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TECHNICAL PROGRESS REPORT

NOVEMBER 1993

SPECIALIZED DATA ANALYSIS FOR THE SPACE SHUTTLE MAIN ENGINE AND DIAGNOSTIC EVALUATION OF ADVANCED PROPULSION SYSTEM COMPONENTS

NASA CONTRACT NO. NAS8-39725

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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SPECIALIZED DATA ANALYSIS AND DIAGNOSTIC EVALUATION OF SSME AND ADVANCED PROPULSION SYSTEMS

INTRODUCTION

The Marshall Space Flight Center is responsible for the development and management of advanced launch vehicle propulsion systems, including the Space Shuttle Main Engine (SSME), which is presently operational, and the Space Transportation Main Engine (STME) under development. The SSMEs provide high performance within stringent constraints on size, weight, and reliability. Based on operational experience, continuous design improvement is in progress to enhance system durability and reliability. Specialized data analysis and interpretation is required in support of SSME and advanced propulsion system diagnostic evaluations.

Comprehensive evaluation of the dynamic measurements obtained from test and flight operations is necessary to provide timely assessment of the vibrational characteristics indicating the operational status of turbomachinery and other critical engine components. Efficient performance of this effort is critical due to the significant impact of dynamic evaluation results on ground test and launch schedules, and requires direct familiarity with SSME and derivative systems, test data acquisition, and diagnostic software.

Under contract NAS8-39725 with subcontract support from Wyle Laboratories, SUMMA Technology, Inc. is performing detailed analysis and evaluation of dynamic measurements obtained during SSME and advanced system ground test and flight operations, including analytical/statistical assessment of component dynamic behavior, and the development and implementation of analytical/statistical models to efficiently define nominal component dynamic characteristics, detect anomalous behavior, and assess machinery operational condition. In addition, the SSME and J-2 data will be applied to develop vibroacoustic environments for advanced propulsion system components, as required.

This study will provide timely assessment of engine component operational status, identify probable causes of malfunction, and indicate feasible engineering solutions. This contract will be performed through accomplishment of negotiated task orders.

REPORTS

In addition to monthly technical reports, informal data summaries of SSME test results are prepared and presented at irregular intervals. Software routines are provided for application on MSFC computers. The final report will document all results, analyses and computer software generated under this contract.

TECHNICAL PROGRESS

This is the November 1993 technical progress report on the specialized data analysis and diagnostic evaluation of SSME and advanced propulsion system components. Work continued on ED23 system hardware and software capability improvement, and statistical analysis to support ATD acceptance ("green run") Vibration Criteria Definition. Specific tasks accomplished in this reporting period are summarized as follows:

- **Statistical Characterization of ATD Vibration Data** (W. Swanson/Wyle). The Pratt & Whitney ATD statistical analysis for determination of a green-run specification was updated to include static firing test data not previously available. No dramatic change was noted when this data was included in the data base. The distribution still indicates a bi-modal type of function, especially evident on the turbine end of the pump at 104% PWL. The analysis included the synchronous vibration levels at 100%, 104%, and 109% PWL. Some preliminary results are illustrated in Figures 1-6, attached. It is noted that the available sample size is quite limited. Application of these results to green run criteria definition is in progress.

- **Optical File Server Tasks** (R. Smith/Summa). The optical file server hardware arrived mid-October. Hardware and software checkout is near completion. Real world optical file server performance capabilities have been baselined. Plans to upgrade the server to triple its online capacity are finalized and in procurement. Initial loading of SSME dynamics data has begun. Approximately 96 SSME tests have been loaded by Boeing computer technicians without problem. Methods of processing this vast volume of online data are under investigation.

- **ED23 Dynamics Software Development and Porting** (W. Smith/Summa). Software changes to allow use of the on-line optical data base are being worked. Additional needed software changes identified by optical file server testing are scheduled to be implemented. Port and update of older ED23 analysis code from Masscomp computers to newly acquired Sun computers continues.

- **Diagnostic Methods Presentation** (T. Coffin/Wyle). Examples, from previous reports, illustrating application of hyper-coherence non-stationary (Wigner) methods and wide-band demodulation techniques were reviewed for inclusion. Several simple analytical (simulation) examples are attached. These will be followed by real-world applications based on SSME evaluations. Figure 7 illustrates the application of hyper-coherence filtering to extract a corrupted sine wave in noise. Figures 8-10 show the extraction of two modulated sine waves, representing highly non-stationary behavior. Figure 11 illustrates three distinct algorithmic approaches to extract a modulation signal. Practical illustrations are under evaluation.

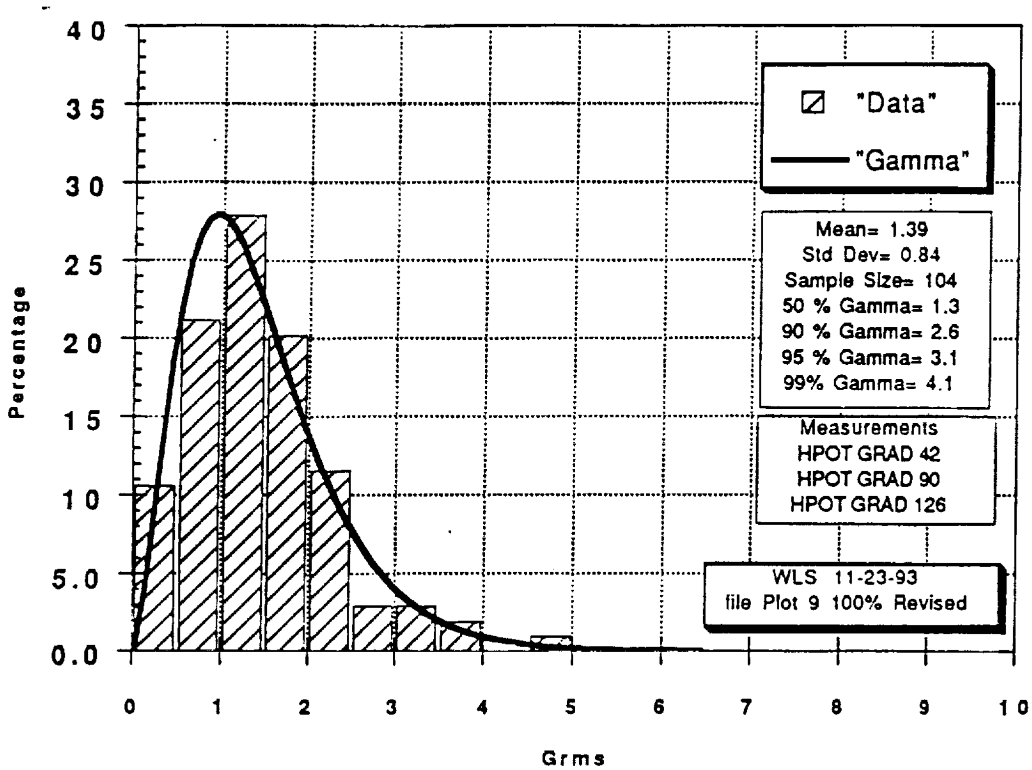
EFFORT PLANNED FOR NEXT REPORTING PERIOD

The above systems integration and analysis investigations will continue next month. ED/23 1994 hardware plans and requirements definition will be completed. ATD statistical results will be extended as testing continues. Preparation of the above technical presentation will be completed. Coordination of task order priorities and schedules will also be performed.

Prepared by	Reviewed and Approved by
Tom Coffin, Project Engineer Wyle Laboratories	W. Richardson, Program Manager Summa Technology

Fig 1.

