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SACRAMENTO PLANT

REPORT NO. RN-TM-0427

WIDE-BAND DATA-PROCESSING AND
ANALYSIS CAPABILITY

JUNE 1967

MAILED

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NERVA PROGRAM

CONTRACT SNP 1

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CLASSIFICATION CATEGORY

UNCLASSIFIED

Unclassified - D. B. Rude

CLASSIFYING OFFICER

6/9/67

DATE

AEROJET - GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

REPORT NO. RN-TM-0427

WIDE-BAND DATA-PROCESSING AND
ANALYSIS CAPABILITY

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CONTENTS

	<u>Page</u>
I. Introduction	1
II. Technical Discussion	3
A. Wide-Band Data-Processing System	3
1. General Procedure	3
2. Wide-Band Data-Converter Output Format	3
3. Quality Control and Error Checking	7
4. Wide-Band Data-Converter Sampling Rate	7
5. Calibration	8
6. Selection of Data to be Processed	8
7. Data-Processing Provisions	8
8. Technical Description of Wide-Band Data Converter	9
9. Features of Wide-Band Data Converter	9
10. Operation of Wide-Band Data Converter	10
B. Digital, Hybrid, Dynamic-Data, Spectral-Analysis System	10
C. Equipment Capability	25
D. Dynamic-Analysis Computer Program	31
E. Present NRO Transfer-Function Analysis	34
F. Present NRO Analysis Activity	34

ILLUSTRATIONS

<u>Figure No.</u>		<u>Page</u>
1	Equipment Block Diagram for Processing Wide Band Data	4
2	Sample Data Request Form	5
3	Tape Format for Gapless Tape	6
4	Dynamic-Data Processing Systems	13
5	Hybrid Analysis System	15
6	Plotted Data System	16
7	Power Spectral Density Analysis Plot	19
8	Tabular Data System	20
9	Spectrum Analysis Data Tabulation	22
10	Spectrum Analysis Data Summary	23

TABLES

<u>Table No.</u>		<u>Page</u>
1	SA-12 Spectrum Analyzer; Spectral Widths, Filter Band Widths, and Analysis Times	17
2	Recorder-Reproducers	28
3	Signal-Processing Equipment	29
4	Recording Equipment	30

I. INTRODUCTION

This report describes the high-frequency (0 to 20,000 cps) data-analysis capability and the procedures that are used to evaluate NERVA data at Aerojet-General Corporation's Sacramento Plant.

The discussion specifically describes analyses that are applicable to NRO (Aerojet's Nuclear Rocket Operations) and does not describe the total Aerojet capability. The Aerojet analysis facilities have been developed over many years to support liquid-rocket, solid-rocket, and other testing activities and now represent an extensive and highly flexible capability in terms of equipment, experienced operating personnel, and management direction.

The facilities, equipment, and related programs and procedures have been primarily financed by other programs, but all are available to the NERVA program. NRO intends to utilize this potential and make changes as appropriate to satisfy the needs of the NERVA program in terms of wide-band data analysis.

The ultimate purpose of wide-band data analysis is to support the systems-evaluation requirements of the NERVA engine. To achieve this purpose, all variables that can influence the test data must be accounted for and be fully understood so the data can be properly interpreted.

This report is limited to a description of the data processing and data analysis that will be performed at Aerojet once the FM analog tapes (FM-FM multiplex tapes for NRX tests) are received. The objective of NRO data-processing and data-analysis programs is to establish an automatic data-processing program that will rapidly yield valid data for use in interpreting test data.

The wide-band data-processing system is described in detail to show the present Aerojet capability, and some of the equipment and analytical programs

that have been used are described. The hybrid frequency-analysis program that was developed to meet NRO requirements is discussed in sufficient detail to provide an understanding of its capability and use.

II. TECHNICAL DISCUSSION

A. WIDE-BAND DATA-PROCESSING SYSTEM

1. General Procedure

Magnetic tapes are received from the Nevada test site with the test data recorded in the form of voltages. The tape is processed in accordance with the block diagram shown in Figure 1. Included in the data processing are quality-control checks for validity, special provisions for efficiency and economy of time, and options for performing special-purpose analyses. All wide-band data analysis and special-purpose analyses are requested on a special form (Figure 2) to expedite the processing and analysis of wide-band data and to ensure that the request is made correctly.

2. Wide-Band Data-Converter Output Format

The wide-band data converter is a high-speed digitizing system that provides for multiple inputs to 48 channels. The unit places the data input in proper format after it has been digitized and places the data on an IBM-compatible tape having a character density of 800 bits/in. This operation is performed in two steps. First, the tape is placed on an IBM-compatible tape having a character density of 556 bits/in., in a gapless format as shown in Figure 3. In the second step, the A record bit is broken up to have a 3/4-in. gap for each record, and a longitudinal parity check is added so that the gapped tape, which has been initially edited, contains 800 bits/in. This two-step procedure increases flexibility and reduces processing and computer time.

Vertical and horizontal parity are checked on the gapped tape. In addition, the gap format, record length, and total character count are checked by means of a tape dump. At this time, proper timing and the validity of the data can be verified.

