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NUCLEAR ROCKET OPERATIONS
SACRAMENTO PLANT

REPORT NO. RN-S-0308A
TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE
ETS-1 DATA-ACQUISITION SYSTEM
FINAL ACCURACY TEST SPECIFICATION

NERVA PROGRAM

CONTRACT SNP-1

SEPTEMBER 1967

MASTER

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ETS-1 DATA-ACQUISITION SYSTEM
FINAL ACCURACY TEST SPECIFICATION

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1.0 GENERAL

This document describes the types of tests and the factors to be considered in providing an estimate of the accuracy of the diagnostic portion of the ETS-1 data-acquisition system. The system accuracy will be defined as the difference between a known signal input and the corresponding recorded output signal expressed in statistical terms. An accuracy statement shall be made about the analyzed data after conversion to engineering units.

This statement will be made for each operational mode tested. Simulated or transducer signals shall be applied at the north-terminal-room interface.

The statement of accuracy will state values for each mode that will include the mode bias, mode precision, and a 99% confidence interval whose boundaries will include 99.9% of the observations. The test plan includes provisions for isolating errors attributable to variables such as drift, linearity, and frequency response. Secondary objectives and test programs are described to enable these additional studies to be made and performance parameters to be evaluated, if required, without unduly affecting the primary objective of determining the accuracy for each mode.

Preliminary test data already obtained have permitted determination of the accuracy of a portion of the ETS-1 digital data system. The tests, which met the requirements of Report RN-S-0308, ETS-1 Data Acquisition System Accuracy Test Specification, were designed to aid in defining the overall test plan for comprehensive determination of the uncertainty of the ETS-1 digital data system.

The results of the preliminary tests, which AGC documented in Report RN-S-0389, indicated that ETS-1 has an excellent narrow-band data system.

2.0 SCOPE

The diagnostic portion of the ETS-1 data-acquisition-system accuracy test will include test diagnostic channels, digital data subsystems, and analog recorders, as depicted by Figure 1. Simulated transducer inputs to diagnostic channels will be inserted at the north terminal room. An addendum to this specification is planned at a later date to evaluate the performance of cables extending beyond the north terminal room out to the engine-TSA remote interface and to critical facilities-instrumentation interfaces.

3.0 SUMMARY OF REVISIONS TO RN-S-0308 SPECIFICATION

The results of the preliminary ETS-1 data-acquisition accuracy tests indicated that ETS-1 has an excellent narrow-band data system. The magnitudes of the errors observed were sufficiently small (0.01 to 0.20%, full scale) to justify a complete revision of the accuracy test plan defined in Report RN-S-0308.

Several of the tests were redundant. Factors that could have contributed significantly to the overall accuracy are now considered to be trivial. To obtain the most meaningful and useful data from the subsequent series of tests, a revised test specification is issued that delineates eight test modes to replace the 26 modes defined in Report RN-S-0308.

Specification revisions based on analysis of the preliminary test data are listed below.

1. Reduce the 26 operational modes described in Report RN-S-0308 to eight modes. The preliminary test data have shown that several of the signal paths can now be considered redundant because they differ by only a single factor (e.g., data sampling rate, slight differences in mode card impedances, or addition or deletion of a recorder in the circuit).

Figure 1 - ETS-1 Data Acquisition System Accuracy Test

2. Evaluate drift for several thermocouple references.

3. At least 20 channels are required to evaluate digital-data system accuracy through the various paths. It is recommended that ten channels be routed to each subsystem to verify the differences of 0.085% observed between Subsystem 1 and Subsystem 2. For each test condition, 640 data points are adequate to permit results to be evaluated within a $\pm 0.01\%$ accuracy.

4. Evaluate the influence of the bimodal distribution observed during the preliminary tests by rerunning a strain-gage mode with at least 20 channels for each subsystem. The purpose of this test is to evaluate the pattern and cause of extreme data channels such as those observed in the preliminary tests. Provisions should be made to permit a rerun of this test if more data are needed before corrective action can be taken.

5. Extend the resistance-temperature-transducer mode to include constant-current signal conditioners as well as the triple-bridge signal conditioners. Originally, only the triple-bridge signal conditioner was considered.

6. Include an evaluation of the LVDT and the speed-and flow-modes. The speed-and-flow mode includes a frequency-to-dc conversion. These modes were not included in the test plan of Report RN-S-0308.