P&W ATD High Pressure Oxidizer Turbopump (HPOTP)
Silicon Nitride Bearings 100% PWL
Synchronous (None Event Tests) TURBINE-Revised



P&W ATD High Pressure Oxidizer Turbopump (HPOTP)
Silicon Nitride Bearings 100% PWL
Synchronous (None Event Tests) TURBINE

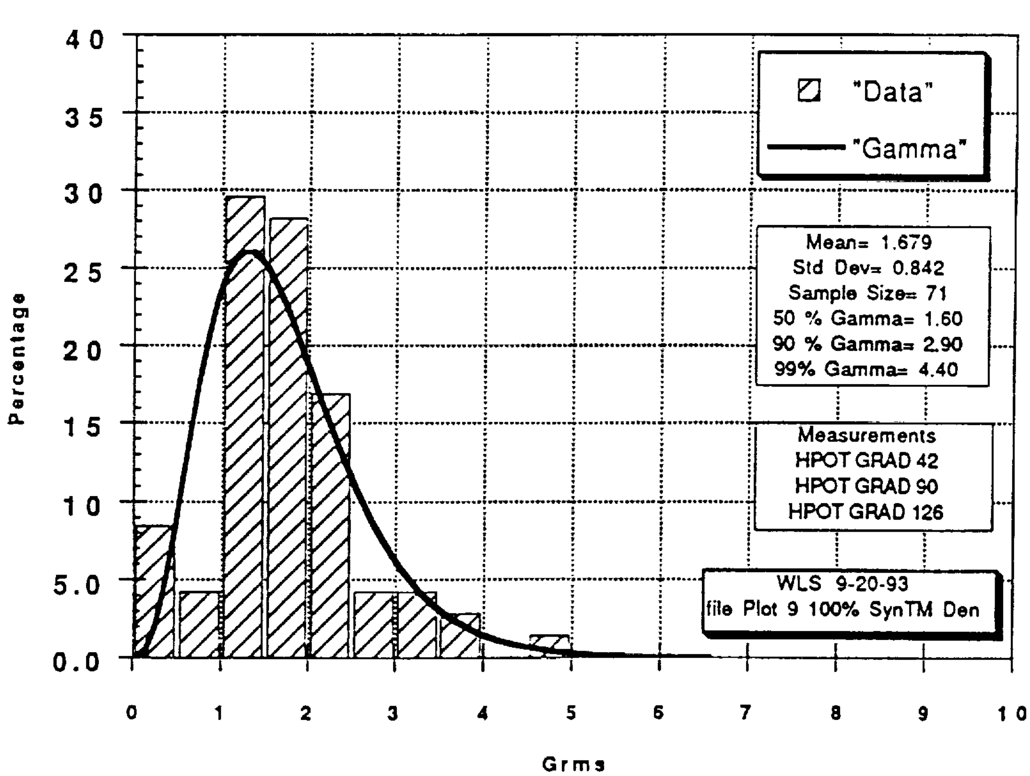
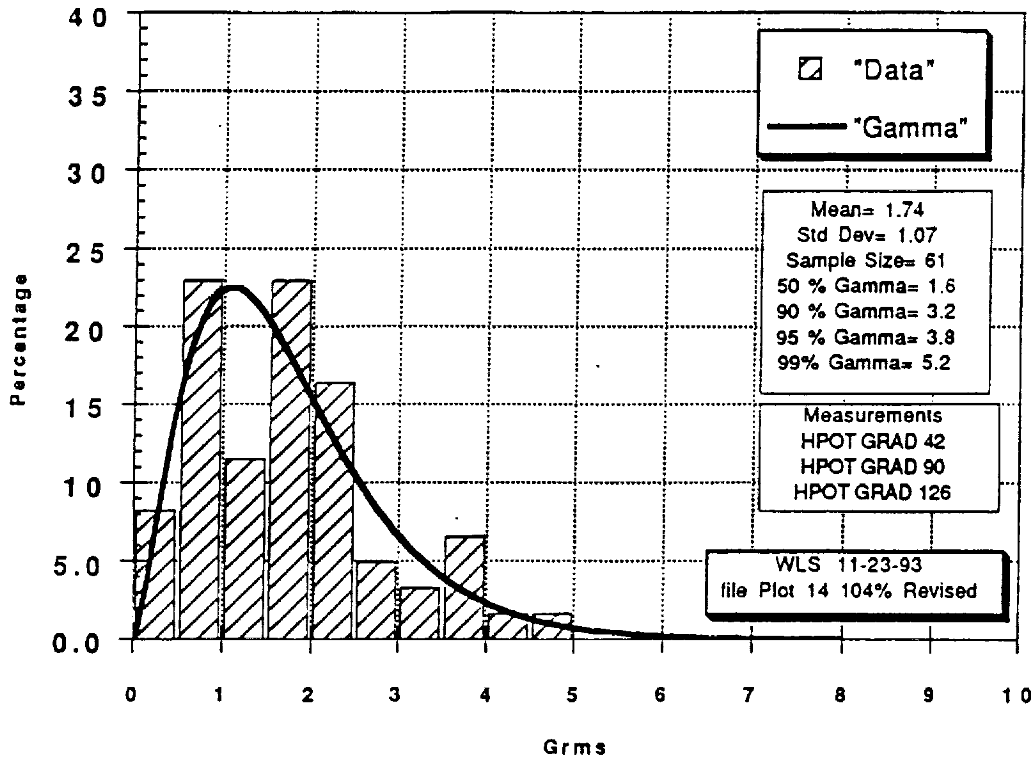


Fig 2.

P&W ATD High Pressure Oxidizer Turbopump (HPOTP) Silicon Nitride Bearings 104% PWL Synchronous (None Event Tests) TURBINE-Revised



P&W ATD High Pressure Oxidizer Turbopump (HPOTP) Silicon Nitride Bearings 104% PWL Synchronous (None Event Tests) TURBINE

