Space Shuttle Main Engine Vibration Data Base

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N88-13631

In order to evaluate Space Shuttle Main Engine (SSME) vibration data without having to constantly replay analog tapes, the SSME Vibration Data Base was developed. This data base contains data that have been digitized at a high sample rate for the entire test duration. It provides quick and efficient recall capabilities for numerous computation and display routines. This paper describes the data base components as well as some of the computation and display features.

INTRODUCTION

The Space Shuttle Main Engine (SSME) single engine test program has been active since 1975. Following each test, engineers have been responsible for reporting on the dynamic characteristics of the engine and its components. Since 1983, the SSME Vibration Data Base has been online to assist in the day-to-day data evaluation as well as diagnostic problem definition and solution.

The primary objective of the SSME Vibration Data Base is to make available to the dynamicist, in an efficient, systematic, and timely manner, data analysis techniques which can be used in the evaluation of the operational integrity of the SSME turbomachinery. The vast majority of the evaluations can be performed with conventional power spectral density (PSD) and root-mean-square (RMS) time history analysis. For those cases where these types of analyses are not adequate or where failures or major incidents occur, the analog magnetic tapes are available for more detailed and elaborate analysis.

DATA BASE COMPONENTS

The SSME Vibration Data Base consists of three components: (1) Power Spectral Density (PSD) Isospectral Data Base, (2) Diagnostic Data Base, and (3) Anomalous Frequency Data Base. The Isospectral and Diagnostic Data Bases will be described in this paper. Each data base is a self-contained software system, with the Diagnostic Data Base receiving its data values directly from the Isospectral Data Base through electronic transfer.

ISOSPECTRAL DATA BASE

The Isospectral Data Base is housed on the UNIVAC 1100/90 series mainframe computer at NASA's Slidell Computer Complex, Slidell, LA. The basic unit of this data base is the power spectral density. For routine single engine tests, all of the necessary analysis required for data review reporting can be derived from PSD formatted data. Since the data are in the frequency domain, any discrete frequency can be easily detected and classified in terms of its speed and amplitude. Each measurement contained in the data base consists of contiguous PSD's over the entire test duration. The PSD frequency range can be up to 5 kHz; however, most of the data to date are good to 2.5 kHz.

By maintaining dynamic data in PSD form and contiguous over the entire single engine test duration, several techniques can be utilized to extract information from the data. Since its inception, many algorithms have been developed to provide analysis insight into SSME dynamic data. Some of these algorithms are: Shaft speed tracking filter for fundamental and harmonic discrete frequency tracking, classification of discrete frequencies not related to shaft speed, and turbopump speed histograms. Also available are several display programs. These include: PSD ensemble average, 3-dimensional water fall "isoplots," and floating average summary table of measurement amplitudes. Because these data are digitized once and subsequently data based, the need for constant use of analog tapes is eliminated. This provides quick turnaround for all of the above analysis procedures.

The Diagnostic Data Base consists of summarized RMS amplitudes computed for a select group of engine instrumentation. These values can be displayed in tabular or graphic form and are primarily used for overall description of pump health as well as trend analysis. A powerful statistics routine has been developed to provide statistical models which characterize normal and abnormal behavior and establish and update engine redline cutoff values.

ISOSPECTRAL ALGORITHMS AND DISPLAY ROUTINES

Synchronous Speed Tracking

For each SSME component (specifically the high and low pressure turbopumps), the shaft rotation frequency can be identified within the PSD's through a speed detection algorithm. Given the operating power level of the engine, the algorithm computes a predicted shaft speed. It then operates on a spatial average across all measurements within a given component (this reduces background noise and enhances discrete frequencies). From the spatial average, the discrete peak associated with the shaft rotation can be easily identified. This allows the program to track not only the fundamental frequency, but also its harmonics. For routine analysis, the first 4 harmonics are analyzed and data based. Also important is the fact that certain "anomalous" frequencies (those not associated with any shaft rotations) can be easily detected and their amplitude tracked as well.

Display Routines

Several display routines are available in the data base. Most are menu driven and can be manipulated to suit most any need. Ensemble average PSD's can be displayed for any frequency range, starting at any time in the test and averaging for any period of time. Also available is a three-dimensional "waterfall" plot, or an isoplot. This plot displays frequency in the x-axis, time in the y-axis, and amplitude in the z-axis. It utilizes hidden line computations to display the 3-D effect. This display is perfect for identifying the presence of discrete frequencies present during a test. An example display is shown in Figure 1.