7. AGC will compute means, standard deviations, and percent error, $\frac{\text{output} - \text{input}}{\text{input (FS)}}$, of each channel variable from the test data.

8. An AGC-Sacramento observer will be present during each test; first-hand observation of the test helps in the subsequent analysis.

3.1 REVISED TEST PROGRAM

Figure 1 describes the signal paths (modes) for the revised accuracy tests. The revised test program reduces the evaluation of 26 operational modes to eight tests. The accuracy test objectives will require an evaluation of the error that can result in the different possible signal paths through the digital and wide-band data system but will not consider transducer errors.

4.0 OBJECTIVES

The primary objective, which has not changed, is to determine the data-acquisition-system accuracy for each normally used signal path. Figure 1 defines the signal paths to be evaluated for the remainder of the test program. The accuracy for each signal path will include the mean error (bias), an estimate of the random variation (noise), and a 99% confidence interval such that 99.9% of the data points fall within the boundaries of error indicated. The unit of error will be the end-to-end system error where system error is calculated by using the following equation:

$$\text{percent error} = \frac{(E\text{-OUT}) - (E\text{-IN})}{(E\text{-IN})} \frac{(FS)}{(FS)} \times 100,$$

where

E-OUT	≈	observed output,
E-IN	≈	known simulator input, and
E-IN (FS)	≈	full-scale simulator input.

A wide-band accuracy test program has been added and is described in Paragraph 5.6.5 (Mode 6, analog).

In addition to the secondary objectives achieved during the preliminary test, the following secondary objectives will be achieved during the remaining test programs.

- a. Evaluate more completely the multiplexer channel variation observed in the preliminary test.
- b. Evaluate the analytical program for converting raw count data to engineering-unit data for the thermocouple and RTT channels.
- c. Evaluate the inaccuracies attributable to reading errors in the strip chart and oscillograph recorders.
- d. Evaluate the accuracy and linearity of the magnetic-tape recording system.
- e. Document linearity and subsystem differences for each of the signal paths.

4.1 PROGRAM PHASES

4.1.1 Phase I - Test Plan

The test specification presented herein describes the purposes, criteria, and type of data and analysis required to derive the accuracy objectives in the most economical, timely, and expedient manner.

4.1.2 Phase II - Preparation of Test Procedure

A set of test procedures shall be prepared by NTO to conduct the tests specified in Section 5 of this test specification and shall be submitted to NRO for an integrated (NRO-WANL) review prior to the initiation of testing.

4.1.3 Phase III - Performance of Tests

NTO shall perform tests according to the accepted procedures. NRO personnel shall witness the tests and shall be responsible for reviewing any departures from the procedures that are made prior to testing.

4.1.4 Phase IV - Test-Data Report

The test data shall be reduced in accordance with standard NTO procedures. The data tapes shall be processed by NTO, converted to engineering units, and reported with other testing details in accordance with Section 5.5.3 of this test specification.

4.1.5 Phase V - Data Analysis

The test data and supplementary information detailed in accordance with Section 5 shall be analyzed by NRO as described in Appendix C of this test specification. The analysis will entail study of the variation pattern of each of the test factors or combination of test factors (noise, channel-to-channel variability, linearity, drift, and subsystem differences), thus resulting in arrival at test requirements that enable the ETS-1 accuracy objectives to be achieved with a minimum number of tests and expense for deriving equivalent accuracy estimates in the other modes to be tested.

4.1.6 Phase VI - Performance-Evaluation Report

After the data analysis is completed, NRO shall issue an analysis report containing, as minimal information, the data specified in Section 7. The final analysis report shall be reviewed by NTO and WANL prior to issuance.

5.0 TESTING

5.1 GENERAL DESCRIPTION

The signal paths to be evaluated (Figure 1) consist of the transducer signal conditioners, two digital data-acquisition subsystems, cables, patch boards, termination boxes, tape transports, strip-chart recorders, FM tape recorders, and optical oscillographic recorders.

These tests shall be conducted to produce the data necessary to evaluate system performance (not including transducers). Each mode shall be tested in accordance with the following paragraphs. A signal will be introduced with a transducer simulator or a transducer that shall be used as the source of the reference signal. These transducer simulators or transducers shall be connected at the north terminal room. A test of the system extending beyond the north terminal room out to the engine-TSA remote interface and critical facilities instrumentation interfaces will be proposed at a later date. The detailed test program for each mode is described in the following paragraphs.