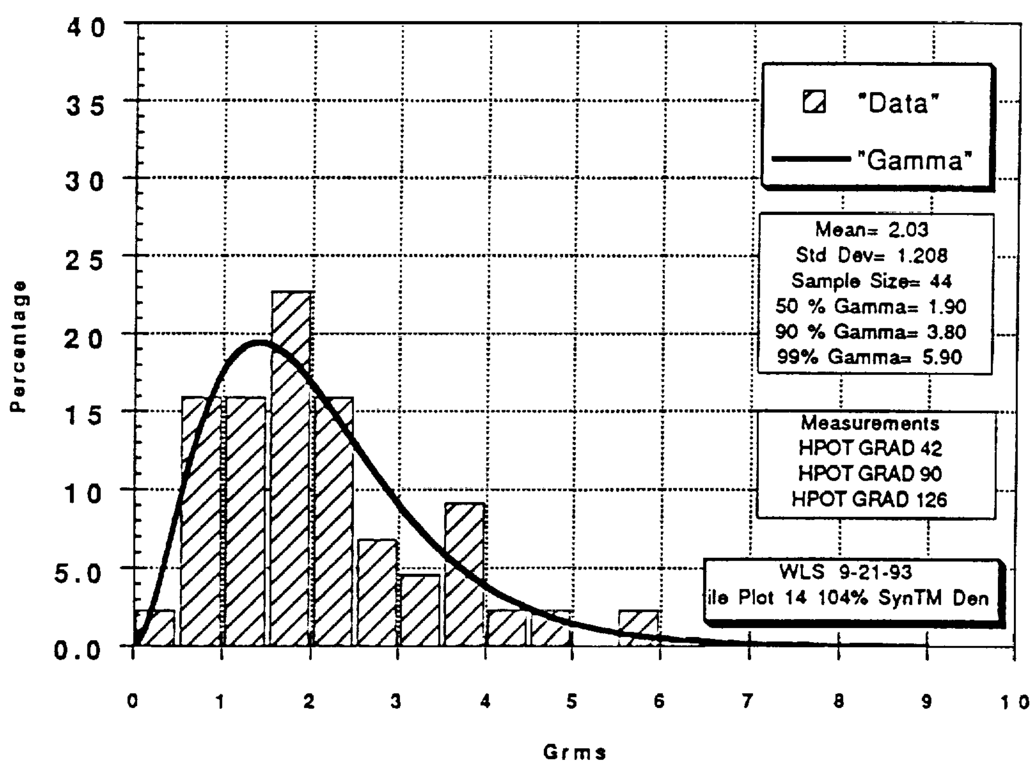
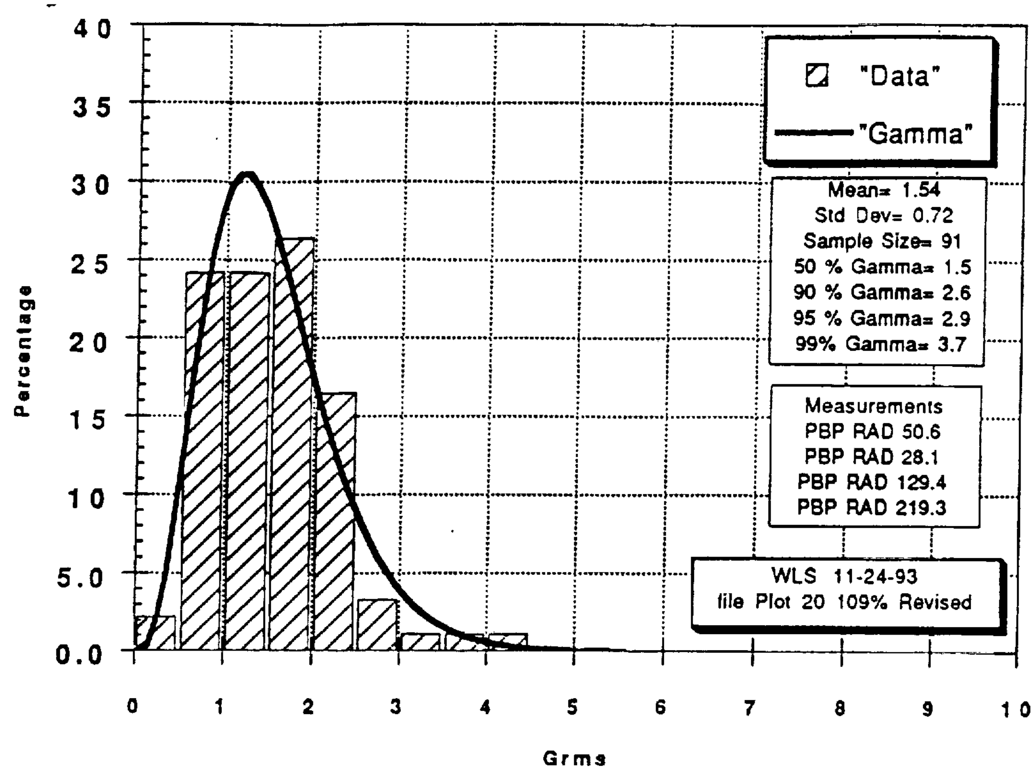


Fig 3.

P&W ATD High Pressure Oxidizer Turbopump (HPOTP)
Silicon Nitride Bearings 109% PWL
Synchronous PBP RAD-Revised



P&W ATD High Pressure Oxidizer Turbopump (HPOTP)
Silicon Nitride Bearings 109% PWL
Synchronous PBP RAD

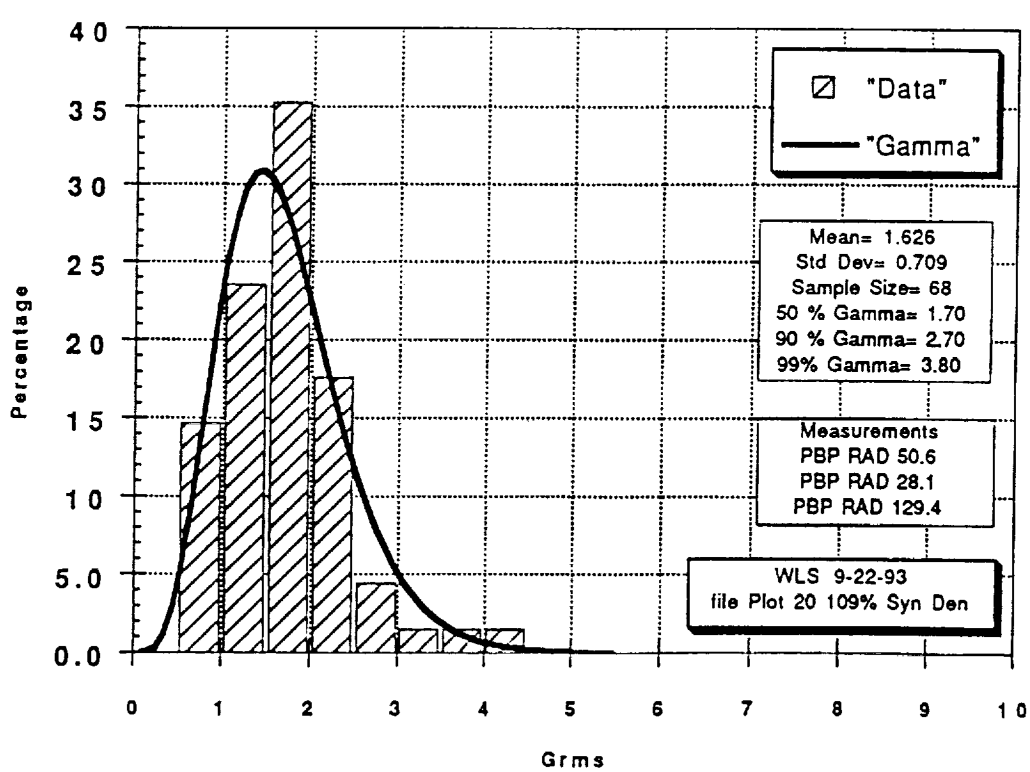
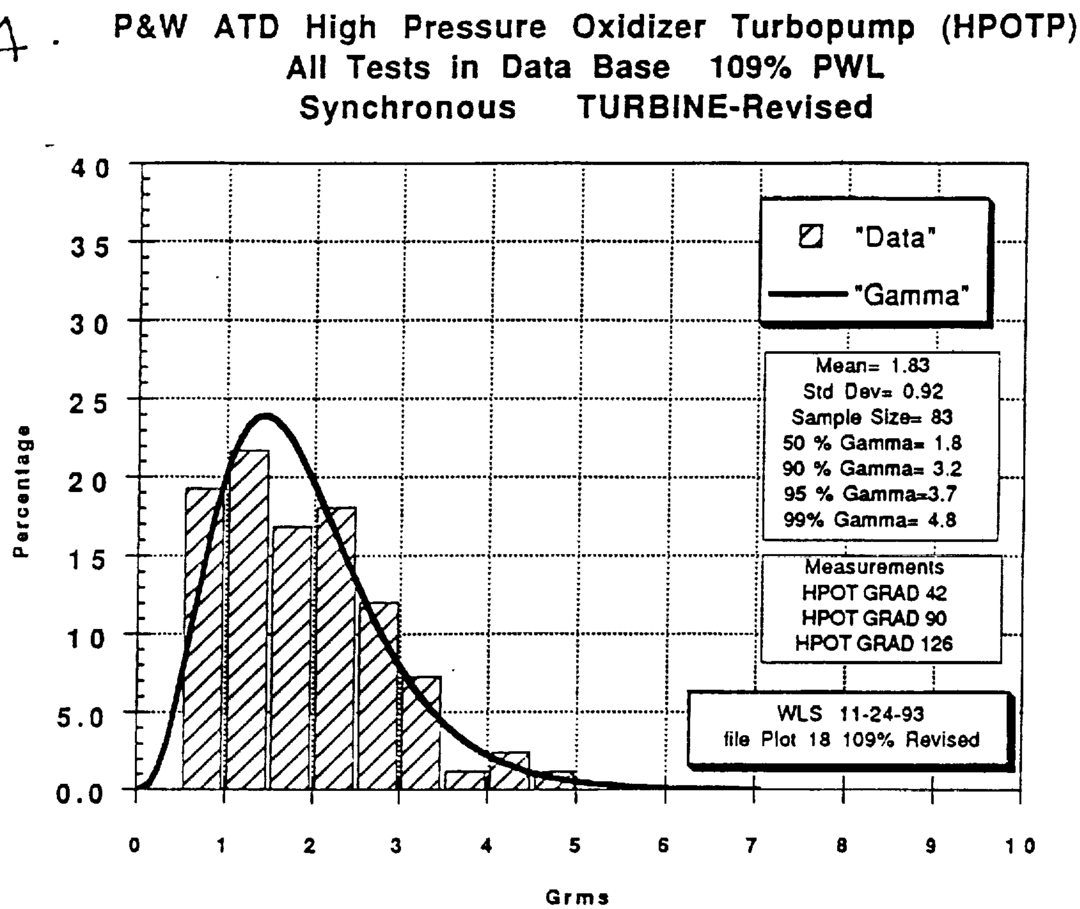