Figure 1 Equipment Block Diagram for Processing Wide Band Data

RECON DATA PROCESSING REQUEST - AGO TEST AREA

Request No.				
Requested by: <i>H. BENENSON</i>	Dept. <i>7830</i>	Lxt. <i>6701</i>	Slag. <i>2019A2</i>	Approved by: <i>GWA 157500</i>
Date of Request <i>11-27-66</i>	Date Required <i>11-27-66</i>	Budget Limit (M.H.) <i>12 M.H.</i>	J.O. No. <i>0914-15-004</i>	Security Class. <i>L/NCL</i>
Test No. <i>NRX-EST-EP II B</i>		Test Facility: <i>NTD J-2</i>		
Type of Data Required: <i>TRANSFER FUNCTION ANALYSIS (COMPUTER PROGRAM 2909)</i>				
Function	Tape/Track	Cal. Ref.	Cal. Eng. Units	
(1) <i>S 928 - 4 X</i>	<i>K-2 70 KC</i>	<i>± 100% STEP</i>	<i>± 100 RPM</i>	
(2) <i>P-942 - "</i>	<i>J-6 52.5 KC</i>	<i>"</i>	<i>± 20 PSI</i>	
(3) <i>P-923 "</i>	<i>J-10 40 KC</i>	<i>"</i>	<i>± 20 PSI</i>	
(4) <i>D-909 "</i>	<i>K-5 22 KC</i>	<i>"</i>	<i>± 4.5°</i>	
(5) <i>P-930 "</i>	<i>J-11 22 KC</i>	<i>50 CPS, 100% AC</i>	<i>25 PSI P-P</i>	
<p>SAMPLE DATA REQUEST FORM</p>				
Tape Format: Record Speed <u><i>60</i></u> IPS Format <u><i>FM/FM MULTIPLEX</i></u>				
Type of Recorder <u><i>AMPEX FR-100</i></u> No. of Tracks <u><i>14</i></u>				
Special Instructions: <i>DATA TIME: 28750 TO 29050 SEC.</i> <i>SINUSOIDAL FREQ'S: 0.1, 0.16 AND 0.63 CPS</i> <i>COMMAND: (1) (1) (1) (4) (4) (4)</i> <i>RESPONSE: (2) (3) (5) (1) (2) (3)</i>				
December 7, 1966				

Figure 2 - Sample Data Request Form

3. Quality Control and Error Checking

In addition to checking the gapped tape, a formal quality-control procedure is followed for all analog tapes that are processed. The analog tape is reproduced on a Minneapolis Honeywell Visirecord oscillograph, a low-cost, self-developing, immediately available record that can be retained as long as four months. Each record is checked for the requested information, proper timing, valid channels, valid functions, skipped data points, and other observable information. Invalid data points are deleted, and questionable data are flagged. If a channel is too noisy, smoothing is prescribed; if obviously invalid, no analysis is performed. The quality-control procedure has saved considerable time, cost, and effort and has improved the quality of the information.

4. Wide-Band Data-Converter Sampling Rate

The wide-band data-converter systems can scan at a variable rate adjustable from 100 to 10,000 samples/sec. Further flexibility is provided by two modes of sampling; one mode is called the intermittent record sample (IRS), and the other, the standard sample mode. The IRS is a record sampling mode in which 0.1 to 10 records/sec can be sampled. This mode provides for any desired low-frequency level. The standard sampling mode permits sampling of words at rates from 100 to 10,000 samples/sec. The present procedure with the above options requires only two sampling rates, 3750 and 10,000 samples/sec, to satisfy existing requirements. If higher sampling rates are required, rates as high as 320,000 s/s can be achieved by using time-expansion techniques (that is, the tape speed can be reduced to as low as 1/32 of its initial speed).

5. Calibration

Aerojet is currently performing system calibration only as provided on the analog tapes. The voltages from the tape are converted to engineering units by using a two-point conversion index and assuming that linearity exists. These two points are taken from the dc voltage levels that are obtained by voltage-substitution calibration at the Nevada Test Operations.

Transducer calibration can be achieved with six-degree (higher if needed) polynomial fit and is being used in other programs.

6. Selection of Data to Be Processed

The processing program is very flexible. As shown in Figure 2, any isolated time period can be specified for any set of channels and for any type of analysis. In addition to the routine types of analyses, special requests can be made to obtain any information that may be useful for interpreting the data. That is, by means of the form shown in Figure 2, input or output analog and engineering-unit data can be requested and recorded at any digital sampling speed for any time interval. This type of flexibility and interaction between engineering and processing personnel facilitates data interpretation and use.

7. Data-Processing Procedures

Several data-processing procedures exist that are essentially standard, depending on the type and method of analysis. To utilize data equipment most efficiently, two input buffers are used. As data are processed for computer use, the second buffer is used; when this processing is completed, the procedure is reversed. Data-plotting routines are worked into the data-analysis program to perform on-line plotting as required. Because most procedures depend on the specific function, details of existing procedures will not be discussed at this time.

8. Technical Description of Wide-Band Converter

The following data are presented in summary form to define the wide-band converter:

- a. Sampling rate: 100 to 10,000 samples/sec
- b. Number of channel inputs: 1, 2, 10 (option exists to permit variable channel inputs to 48 by appropriate patching)
- c. Input impedance: to 100 megohms (for differential input)
- d. Input voltage: variable through ± 5 v in six steps (± 10 mv, ± 30 mv, ± 100 mv, ± 300 mv, ± 1 v, ± 5 v)
- e. Conversion accuracy: $\pm 0.06\%$ full scale (worst case)
- f. Output format: IBM-compatible blocks, variable number of characters from 200 to 1600 characters in length for steps of 200 characters
- g. Converter output: 16 bits BCD plus sign
- h. Display: Decimal display of any selected channel is available on the front panel

9. Features of Wide-Band Data Converter

- a. Computer tape may be searched for start times if unmodulated time code is on tape. Any number of starting times may be located in the order found on the tape.
- b. End-of-file marks may be placed on tape at any desired stopping point.
- c. Output format is so arranged that the times at which any samples are taken can be pinpointed (by utilizing the commutator position of the multiplexer to define the time).
- d. Digital Sampling: 400-point commutator that can be patched to provide sampling of 10,000 samples/sec variable down to 100 samples/sec.
- e. Parity checks are provided to ensure proper operation of tape writing circuits.