An amplitude versus time plot package is available for many types of time domain plotting. RMS time histories are displayed in this package, as well as the turbopump speed trace (Figure 2). This routine can be used to plot RMS amplitudes versus the turbopump speed to detect certain types of pump responses to critical operating speeds.

The data base can recall the turbopump speed trace and calculate/plot a speed histogram. This plot annotates the length of time the pump was operating at each encountered speed. This display is useful in defining the amount of time spent at potentially detrimental speeds.

Last, a summarized RMS table can be displayed, which defines a single value (in units RMS) to characterize each measurement response at each power level. This routine was designed to simulate the engineering judgment used in extracting these summary RMS levels. The table is produced by an algorithm which computes a running 11 point average across each power level duration. The values computed by this algorithm are used in each post-test data review and are the primary input for the Diagnostic Data Base.

DIAGNOSTIC DATA BASE FEATURES

The diagnostic data base is primarily used for test-to-test trend analysis and statistical amplitude definition for pump and engine lifetimes. The data base is housed on a TransEra 6040 40 Mbyte Winchester disk which interfaces to a Tektronix 4054 microcomputer. Summarized RMS values are contained for 16 accelerometer measurements, 8 on the high pressure fuel pump and 8 on the high pressure oxygen pump. The data base has recently been modified to house additional measurements located on the two low pressure pumps. For each single engine test or Space Transportation System (STS) flight, several other parameters are stored. These parameters include the power profile (engine thrust versus time), serial numbers of the various engine components, and the rotating shaft speed at each analysis power level.

A parameter search file is maintained for the data base which allows quick recall of any and all tests associated with certain engine hardware. The parameters housed in this file are: High pressure oxygen and fuel turbopump serial numbers, engine serial number, and the high pressure oxygen turbopump configuration build number. For any processing option in the master menu, data can be recalled using any