Fig 4.


P&W ATD High Pressure Oxidizer Turbopump (HPOTP)
All Tests in Data Base 109% PWL
Synchronous TURBINE-Revised
Percentage
Grms
"Data"
"Gamma"
Mean= 1.83
Std Dev= 0.92
Sample Size= 83
50 % Gamma= 1.8
90 % Gamma= 3.2
95 % Gamma=3.7
99% Gamma= 4.8
Measurements
HPOT GRAD 42
HPOT GRAD 90
HPOT GRAD 126
WLS 11-24-93
file Plot 18 109% Revised

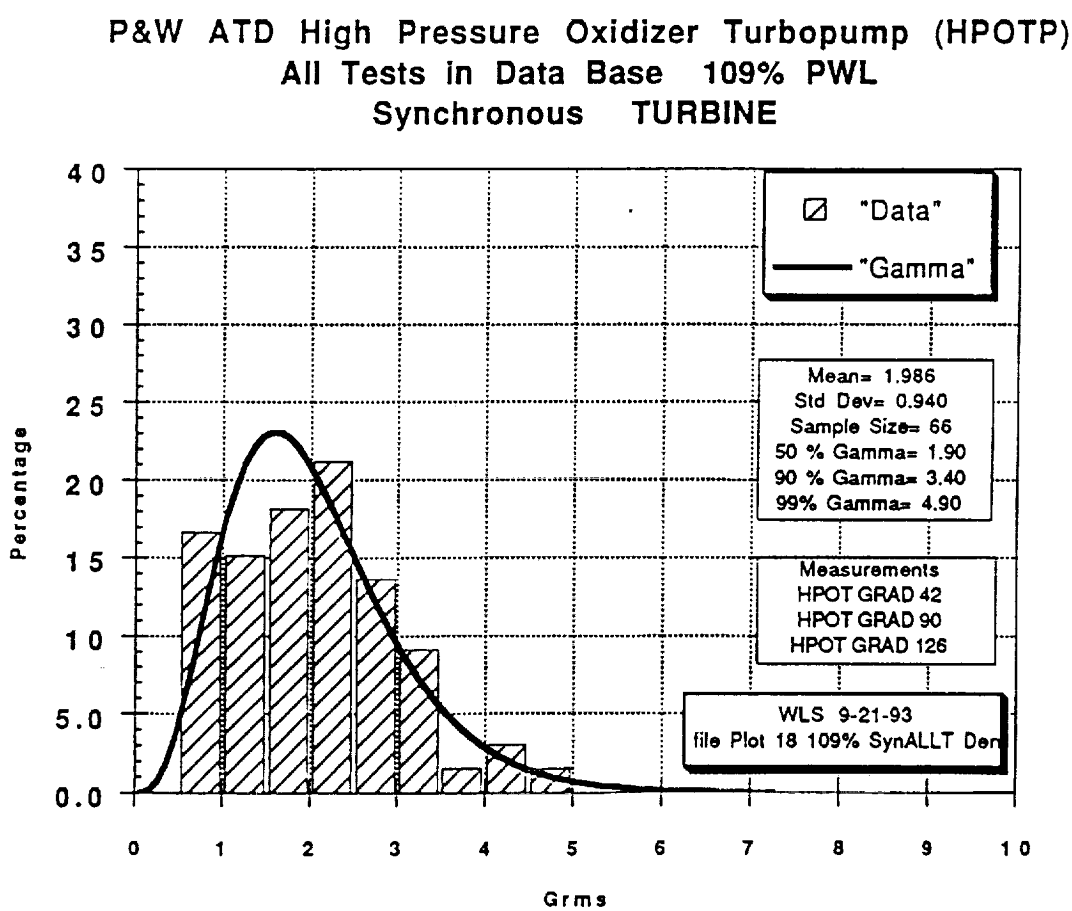
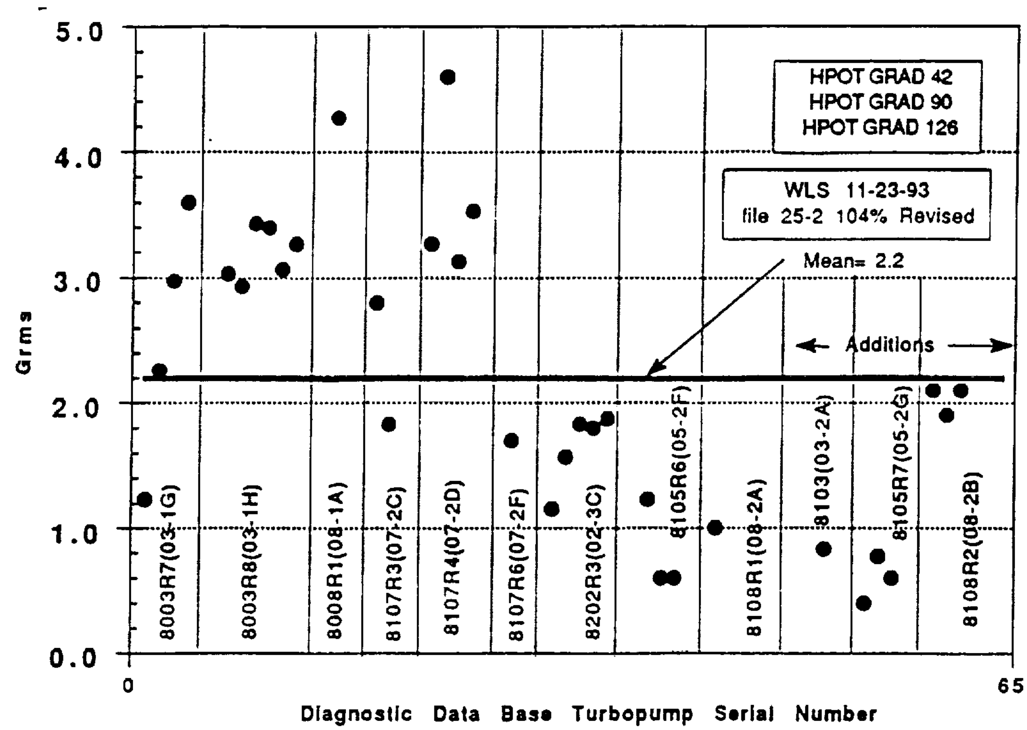