- f. An internal time base is provided that will permit digitizing of signals not employing normal time code format. Time information is inserted by the converter itself and is continually updated on the output tape. An exact length of the digitized record can be obtained in this mode by utilizing computer program methods.
- g. The output tape provides an indication of time, digitizing speed, number of channels sampled, horizontal and vertical parity, and data.

10. Operation of Wide-Band Data Converter

The wide-band data converter has been used for NRX test data as defined by the flow diagram shown in Figure 1. In normal operation, analog signals are taken from either a Sangamo 4700 or Ampex FR 1200 analog recorder and connected by means of a patch panel to the EMR Model 70 data discriminators. The output of these discriminators is identical to the input signals recorded at the time the test was made and could be patched to a number of locations. Anti-aliasing filters are used to condition these signals to prevent sampling errors. This conditioning is accomplished by using discriminator output filters or built-in filters in the digitizer. Signals are then applied directly to the wide-band data converter from the patch panel. The signal is also paralleled into a Minneapolis Honeywell oscillograph for simultaneous plotting of the signal being digitized. The data are now in a form to be used by the IBM 360-40 computer or the plotting equipment, or both.

B. DIGITAL, HYBRID, DYNAMIC-DATA, SPECTRAL-ANALYSIS SYSTEM

During the initial study phase, it became apparent that the volume of acquired dynamic data would far exceed the normal processing capacity of the analog analysis systems Aerojet had at the time. These systems were inherently slow and unadaptable to high-speed processing of large quantities of data. The weak link in the chain of data processing and analysis was found to be the time required to obtain an accurate description of the energy

distribution as a function of frequency for transient or steady-state phenomena. This problem was resolved by development of a hybrid real-time processing system comprising a combination of analog and digital computer techniques.

In this report, the term dynamic data is defined as the analog representation of any pressure, vibration, or other forcing function whose characteristics change with time. Characteristics may be divided into two separate classes:

- (1) Amplitude -- The instantaneous value of the function at any point in time.
- (2) Frequency -- The number of complete cycles of amplitude per unit time.

Because dynamic data are typically complex in structure and do not lend themselves to a simple type of analysis, a description of the data requires an analysis of such individual properties as instantaneous value, rise time, decay, frequency distribution, and power-density spectrum.

1. The Prehybrid Dynamic-Data Processing and Analysis Methods

Before the hybrid analyzer was installed, three basic methods were used to display and analyze dynamic data:

- (1) Direct playback from a tape to a Miller cathode-ray oscillograph, which required manual reduction of frequency components and associated amplitudes. (This method was too time-consuming and inaccurate for mixed-frequency modes.)
- (2) The seven-band spectral system, in which frequencies of interest were band-passed and replayed from an FM tape directly to a Miller cathode-ray oscillograph or a CEC oscillograph at reduced tape speed. (Individual interpretation was the major source of error on this system, and frequency spectral coverage was limited.)

- (3) The heterodyne wave analyzer, which requires a tape loop and a minimum of two sec of real-time data for analysis. (Although this was the best method of analysis, the time expended was excessive.)

These prior methods of data presentation are shown schematically in Figure 4. The weak link becomes quite evident upon examination of the diagram, because approximately 80% of the processing systems were being used to extract frequency information.

The heterodyne spectral wave analyzer was the most accurate device for determining frequency but required a minimum of 2 sec of continuous input data for tape loop storage and 1200 sec of operating time to produce one analysis. This time requirement was prohibitive for the processing of large volumes of data. The analysis of transient frequency characteristics required time-consuming manual reduction of oscillograph records, which was not only costly, but gave questionable results because of the variability in data interpretation among the individuals involved.

2. NRO Program Requirements

The immediate requirement was for rapid processing of transient and steady-state energy vs frequency information, to permit immediate evaluation and analysis. Other information requirements, such as phenomena propagation times, instantaneous energy values, and envelope characteristics, were readily available from high-speed oscillograph records.

The main objective became development of an automatic, high-speed, electronic, data-processing system that would accurately describe transient and steady-state energy spectra at a minimum cost. A market survey indicated that the available analog processing systems were too slow and would not satisfy the objectives. The next step was to investigate the potential application of high-speed digital systems, and a system was found that satisfied the requirements.

Figure 4 - Dynamic-Data Processing Systems

3. Operational Description of the Hybrid Analyzer

The hybrid system is shown in Figure 5 as it was originally proposed. The Model SA-12 spectrum analyzer manufactured by General Applied Science Laboratories in Westbury, Long Island, New York, was selected for the analog spectrum-to-digital conversion portion that became the heart of the hybrid system.

The analyzer consists basically of two sections. The first is a digital-loop section in which the analog data are digitized with 8-bit resolution at a rate at least four times the highest frequency of interest (Figure 6). These digitized data are inserted into a recirculating, magnetostrictive, delay-line storage system in such a manner that the data are effectively sped-up by a factor of 50. By selecting proper combinations of tape reproduction speed and digital sampling rate, as little as 12 millisecond of real-time data may be accurately analyzed (see Table 1). These data samples may be taken anytime during the run with a gating circuit operated by the 17-bit time code recorded on the tape. This gated sample may be stored and recirculated continuously for analysis or may be taken by increments progressively in time throughout the test wherever a frequency-amplitude-time profile is desired.