5.2 TEST EQUIPMENT

5.2.1 Simulators

The following types of simulators and transducers will be required to simulate the transducers to be connected to the types of channels under test. Simulators and transducers are described in Appendix B.

- a. Thermocouple; chromel-alumel, copper-constantan
- b. Strain gage; 350-ohm, 4-arm bridge
- c. Resistance temperature transducer
- d. Swept potentiometer
- e. Analog voltage, ac and dc function generators

The above types of simulators shall have their accuracy traceable to the National Bureau of Standards. Where applicable, the simulators shall be consistent with the design schematics in Appendix B of this test specification.

5.2.2 Test Equipment

All test equipment used shall have been calibrated within 60 days or less prior to use; the time interval between calibration and test shall be as short as practical. A complete description of all additional test equipment (oscilloscopes, voltmeters, etc.) shall be included in the test Data Report (See Section 5.5).

5.3 TEST PROCEDURES

A test procedure shall be written specifying how each test shall be performed consistent with specification. The test conditions shall be outlined in detail; sample data sheets shall be included in the test procedures.

5.4 TEST CONDITIONS

5.4.1 Test Data

The ETS-1 data-acquisition test program shall be set up and operated in a manner typical of a normal engine test program. Other operations at ETS-1 that typify normal testing operations shall be continued as a normal environmental condition. Sufficient data shall be supplied to indicate any environmental conditions that could affect the test results.

5.4.2 Channel Calibration

Each channel shall be electrically calibrated in accordance with normal NTO pretest setup procedures. The 0-, 25-, 50-, 75- and (when applicable) 100% calibration steps shall be made. These calibration procedures shall be compatible with the requirements of Appendix A.

5.5 TEST-DATA REPORT

After the tests set forth in this test specification are completed, a test report shall be issued by NTO for use in evaluating the data-acquisition system. This report shall contain, as minimal information, the data specified herein.

5.5.1 Test-Setup Description

The test report shall include a brief description of each test setup. Detailed test-setup data sheets shall be appended to the report.

5.5.2 Test Procedure

The complete test procedure shall be attached as an appendix to the test report. Any deviation from the test procedures or the test setup or from normal maintenance or testing conditions shall be reported.

5.5.3 Test Results

The complete digital data obtained shall be converted to engineering units in accordance with NTO data procedures and shall be included in the report. A description of the tape format shall be provided. Copies of raw data, calibration corrected, and engineering-unit data tapes, together with copies of all analog and strip-chart data and other tests records, shall be supplied to NRO with the test report for analysis and evaluation. Data shall

be annotated to indicate any known causes of data error or conditions that may have influenced the test results.

5.5.4 Recommendations

Any recommendations for improving the operations, procedures, or equipment associated with the data-acquisition system shall be provided.

5.6 TEST MODES

The required test modes are explained in detail below. Refer to Figure 1 for individual signal routing through the data-acquisition system and onto end recorders.

5.6.1 Mode 1a and 1b - Strain Gage

a. General

Two strain-gage signal paths replace the nine modes defined in Report RN-S-0308. The original test program included multiple checks of some parameters and included various interaction effects. Because the variation of the end-to-end error is expected to be on the order of 0.1 or 0.2% of full scale, multiple studies are felt to be unjustified.

b. Tests 1a and 1b

Using a strain-gage simulator (Figure 3, Appendix B), route the signal to the strain-gage signal conditioner and to the low-level patch board and patch to the low-level path in the digital data system. From this point the two tests differ.

(1) Test 1a

Route 1a through the narrow-band amplifier to the 10-sample/sec multiplexer. Run the test 64 sec to record 640 points on ten channels of Subsystem 1 and ten different channels of Subsystem 2 at four levels: 0-, 25-, 50-, and 75% of full scale.

(2) Test 1b

Route 1b through the wide-band amplifier to the high-level patch. Connect ten channels, five channels from each subsystem, to the strip chart, oscillograph, and FM magnetic-tape recorders. Route the signal through a 40-cps low-pass filter, and digitize at a 100-sample/sec rate. Patch at least 20 channels to each subsystem so that at least 40 channels of data will be available to study the variability expected in some of the multiplexer channels. Provisions must be made to permit rerunning this test without changing the setup to study the cause of the difference. Run all channels at 0-, 25-, 50-, and 75% full scale for 6.4 sec. Record the ten channels on the three recording systems for the same 6.4 sec at 75% of full scale. The purpose of recording these data is to evaluate readability.