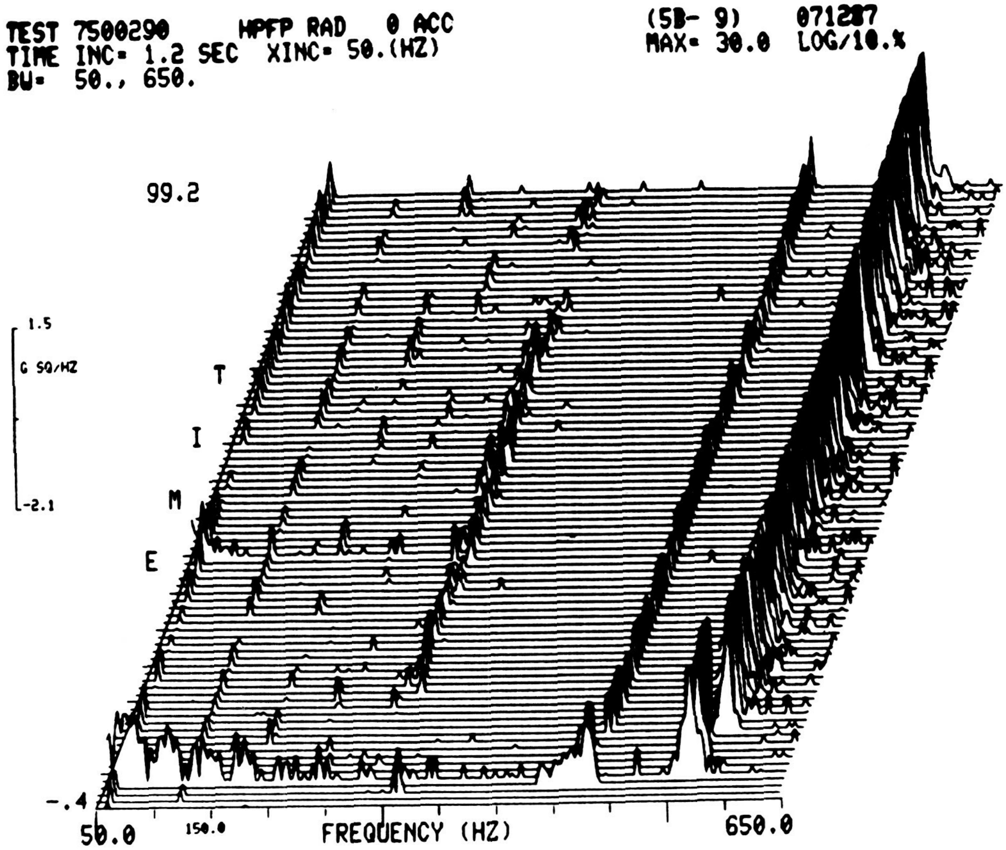

Fig. 1 Isospectral Display

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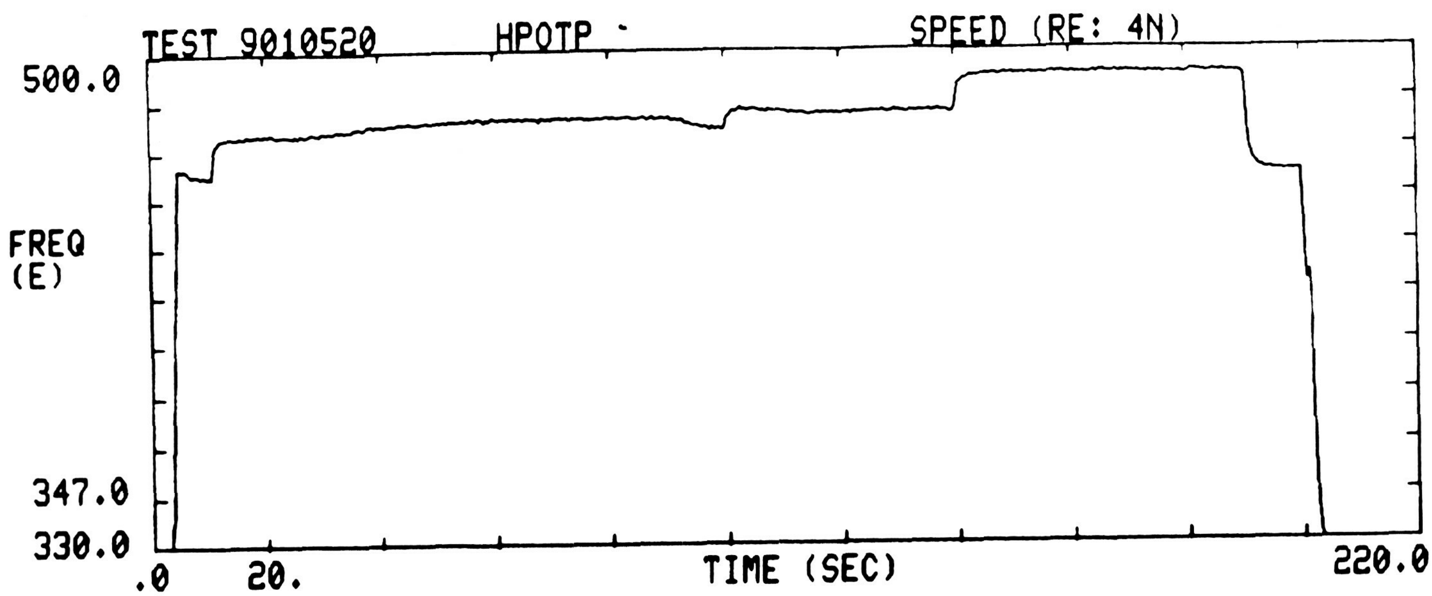

Fig. 2 SSME Component Speed Trace

of the above parameters. For example, a statistics package can be run on a particular oxygen turbopump and compared to the entire test program statistics output.

Processing Options

The Diagnostic Data Base can produce several types of tabulated and plotted information. One processing option available lists the run time activity in seconds at each engine power level for any search file component (Figure 3). This has been helpful in determining the current lifetime on pump bearings. It also provides a quick recall of a pump or engine's previous history for comparison to current activity. Another processing option plots the summarized RMS values versus their respective test numbers (Figure 4). This output once again can be limited to a specified engine component through use of the search file. This display is helpful in that it highlights any trends which may be present in the data.

The most powerful processing option in the data base is the statistical package. This option computes several statistical functions over any desired tests. One of the primary outputs of this package is a table which denotes for each measurement the sample size, mean G RMS level, maximum G RMS level, and the standard deviation (Figure 5). The values are broken down by each of the three active SSME test stands. The second output consists of a probability distribution or probability density plot (Figure 6). These plots can be configured by the user to overlay classical statistical functions, such as the normal or gamma curve, on the actual data. The use of these classical functions provide a continuous definition and enhance data characterization. The statistical package has been used extensively in the definition of engine redline, or cutoff, levels.