Data stored in the digital loop are reconverted to analog in the sped-up form, and actual data frequencies are translated upward in frequency by the sped-up factor. The data are then fed to the second section of the analyzer, which is a conventional-sweep spectrum analyzer. This analyzer operates at a carrier frequency of 600 kc and is equipped with both a crystal lattice filter for narrow-band analysis and a stagger-tuned amplifier for wider-band survey work.

The output of the analyzer is available in both analog and digital form. The analog output is generally used when an X-Y spectral plot

Figure 5 - Hybrid Analysis System

Figure 6 - Plotted Data System

TABLE 1

SA-12 SPECTRUM ANALYZER; SPECTRAL WIDTHS, FILTER
BAND WIDTHS, AND ANALYSIS TIMES

Tape Speed	Analysis Spectrum, cps	Narrow Filter Band Width, cps	Wide Filter Band Width, cps	Effective Data Storage Time, sec	Analysis Time, sec	
					Narrow Band	Wide Band
1/1	0.01-5	0.01	0.1	100 sec	1000	100
1/2	10	0.02	0.2	50	1000	100
1/4	20	0.04	0.4	25	1000	100
1/8	40	0.08	0.8	12	1000	100
1/16	80	0.16	1.6	6	1000	100
1/1	0.125-62	0.125	1.25	8 sec	80	8
1/2	125	0.25	2.5	4	80	8
1/4	250	0.5	5.0	2	80	8
1/8	500	1.0	10.0	1	80	8
1/16	1000	2.0	20.0	0.5	80	8
1/1	0.5-250	0.5	5.0	2.0 sec	20	2
1/2	500	1.0	10.0	1.0	20	2
1/4	1000	2.0	20	0.5	20	2
1/8	2000	4.0	40	0.25	20	2
1/16	4000	8.0	80	0.125	20	2
1/1	2.0-1000	2.0	20.0	0.5	5.0	0.5
1/2	2000	4.0	20	0.25	5.0	0.5
1/4	4000	8.0	80	0.125	5.0	0.5
1/8	8000	16.0	160	0.062	5.0	0.5
1/16	16,000	32.0	320	0.031	5.0	0.5
1/1	10.0-5000	10.0	100.0	0.1 sec	1.0	0.1
1/2	10,000	20.0	200	0.05	1.0	0.1
1/4	20,000	40.0	400	0.025	1.0	0.1
1/8	40,000	80.0	800	0.012	1.0	0.1

of a stored recirculated data sample is desired. Digital output in the real-time mode is generally recorded on an FR400 tape compatible with computer format. The computer can manipulate the data in many ways for presentation, the most common being the complete tabulation of time vs frequency and amplitude. Any selected portion can be summarized and plotted automatically by using a Cal-Comp tape plotter system. A representative plot is given in Figure 7.

4. Present System Configuration

The present hybrid system processes data in two basic formats: it presents on-line spectral plots of short-duration transient data or creates a digital tape containing spectral time-history data for computer processing. Figures 6 and 8 show the present system block diagrams used for both formats. The most significant operational difference between the two formats is that the transient data for on-line plots of energy vs frequency are locked-up or stored in digital memory, whereas the spectral time-history data are processed with the system operating in real-time continuous mode.

5. Data Formats

a. Short-Duration Transient Data

Short-duration transient data appear in the form of plots in which the energy amplitude, in engineering units, is found on the ordinate and the frequency is found on the abscissa. The minimum transient duration that can be accurately plotted is found under the column heading, "Effective Data Storage Time," in Table 1, which also shows the associated narrow or wide analysis band widths.

Figure 7 - Power Spectral Density Analysis Plot

Figure 8 - Tabular Data System

b. Computer-Processed Data

The hybrid system generates a digital tape that contains amplitude, frequency, and time information in a form compatible for computer processing. With digital tape input, the computer is then directed to process and reformat the data by using one or more of several mathematical programs that are also available as tape input. Some of the computer-processed data formats are described below.

(1) Time-History Tabulations

These listings provide a three-dimensional time-history survey of the dynamic data as shown in Figure 9, which is a portion of a 20- to 10,000-cps computer tabulation. Frequency appears across the top, time in the left-hand vertical column, and energy in the center area. The system reads out a complete line of spectral information every 50 millisec, commensurate with a 20- to 10,000-cps frequency analysis. Summary statistics are also listed at specified time intervals, as shown in Figure 10.

(2) Computer-Generated Plotter Tape

Several of the computer programs provide a statistical treatment and reformatting of the data, which are recorded on a plotter tape. The plotter tape is then installed on an automatic plotting system that scales, annotates, and plots the required data in one operation. The three main plotted formats are:

(a) Power spectral density in the form of

$$\frac{2}{X}/\text{cps vs frequency (Figure 4)}$$

TEST NUMBER STAND DATE DURATION TRACK FUNCTION RANGE CPS EDIT PRESET
NRX-101-10-28 JAF 0.0 3 P-939 1000 6.874E-02 5.728E-01