5.6.2 Mode-2 Resistance Temperature Transducer (RTT)

a. General

One RTT test will replace the two tests scheduled in Report RN-S-0308. This single test can achieve all the desired objectives. RTTs are generally utilized for measurements in three basic temperature ranges:

(1) narrow-range (35 to 60°R) cryogenic, (2) wide-range (35 to 610°R) cryogenic, and (3) noncryogenic (360 to 560°R). Two principal types of signal conditioners are used for these ranges, the constant-current signal conditioners for cryogenic measurements and triple-bridge signal conditioners for noncryogenic measurements. This test will enable the following goals to be achieved:

1. Accuracy of RTT signal paths,
2. Evaluation of different range mode cards,
3. Evaluation of constant-current and triple-bridge signal conditioners,
4. Evaluation of linearity for wide-range cryogenic measurements.

b. Test 2

Route the RTT signal from the RTT simulator (see Figure 1, Appendix B) to the signal conditioner. Two simulators will be used; one will route the signal to the triple-bridge signal conditioner, while the second will route the signal to the constant-current signal conditioner. The triple-bridge circuit will include a range of temperatures from 360 to 610°R (mode card RTI0), and data will be taken with resistance settings of 1380.0 ohms (492°R) and 1736.6 ohms (610°R). The constant-current circuit will be evaluated for narrow- and wide-range cryogenic temperatures: therefore, two mode cards will be required. The narrow-range cryogenic card will include the range of 35 to 60°R (mode card CC01) and will be tested at resistance settings of 5.584 ohms (0%) and 33.212 ohms (100%). The wide-range cryogenic card will include the temperature range of 35 to 610°R (mode card CC03) and will include readings at all six resistance readings shown in Figure 1 of Appendix B. Only one channel at a time can be tested with the RTT simulators. Each of the three ranges will be tested for 64 sec for ten channels in Subsystem 1. The conditioned signal for all three ranges will be routed to the low-level patch board, to a narrow-band amplifier, through a 4-cps low-pass filter, and then sampled at a rate of 10 samples/sec, high level.

5.6.3 Mode 3 - Swept Potentiometer

a. General

The swept-potentiometer mode is unchanged. This mode permits an evaluation of the passive signal conditioner patched to a high-level patch. The swept-potentiometer simulator is shown in Figure 2 of Appendix B.

b. Test 3

Route the signal from the simulator to the signal conditioner, to the high-level patch, through a 4-cps low-pass filter, and then sample at a rate of 10 samples/sec, high level. Test at 0, 25, 50, 75, and, if possible, at 100% of full scale for 64 sec for 5 channels.

5.6.4 Modes 4 and 5 - Chromel-Alumel (C-A) and Copper-Constantan (C-C) Thermocouples

a. General

Two thermocouple modes will replace the 12 proposed thermocouple modes described in Report RN-S-0308. A review of the preliminary data and all the possible thermocouple signal paths indicates that factors such as adding a strip-chart recorder, changing the sampling rate, and studying different thermocouple types are not the sort of information required for the digital data system accuracy. Approximately 85% of the thermocouples are C-A and C-C types, and both are routed through precision thermocouple reference junctions.

The signal-conditioning mode cards for all thermocouple channels are basically the same and exhibit very similar electrical characteristics, thereby obviating the evaluation of differences. Tests 4 and 5 are

conducted so that, in addition to obtaining accuracy estimates of the signal paths, (1) low-level and high-level signal paths can be evaluated and (2) the drift of thermocouple reference junctions can be determined.

b. Tests 4 and 5 - C-C and C-A Thermocouples

Actual thermocouples will be used to provide input signals at the 0°C ice-bath reference temperature. A digital-voltmeter reading will be taken at the signal-conditioning input. Route the signal through the low-level patch. At this point, different signal paths are taken.

(1) Test 4

A C-C thermocouple output will be digitized at 10 samples/sec, low level, direct from the low-level patch. Twenty channels will be tested, ten channels to Subsystem 1 and ten channels to Subsystem 2 for 64 sec at the test temperature.

(2) Test 5

A C-A thermocouple, will be routed to the narrow-band amplifier and the high-level patch and 4-cps low-pass filter to be sampled at 10 samples/sec, high level. Temperature reference junctions shall be monitored at 2, 4, 8, and 12 hr to evaluate temperature stability by using the internal RTTs.

