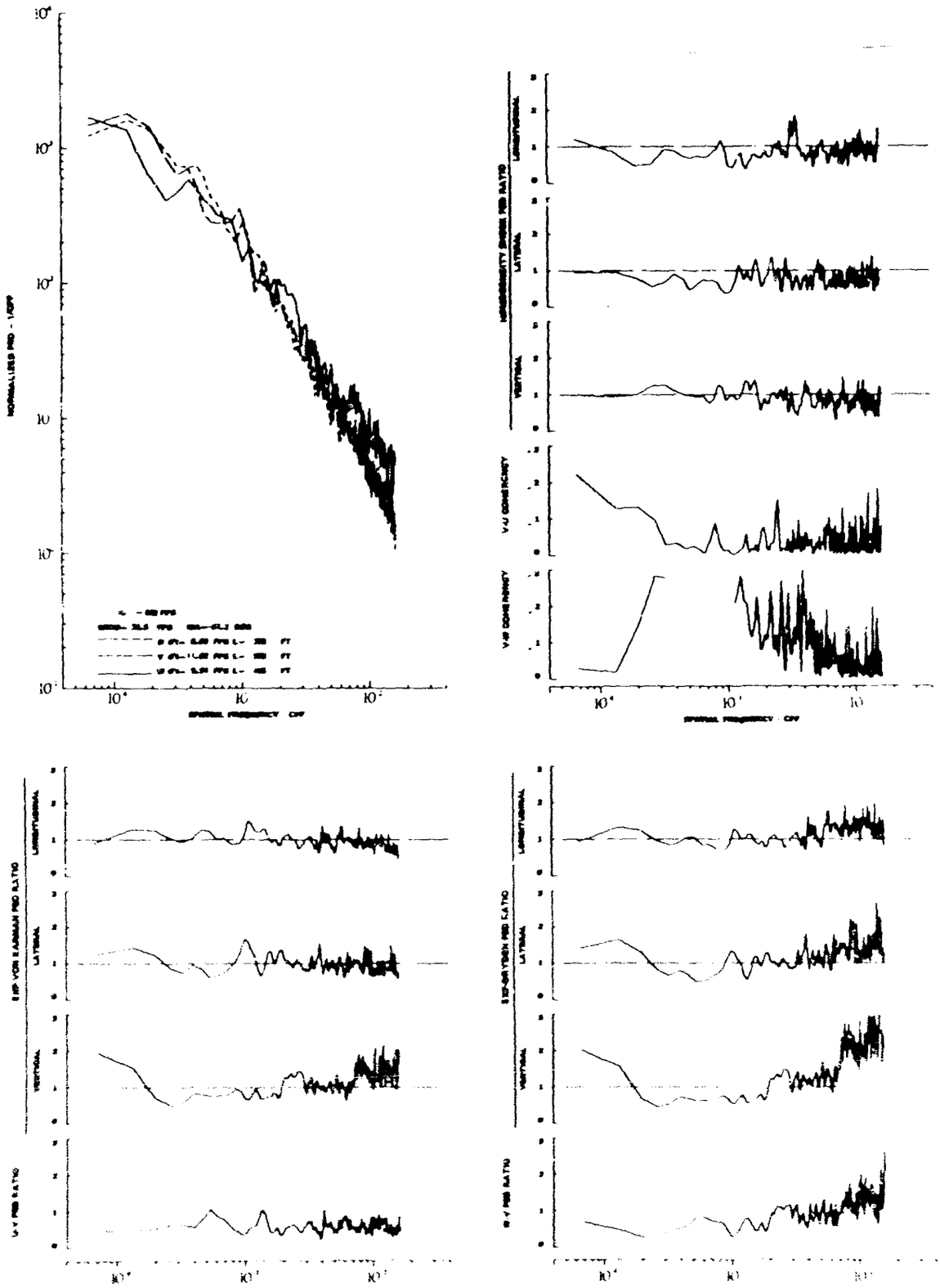


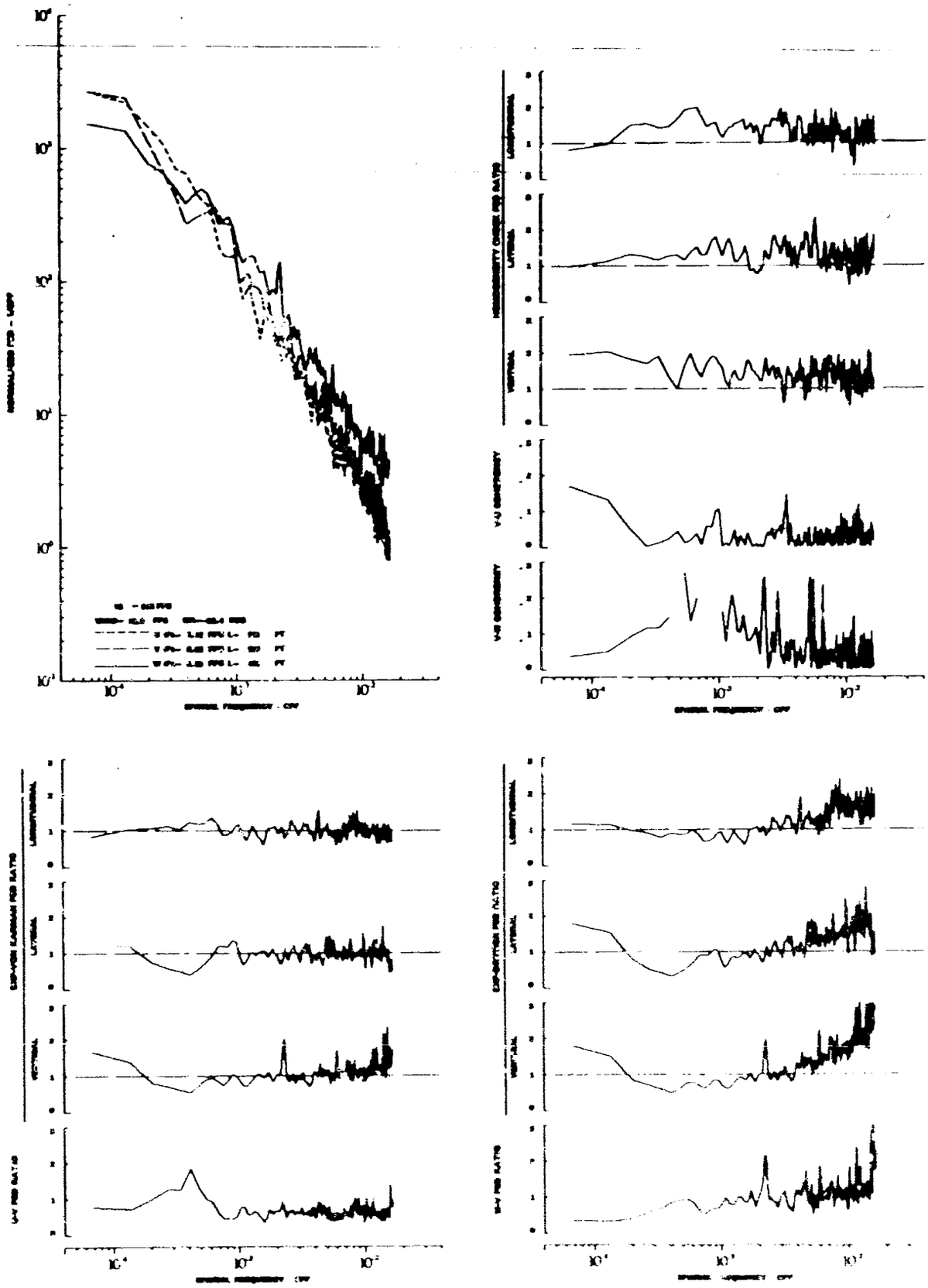
Turbulence Spectra Data For Test 218, Leg 8, Category 123213



Turbulence Spectra Data For Test 219, Leg 3, Category 112213



Turbulence Spectra Data For Test Z19, Leg 5, Category 112213



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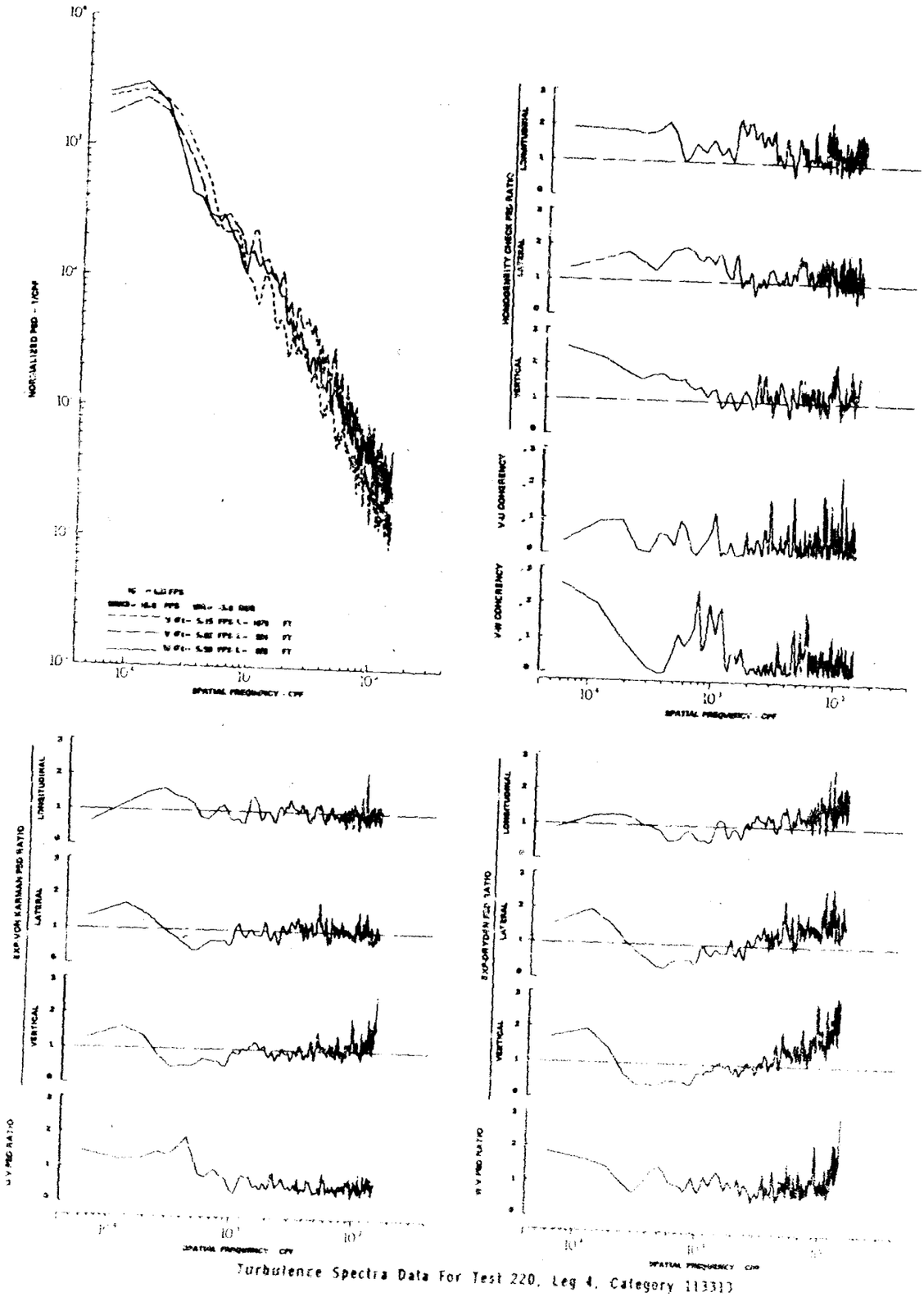

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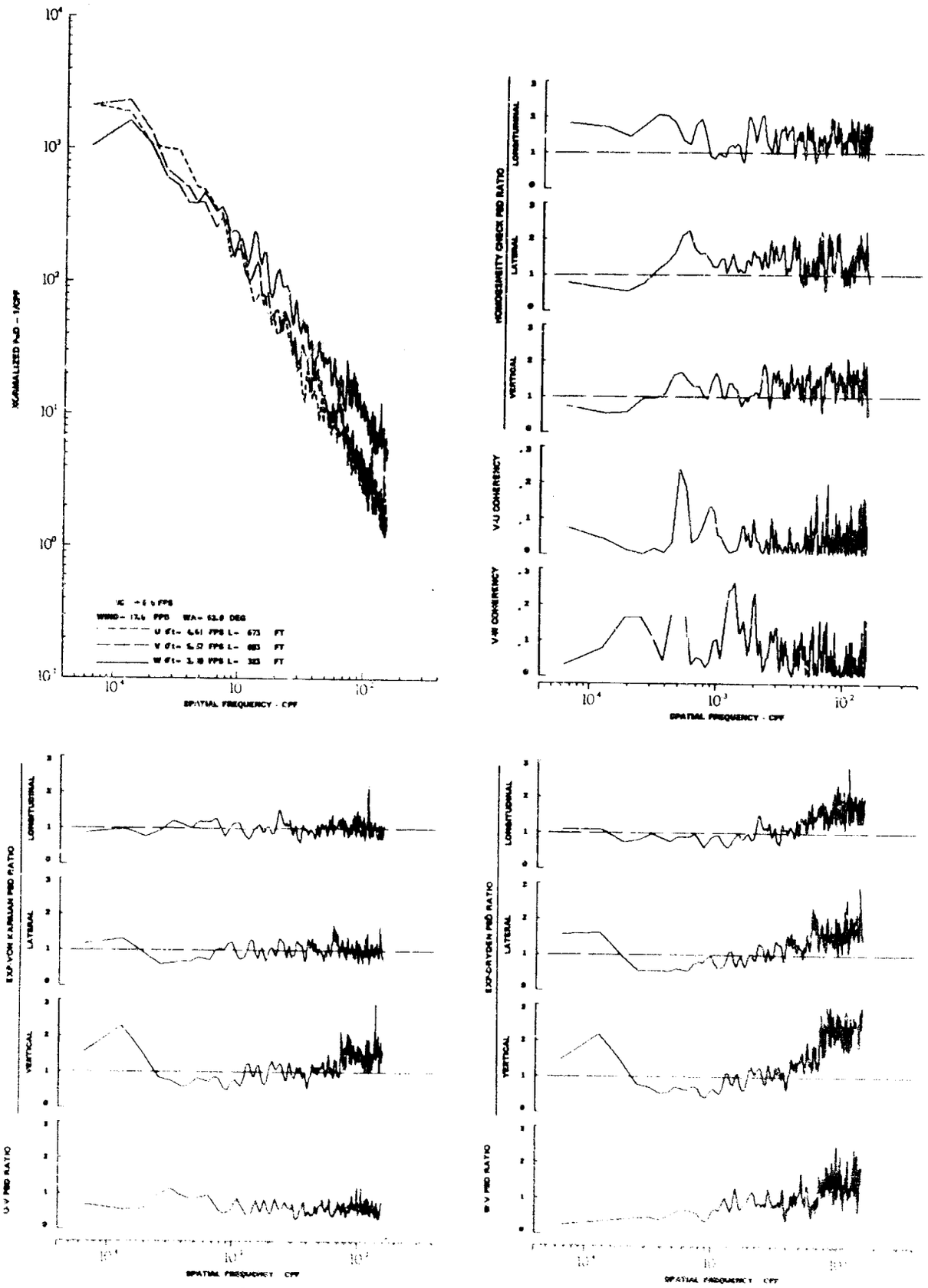
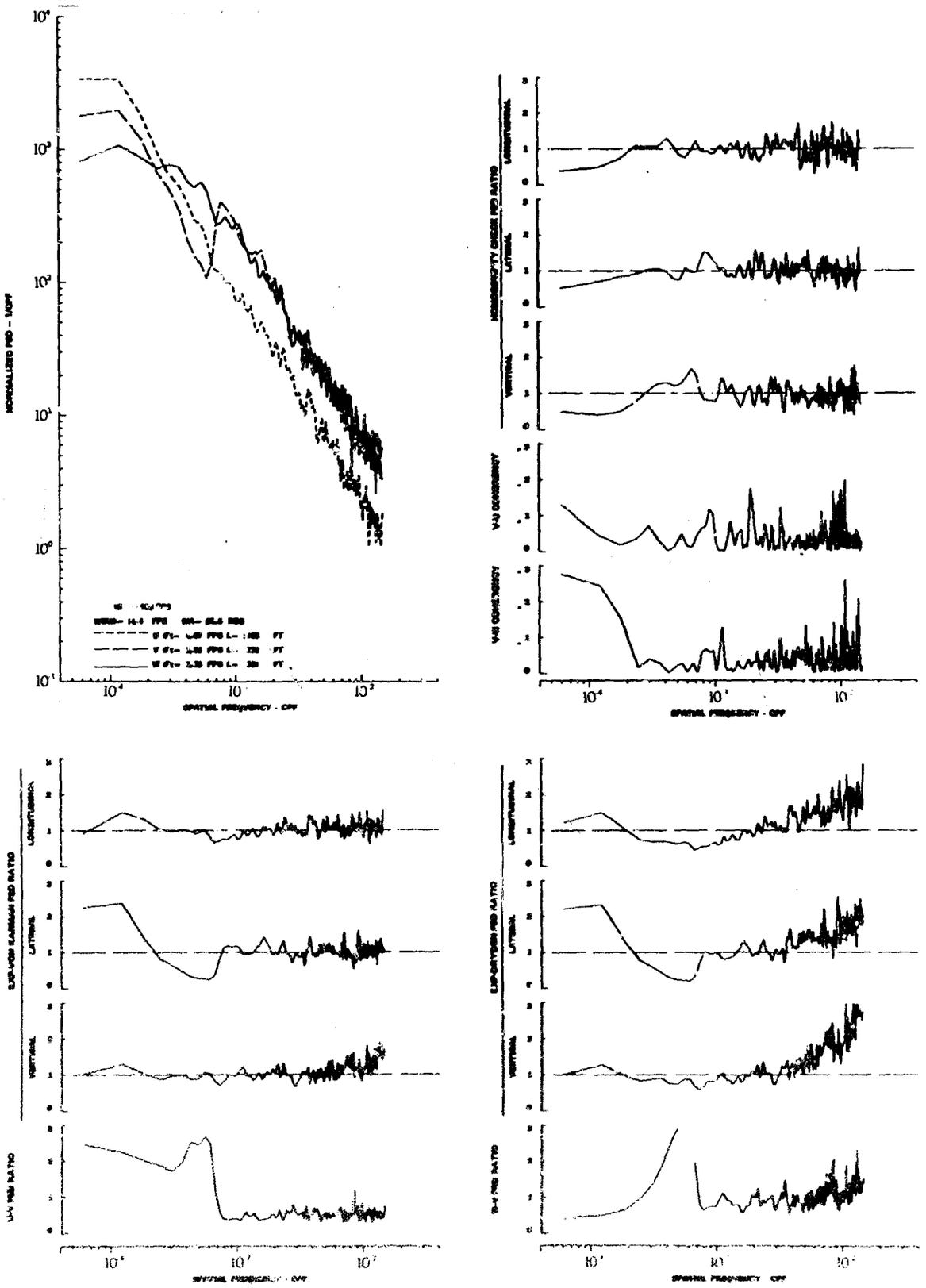
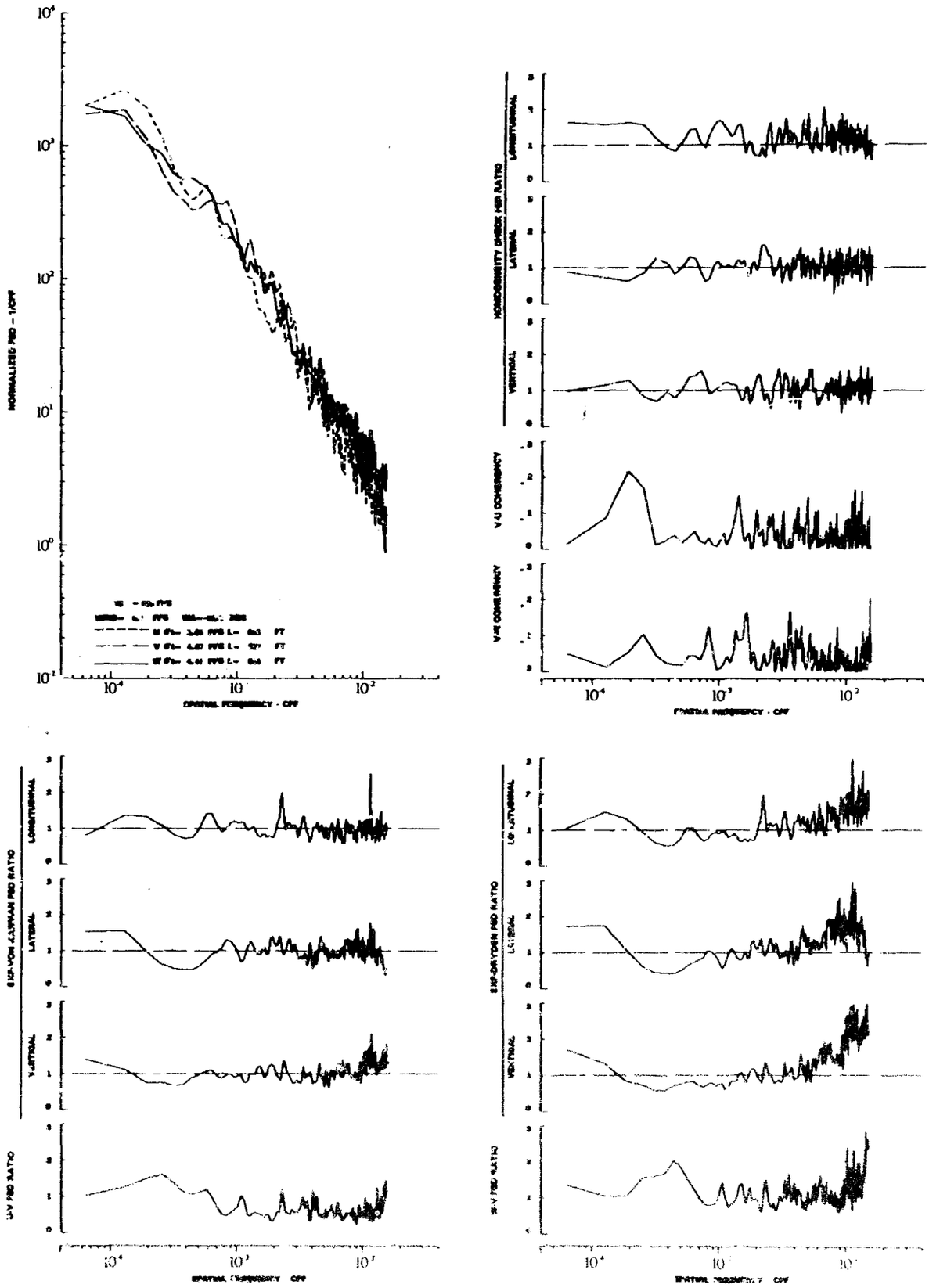


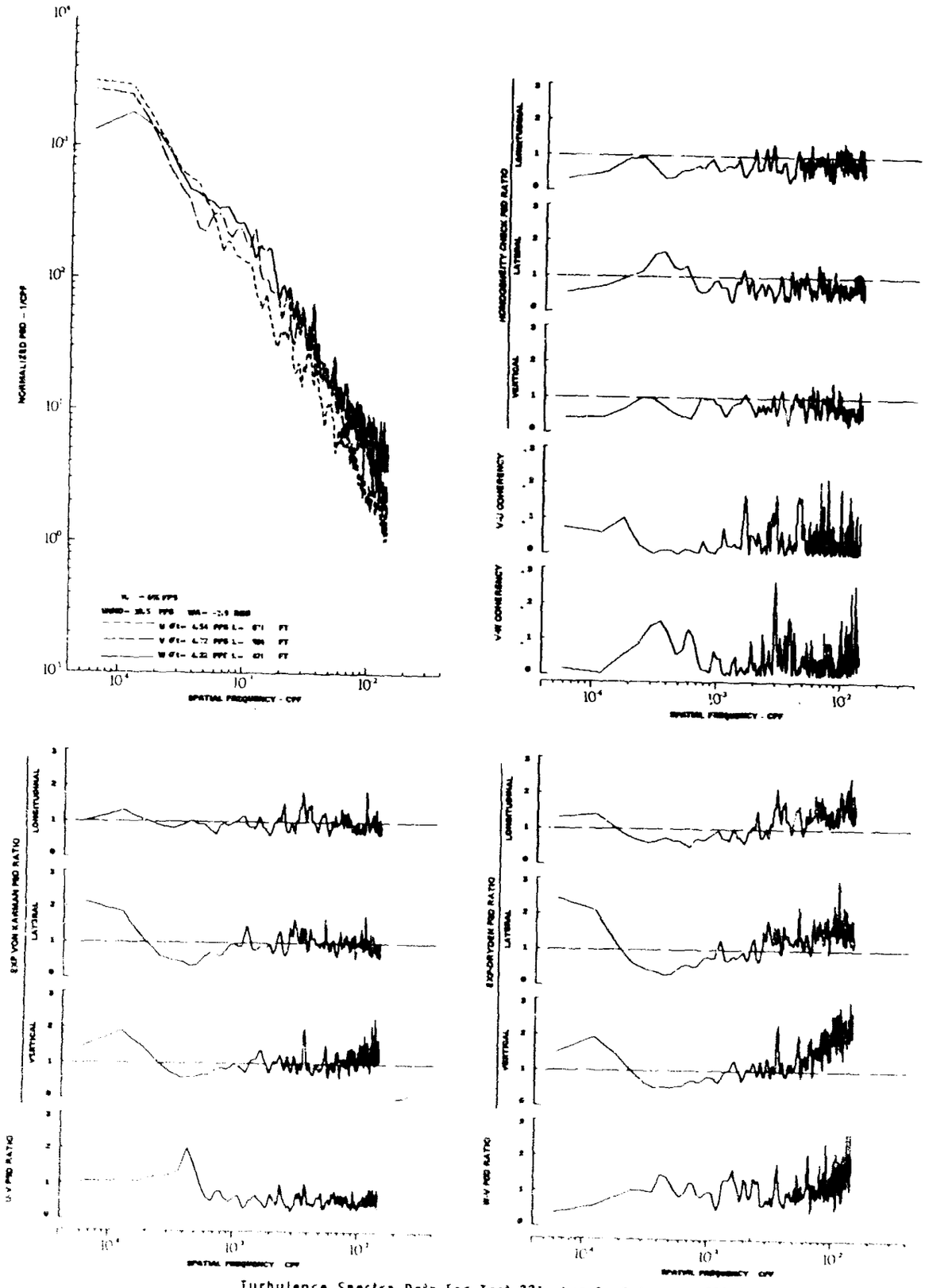
Turbulence Spectra Data For Test 220, Leg 6, Category 113313



Turbulence Spectra Data for Test 220, Leg 8 Category 413313



Turbulence Spectra Data For Test 221, Leg 1, Category 122213



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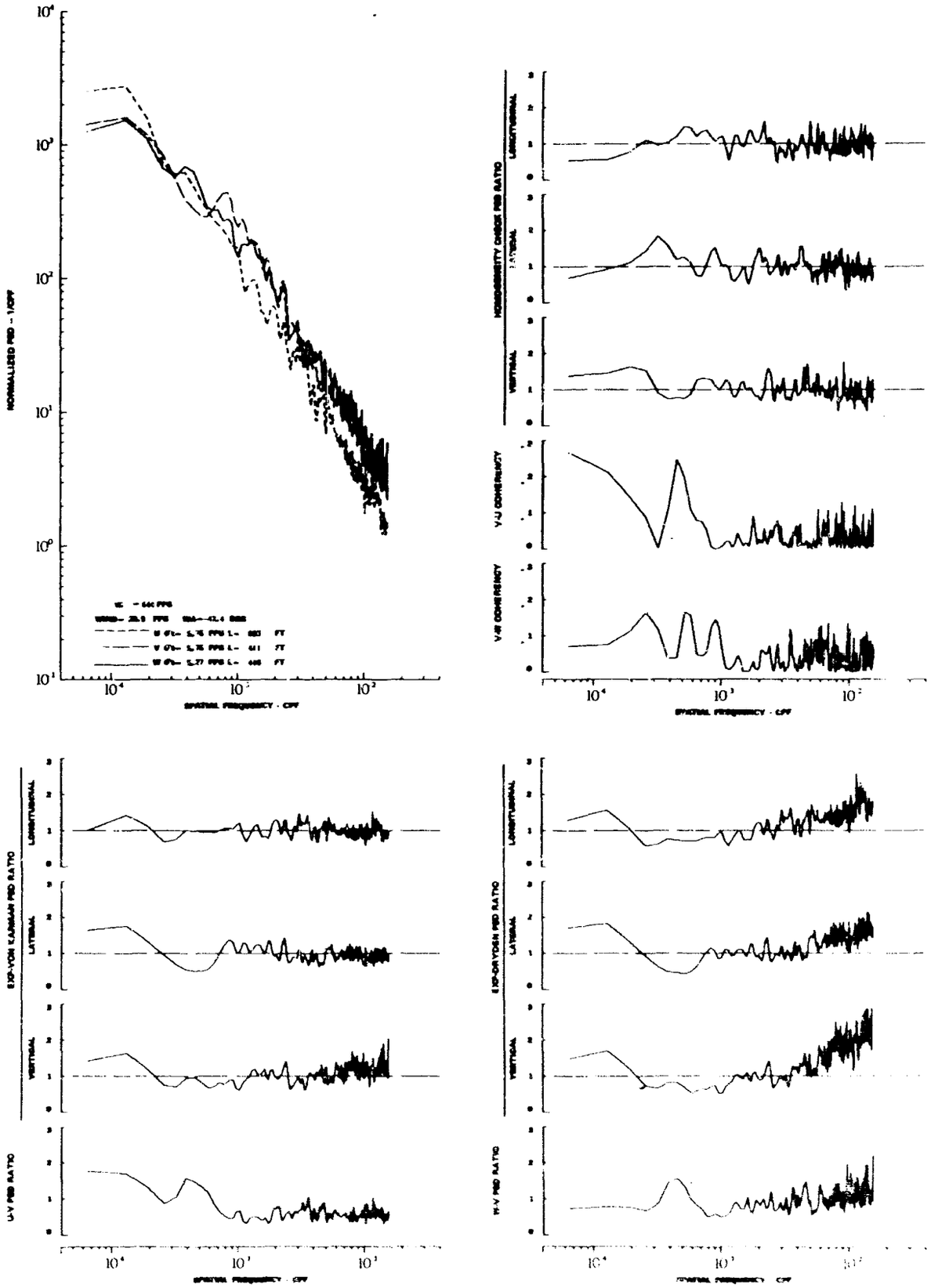

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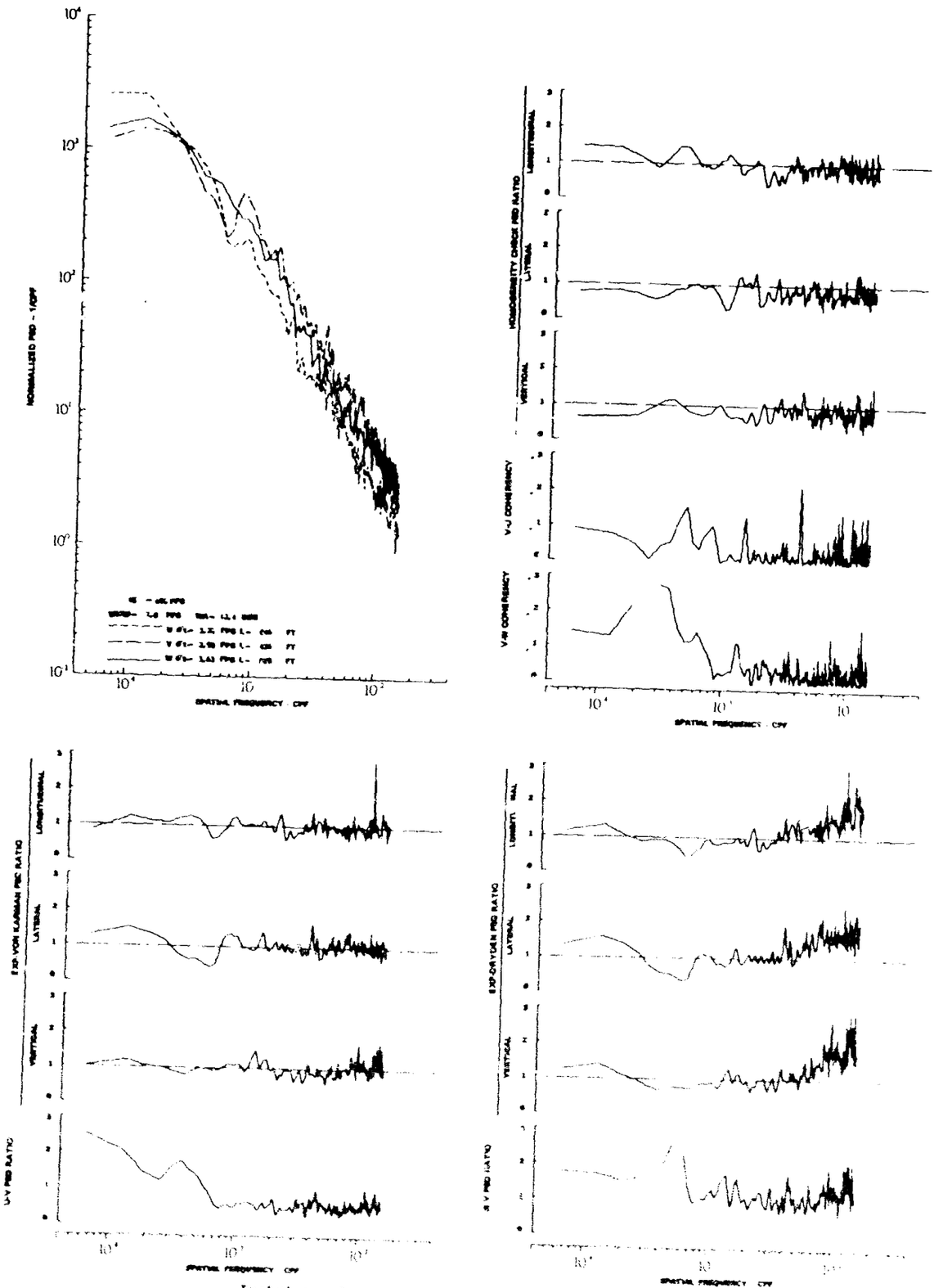

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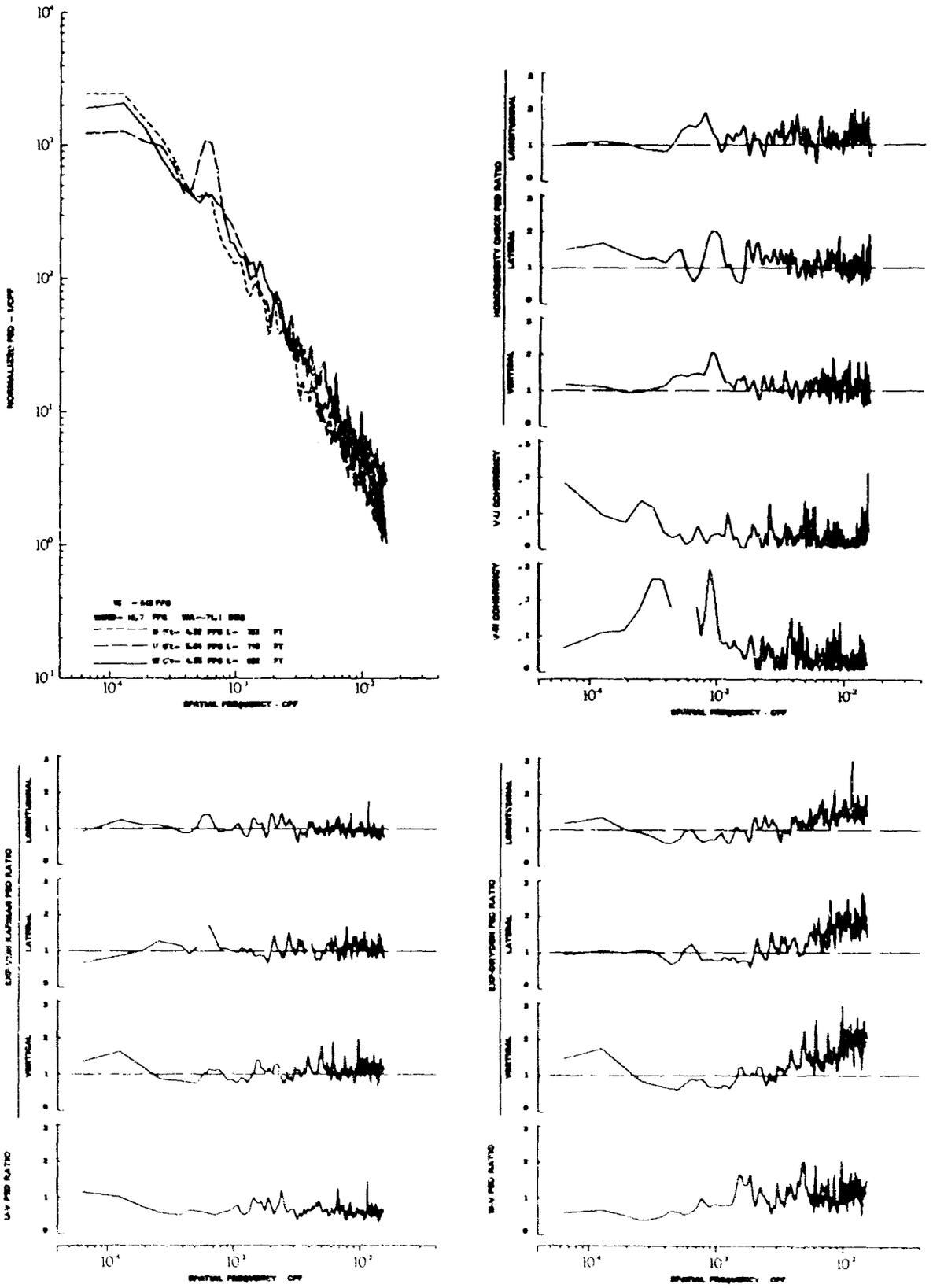

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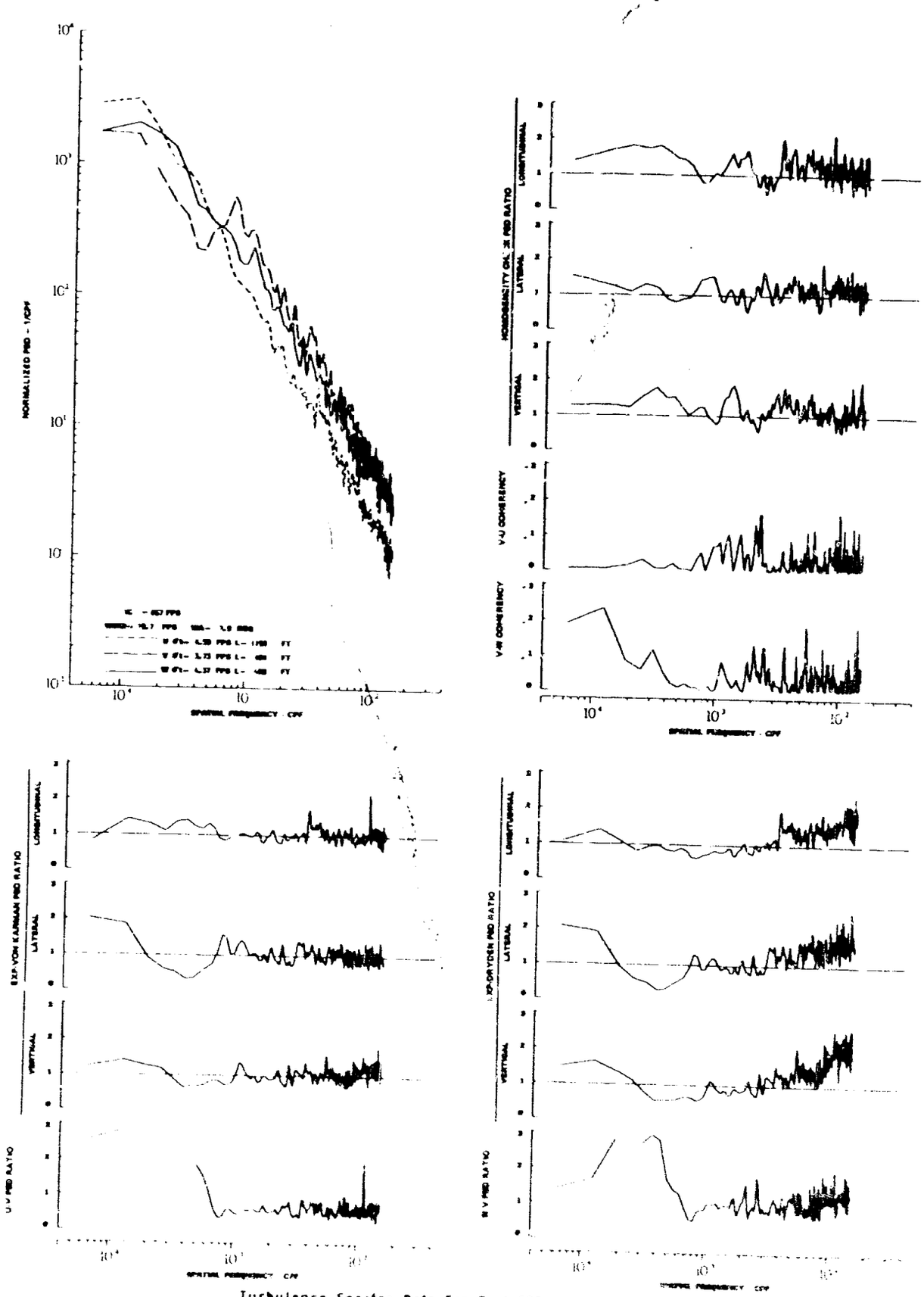
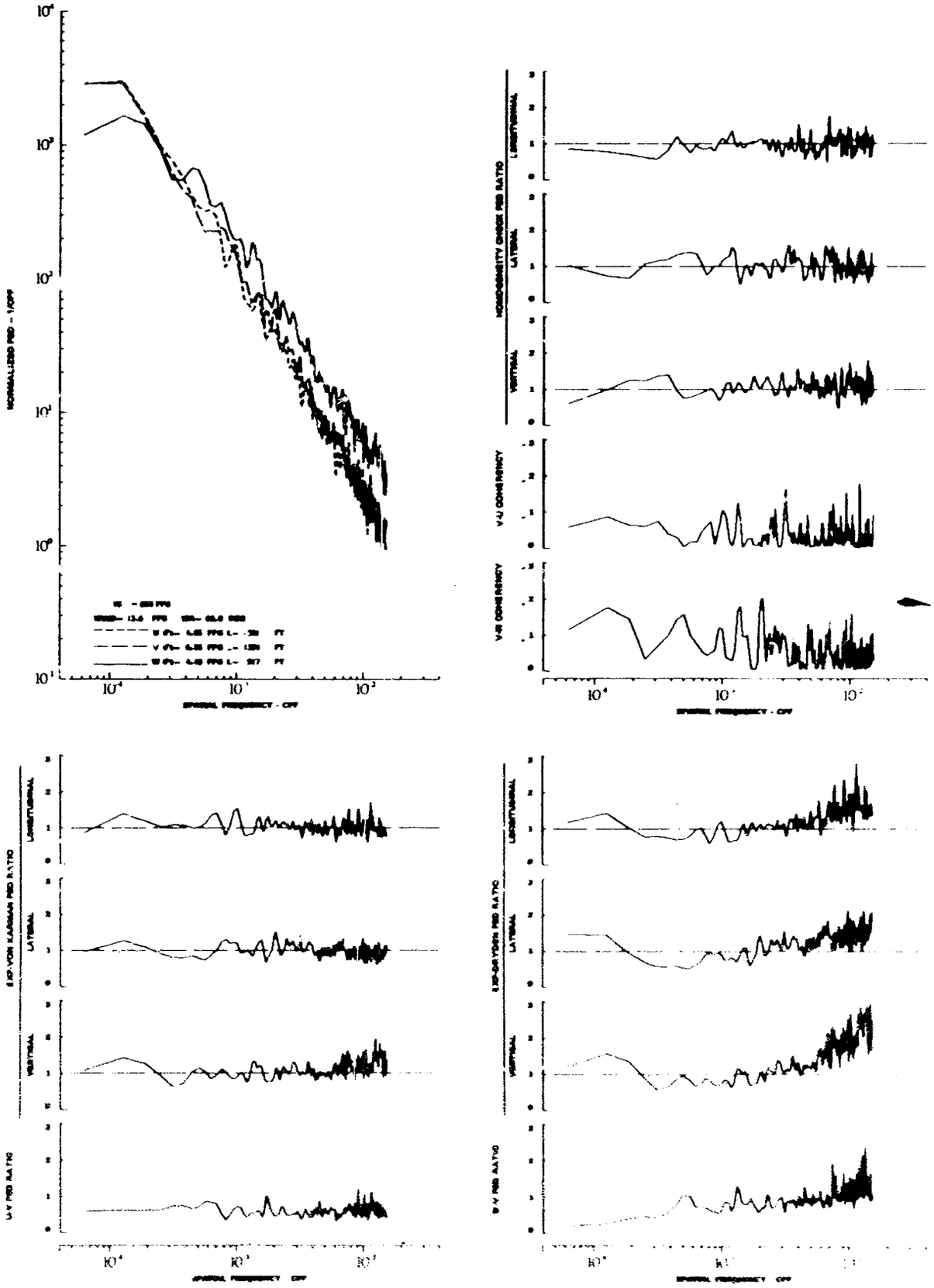
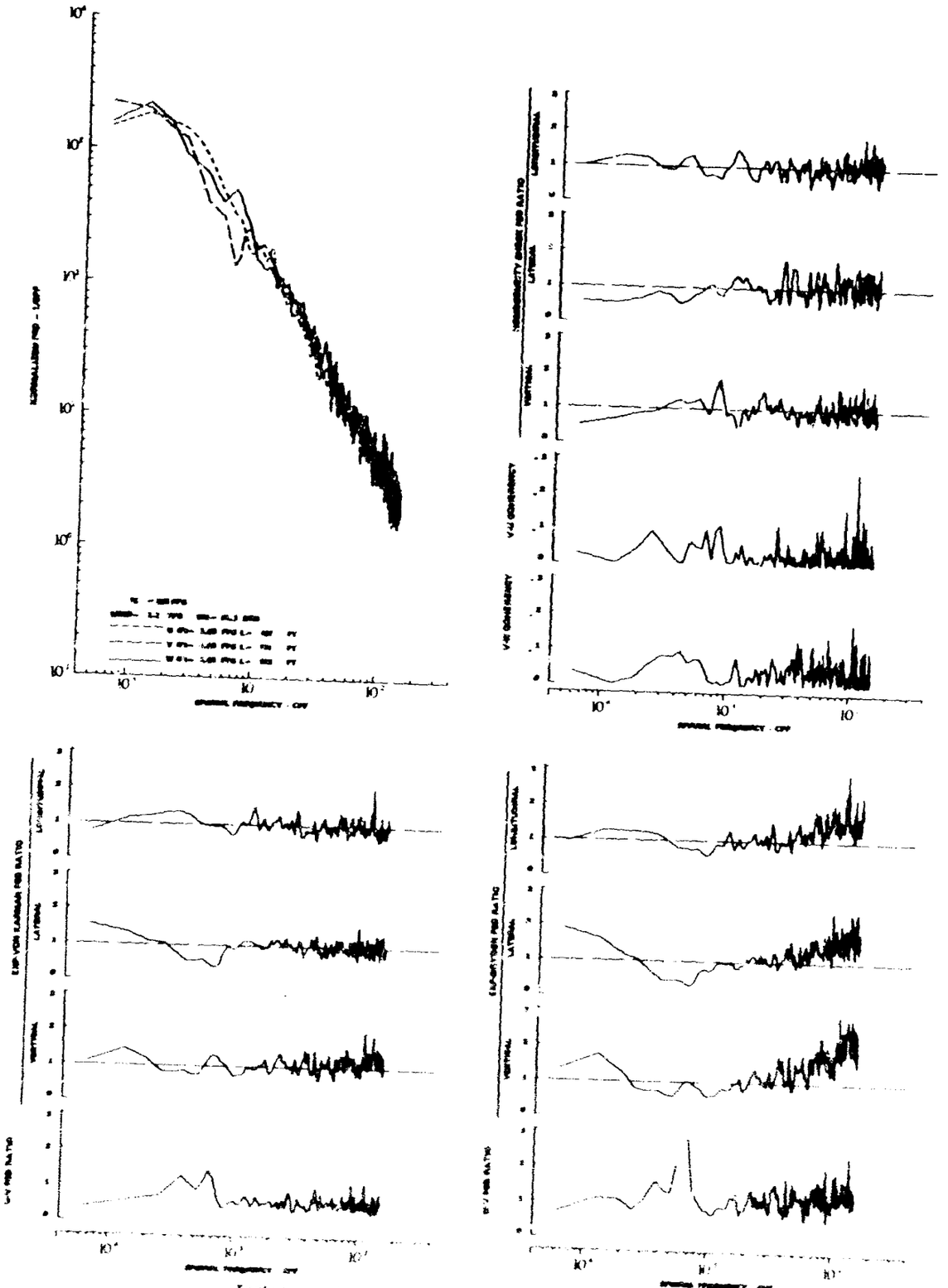


Turbulence Spectra Data For Test 222, Leg 4, Category 124313



Turbulence Spectra Data For Test 222, Leg 6, Category 123313



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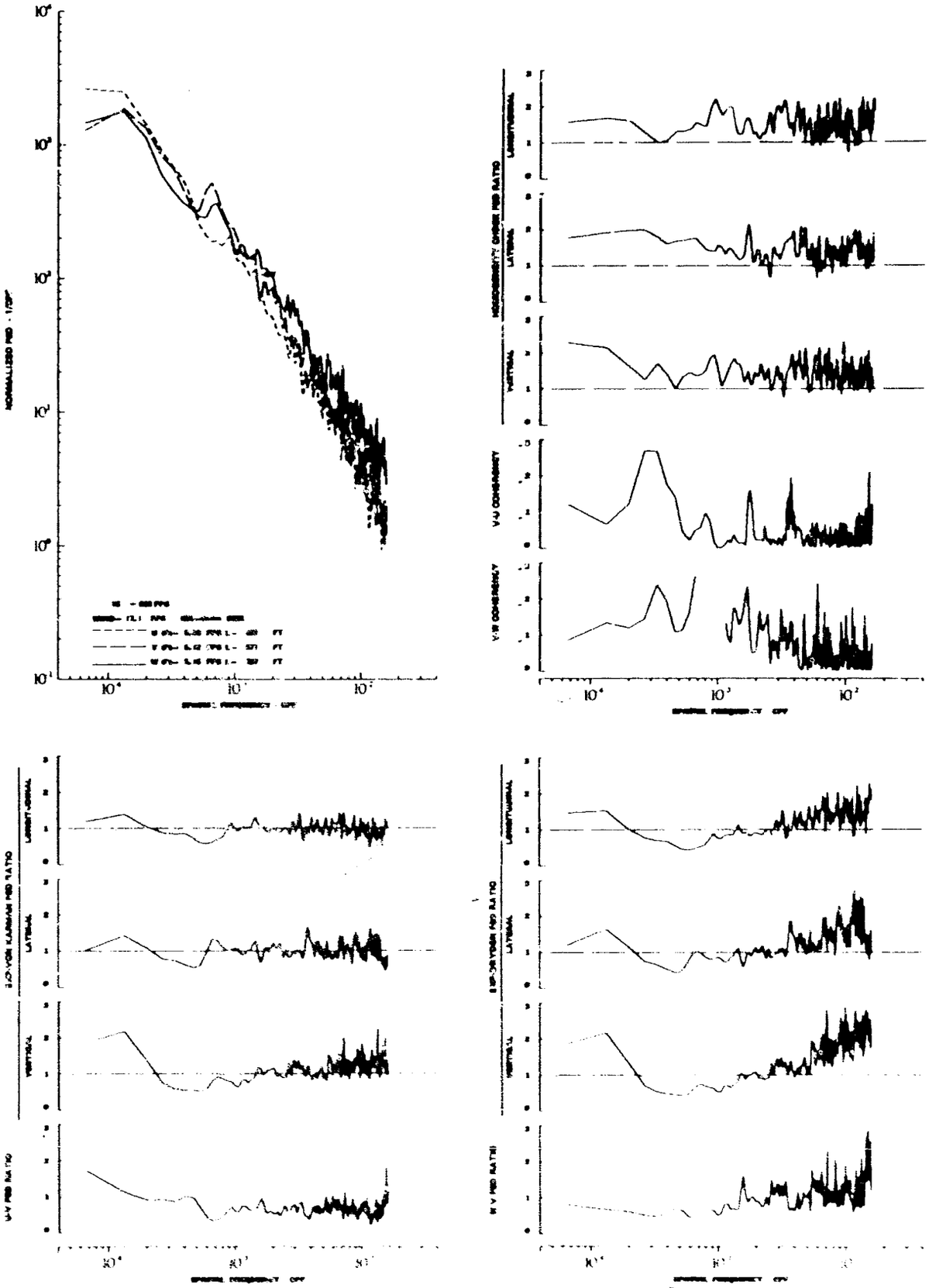
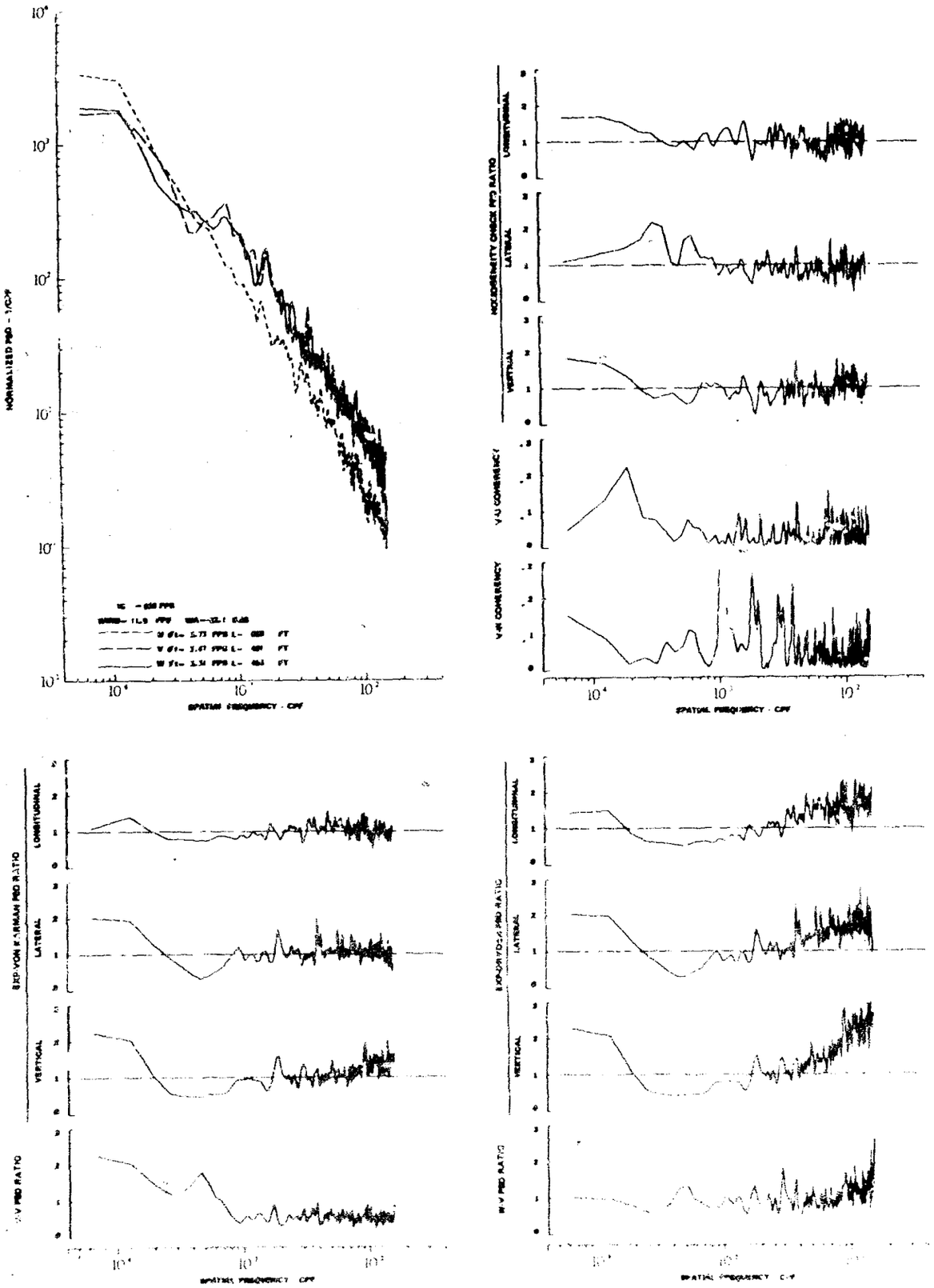
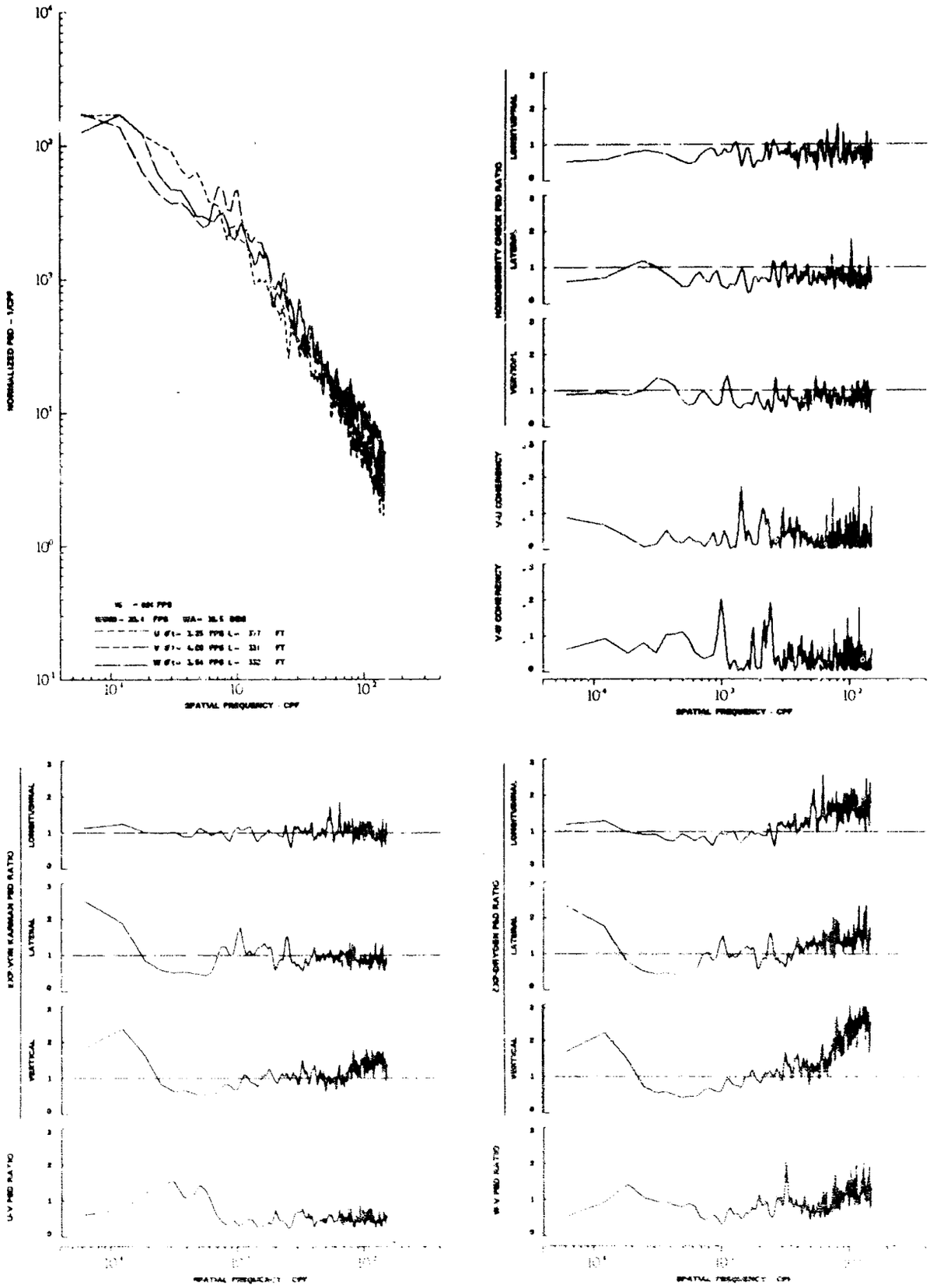


Turbulence Spectra Data For Test 224, Leg 2, Category 112213



Turbulence Spectra Data for Test 224, Leg 4, Category 114213



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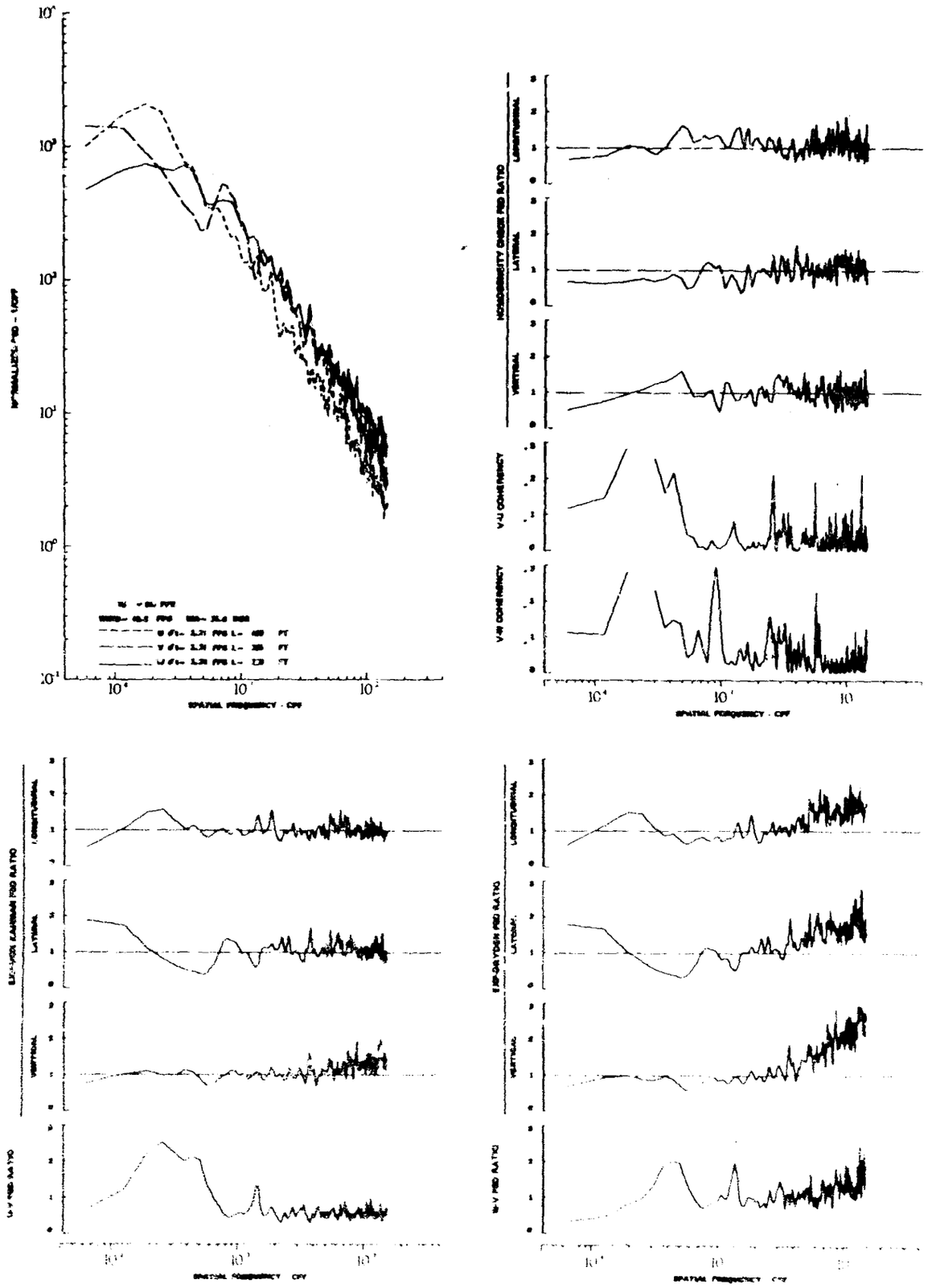
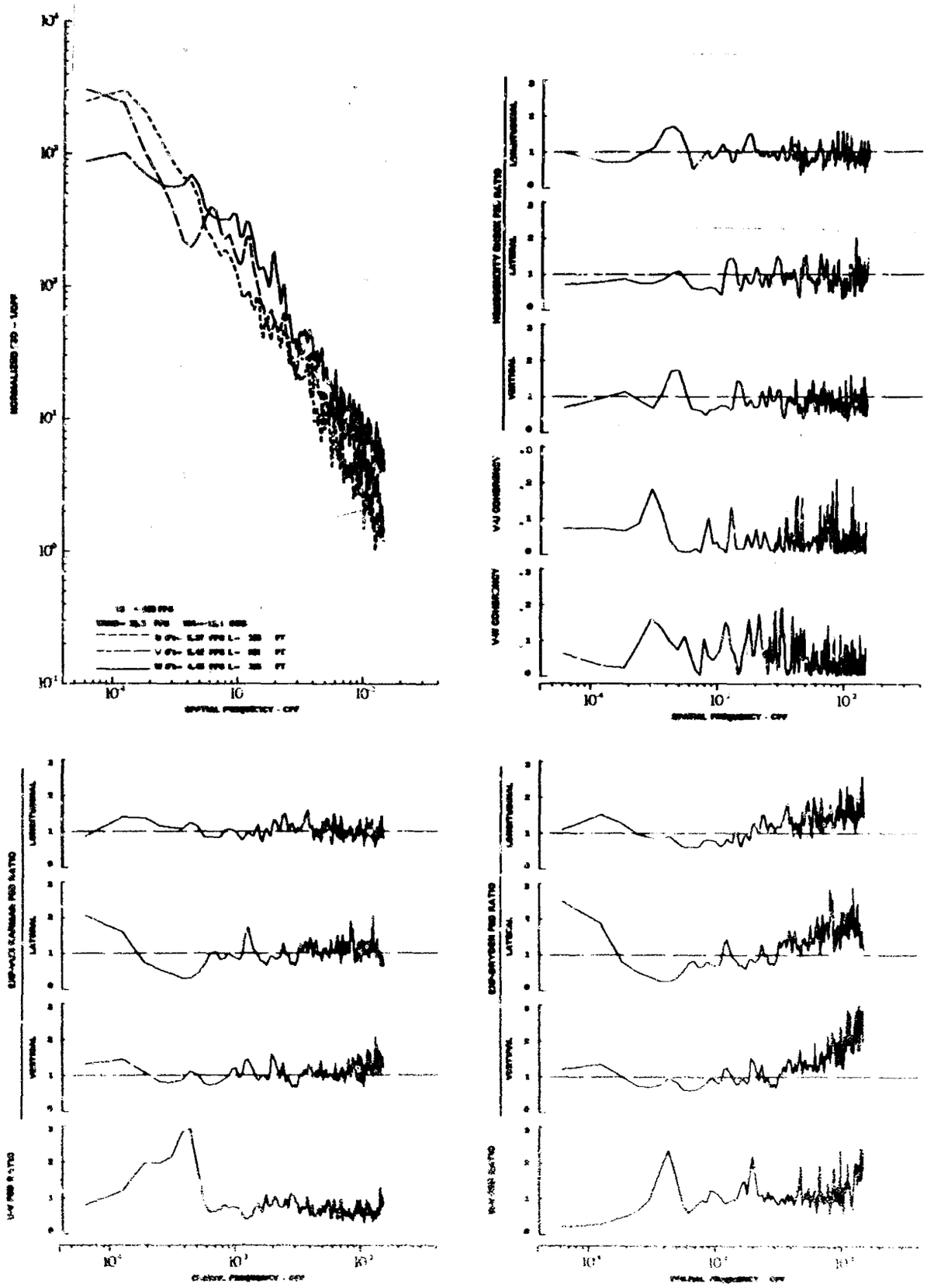
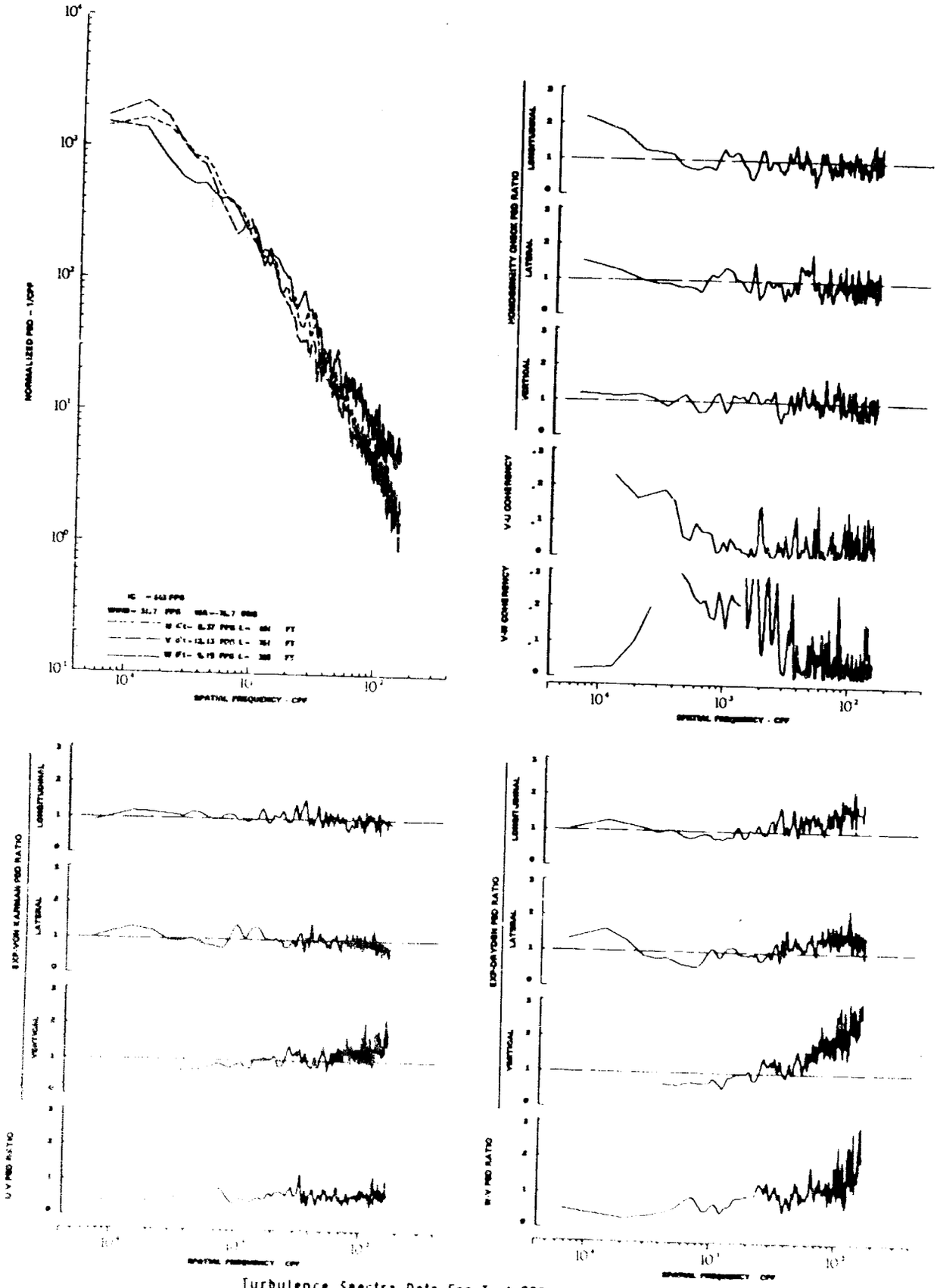


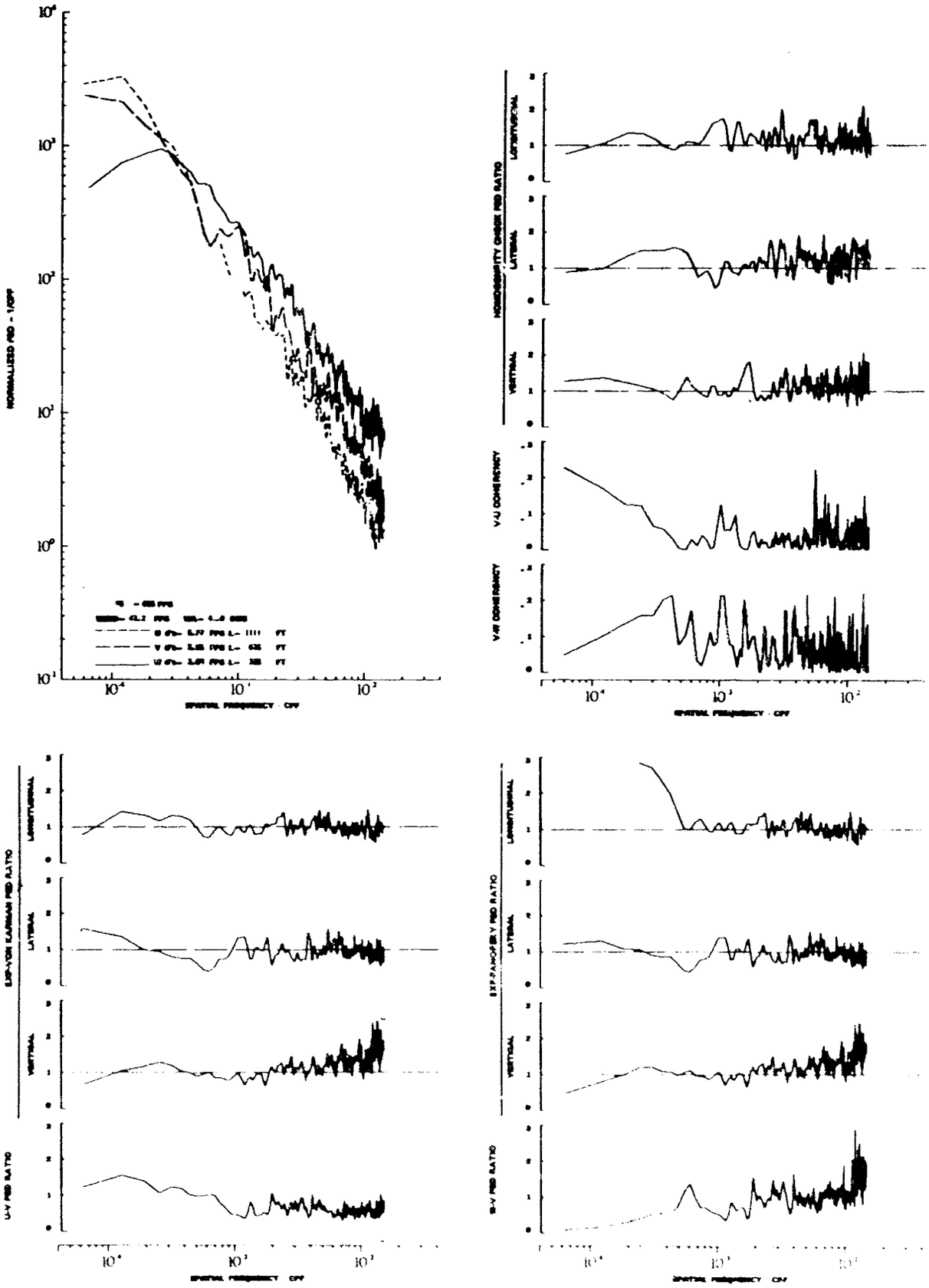
Turbulence Spectra Data For Test 224, Leg 8, Category 413213



Turbulence Spectra Data For Test 225, Leg 3, Category 111313



Turbulence Spectra Data For Test 225, Leg 5, Category 114313



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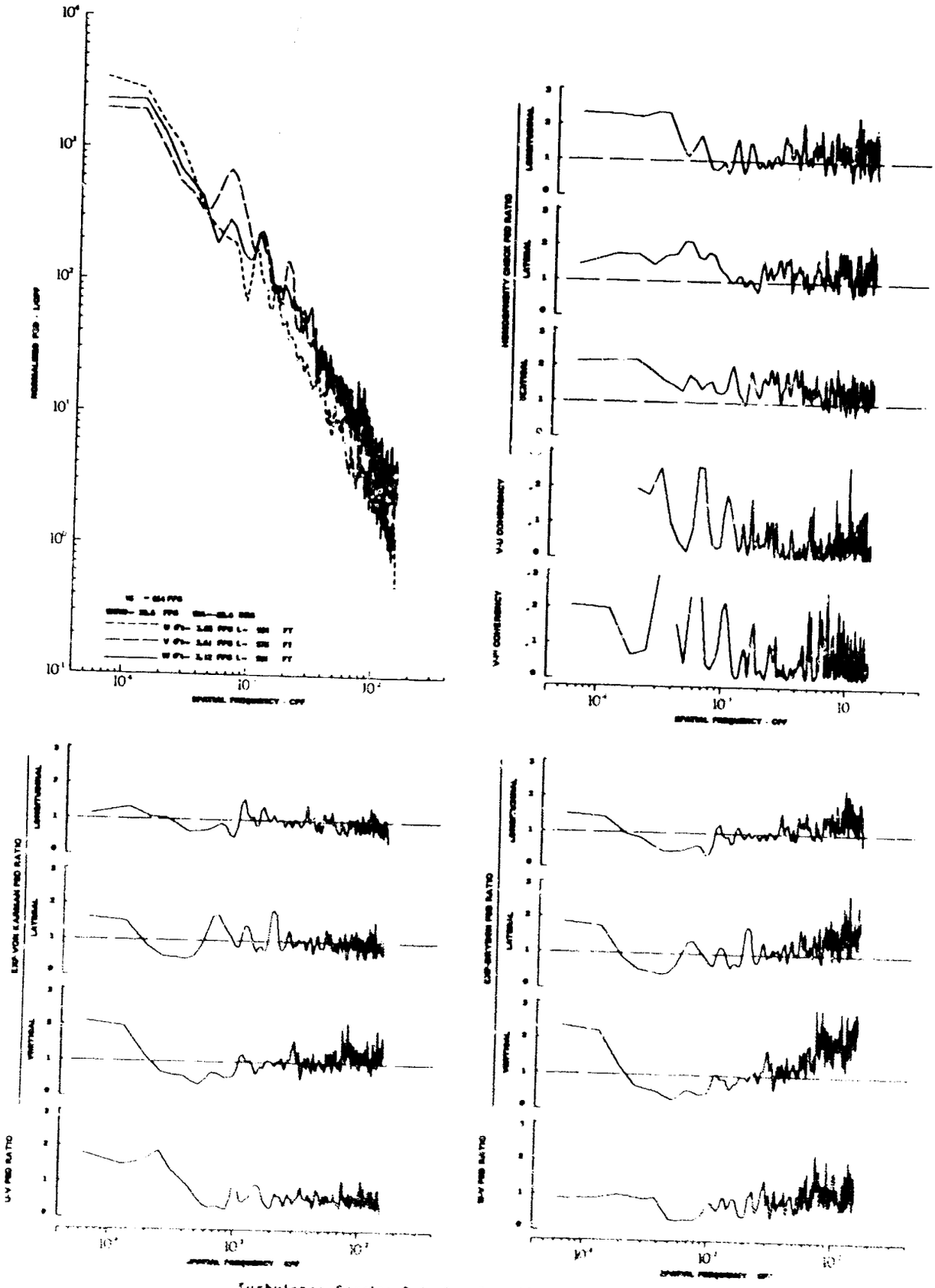
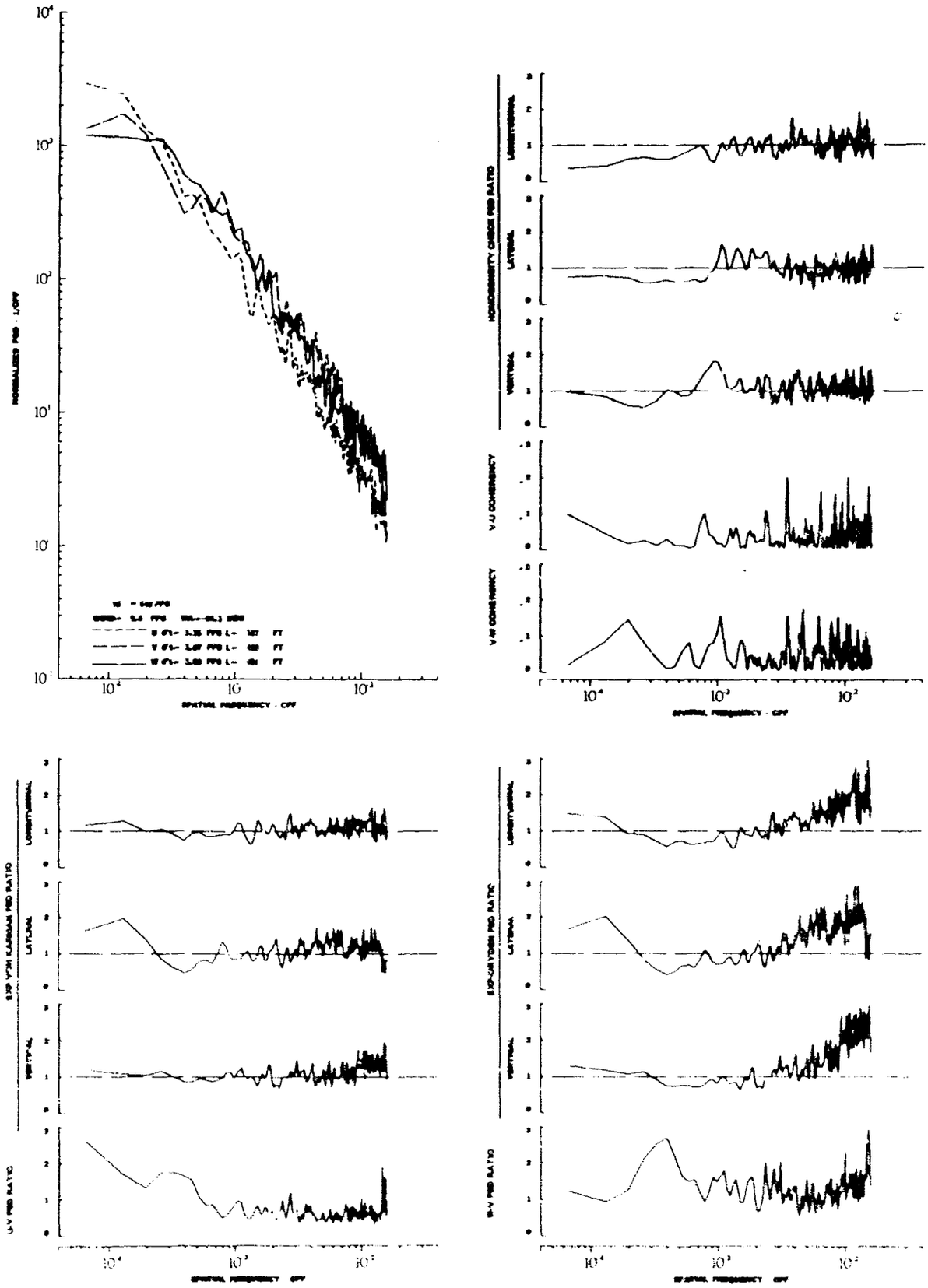