FREQUENCY IN CPS MULTIPLY LISTED VALUES BY 0.001000 TO CONVERT TO PSI RMS

	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500
<i>t₀ = 15050 SEC.</i>																									
1.012	783	125	77	36	27	46	27	23	19	23	13	32	23	4	19	23	233	321	46	23	4	18	18	23	18
1.012	682	215	33	46	27	50	23	23	32	36	36	55	27	23	23	36	284	320	50	18	9	13	23	23	4
1.534	677	113	46	+1	32	46	27	23	23	23	41	119	27	23	23	41	224	325	41	23	18	18	23	13	9
2.015	641	77	64	+1	24	41	23	13	27	23	27	59	13	18	23	23	219	238	41	23	9	13	23	13	13
2.517	712	324	73	41	27	32	23	18	27	23	36	114	13	13	13	32	229	320	41	23	4	18	18	9	13
3.019	731	23	7	+6	27	41	23	23	13	23	23	32	13	18	13	36	256	320	46	23	0	23	23	0	13
3.541	673	192	72	27	32	50	23	13	13	23	27	32	23	9	13	36	256	325	41	23	9	18	13	13	23
4.023	578	27	78	41	27	64	27	23	23	13	23	46	13	23	18	36	279	339	46	27	23	9	27	18	4
4.545	749	307	64	46	23	27	23	27	19	23	27	73	18	23	23	41	229	265	46	23	13	9	13	18	4
5.038	714	220	41	20	36	46	23	23	23	23	36	110	13	23	18	23	252	311	46	27	23	9	23	18	13
5.545	651	196	46	30	23	41	23	23	23	13	27	101	23	18	23	36	270	325	50	23	13	13	18	18	4
6.021	675	257	57	46	28	46	23	23	23	23	28	108	23	23	17	51	234	269	40	23	17	11	17	17	5
6.507	765	07	7	41	23	27	23	23	13	18	23	52	13	13	13	27	252	284	50	23	13	13	18	13	4
7.005	621	261	73	36	27	41	23	18	23	13	23	46	18	9	4	23	252	288	46	23	0	18	18	4	18
7.507	72	167	55	30	23	50	23	9	23	13	23	36	23	9	23	32	252	316	36	23	4	18	23	4	0
8.007	73	47	7	32	32	37	23	18	23	13	27	78	18	13	13	41	242	256	41	23	18	18	18	9	9
8.512	52	321	52	+1	27	23	23	18	18	9	52	110	18	13	9	27	233	302	41	23	9	13	18	18	4
9.012	637	235	67	+1	23	43	23	23	13	13	32	91	18	4	18	46	233	302	41	18	9	9	23	9	4
9.514	660	10	60	32	36	64	32	23	23	13	32	87	23	23	23	41	270	302	41	23	23	18	23	13	9
10.016	579	201	50	23	23	55	27	23	13	23	32	27	23	23	18	46	261	293	41	23	9	18	23	18	4
10.517	631	27	75	27	27	36	23	18	19	9	27	36	18	9	18	36	261	279	46	23	23	18	23	23	4
11.020	650		57	36	32	23	27	23	27	13	23	46	23	13	23	46	288	330	46	13	13	0	23	9	9
11.522	677	16	73	27	23	23	23	13	23	13	32	78	18	13	9	27	252	288	50	18	9	13	27	9	4
12.024	724	247	7	41	27	27	27	18	23	18	23	73	23	13	18	32	270	339	50	23	18	23	27	18	0
12.526	710	33	6	35	23	32	23	13	23	19	32	91	18	13	9	23	233	265	46	18	23	0	27	9	0
13.028	73	201	43	41	32	50	23	13	18	23	23	50	32	4	27	27	247	284	41	23	4	13	23	4	9
13.530	551	105	5	30	41	46	27	19	36	23	23	27	23	23	18	32	242	334	46	23	9	9	23	13	4
14.032	71	55	7	41	23	41	23	27	13	23	41	18	13	9	41	265	270	41	13	18	0	23	23	0	0
14.534	678	52	63	36	27	32	23	4	13	13	23	30	9	18	13	36	247	321	41	23	9	9	23	9	9
15.036	677	201	78	7	27	36	23	18	23	18	36	78	23	13	23	32	252	298	46	23	23	9	23	13	13
15.538	663	17	62	32	27	36	27	23	23	23	37	87	18	13	18	46	256	293	46	23	23	4	23	23	4
16.040	673	213	67	27	32	41	27	32	13	18	36	105	23	18	23	50	279	334	50	23	18	4	23	23	4
16.542	714	61	73	36	36	50	27	24	23	13	27	55	18	23	23	32	261	261	46	27	23	13	32	23	4
17.044	623	15	3	23	30	34	23	23	27	13	27	78	13	23	18	23	261	316	46	23	18	4	23	9	4
17.546	711	145	64	26	27	23	23	18	13	13	41	23	18	18	27	219	256	32	23	18	4	23	13	4	4
18.048	646	164	55	40	36	36	27	23	9	13	23	27	23	23	27	27	219	242	46	23	18	4	23	23	0
18.550	677	23	4	46	23	27	23	9	18	27	41	82	13	18	23	41	234	279	46	23	0	18	27	23	0
19.052	660	21	5	41	32	56	27	18	23	2	46	87	23	23	13	36	279	325	46	18	13	13	23	13	0
19.554	636	145	55	22	30	50	23	18	27	13	30	119	23	23	23	41	265	311	55	23	23	4	23	18	4
20.056	773	15	2	33	23	41	32	23	23	27	46	23	23	27	50	279	330	46	23	13	9	23	4	9	9
20.558	637	224	37	27	41	41	23	23	13	18	23	73	23	23	23	36	265	311	46	23	18	9	23	23	0
21.060	725	207	77	27	23	27	23	19	27	13	27	13	18	32	41	247	293	41	23	18	9	23	18	18	18
21.562	556	155	63	36	23	36	23	19	27	18	27	35	23	13	18	46	275	298	50	23	23	13	32	18	9
22.064	637	1	64	46	32	27	13	18	23	23	46	114	23	18	23	46	238	288	55	23	23	18	32	23	13
22.566	677	2	7	32	27	36	23	13	23	13	30	82	23	18	9	27	242	298	50	23	13	23	23	18	9
23.067	691	261	30	6	30	41	23	23	23	3	41	123	23	23	18	36	275	302	46	23	23	23	23	13	4
23.569	715	178	5	27	23	46	23	17	23	18	23	36	13	13	13	36	256	307	50	23	23	18	23	13	9
24.071	672	163	53	41	27	23	18	24	13	23	23	59	19	13	23	41	247	268	50	23	13	18	23	9	13
24.573	673	211	7	50	27	32	23	23	9	23	23	27	23	4	13	23	261	268	36	23	18	9	23	23	4
25.075	573	21	7	50	27	27	23	23	27	27	36	64	18	13	18	27	224	297	50	23	23	23	18	18	4
25.577	703	211	7	36	32	23	23	23	27	23	27	87	23	19	13	36	229	275	41	23	9	18	23	18	4
26.079	42	163	3	0	0	0	0	0	0	0	0	183	0	0	0	0	206	252	0	0	0	0	0	0	0