SUMMARY

The SSME Vibration Data Base has been the major force in automating dynamic data processing for SSME hot firings. It has demonstrated the feasibility of storing high sample rate data for long time periods and is the primary data evaluation tool for SSME dynamic data analysis. The continuing development of sophisticated computation, tracking, and display software will provide engineers with deeper insight and more complete information as to the dynamic environment of the SSME and its components.

SSME LIFETIME ANALYSIS

ENGINE SERIAL # 0210

TEST #	SER#	DUR	65%	90%	100%	102%	104%	106%	109%	111%	OTHER	RAMP
			>>>>>>>>>>>>>>>>>>	RUN SECONDS AT	<<<<<<<<<<<<<<<<							
A3-277	0210	200	0	0	11	0	184	0	0	0	0	6
A3-278	0210	200	0	0	11	0	184	0	0	0	0	6
A3-279	0210	200	0	0	11	0	184	0	0	0	0	6
A3-280	0210	200	0	0	11	0	184	0	0	0	0	6
A3-281	0210	200	0	0	11	0	184	0	0	0	0	5
A3-282	0210	200	0	0	11	0	184	0	0	0	0	6
A3-283	0210	300	0	0	10	0	284	0	0	0	0	6
A3-284	0210	300	0	0	11	0	284	0	0	0	0	6
A3-285	0210	223	0	0	5	0	0	0	212	0	0	6
A3-286	0210	300	0	0	11	0	284	0	0	0	0	6
A3-287	0210	300	10	0	11	0	266	0	0	0	0	14
A3-289	0210	300	0	0	11	0	284	0	0	0	0	5
A3-290	0210	300	0	0	11	0	284	0	0	0	0	5
TOTAL			10	0	132	0	2790	0	212	0	0	79

TOTAL OPERATIONAL TIME = 3223 SECONDS

Fig. 3 Engine Lifetime Activity Table

Synchronous @104% Power Level

Test Stand	LOX PBP RAD 45 # Tests	$\bar{G}$ rms	Sig	Max G rms	LOX PBP RAD 135-1 # Tests	$\bar{G}$ rms	Sig	Max G rms	LOX PBP RAD 135-2 # Tests	$\bar{G}$ rms	Sig	Max G rms
A1	73	2.4	1.2	6.8	32	2.4	1.4	8.2	71	2.5	1.2	7.6
A2	87	2.1	1.1	6.2	49	2.3	1.5	7.9	81	2.0	1.2	8.4
A3	53	2.8	2.6	8.6	24	4.5	2.6	9.1	46	2.7	2.3	8.3
Combined	213	2.4	1.7	8.6	105	2.9	2.0	9.1	198	2.3	1.5	8.4

STATISTICAL SUMMARY OF SSME VIBRATION DATA 7 JUL 87

Synchronous @104% Power Level

Test Stand	LOX PBP RAD 180 # Tests	$\bar{G}$ rms	Sig	Max G rms	LOX PBP RAD 225 # Tests	$\bar{G}$ rms	Sig	Max G rms	LOX TURB RAD 45 # Tests	$\bar{G}$ rms	Sig	Max G rms
A1	10	2.9	2.3	7.8	70	2.7	1.4	8.8	19	1.0	0.5	2.5
A2	17	3.0	1.3	6.2	77	1.9	1.1	7.8	17	1.1	0.5	2.6
A3	25	4.1	2.4	7.8	28	1.7	1.7	6.9	18	1.2	0.7	2.4
Combined	52	3.5	2.1	7.8	175	2.2	1.4	8.8	54	1.1	0.6	2.6

TEST #'S A1300-533, A2200-428, A3200-290.