Turbulence Spectra Data For Test 226, Leg 4 Category 122113



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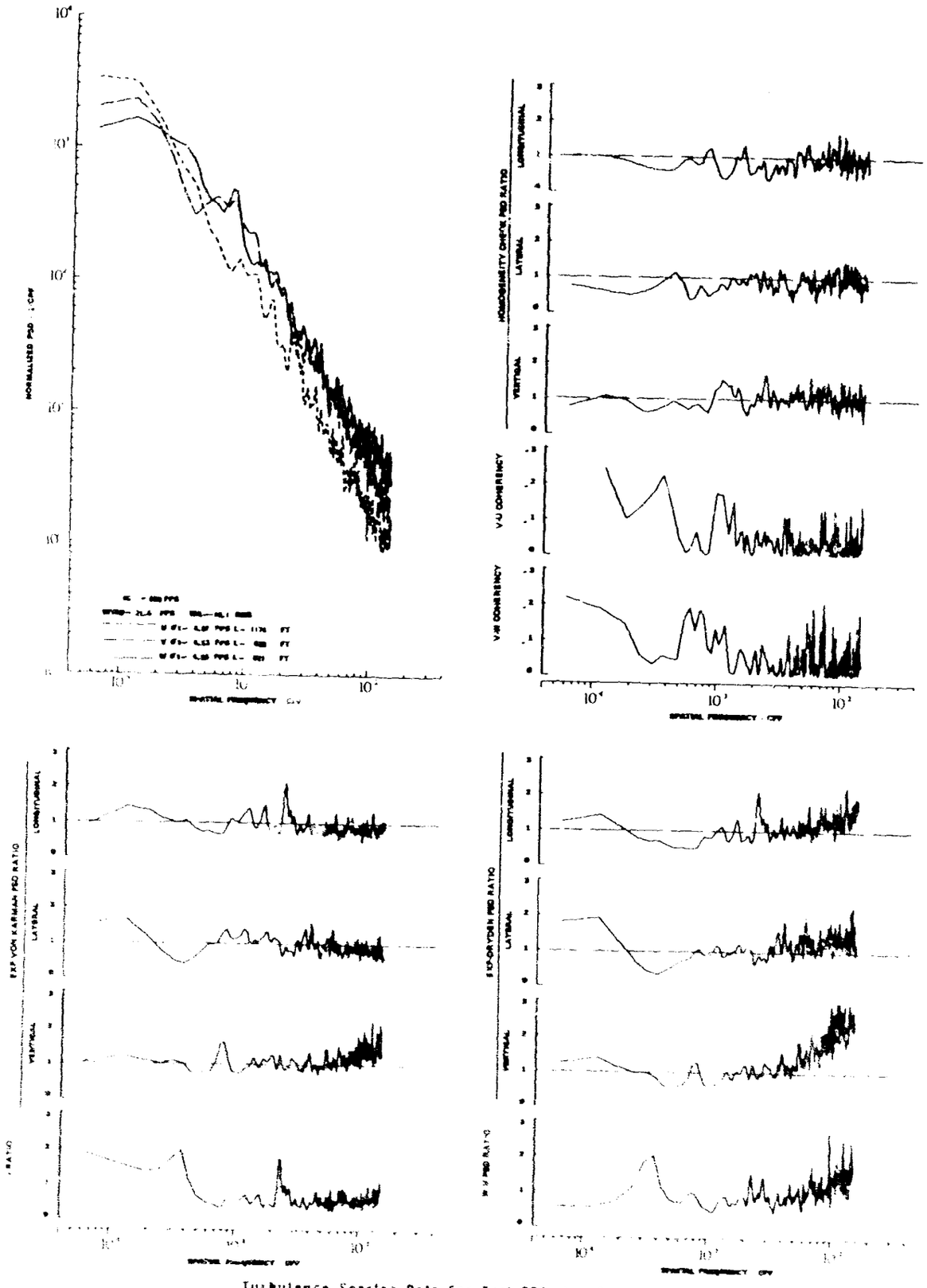

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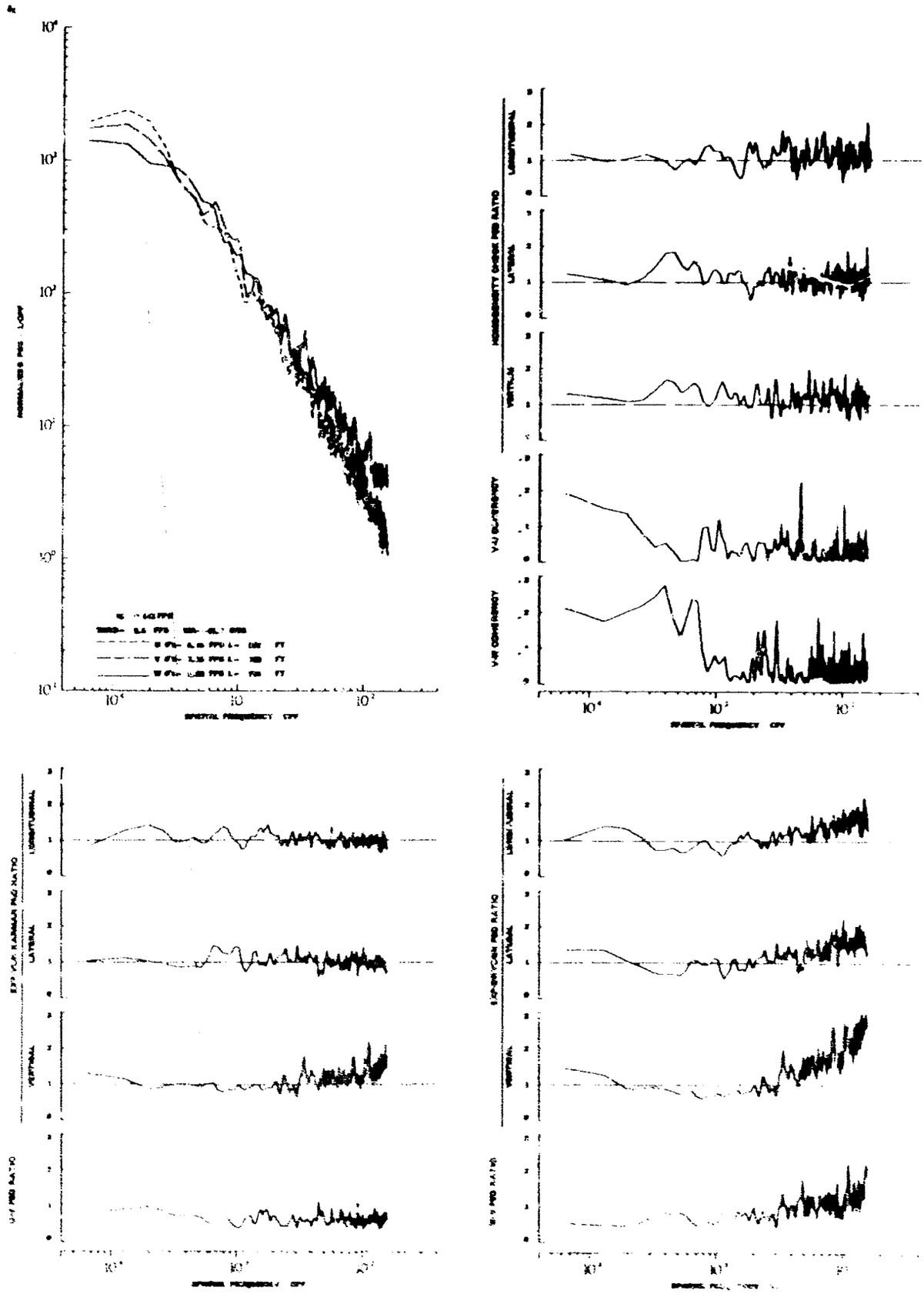

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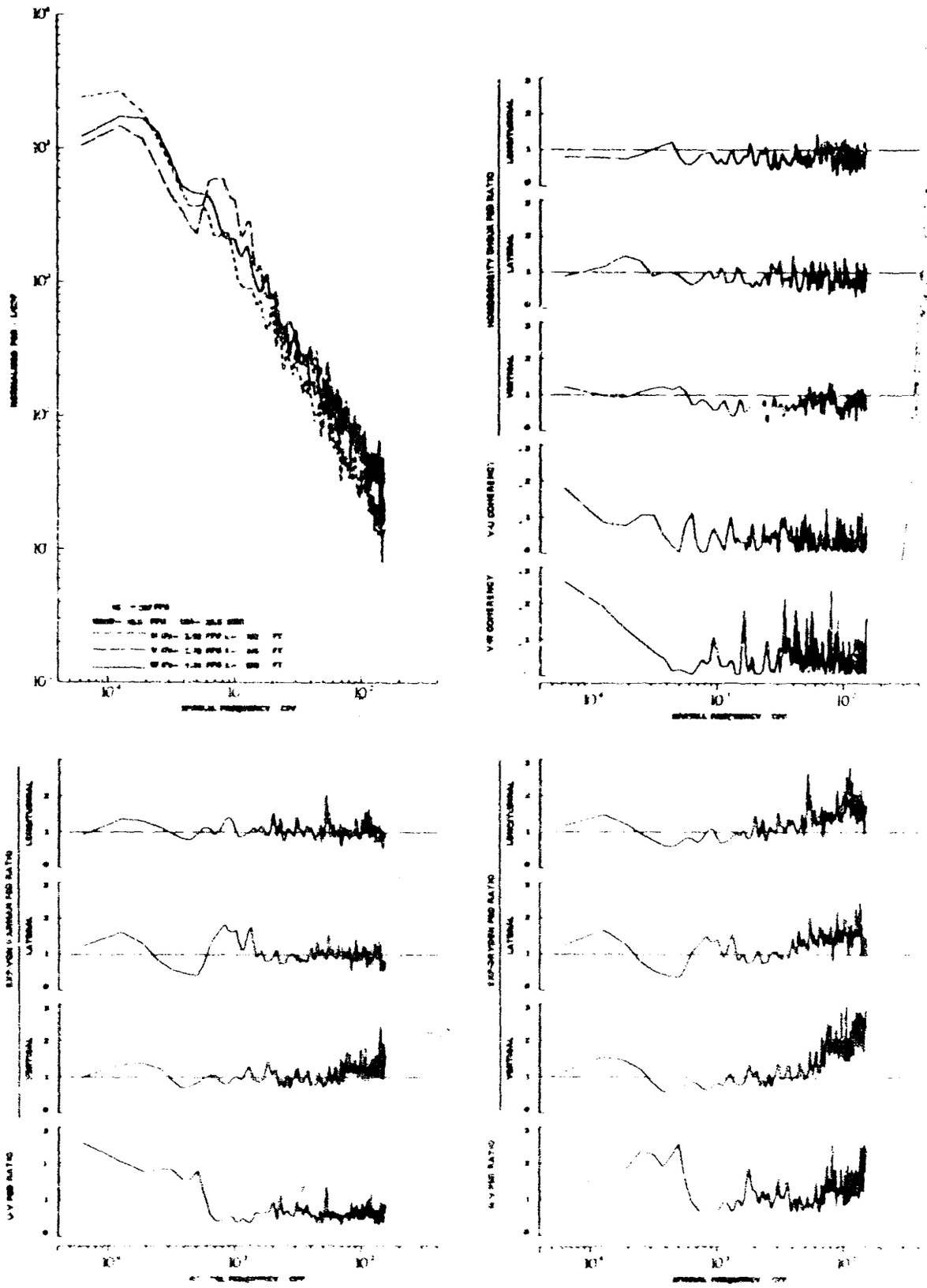
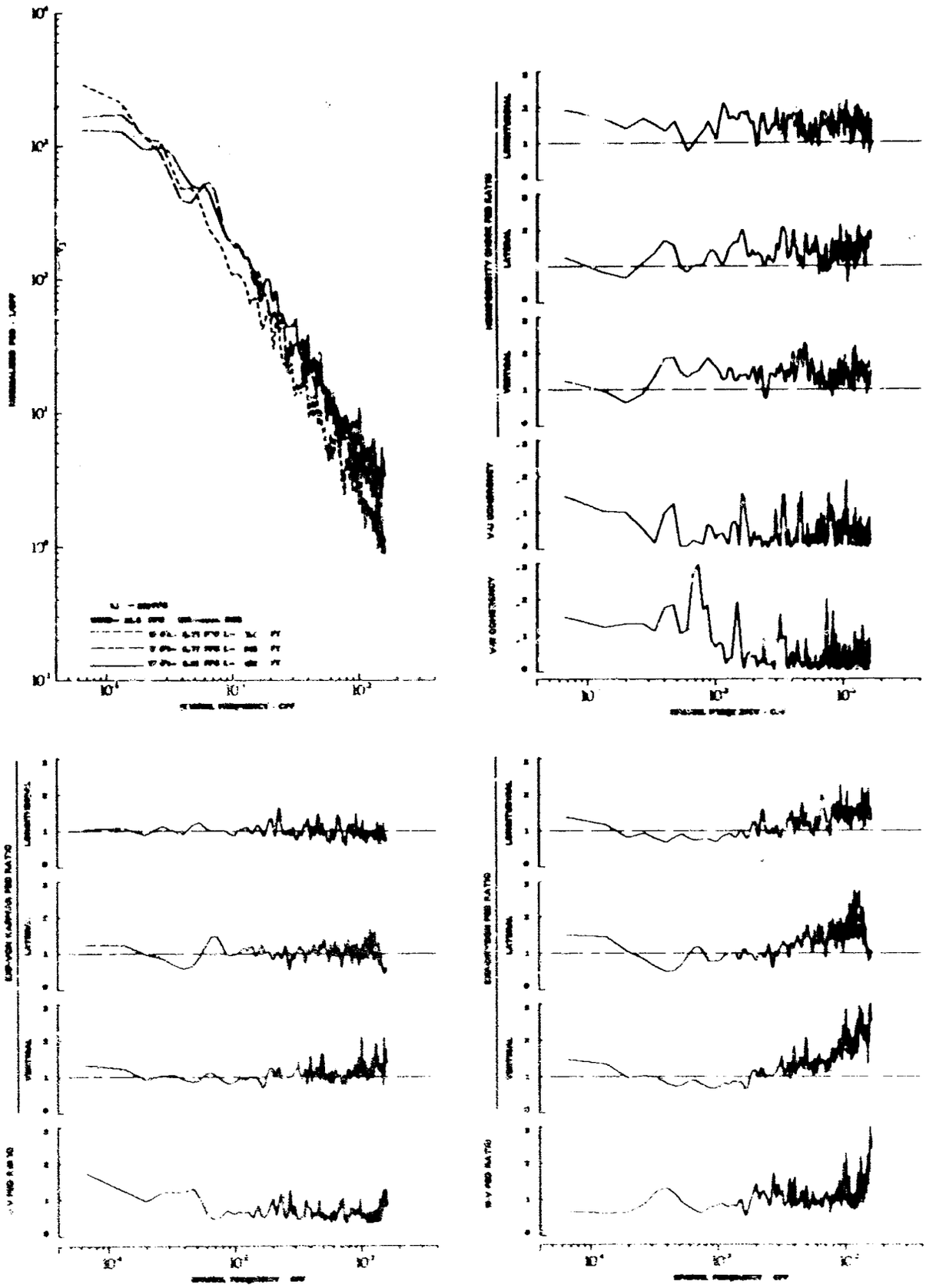
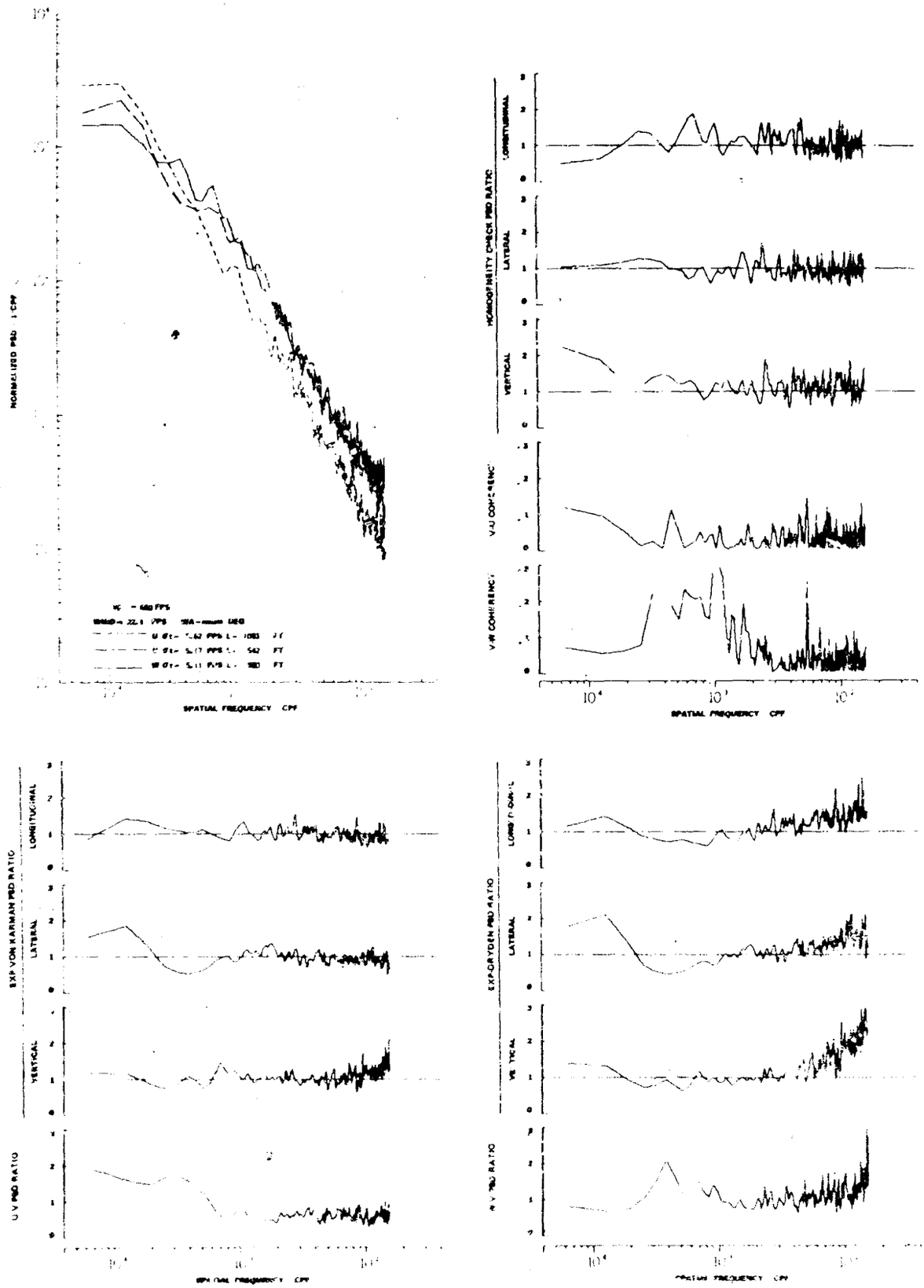


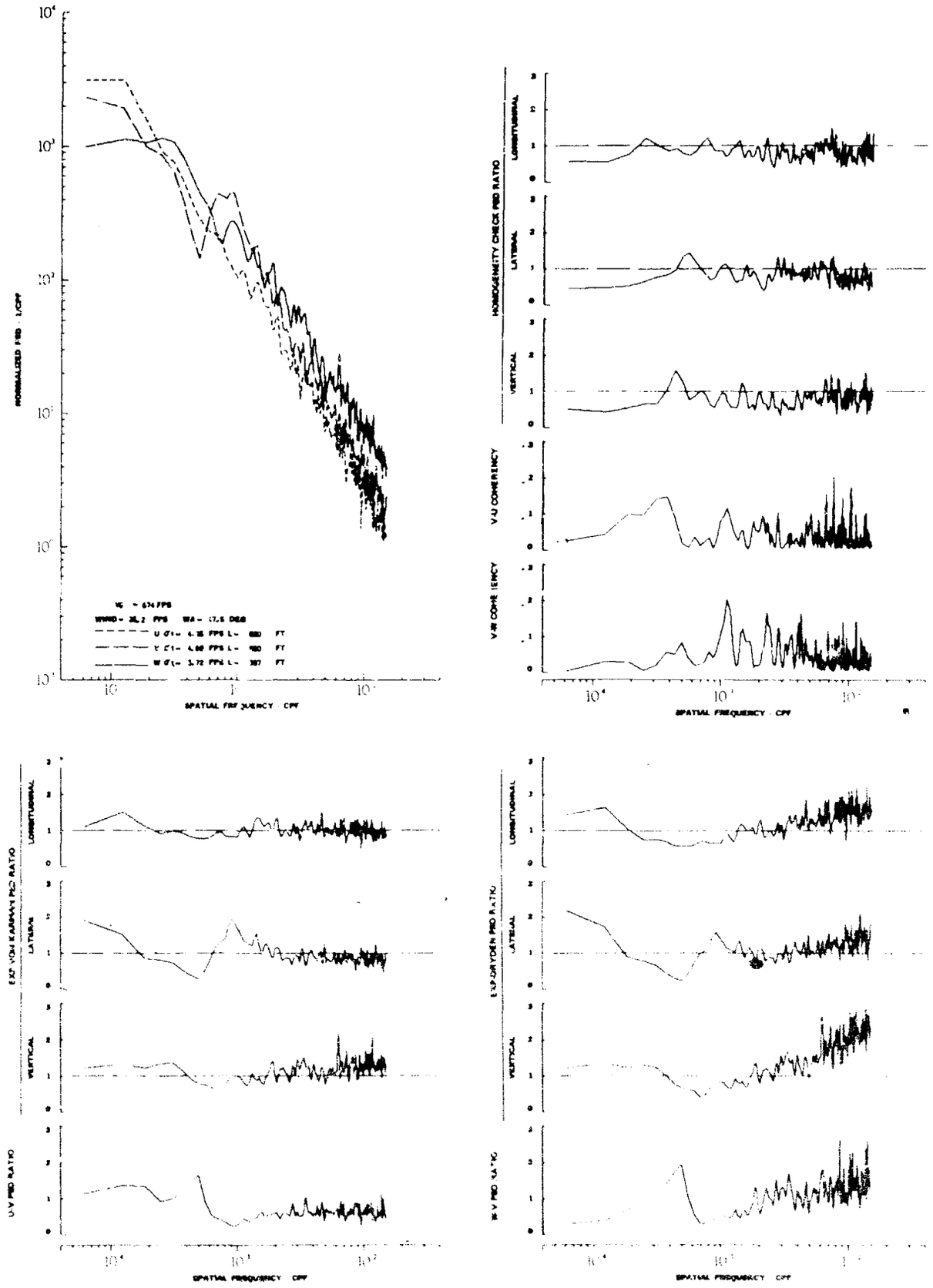
Turbulence Spectra Data for Test 227, Leg 7, Category 123213



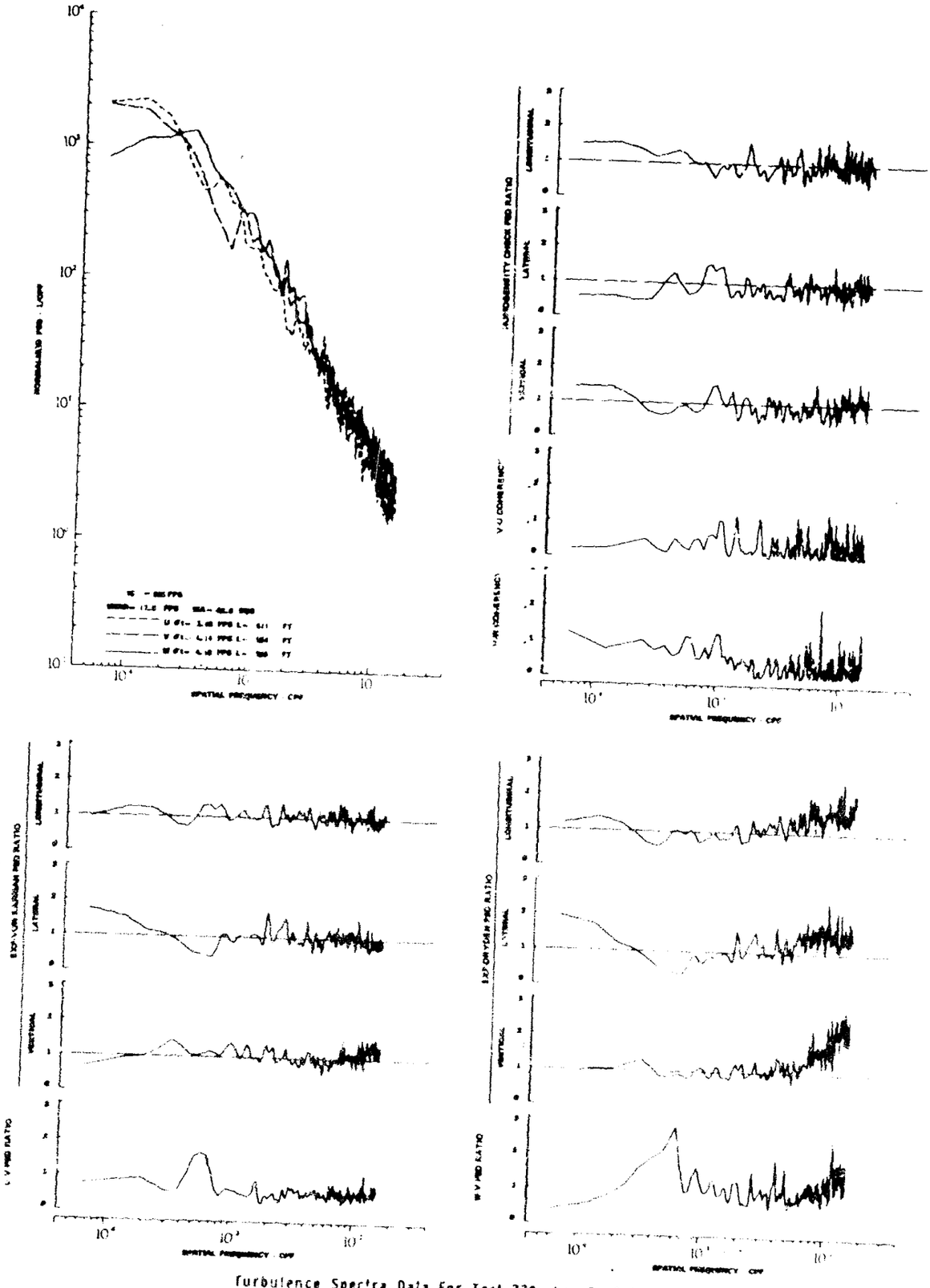
Turbulence Spectra Data For Test 228, Leg 2, Category 175313



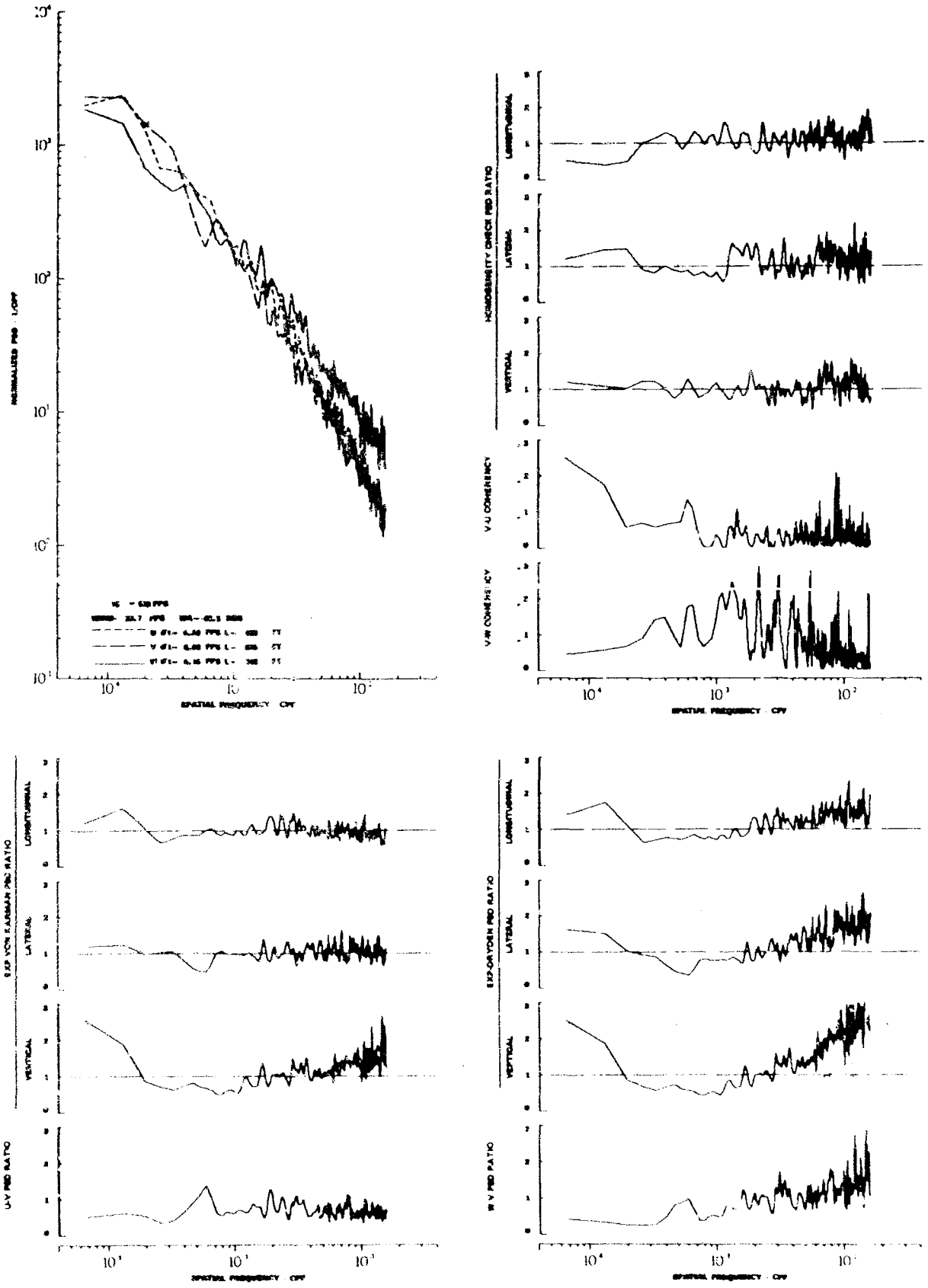
Turbulence Spectra Data For Test 22S, Leg 4, Category 124313



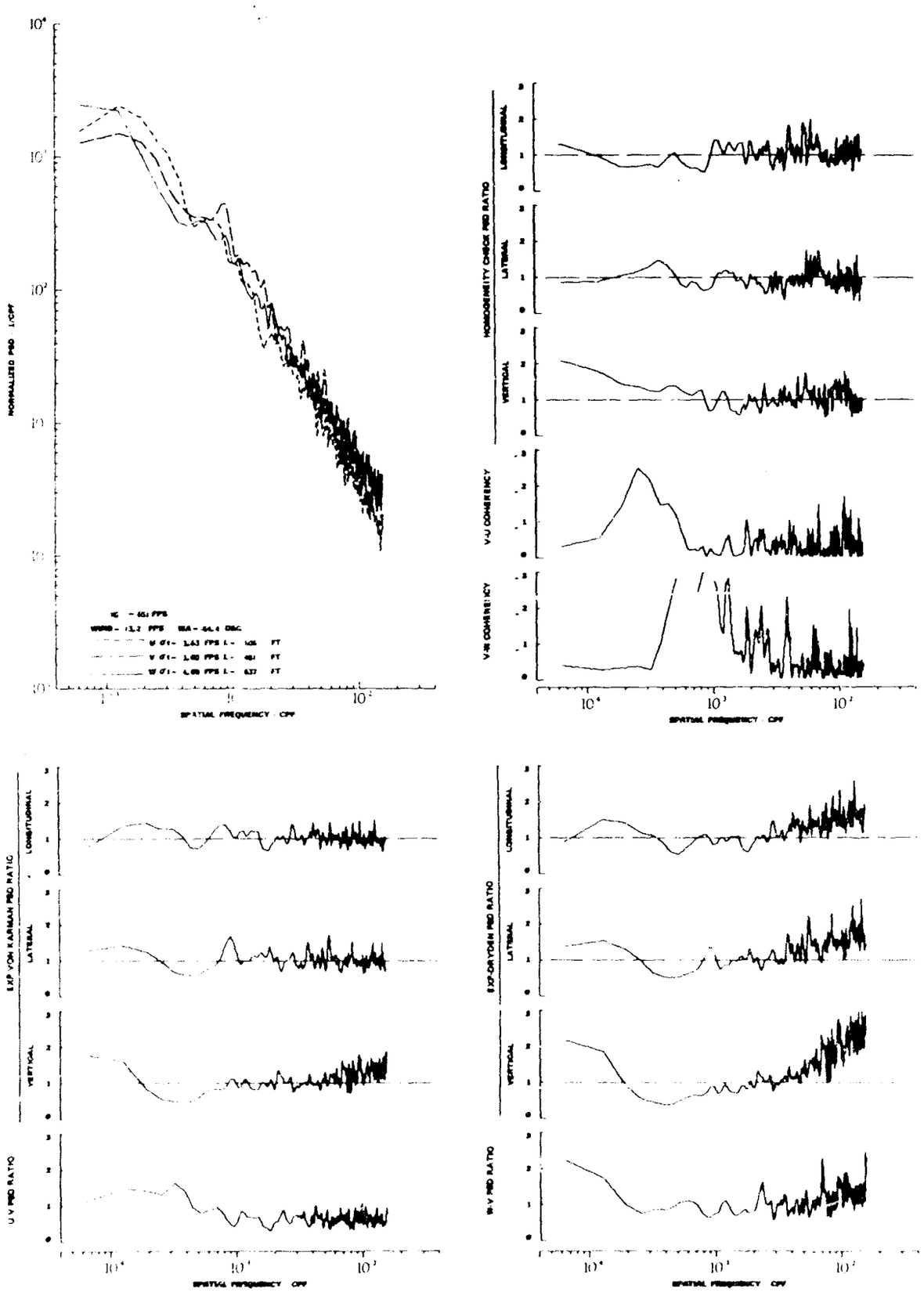
Turbulence Spectra Data For Test 228, Leg 6, Category 123313



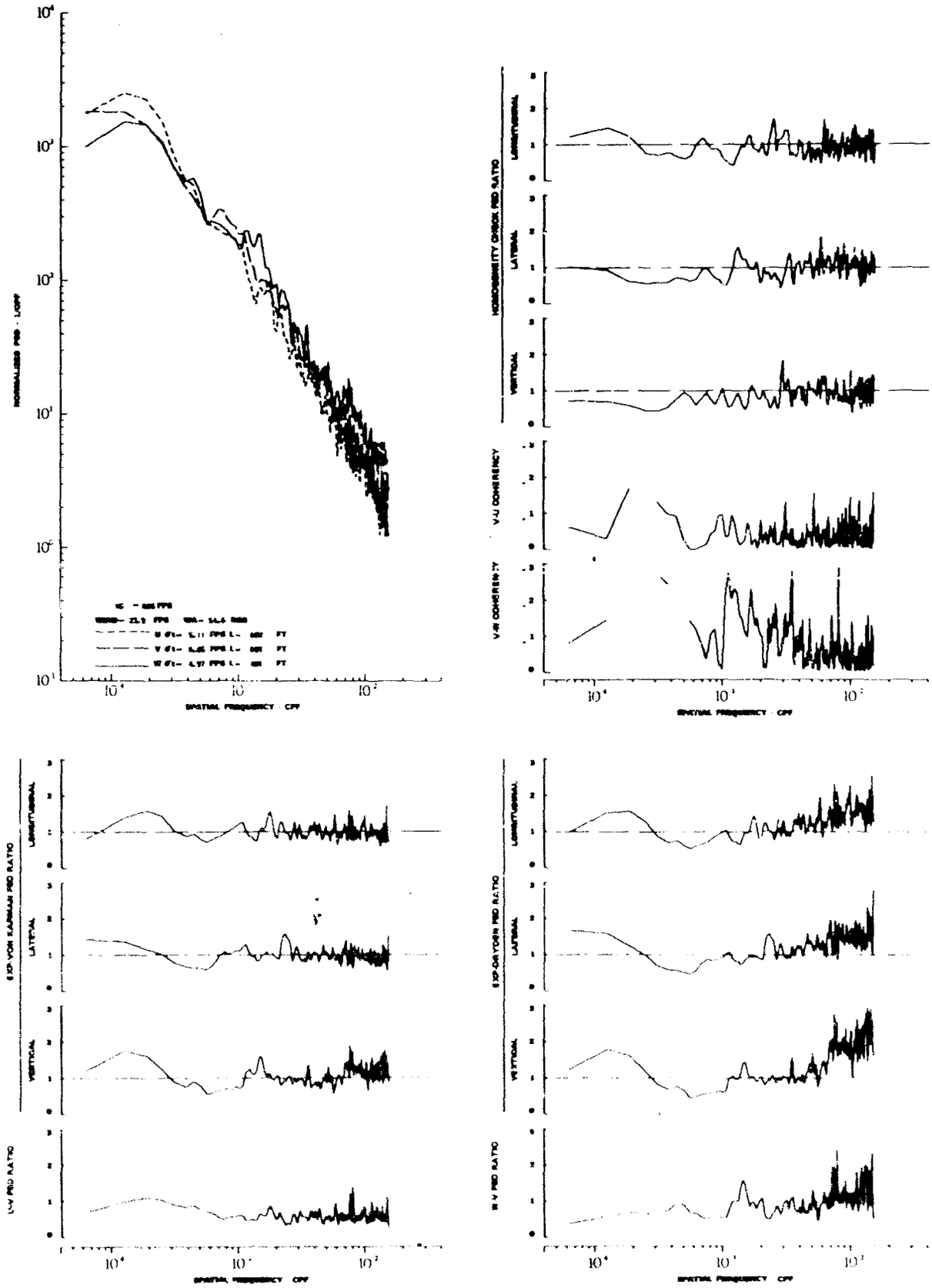
Turbulence Spectra Data For Test 228, Leg 8, Category 423313



Turbulence Spectra Data For Test 229, Leg 5, Category 112113



Turbulence Spectra Data For Test 230, Leg 4, Category 113213



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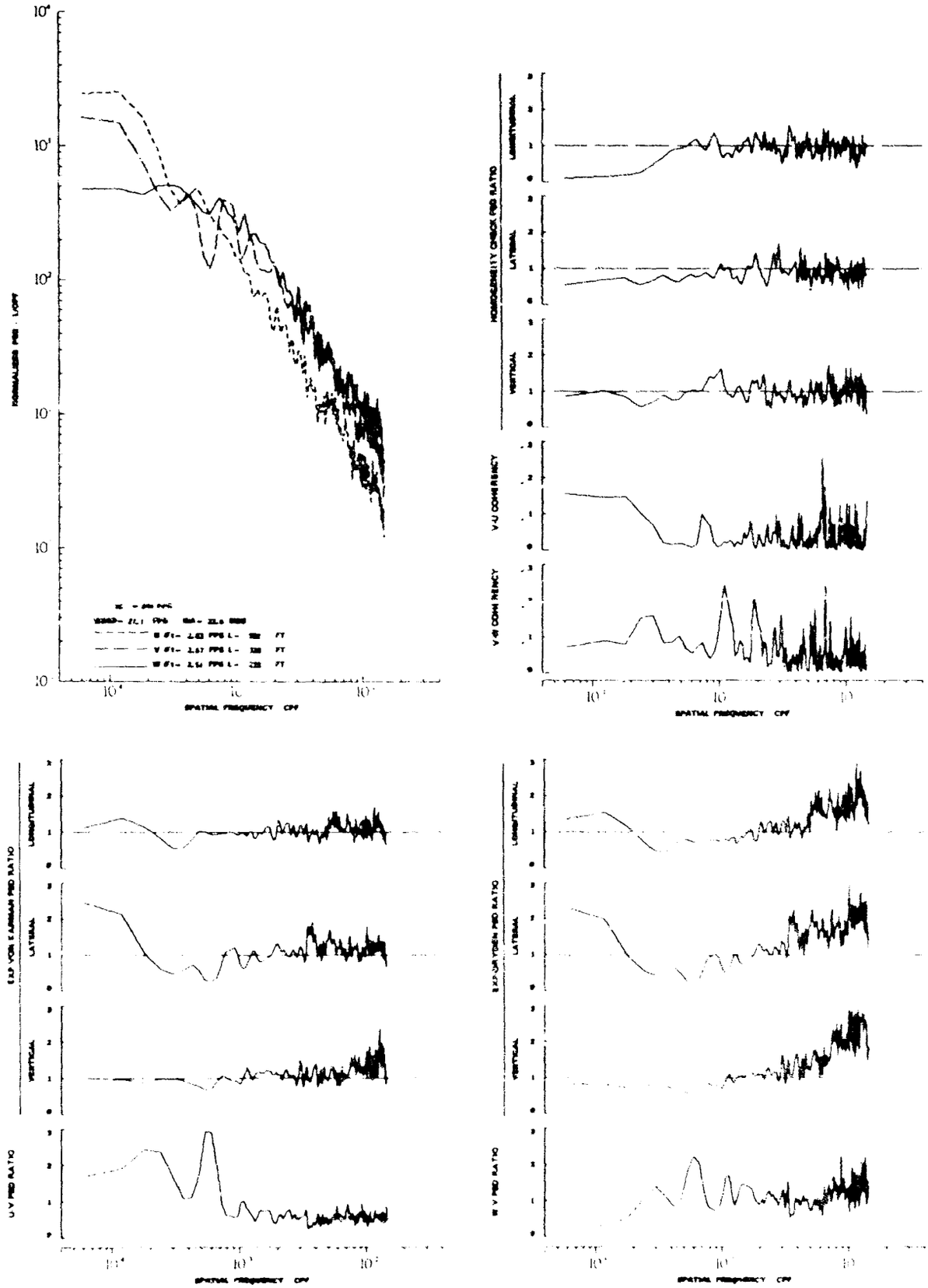

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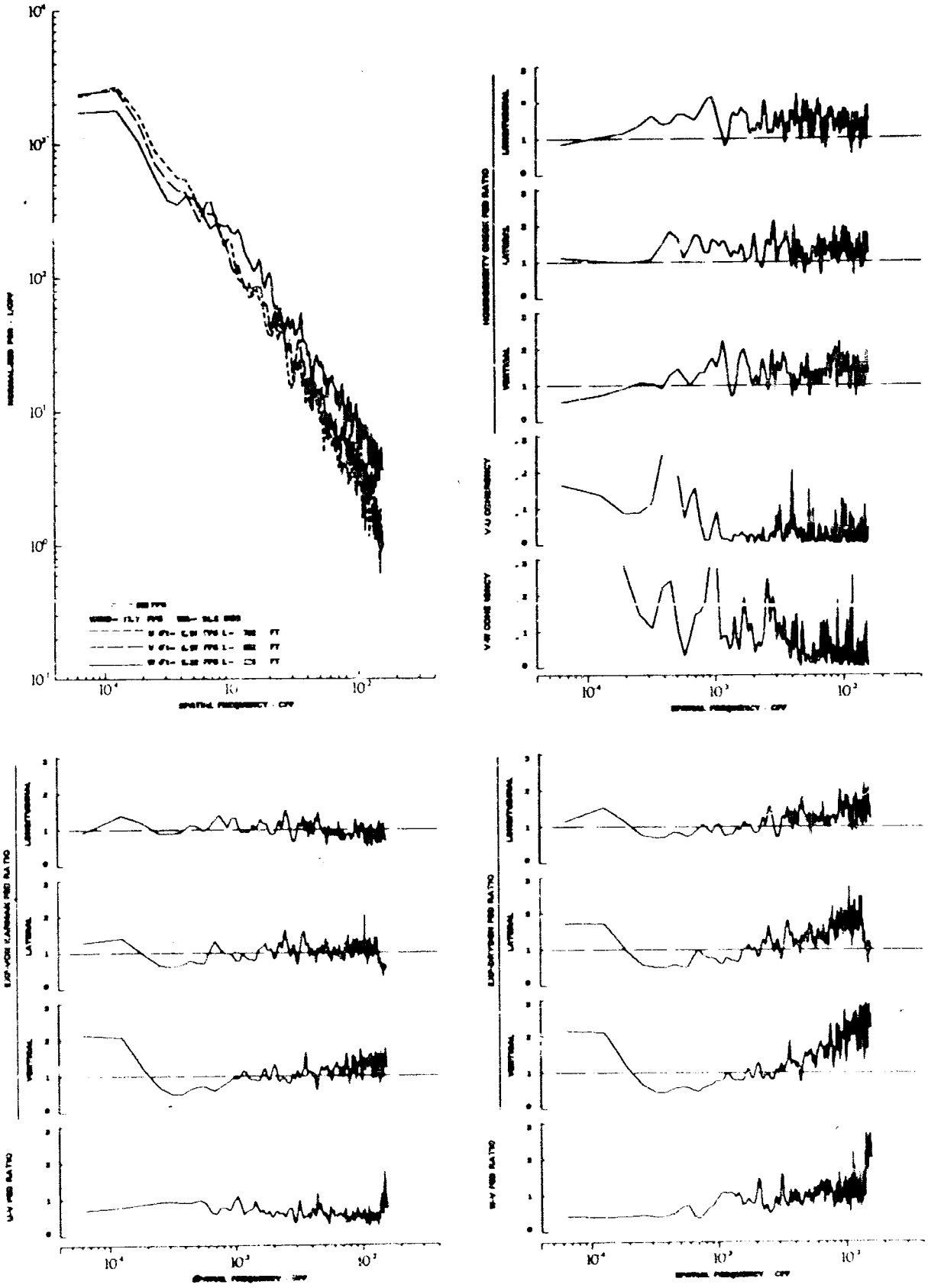

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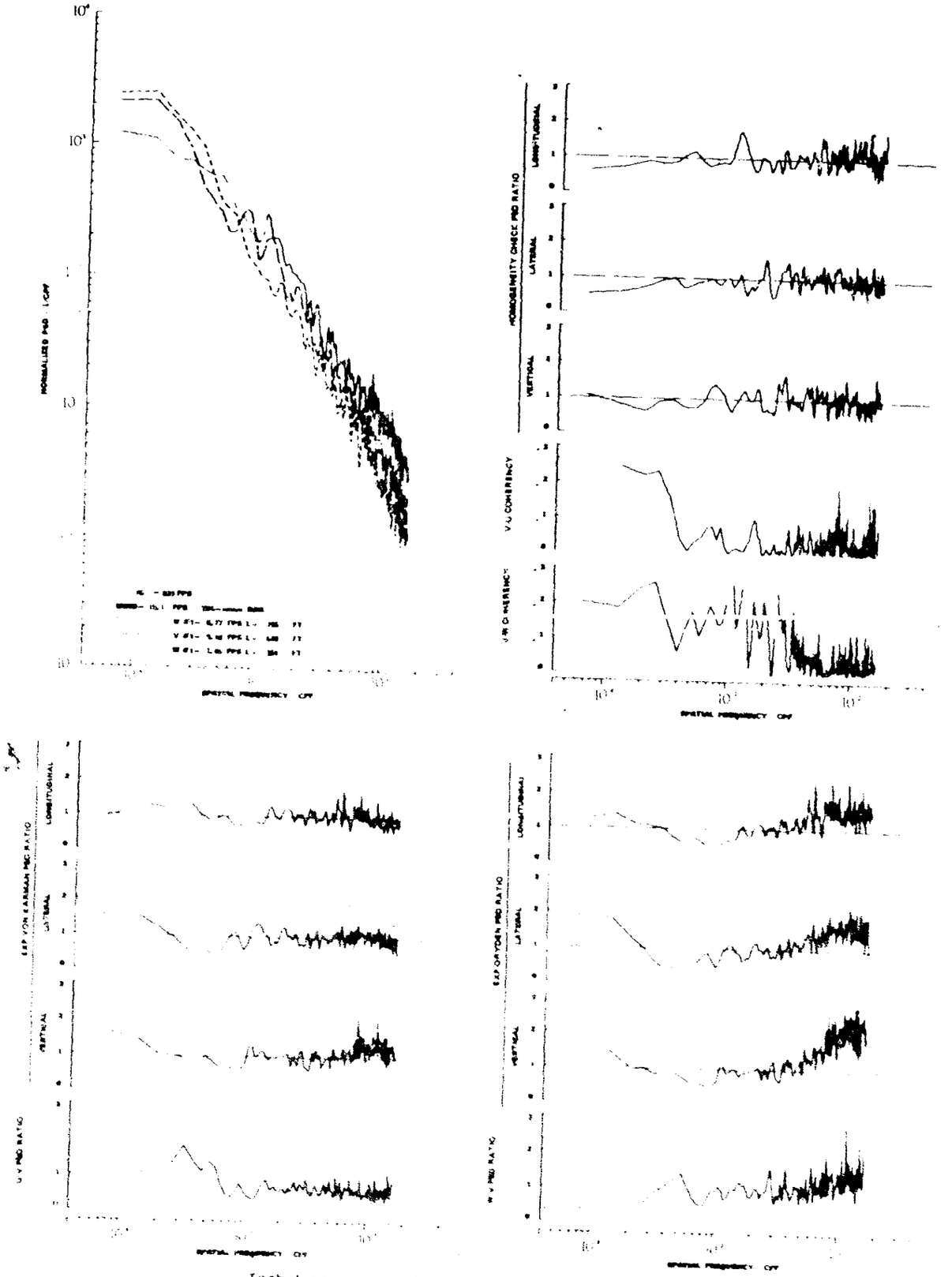
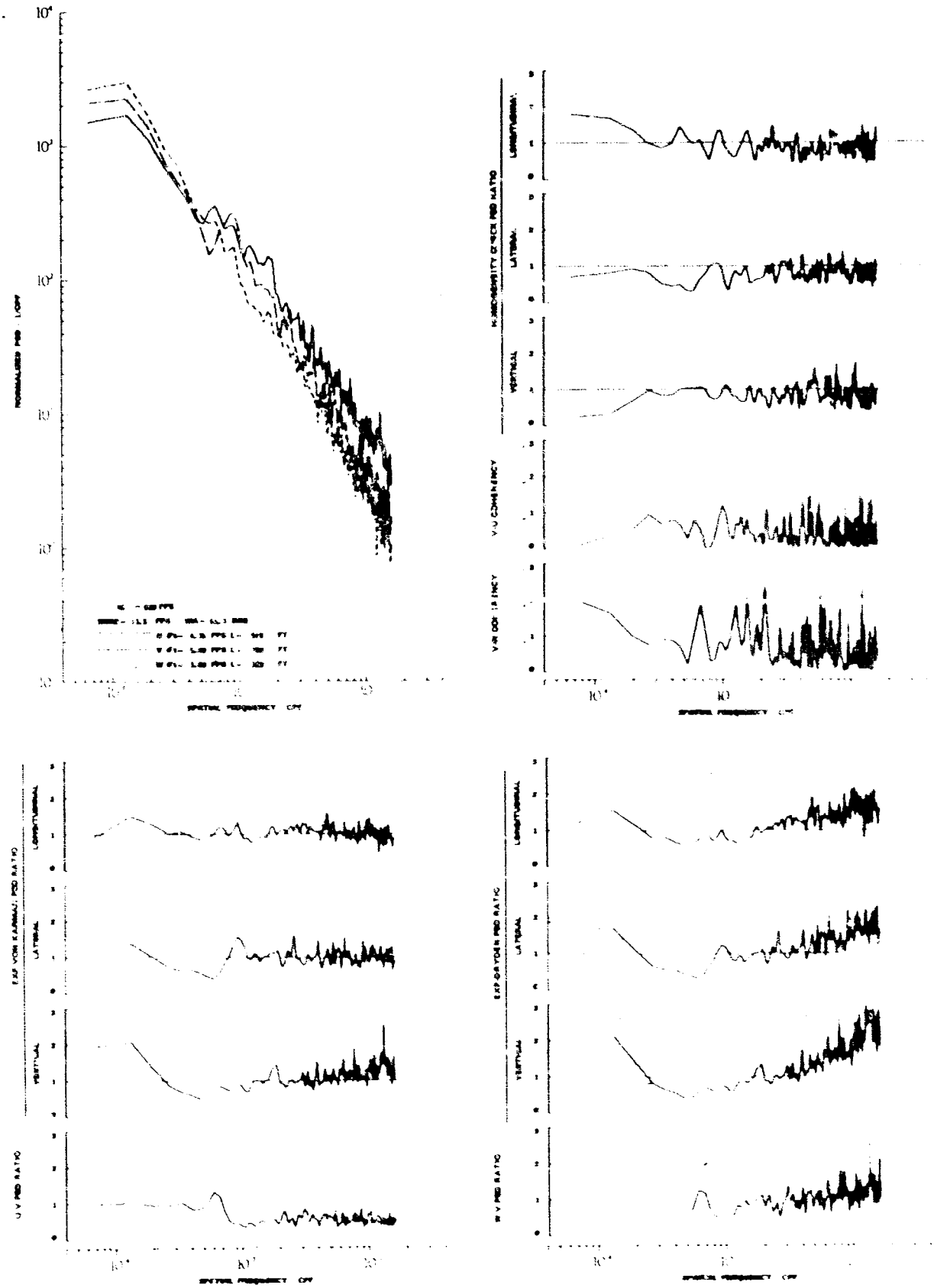


Turbulence Spectra Data For Test 233, Leg 5, Category 114313



Turbulence Spectra Data For Test 231, Leg 7, Category 114313

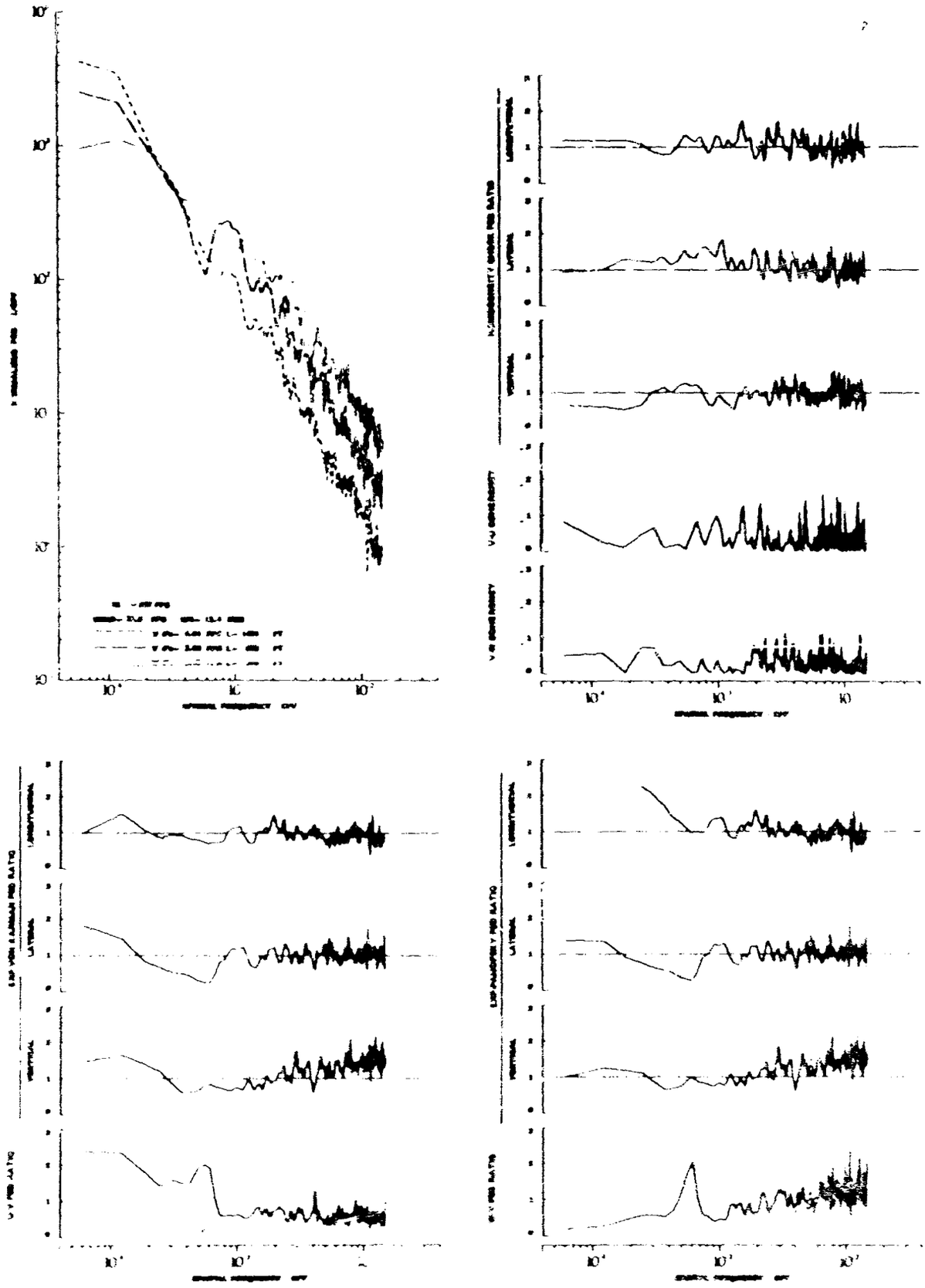
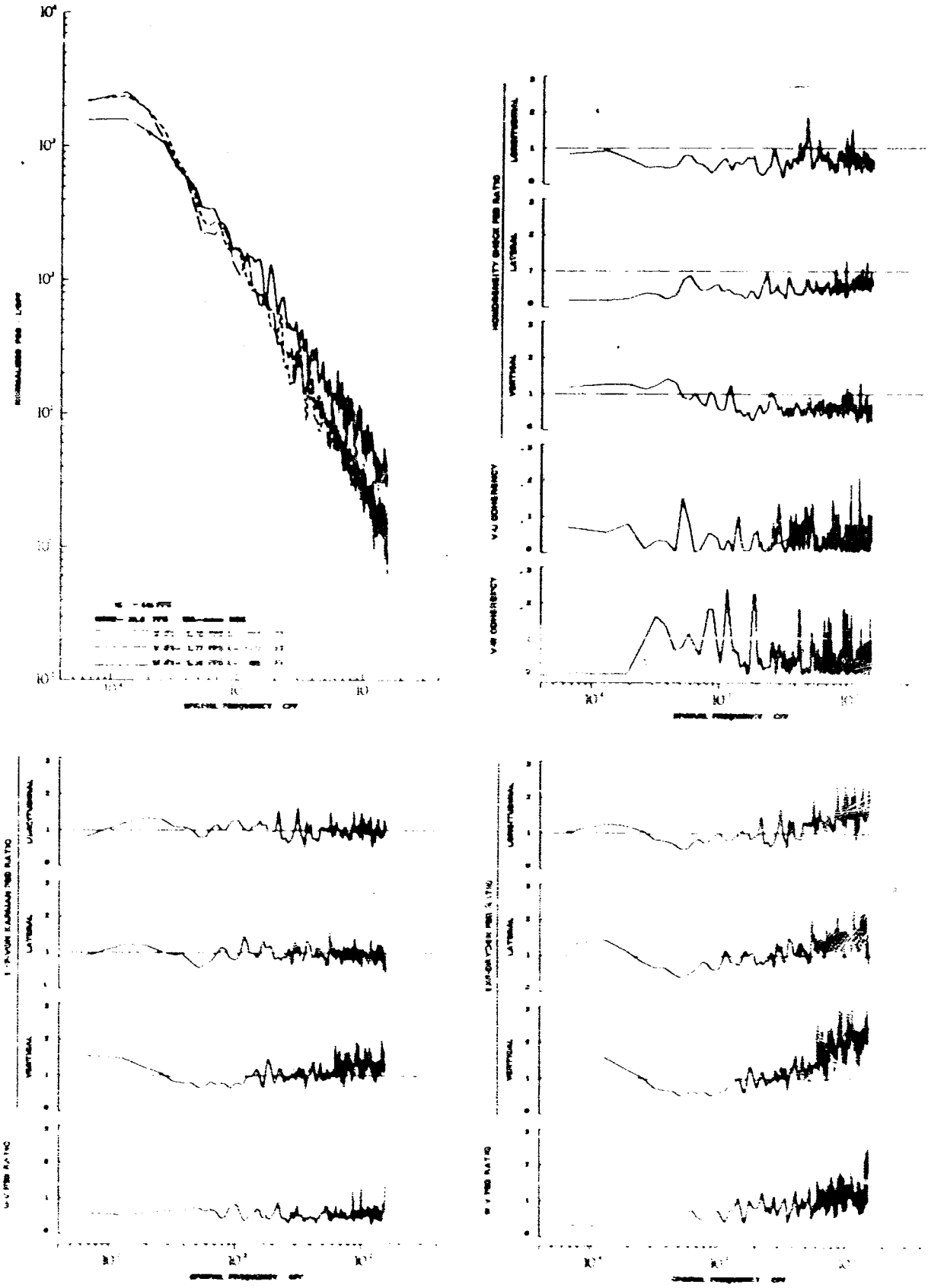
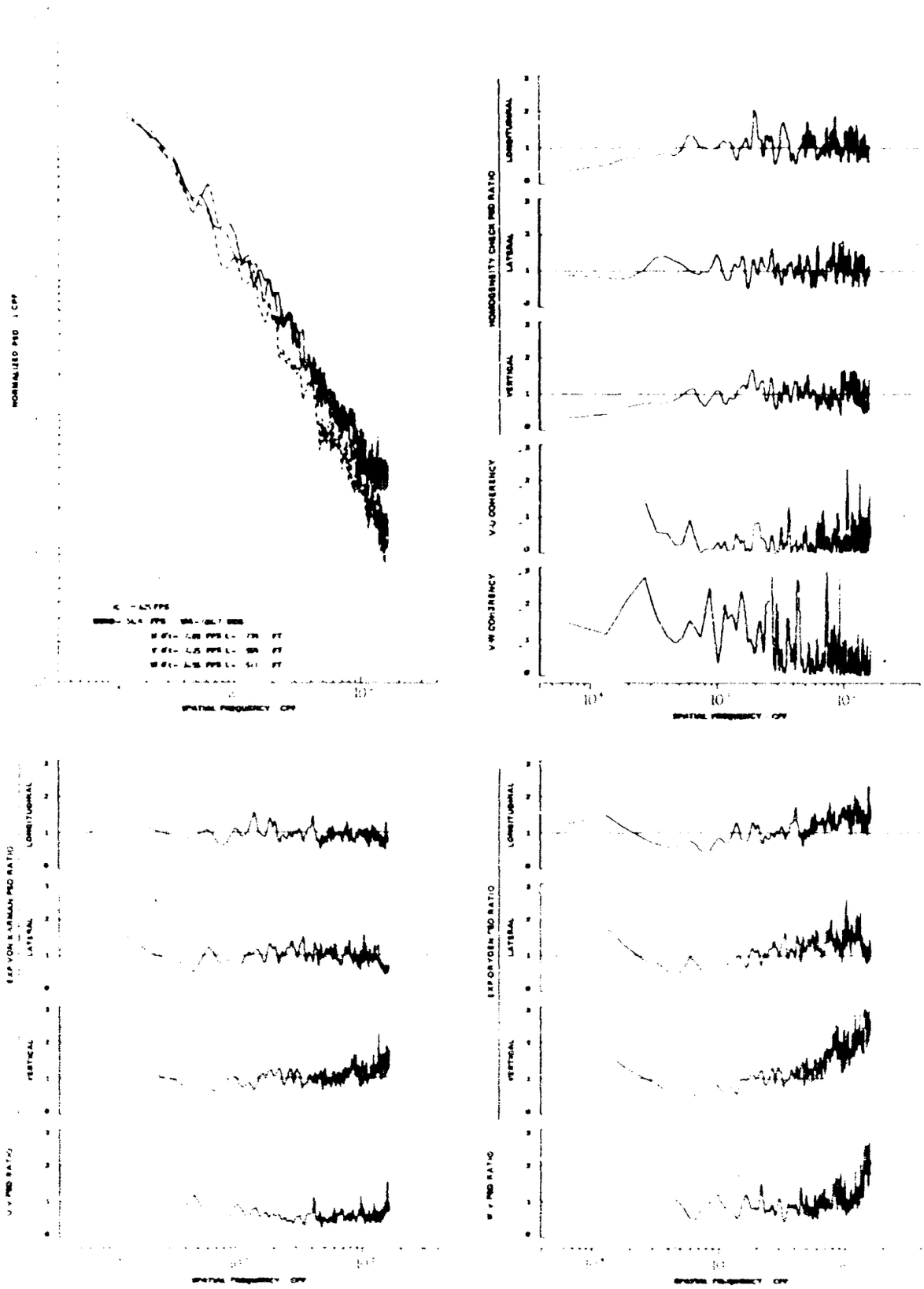


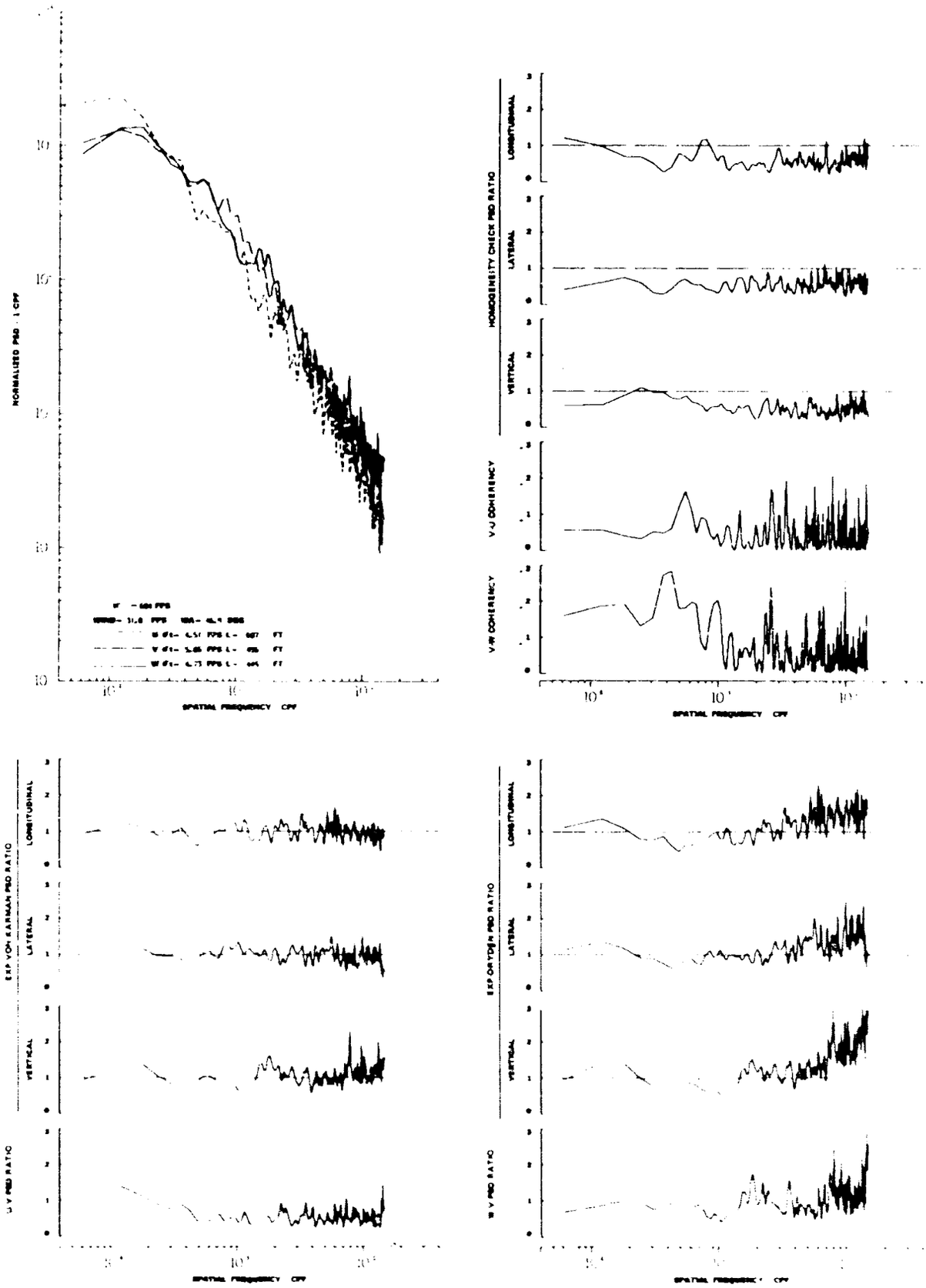
Figure 3.326 Turbulence Spectra Data For Test 231, Leg 8, Category 614313



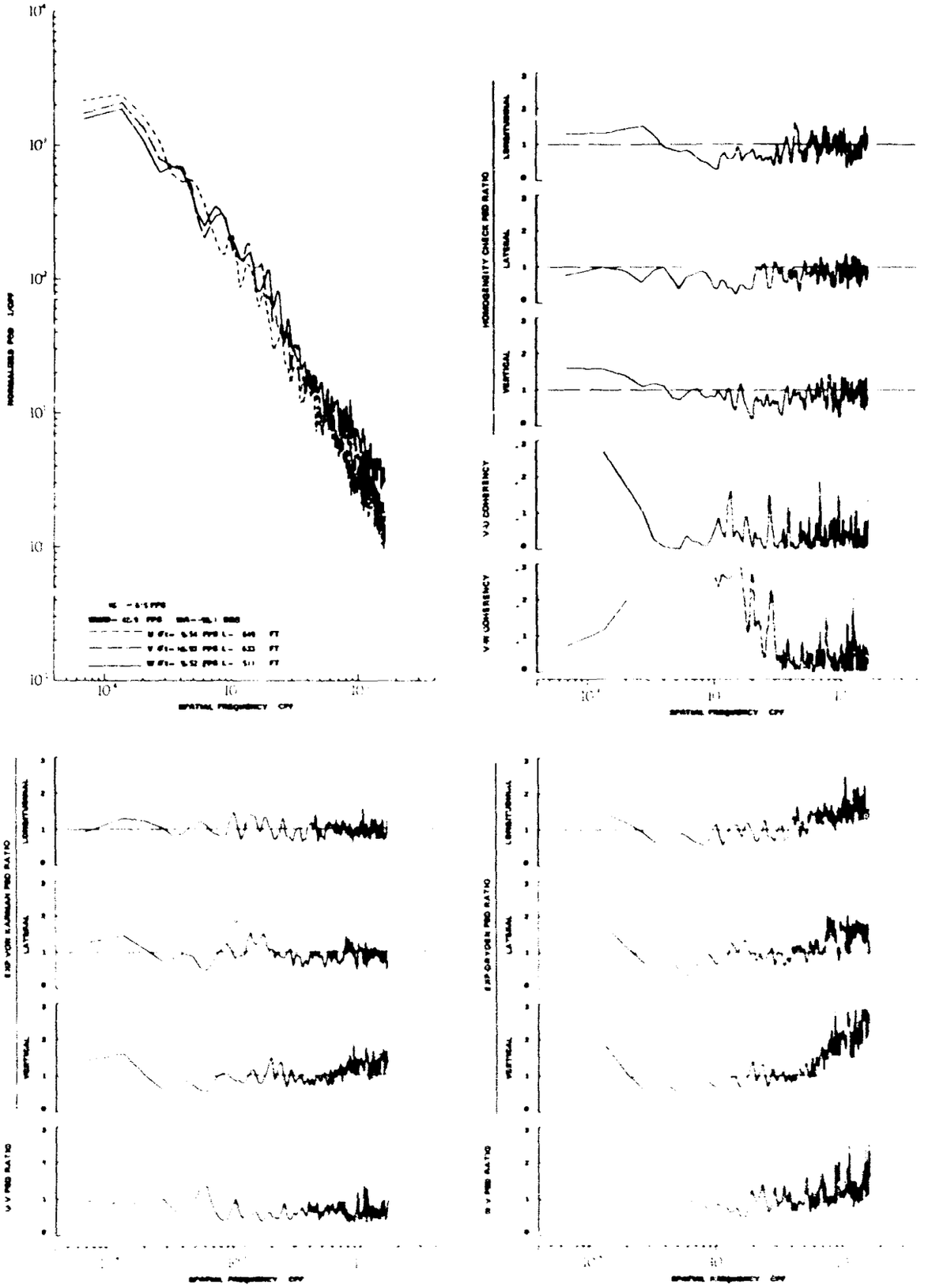
Turbulence Spectra Data For Test 232, Leg 4, Category 122113



Turbulence Spectra Data For Test 233, Leg 1, Category 123233



Turbulence Spectra Data For Test 233, Leg 3, Category 3213



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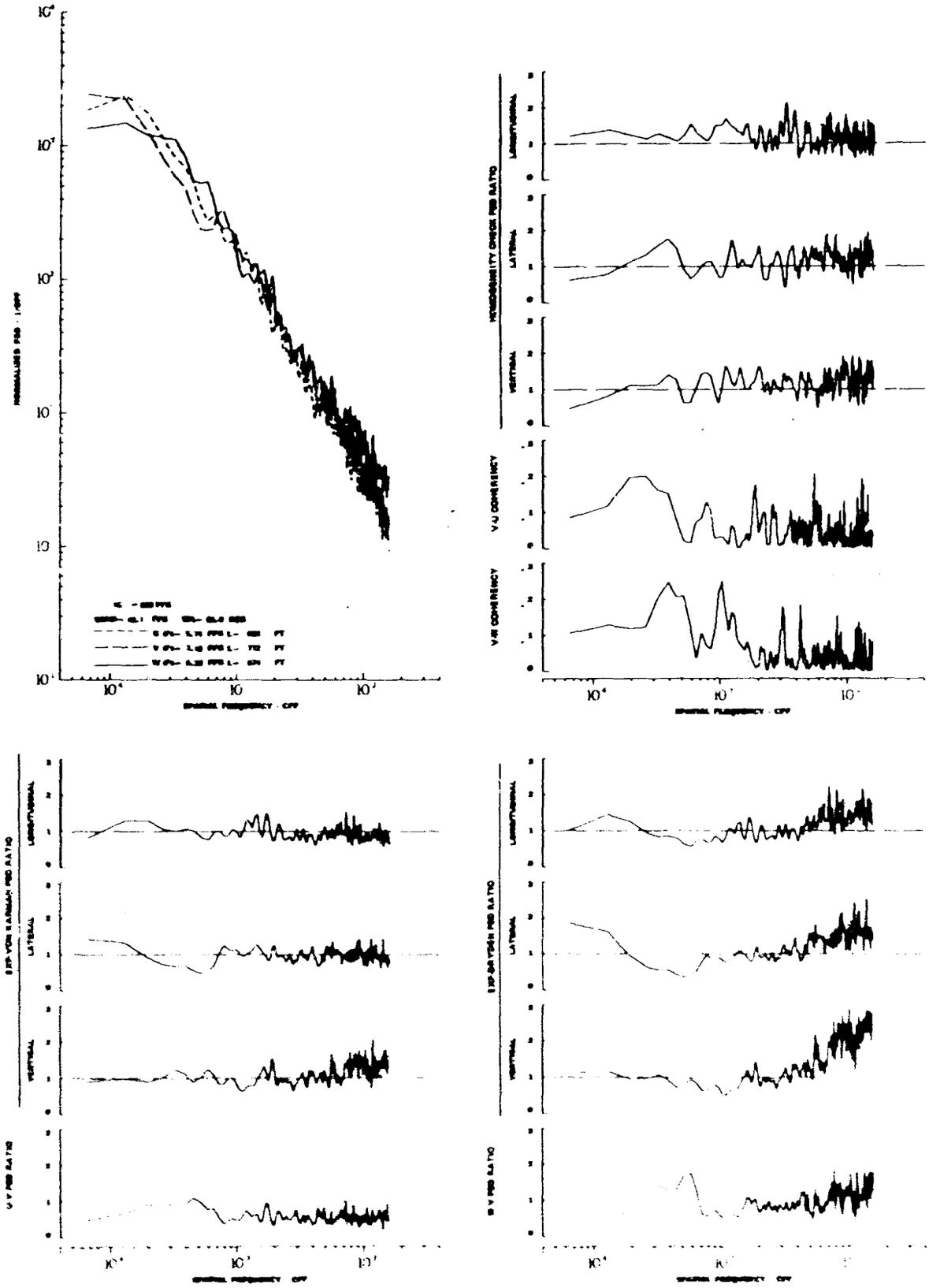