0.904 IS APPARENT TIME OF F52 - FOLLOWING LIST TIMES ARE REFERENCED TO F52.

Figure 9 - Spectrum Analysis Data Tabulation

TEST NUMBER	STAND	DATE	DURATION	TRACK	FUNCTION	RANGE CPS	EDIT	PRESET
NRX-EST-EP-2B	JAF		0.0	3	P-939	1000	6.874E-02	5.728E-01
DATA SUMMARIZED FROM			10.000 TO	20.000 SECONDS.	100 SAMPLES PER FREQUENCY.			
CENTER FREQUENCY	AVERAGE AMPLITUDE	RMS AMPLITUDE	MAX AMPLITUDE	TIME OF MAX AMPLITUDE	TIME OF LAST VALUE EXCEEDING PRESET LEVEL	OVERSCALE INDICATOR		
20	0.631	0.685	0.848	11.523	19.956			
40	0.214	0.221	0.367	12.126	0.0			
60	0.068	0.070	0.115	11.724	0.0			
80	0.077	0.039	0.069	12.126	0.0			
100	0.030	0.032	0.069	15.242	0.0			
120	0.076	0.039	0.069	12.628	0.0			
140	0.025	0.026	0.046	10.720	0.0			
160	0.019	0.022	0.046	13.531	0.0			
180	0.022	0.025	0.069	13.431	0.0			
200	0.018	0.021	0.046	13.149	0.0			
220	0.029	0.032	0.069	19.450	0.0			
240	0.064	0.074	0.137	11.423	0.0			
260	0.021	0.022	0.046	12.527	0.0			
280	0.017	0.020	0.023	10.210	0.0			
300	0.019	0.022	0.046	12.527	0.0			
320	0.036	0.038	0.069	15.941	0.0			
340	0.258	0.261	0.344	15.639	0.0			
360	0.238	0.303	0.435	15.639	0.0			
380	0.046	0.046	0.069	11.423	0.0			
400	0.022	0.022	0.046	16.443	0.0			
420	0.016	0.019	0.023	10.017	0.0			
440	0.009	0.014	0.023	10.118	0.0			
460	0.024	0.025	0.046	11.322	0.0			
480	0.015	0.019	0.023	10.017	0.0			
500	0.005	0.010	0.023	10.419	0.0			
520	0.003	0.009	0.023	11.523	0.0			
540	0.002	0.007	0.023	11.925	0.0			
560	0.004	0.009	0.023	10.319	0.0			
580	0.005	0.010	0.023	10.118	0.0			
600	0.005	0.011	0.023	11.423	0.0			
620	0.003	0.009	0.023	12.928	0.0			
640	0.002	0.006	0.023	13.029	0.0			
660	0.003	0.008	0.023	11.423	0.0			
680	0.004	0.007	0.023	10.319	0.0			
700	0.005	0.011	0.023	10.017	0.0			
720	0.004	0.010	0.023	10.419	0.0			
740	0.005	0.010	0.023	10.921	0.0			
760	0.001	0.005	0.023	10.017	0.0			
780	0.003	0.006	0.023	13.832	0.0			
800	0.002	0.006	0.023	11.322	0.0			
820	0.005	0.010	0.023	10.118	0.0			
840	0.003	0.008	0.023	10.021	0.0			
860	0.005	0.011	0.023	11.322	0.0			
880	0.001	0.006	0.023	12.828	0.0			
900	0.002	0.007	0.023	10.724	0.0			
920	0.003	0.003	0.023	10.118	0.0			
940	0.005	0.011	0.023	10.319	0.0			
960	0.006	0.012	0.023	10.118	0.0			
980	0.004	0.010	0.023	10.118	0.0			

Figure 10 - Spectrum Analysis Data Summary

(b) Mean spectral density in
 $\bar{X}$ /cps vs frequency

(c) Spectral distribution in
 $\bar{X}$ vs frequency

6. Processing Speed and Accuracies

The processing speed of the hybrid system is very fast compared with that of analog-type systems such as heterodyne wave analyzers using tape loop storage. The hybrid system will process and digitize dynamic data in real time when it is operated in any one of its five basic spectral ranges. For example, 20 sec of data for a 10- to 5000-cps analysis may be processed in 20 sec as compared with 8000 sec required on a heterodyne analyzer set for the same degree of statistical confidence. Computer processing time required for the 20 sec of digitized data is approximately 3 min in any data format mode, and the automatic plotting system requires approximately 3 min per plot, plus tape handling time. This speed represents a time savings of nearly 16:1.

The amplitude statistical error for the SA-12 analyzer depends on the mode of operation and input data characteristics. For transient data having periodic components that are continuous throughout the system storage time, the amplitude reconstruction accuracy is within $\pm 10\%$. If the transient duration is less than the system storage time, or if there are components that are not continuous throughout the storage time, the statistical error increases proportionally.

When the system is operated in the continuous digital analysis mode, the amplitude accuracy is within $\pm 5\%$ for sinusoidal or complex periodic data that are continuous throughout each spectrum sample period.