Fig. 4. Statistical Tabulation

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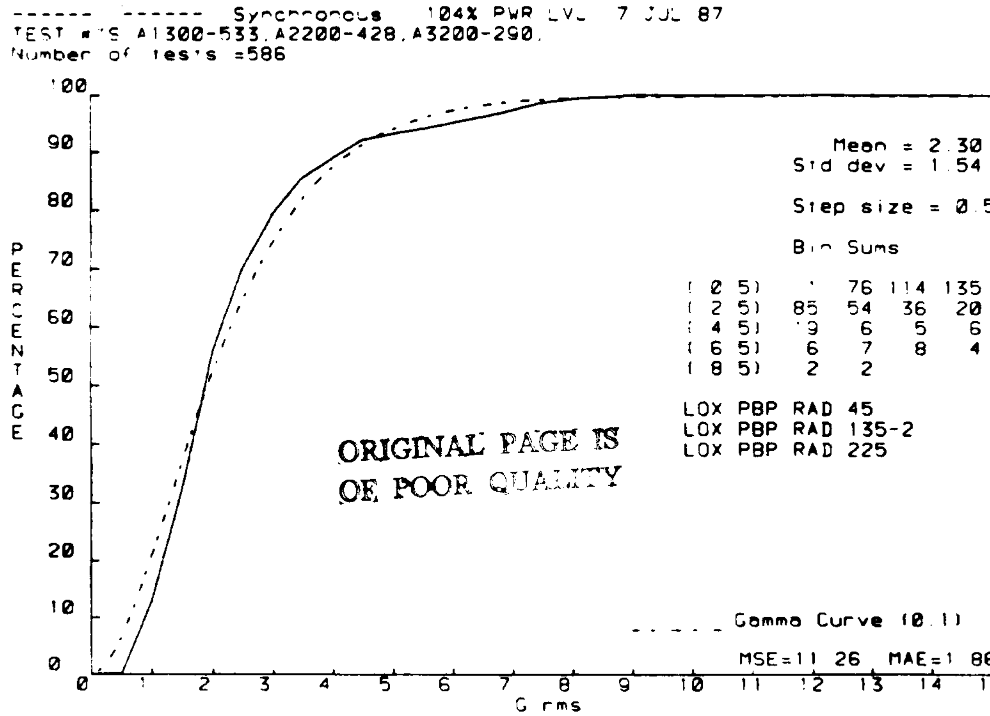

Fig. 5 Probability Distribution

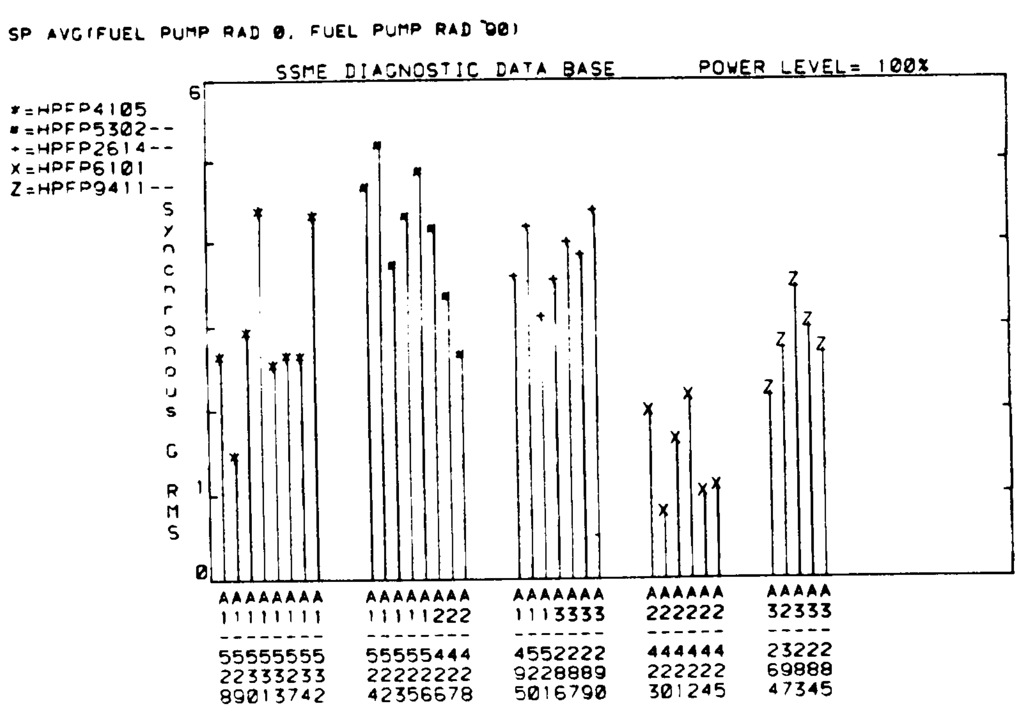

Fig. 6 Plot of RMS Amplitudes for Several Fuel Turbopumps