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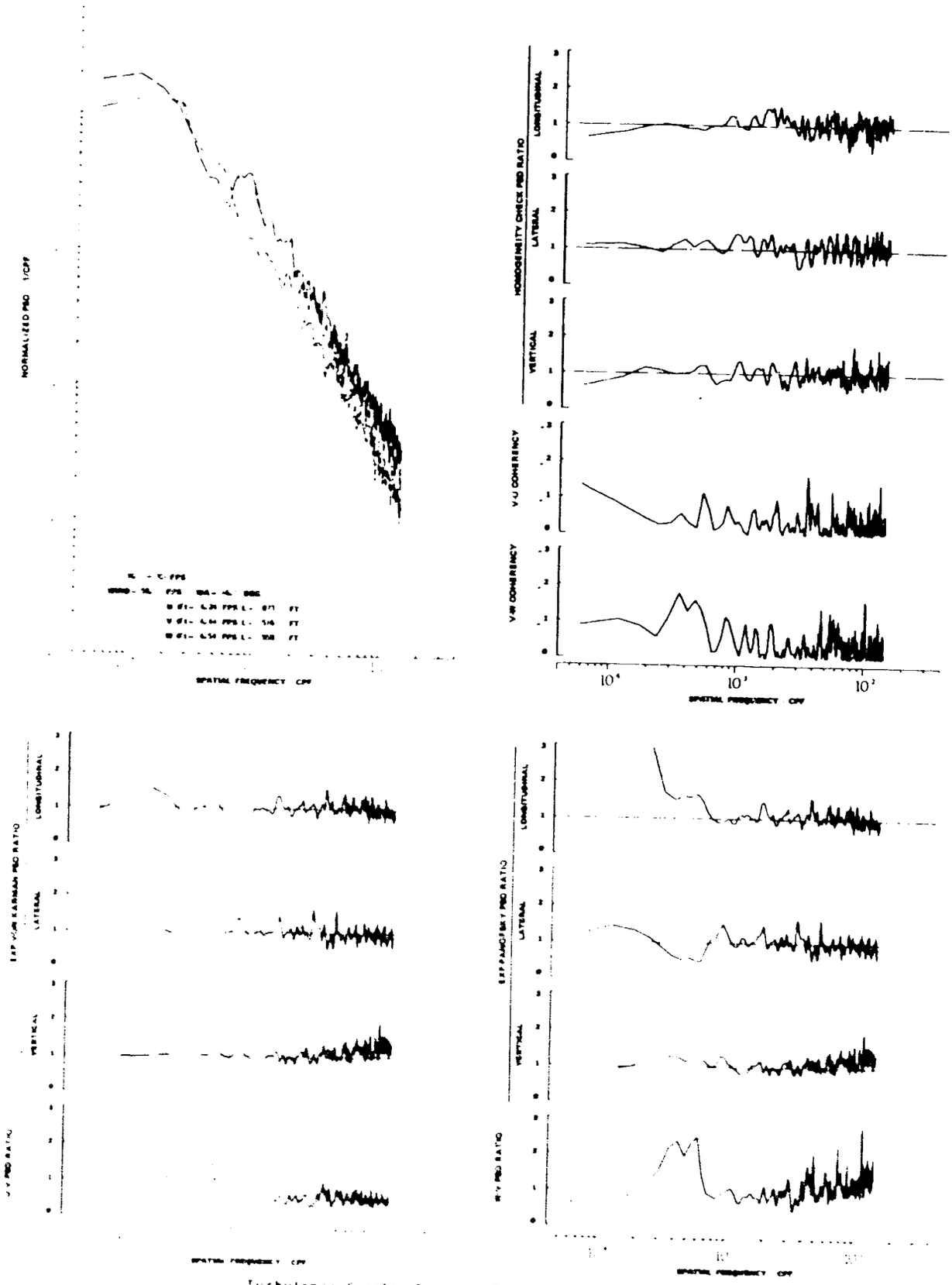
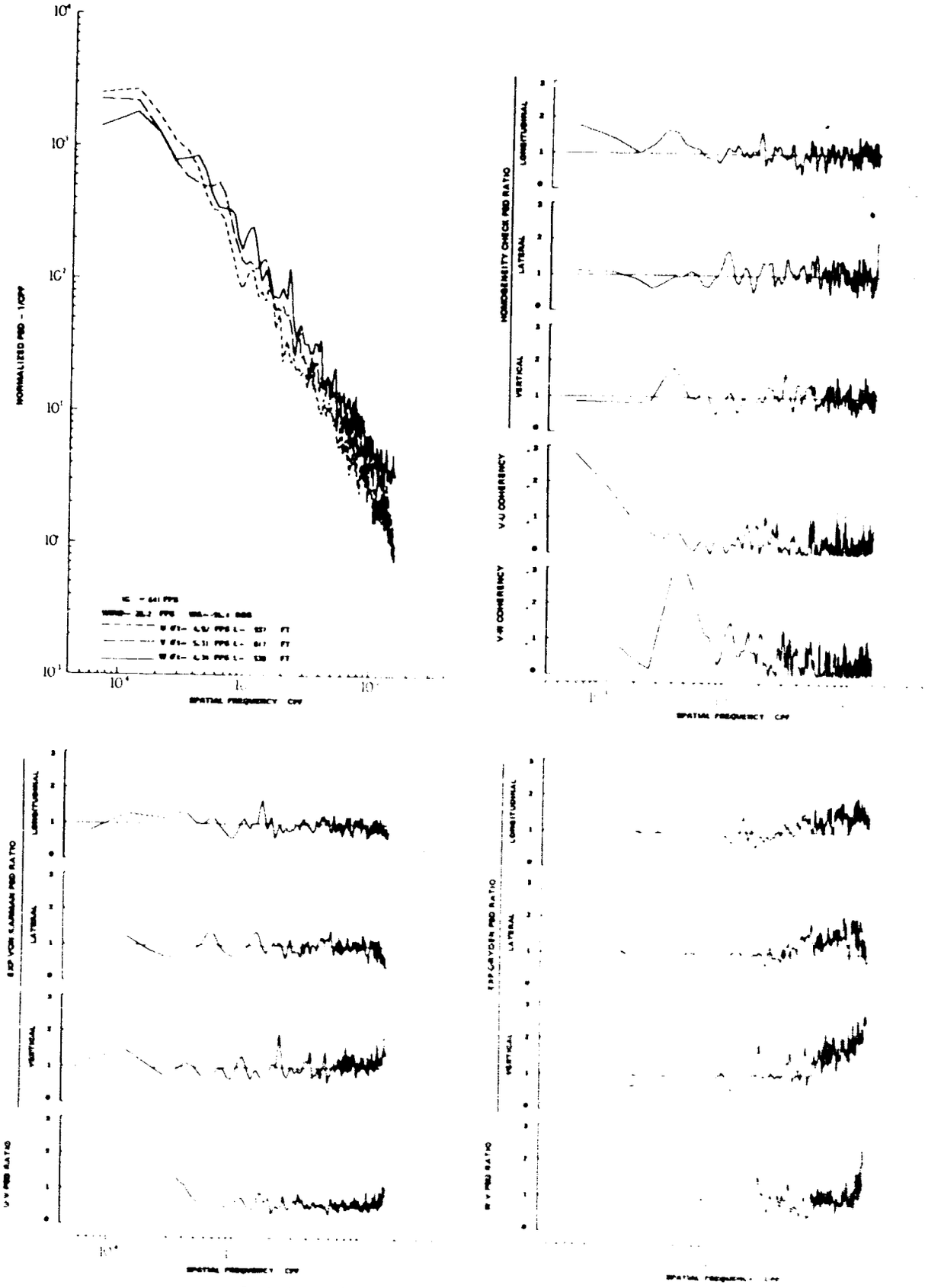
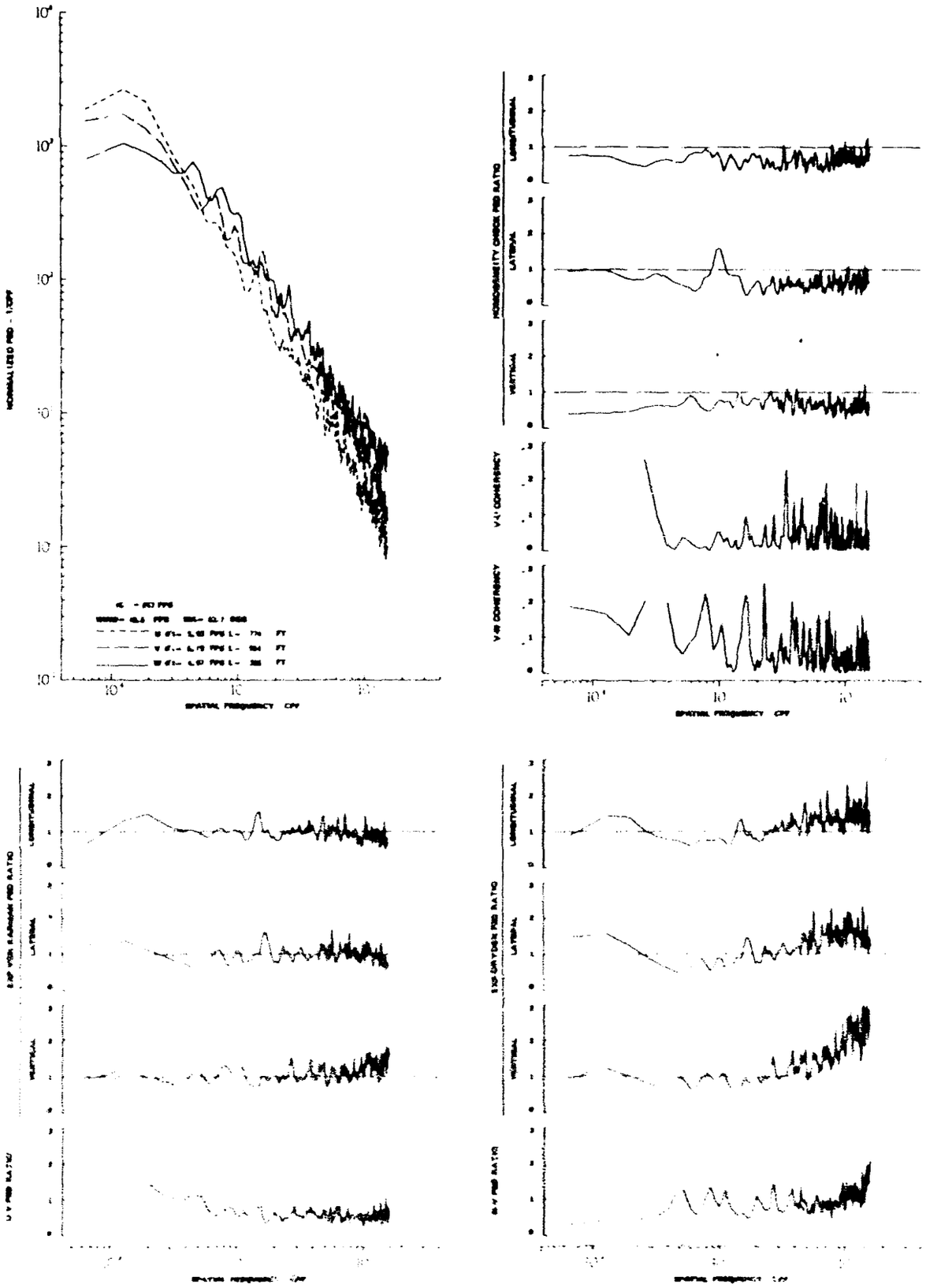


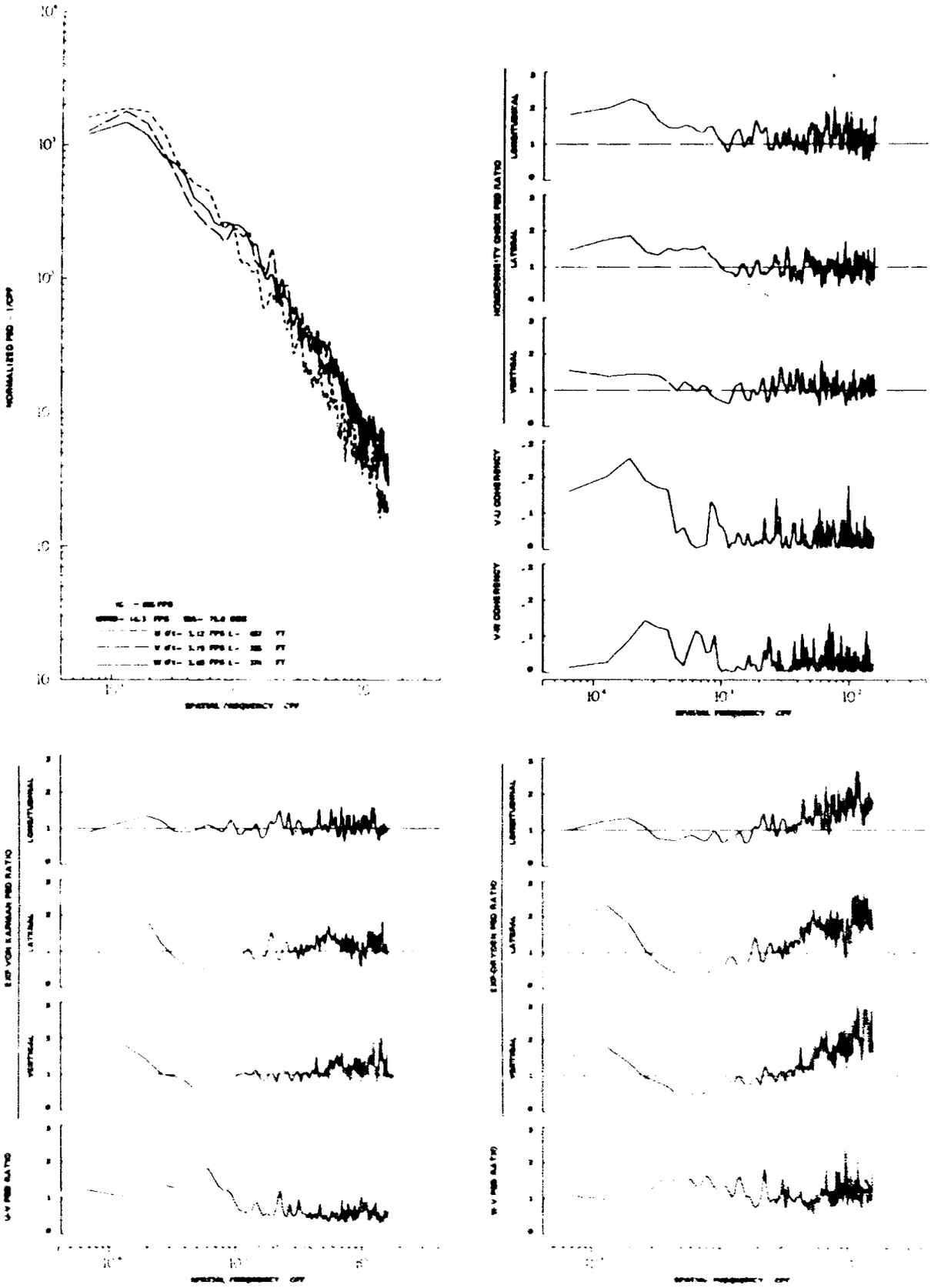
Turbulence Spectra Data for Test 233, Leg 8, Category 473213



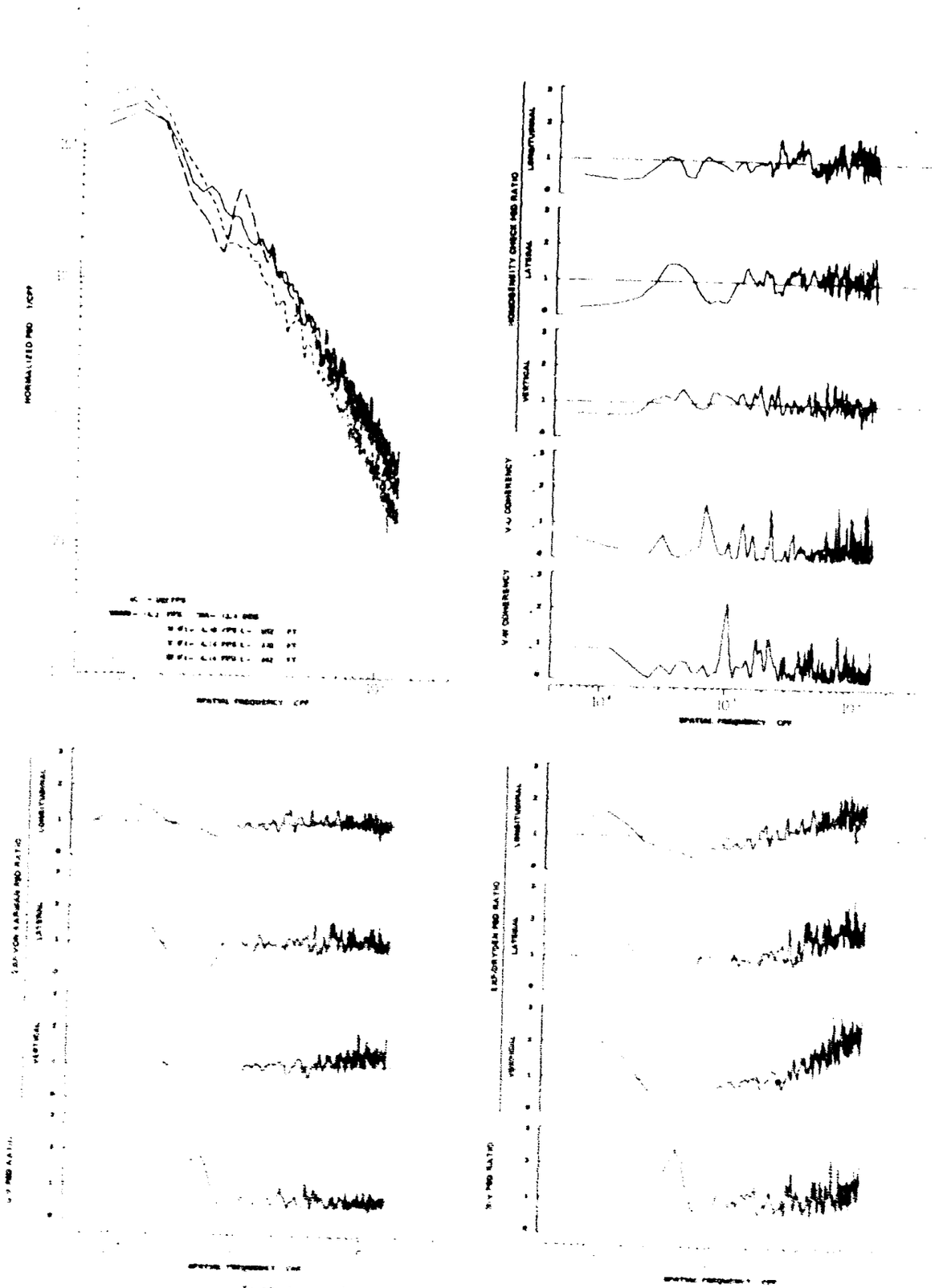
Turbulence Spectra Data For Test 234, Leg 4, Category 122313



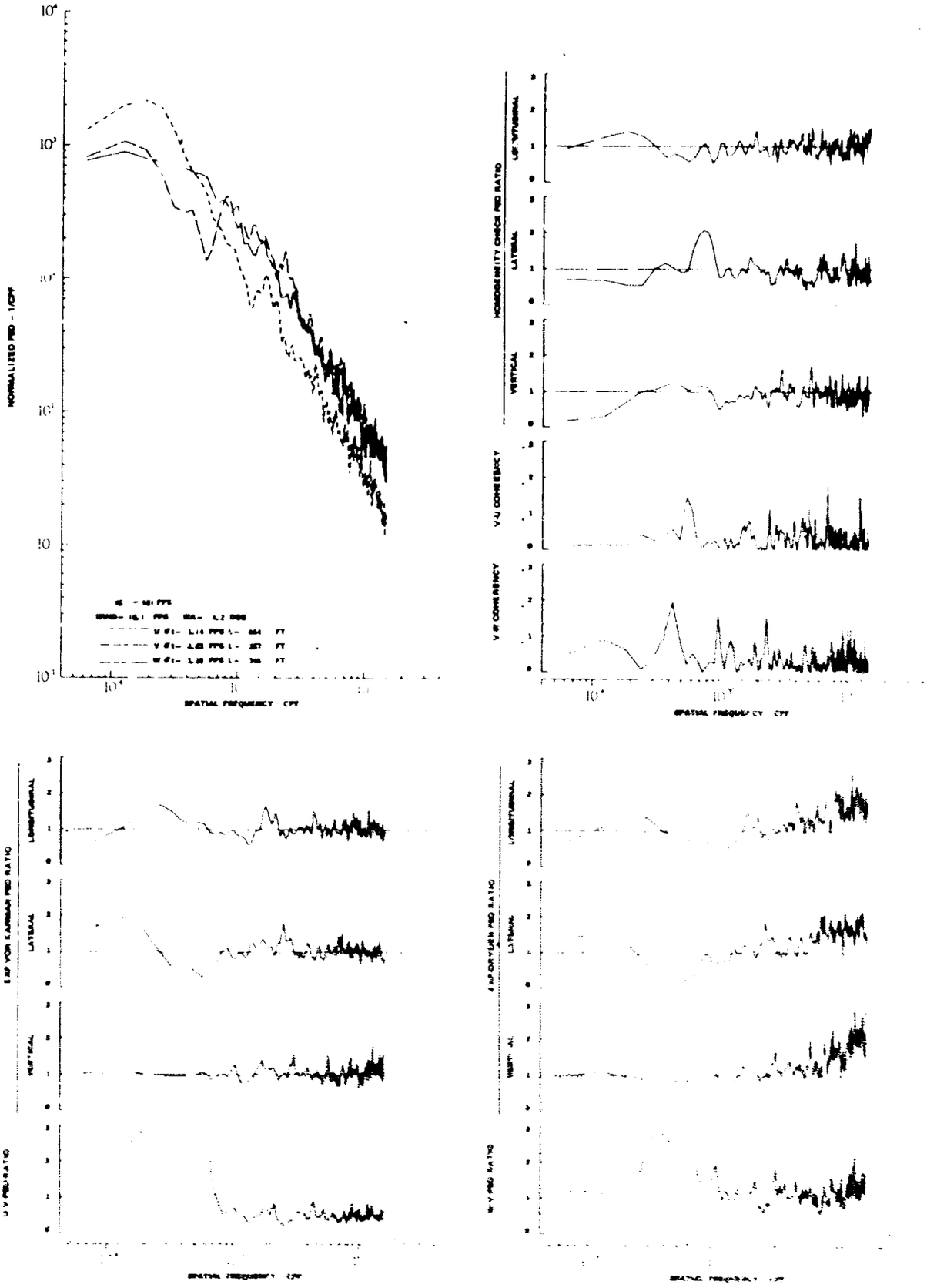
Turbulence Spectra Data for Test 234, Leg 6, Category 123315



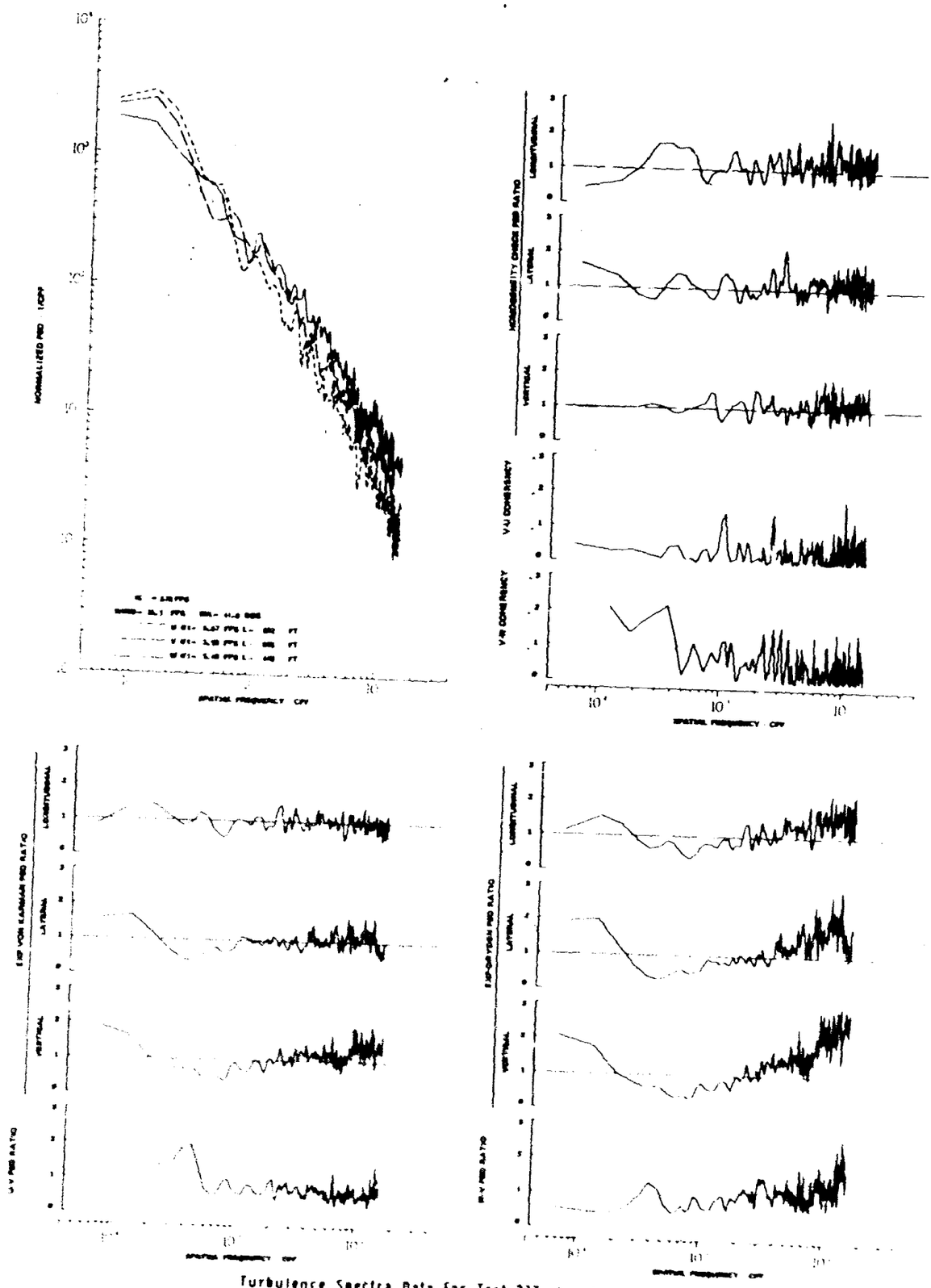
Turbulence Spectra Data For Test 236, Leg 4, Category [1821]



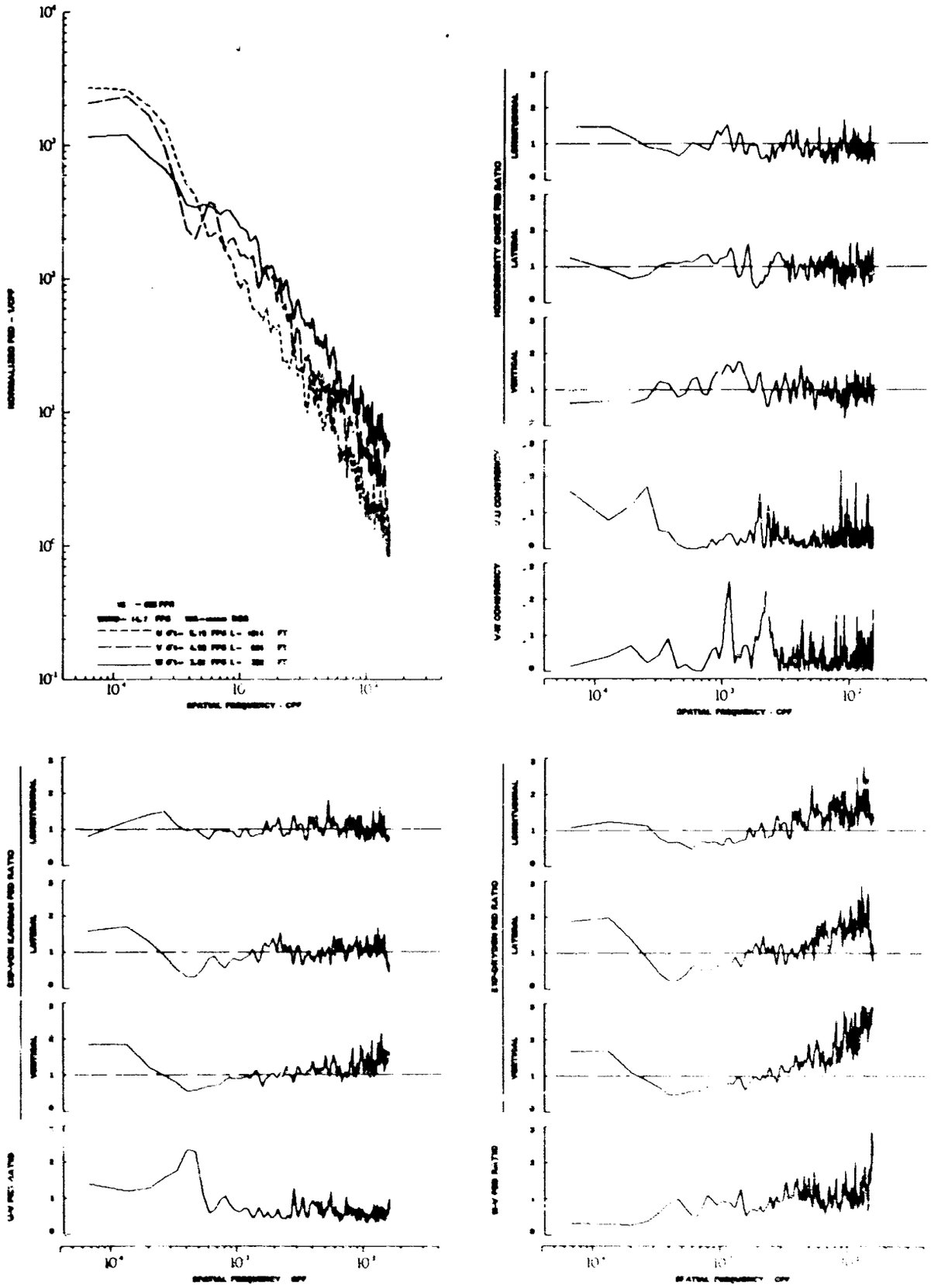
Turbulence Spectra Data For Test 236, Leg 6, Category 113211



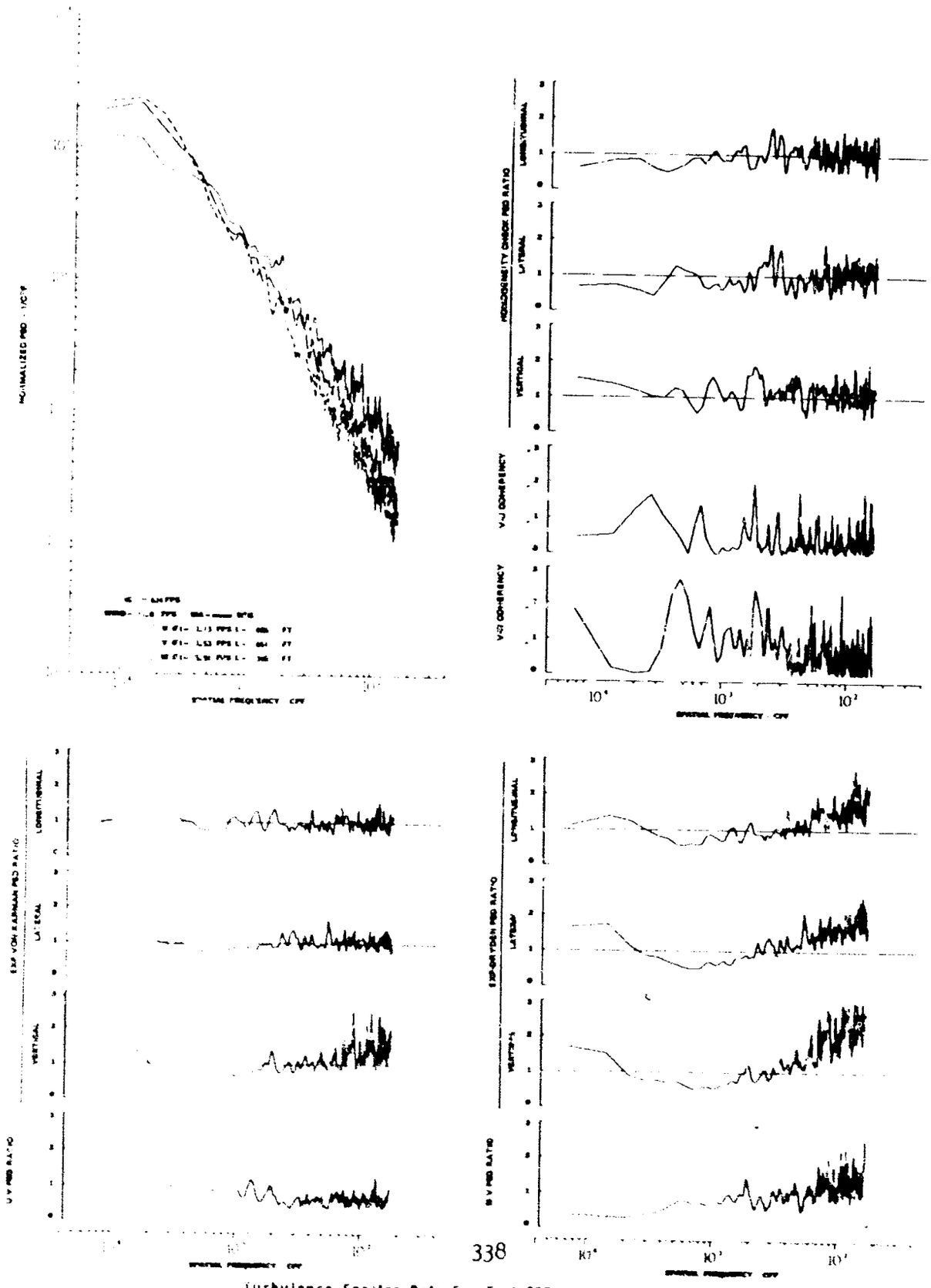
Turbulence Spectra Data For Test 23b, seq 8, Category 4[illegible]



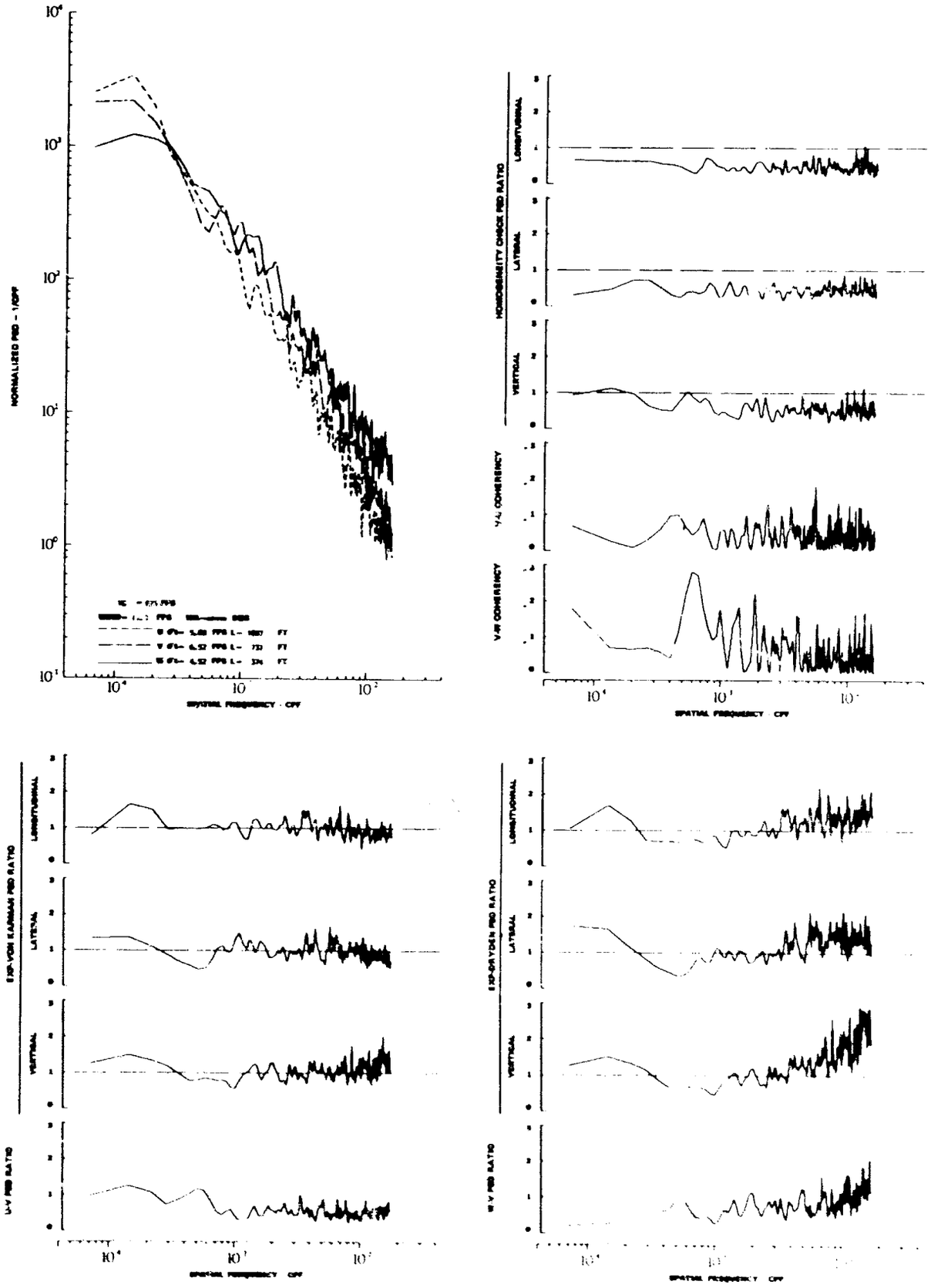
Turbulence Spectra Data For Test 237, Leg 1, Category 113313



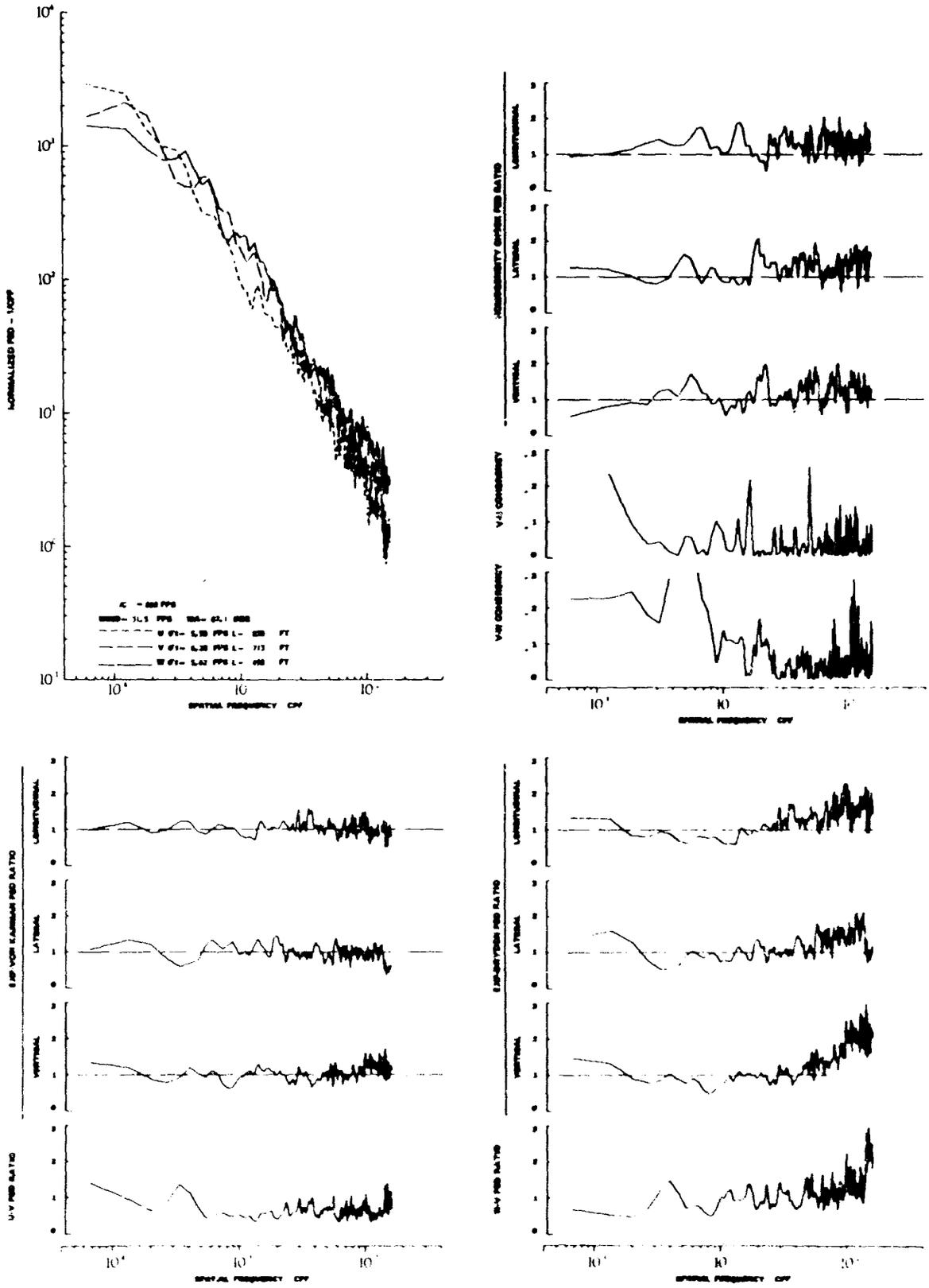
Turbulence Spectra Data For Test 237, Leg 3, Category 113313



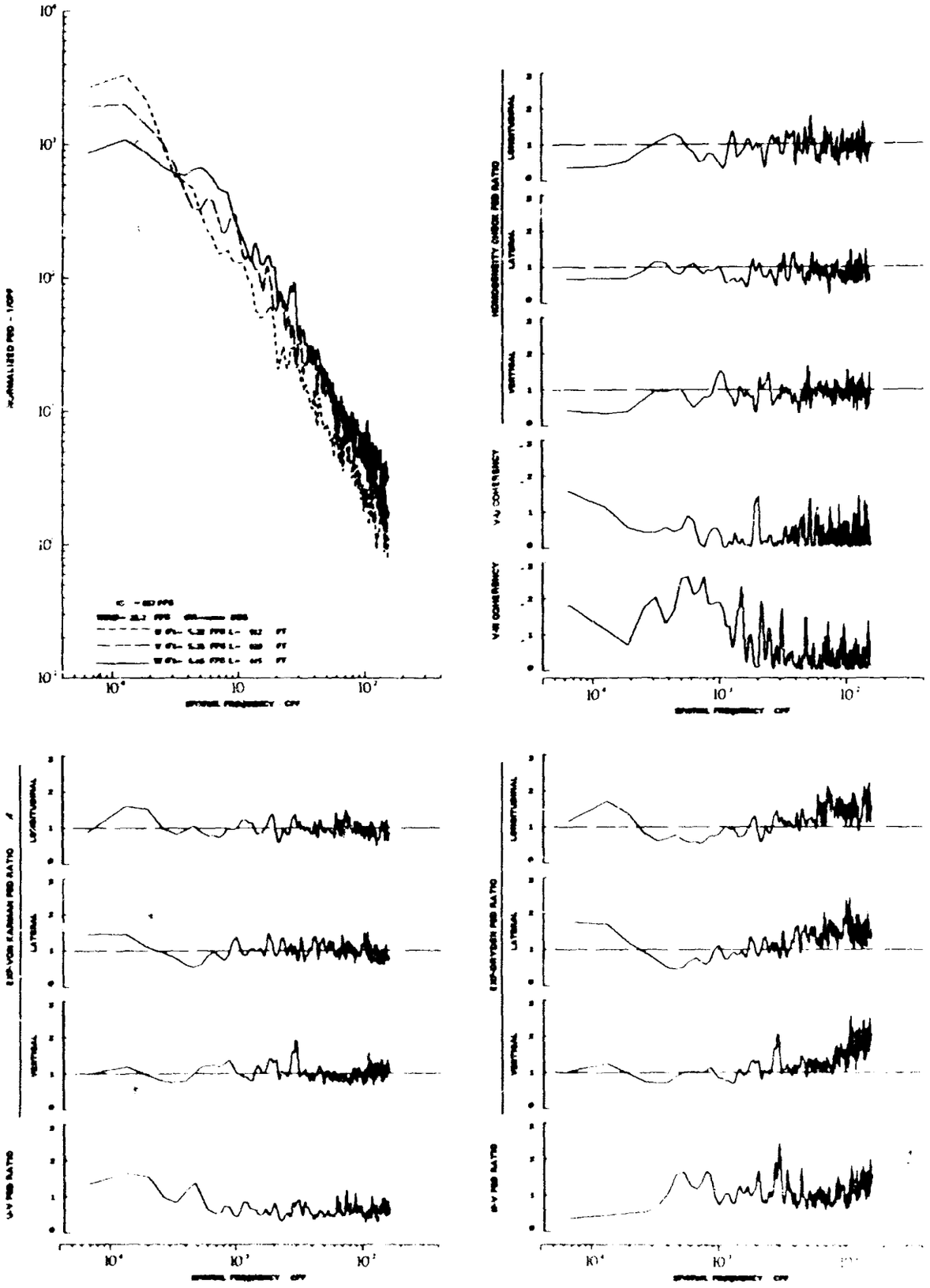
Turbulence Spectra Data For Test 237, Leg 5, Category 113313



Turbulence Spectra Data For Test 238, Leg 4, Category 122113



Turbulence Spectra Data For Test 239, Leg 1, Category 122213



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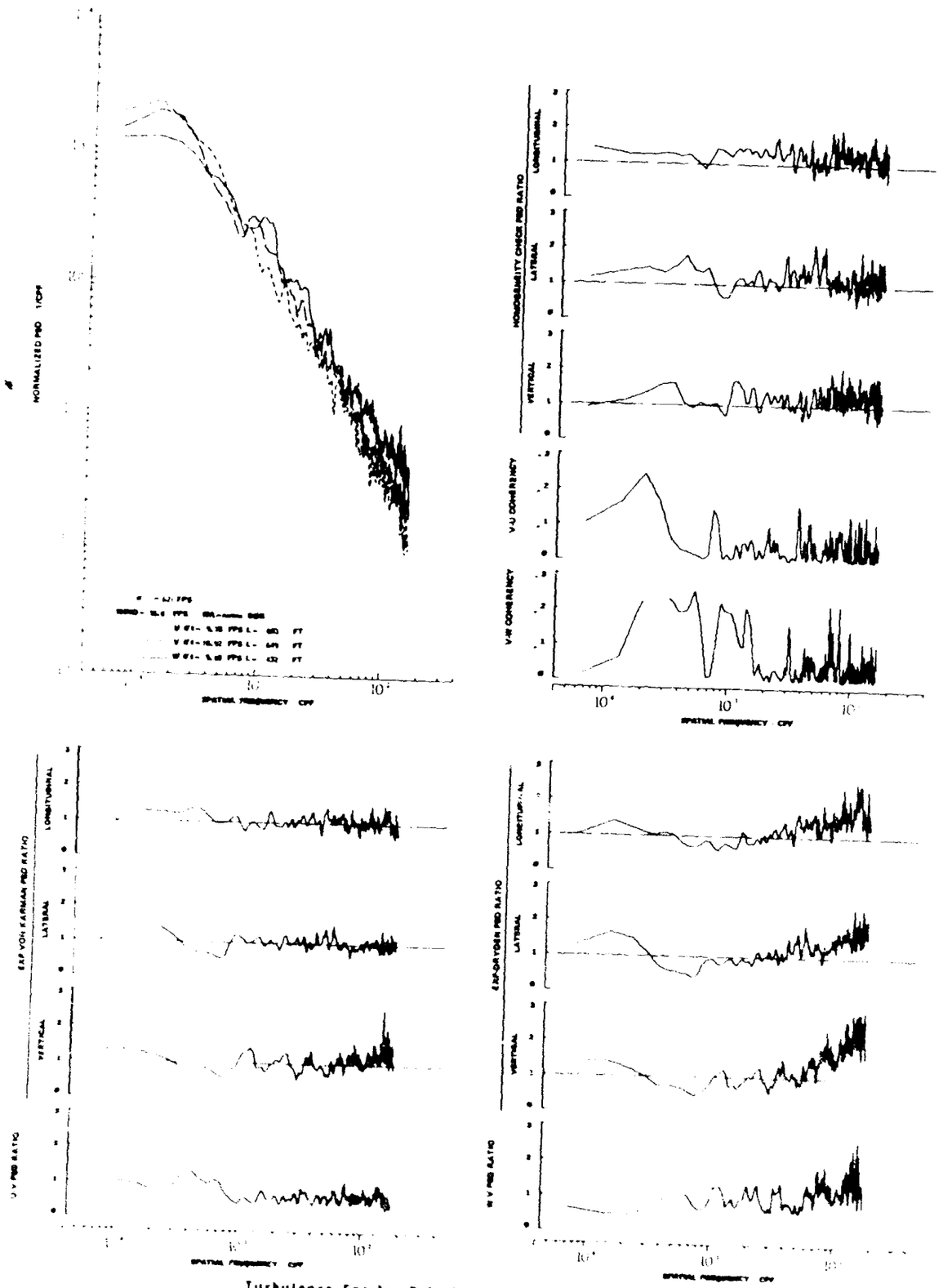
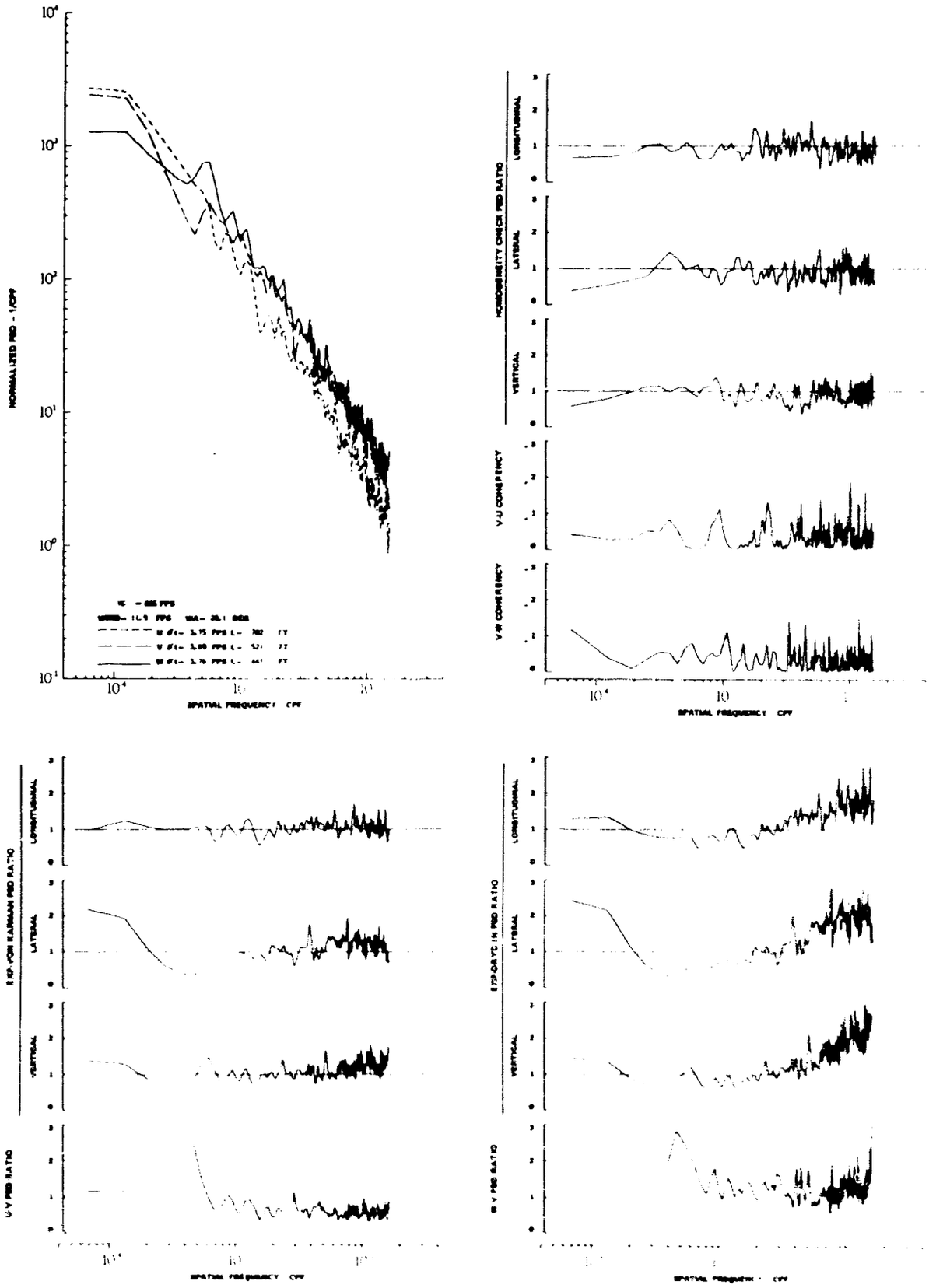
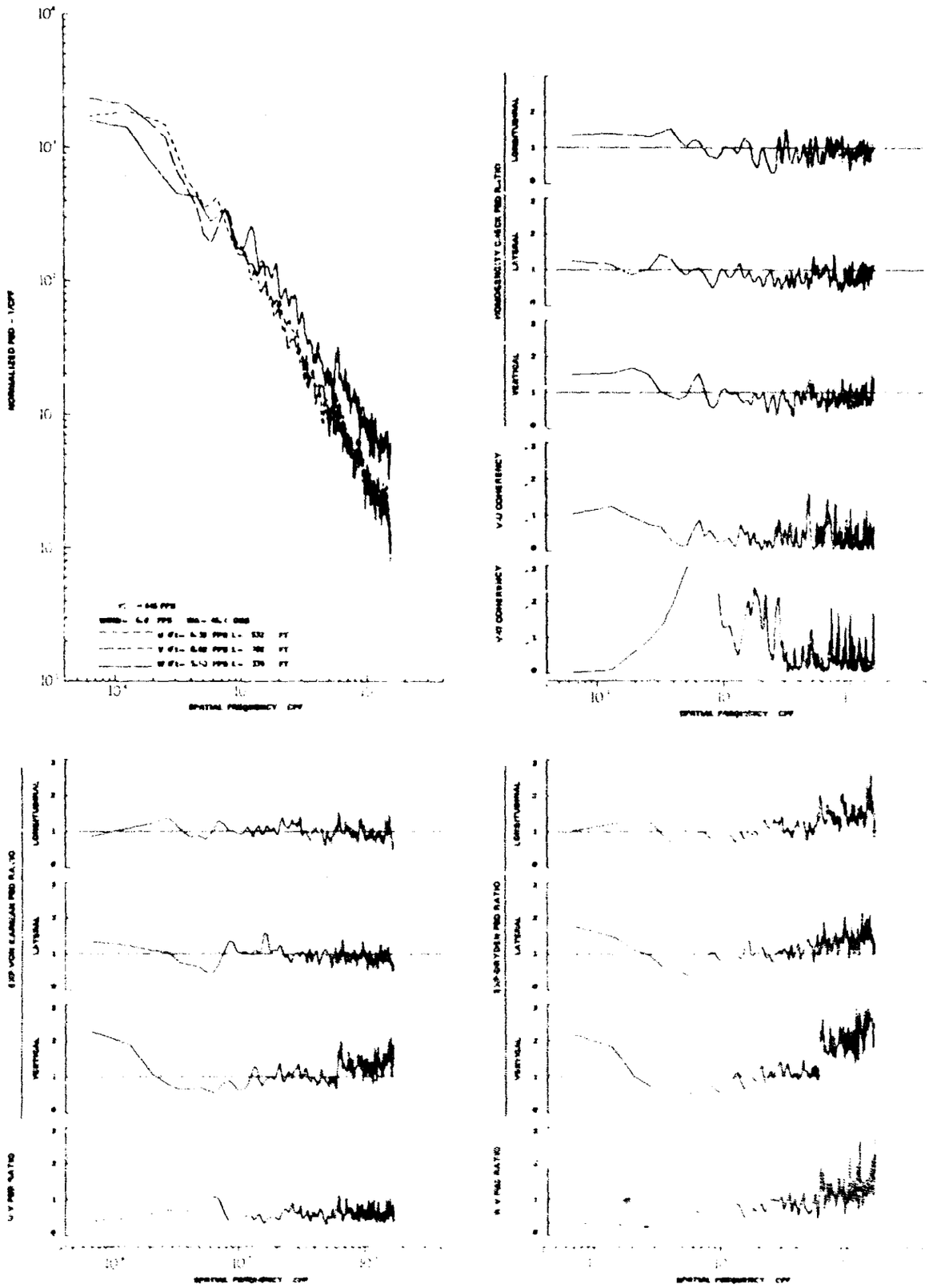


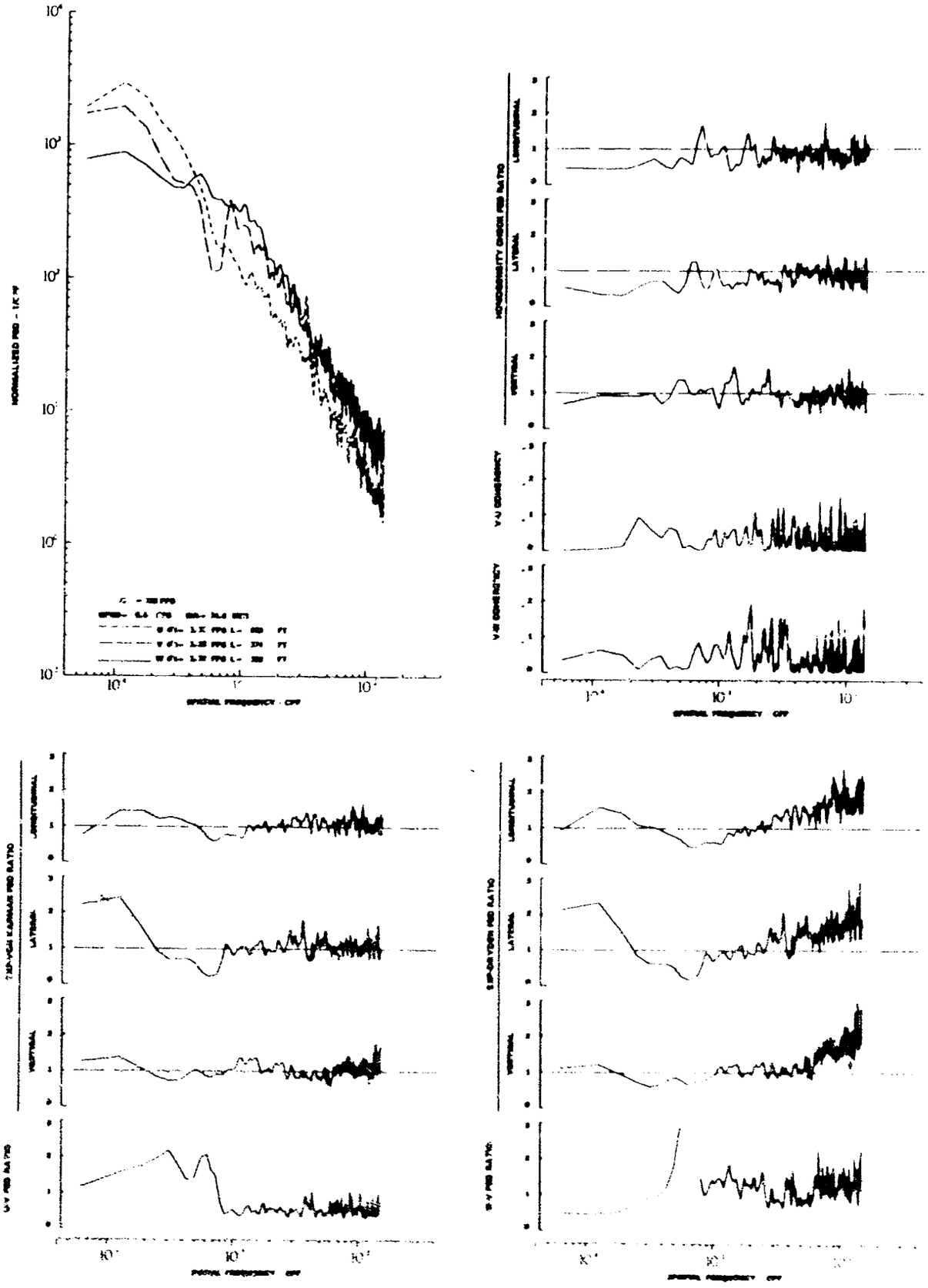
Turbulence Spectra Data For Test 239, Leg 5, Category 123213



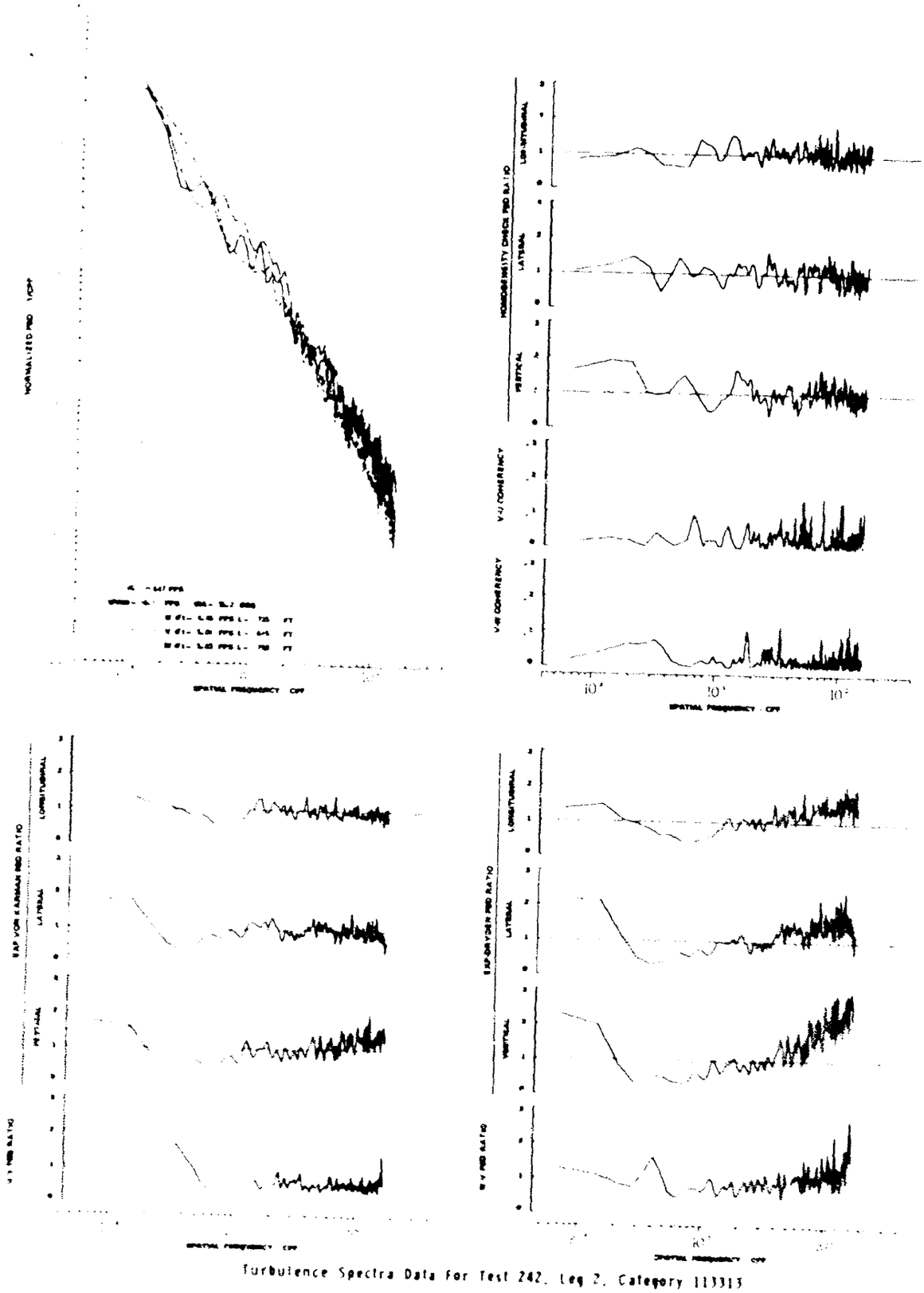
Turbulence Spectra Data For Test 241, Leg 3, Category 112213



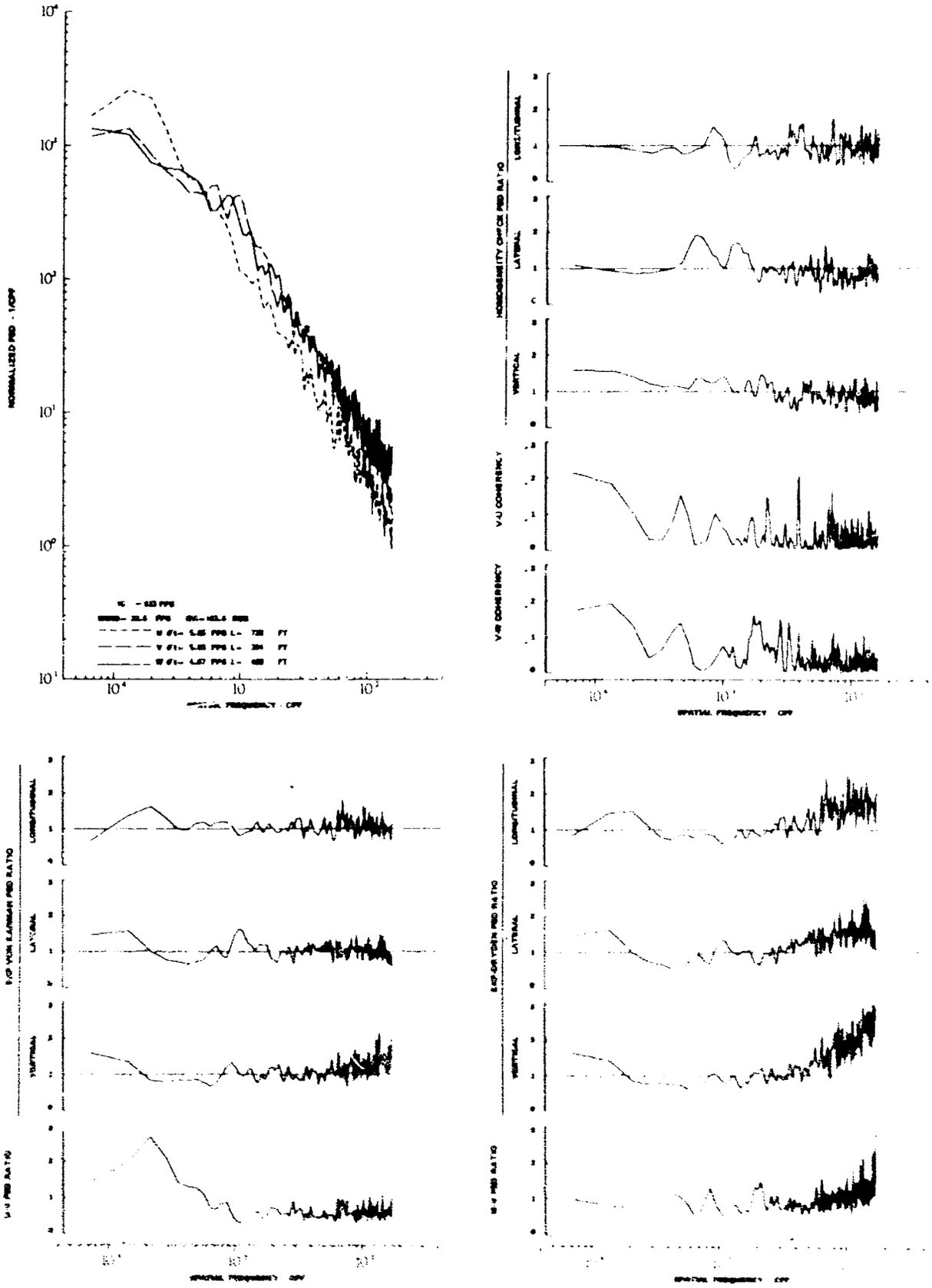
Turbulence Spectra Data For Test 241, Leg 5, Category 112213



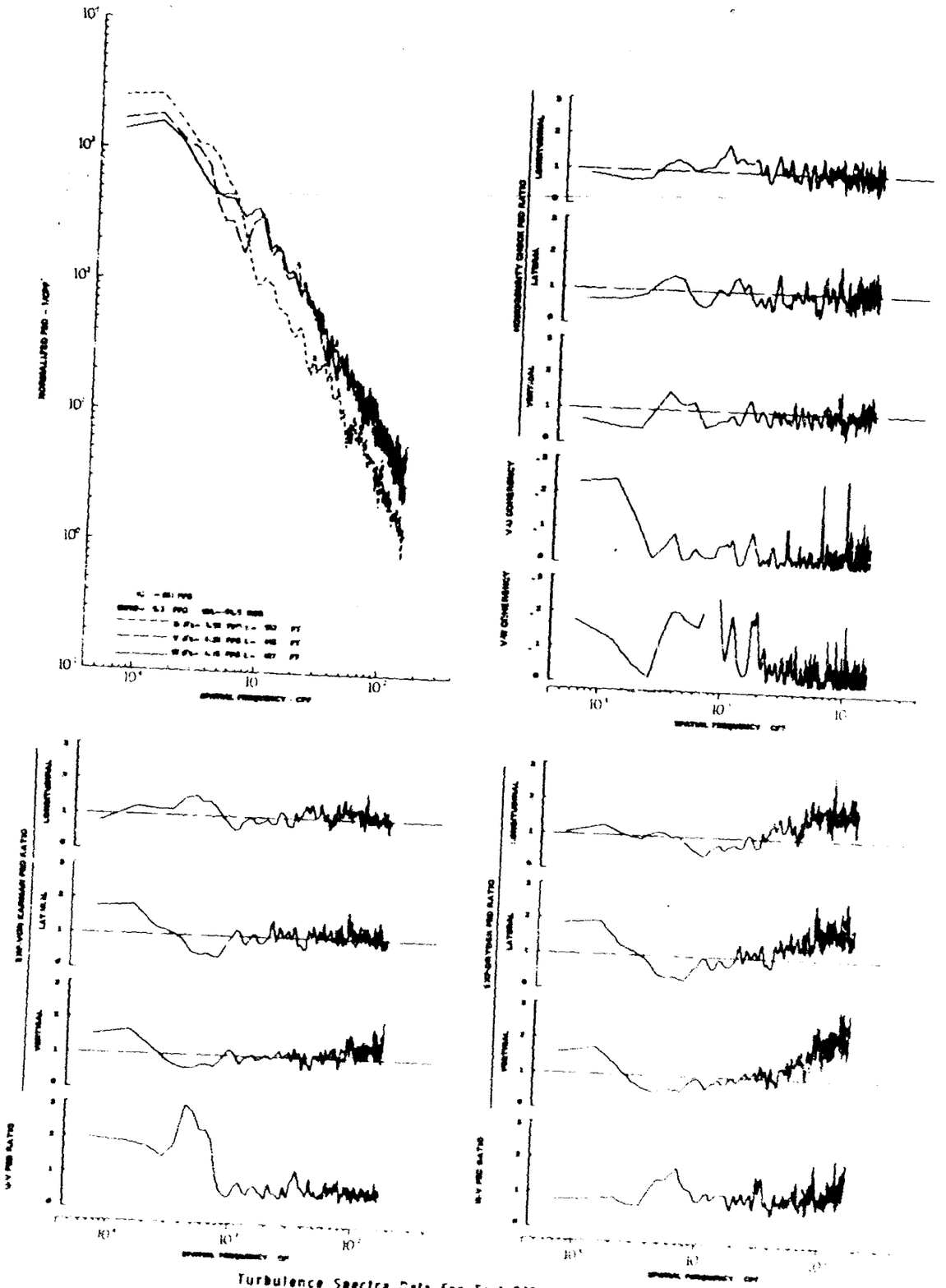
Turbulence Spectra Data For Test 241, Leg 8, Category 413213



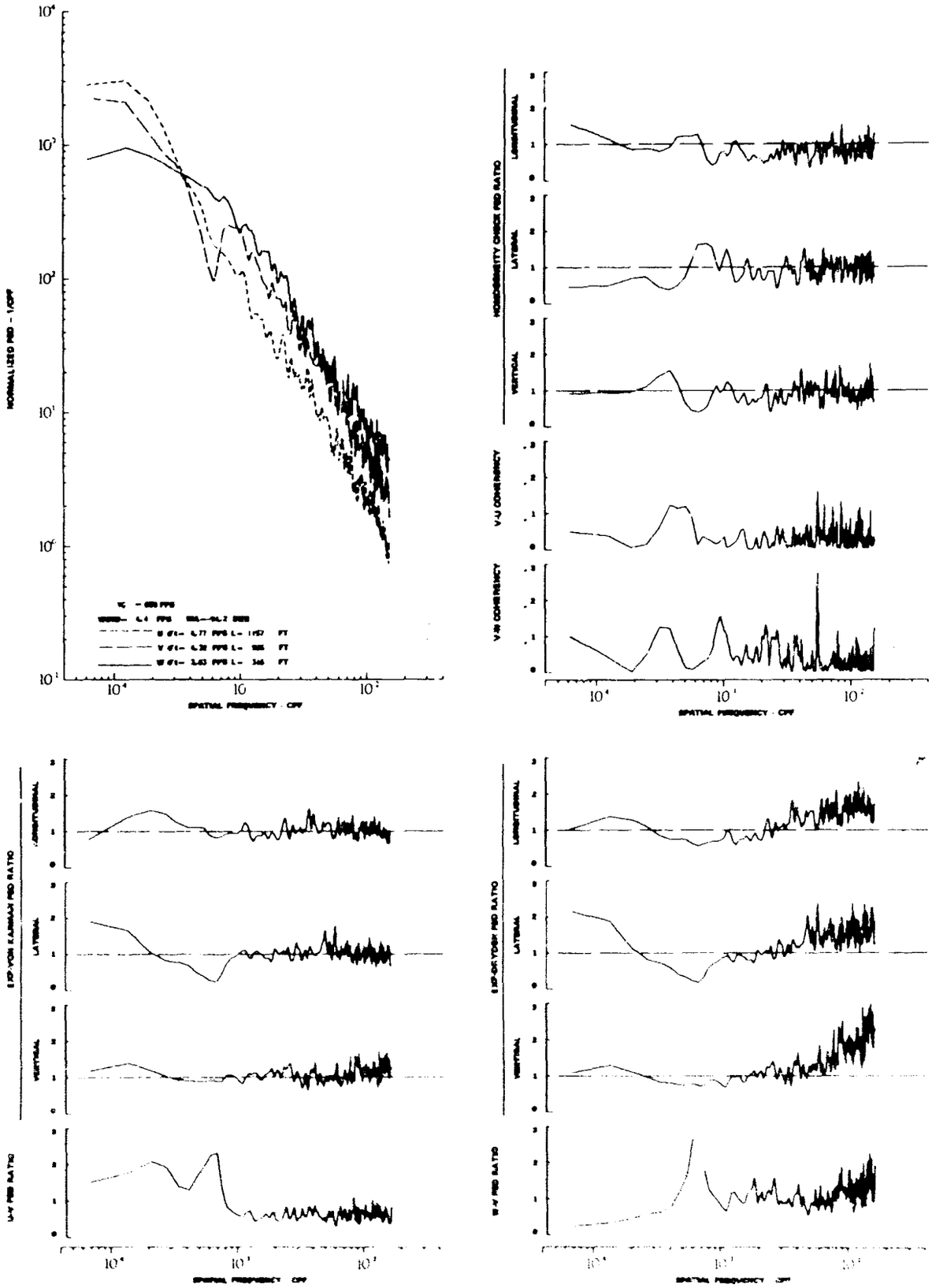
Turbulence Spectra Data For Test 242, Leg 2, Category 113313



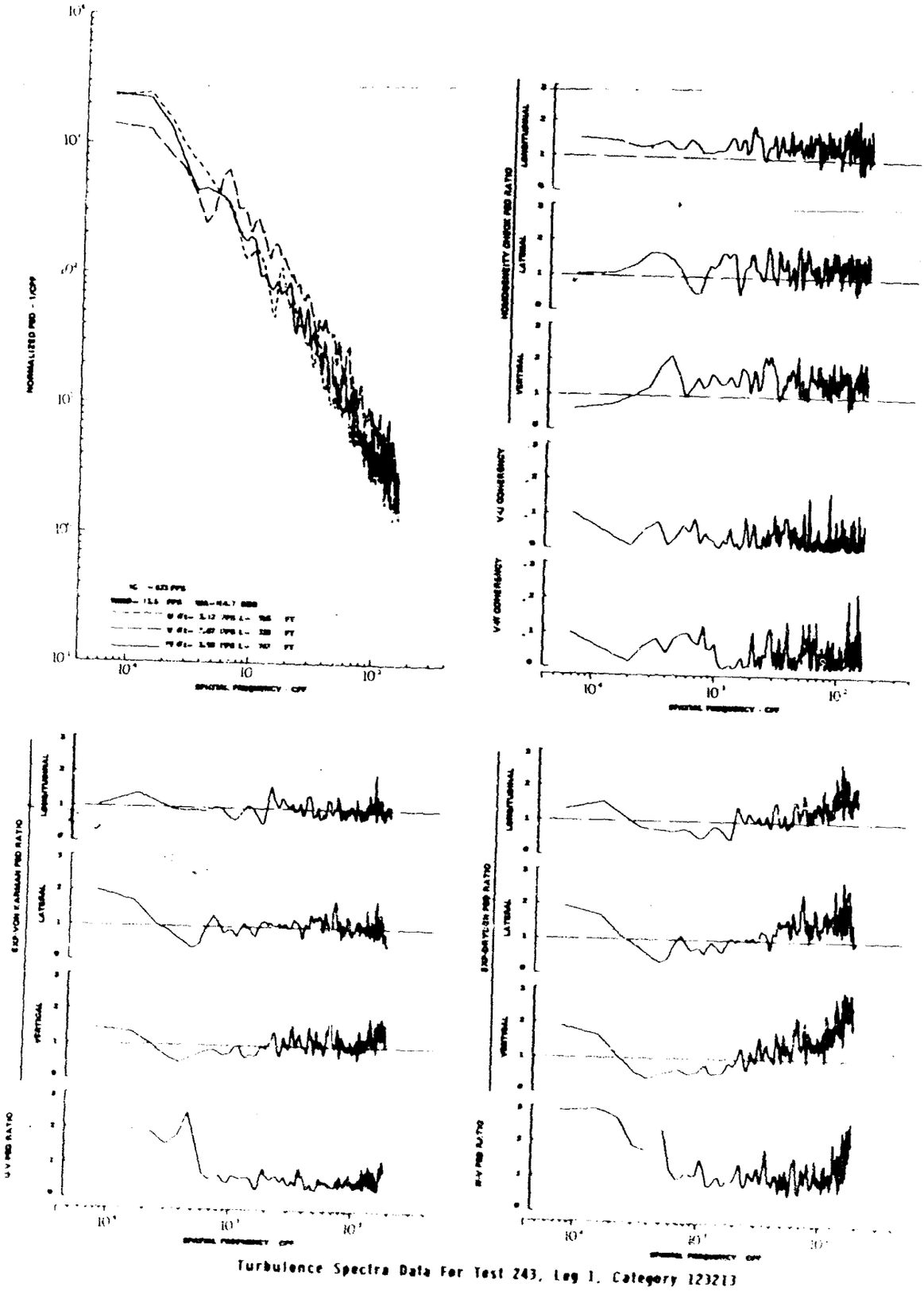
Turbulence Spectra Data for Test 242, Leg 4, Category 113313