P&W ATD High Pressure Oxidizer Turbopump (HPOTP)
All Tests in Data Base 109% PWL
Synchronous TURBINE
Percentage
Grms
"Data"
"Gamma"
Mean= 1.986
Std Dev= 0.940
Sample Size= 66
50 % Gamma= 1.90
90 % Gamma= 3.40
99% Gamma= 4.90
Measurements
HPOT GRAD 42
HPOT GRAD 90
HPOT GRAD 126
WLS 9-21-93
file Plot 18 109% SynALLT Den

fig 5

P&W ATD High Pressure Oxidizer Turbopump (HPOTP)
Silicon Nitride Bearings 104% PWL
Spatial Average Synchronous TURBINE



P&W ATD High Pressure Oxidizer Turbopump (HPOTP)
Silicon Nitride Bearings 104% PWL
Spatial Average Synchronous TURBINE

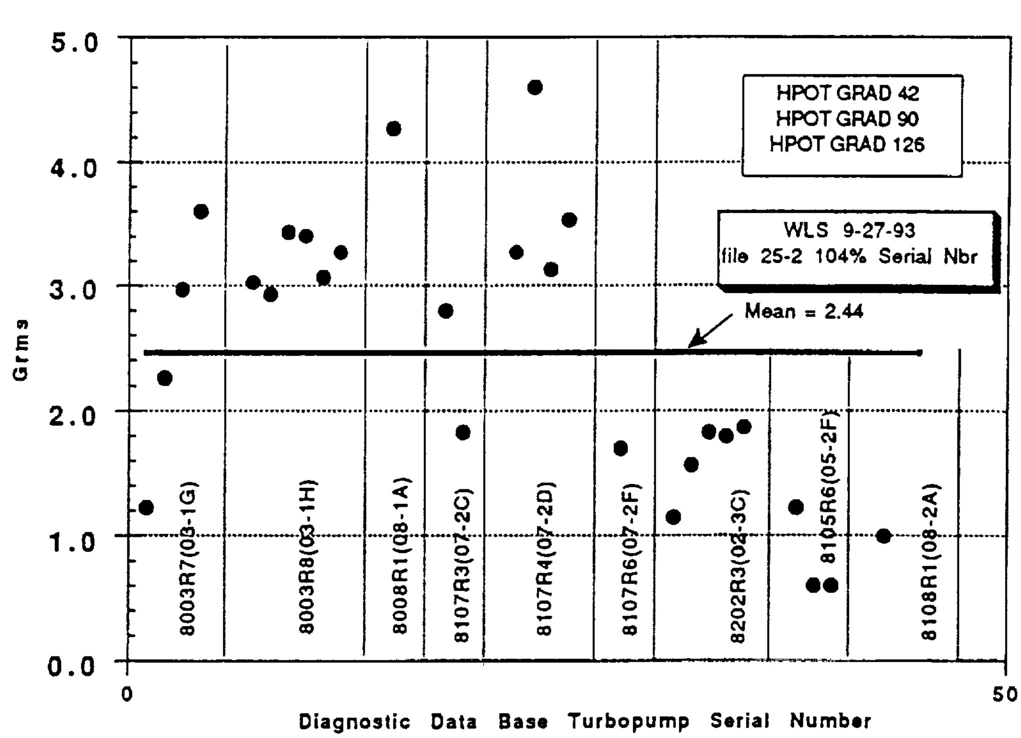
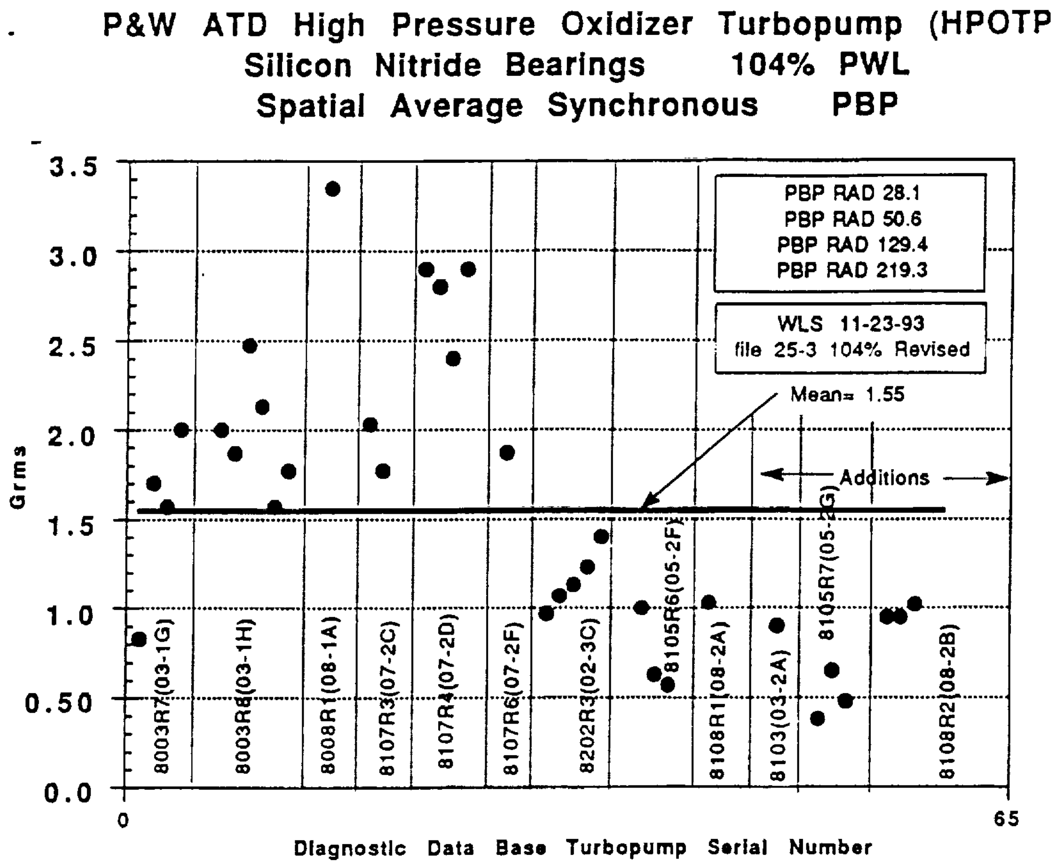
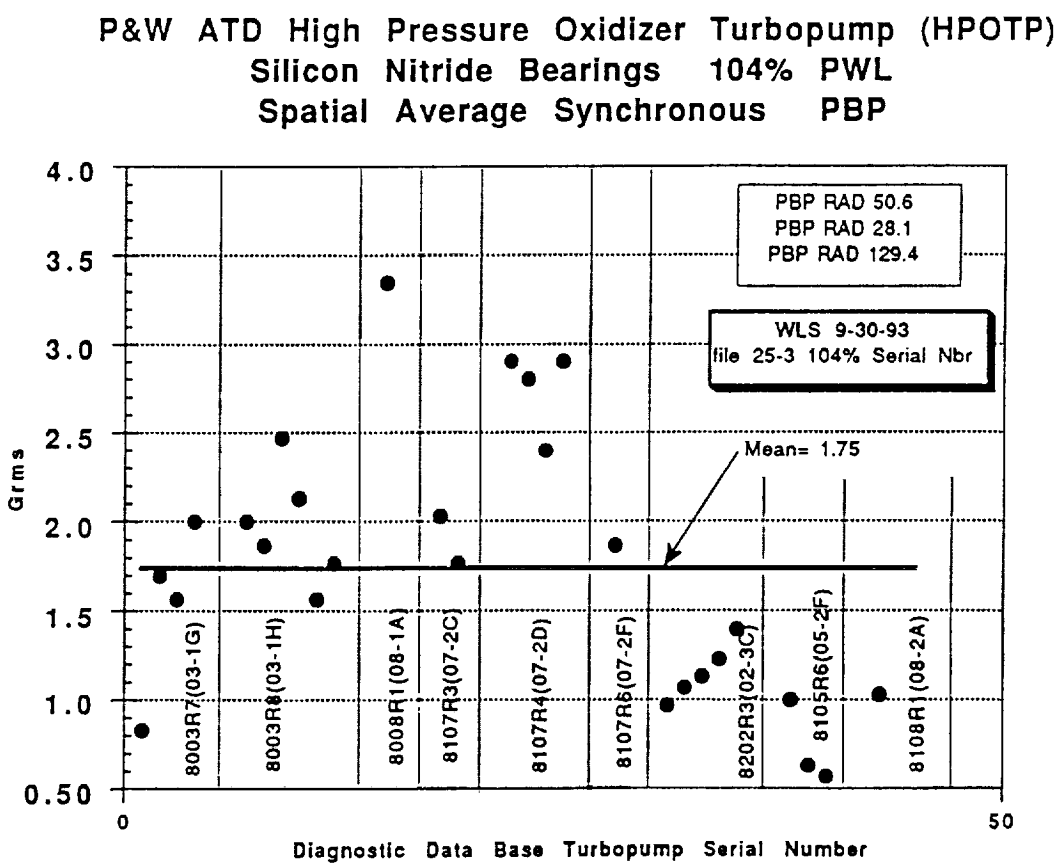
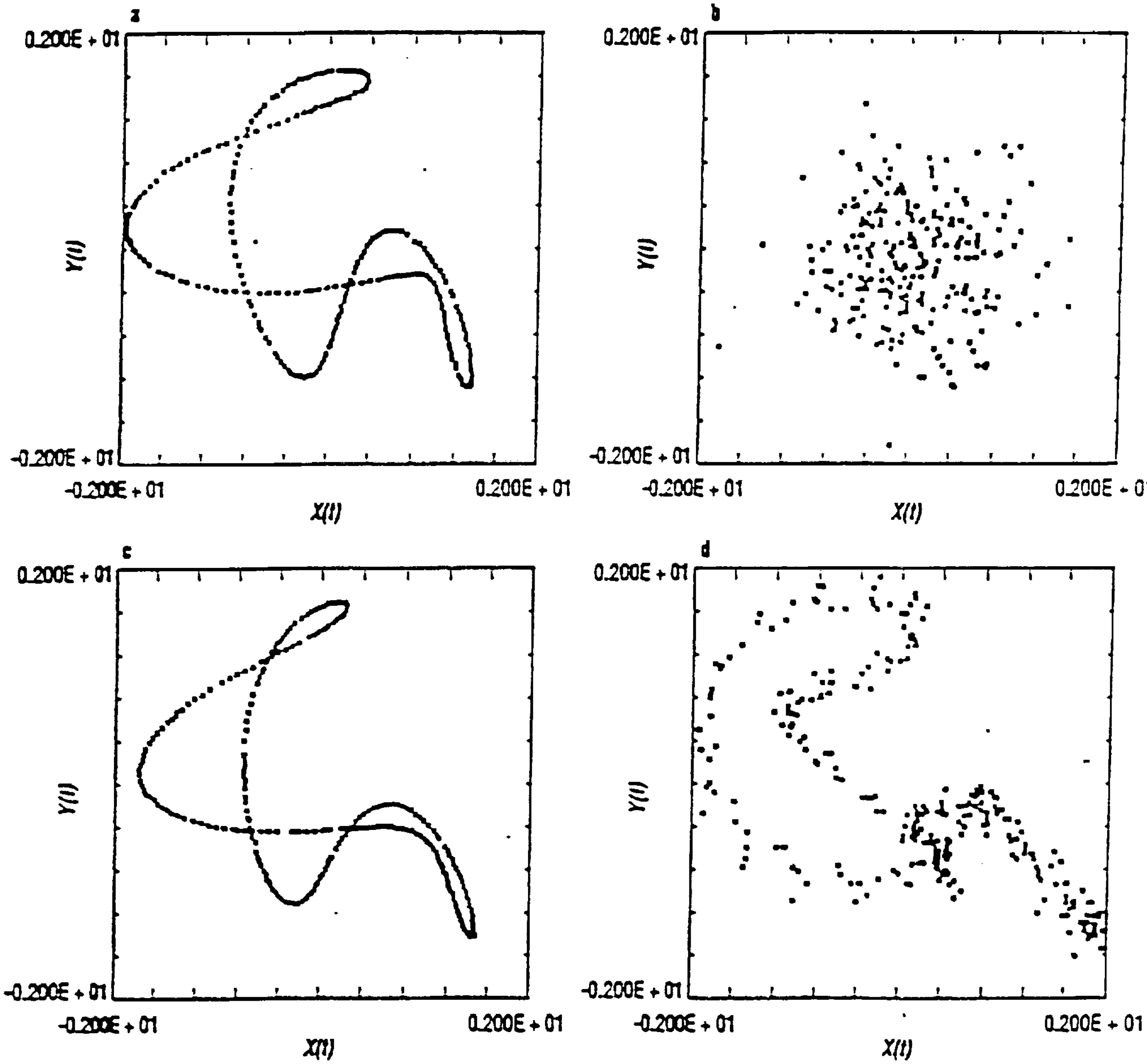


Fig 6.