For random data, which may be assumed to approximate a Gaussian probability density function, the statistical error of the system is expressed as confidence intervals based on the number of degrees of freedom. Typical data of this type are processed with a 90% confidence that the actual mean-square energy value is between 0.8 and 1.3 times the processed value.

C. EQUIPMENT CAPABILITY

Two general descriptions of Aerojet's test-services capability for data reduction and dynamic-data processing follow. All of this equipment is available to NRO as required. The equipment is all being used at present on several programs, and personnel trained in data reduction, dynamic-data processing, and computer programming (for IBM 360-40) are currently available to NRO as required.

1. Data Reduction

a. Automatic Data Processing

Modern automatic equipment is available to reduce and to analyze all types of digital and analog data.

Aerojet's automated systems approach to data reduction provides for the computation, tabulation, plotting, and analysis of data with negligible error. Experienced personnel provide a complete service ranging from development of reduction formula and techniques to application of specialized knowledge in programming decimal, binary coded decimal, and binary computer systems.

As an example of typical test-data processing, digital test data are initially centrally recorded on magnetic tape. An IBM 360 system in the central recording area is programed to derive and apply

transducer-calibration and zero-offset information. Time-history listings, extended computing tapes, programed plotter tapes, and historical data storage in engineering units are then made available with IBM 360 programs. Extended performance calculations are performed on the IBM 360 or in the central computing facility. Data are transmitted to the central computing facility by an IBM 1912 data-transmission unit. Low-frequency analog data are normally recorded on oscillographs or strip charts in the test zones. Test data are reduced, tabulated, and plotted by manual or automatic methods or both. Tape recorders are used to record dynamic data. The tapes are played back to visual records or are plotted. The data are then reduced and analyzed. More extensive data analysis is also accomplished by using a hybrid spectral-analysis system. Analyzed amplitude and frequency data are reproduced into digital form for computer processing. Tabulations of average amplitude vs frequency and time, as well as plots of mean spectral density, power spectral density, and frequency spectrums, are then made available.

Test data are stored on magnetic tape for rapid, economic, and automatic retrieval. Historical records with tabulations to perform statistical analysis of basic test data on each project are categorized by types of tests, hardware tested, and other pertinent information.

b. Equipment and Systems Available

The following equipment and systems are available:

- (1) Benson-Lehner oscillogram and film readers (punched card, tabulation, and plot output).
- (2) California-Computing computer programed plotter.
- (3) Benson-Lehner Model-J tape plotter.
- (4) Electronic Associates tape programed plotter.
- (5) Aerojet-General tape gapper and off-line printer driver.

- (6) Modified General-Applied Science Laboratory hybrid spectral analysis system.
- (7) Analog tape digitizing systems for digital-computer compatibility.
- (8) IBM 360 systems.
- (9) Electronic-data-processing punched-card equipment.

2. Dynamic-Data Processing

The versatile dynamic-data processing facility provides for complete processing and analysis of analog magnetic-tape data.

The Aerojet dynamic-data processing center processes data received on analog magnetic tapes into various forms of usable end information. This equipment is capable of handling a variety of magnetic-tape formats. A wide variety of signal-conditioning and recording devices, experienced personnel, and immediate availability of supporting services leads to a versatile facility for processing magnetic-tape data. Equipment available at the center includes broad categories of tape reproducers, signal processing equipment, and recording equipment. The center also contains an ample complement of support instrumentation, such as counters, oscilloscopes, and meters. All units are regularly serviced and calibrated with test equipment having certifications traceable to the NBS.

Table 2 lists the tape recorder-reproducers available at the processing center. Any of these machines may be used as an input device for any of the signal-processing and recording systems and equipment described in Tables 3 and 4. Table 3 lists the signal-processing equipment that can be used to extract the desired information from the basic taped data.

Table 4 lists the available recording instruments. All the equipment is interconnected through a versatile patching setup that leads to

TABLE 2
RECORDER-REPRODUCERS

<u>Manufacturer</u>	<u>Equipment</u>	<u>Capability</u>
Ampex Fr 1200	1-in., 14-track, interranging instrumentation group, or 1-in., 32-track Ampex.	FM records-reproduces at all speeds and at high or low density.
Sangamo 4784	1-in., 14-track, interranging instrumentation group; 1/2-in. 7-track in-line, 1-in., 32-track Ampex.	FM reproduces at all speeds, and at high or low density; 1/2-in., six 250-ft loops.
Consolidated Electrodynamics Corporation 5-752	1/2-in., 7-track, interranging instrumentation group.	Directly reproduces at 60 or 30 in./sec.
Ampex FL-200	1-in., 14-track, interranging instrumentation group.	Eight 75-ft loops.

TABLE 3
SIGNAL-PROCESSING EQUIPMENT

<u>Manufacturer</u>	<u>Equipment</u>	<u>Capability</u>
General Applied Science Laboratories SA-12	Hybrid spectrum analyzer.	Digital speed up and storage; analog analysis. Tabulations of power spectral density or amplitude versus time and frequency. Analysis of tran- sients of 0.1 sec or less. Range: 0 to 5000 cps. Filters: 0.01 to 100 cps.
Dytronics Mod 722	Filters: high, low, or band pass; eight available.	Range: 0 to 100,000 cps. Attenuation: 36 db/octave.
Electro Mechanical Research 67F	Discriminators: interranging instrumentation group, telemetry.	Eleven channels available; eight are tape-speed compensated.
Bruel and Kjaer 2112 and 2305	Audio spectrometer; true rms level recorder.	Unfiltered, octave or one-third- octave plots versus time or frequency.
Minneapolis Honeywell 9050	Spectrum analyzer.	Range: 3 to 10,000 cps. Filters: 3 to 200 cps. Plot output: 11 x 17-in.
Moseley 60B	Logarithmic converters: two available.	Logarithmic plotting with 11- x 17-in. Electro instru- ments plotters.