Turbulence Spectra Data For Test 242, Leg 6, Category 112313



Turbulence Spectra Data For Test 242, Leg 8, Category 414313



Turbulence Spectra Data For Test 243, Leg 1, Category 123213

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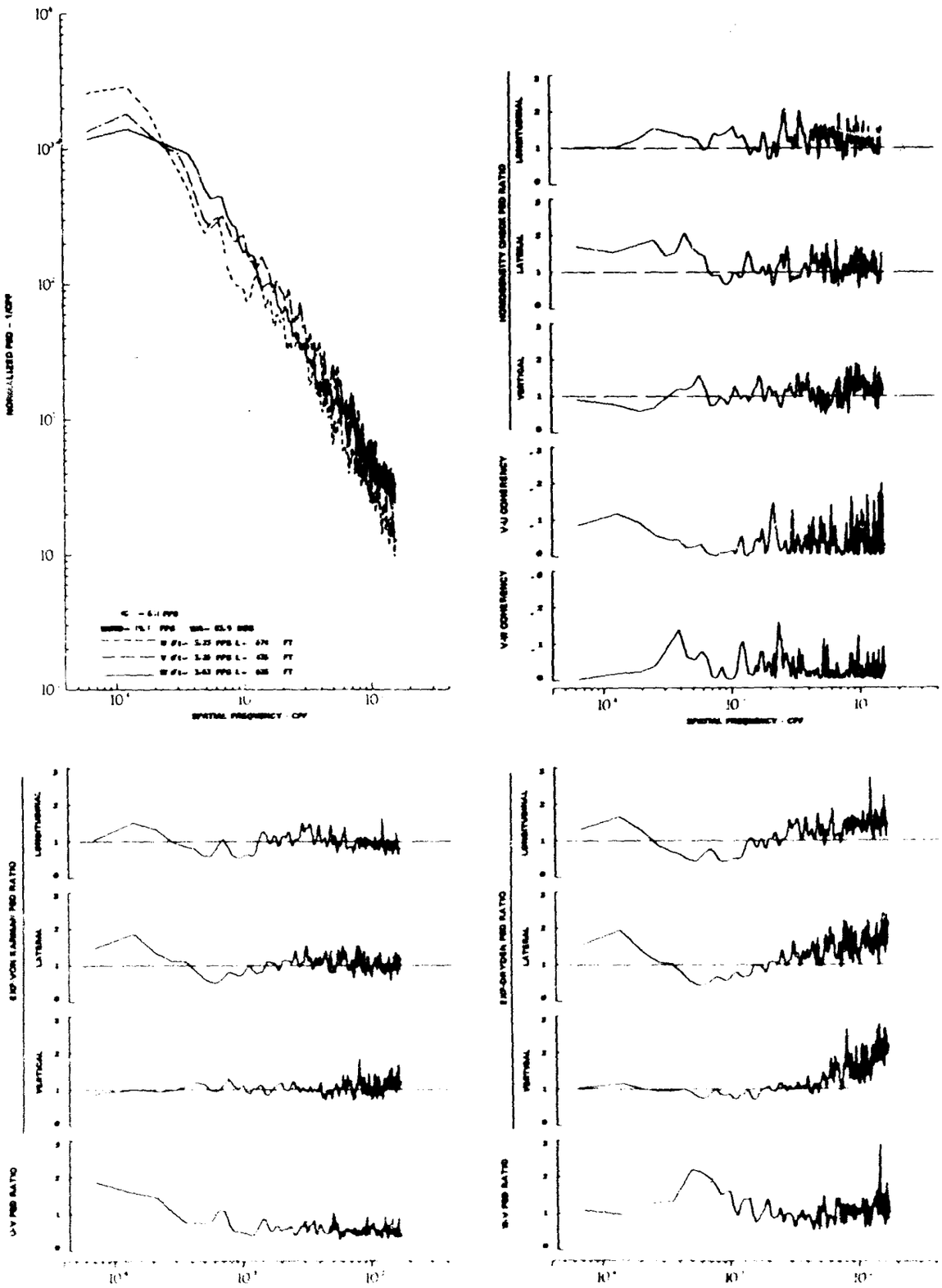
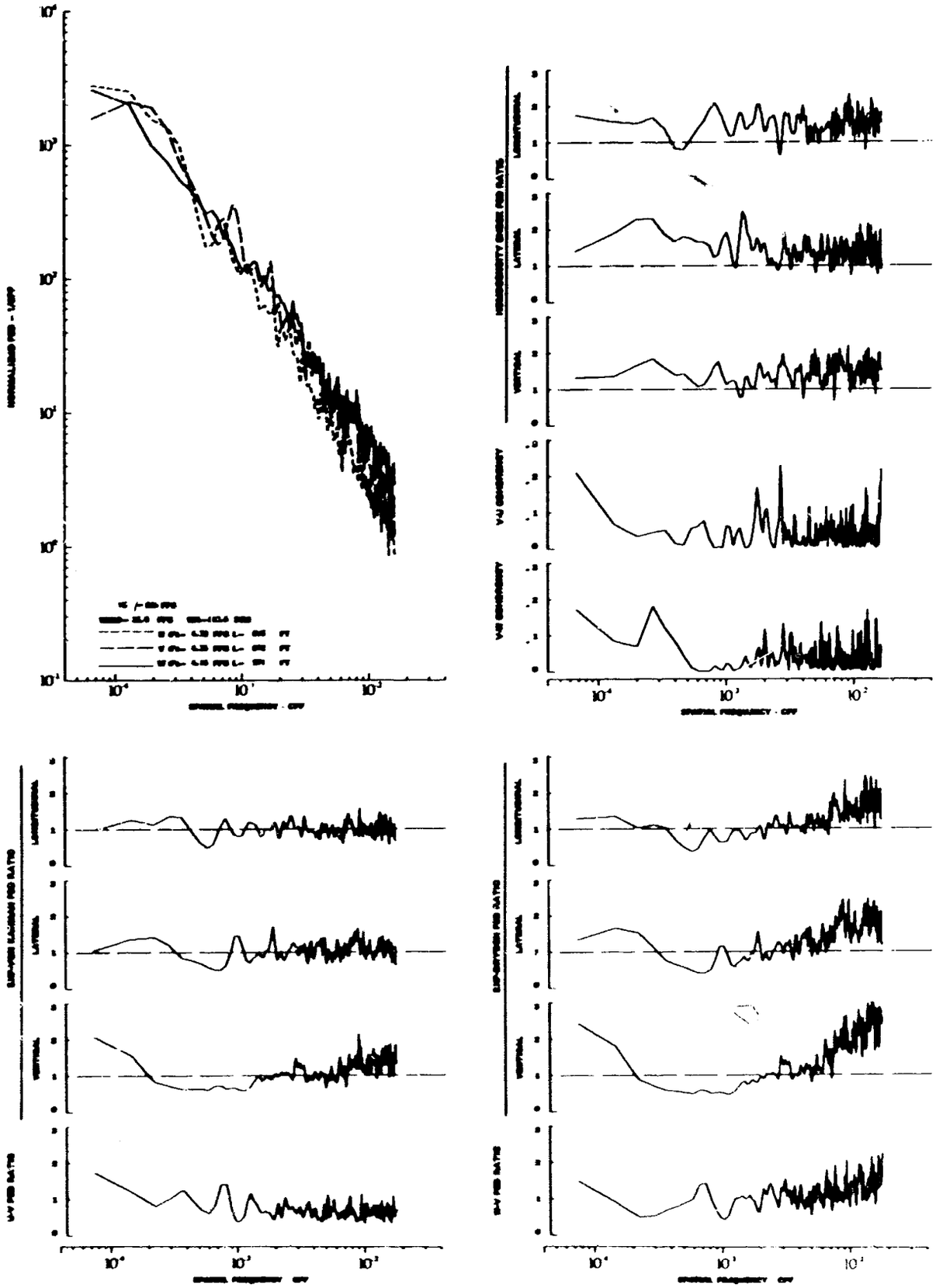
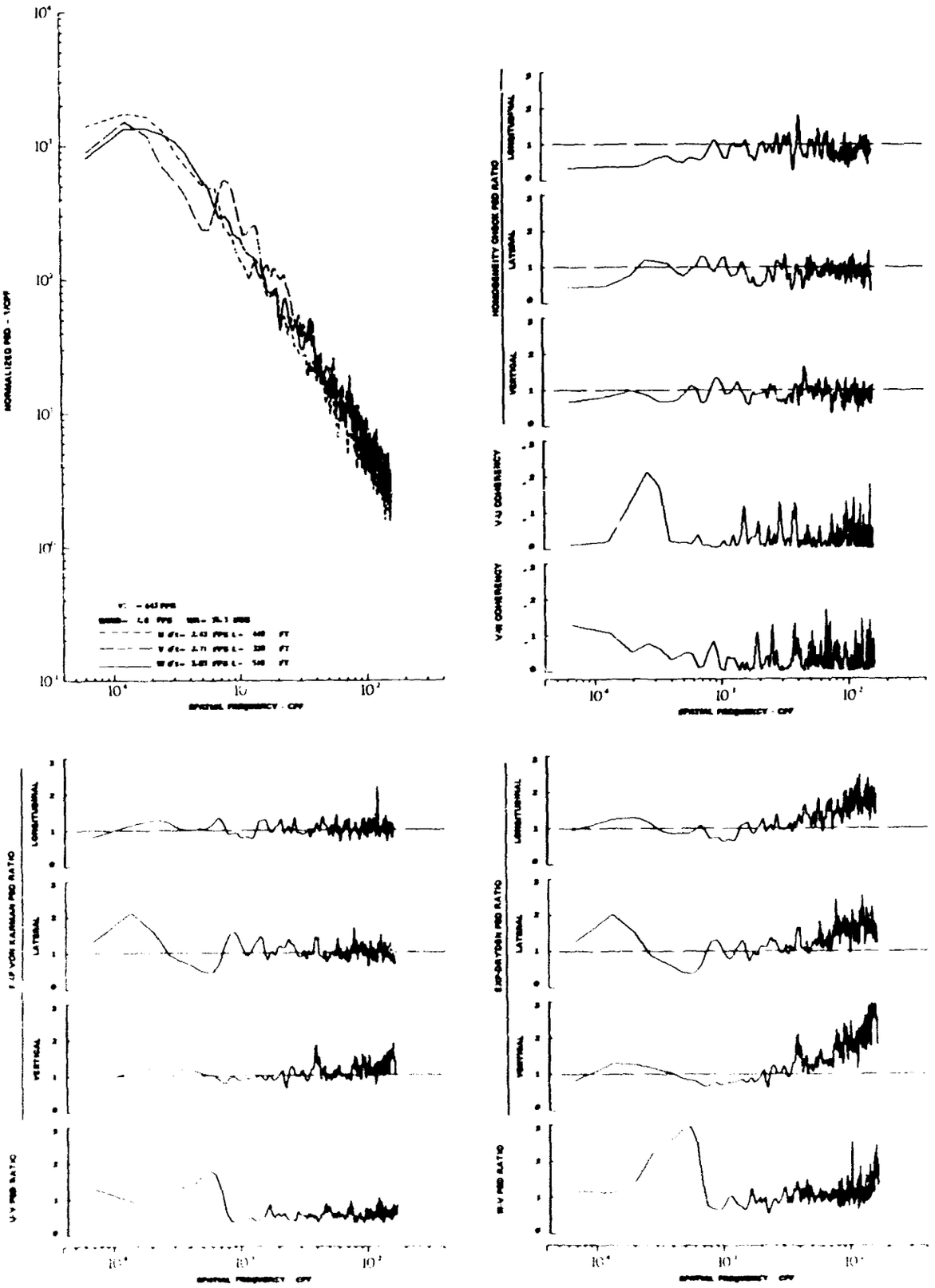


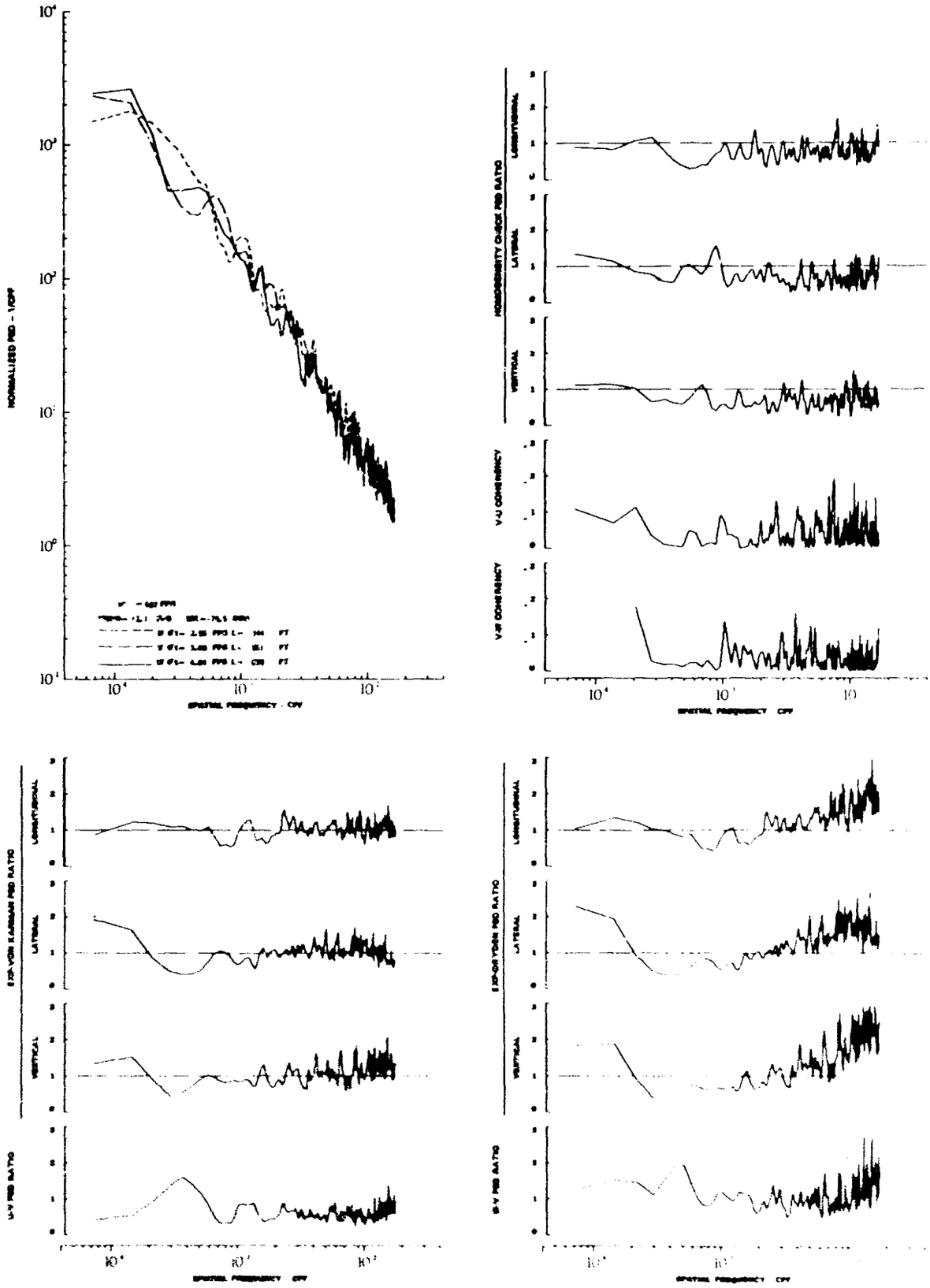
Turbulence Spectra Data For Test 243, Leg 3, Category 122213



Turbulence Spectra Data For Test 243, Leg 5, Category 123213



Turbulence Spectra Data For Test 243, Leg 7, Category 123213



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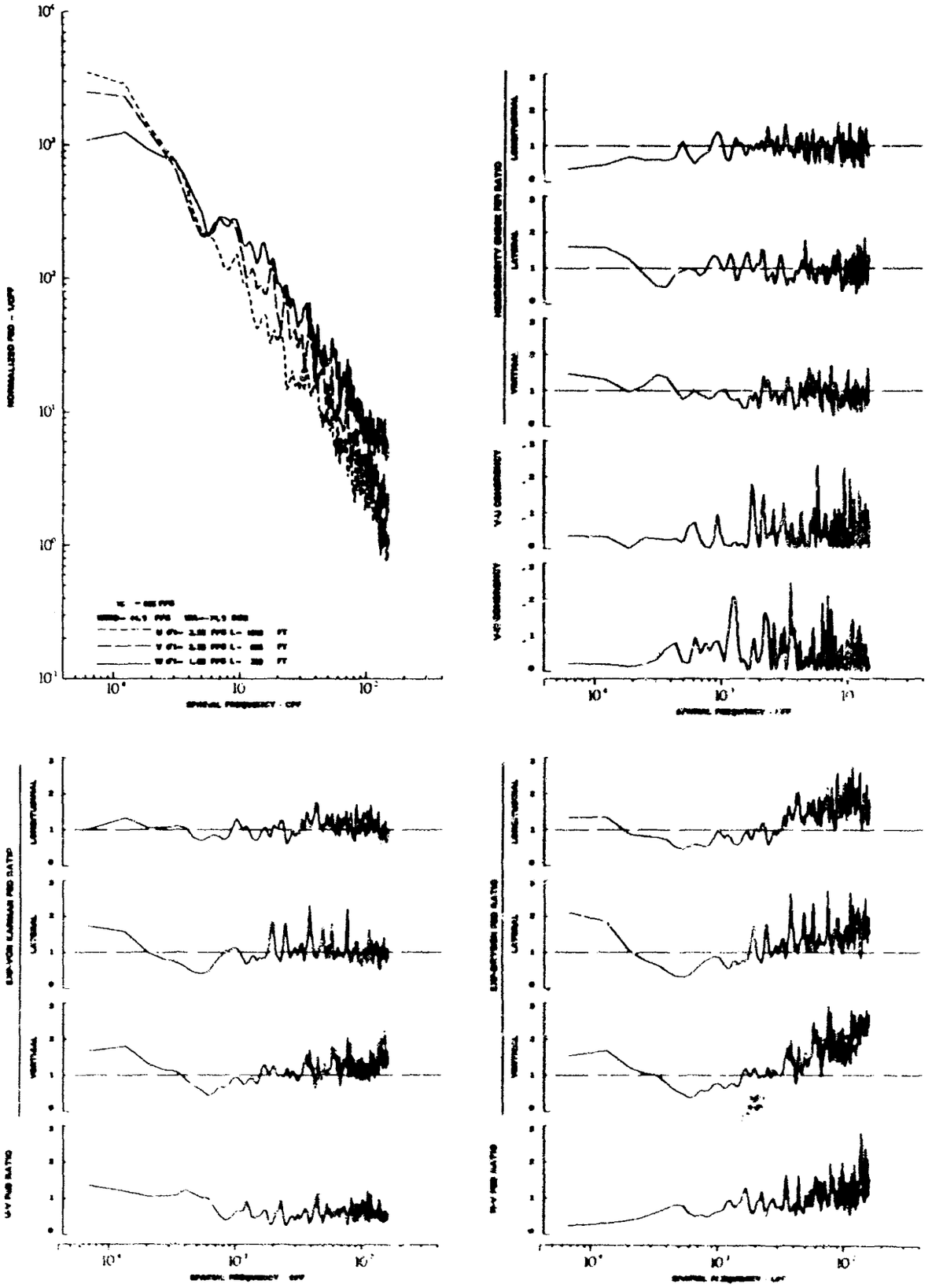
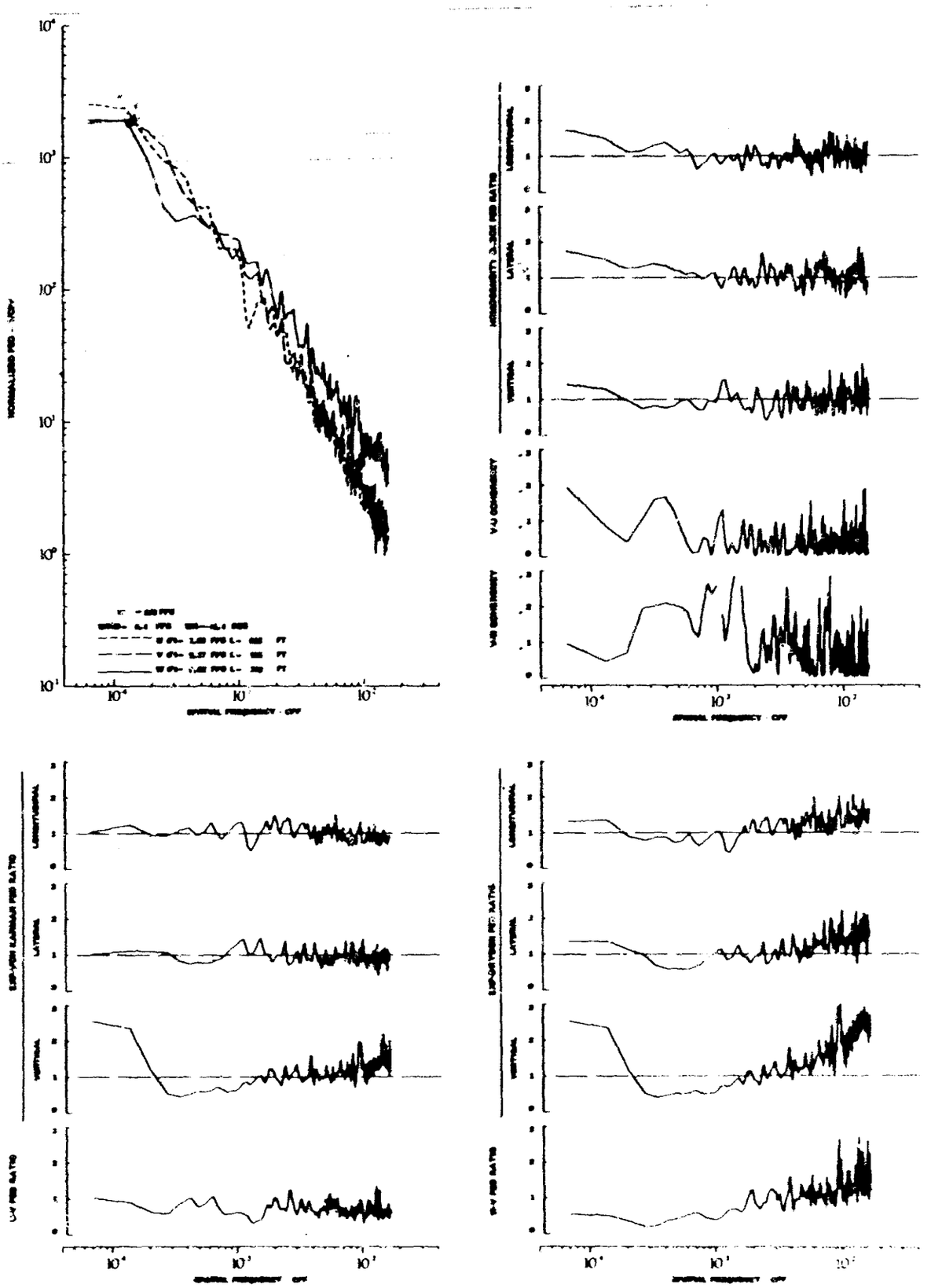


Turbulence Spectra Data For Test 244, Leg 8, Category 422313



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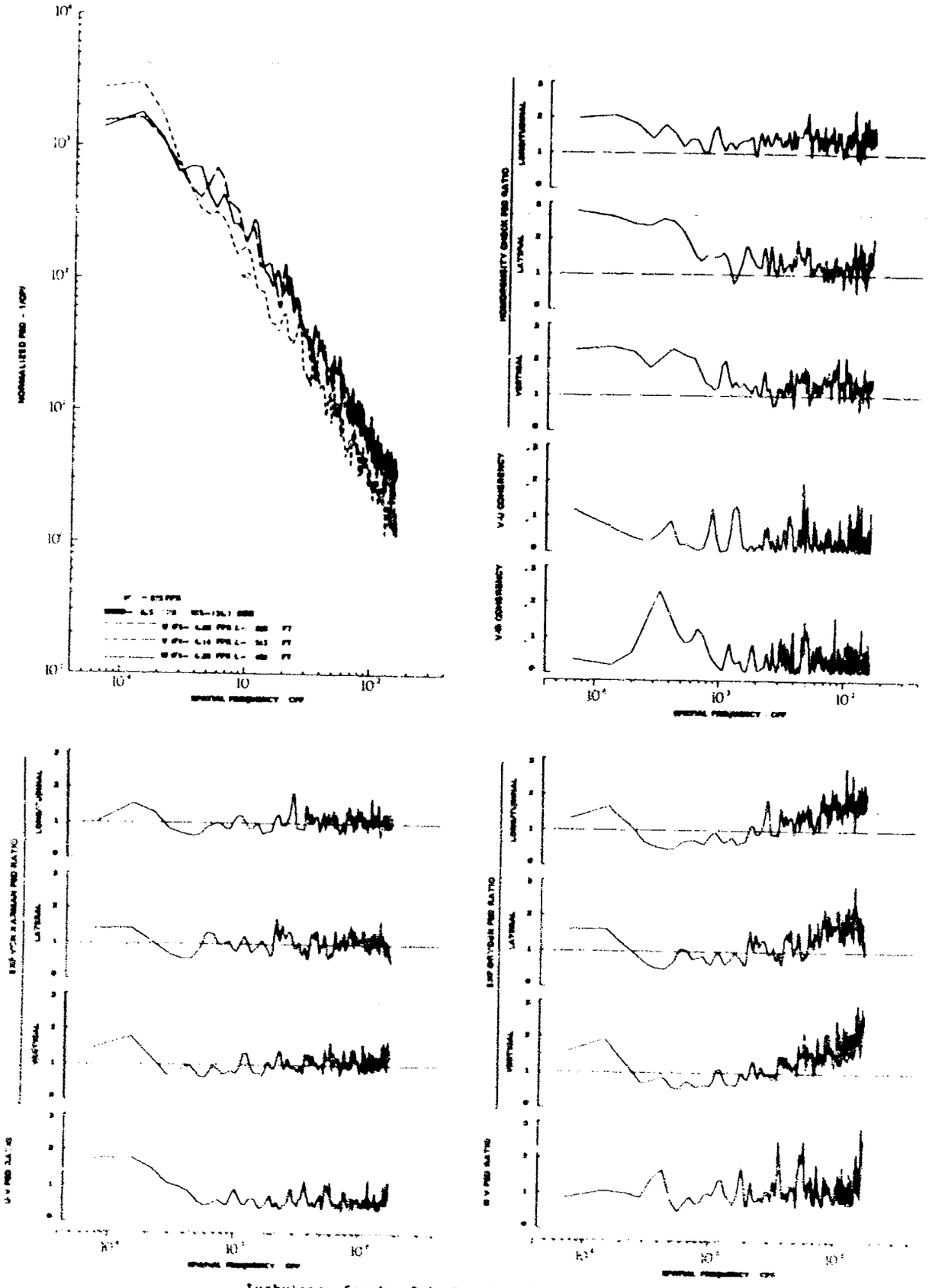

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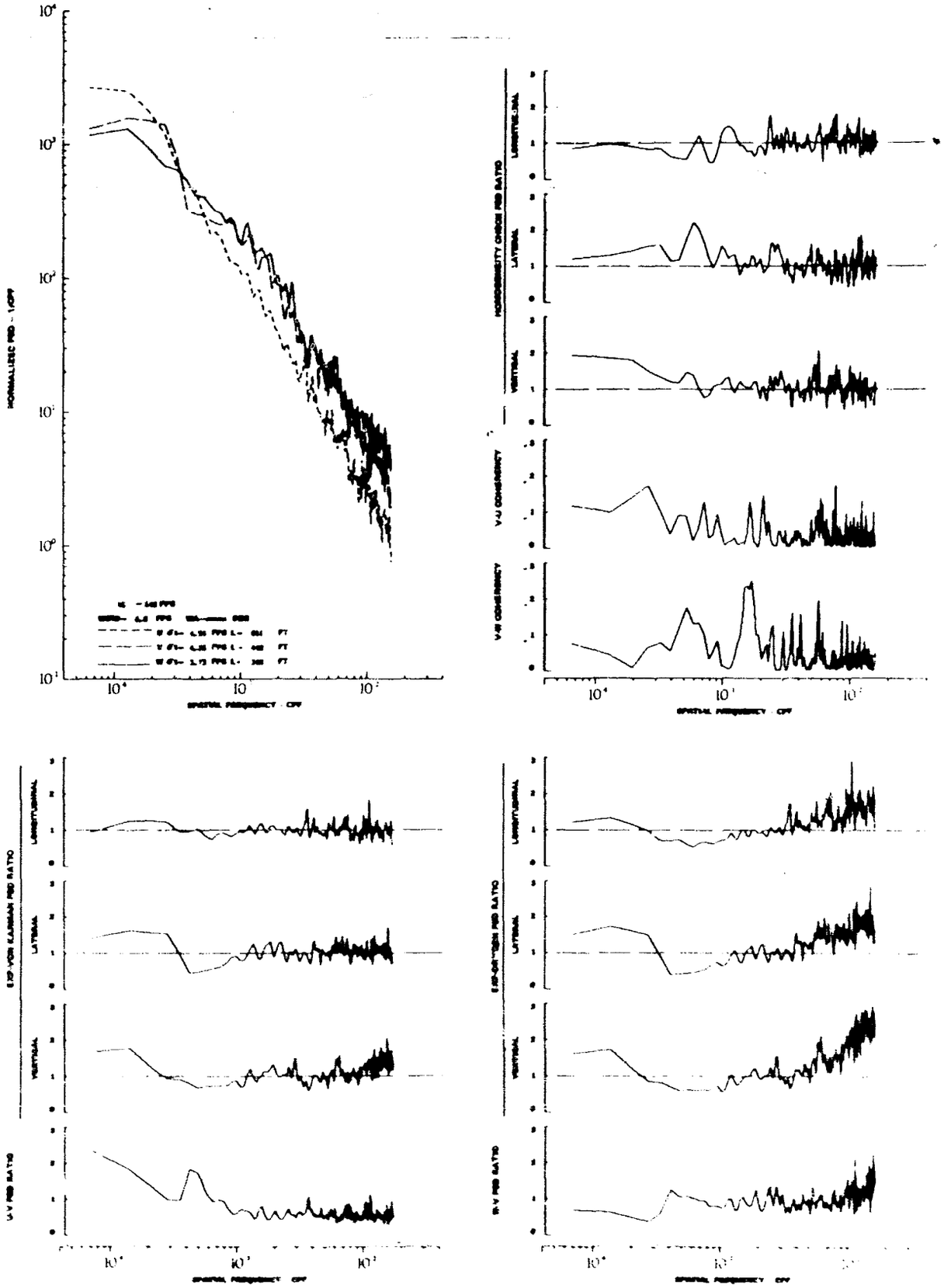

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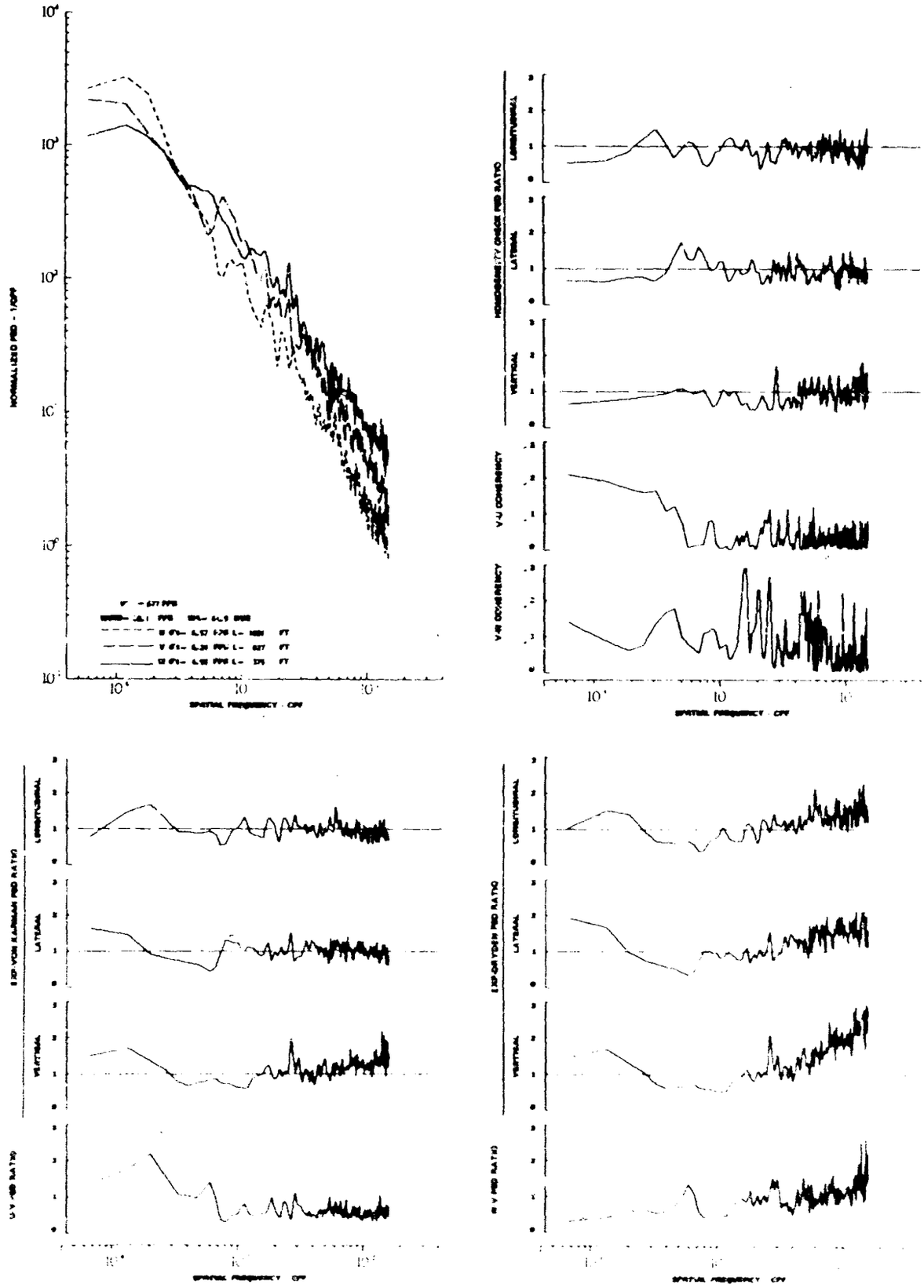

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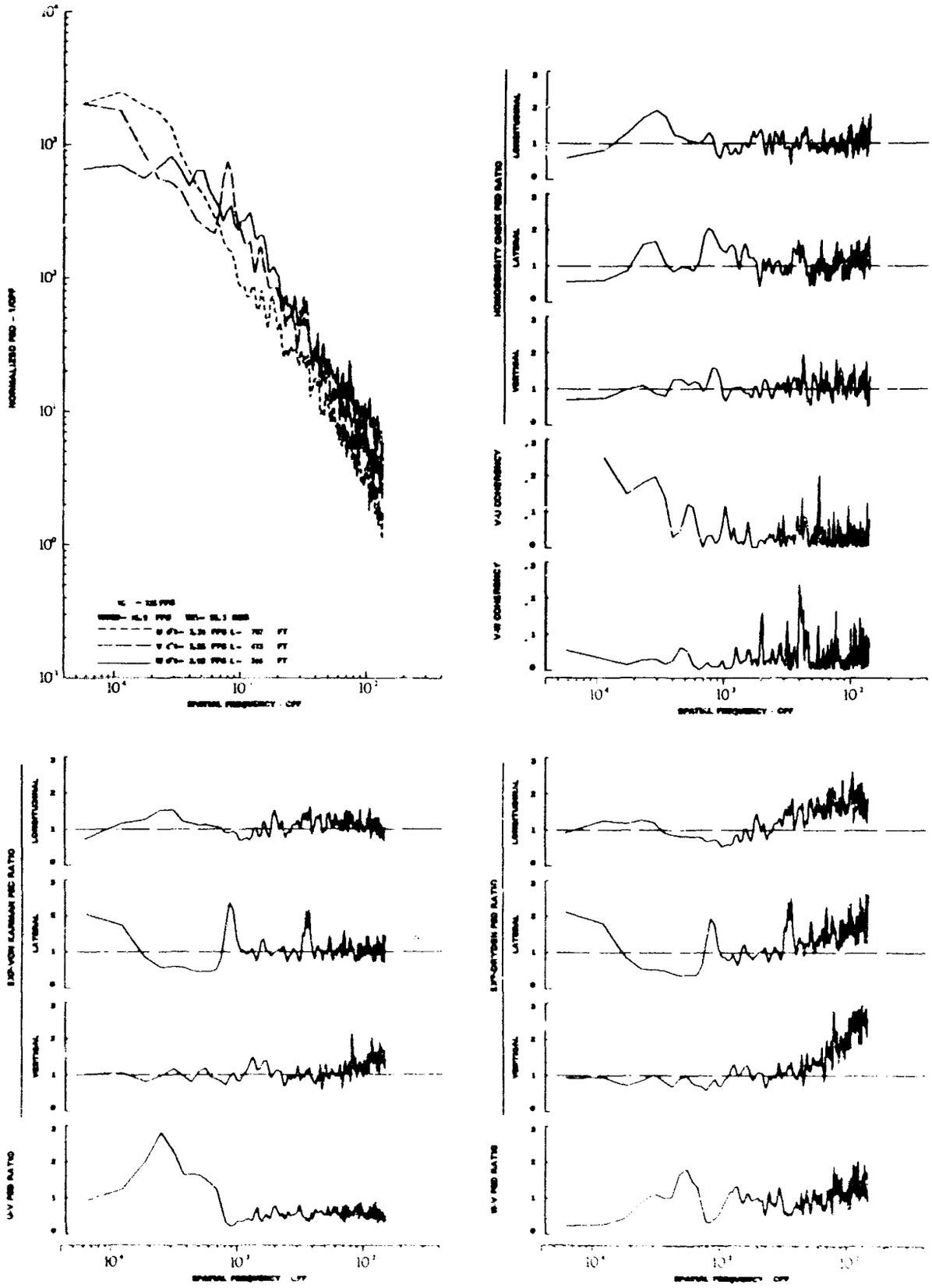

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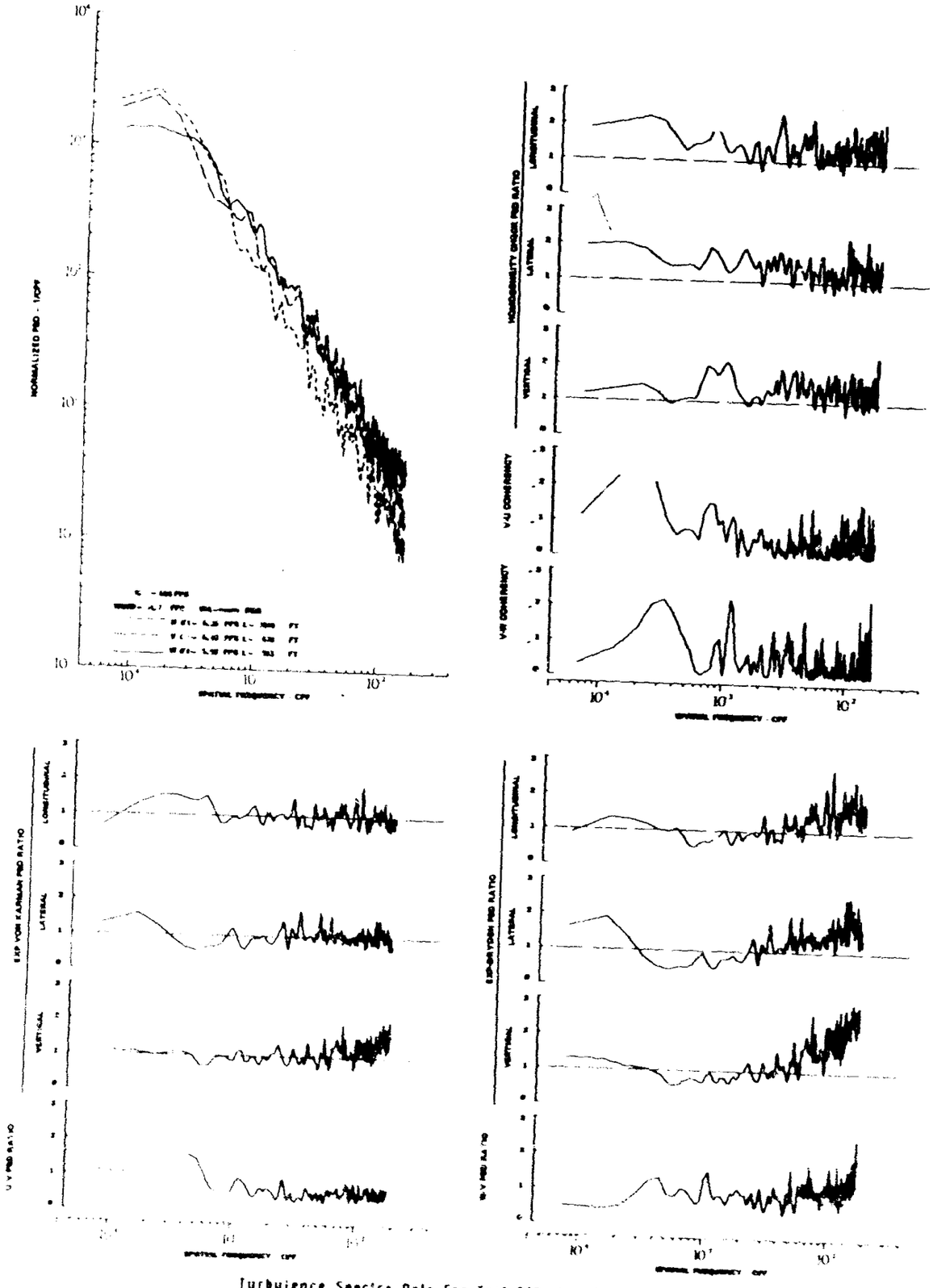

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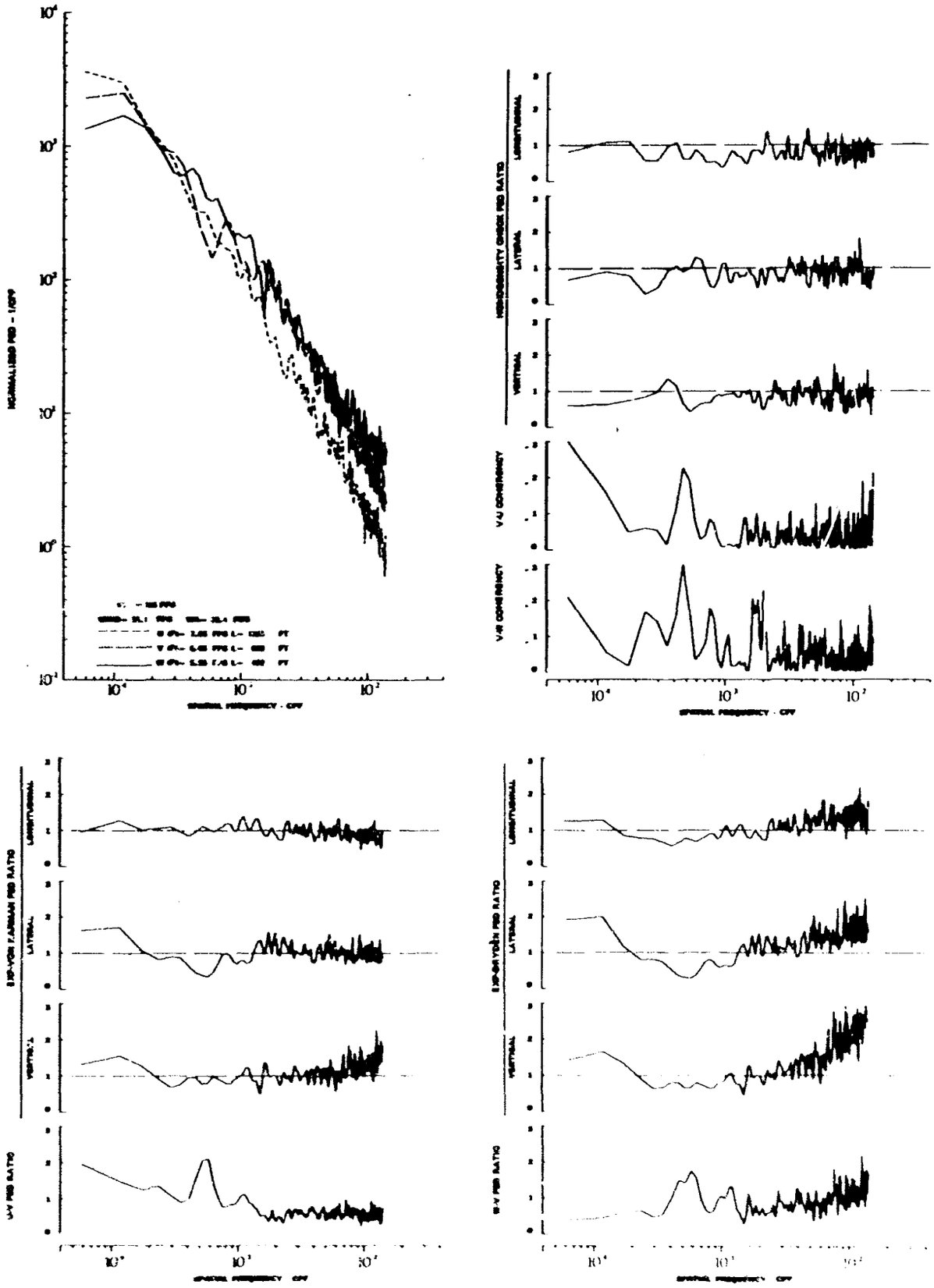

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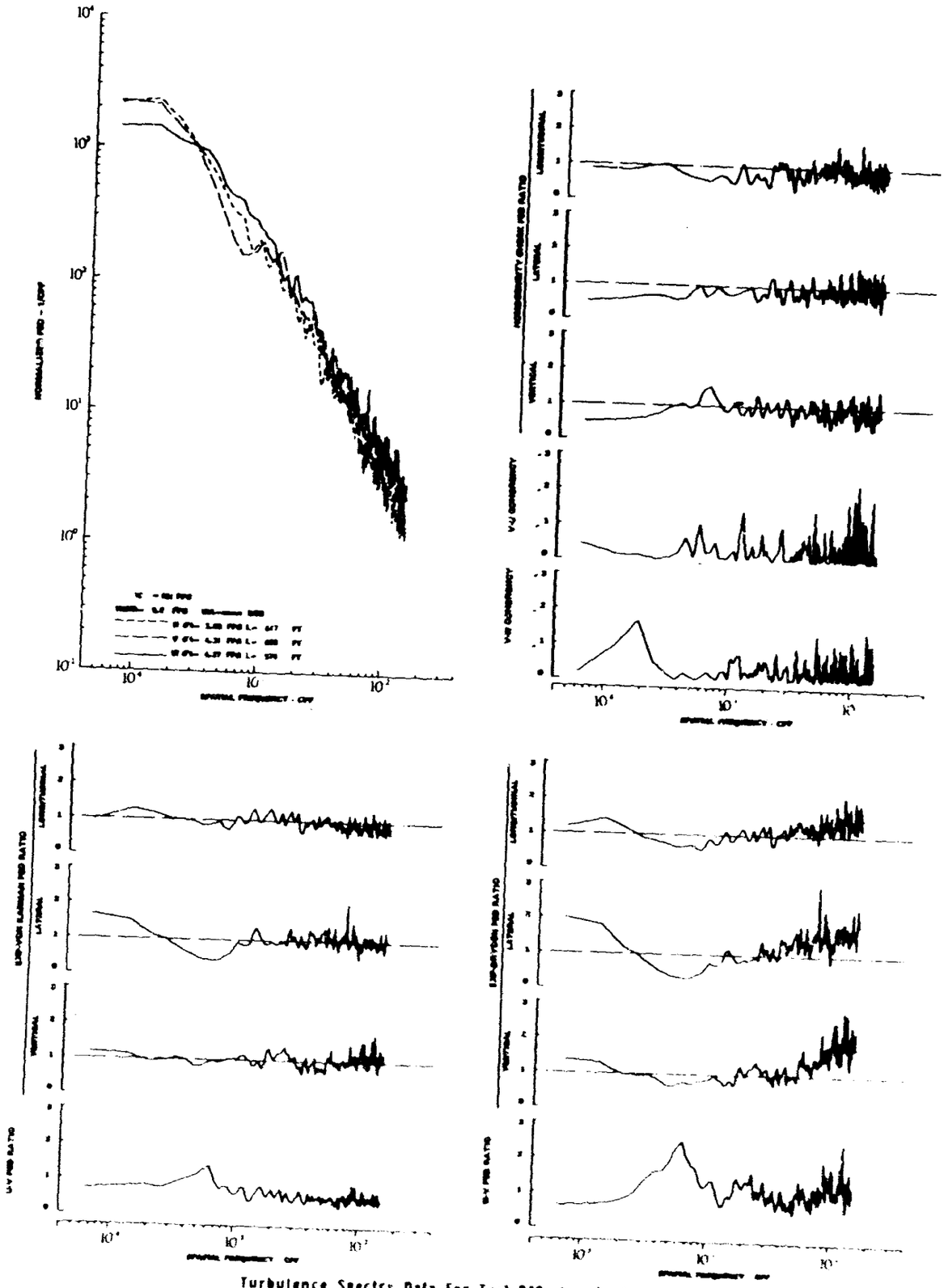
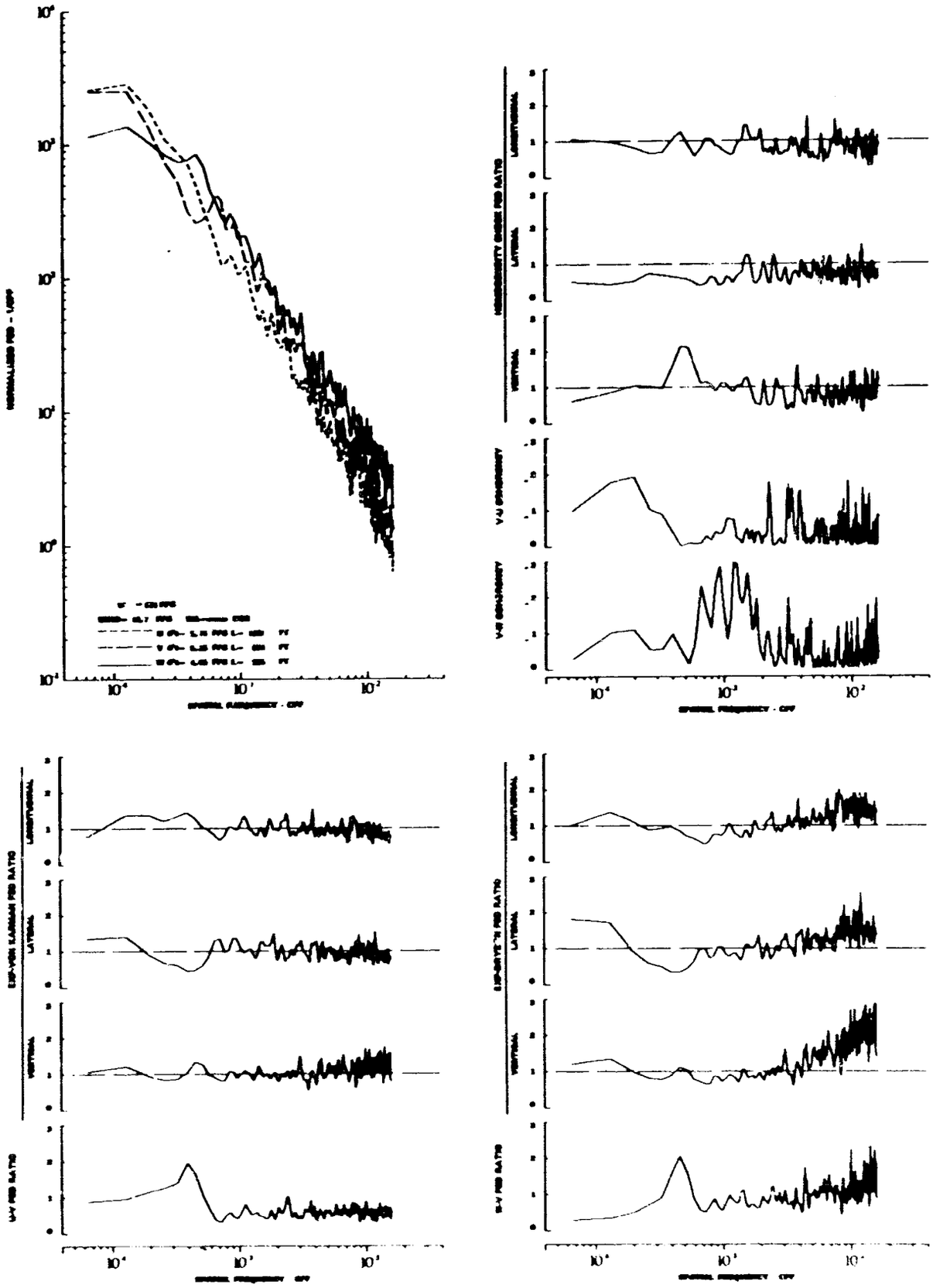


Turbulence Spectra Data For Test 248, Leg 8, Category 424213



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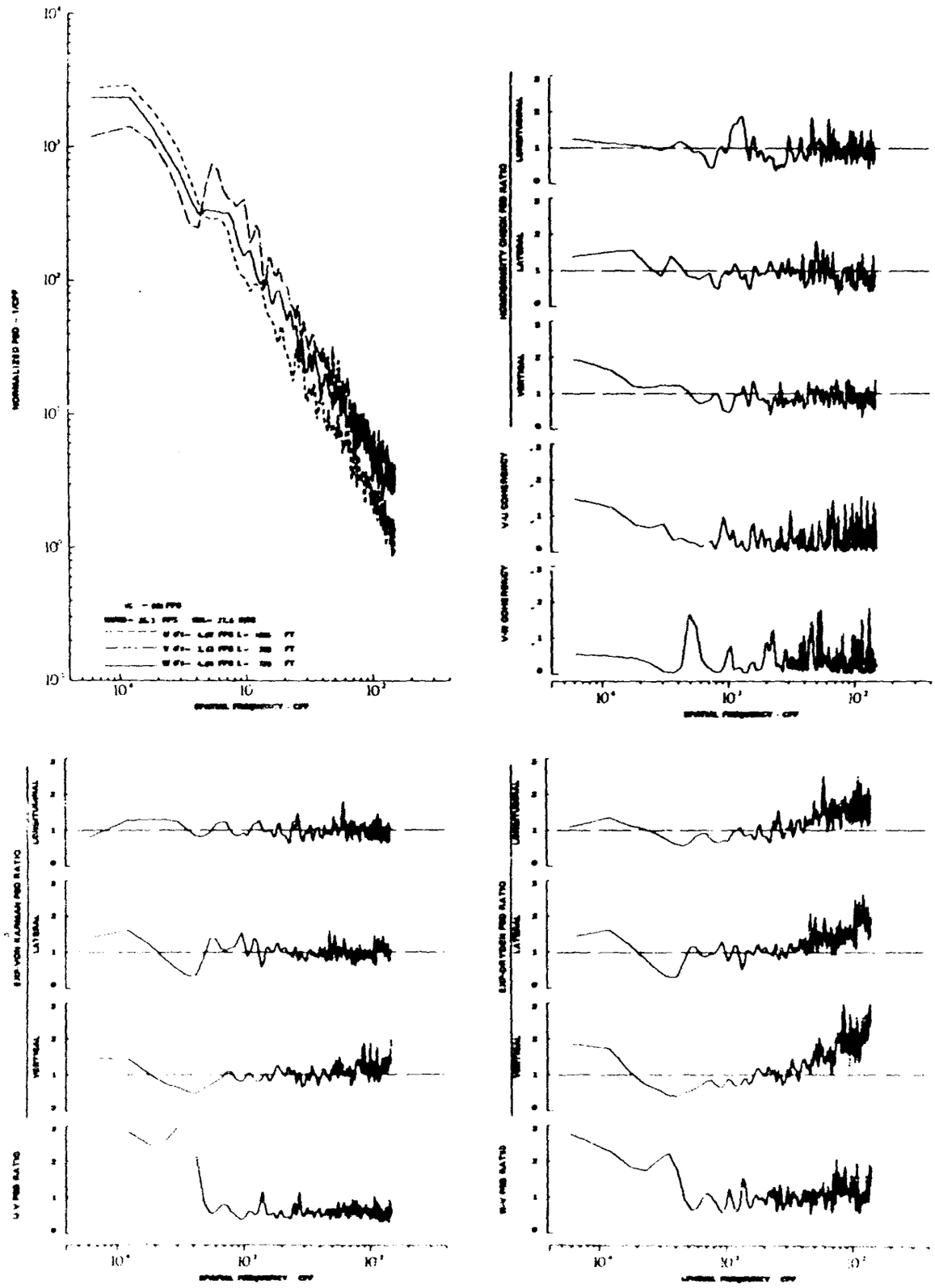

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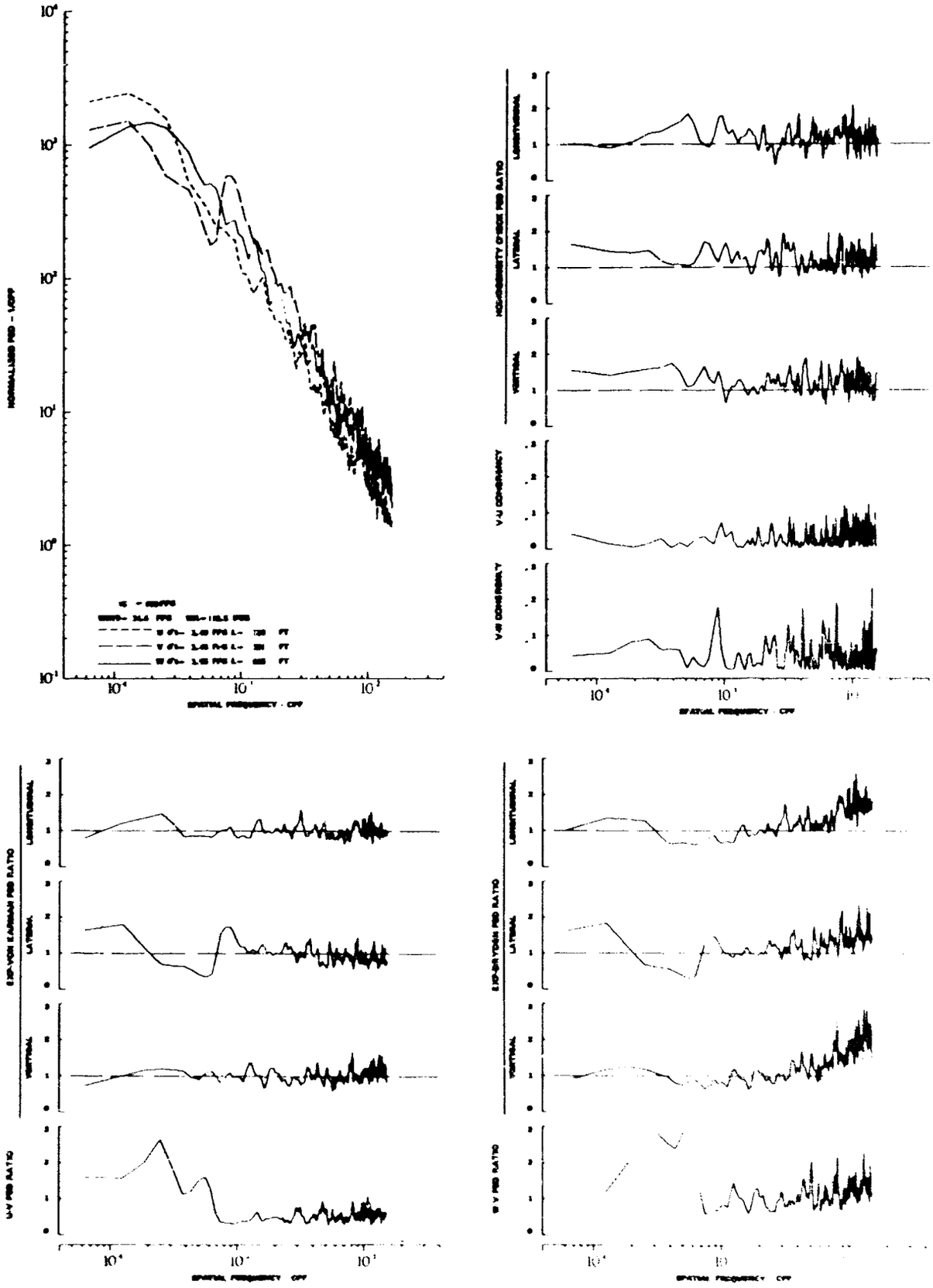
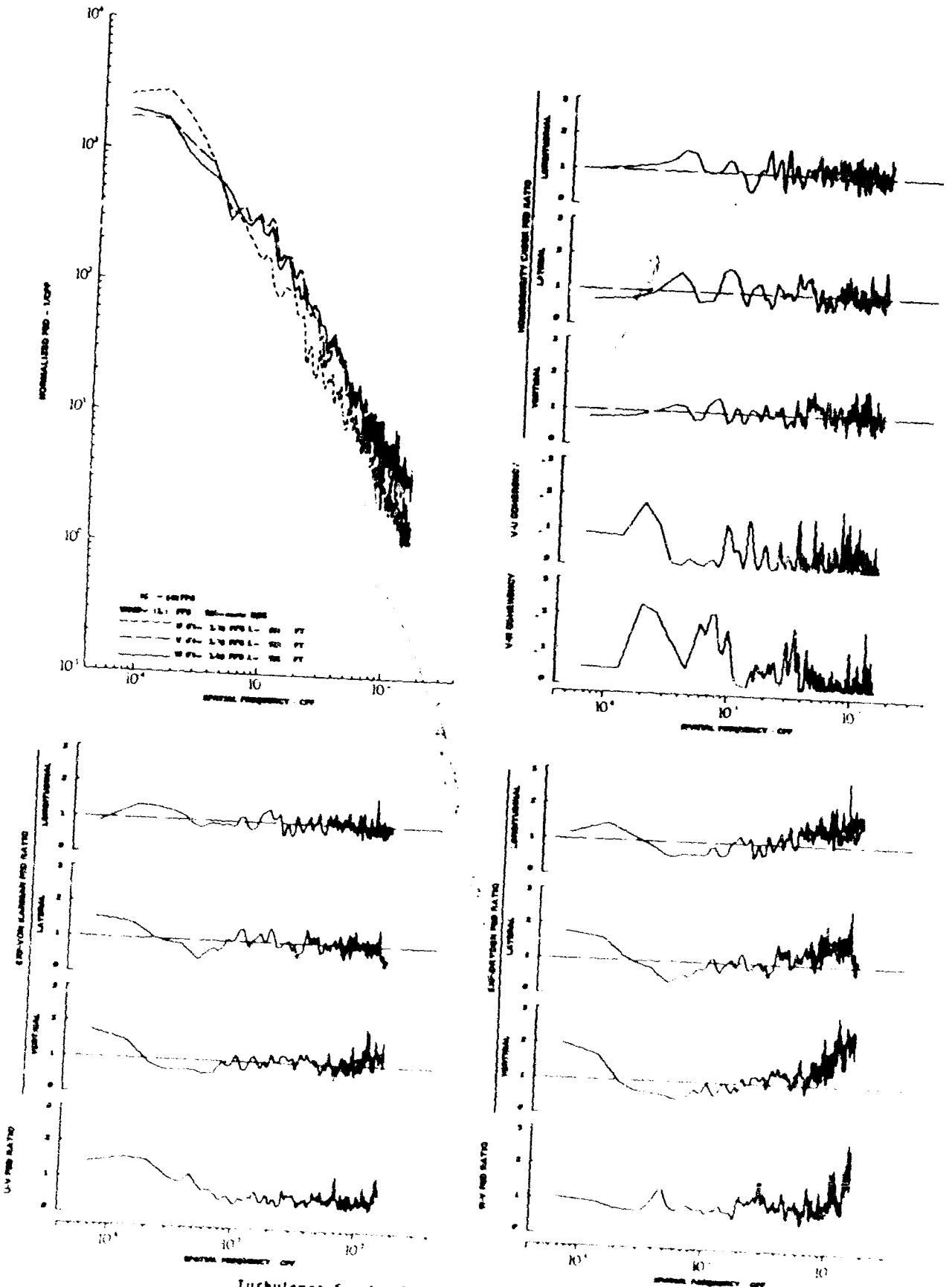
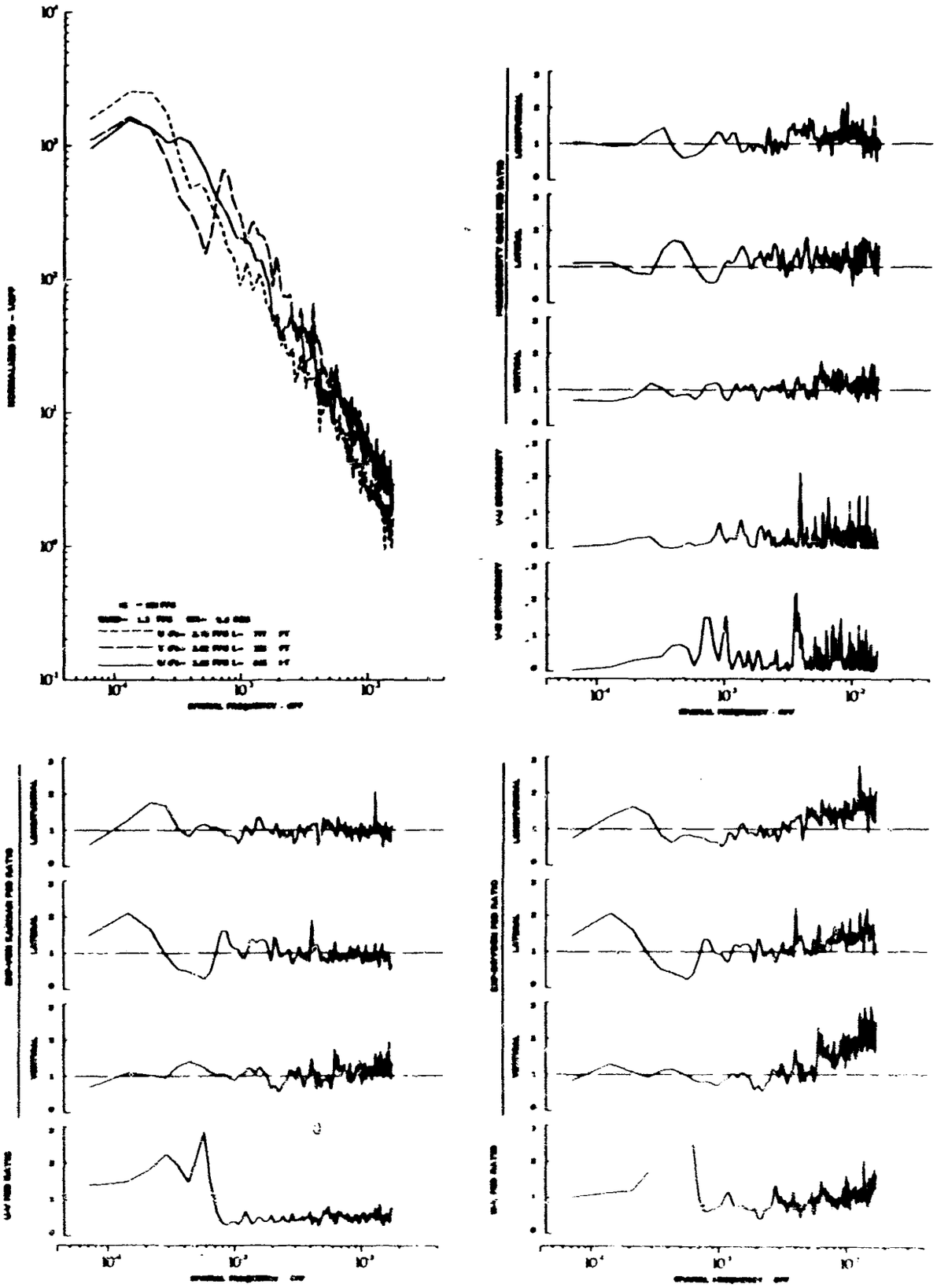


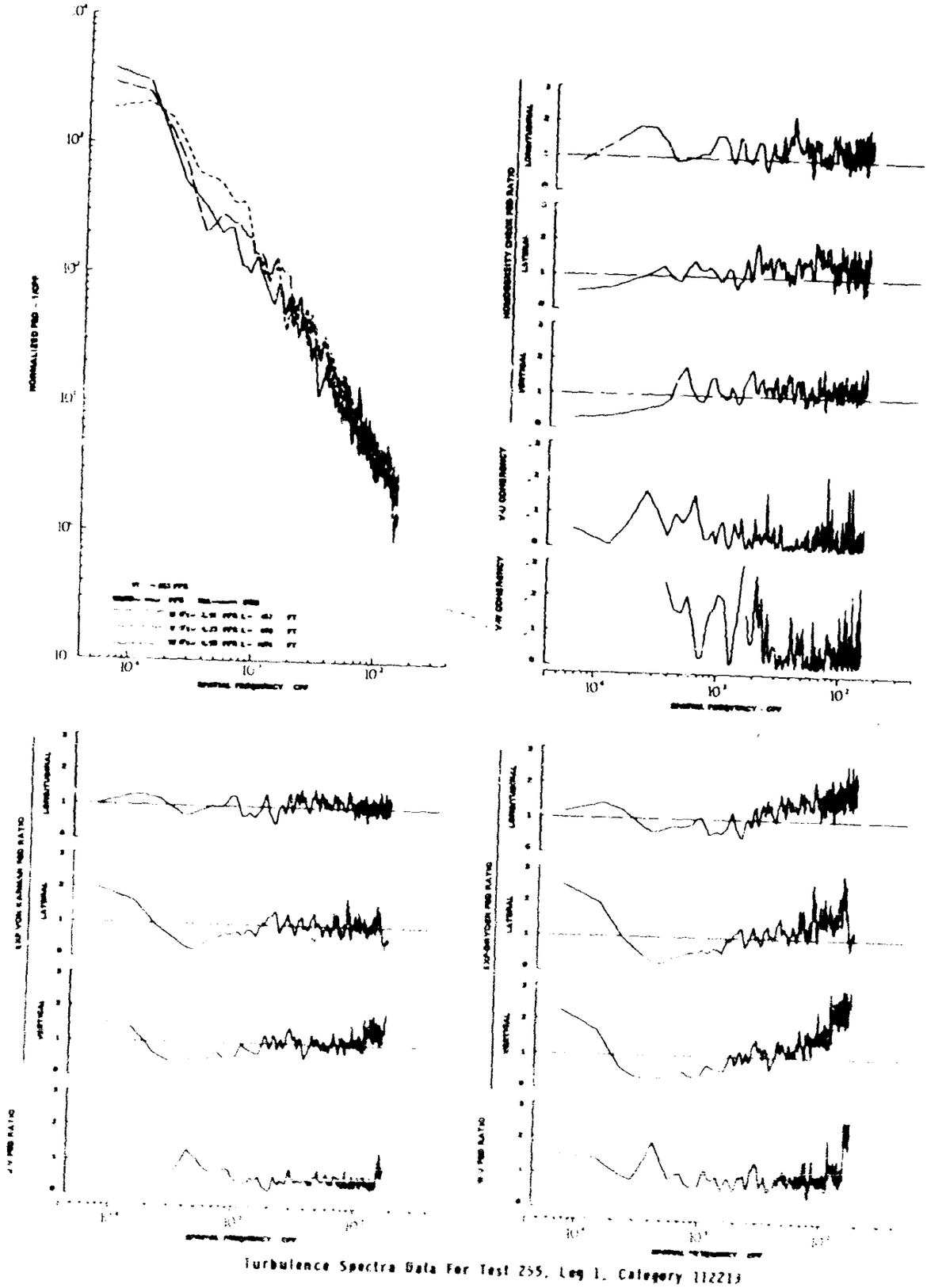
Turbulence Spectra Data For Test 252, Leg 8, Category 424213



Turbulence Spectra Data For Test 253, Leg 1, Category 122313



Turbulence Spectra Data For Test 253, Log 7, Category 122313



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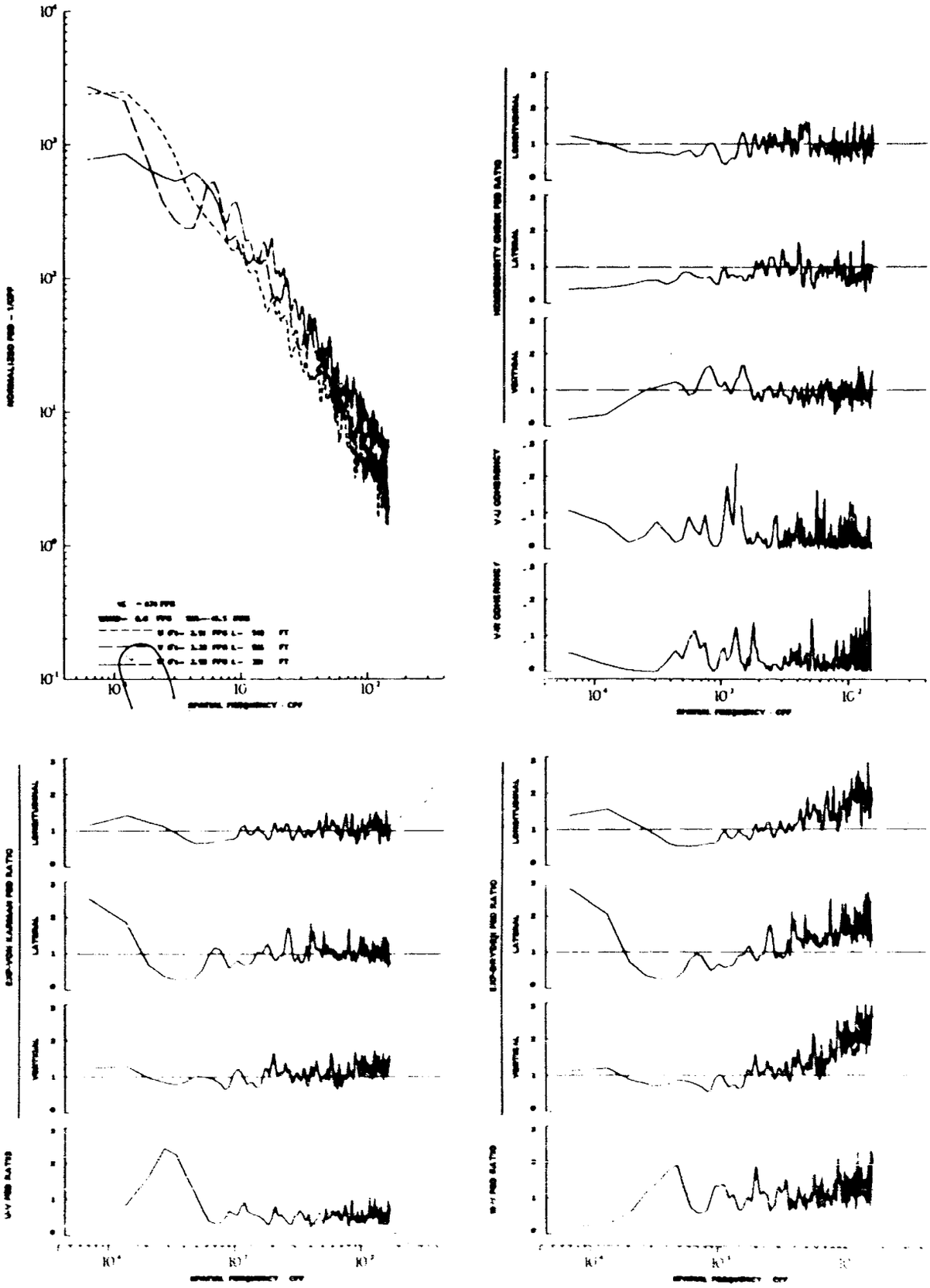

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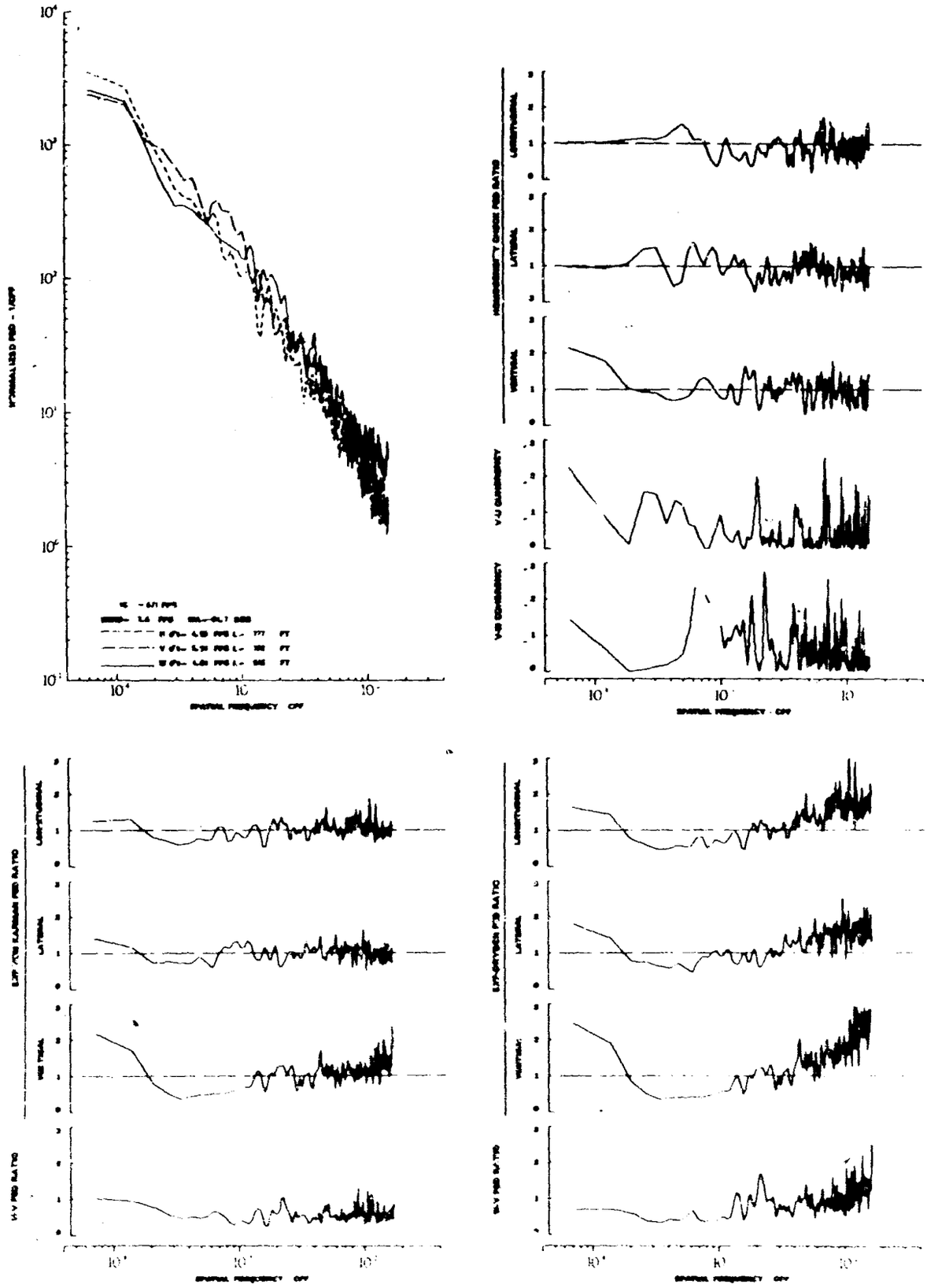
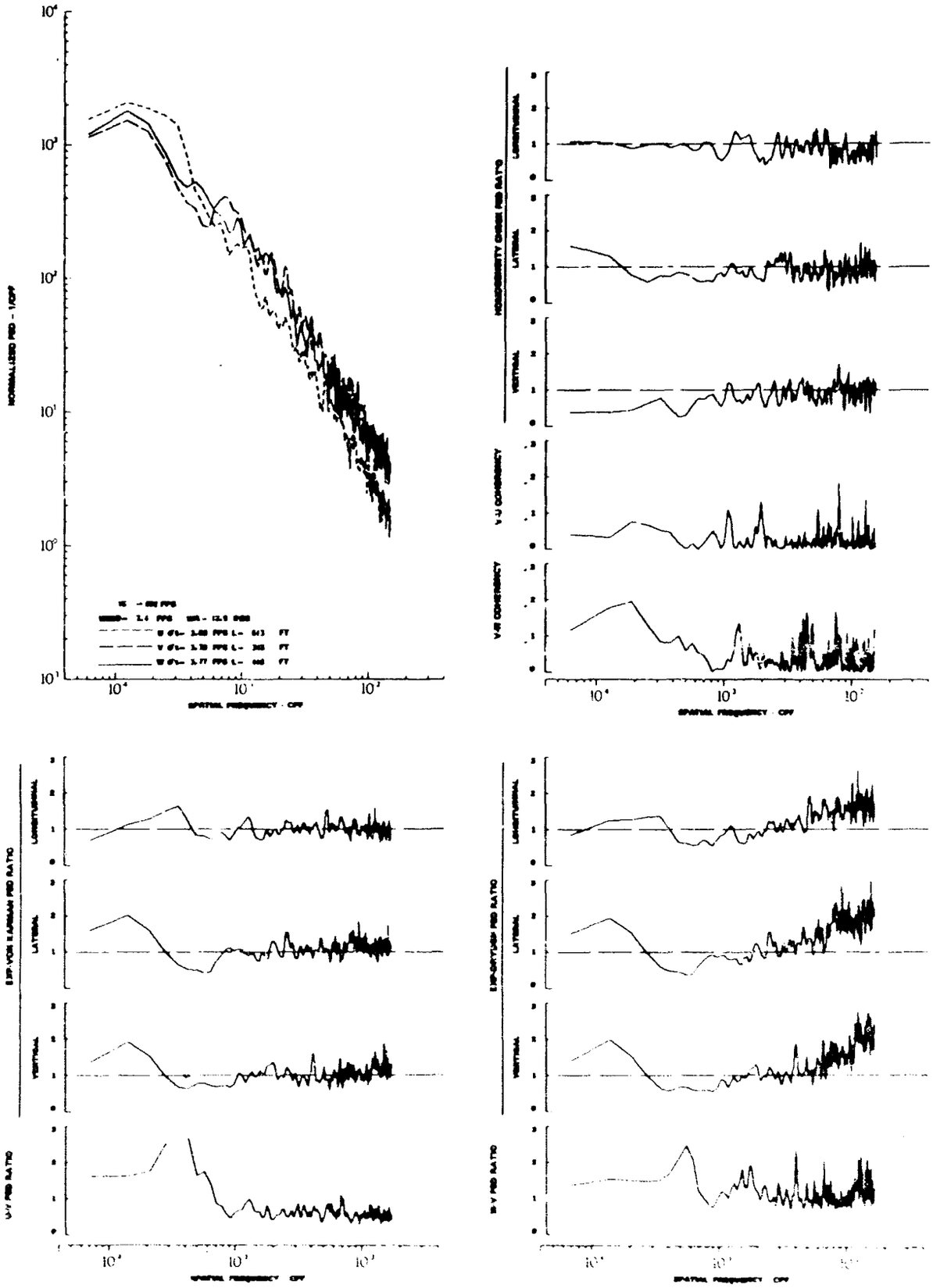