P&W ATD High Pressure Oxidizer Turbopump (HPOTP)
Silicon Nitride Bearings 104% PWL
Spatial Average Synchronous PBP
PBP RAD 28.1
PBP RAD 50.6
PBP RAD 129.4
PBP RAD 219.3
WLS 11-23-93
file 25-3 104% Revised
Mean= 1.55
Additions
Grms
3.5
3.0
2.5
2.0
1.5
1.0
0.50
0.0
8003R7(03-1G)
8003R8(03-1H)
8008R1(08-1A)
8107R3(07-2C)
8107R4(07-2D)
8107R6(07-2F)
8202R3(02-3C)
8105R6(05-2F)
8108R1(08-2A)
8103(03-2A)
8105R7(05-2G)
8108R2(08-2B)
0
65
Diagnostic Data Base Turbopump Serial Number

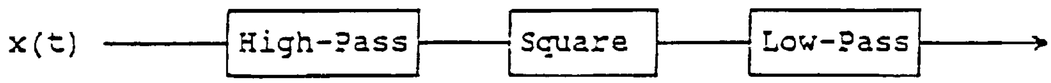

P&W ATD High Pressure Oxidizer Turbopump (HPOTP)
Silicon Nitride Bearings 104% PWL
Spatial Average Synchronous PBP
PBP RAD 50.6
PBP RAD 28.1
PBP RAD 129.4
WLS 9-30-93
file 25-3 104% Serial Nbr
Mean= 1.75
Grms
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.50
8003R7(03-1G)
8003R8(03-1H)
8008R1(08-1A)
8107R3(07-2C)
8107R4(07-2D)
8107R6(07-2F)
8202R3(02-3C)
8105R6(05-2F)
8108R1(08-2A)
0
50
Diagnostic Data Base Turbopump Serial Number



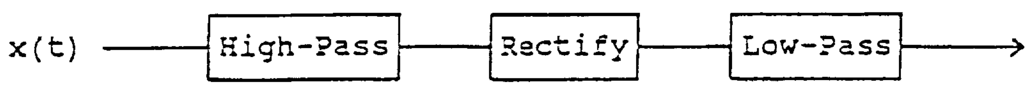
(a) Orbital Diagram of Noise-Free Simulation, (b). Orbital Diagram of Simulation With Additive Gassian White Noise, (c). Recovered Orbital Diagram by Using Hypercoherence Filtering, (d). Recovered Orbital Diagram by Using Comb Filtering

FIGURE ~~2-11.~~ 7 SIGNAL DETECTION BY HYPERCOHERENCE FILTERING

(1) Tri-spectra Method:



(2) Rectify Method (Envelope Detection):



(3) Hilbert Transform Method (Envelope Detection):

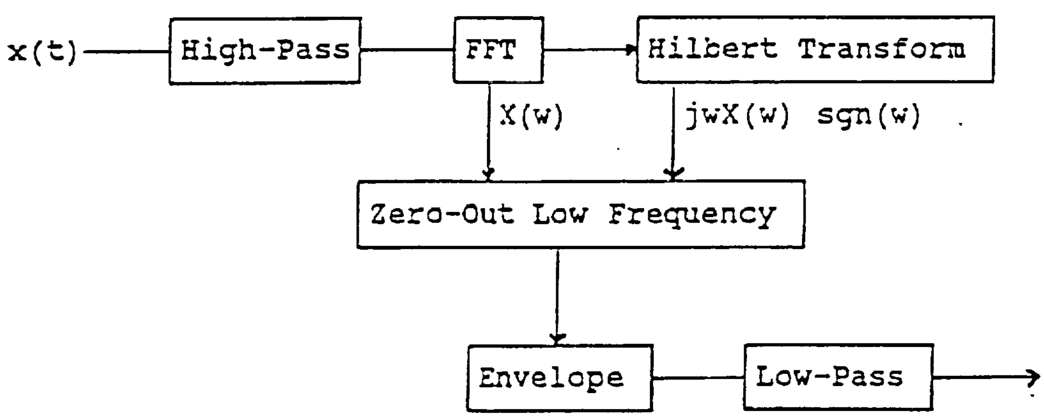


FIGURE 2-~~13~~ 8. ALGORITHMS FOR WIDE-BAND DEMODULATION (WBD)