TABLE 4
RECORDING EQUIPMENT

<u>Manufacturer</u>	<u>Equipment</u>	<u>Capability</u>
Aerofet-General Corporation	High-speed digitizer.	Eight channels at 1000 samples/sec; Two channels at 5000 samples/sec; or one channel at 10,000 samples/sec.
Consolidated Electro-dynamics Corporation 5-119	Oscillograph, 12-in.	Equipped with seven 362 galvanometers and electronic-flash timing lines. Range: 0 to 2500 cps. Paper: 450-ft roll. Principally for quick-look data.
Brue1 and Kjaer 2305	True root-mean-square level recorder.	100-mm chart width; writing rates to 1000 db/sec; linear and db scales available.
Electro-Instruments 400	11- x 17-in. X-Y plotters; two available.	Equipped with logarithmic converters and linear time base for Y-time plotting.
Sanborn	Recorder.	Four channels available.

a large range of possible data-processing combinations. Careful attention to proper electrical interfacing, to maintain correct shielding and grounding through the system, yields a highly flexible, low-noise system.

D. DYNAMIC-ANALYSIS COMPUTER PROGRAMS

Aerojet has been reducing, processing, and analyzing test data for over ten years under a great variety of conditions in many programs. Some of the programs that appear to be applicable or of potential use to the NERVA program have been selected to illustrate Aerojet's capability and experience in dynamic-data analysis. Significantly, these programs are all available to REON at no charge if they are needed in the program of test-data analysis.

1. Program No. 138: Servo Control-System Response

This program was developed to study the gimbal servo-system dynamic response for the Apollo Service Module engine. Sine, ramp, and step inputs are evaluated. The sine wave data are evaluated by means of digital filtering techniques. The ramp and step analysis are confined to derivation response. The analysis will be described in terms of the output plot of this program.

a. Servo control-system response chart shows a plot of the actuator position, rate of travel, and acceleration as functions of time on a single graph.

b. Phase vs frequency is plotted superimposed with a specified requirement for phase angle.

c. Gain vs frequency is plotted for test data superimposed with upper and lower gain specification limits and required break frequency.

d. Closed-loop response plot shows the response output in percent vs time for a closed-loop input. The acceptance region is superimposed on the test data on a single graph.

e. Actuator rate response in radians per second is plotted against time with specified acceptance regions superimposed on the data.

2. Program No. 154: Second-Order System Step Response Gain and Phase Plots

This program was a result of special Gemini study to analyze high-frequency pressure-transducer response when subjected to shock-tube calibration pressures.

a. Phase and gain (transfer functions) are plotted as a functions of frequency based on a step input. These data are also listed in terms of gain, phase, and real and imaginary components for selected frequencies.

b. Analog plot consists of the amplitude in counts or engineering units plotted as a function of time.

3. Program 2901: Hybrid Analyzer (Described in another section of this report)

This program was developed for the Gemini program to evaluate frequency data. NERVA provided a modification to the equipment to make it useful for accelerometer and pressure-transducer analysis of NRX tests.

a. Amplitude vs frequency is plotted for discrete frequency intervals for the average and the square of the average per cps to permit isolation of predominant frequencies of interest.

b. Spectral-analysis plots show average amplitude vs frequency over a selected time period based on a Fourier analysis of dynamic data.

c. Mean-spectral-density charts plot average amplitude vs frequency.

d. Power spectral-density charts plot average amplitude squared per cps vs frequency.

e. Many options are available to list data spectral history tabulations. Some of the more popular are the three-dimensional representation of time, frequency, and amplitude; a summary average per frequency of average amplitude; rms amplitude; and peak amplitude.

4. Program No. 2910: Transfer-Function Program

This program was developed to support an excitation-chamber test program.

Frequency response is computed by using the classical Fourier integral methods. The program provides amplitude ratio, phase, and admittance data.

5. Program 40/174: General Analysis Program

These programs are general-purpose routines to convert analog tapes to engineering units and can plot the data in a wide variety of formats by using various scales, split scales, multiple plots, and adjustable time offsets.

E. PRESENT NRO TRANSFER-FUNCTION ANALYSIS

NRO has established Job No. 2909 to be used for NERVA transfer-function analysis. The program will ultimately accept sine, step, or pseudorandom inputs and process the data directly from NTO tapes for transfer-function outputs. The program will consist of the following outputs.

1. Minneapolis Honeywell Visicord analog tapes.
2. Engineering-unit plots of each function.
3. Frequency plots (gain and phase) of each transfer function.
4. Transfer-function listing.

At the present time automatic processing of both the sine and step inputs has been demonstrated. The Westinghouse Astronuclear Laboratory codes for pseudorandom inputs have been requested for use with Job No. 2909.

F. PRESENT NRO ANALYSIS ACTIVITY

NRO has initiated a systems analysis for evaluation and interpretation of dynamic data. Some of the programs are:

1. Automatic Processing of Sine Transfer Functions

The sine input series during NRX/EST are being evaluated for eight transfer functions for comparison with the pseudorandom analysis performed by WANL. Aerojet is modifying an existing program to perform this analysis.

2. Step Input Analysis

The usefulness and interpretation of step-input test data are being evaluated. Two Aerojet analog programs and the digital step

frequency-response program (WANL-TME-1338) will be evaluated by using step-response data from NRX/EST EP-IV.