Turbulence Spectra Data For Test 255, Leg 5, Category 112213



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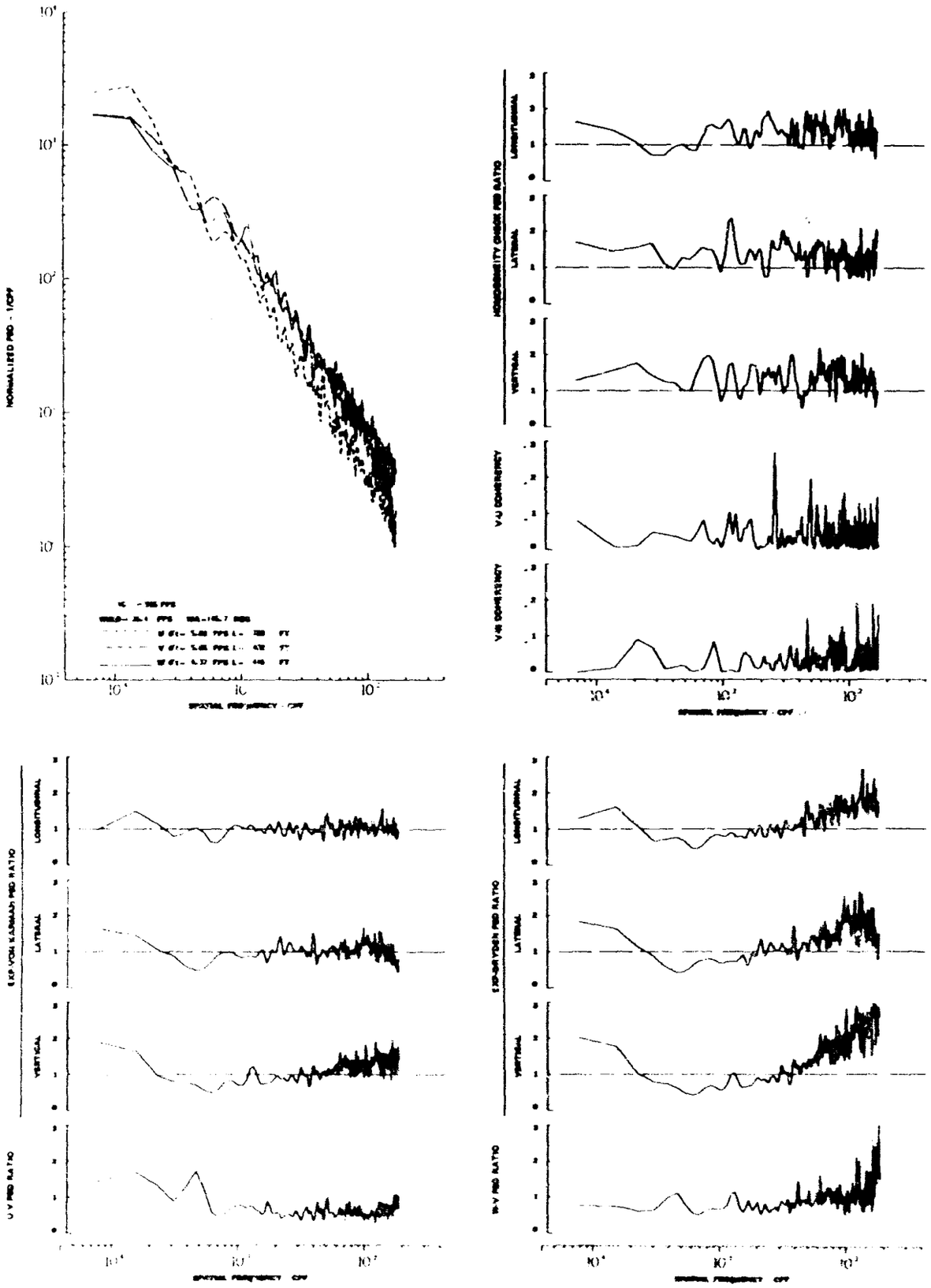
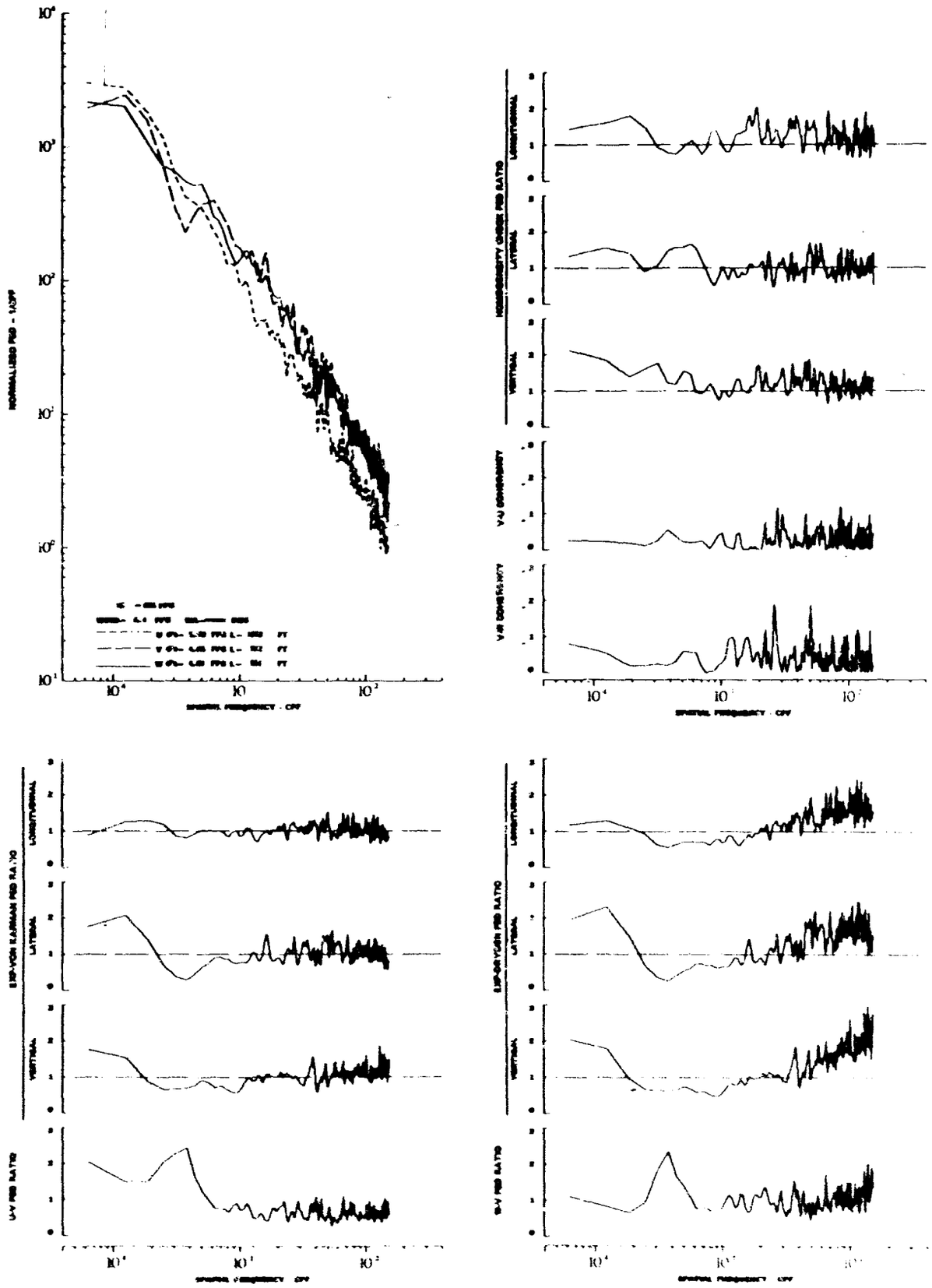
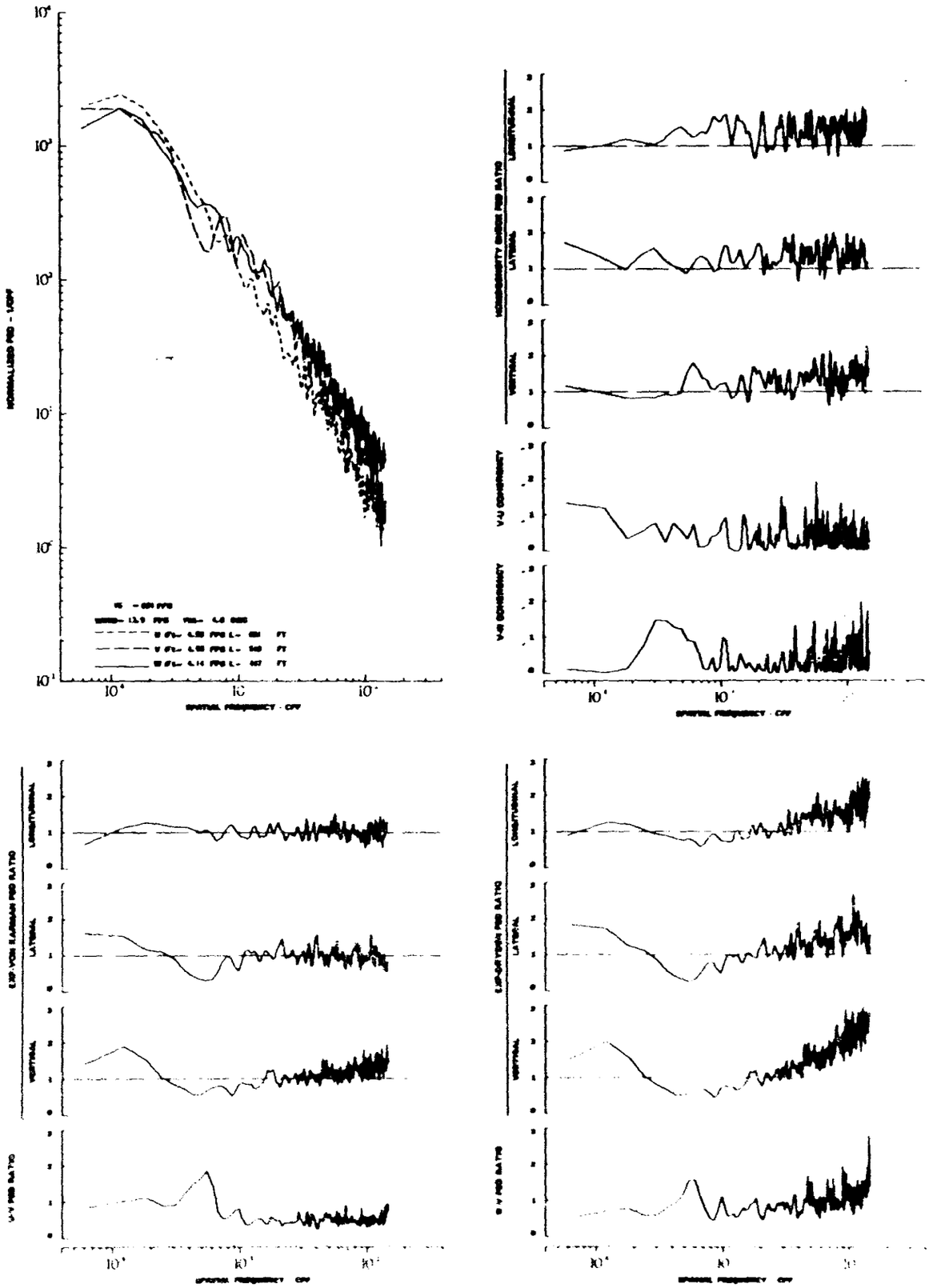


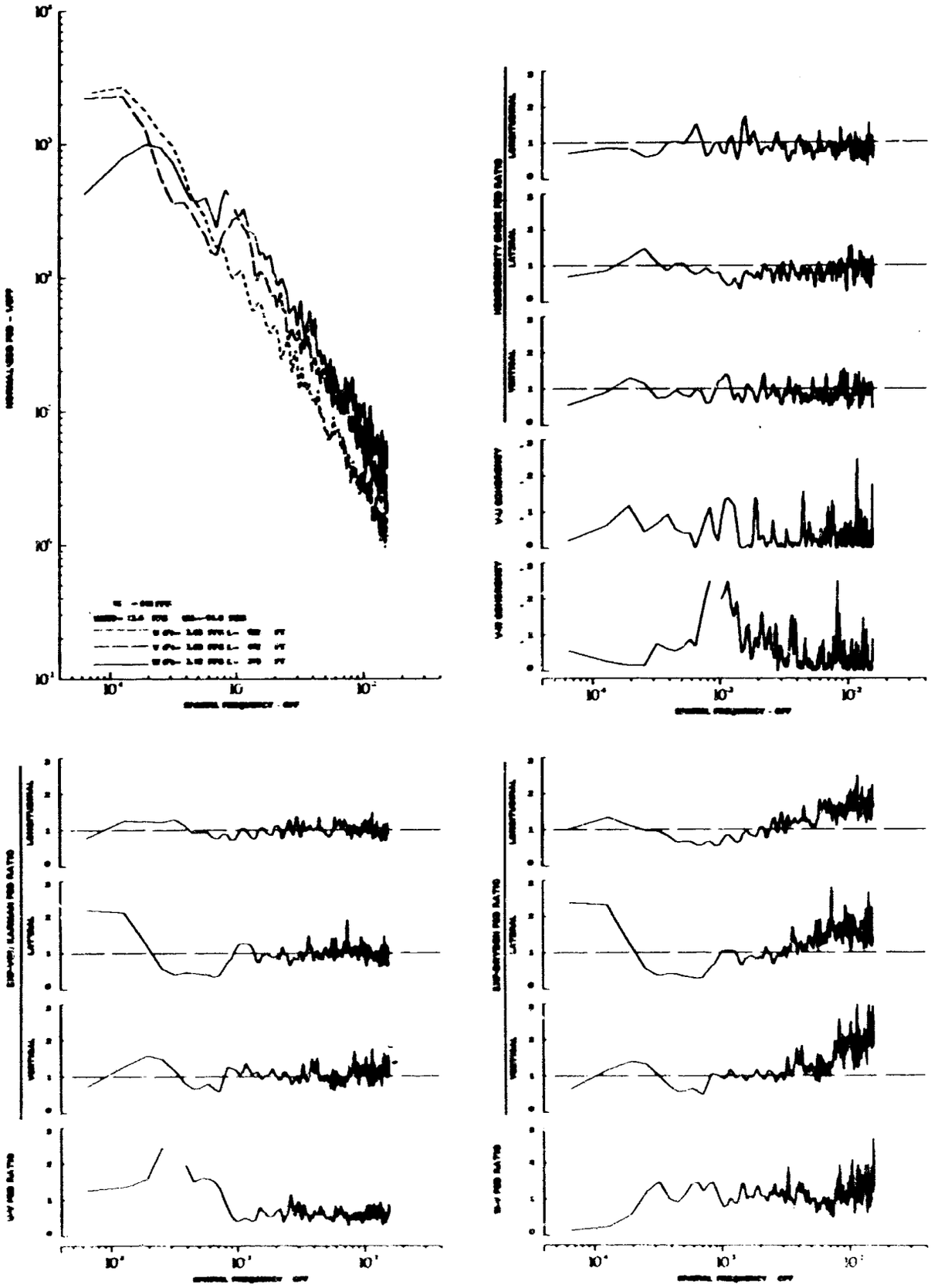
Turbulence Spectra Data For Test 256, Leg 2, Category 113313



Turbulence Spectra Data For Test 256, Leg 4, Category 113313



Turbulence Spectra Data For Test 256, Leg 6, Category 114313



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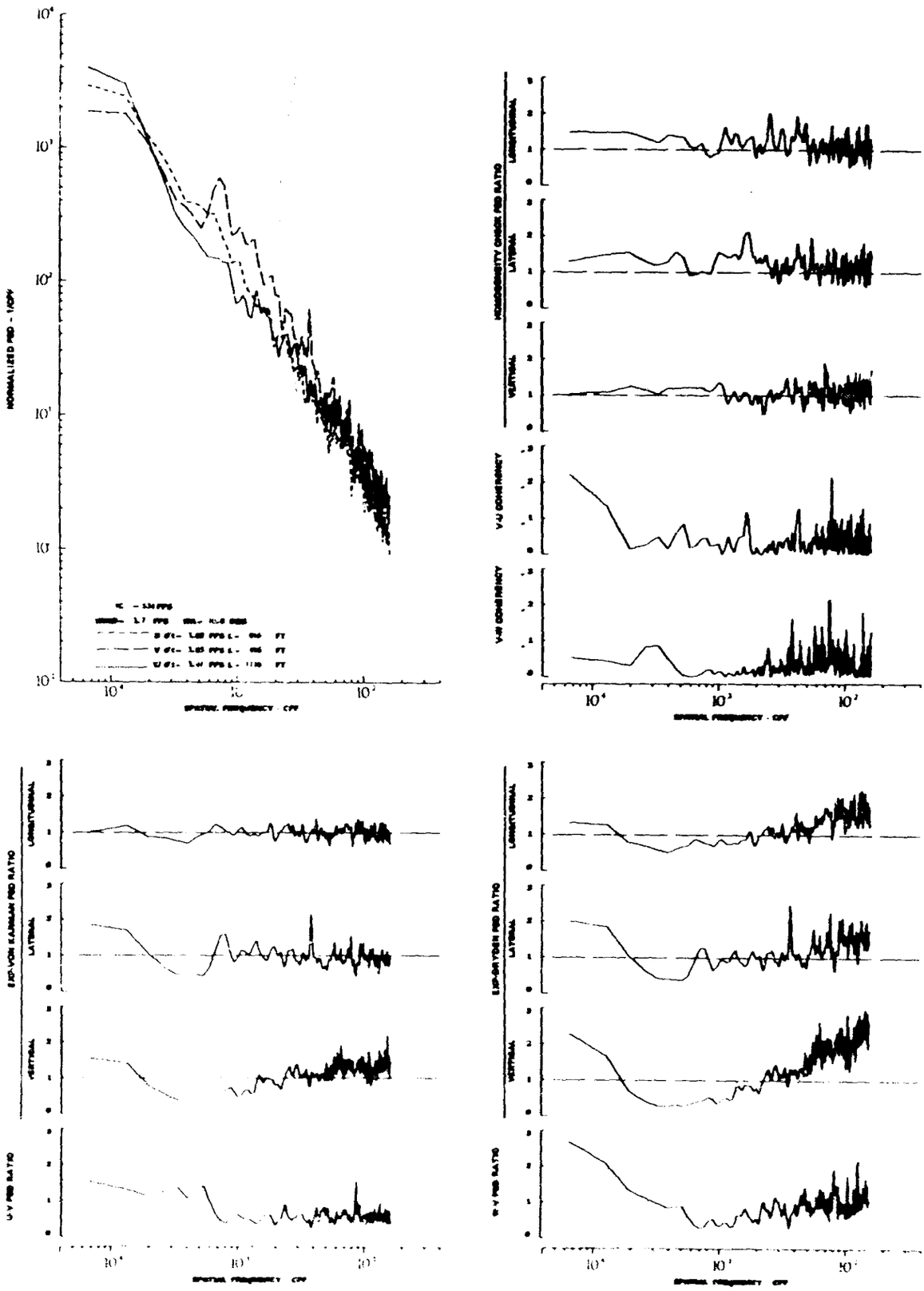

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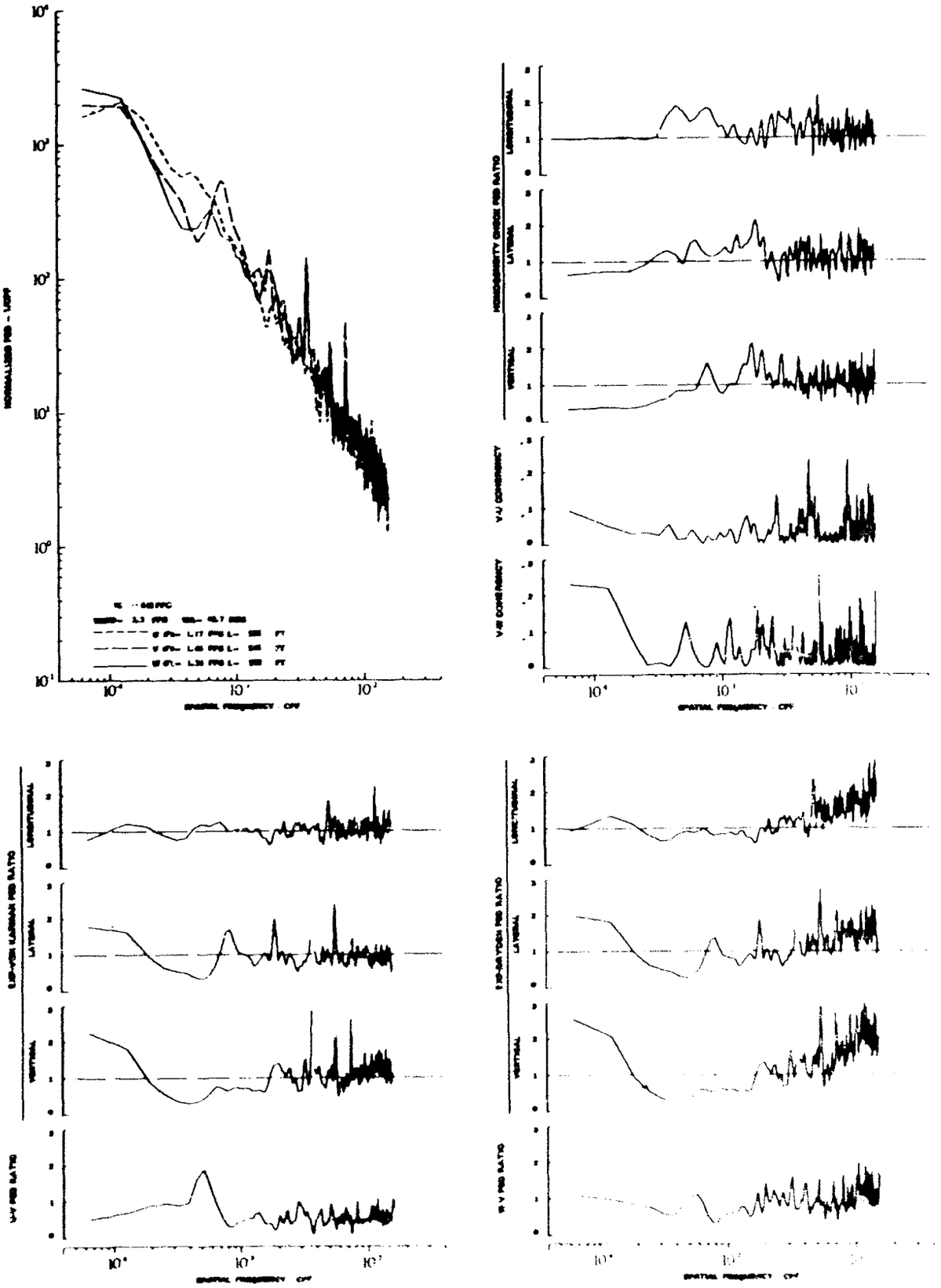
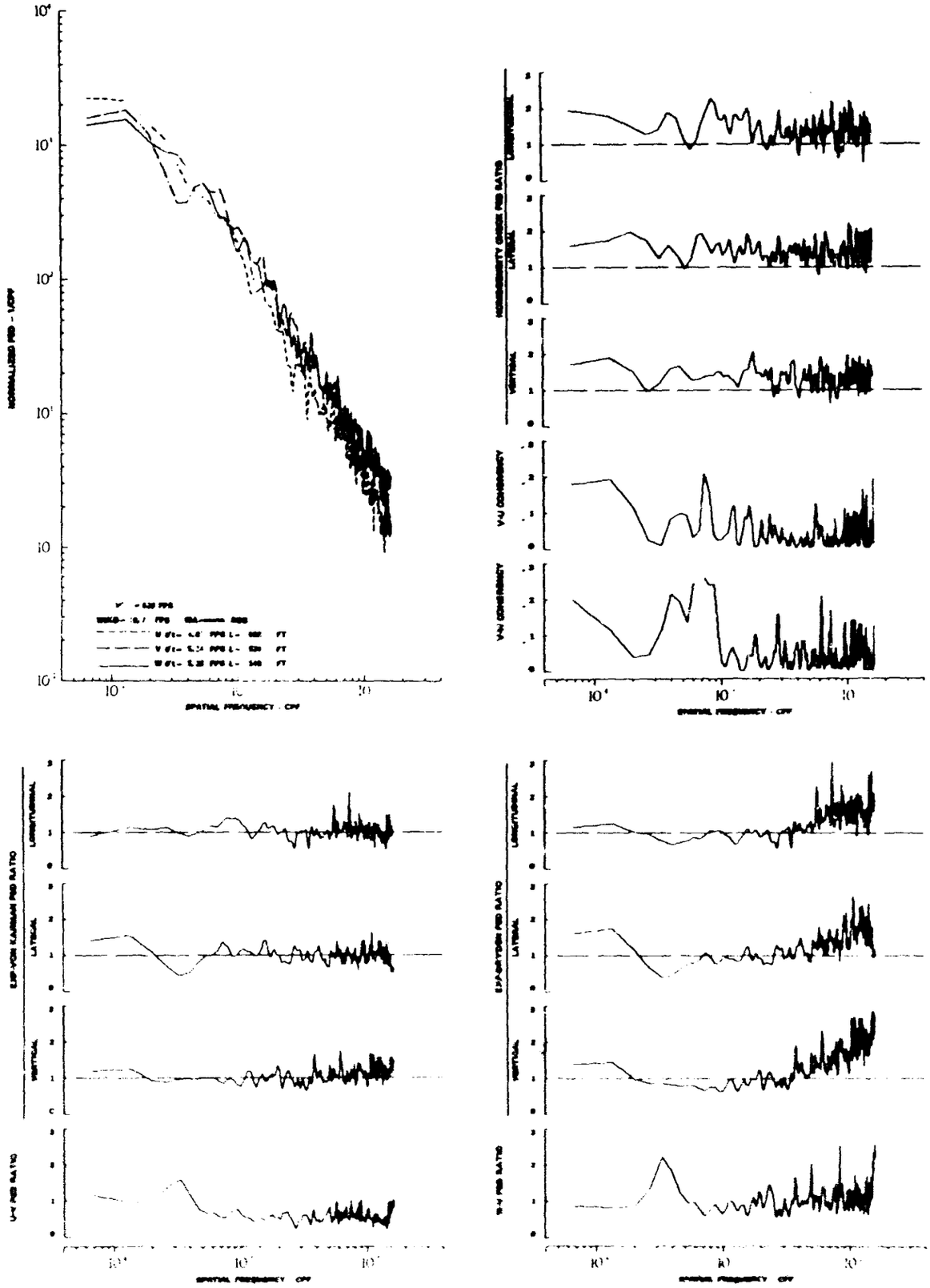
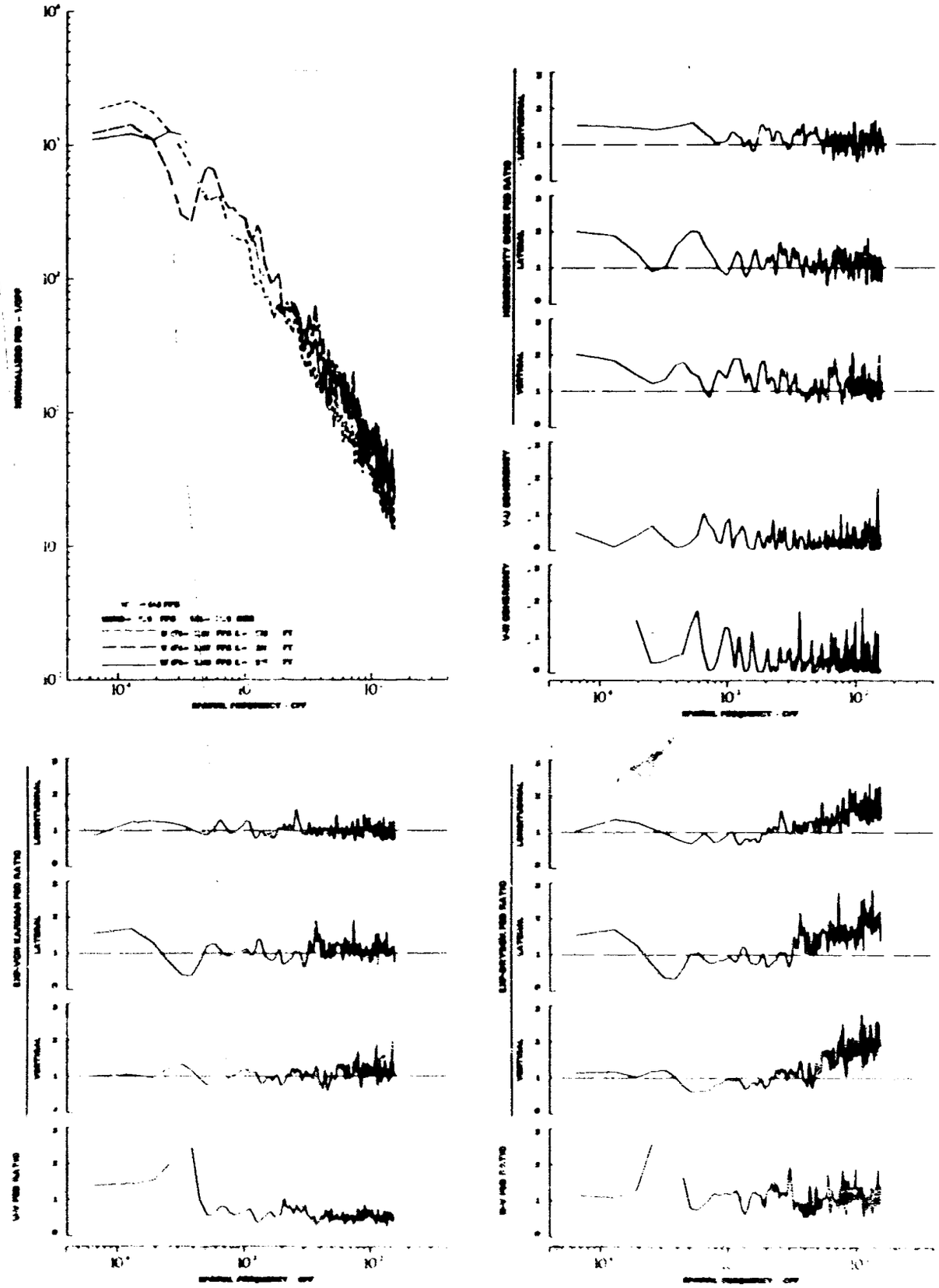


Turbulence Spectra Data For Test 257, Leg 7, Category 122113



Turbulence Spectra Data for Test 258, Leg 2, Category 124213



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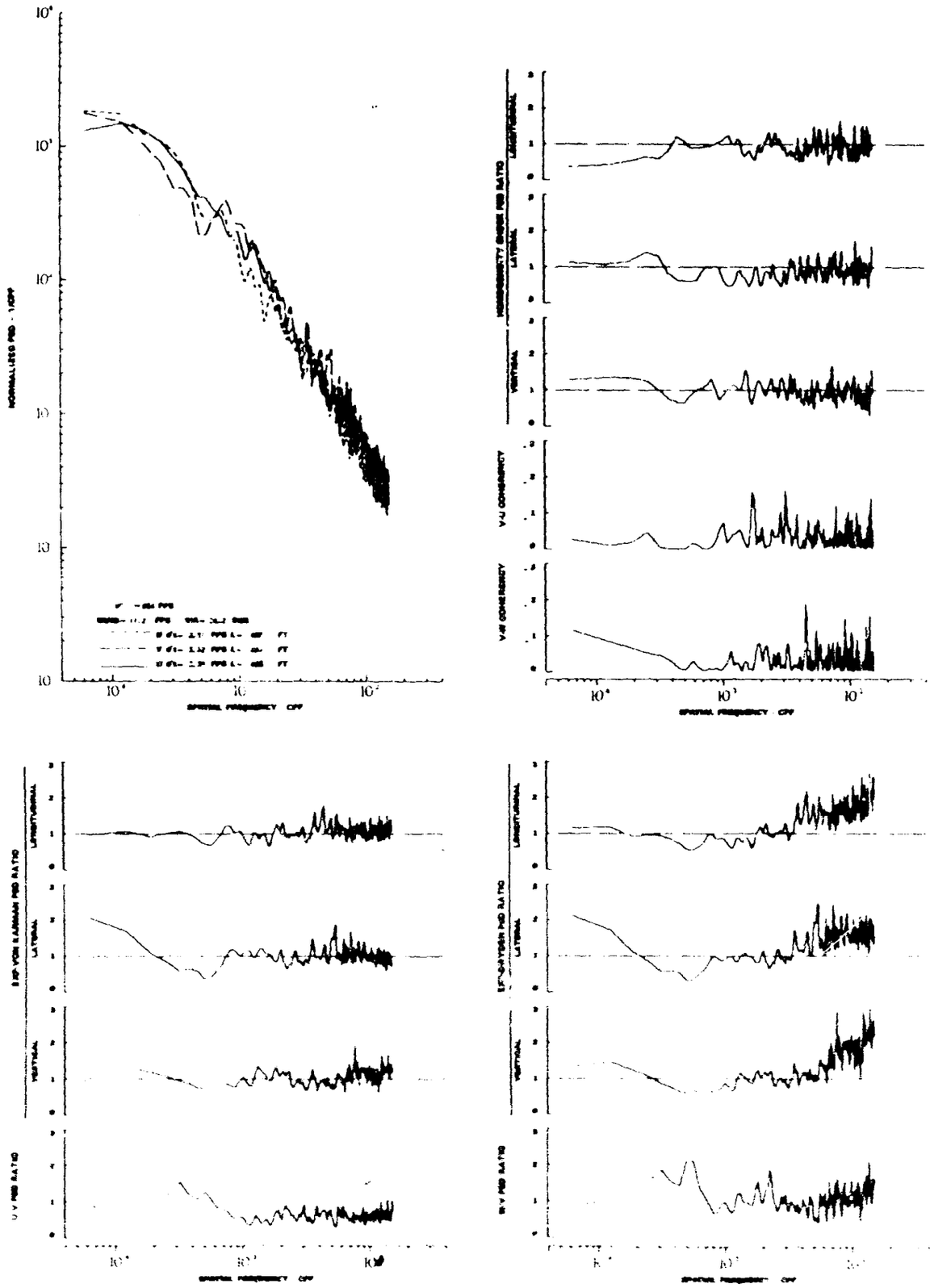

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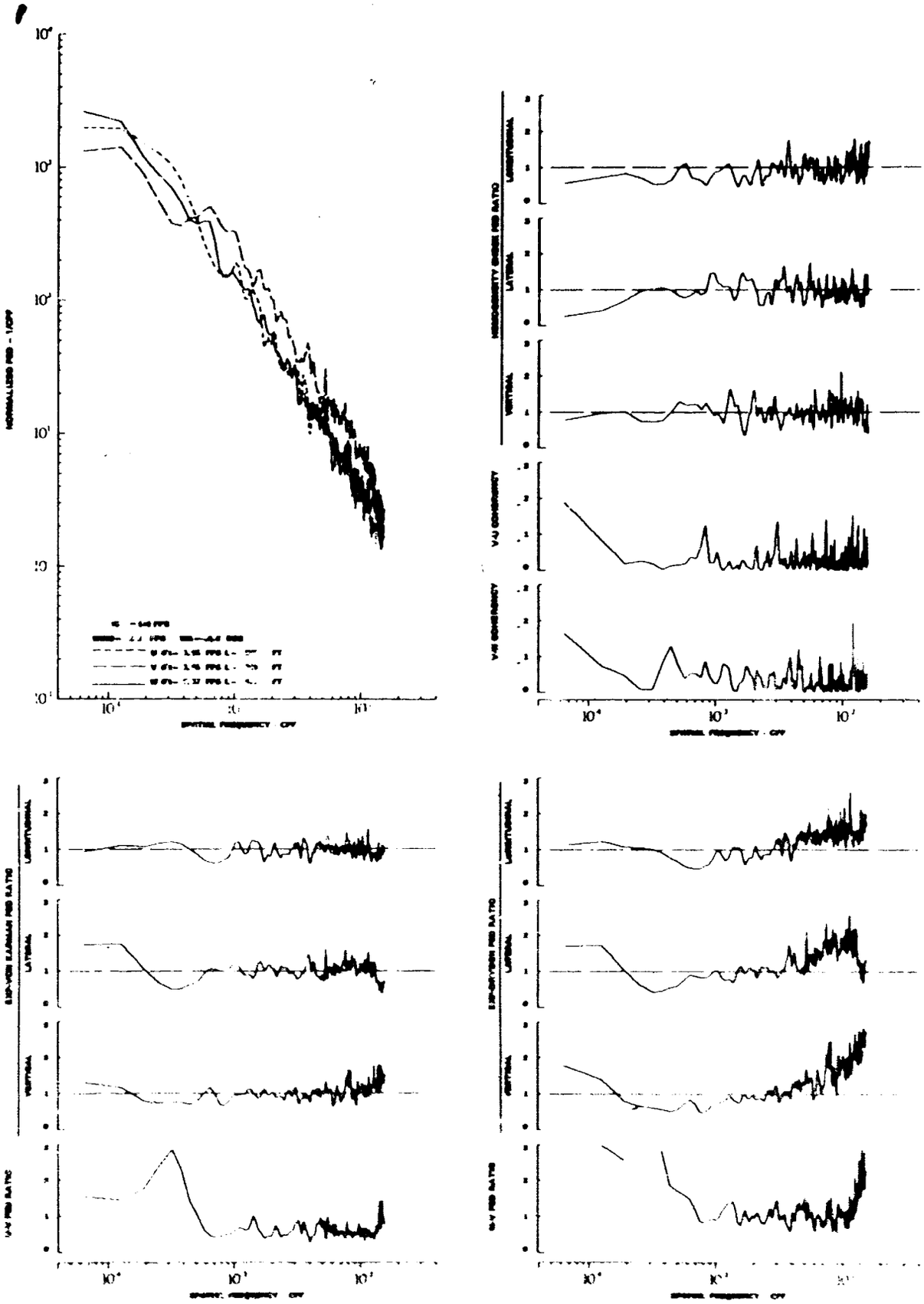

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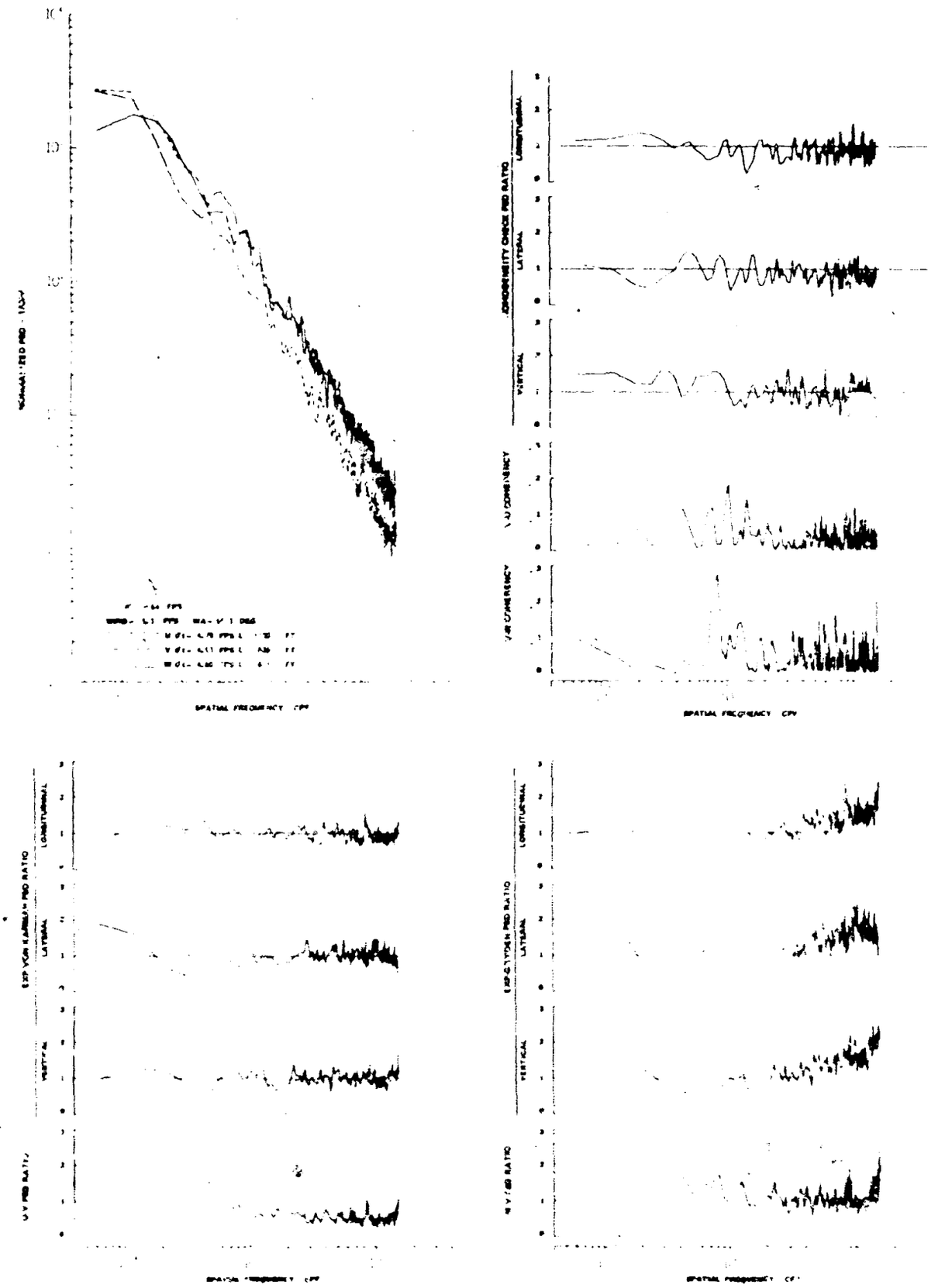
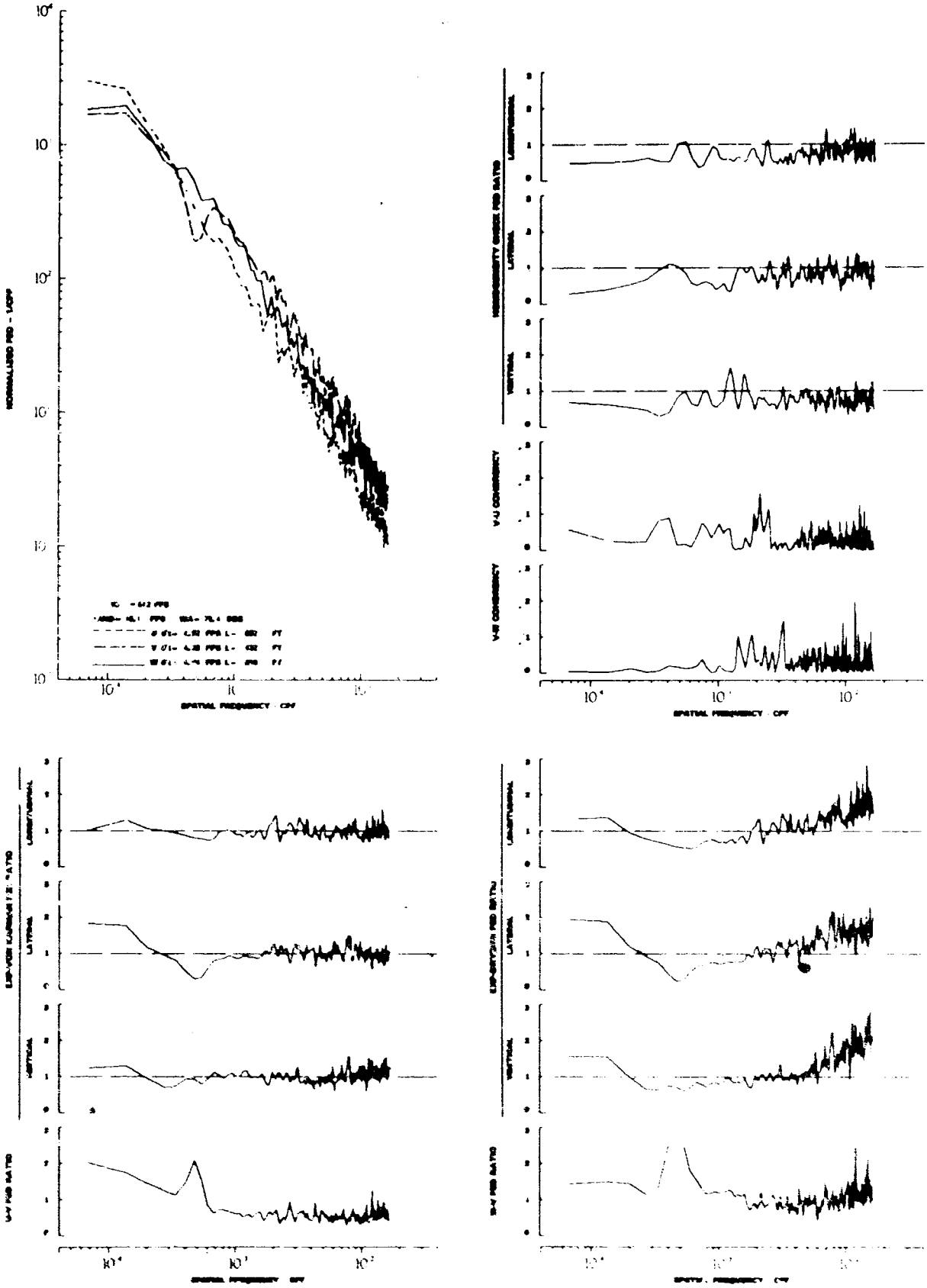
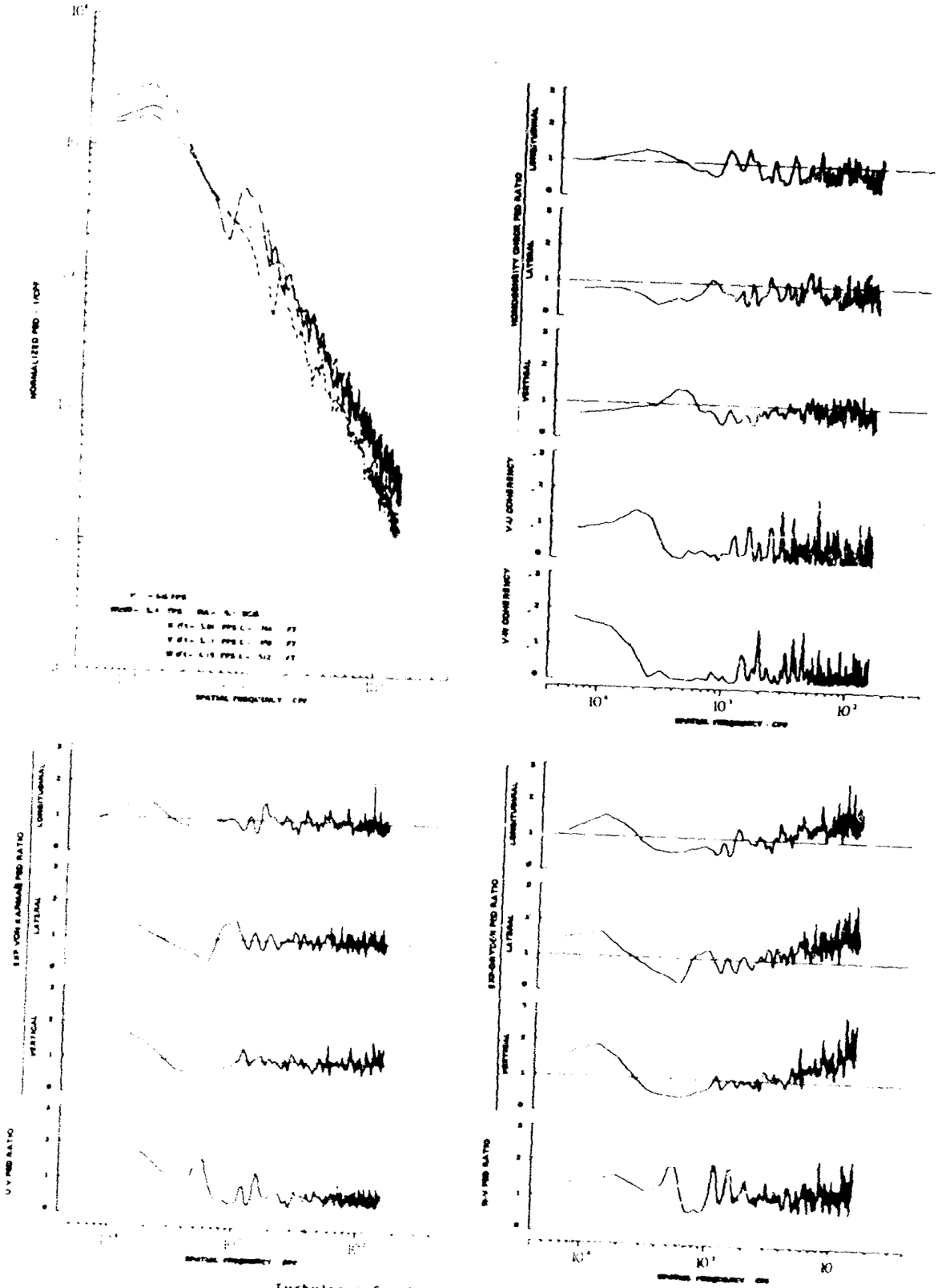


Turbulence Spectra Data For Test 259, Leg 3, Category (2431)



Turbulence Spectra Data For Test 259, Leg 5, Category 123313



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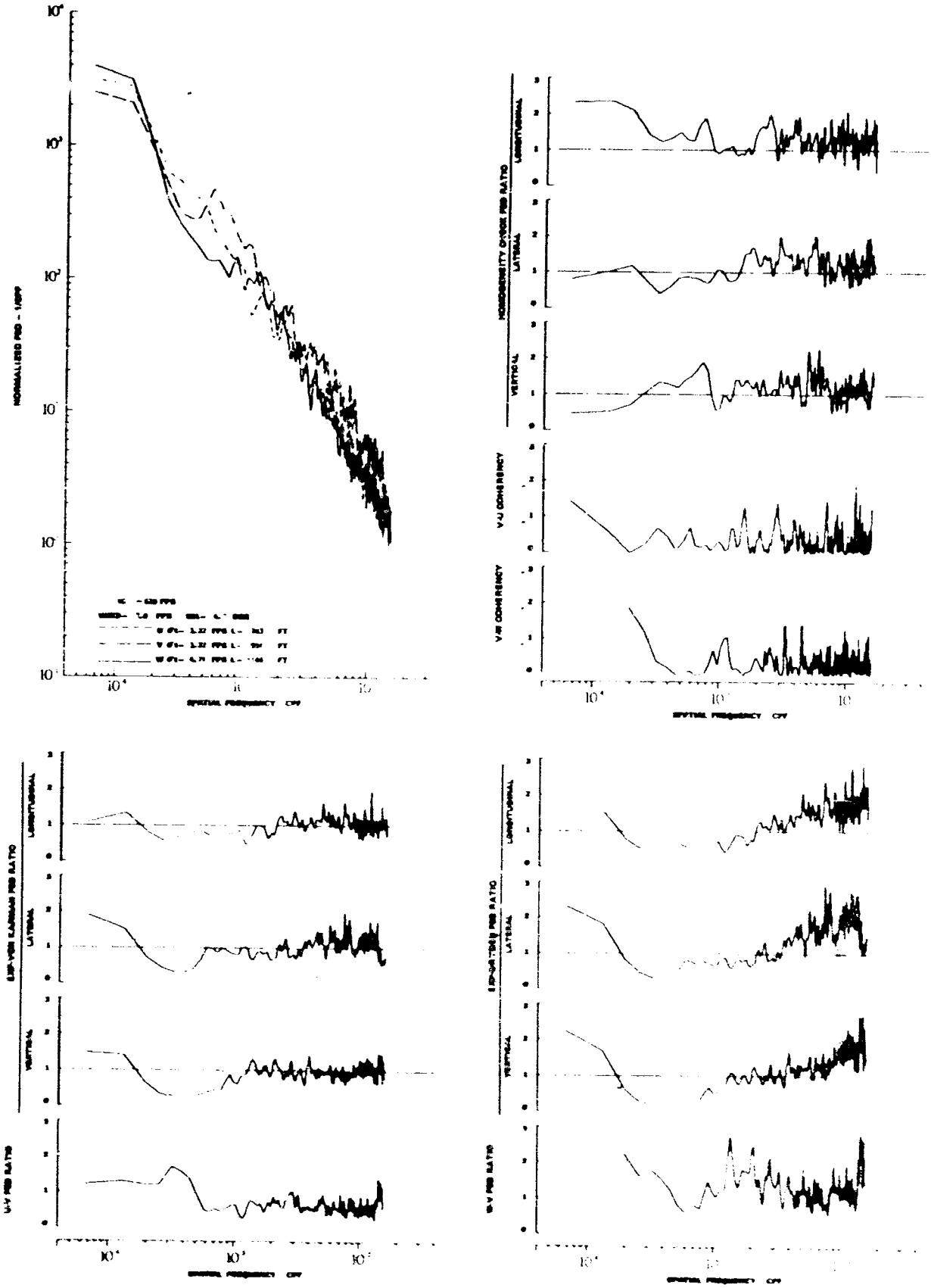
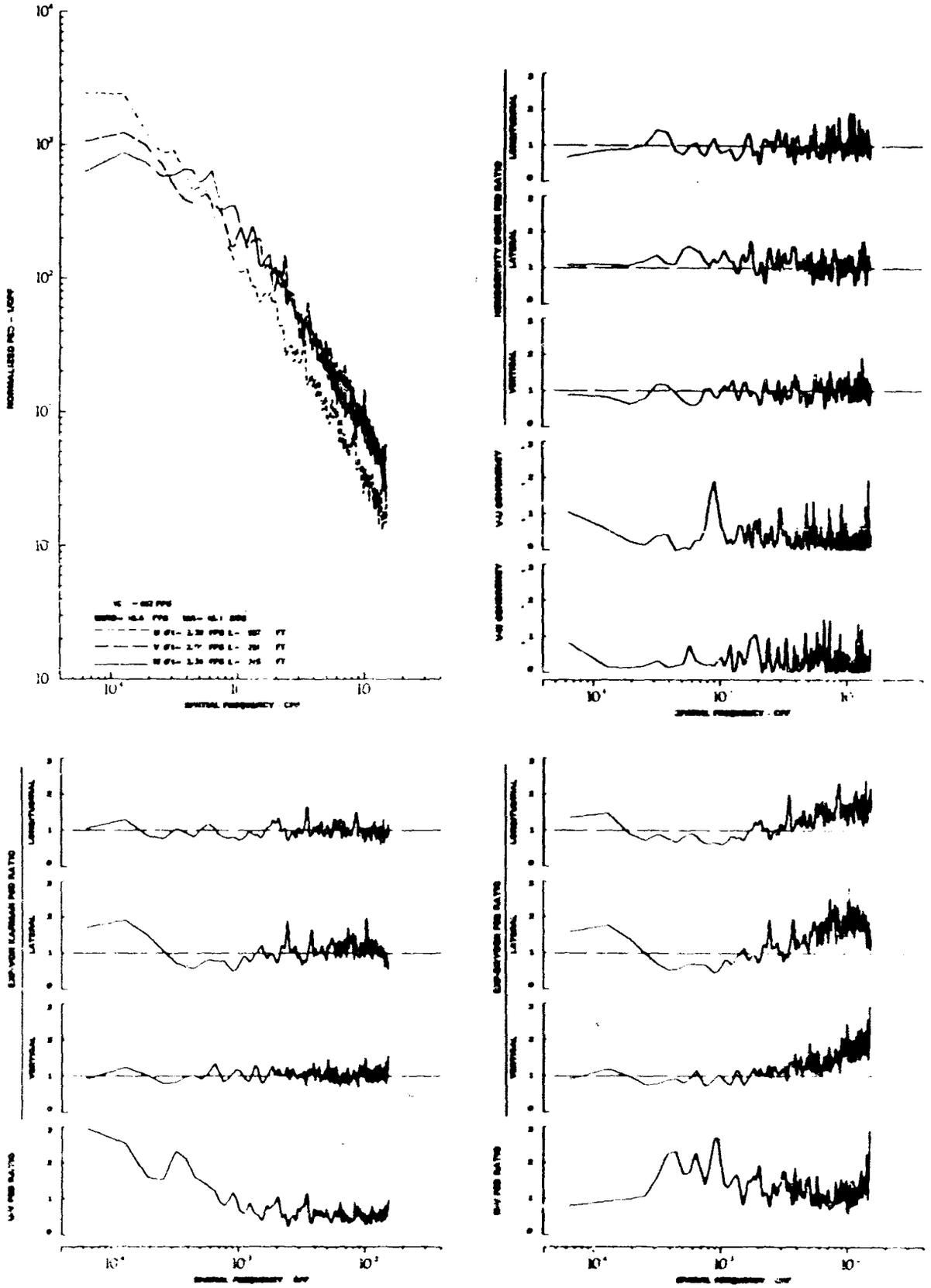
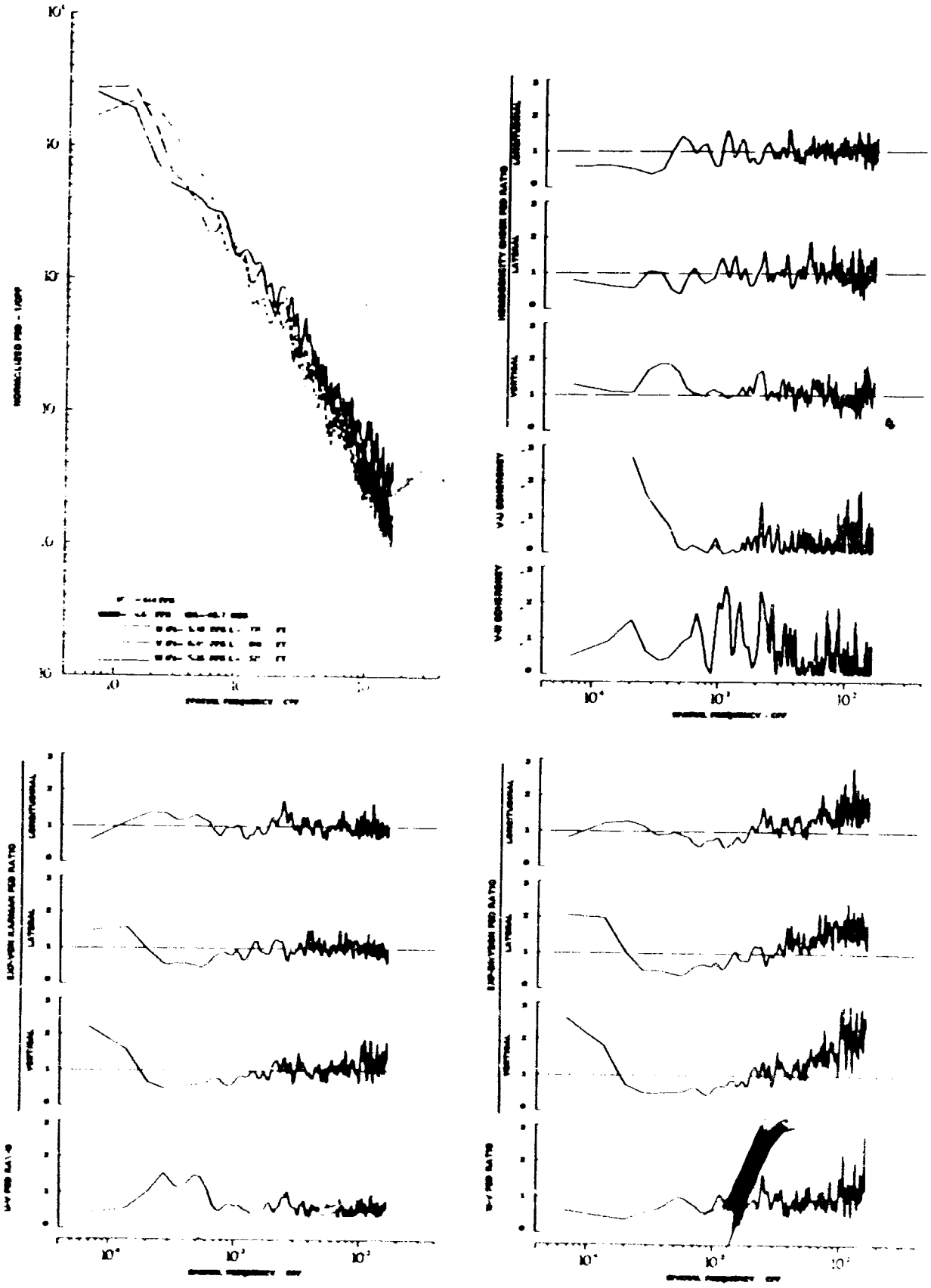


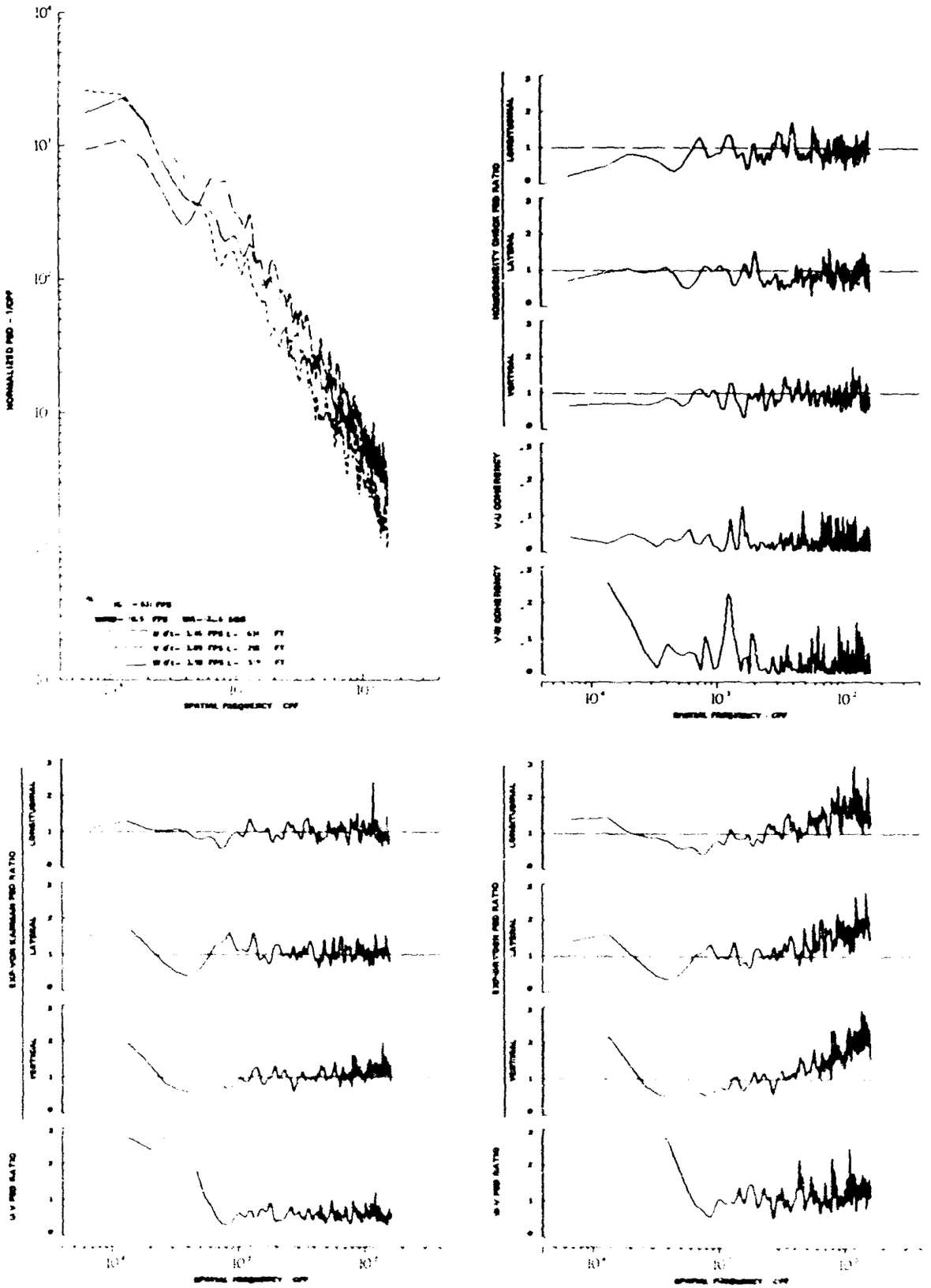
Turbulence Spectra Data For Test 261, Leg 1, Category 112213



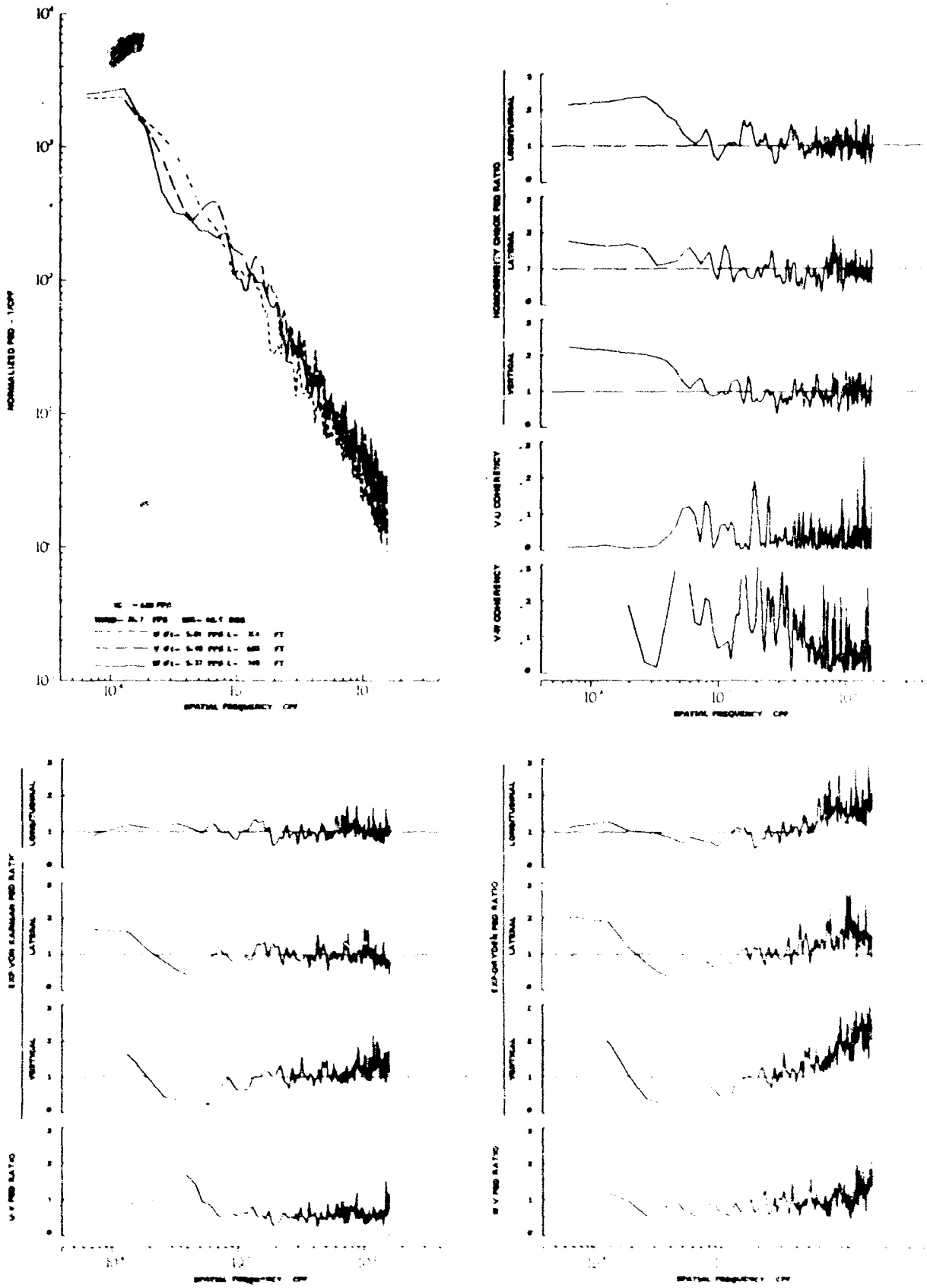
Turbulence Spectra Data For Test 261, Log 3 Category 112213



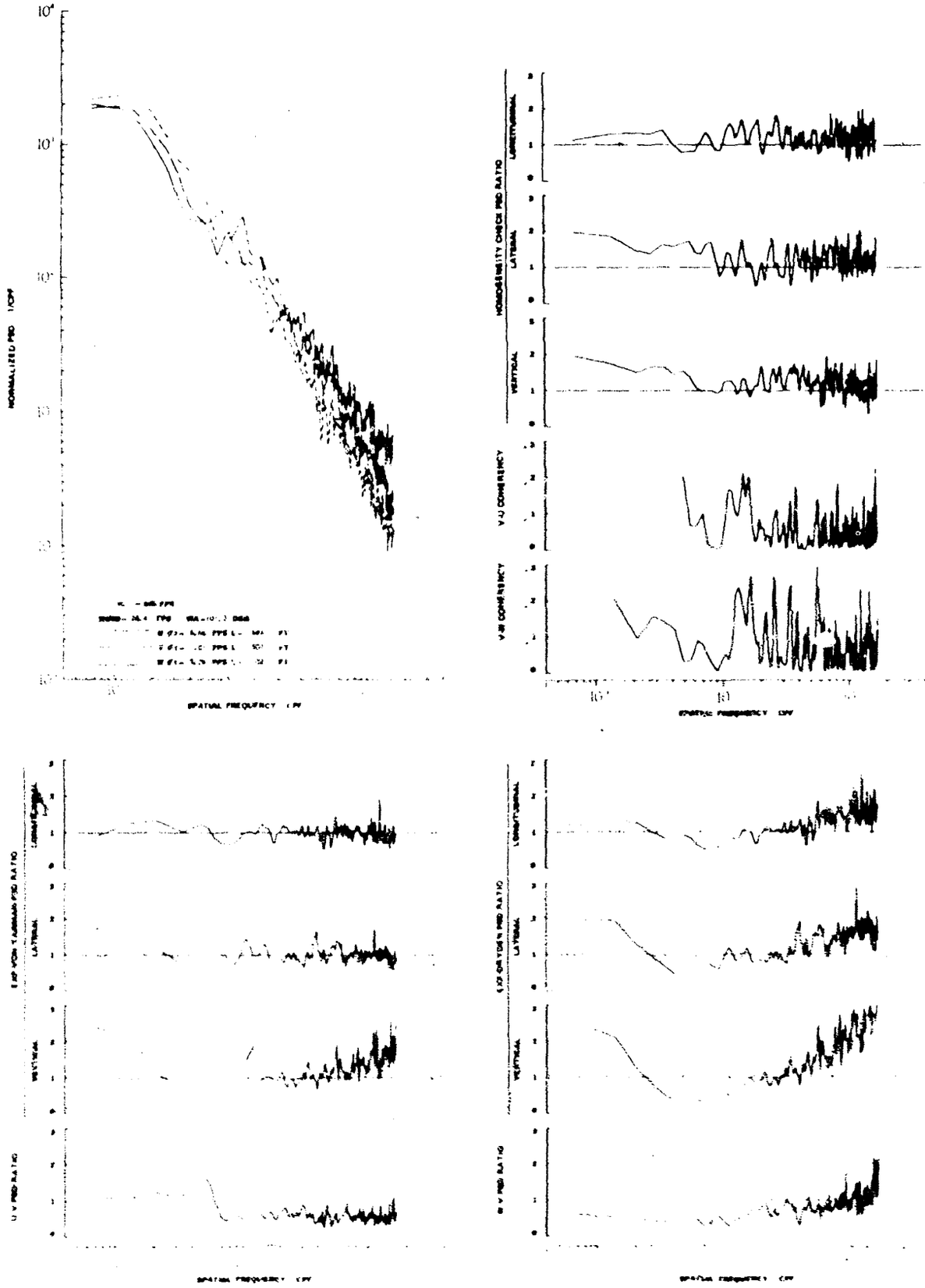
Turbulence Spectra Data For Test 261, Leg 5, Category 112213



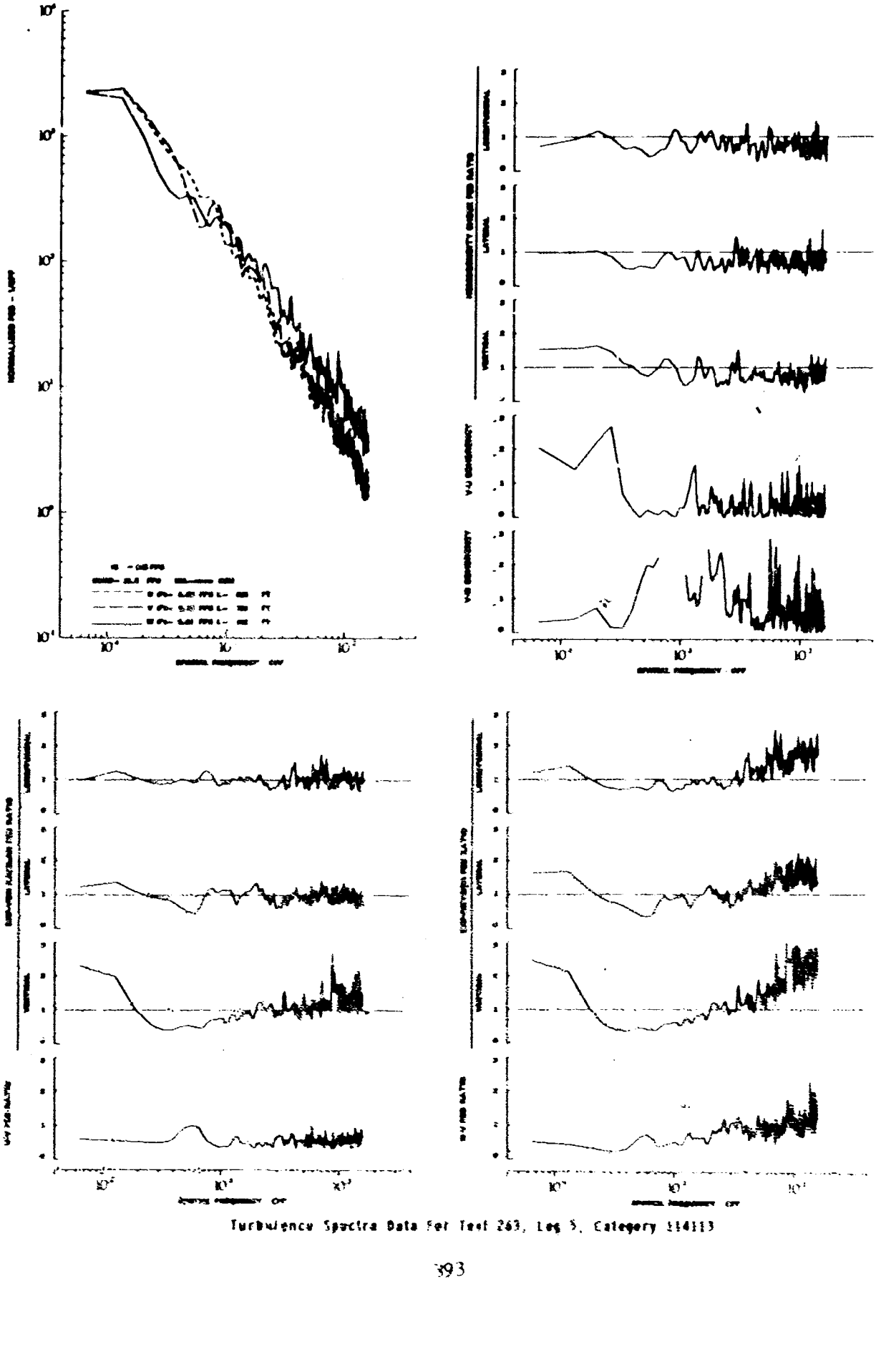
Turbulence Spectra Data For Test 261, Leg 7, Category 113213



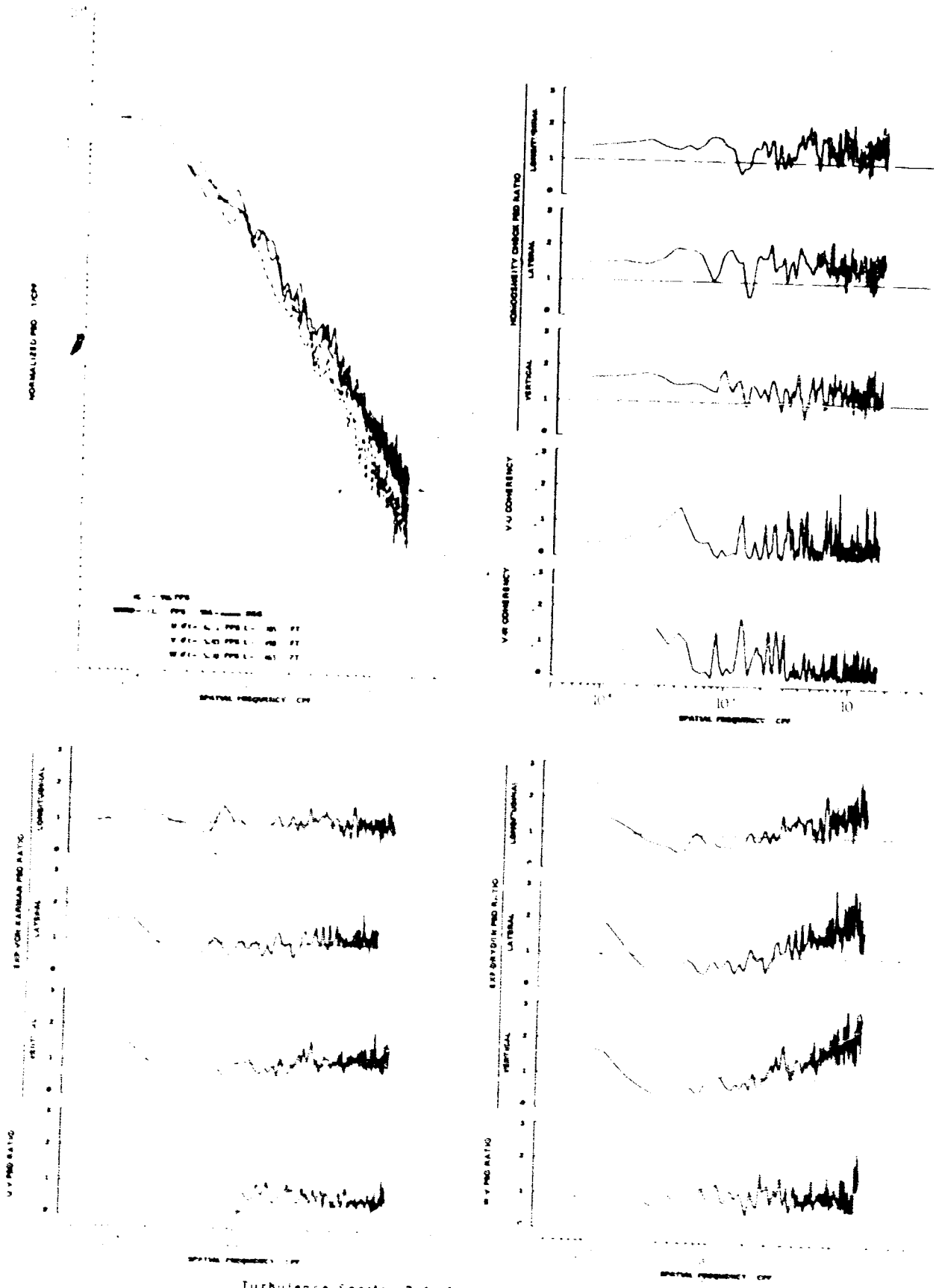
Turbulence Spectra Data For Test 267, Leg 2, Category 112313