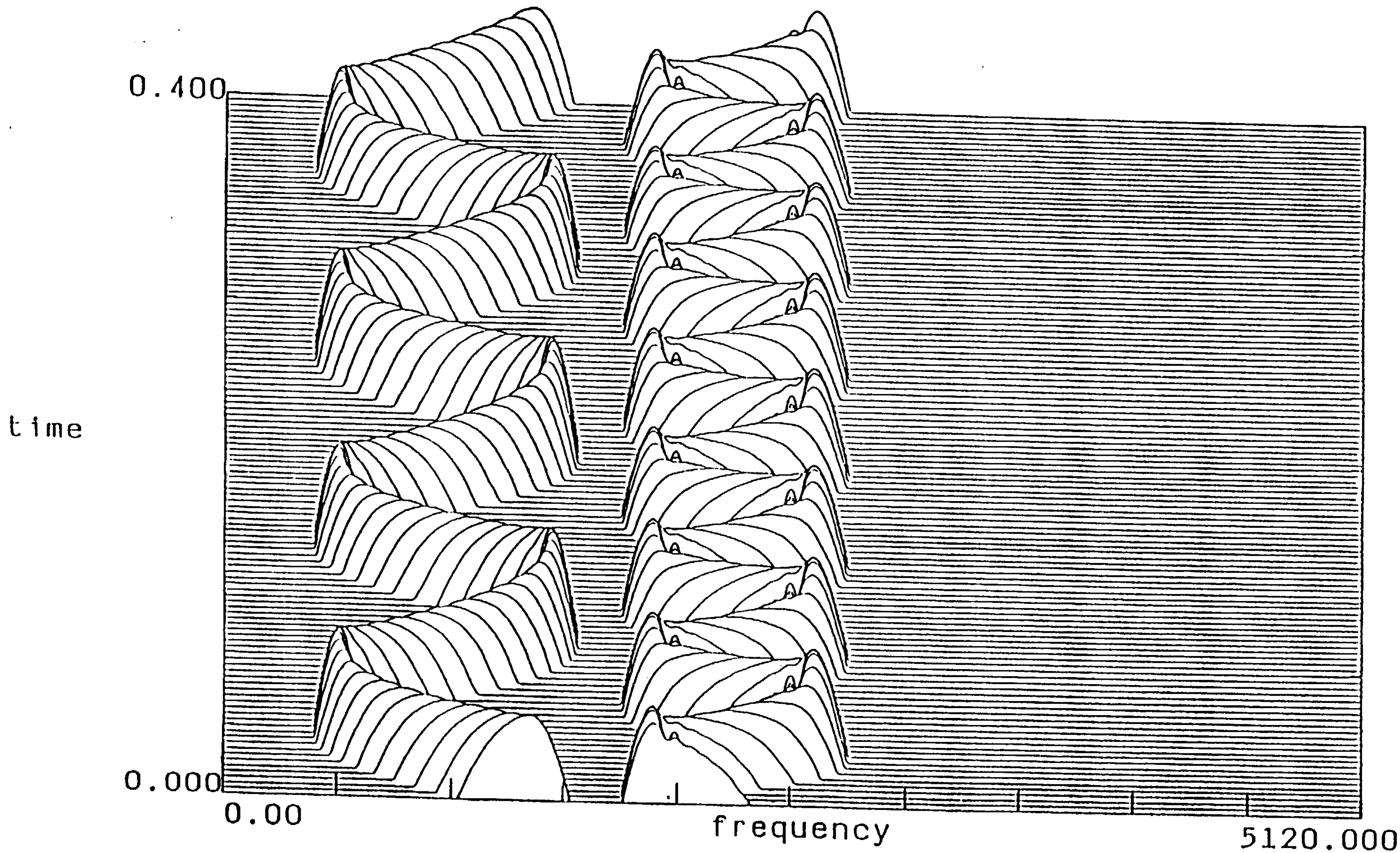


FIGURE ~~2-14~~ 9. FFT ISOPLOT OF TWO MODULATED SINE WAVES

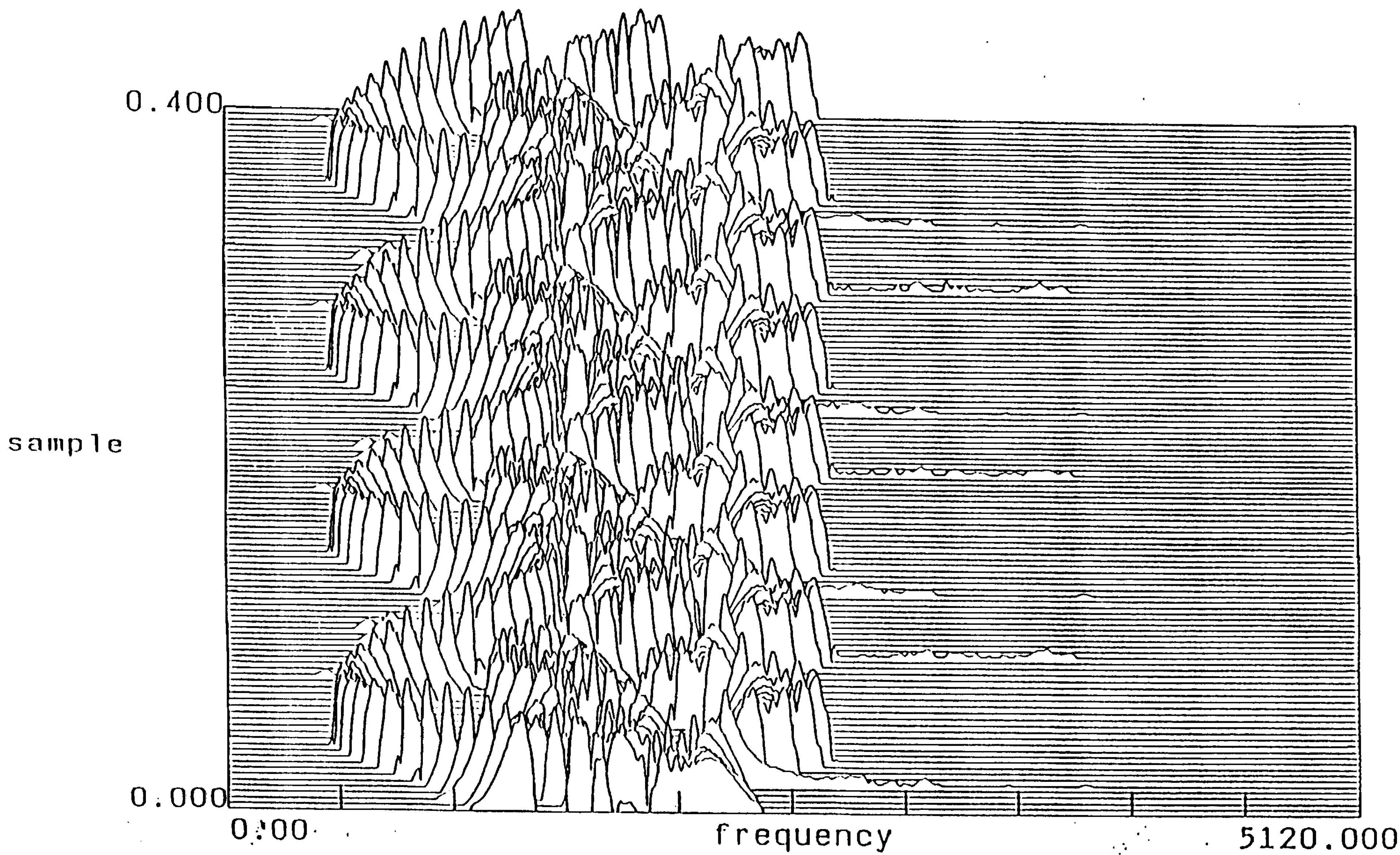


FIGURE ~~2-15~~ 10. WD ISOPLOT OF TWO MODULATED SINE WAVES

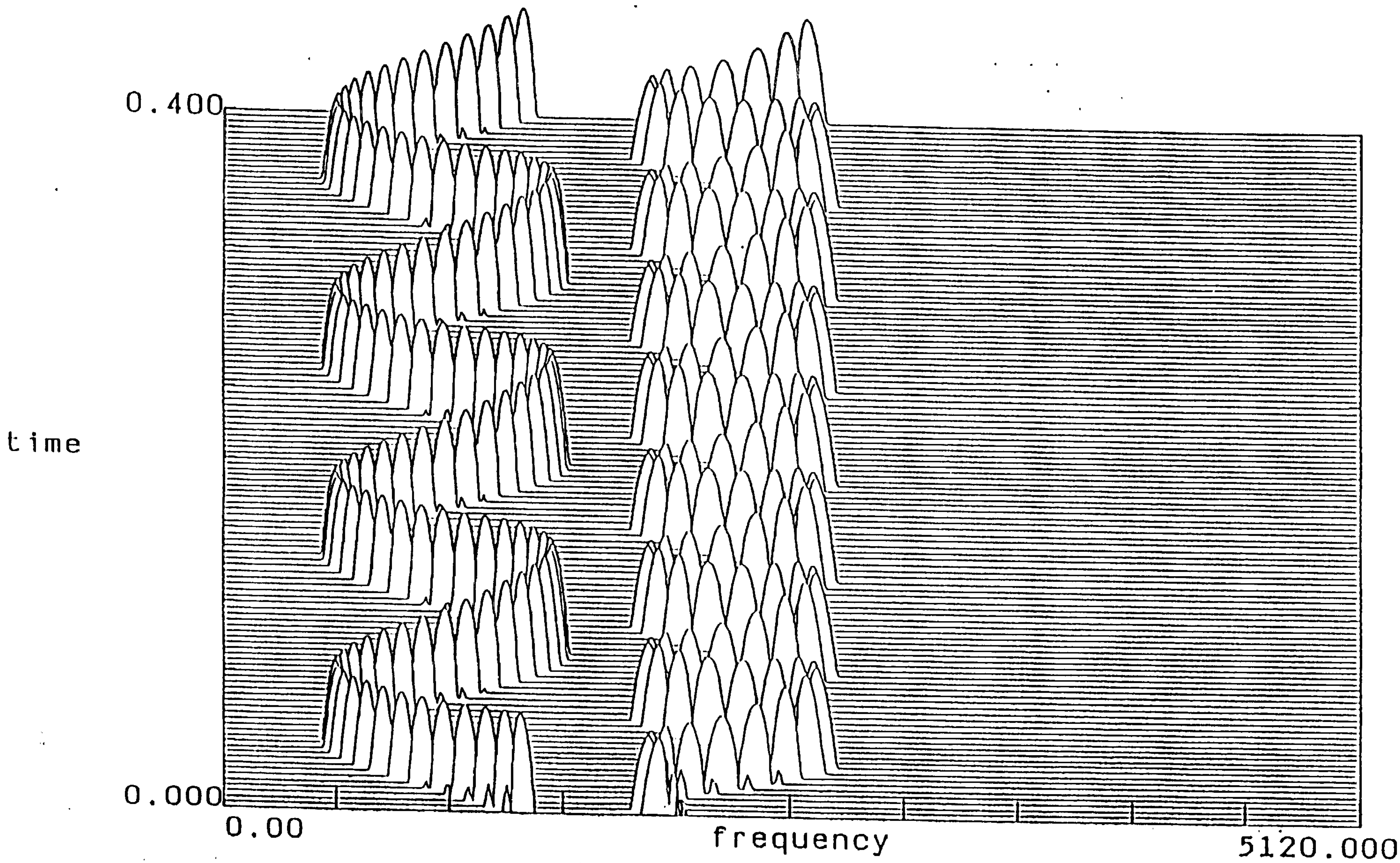


FIGURE 2-16. MWD ISOPLOT OF TWO MODULATED SINE WAVES