Turbulence Spectra Data For Test 262, Leg 4, Category 212313



Turbulence Spectra Data For Test 263, Leg 5, Category 114113



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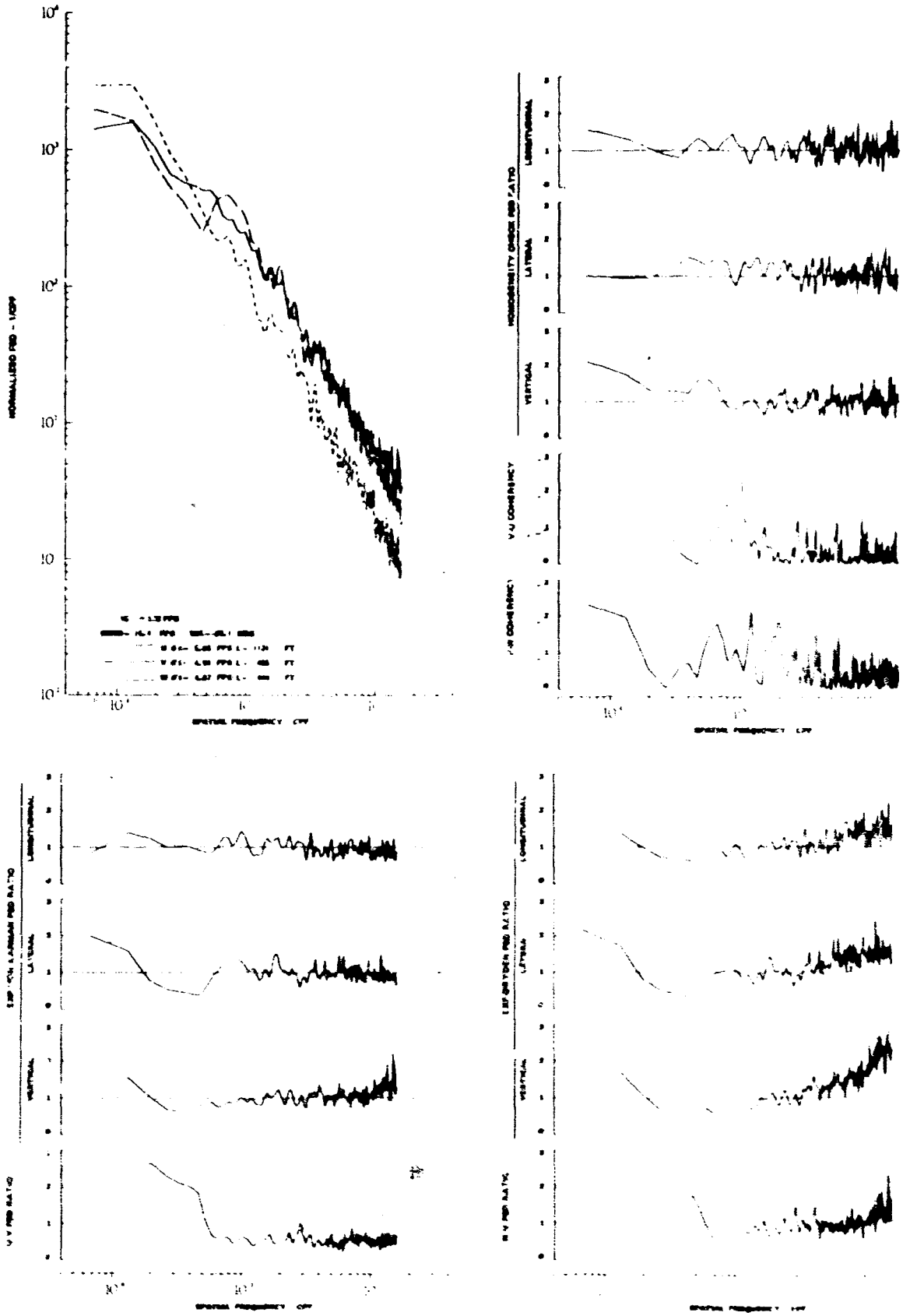
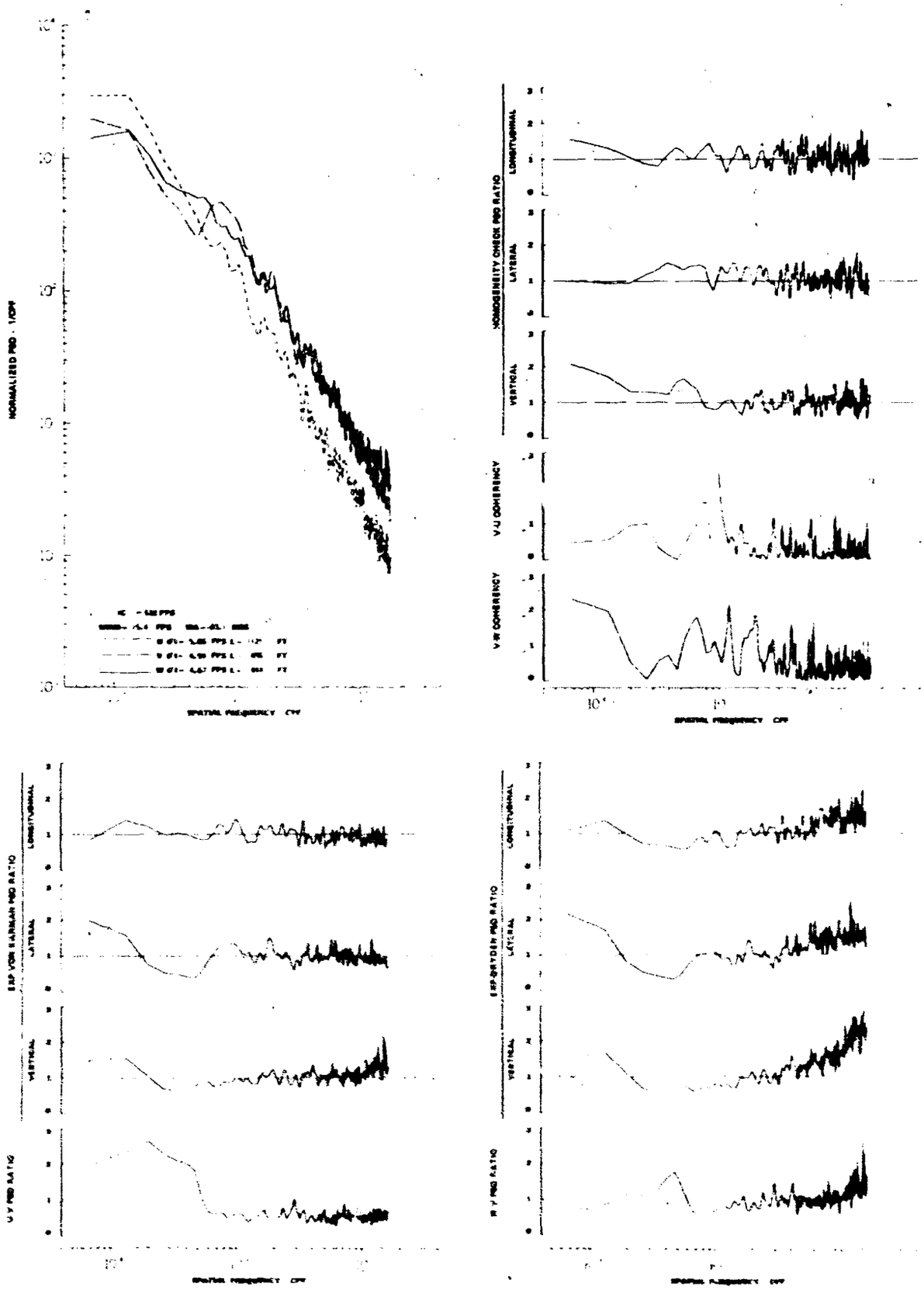
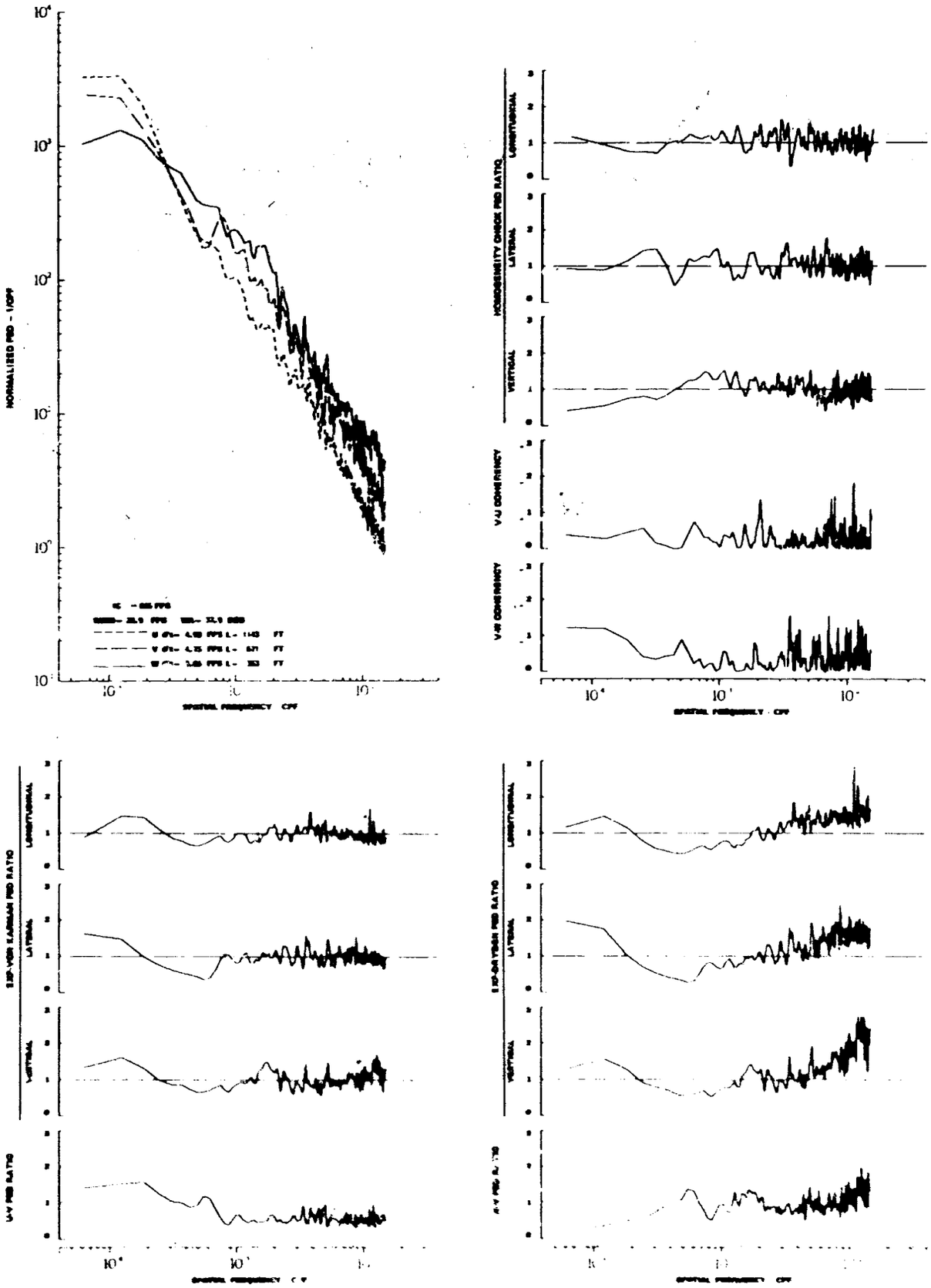


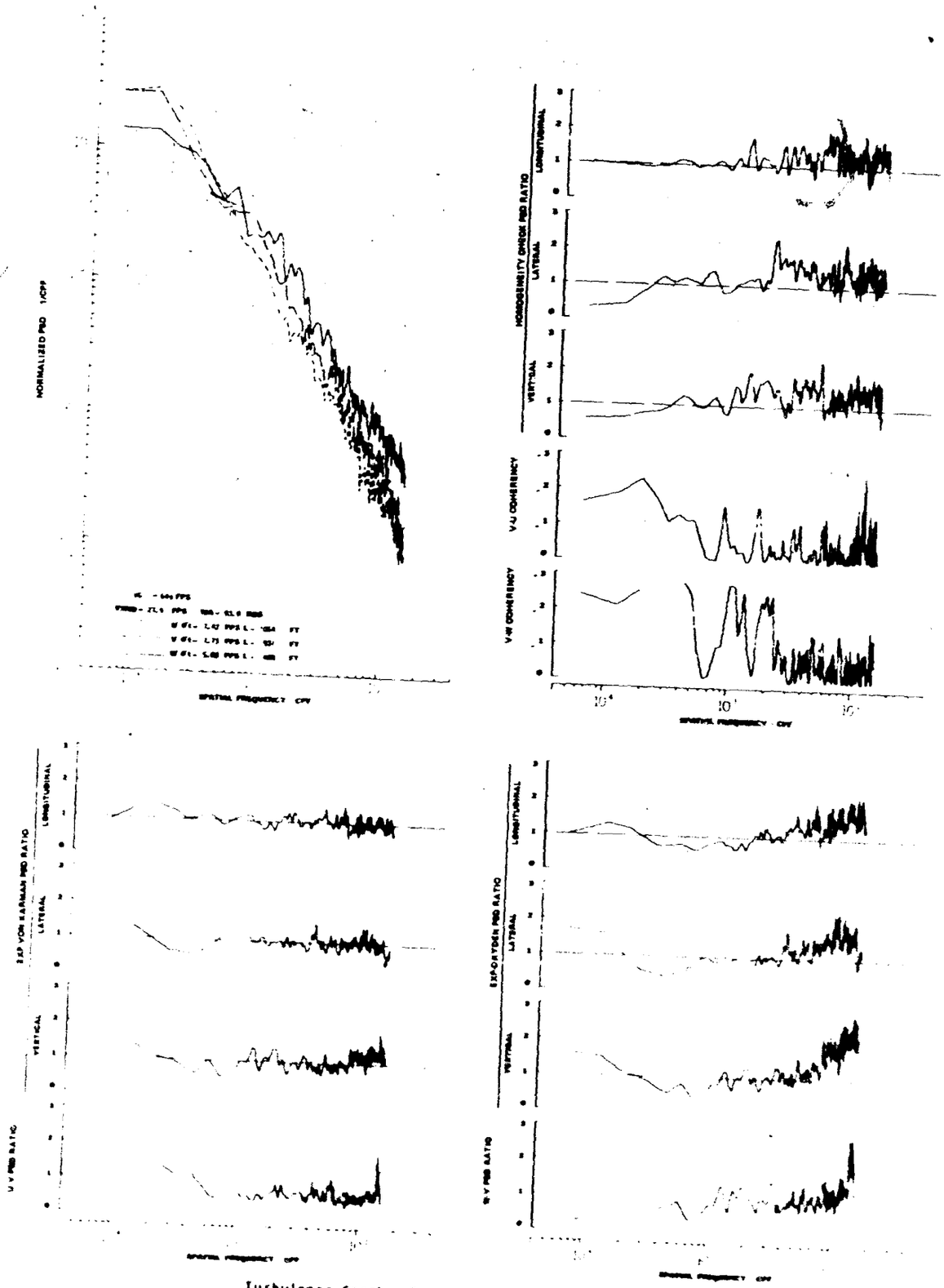
Turbulence Spectra Data For Test 264 Leg 4, Category 114213



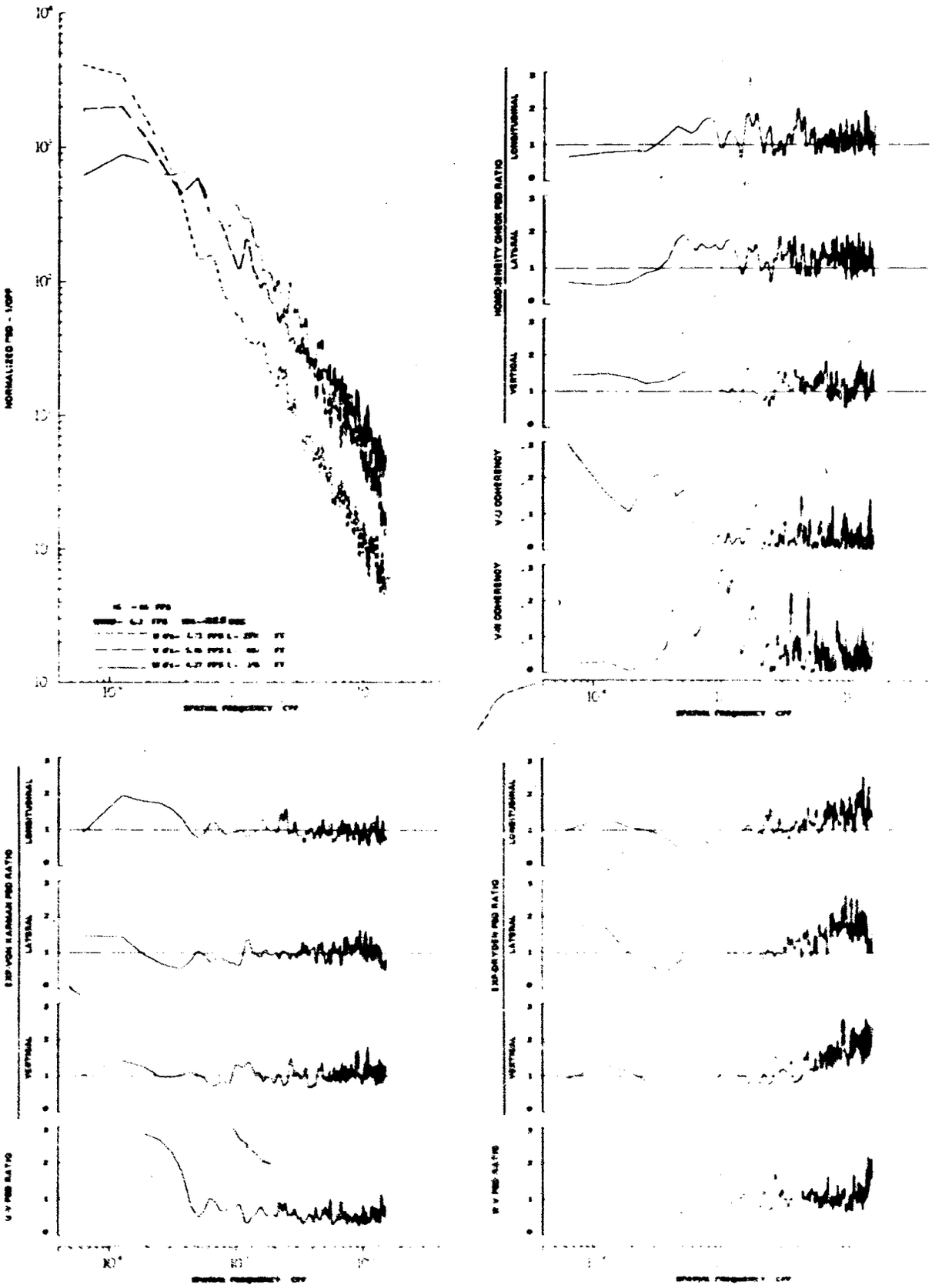
Turbulence Spectra Data For Test 264, Leg 4, Category 114213



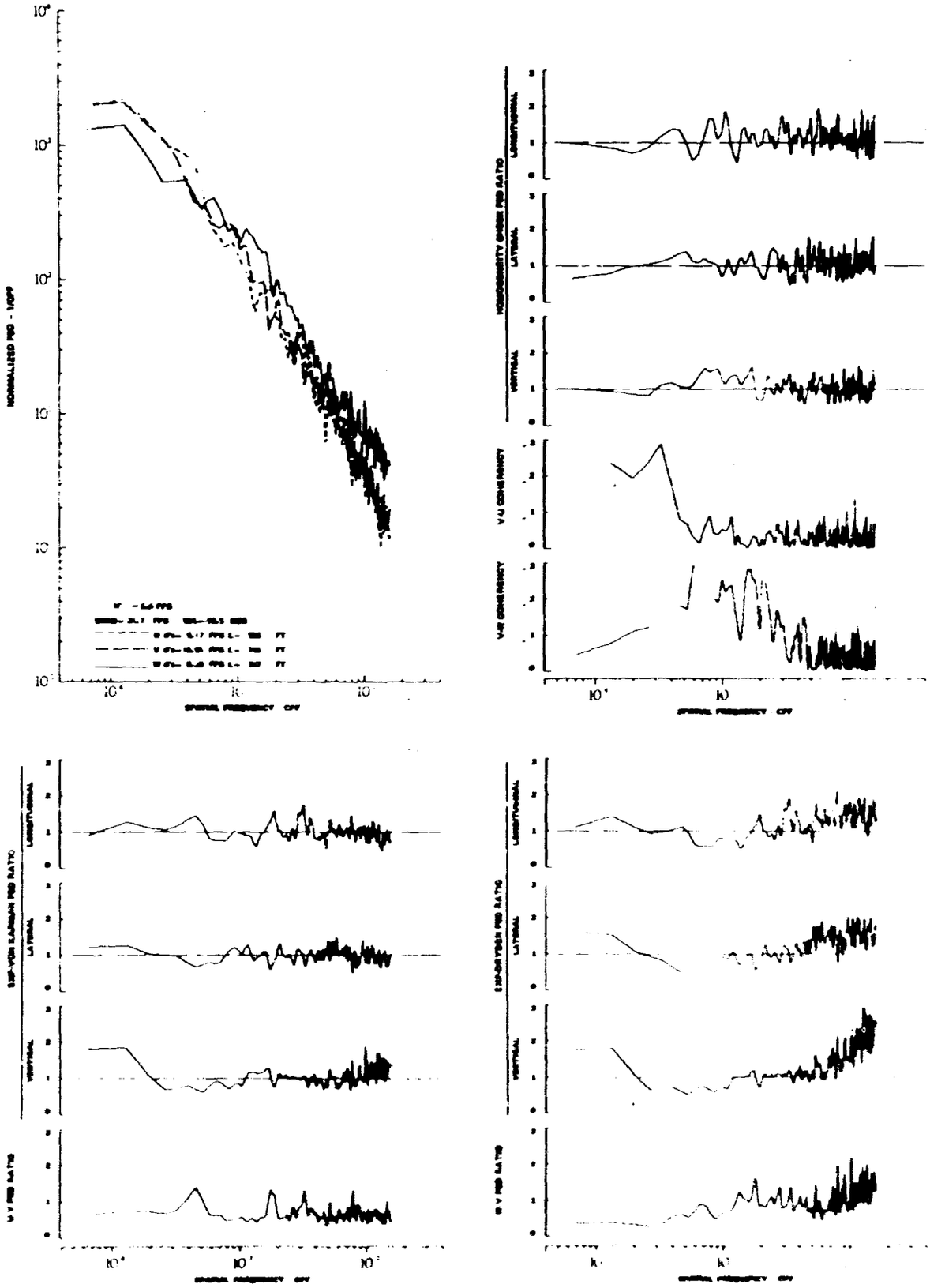
Turbulence Spectra Data for Test 264, Leg 8, Category 414213



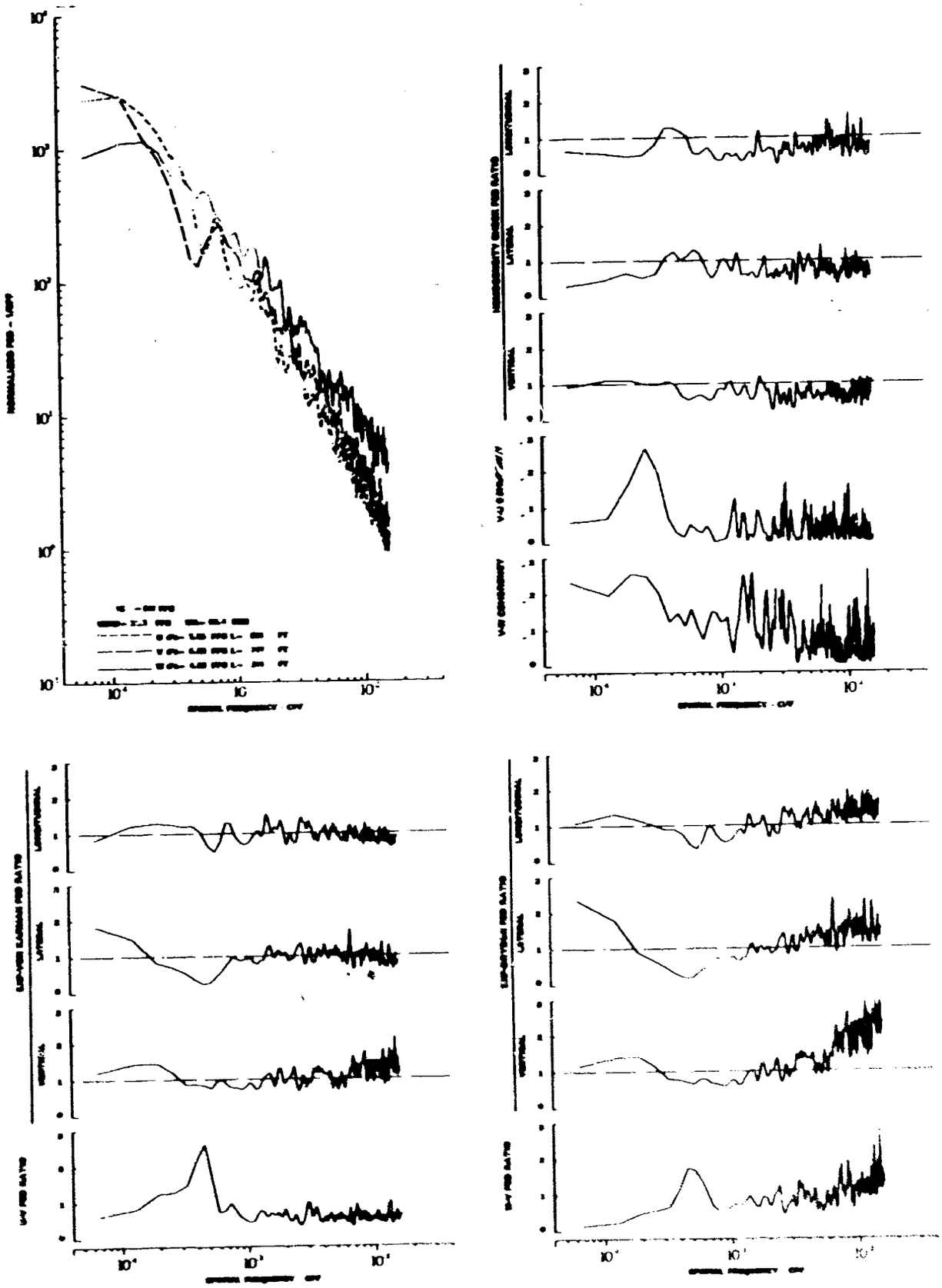
Turbulence Spectra Data For Test 265, Leg 1, Category 112313



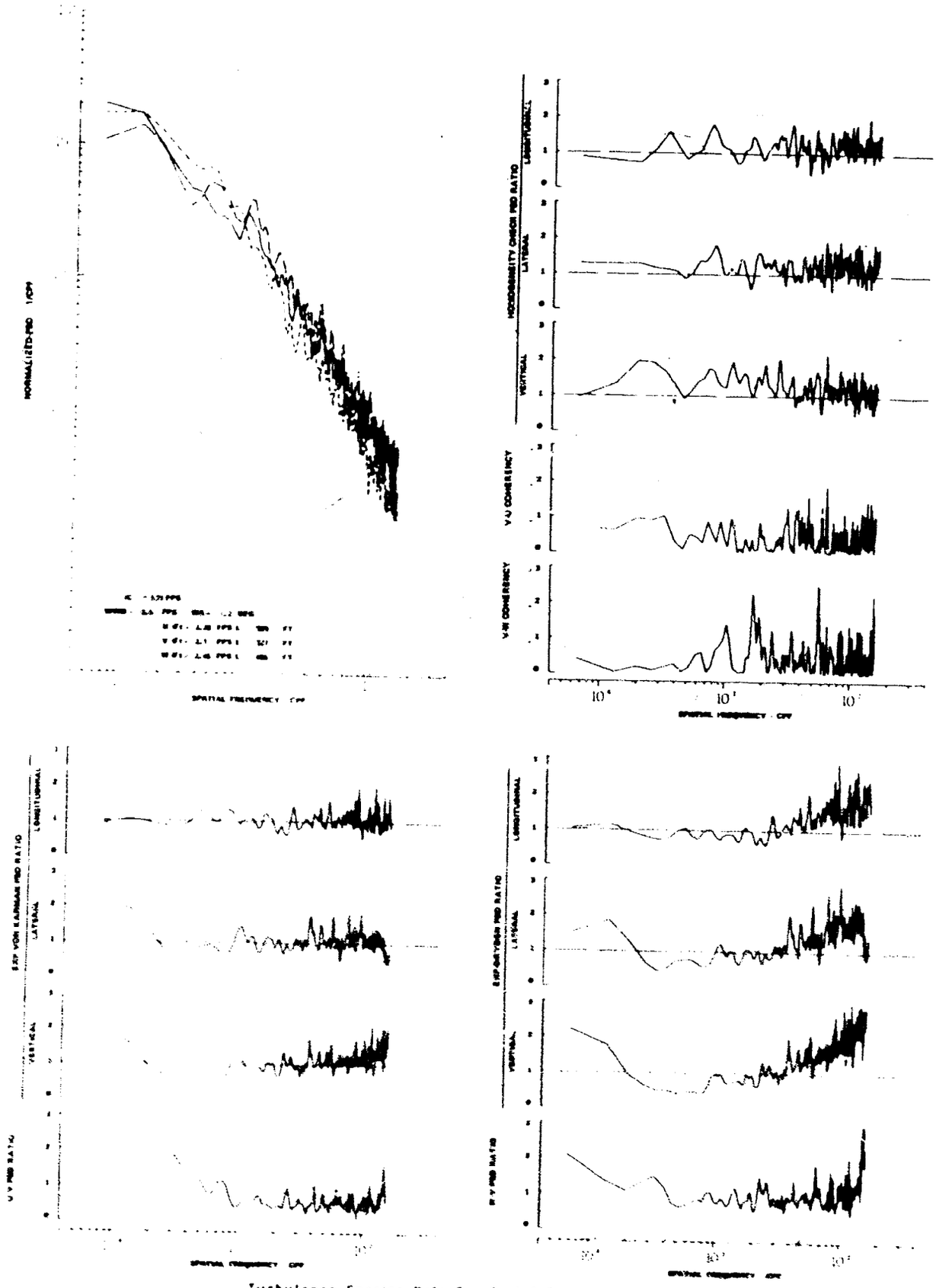
Turbulence Spectra Data for Test 265, Leg 3, Category 113313



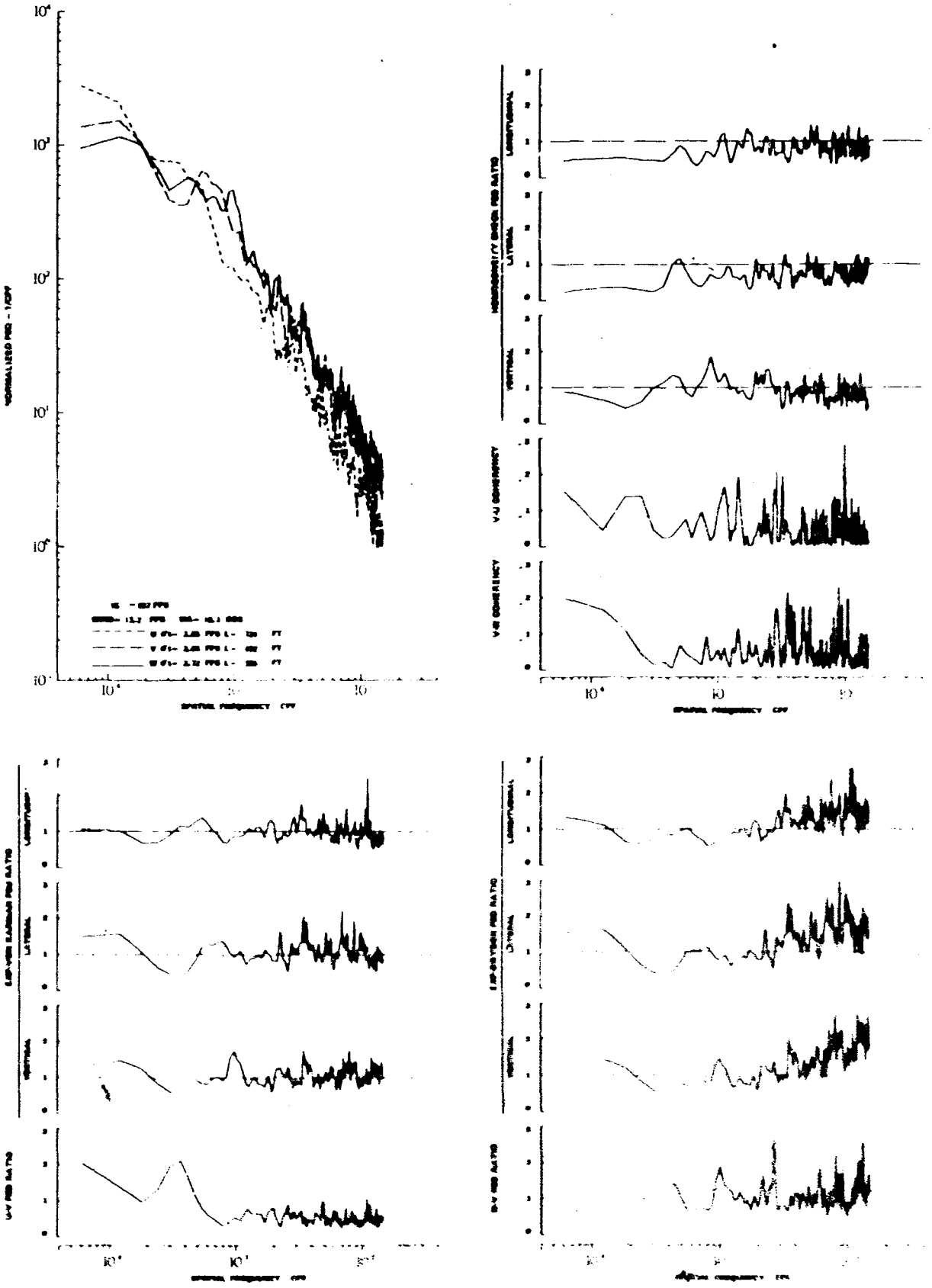
Turbulence Spectra Data For Test 265, Leg 5, Category 114313



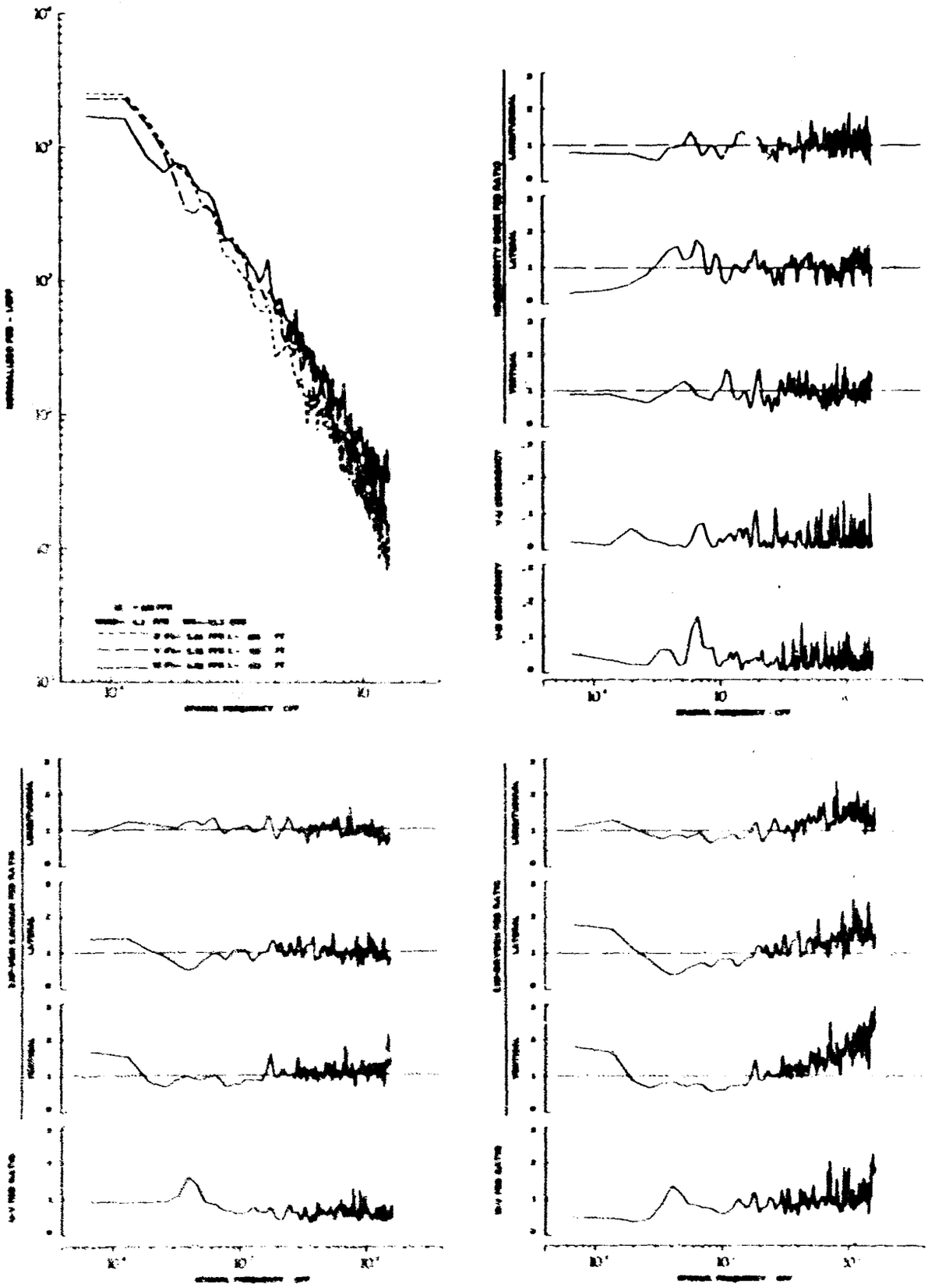
Turbulence Spectra Data For Test 265, Leg 7, Category 114313



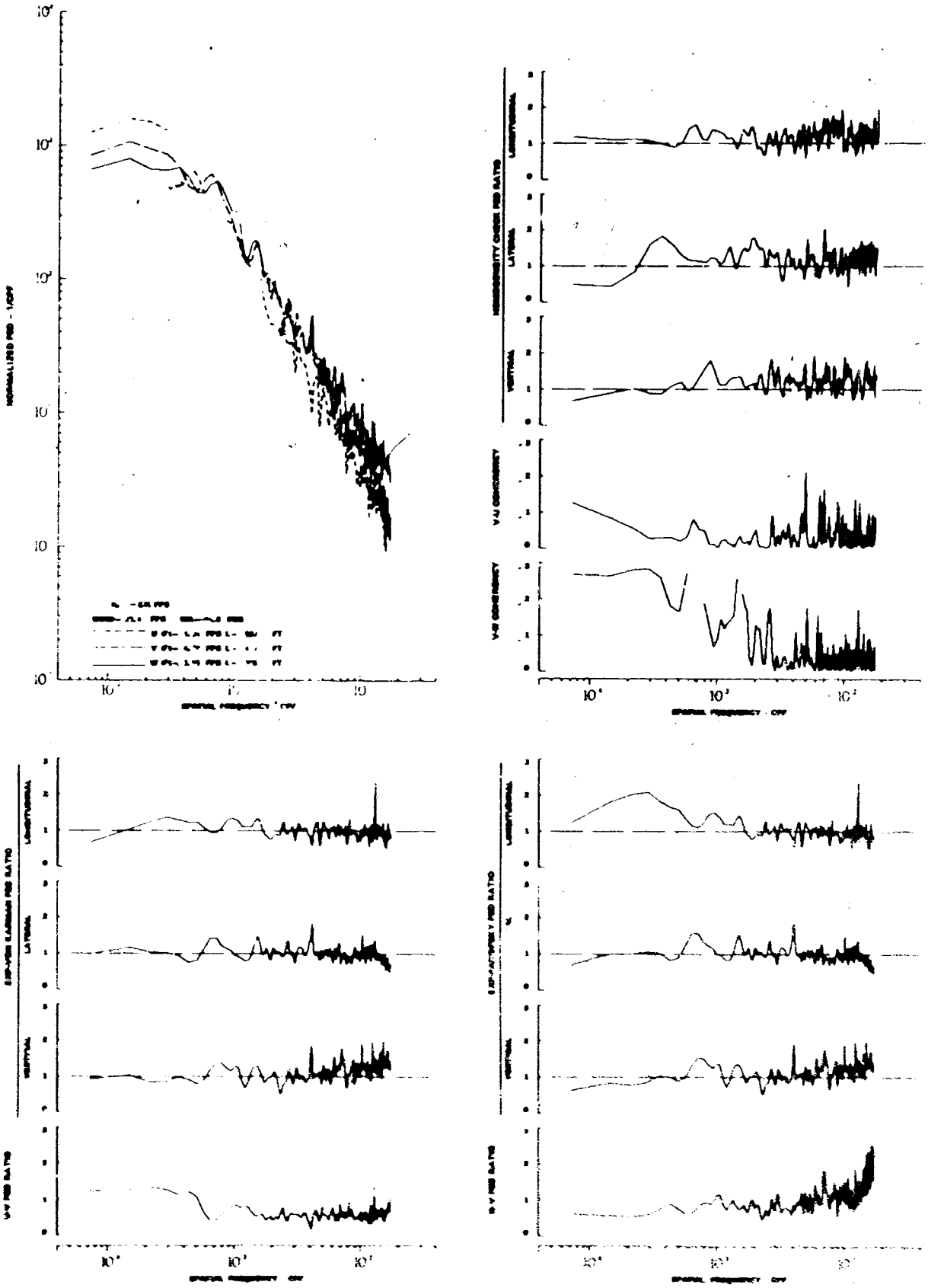
Turbulence Spectra Data For Test 267, Leg 1, Category 121213



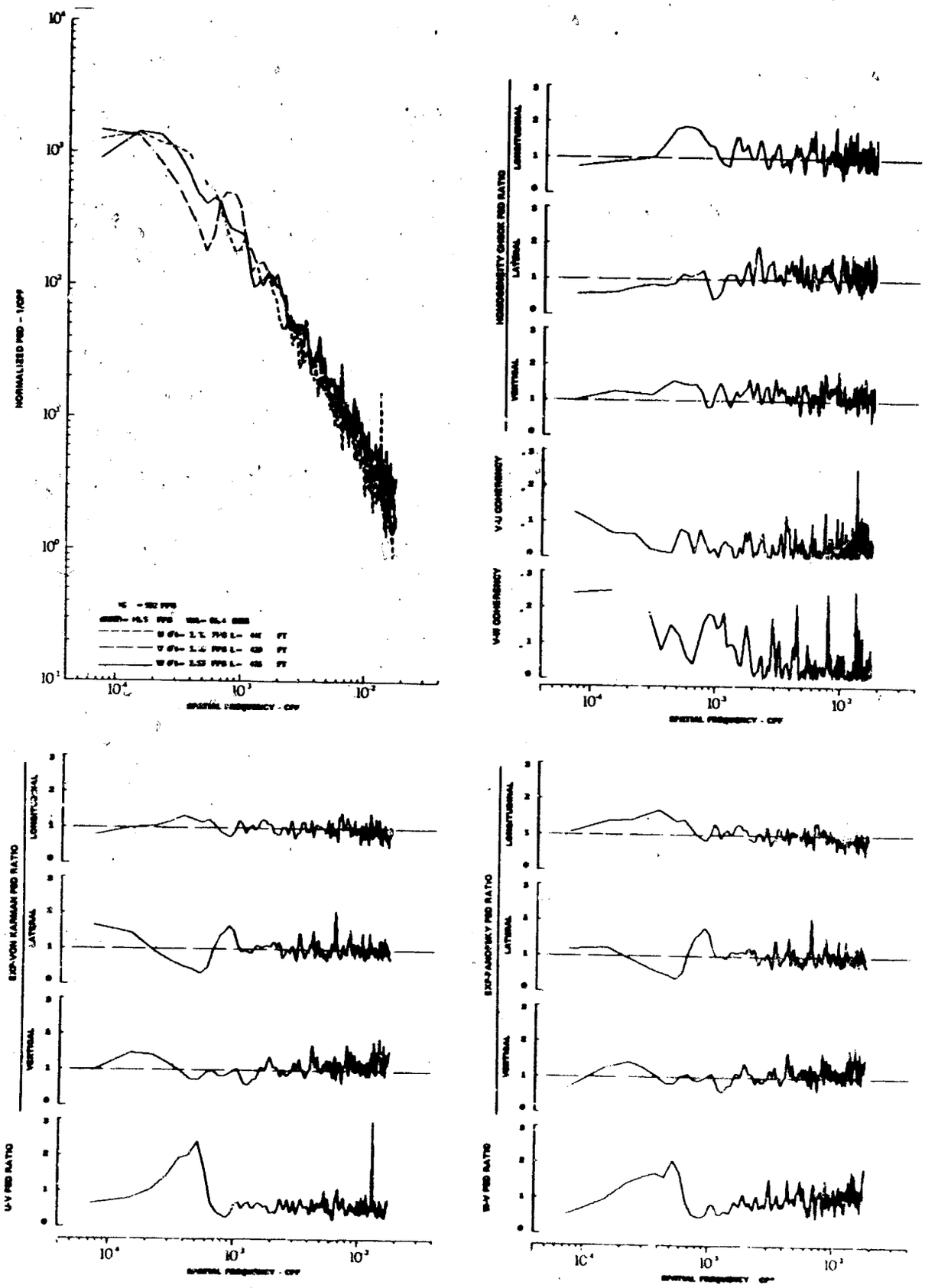
Turbulence Spectra Data For Test 267, Leg 3, Category 121213



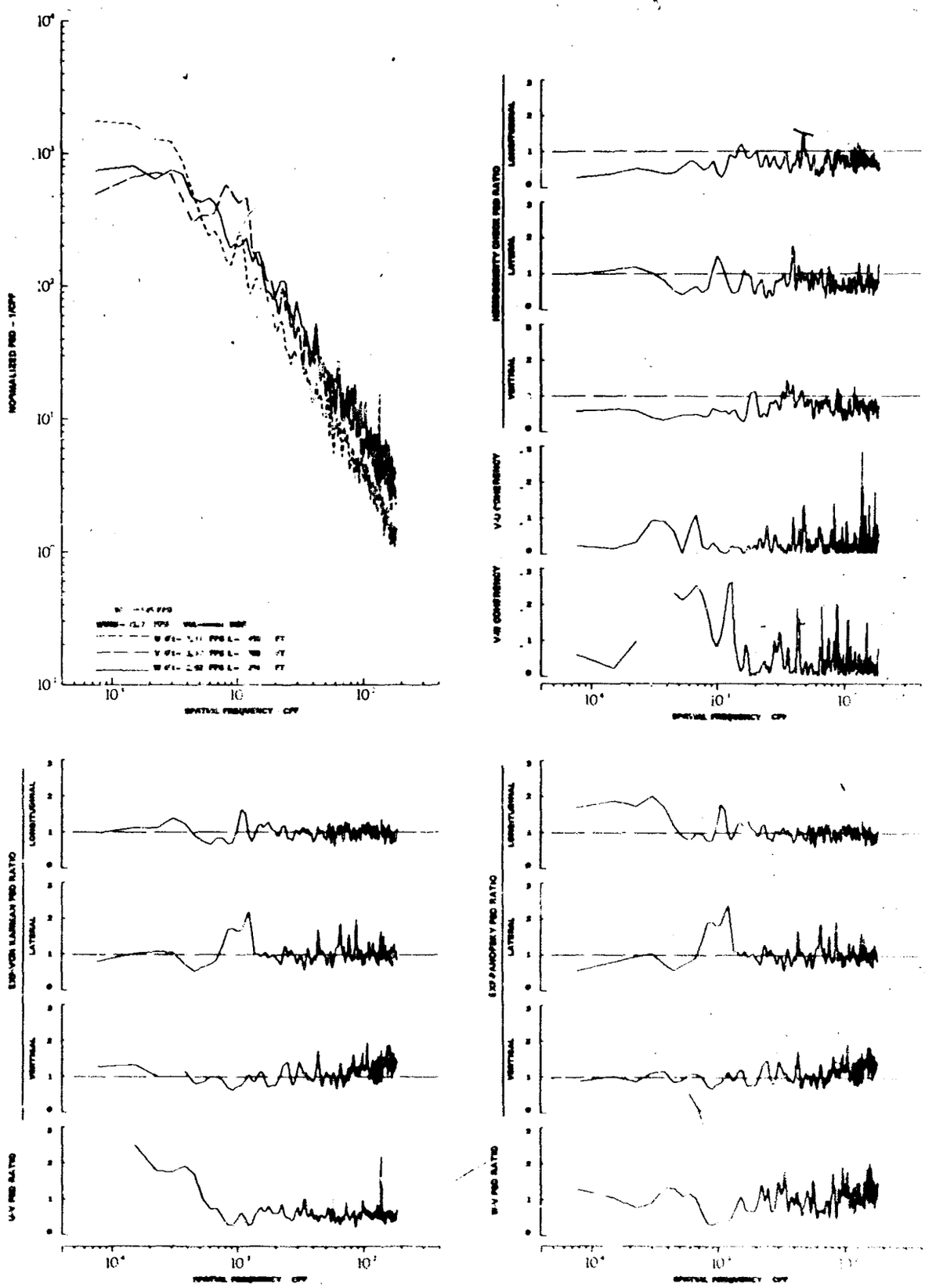
Turbulence Spectra Data For Test 267, Leg 5, Category 124213



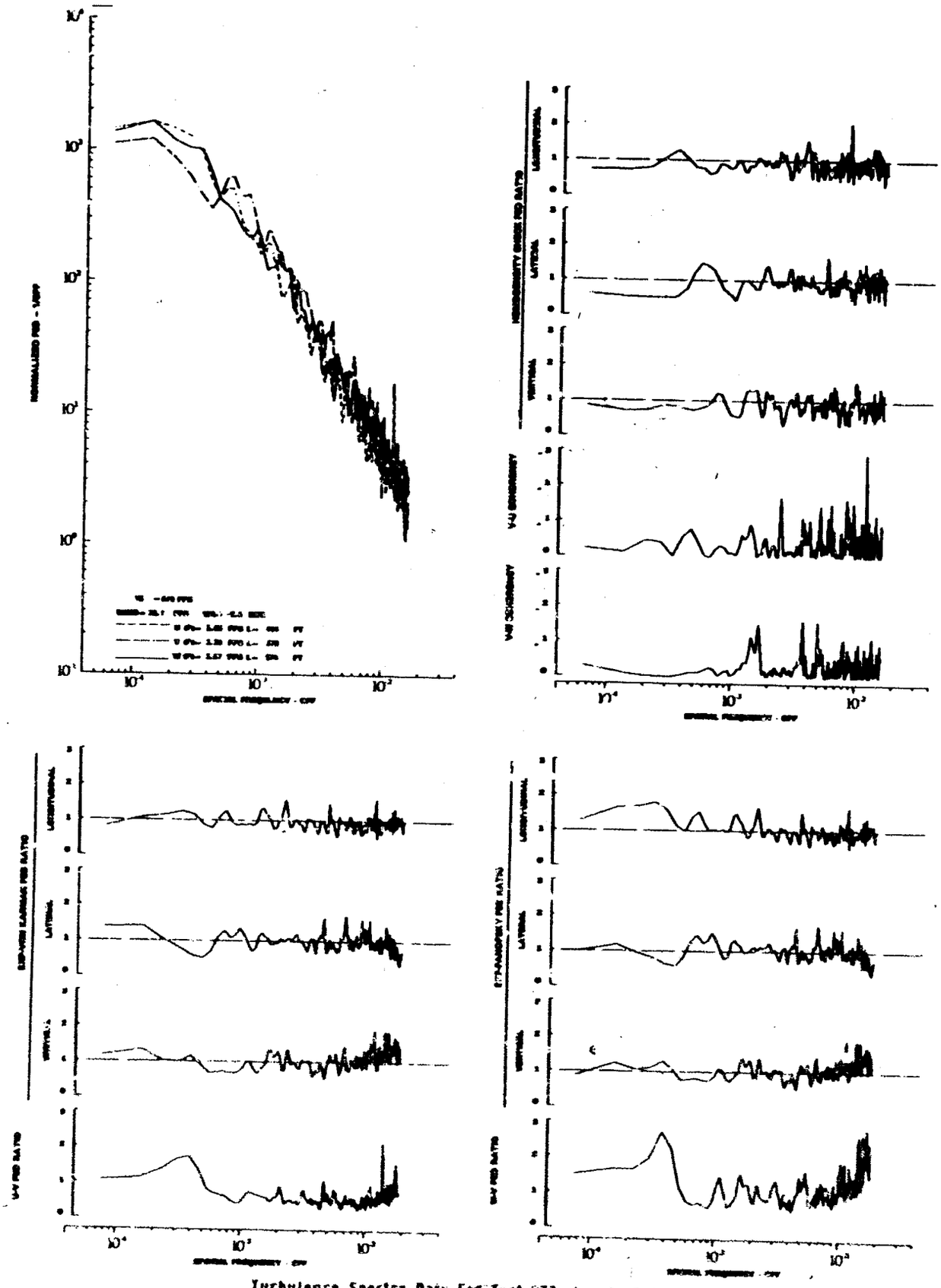
Turbulence Spectra Data For Test 276, Leg 2, Category 223212



Turbulence Spectra Data For Test 276, Leg 6, Category 223212



Turbulence Spectra Data for Test 276, Leg 8, Category 423212



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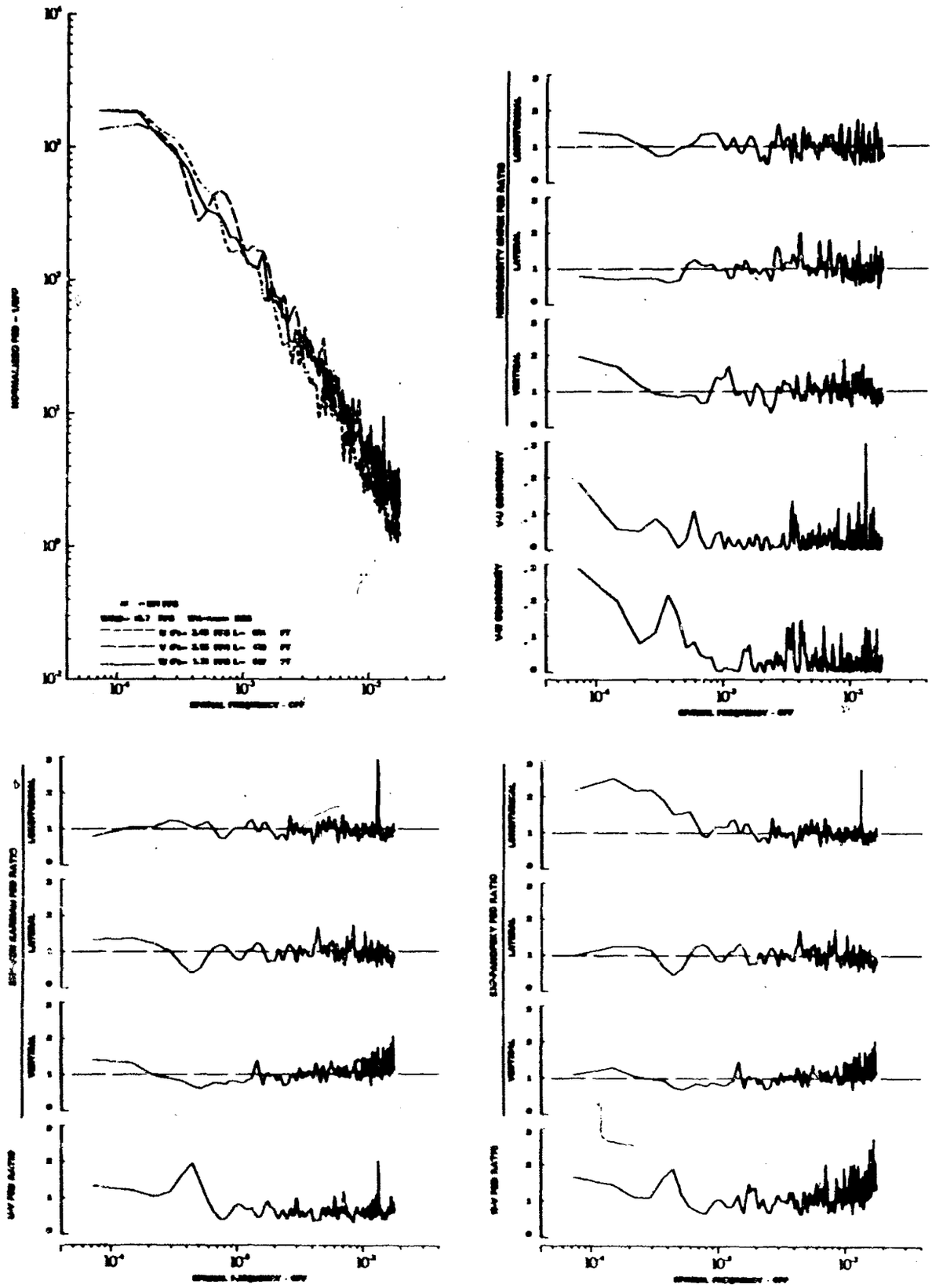

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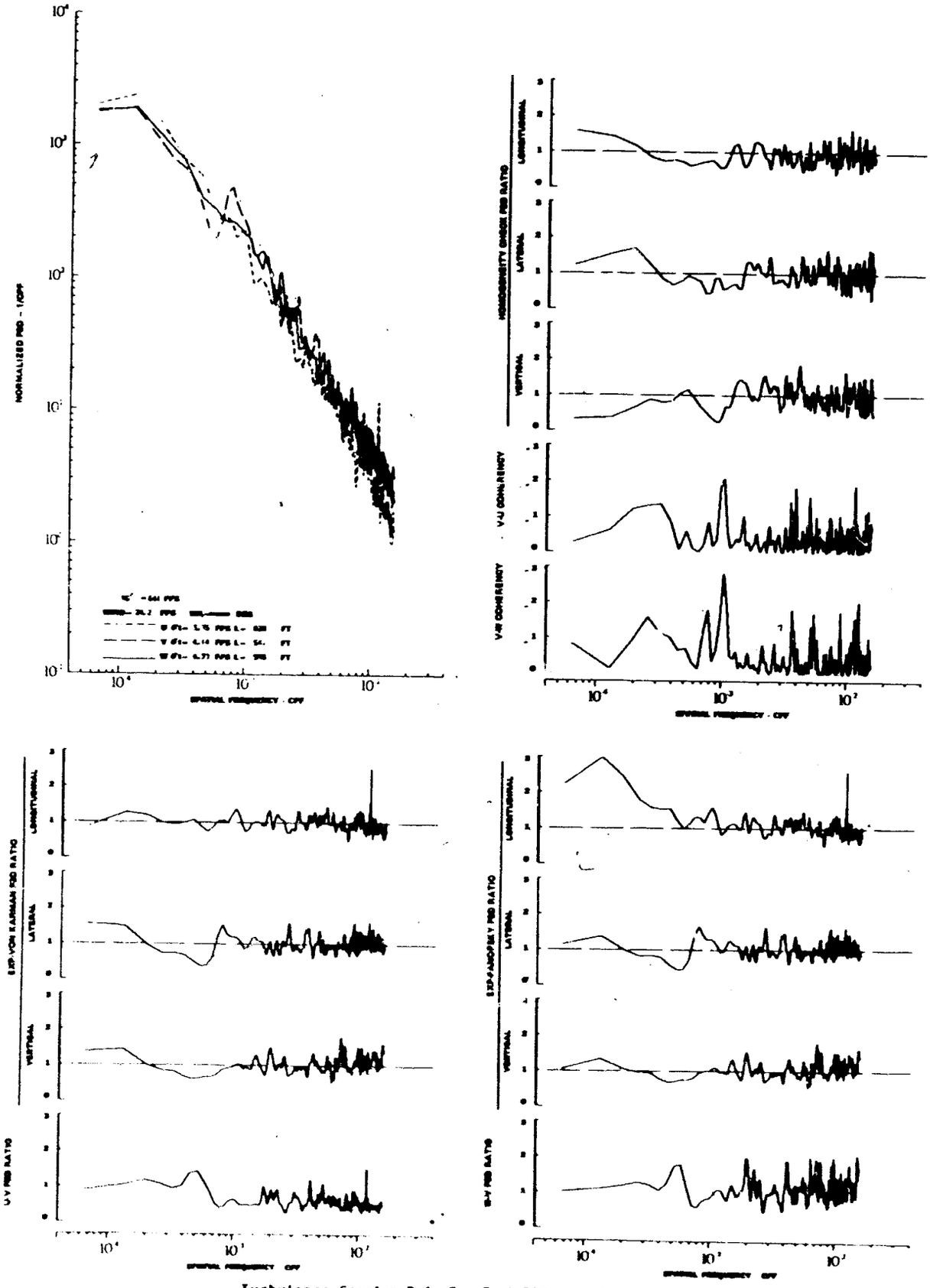

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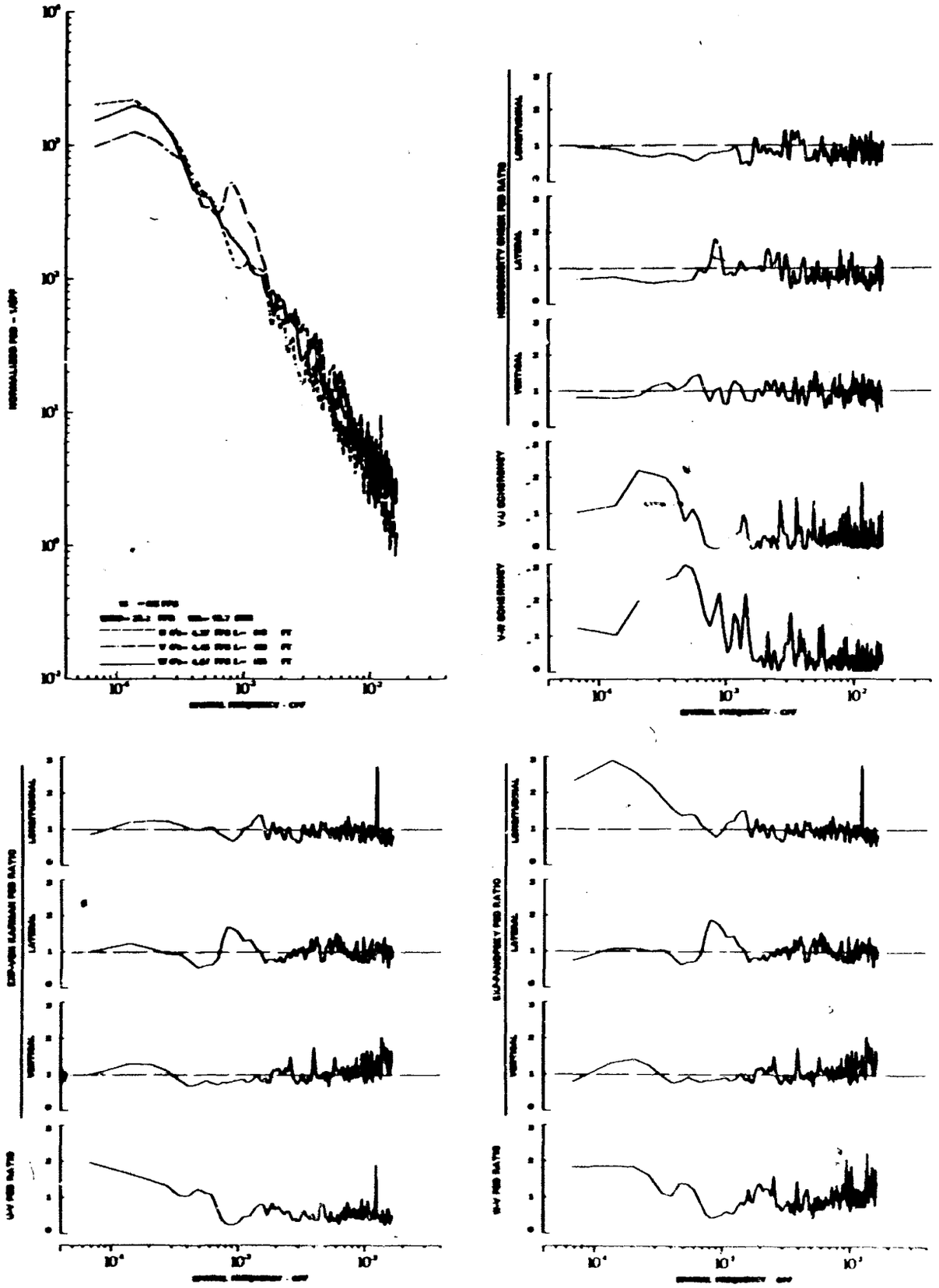

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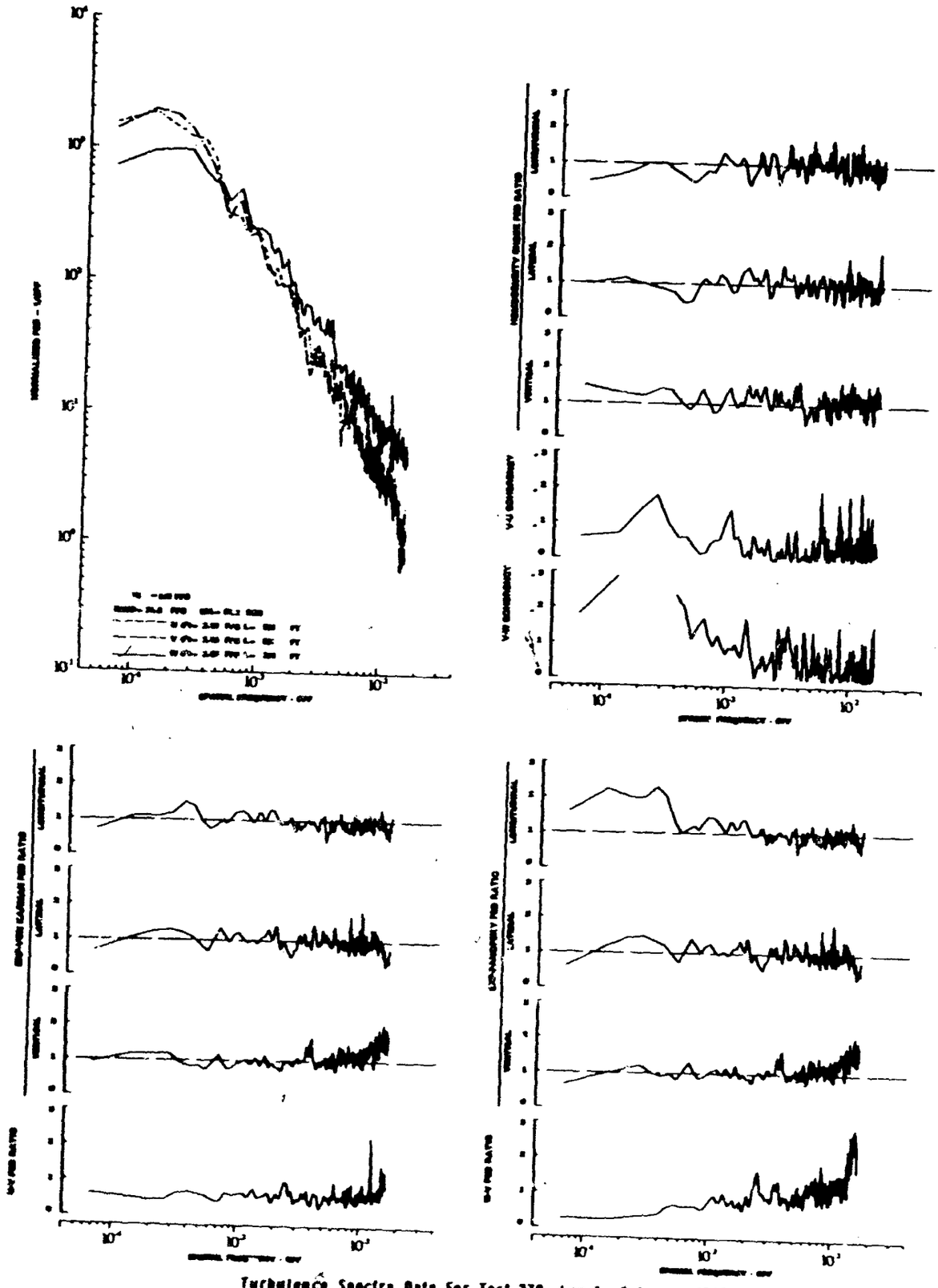

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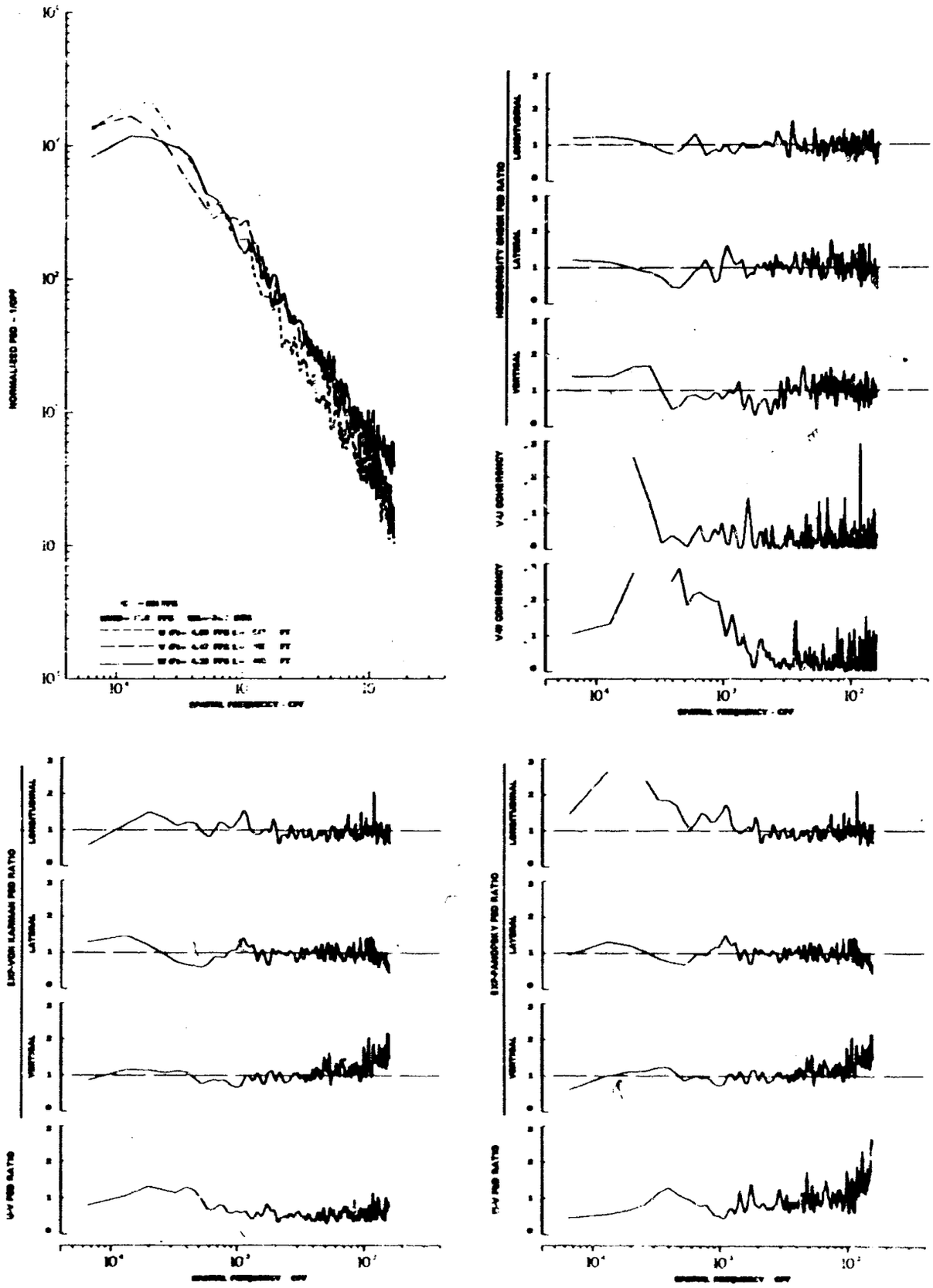

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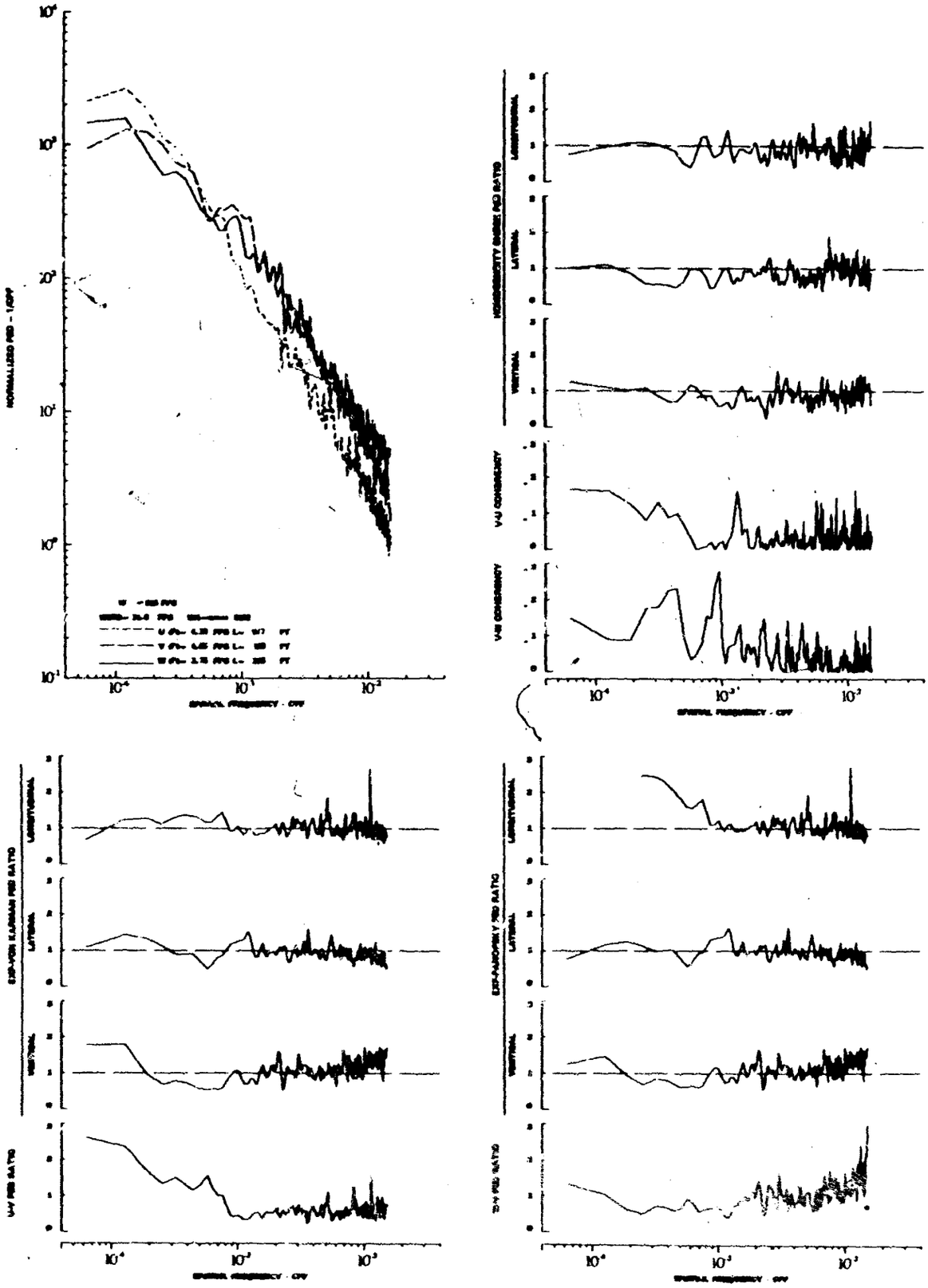

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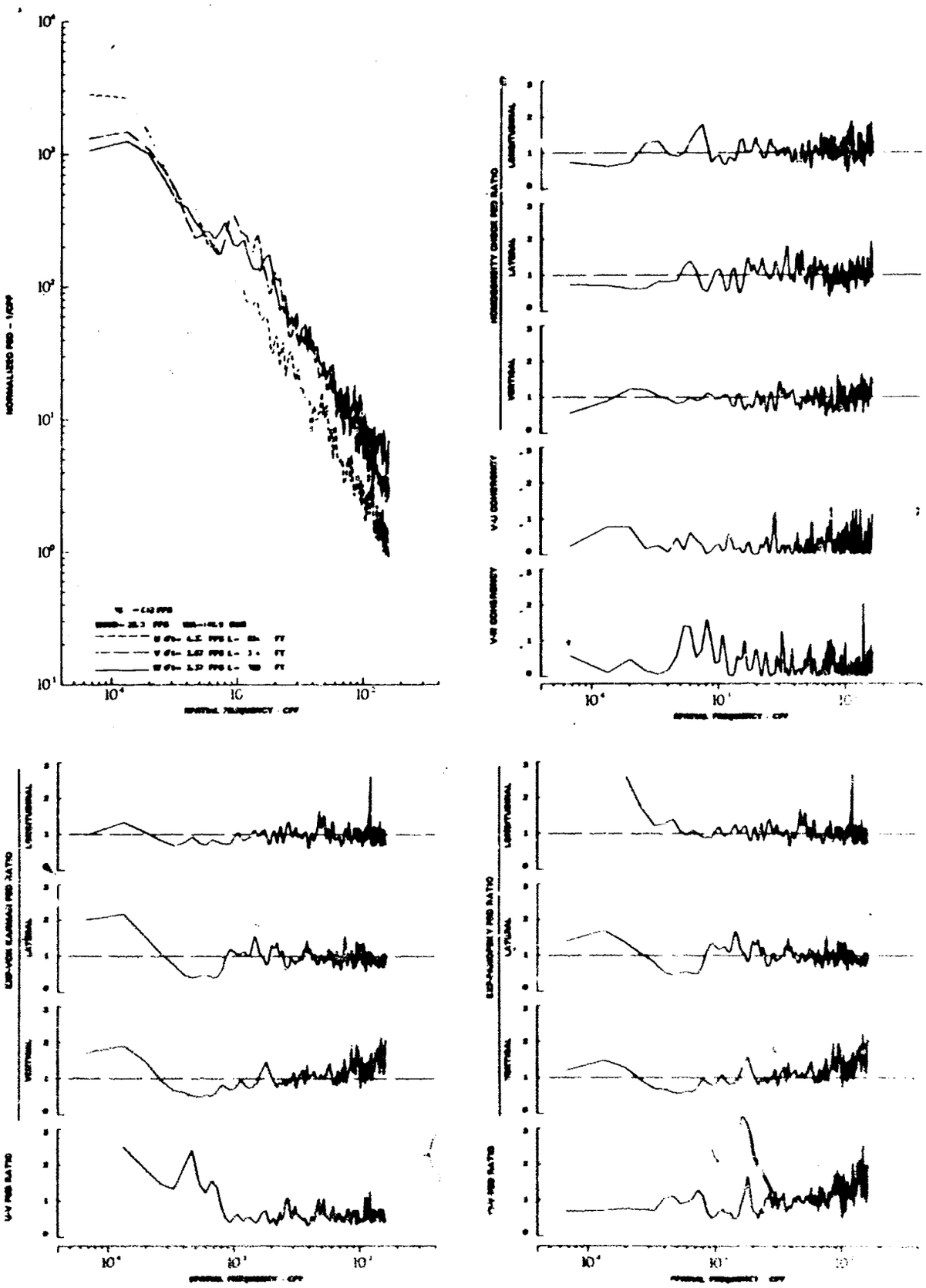

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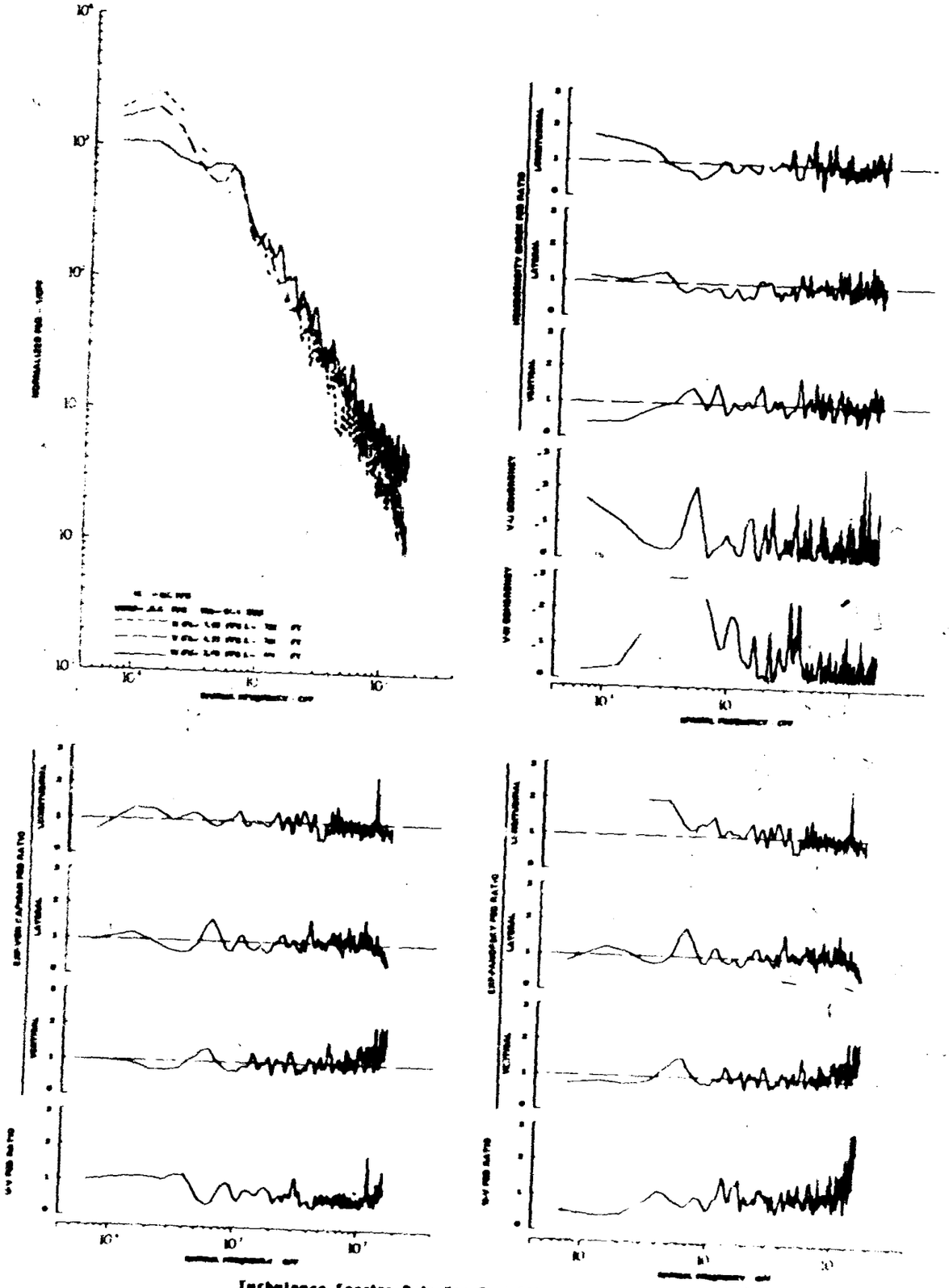

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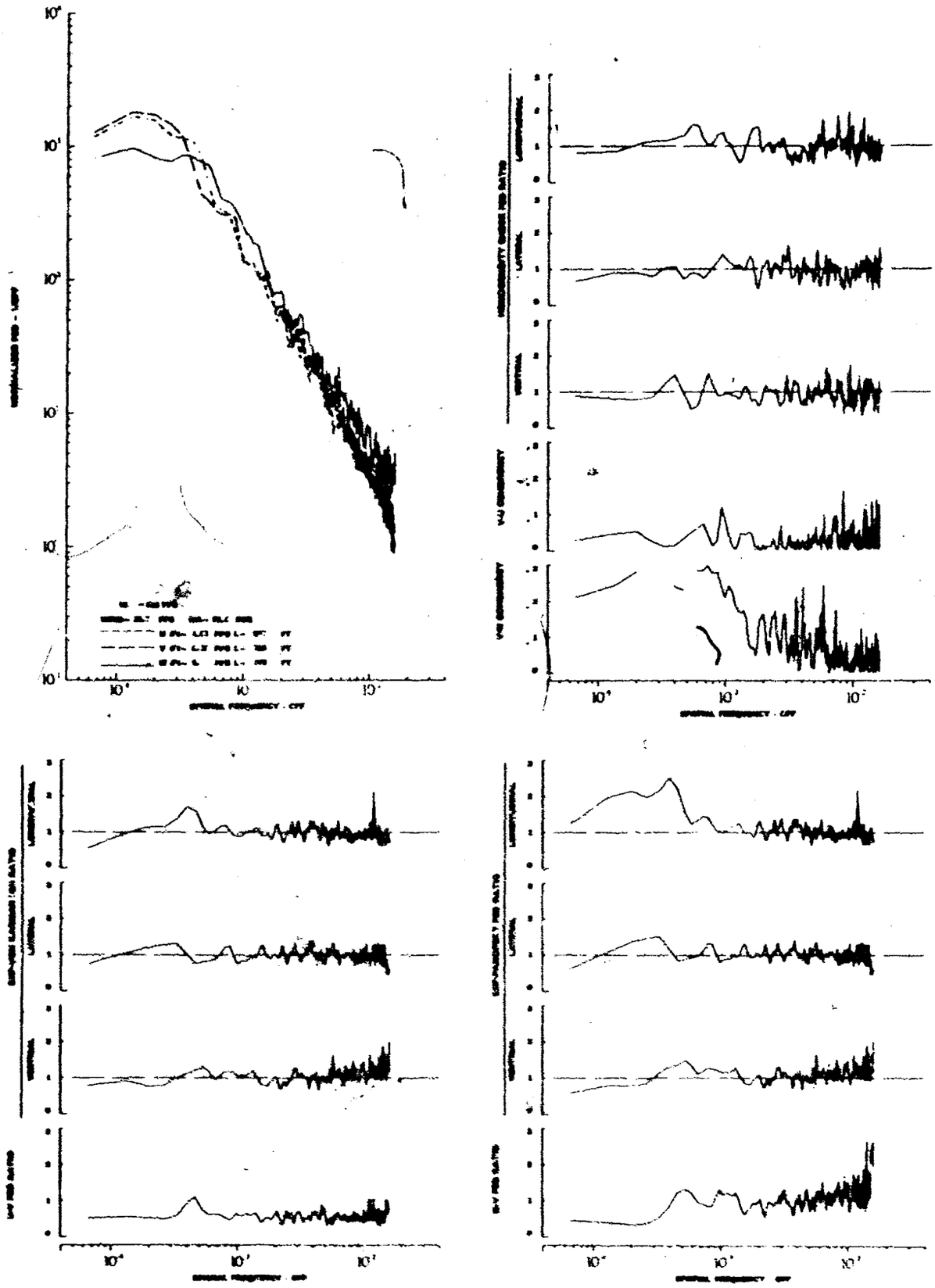

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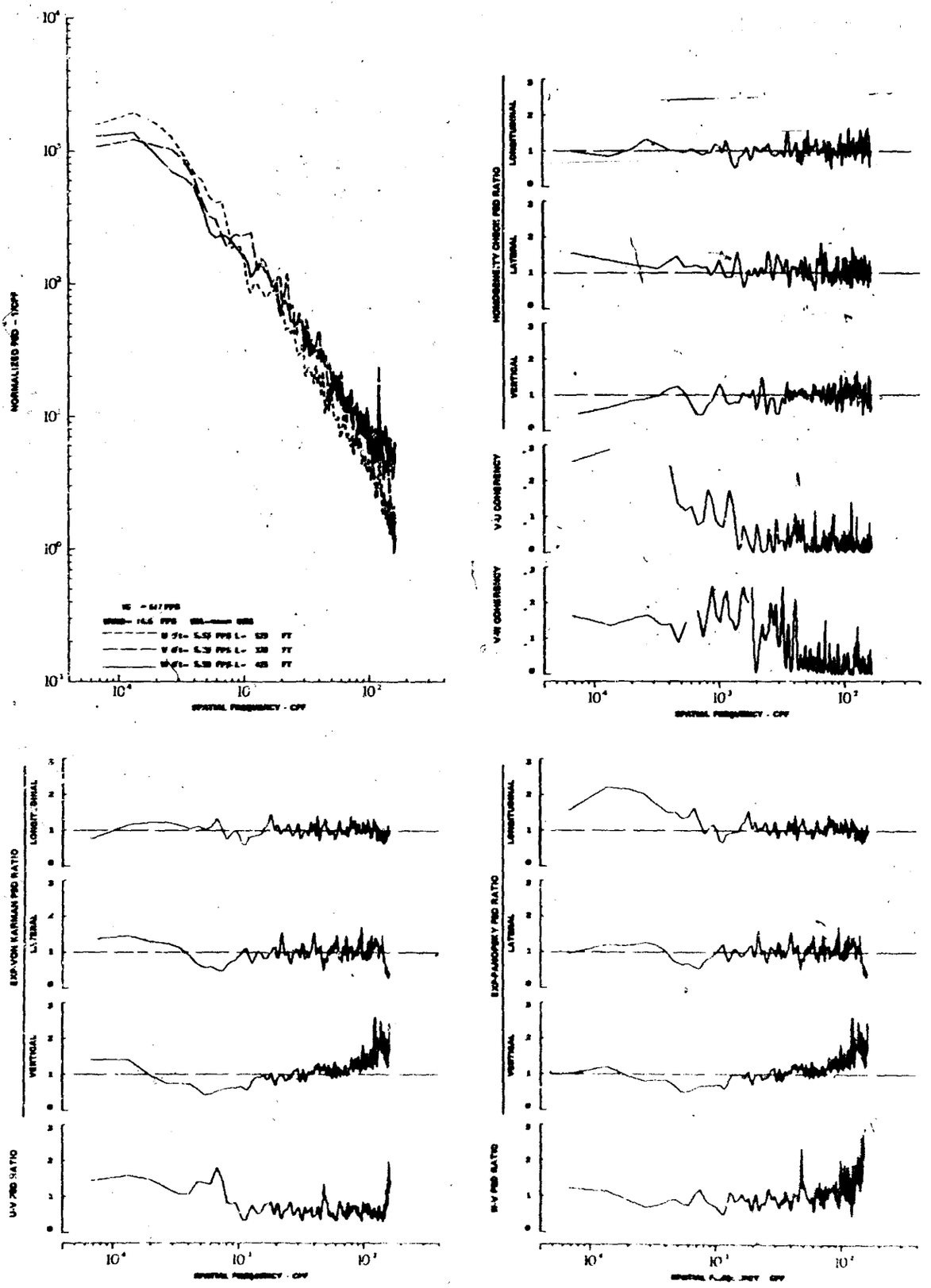

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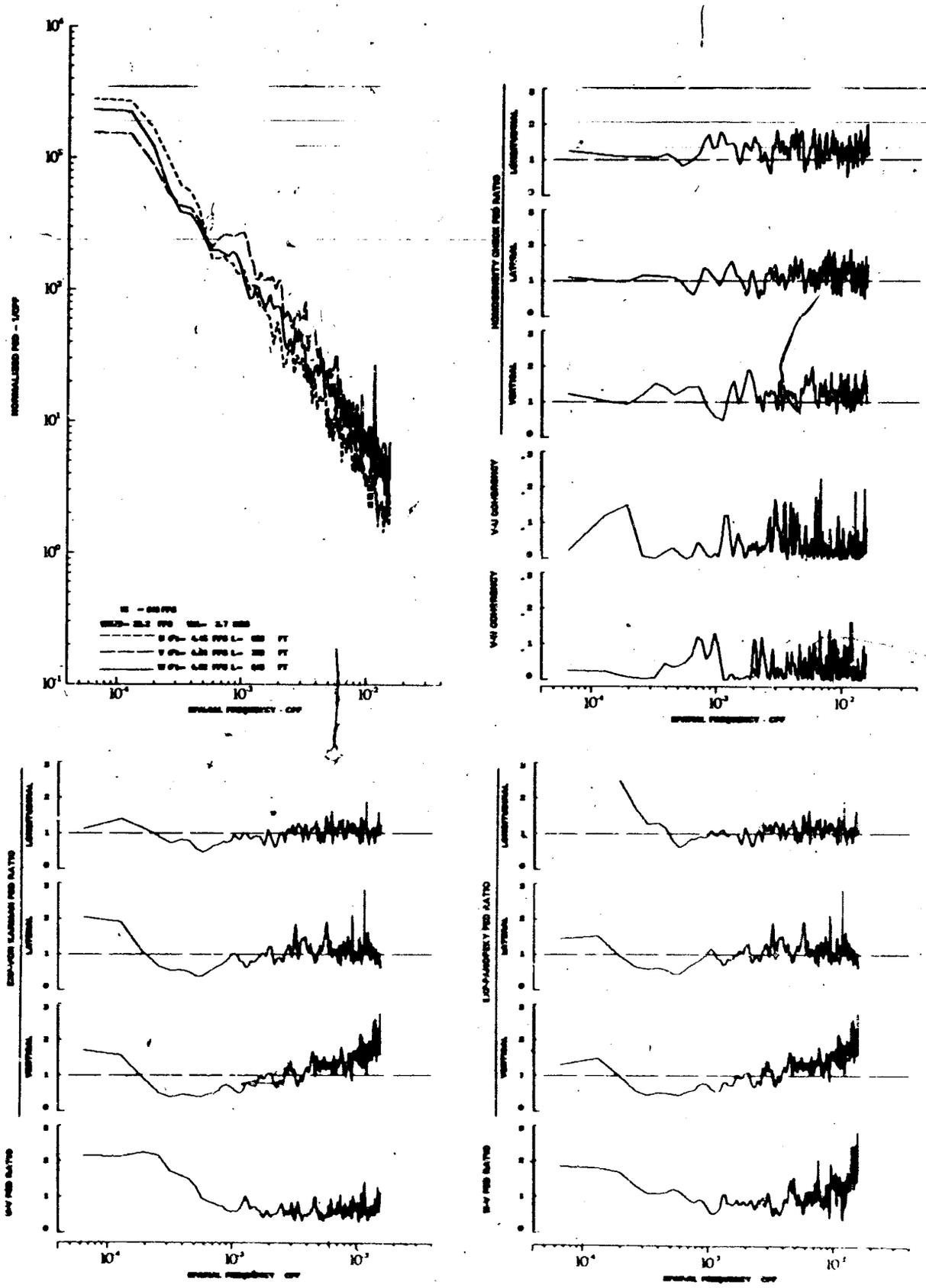

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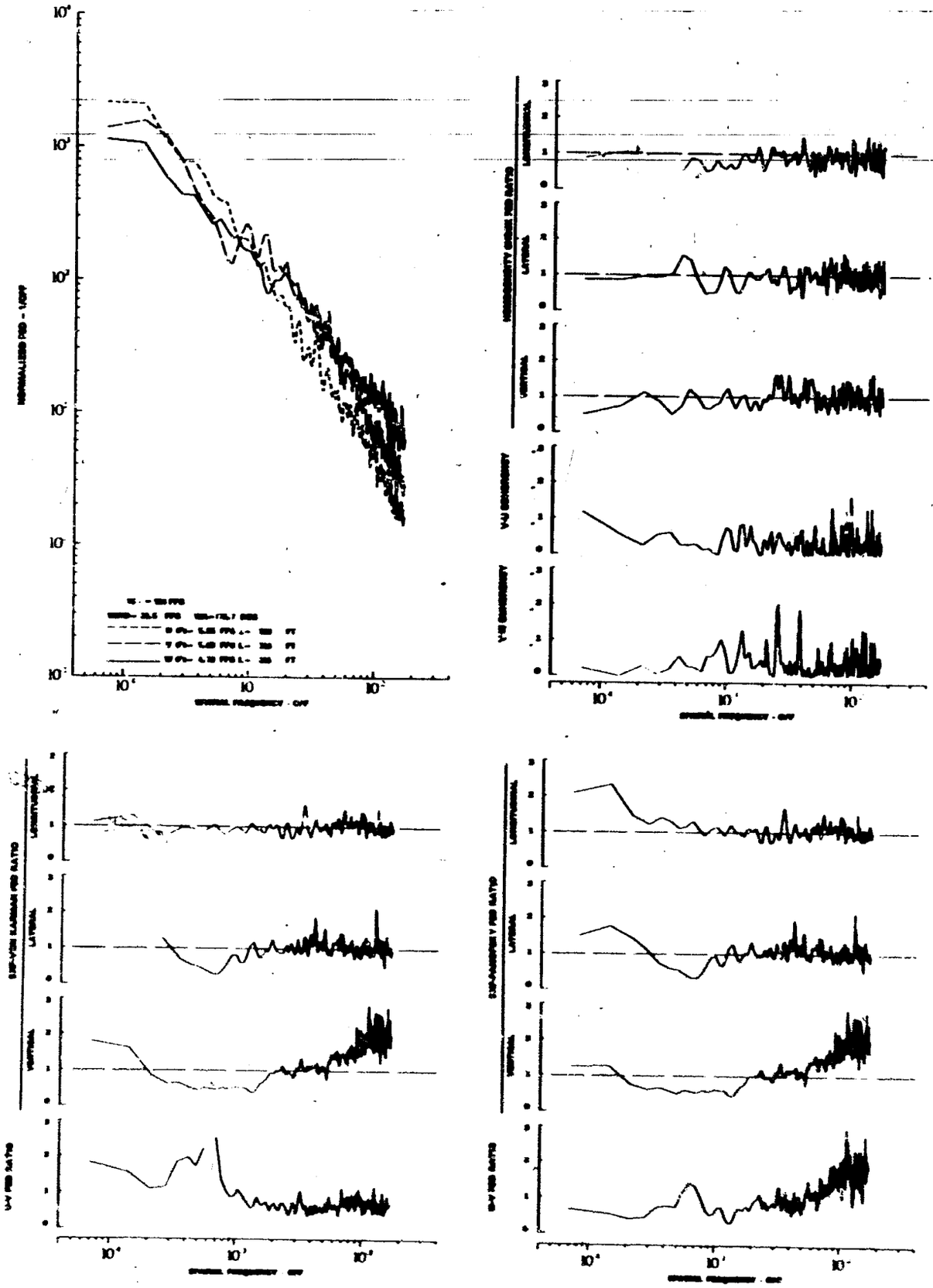

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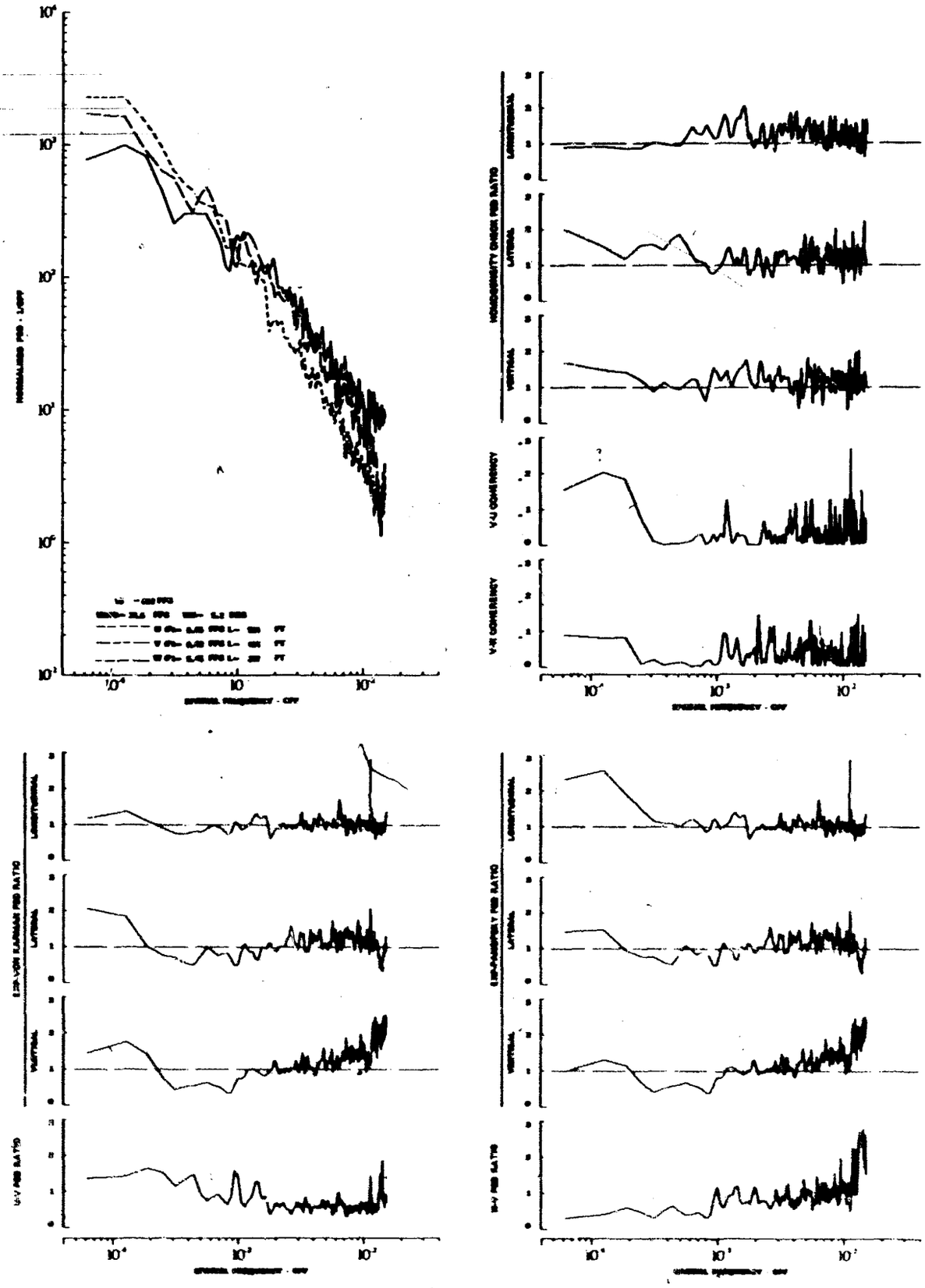

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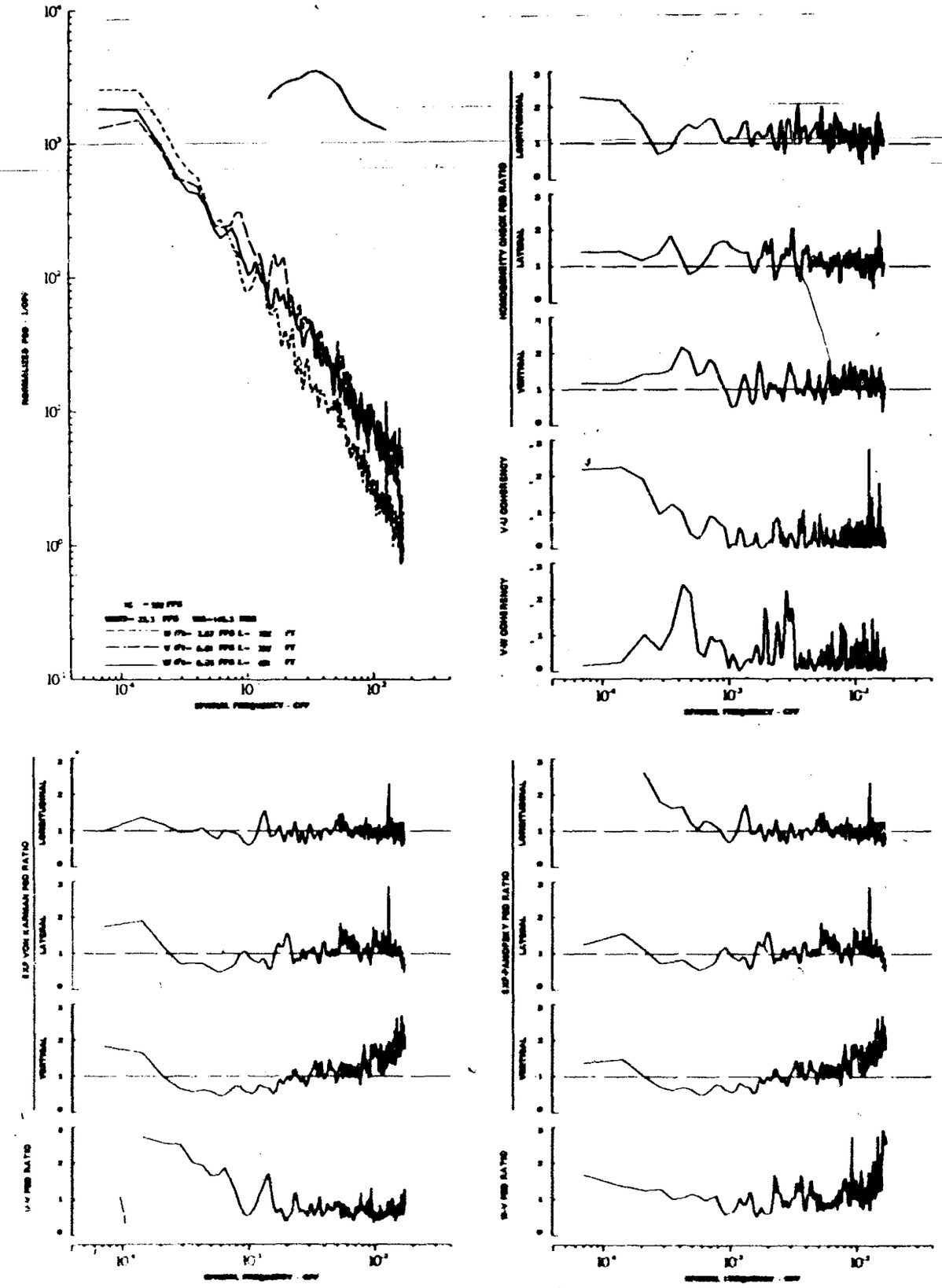

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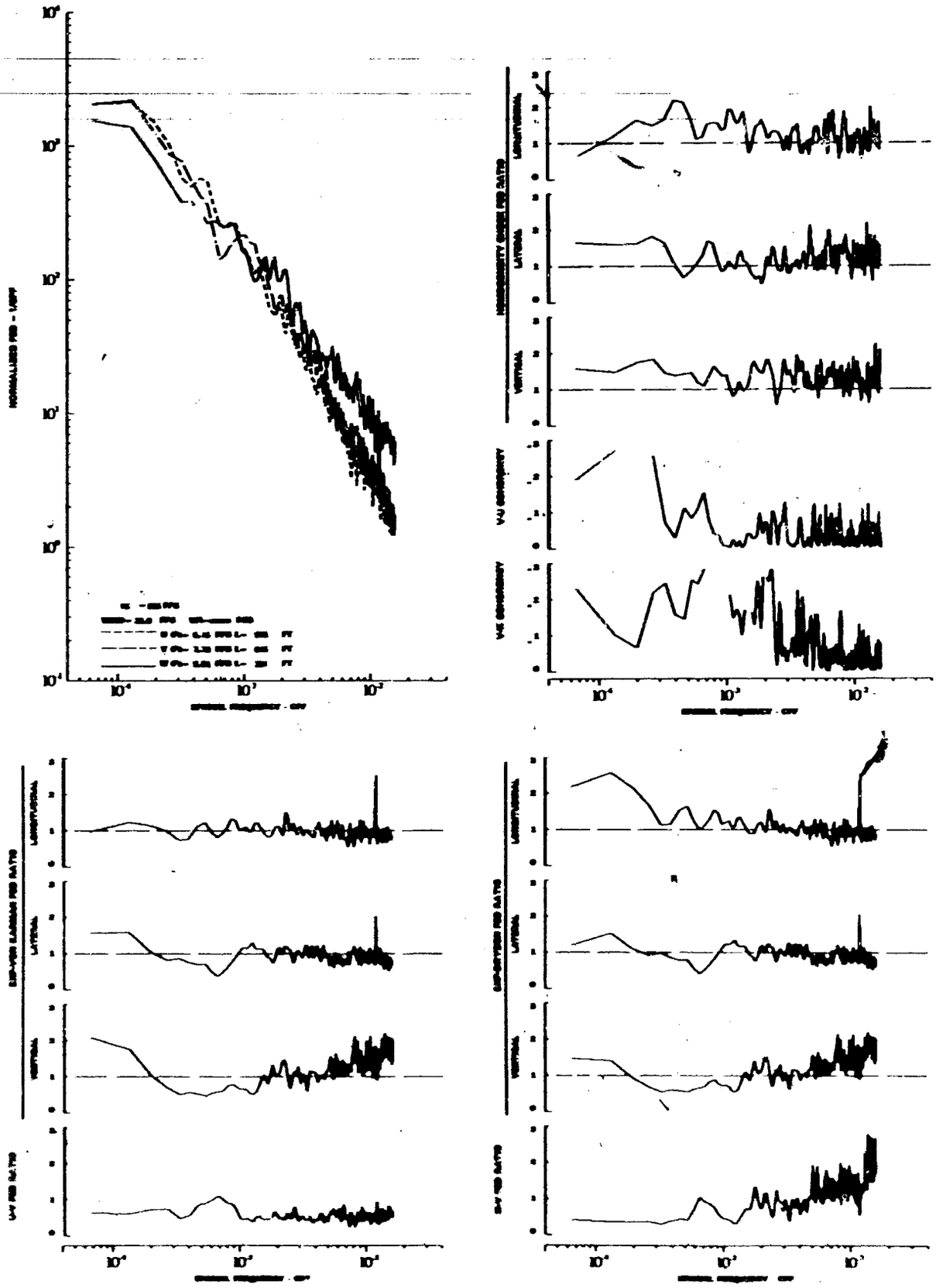

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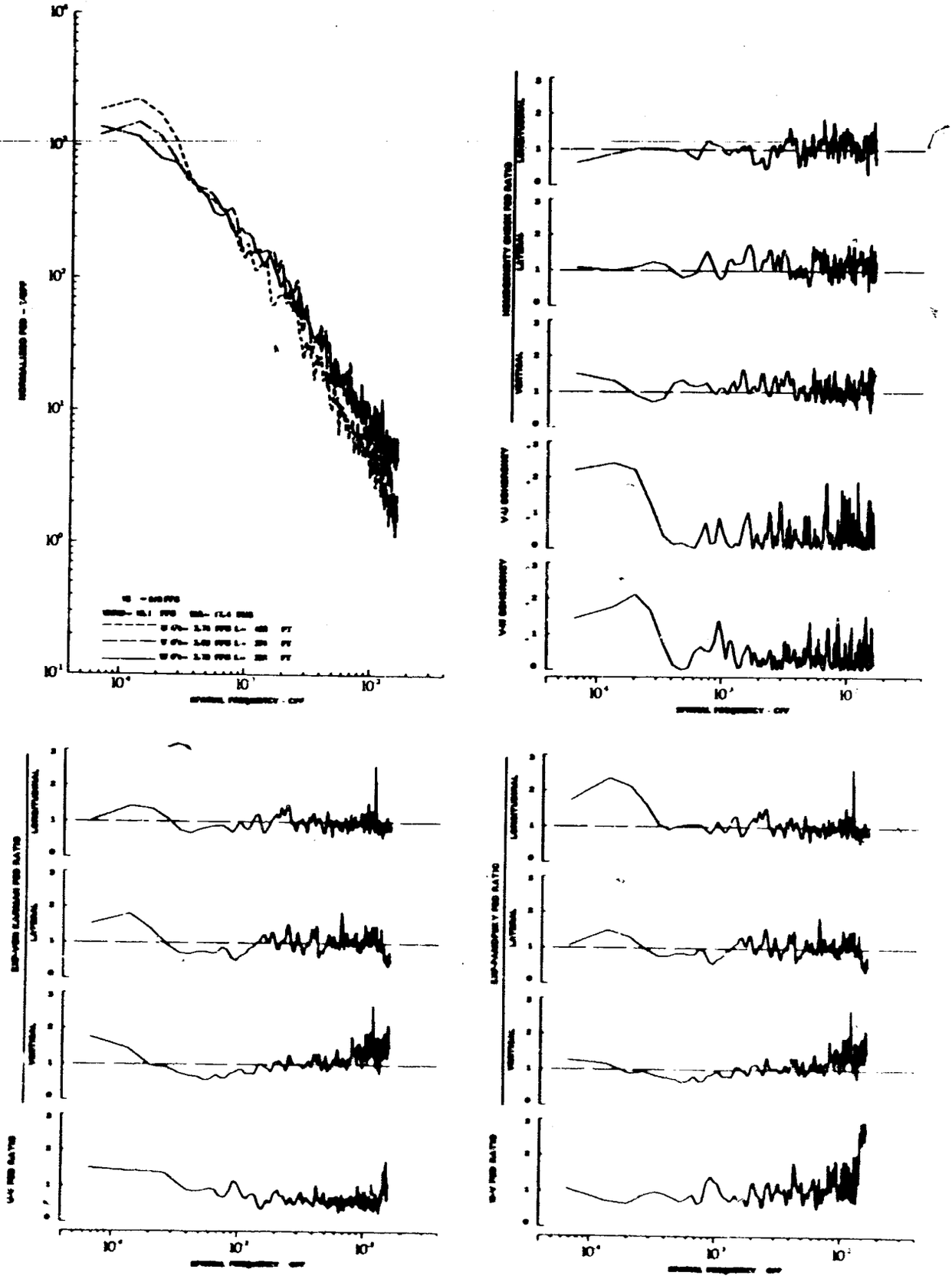

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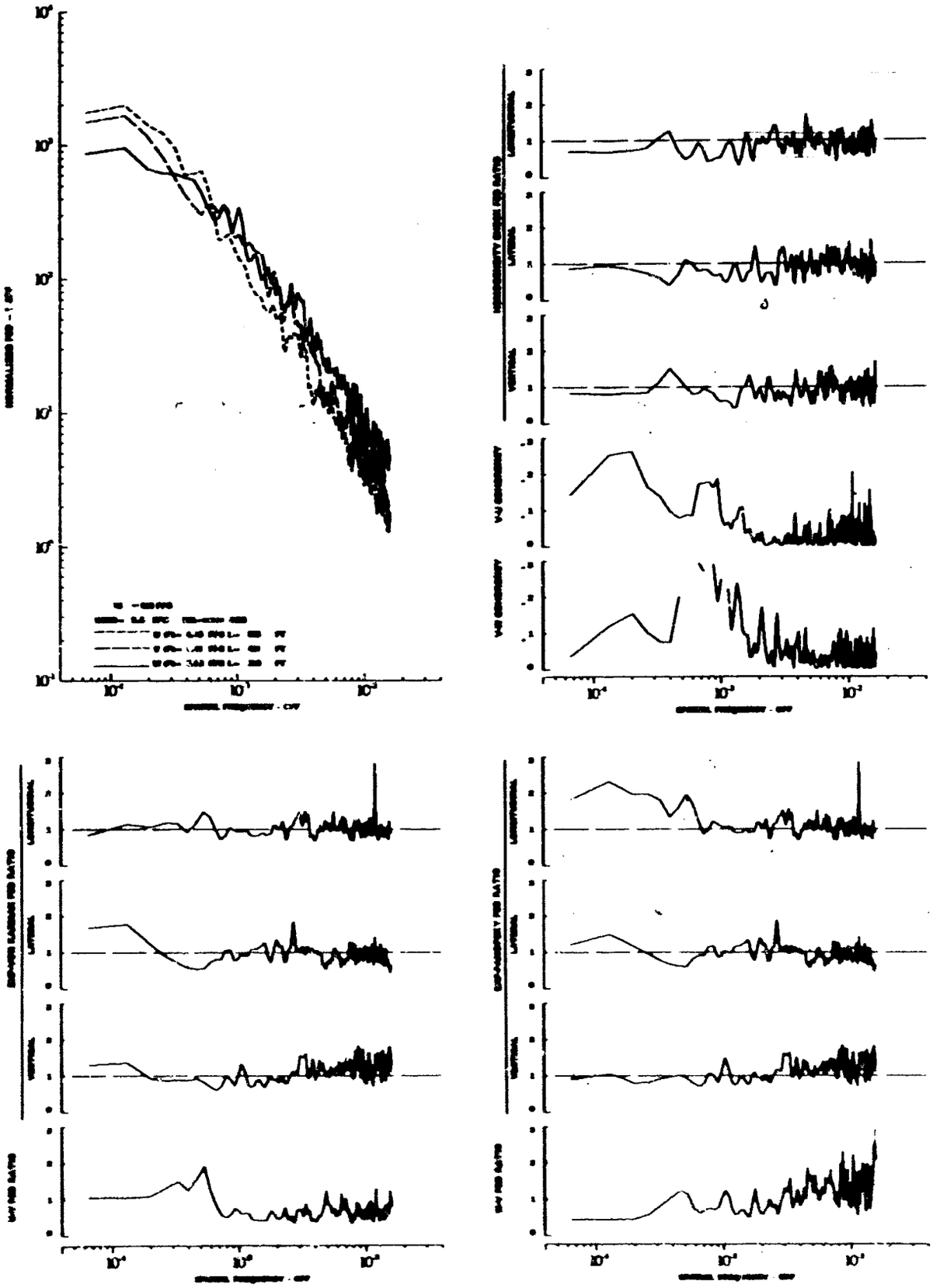

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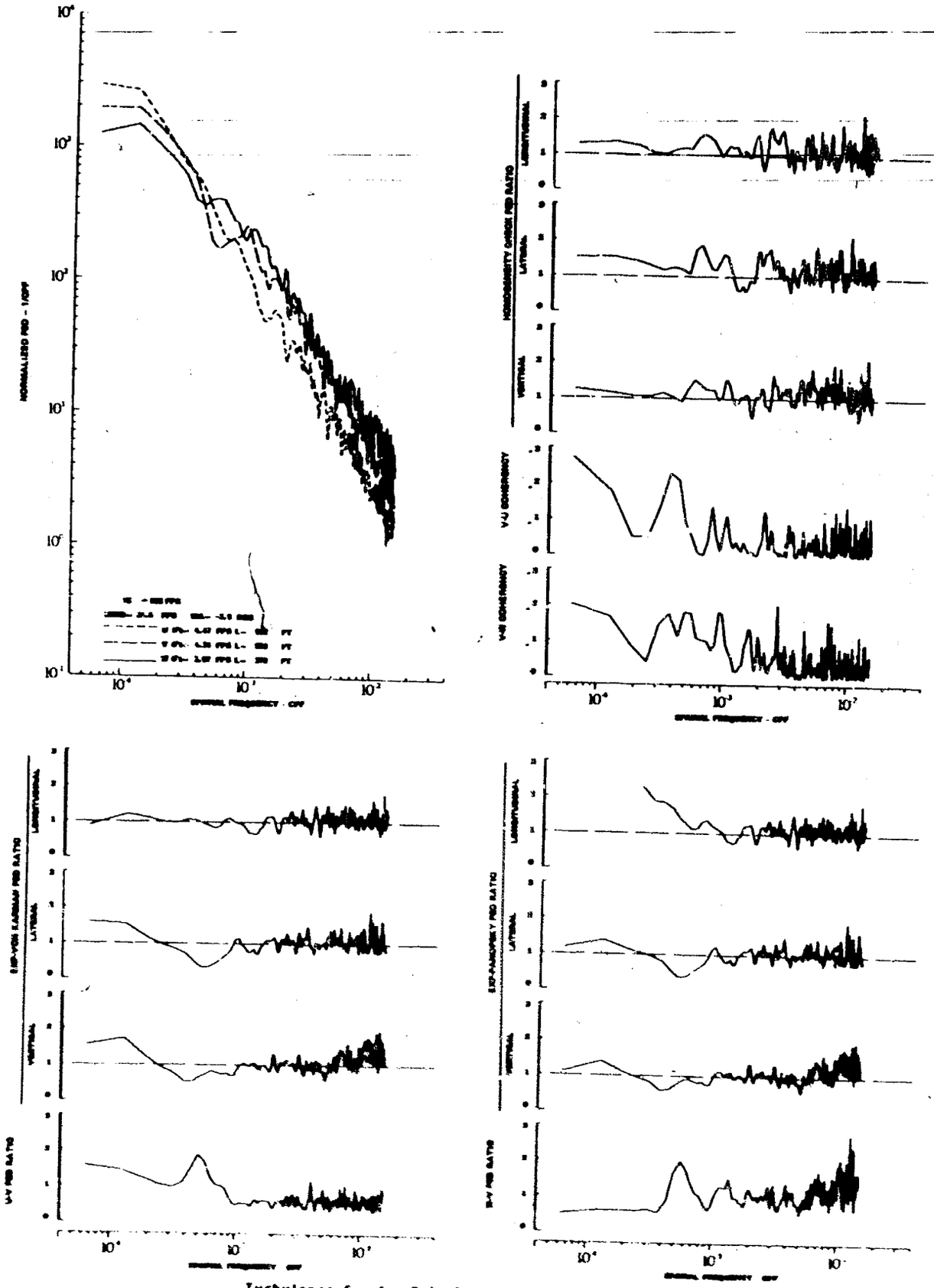

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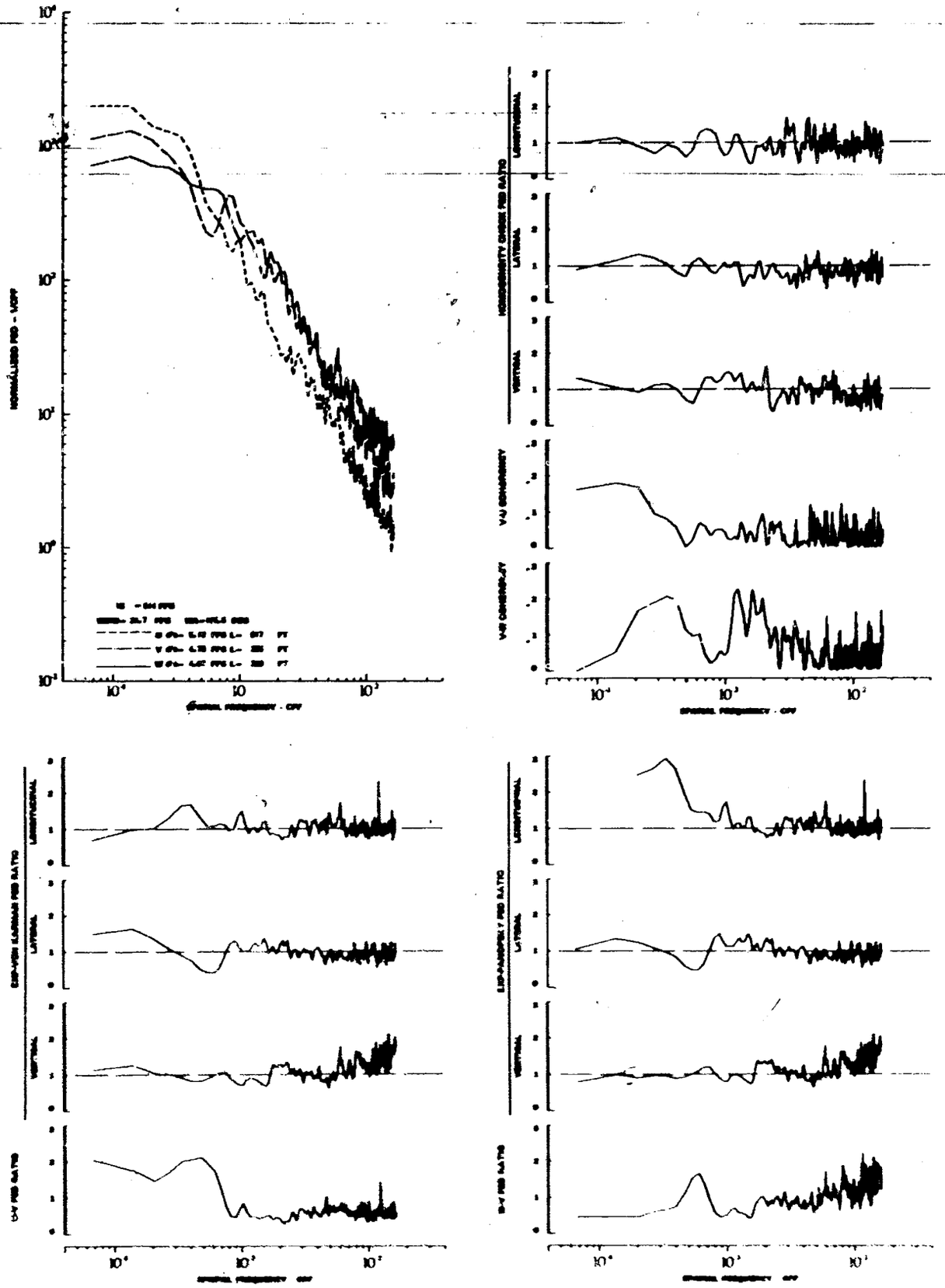

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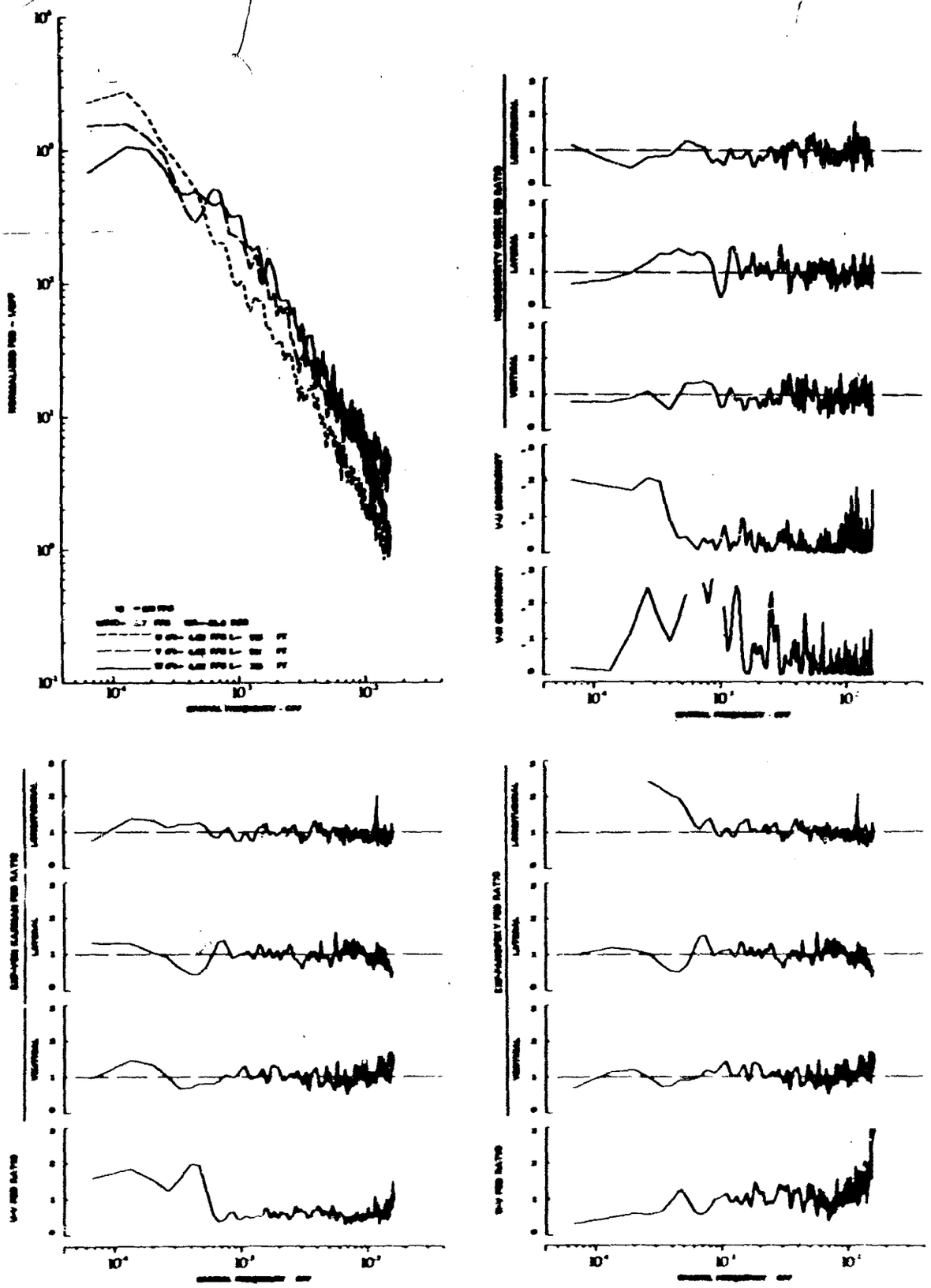

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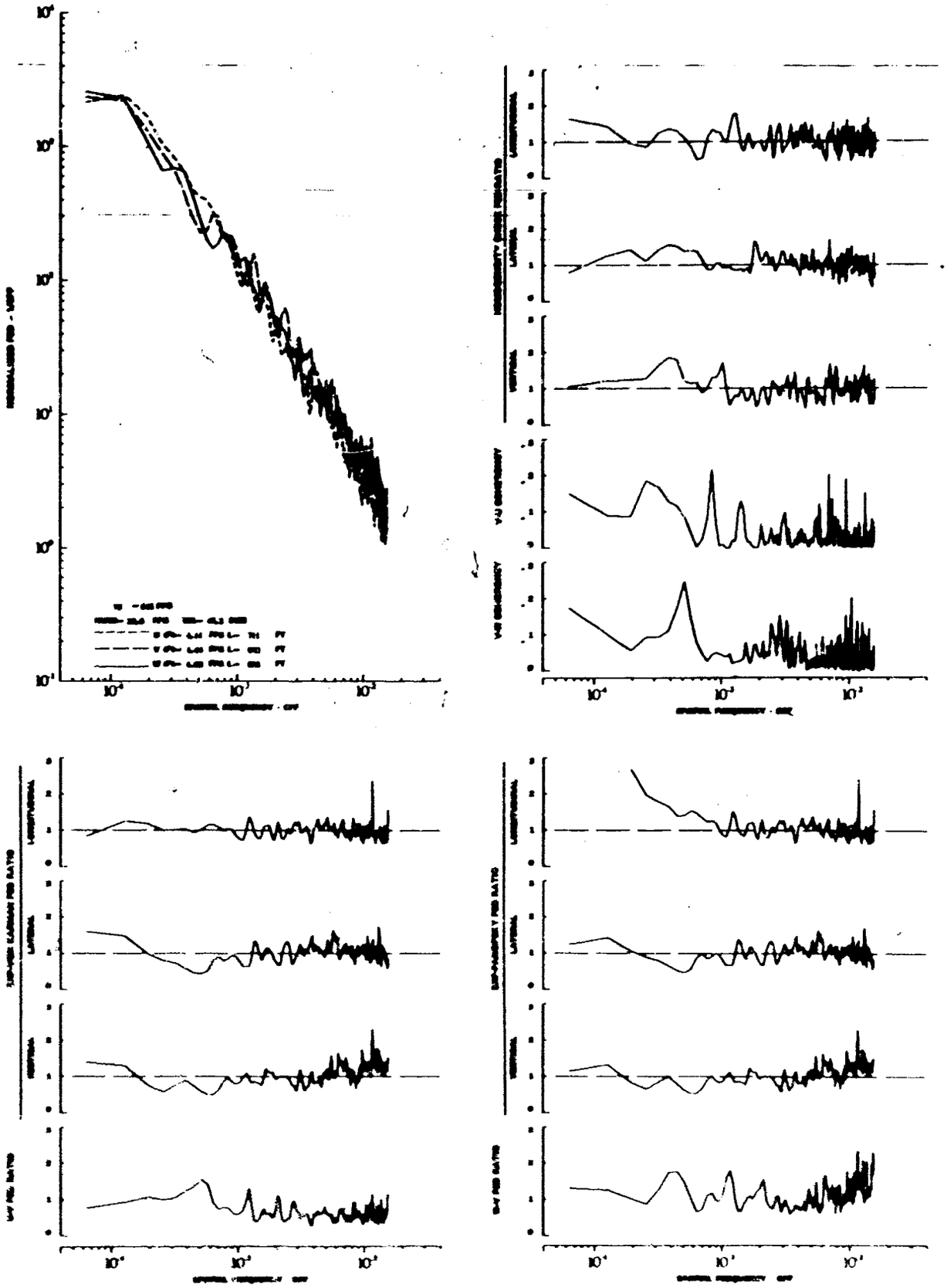

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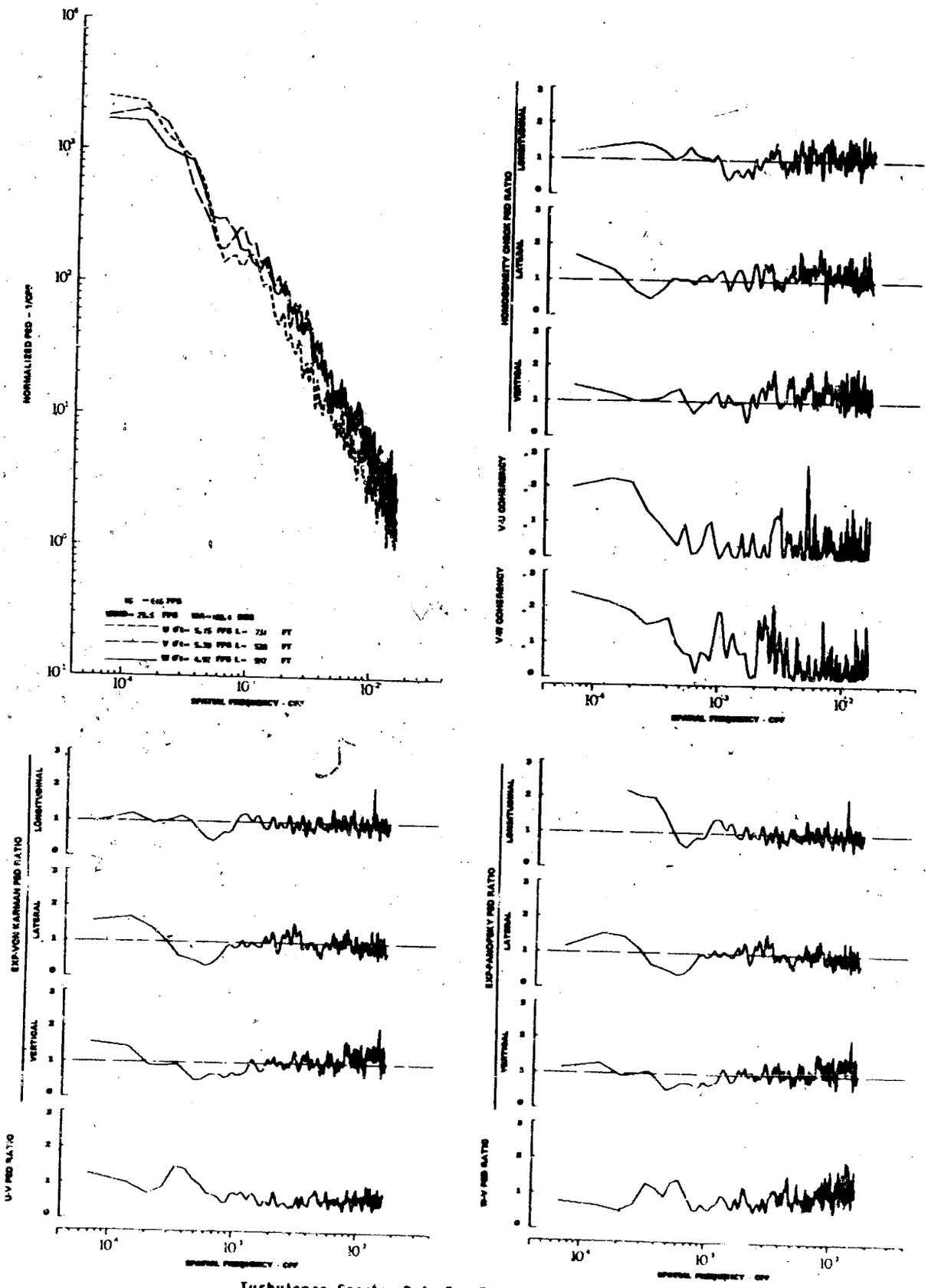

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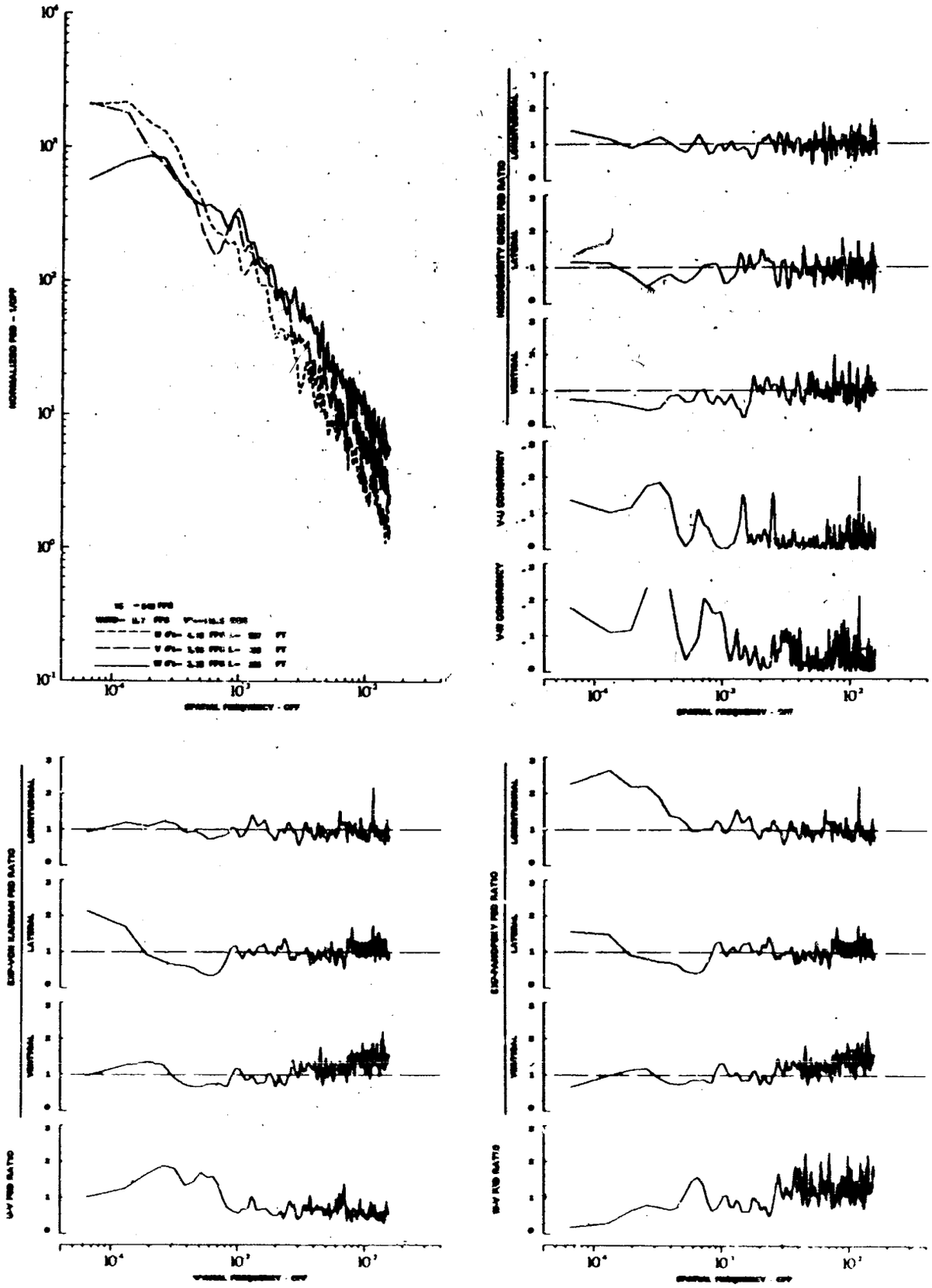

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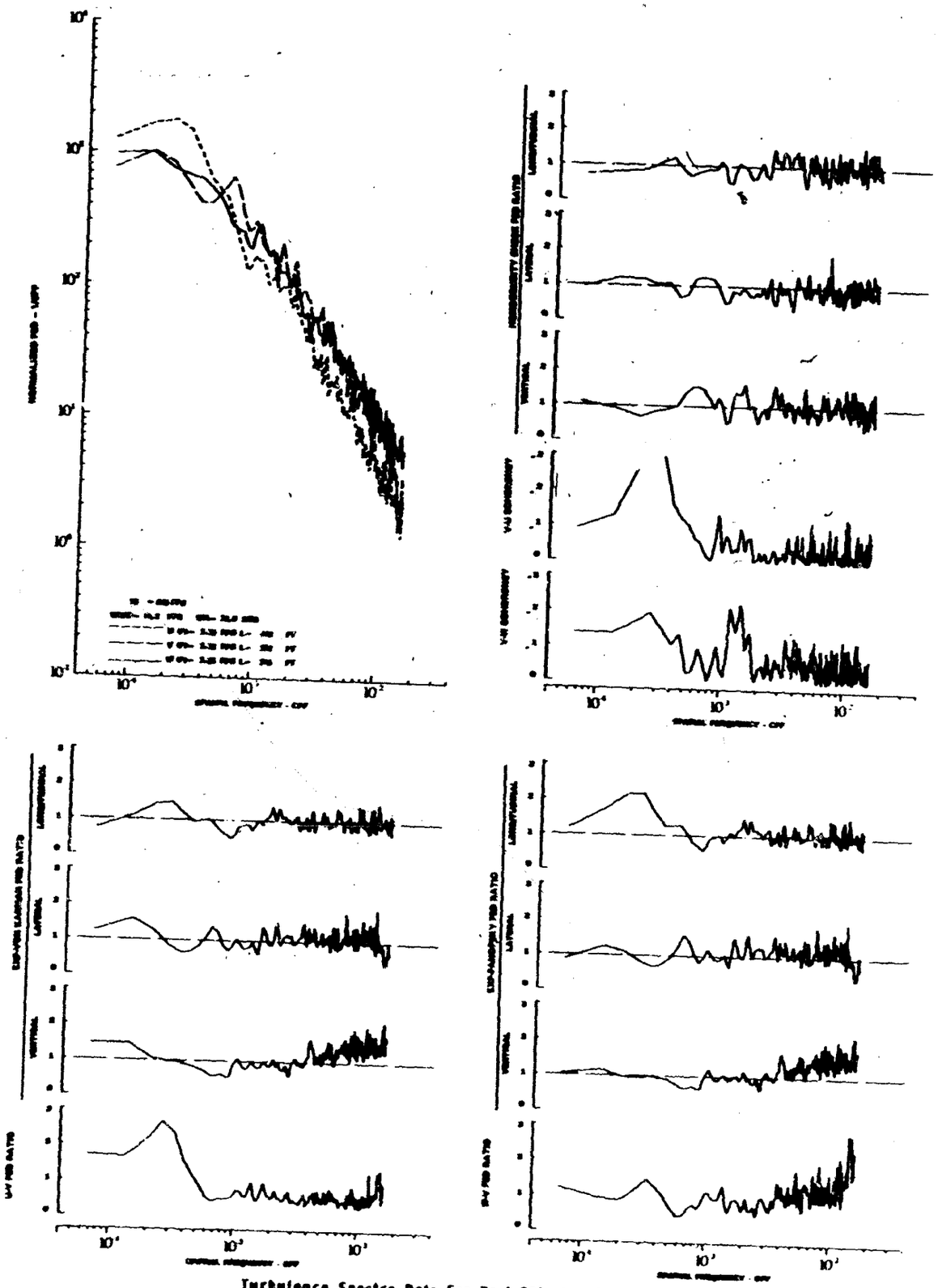

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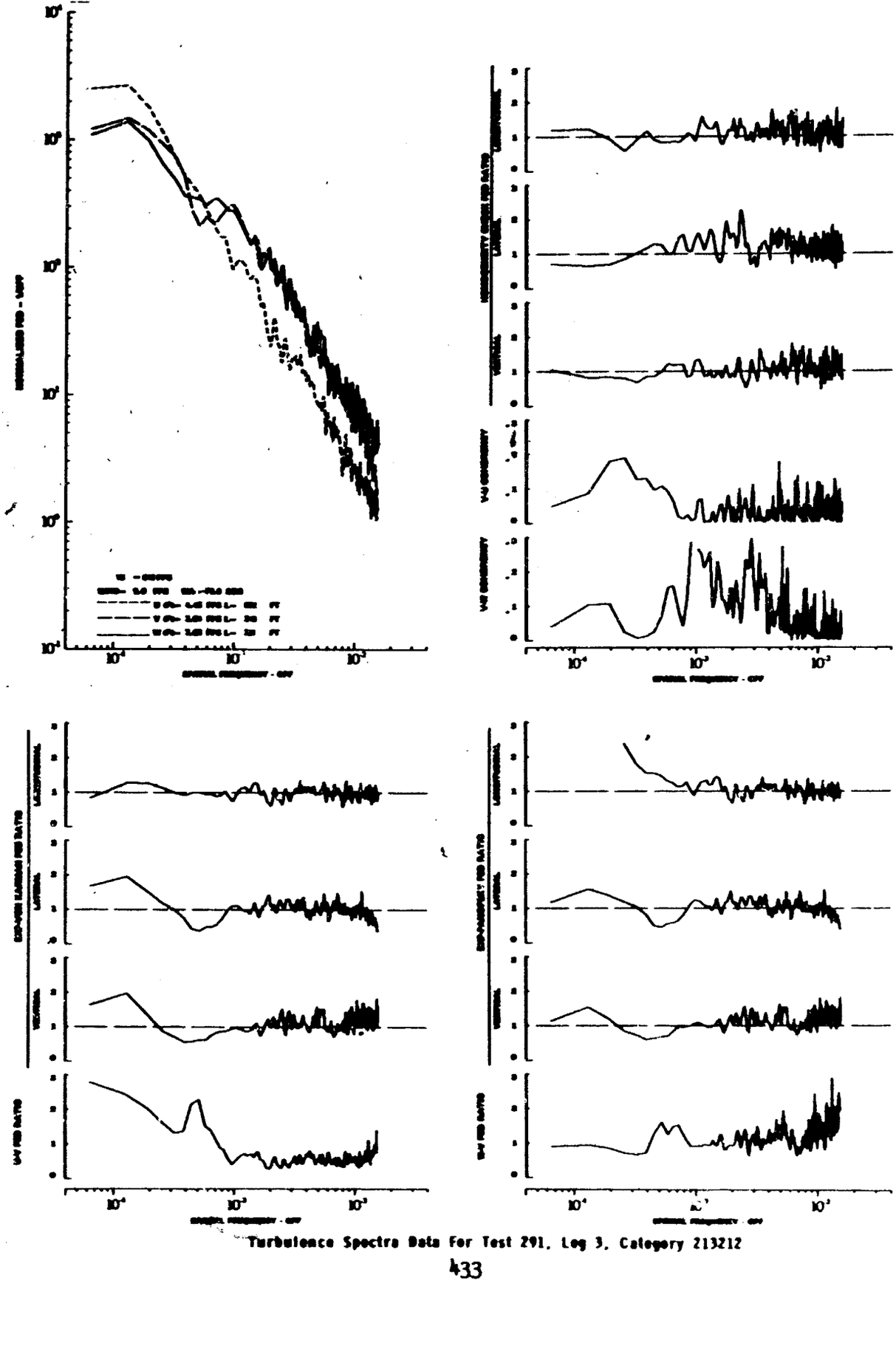

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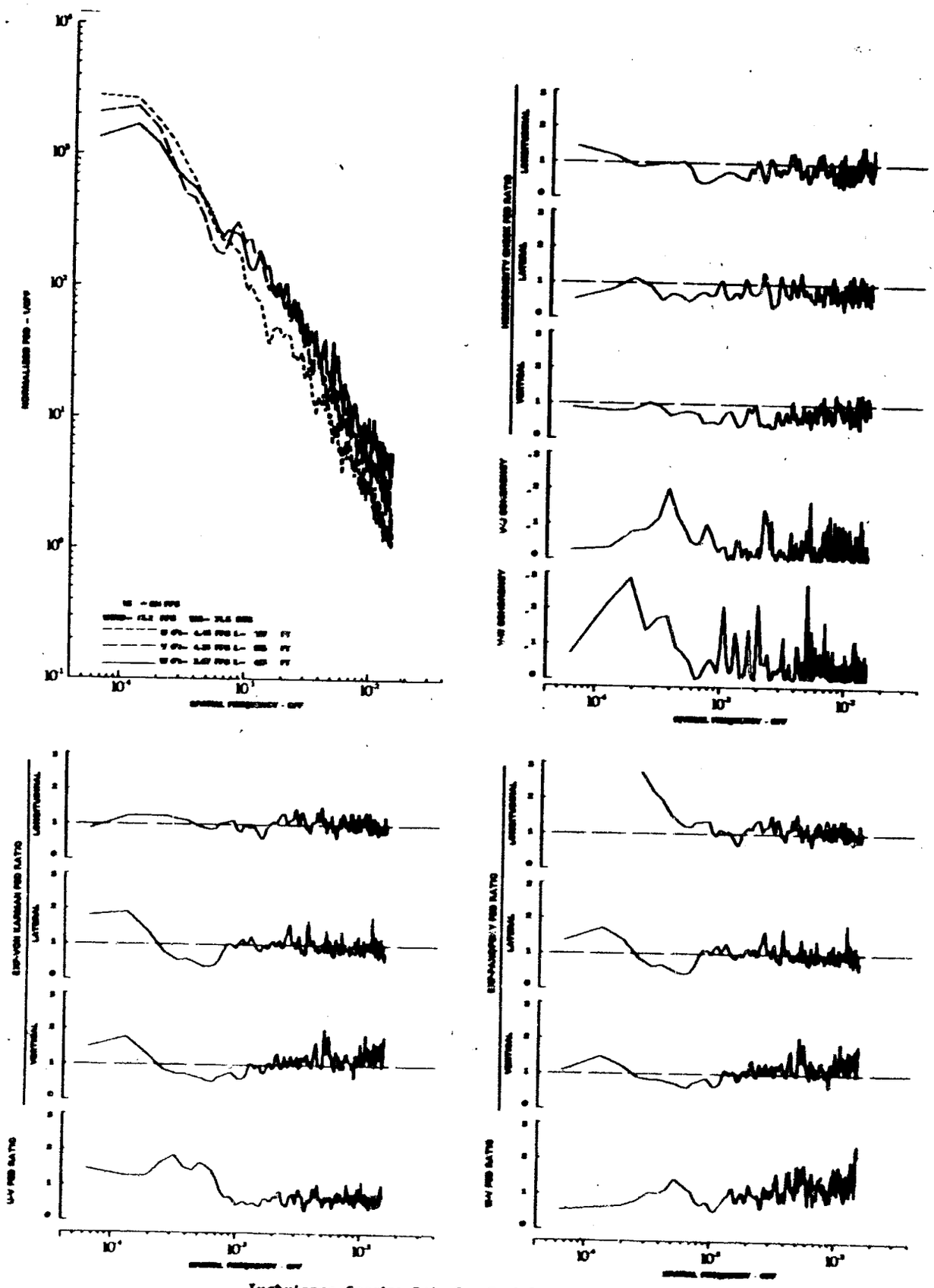

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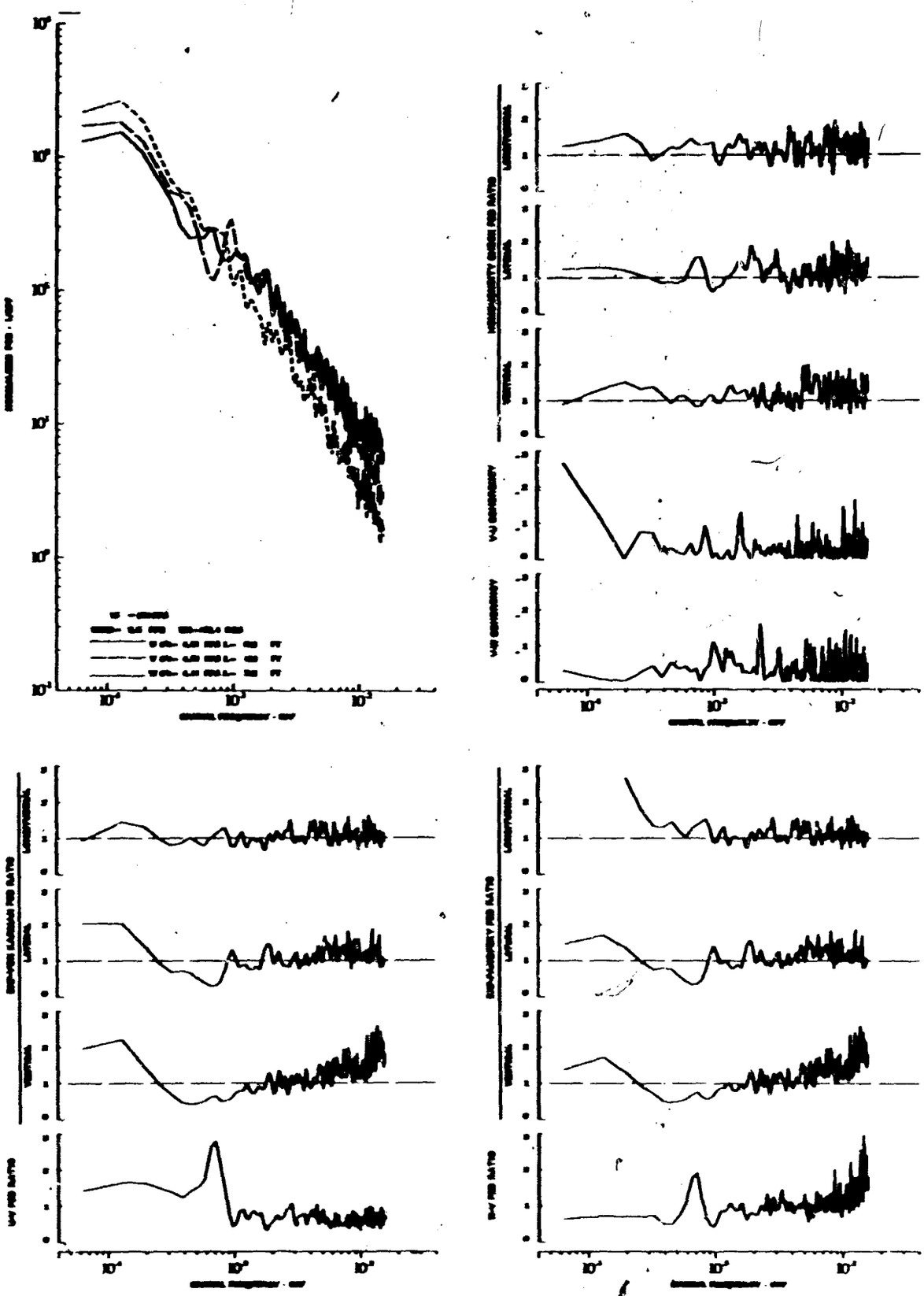

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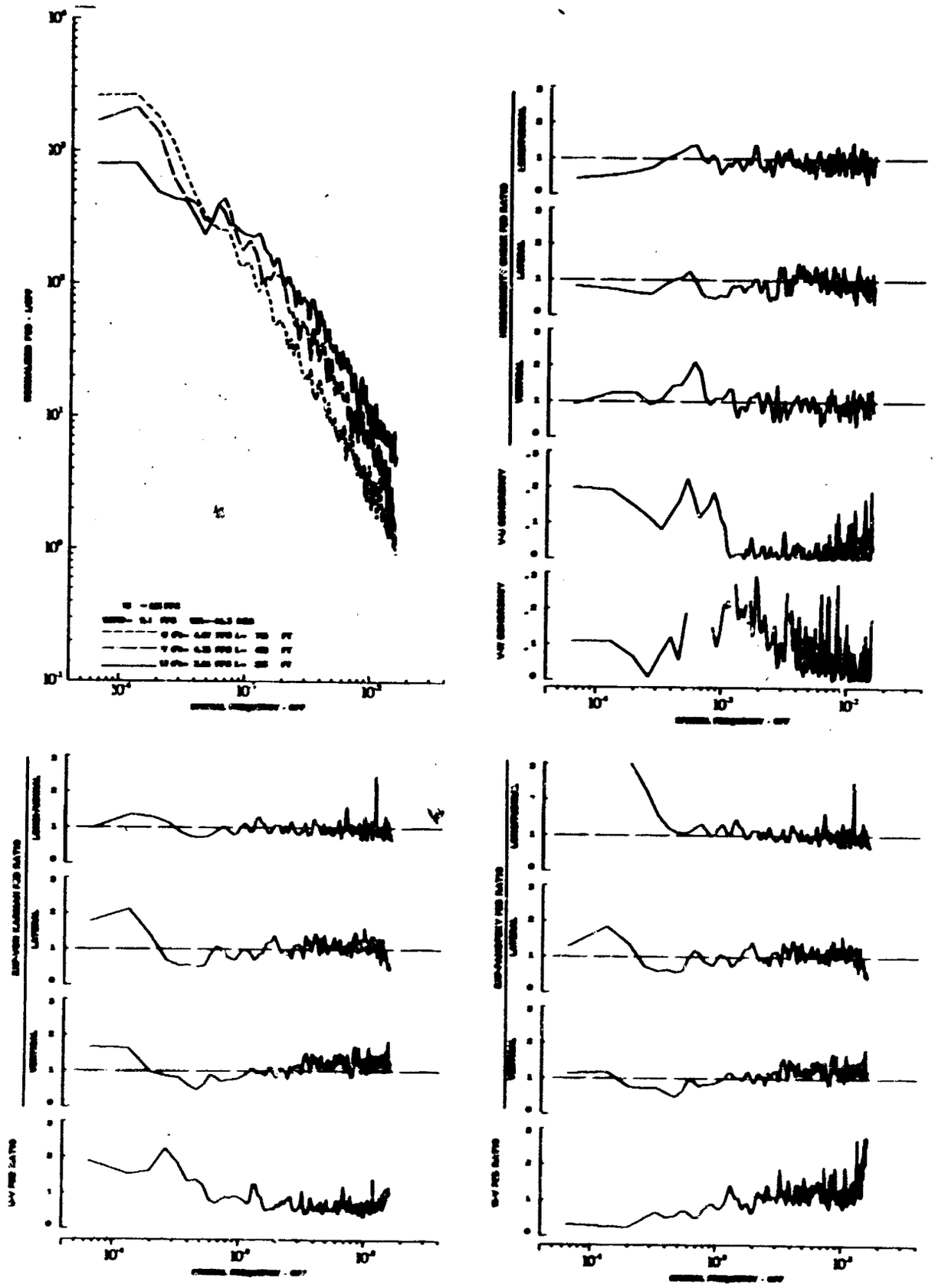

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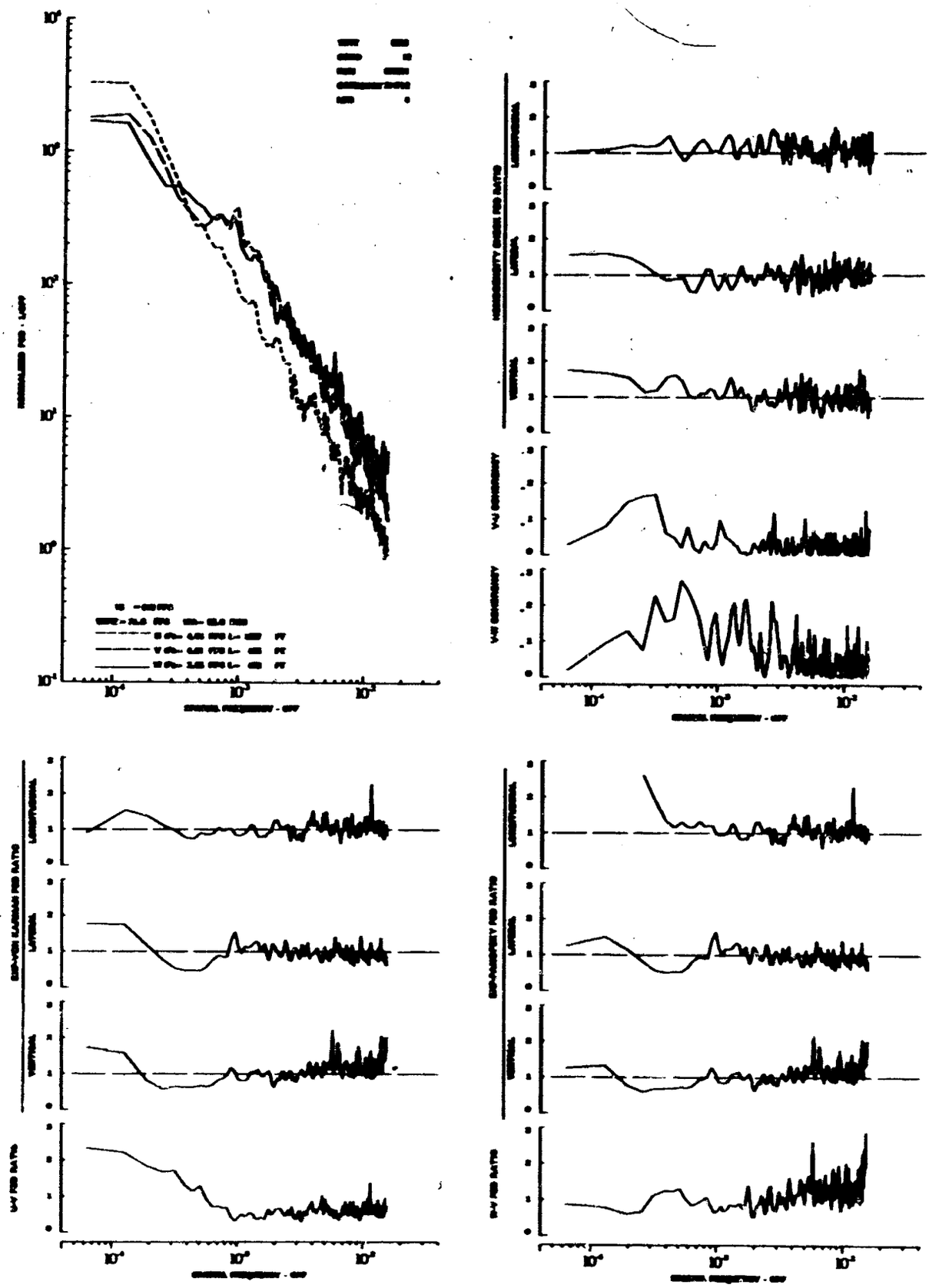

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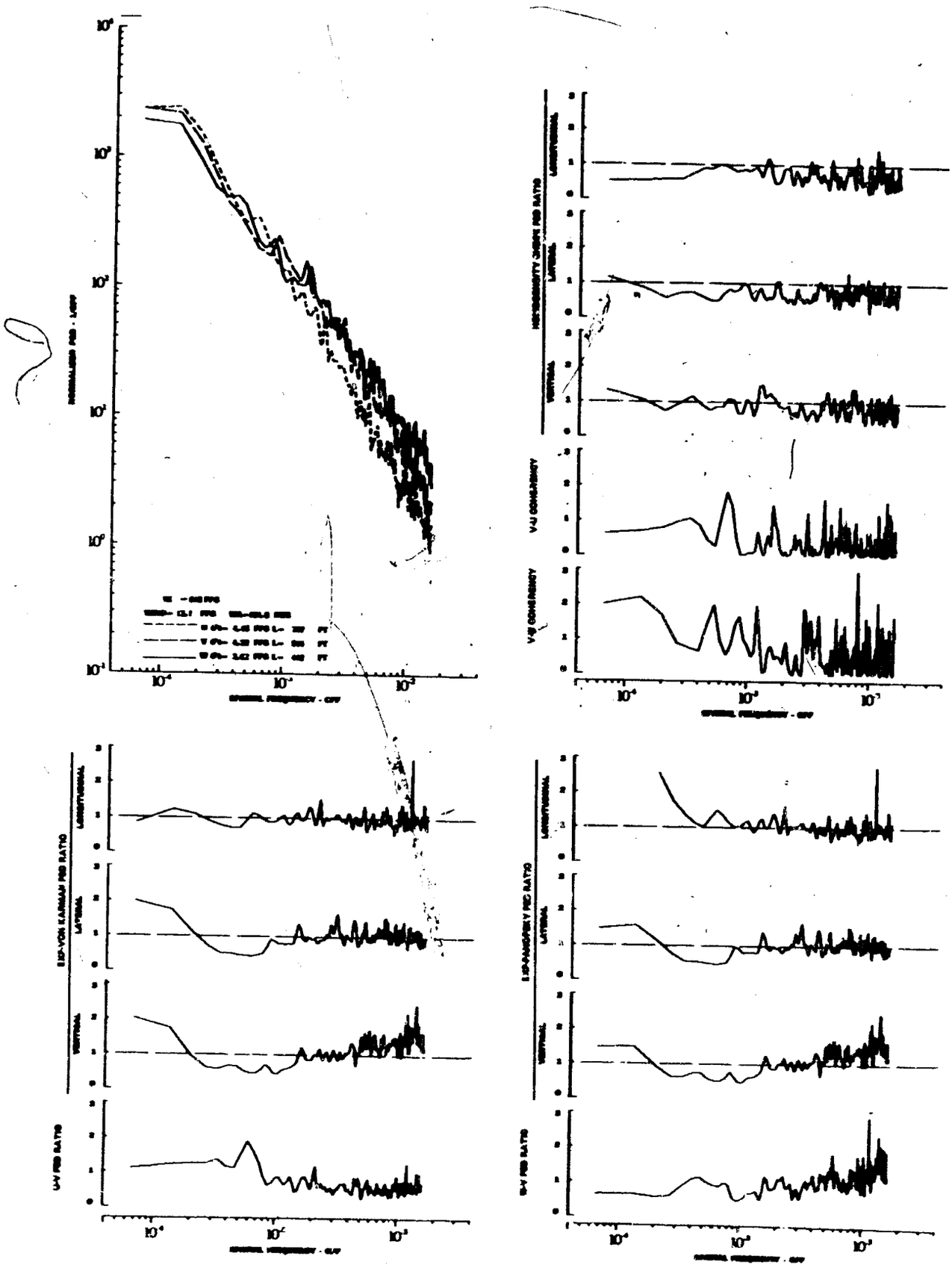

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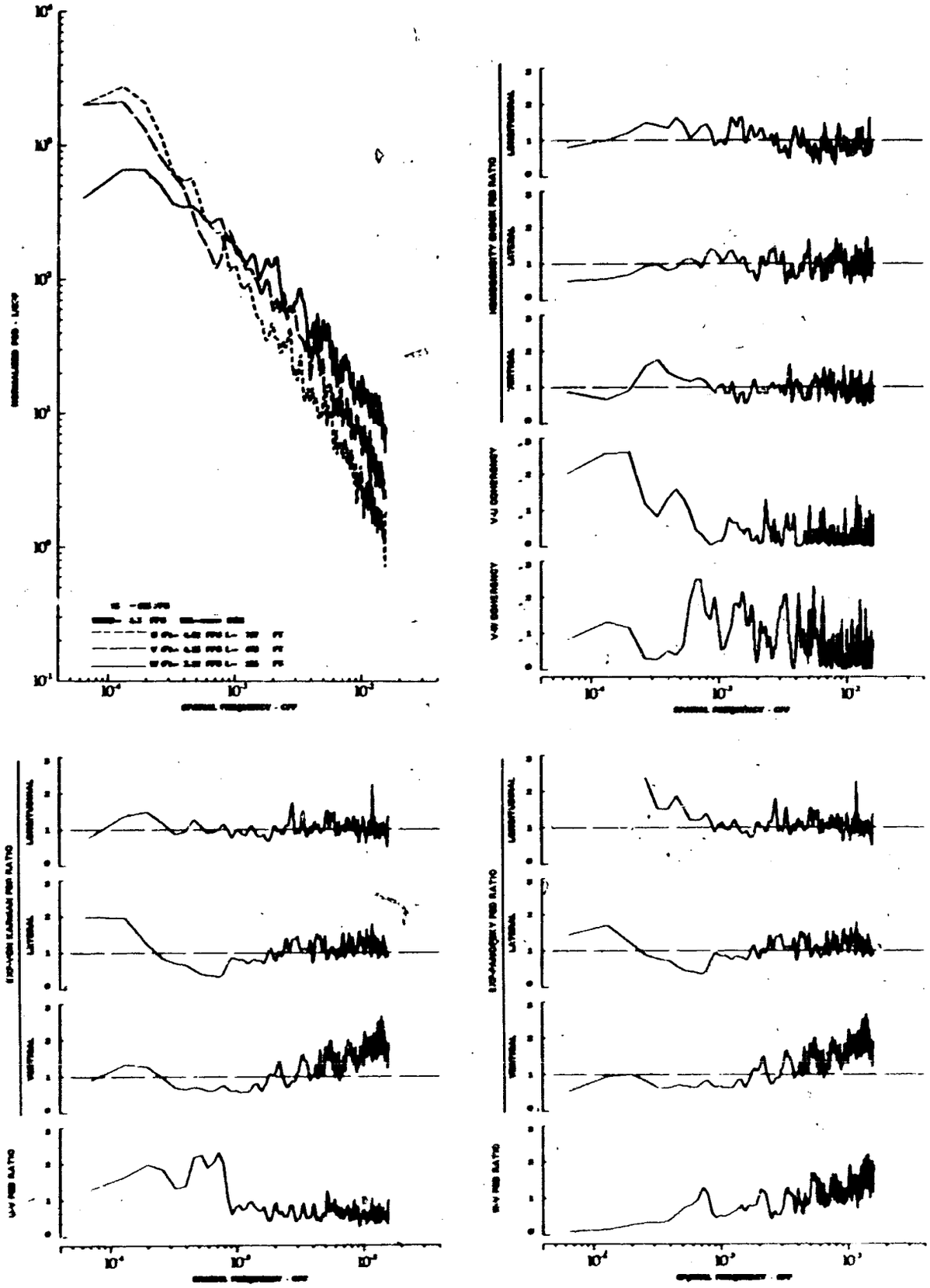

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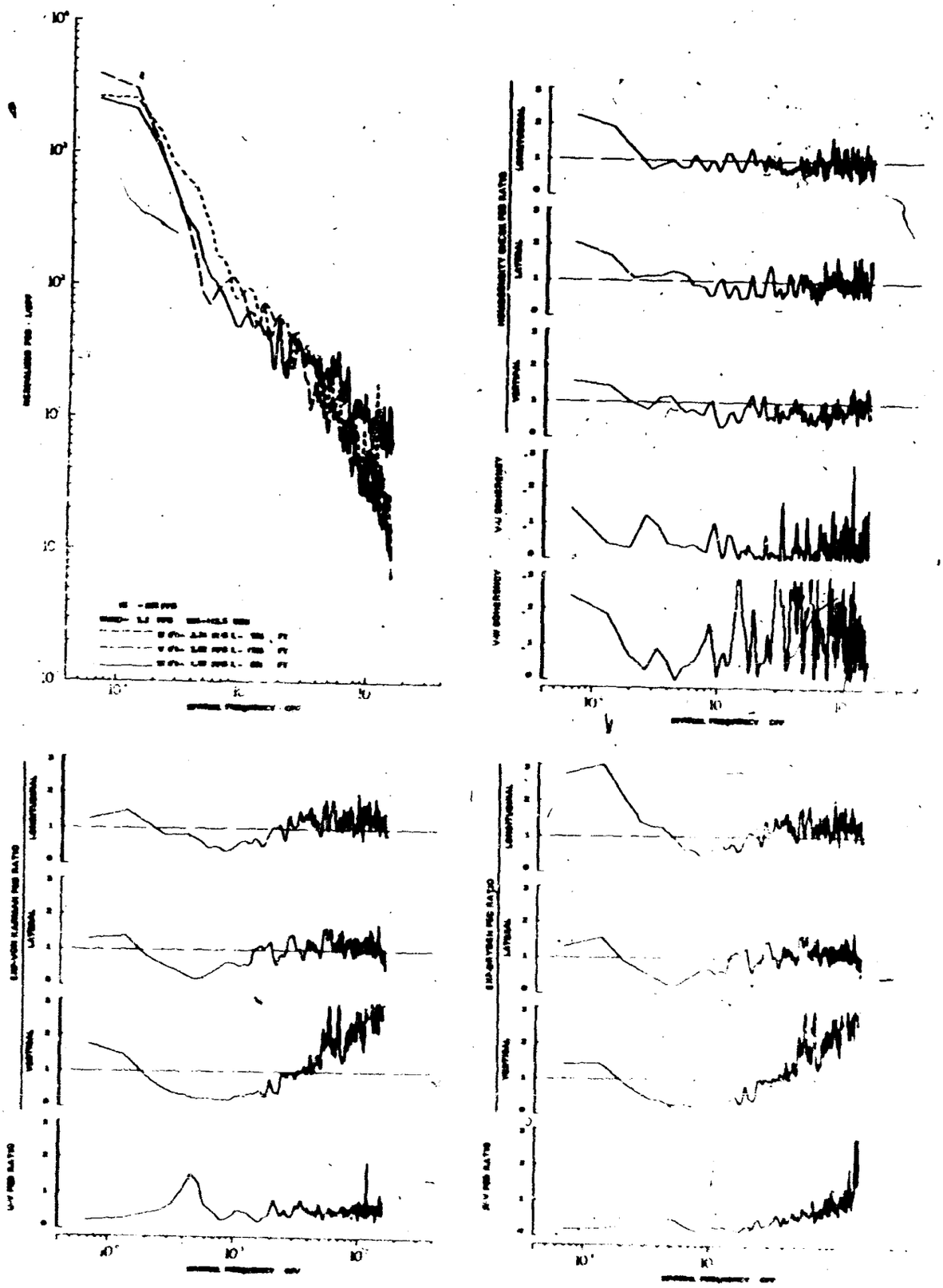

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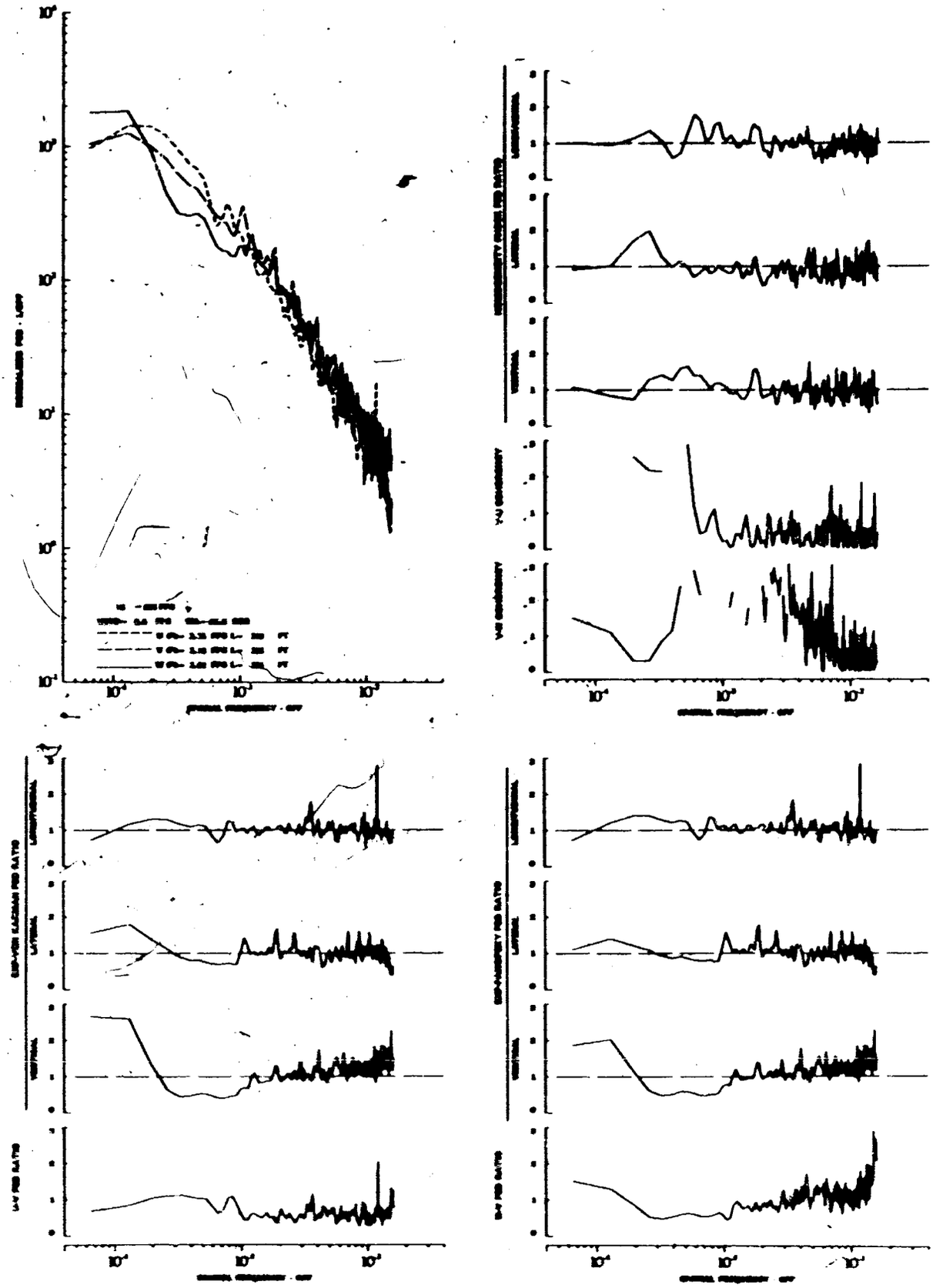

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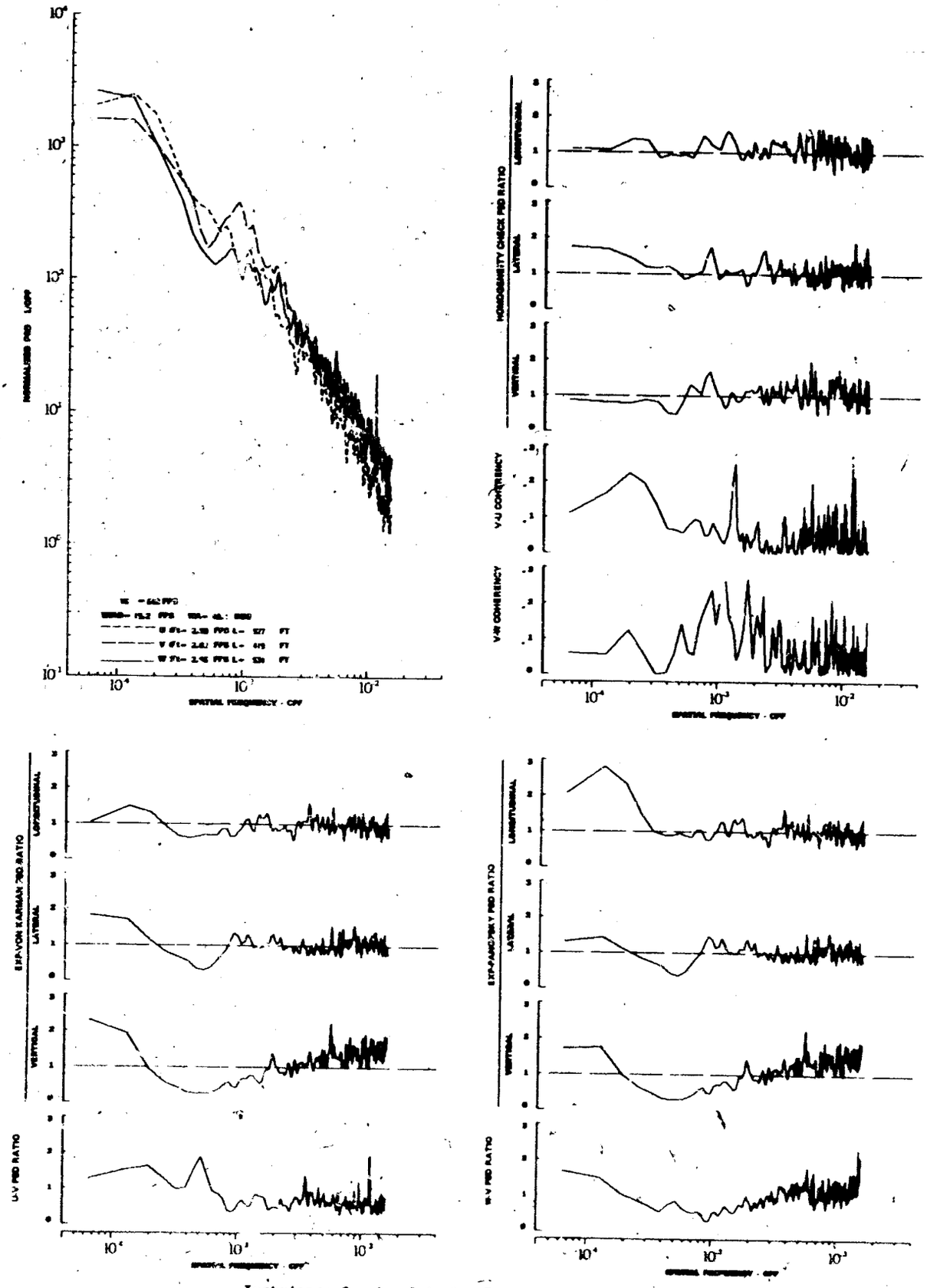

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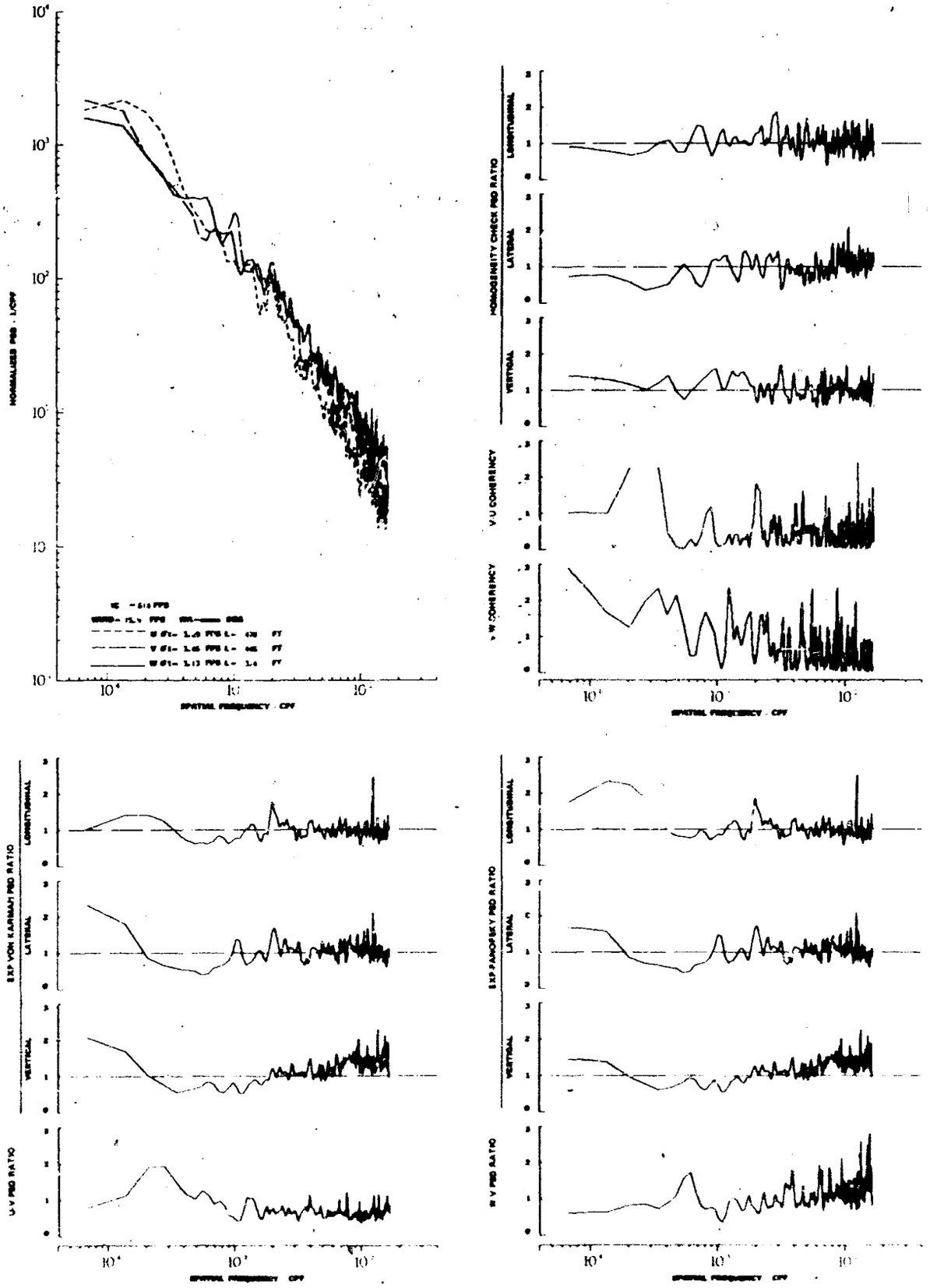

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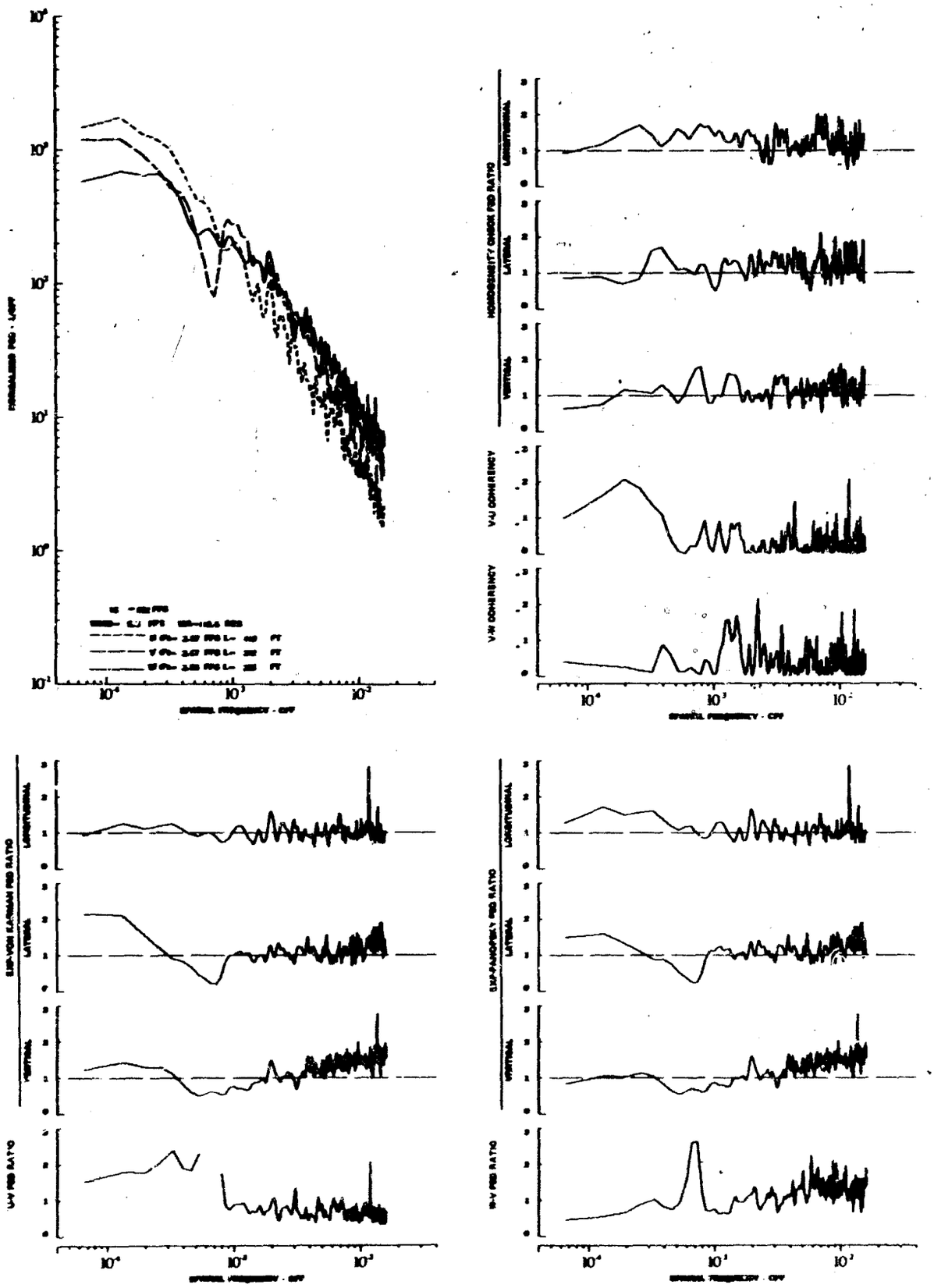

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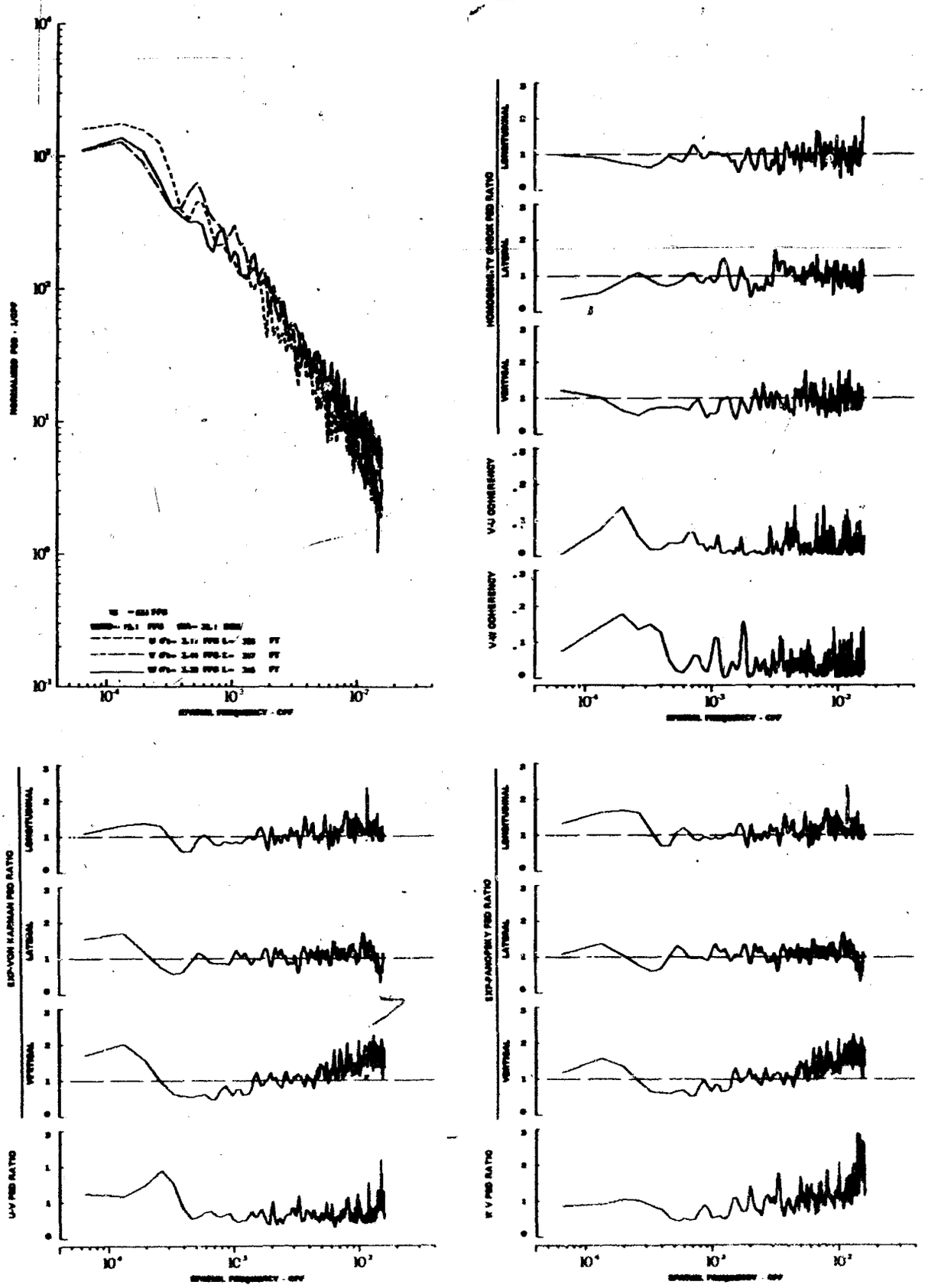

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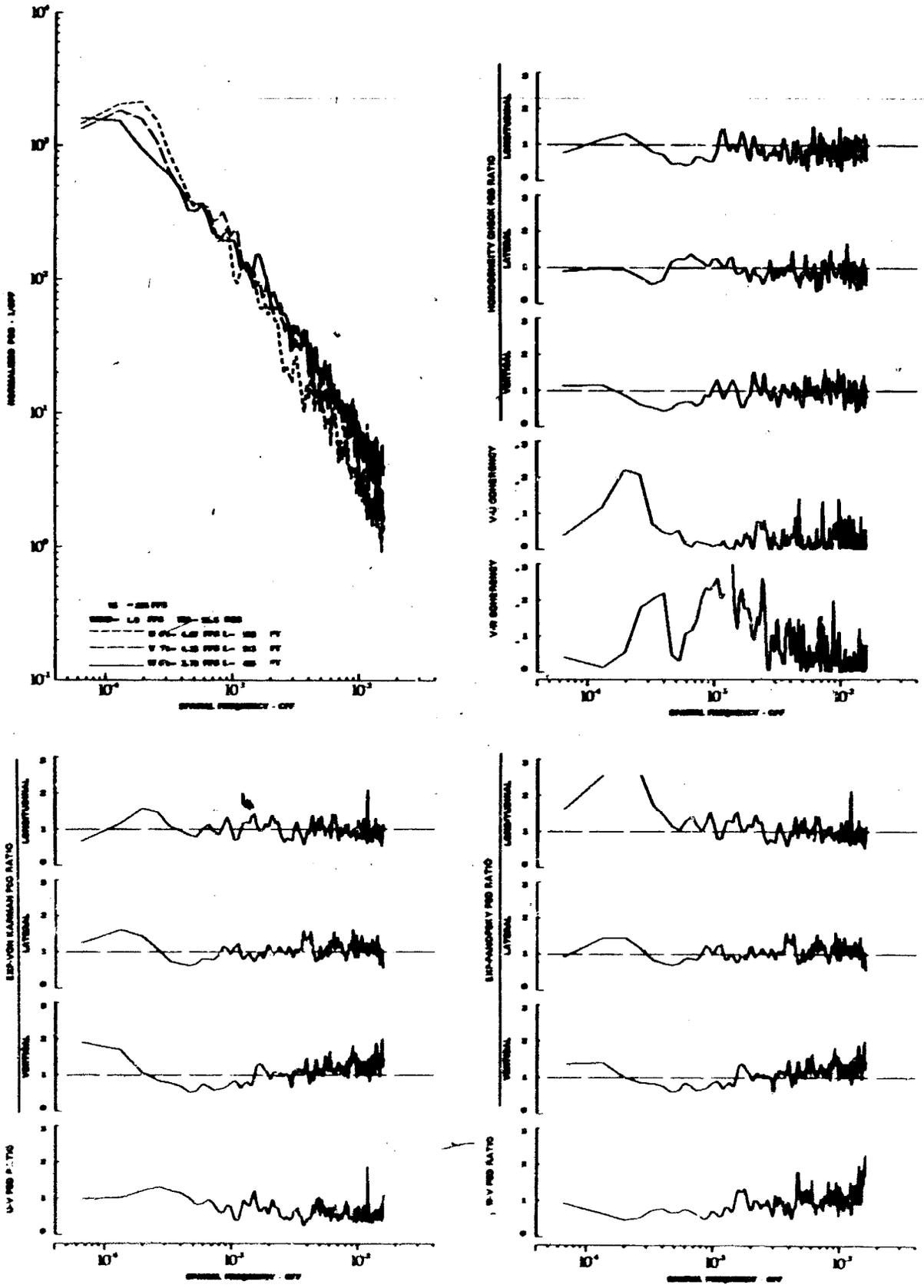

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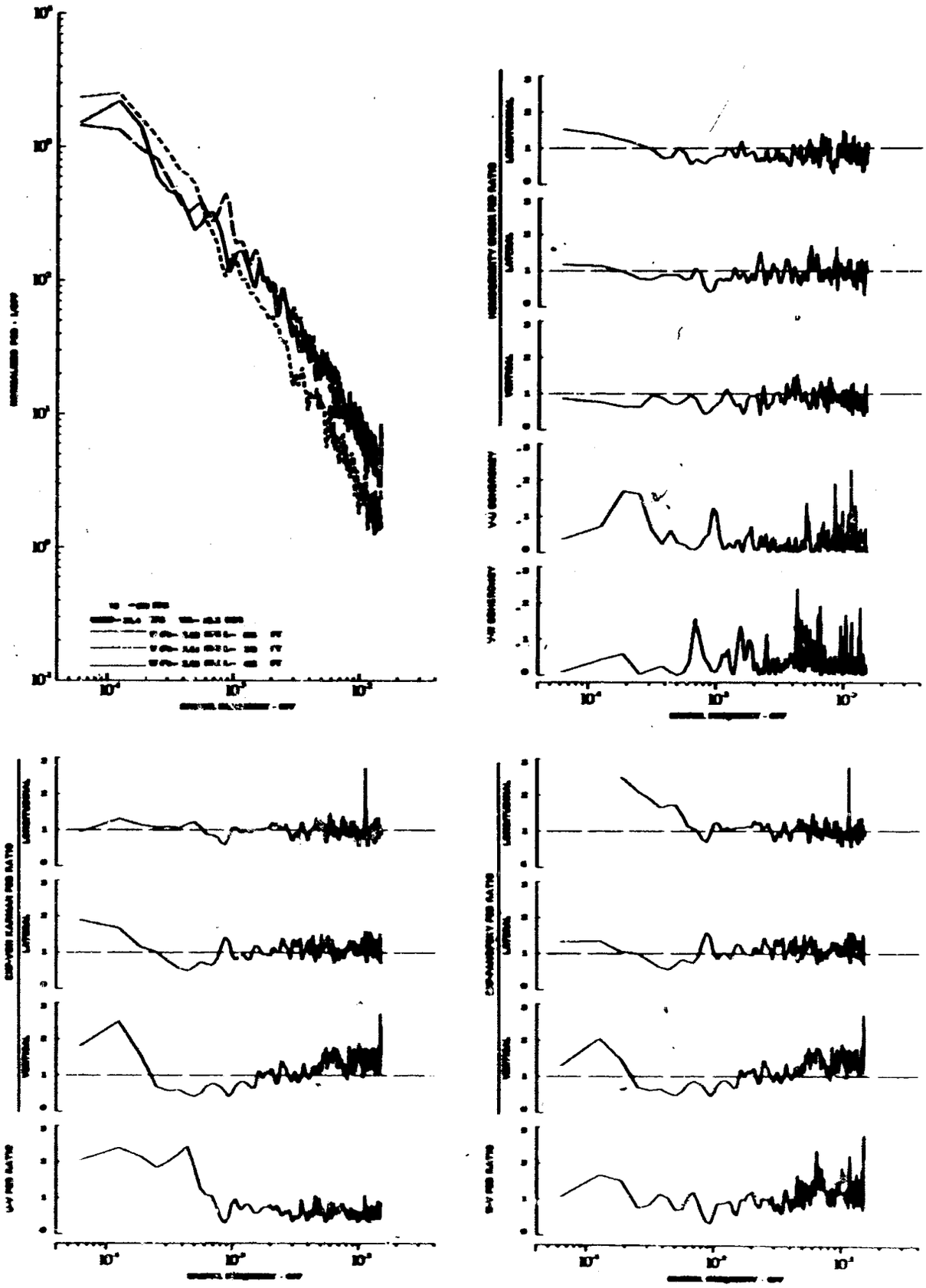

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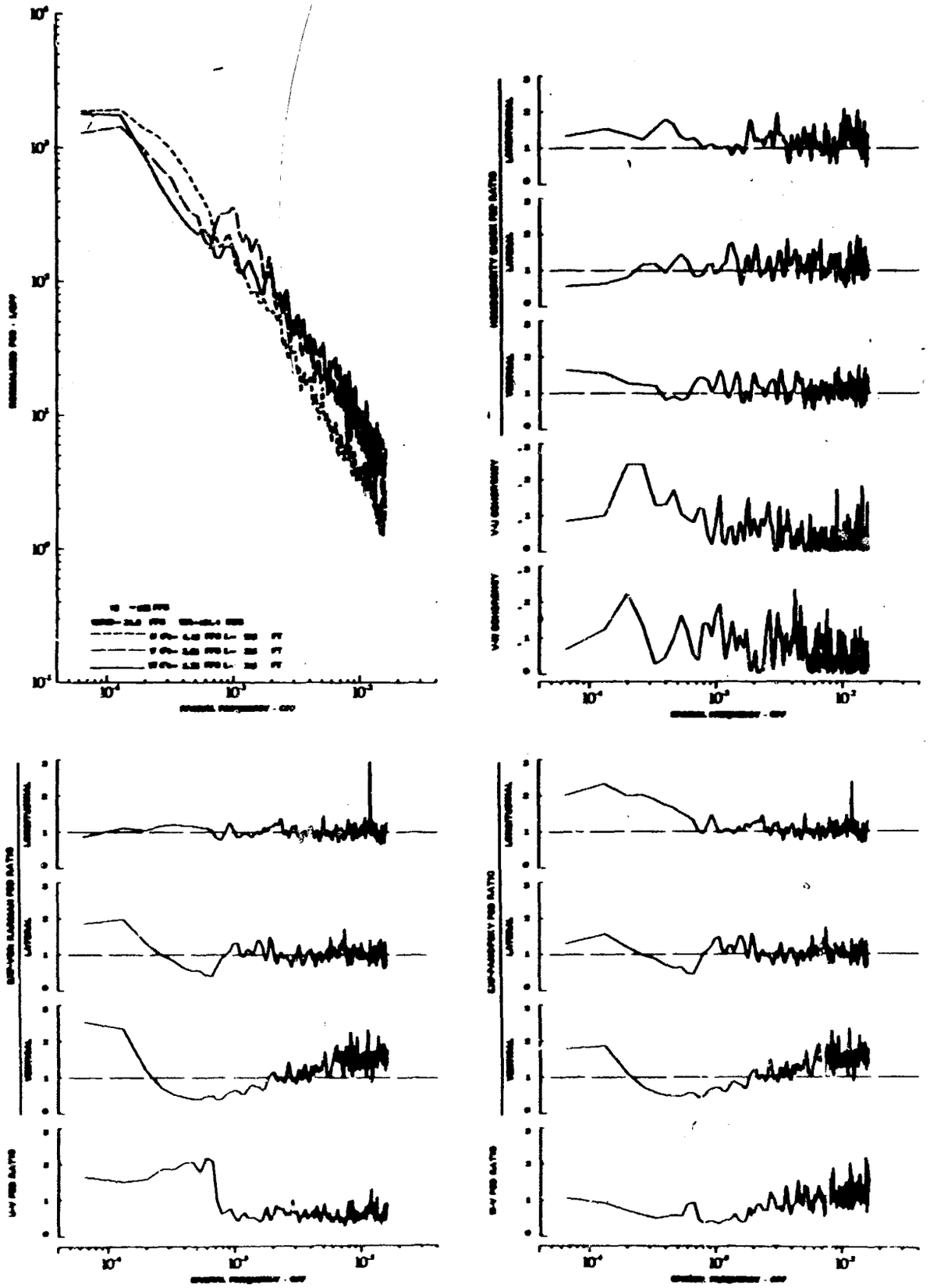

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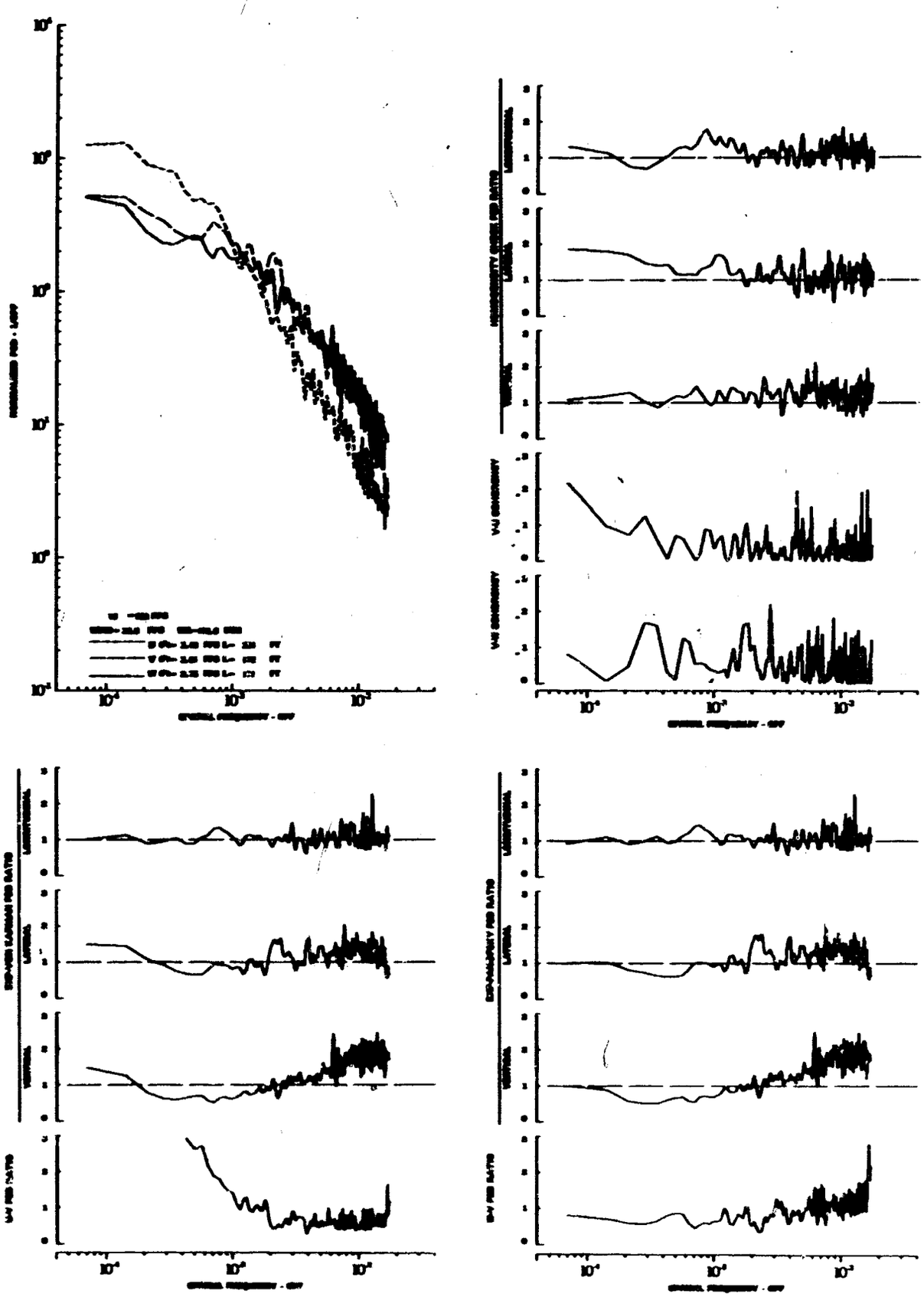

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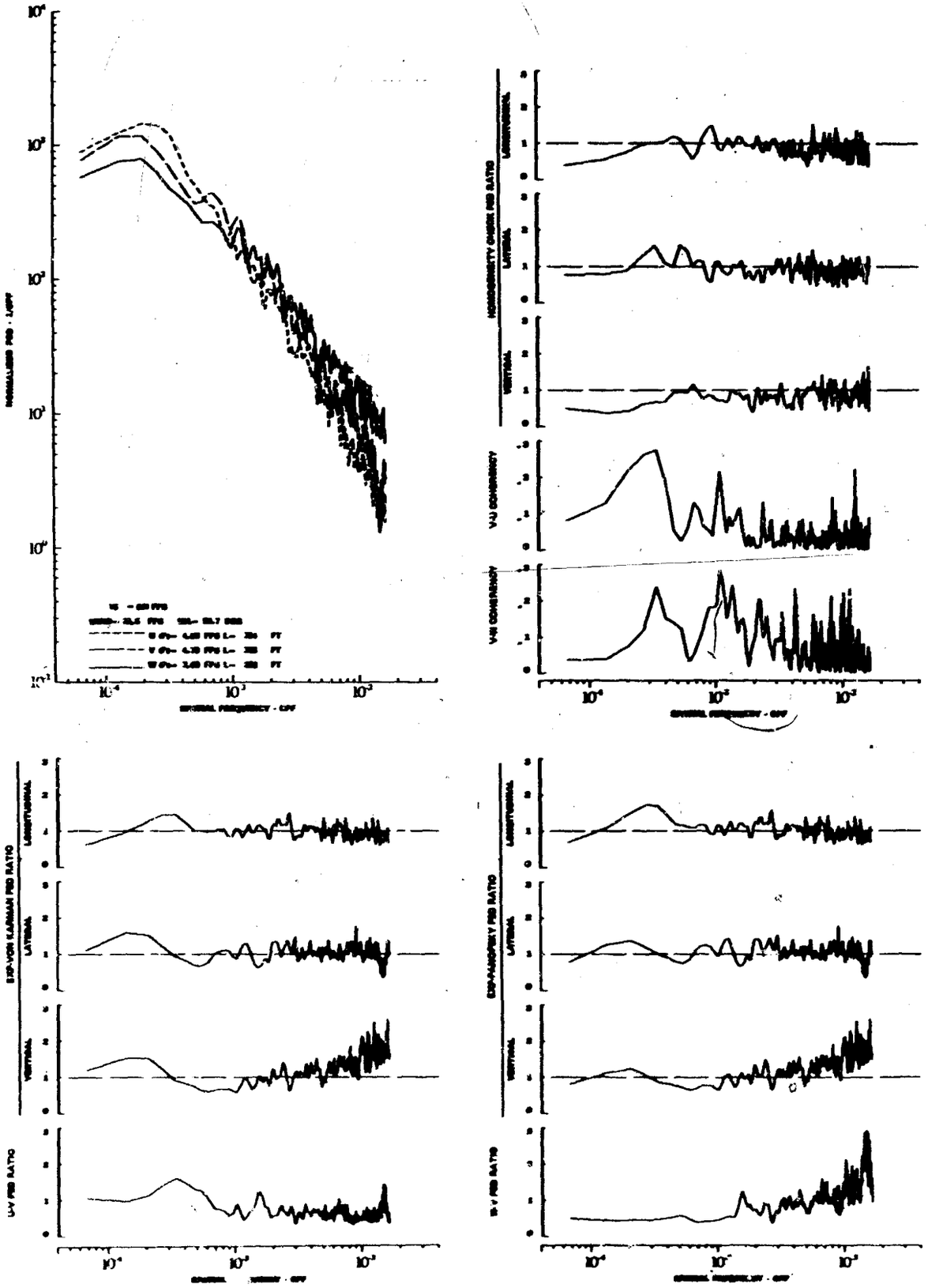

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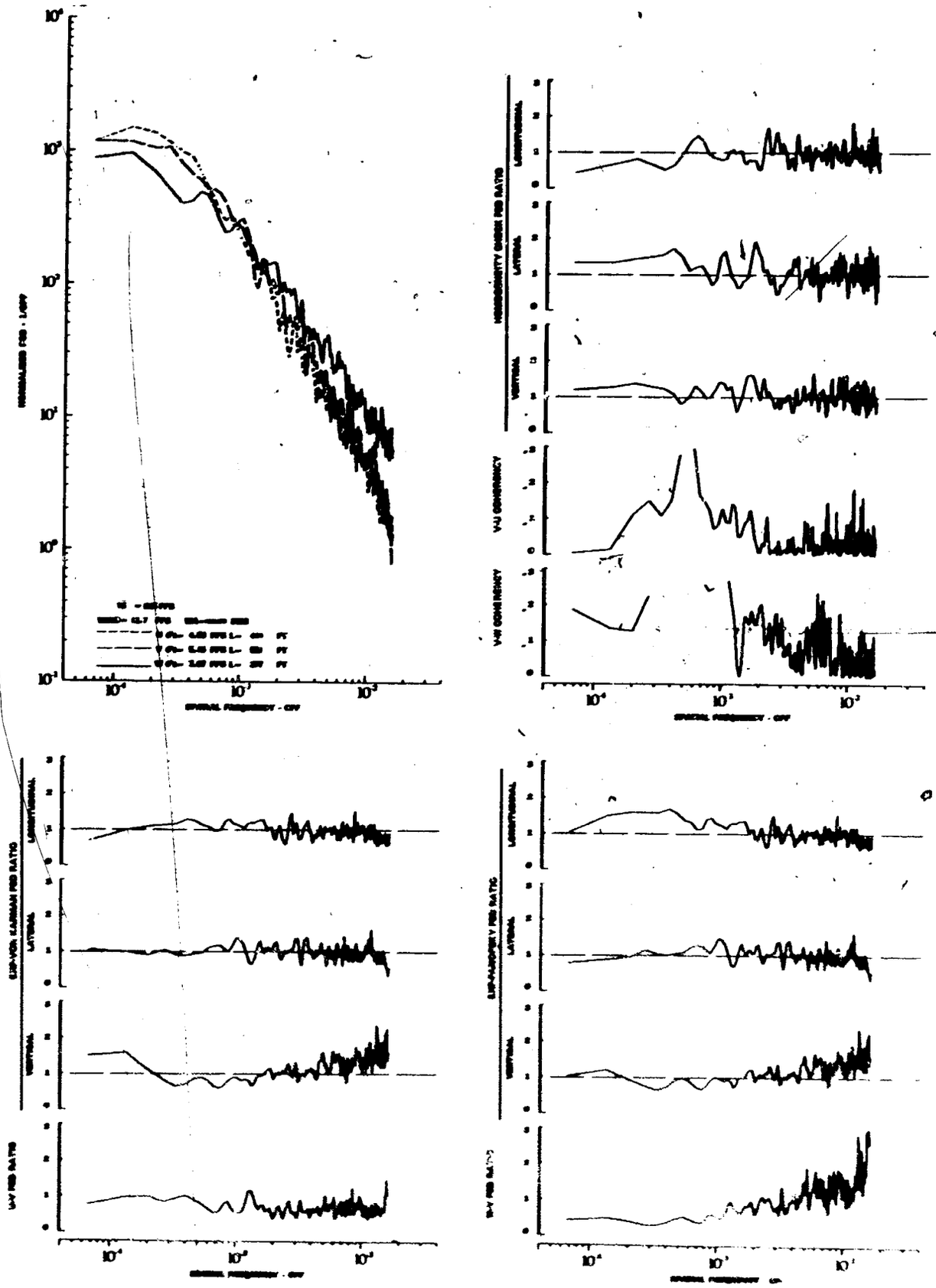

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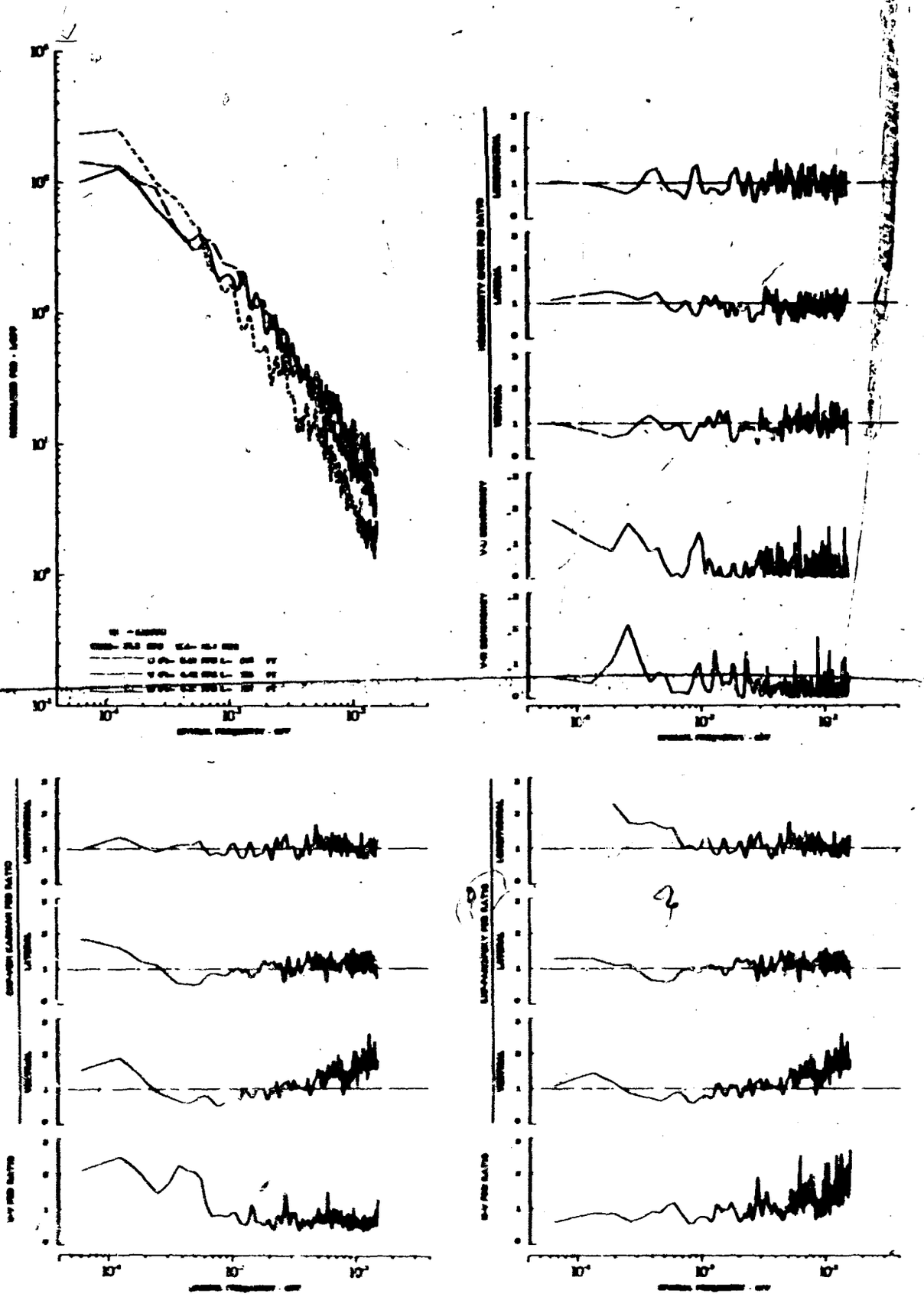

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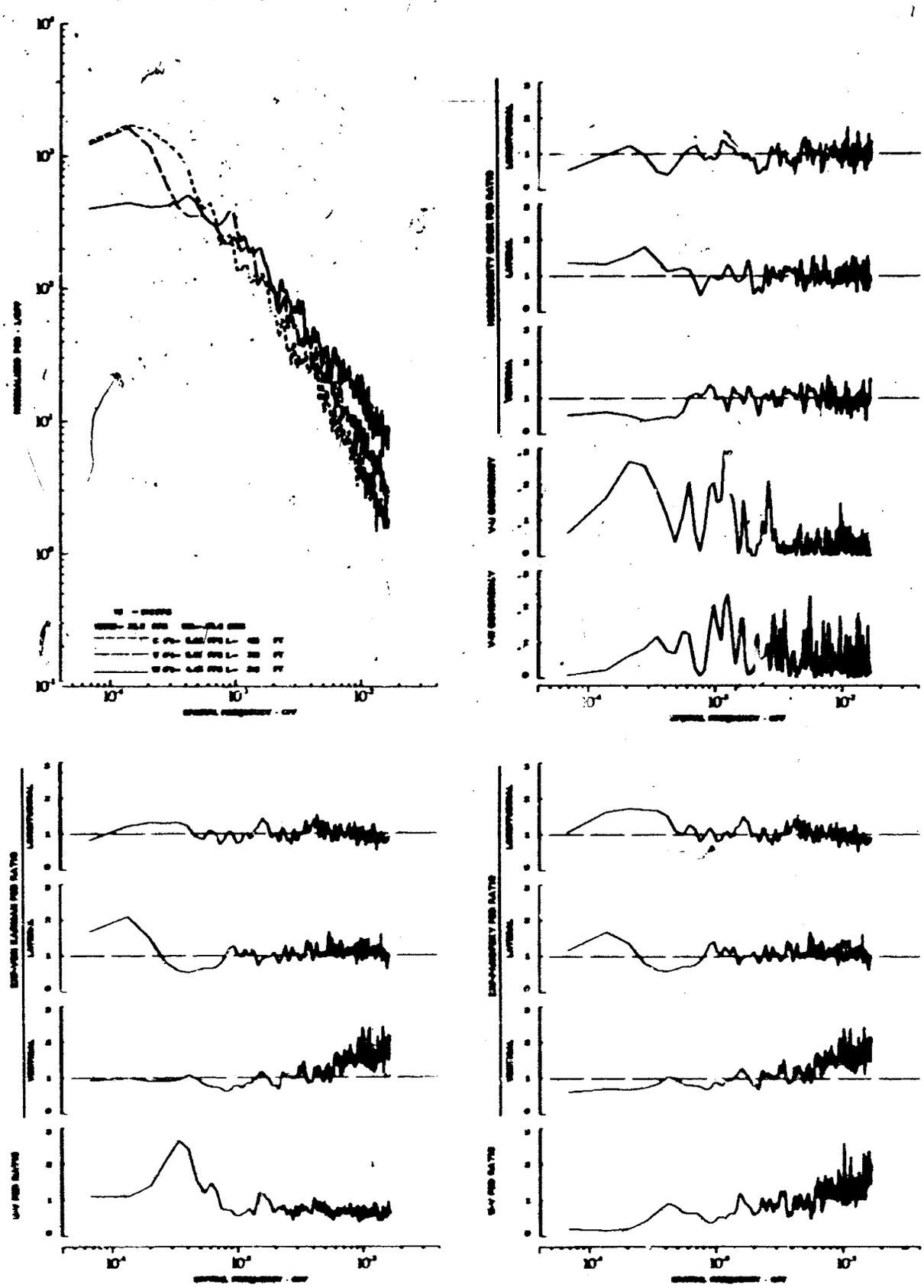

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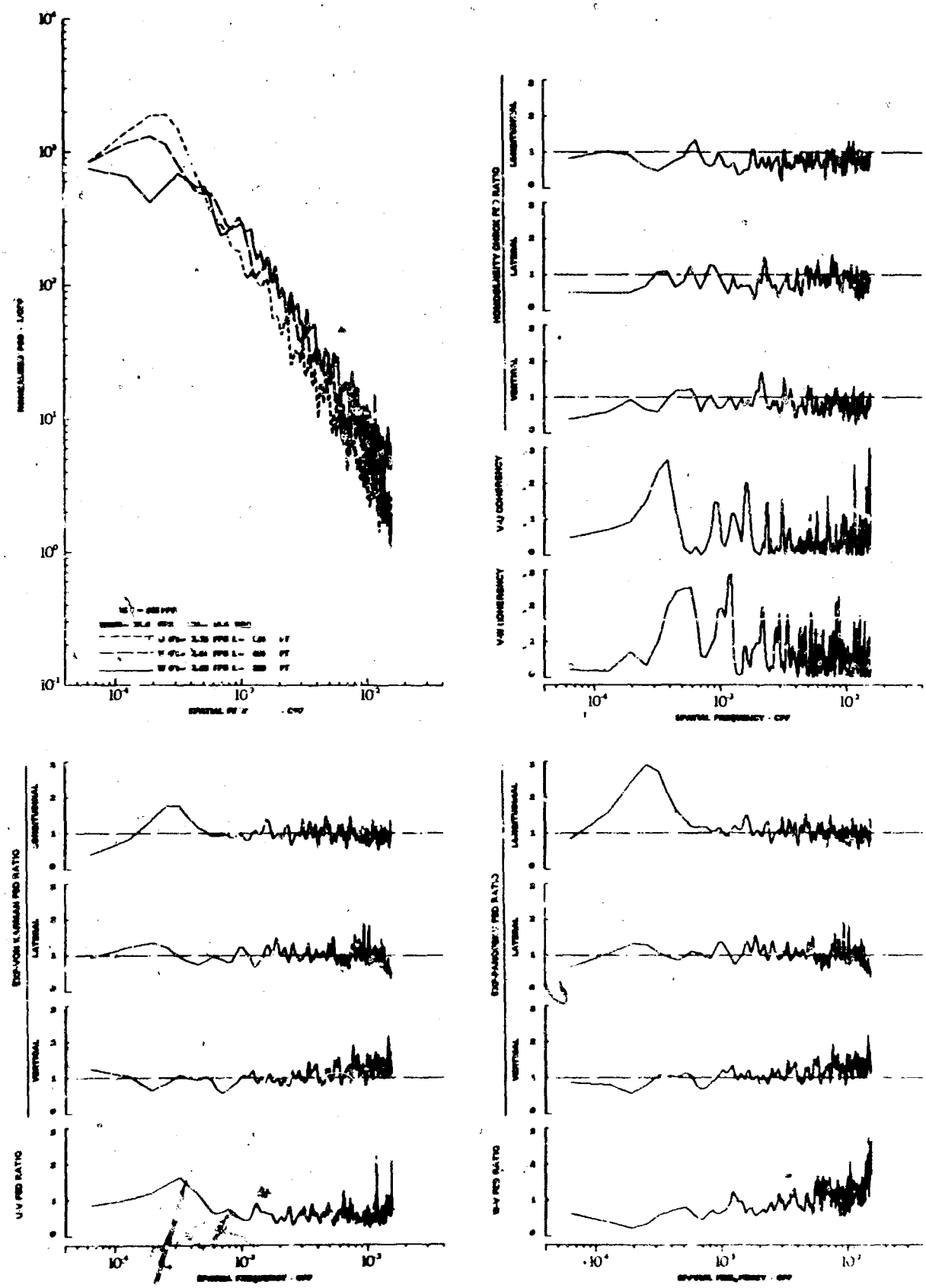

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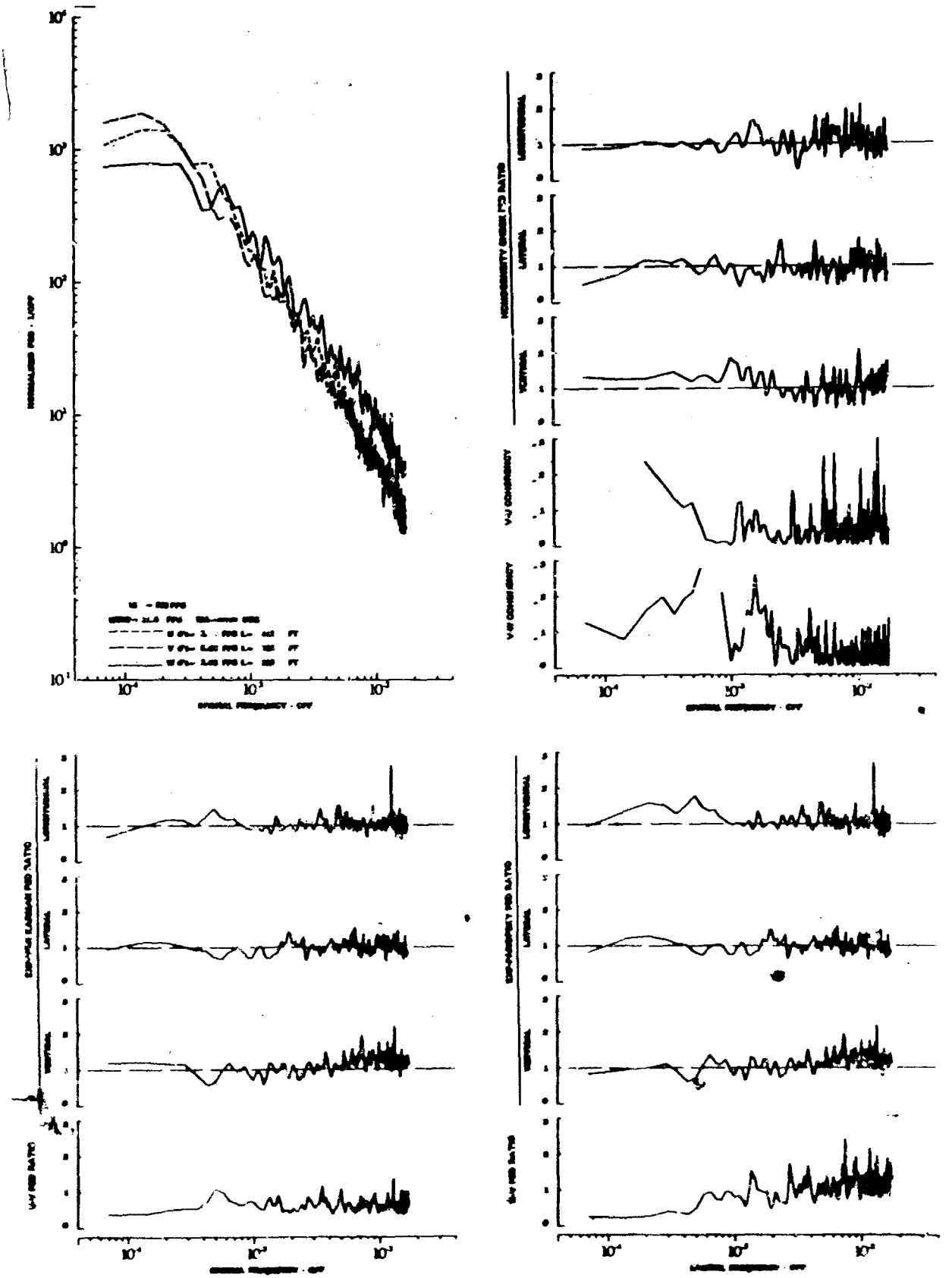

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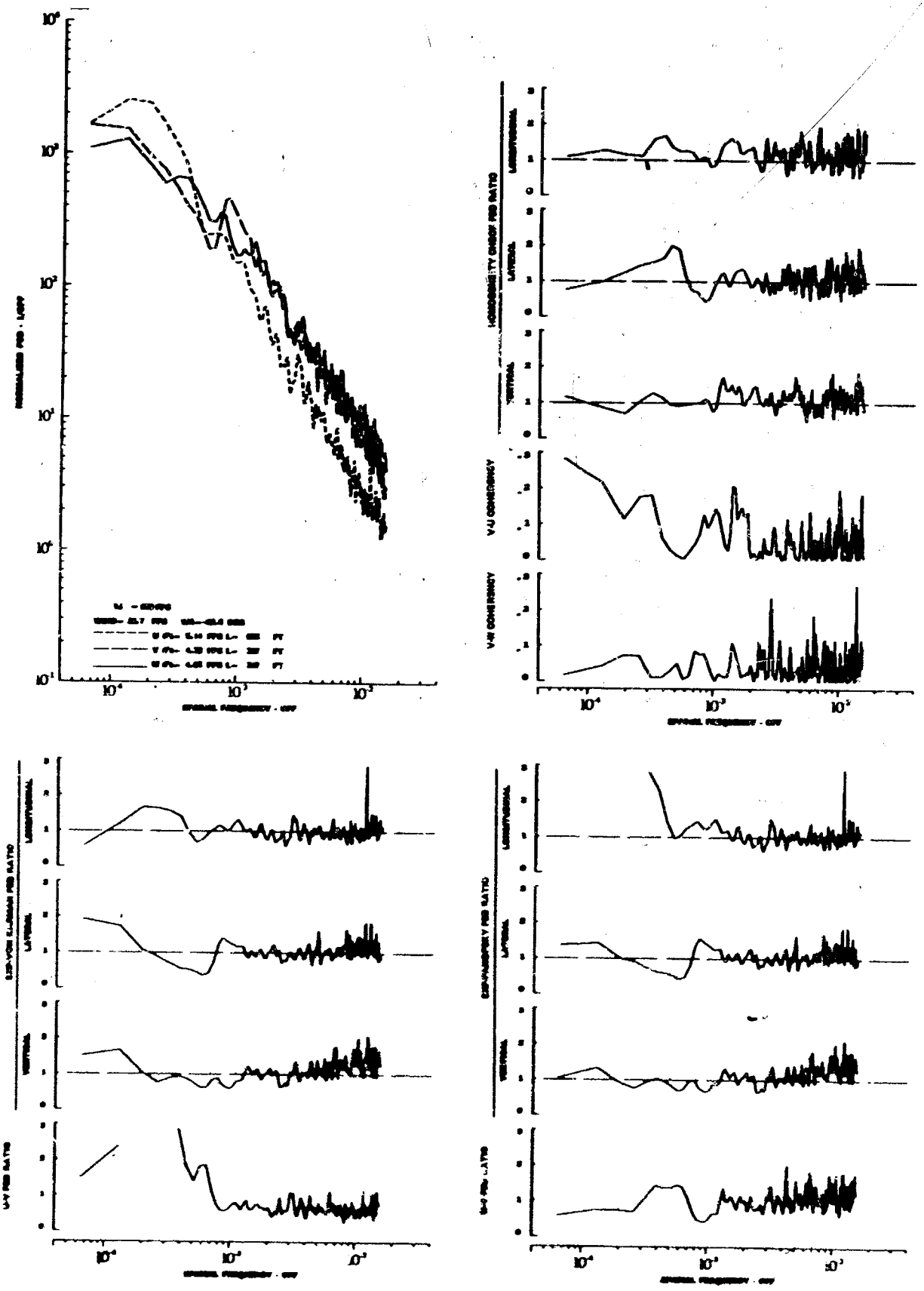

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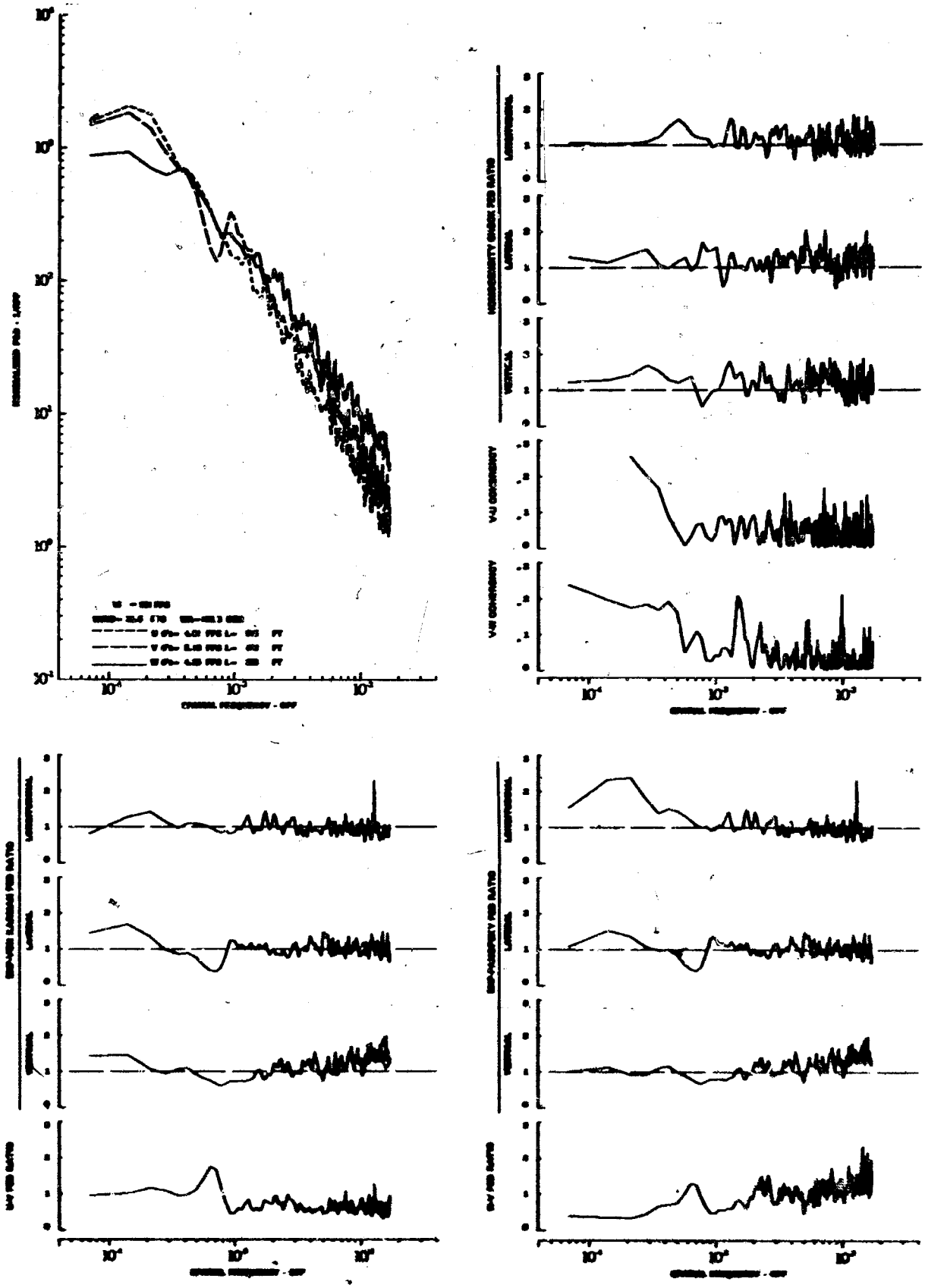

Turbulence Spectra Data for Test 299, Log 7, Category 223322

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13. ABSTRACT This report presents procedures, analysis methods, and final results pertaining to the LO-LOCAT Phase III program. Approximately 150 hours of low altitude (100 - 1000 feet) turbulence and associated meteorological data were recorded from 16 August 1968 through 30 June 1969. A model of the turbulence environment at low-level is presented in terms of gust velocity primary peaks, level crossings, amplitude samples, rms values, and gust maxima, as well as derived equivalent gusts, turbulence scale lengths, and power spectra. Mathematical expressions for turbulence spectra, scale length, and primary peak statistics are shown. Correlations between atmospheric gust velocities and meteorological and geophysical phenomena are evaluated. It was found that gust velocity magnitude at low altitude is most affected by atmospheric stability and terrain. Gust velocity rms values above 1.5 fps may be approximated by truncated Gaussian distributions. For wavelengths less than 15,000 feet, turbulence spectra are best represented by the von Karman mathematical expressions. The turbulence, sampled for 4-1/2 minute intervals over a distance of approximately 32 miles at absolute altitudes below 1,000 feet, was found to be basically stationary, isotropic, and homogeneous. A high percentage of Phase III data were recorded over high mountains since very little high mountain data were recorded under contour flight conditions at low level during Phases I and II. Phase III data are compared with data from Phases I and II and with data from other low altitude programs.

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ALL CAT						
Low Level Turbulence (0-1000 feet)						
Clear Air Turbulence (CAT)						
Gust Velocity Statistics						
Low Level Turbulence Model						
Meteorology (Turbulence)						
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