5.6.5 Mode-6 Analog

a. General

The analog mode in Report RN-S-0308 will not yield data that would be meaningful to the accuracy program. Since data will be collected on magnetic tape and the tape will be used for further data processing, it is

believed that a special test to evaluate linearity, crosstalk, gain and phase distortion, noise, drift, and accuracy would be more appropriate. It is intended that the tape accuracy figure include wide-band data on magnetic tapes.

b. Non-Zero-Suppressed

Utilizing an oscillator or a dc power supply, route the signal from the simulator to the signal conditioner, to the low-level patch board, wide-band amplifier, and onto the magnetic-tape recorder. Run this test in three steps for 20 channels, ten channels to each patch system for a minimum of 10 sec/input. Terminate the other channels of the tape recorder at the signal-conditioner input with an impedance simulating a transducer, and patch each channel in the same manner as for the other 20 input channels. The object of these channels is to determine if any wide-band data-system crosstalk exists during the tests outlined below:

(1) Insert dc voltage levels at 0, 25, 50, 75, and 100% by using the strain-gage simulator.

(2) Using 10-, 500-, and 2000-cps ac signals, insert 3, 6, 15, and 30 mv (peak).

(3) Terminate the input to the wide-band channels into a nominal 120-ohm impedance, and record the wide-band channel noise.

c. Zero-Suppressed

Using an oscillator and a dc power supply for offset, route the signal from the simulator to the signal conditioner, to the zero-suppression equipment, and onto the magnetic-tape recorder. Run this test in two steps for 20 channels, ten channels to each patch system for a minimum of 10 sec/input. Terminate the other ten channels of the tape recorder at the

signal-conditioner input with an impedance simulating a transducer, and patch each channel in the same manner as for the other 20 input channels. The object of these channels is to determine if any wide-band data-system cross-talk exists during the tests outlined below:

(1) Using 1-, 5-, 10, and 50-cps ac signals, insert 3, 6, 15, and 30 mv ac peak and 75 mv dc. Set full-scale range to 100 mv.

(2) Repeat (1) using a square wave at 1 cps only.

d. Drift

Terminate the input to all signal conditioners used in Test b-1 into 350 ohms. Channel patching and routing shall remain the same. Set simulator output to 75% of full scale for all channels. Run the tape recorder 10 sec every hour for 12 hr.

e. Phase Shift

Using an oscillator as a signal source, route the signal through the signal conditioner, a wide-band amplifier, and to the magnetic-tape recorders. Connect an oscillograph recorder across the channel input at the North Terminal Room and record timing and test data. Set the oscillator to 10, 50, 100, and 500 cps at 15 mv, and record 10 sec of data on the oscillograph and the tape recorder at each of the preceding frequencies. Run the oscillograph at 10 in./sec for 10 and 50 cps and at 100 in./sec for the 100- and 500-cps frequencies.

f. Common Mode Rejection

With the system set up the same as in test 6(b), capacitively couple 54 cps to both input lines to the wide-band amplifier.

Insert 1, 5, 10, and 25 v rms with respect to ground, and record the data to determine effects of common mode voltage.

5.6.6 Mode 7, Speed and Flow

a. General

The speed and flow signal path was omitted from Report RN-S-0308 and is now being included because it is an important signal path and includes components not included in the other paths. The signal is fed into a frequency-dc converter producing two signals, an analog signal and a pulsed signal. The pulse and analog signals will be used in this test.

b. Test 7

Route the signal from the simulator to the frequency-dc converter. The pulse and analog signals are patched to the high-level patch and routed directly to the DDS counters and to the 10-sample/sec digitizer. The pulse signal is also patched to the magnetic-tape recorder. Three channels to each subsystem will be tested for 64 sec at 100- and 1000-mv signal levels at frequencies of 0, 4, 8, 12, 16, and 20 kc, with a full-scale range of 20 kc. Repeat using 0, 100, 200, 300, 400, and 500 cps, with a full-scale range of 500 cps. For each of these steps, insert the frequency as a step function; hold each for 64 sec minimum.

5.6.7 Mode 8 - LVDT and VR

a. General

Channel modes that utilize linear velocity displacement transducers (LVDTs) and variable-reluctance (VR) devices were not incorporated in Report RN-S-0308 because of similiarity to other test modes but are being

included at this time. VR channels are covered in speed and flow (mode 7), above. The following test shall simulate and test for LVDT channel accuracy.

b. Test 8

The LVDT demodulator unit will be used in the calibrate mode to simulate an LVDT. The calibrate mode will produce a five-point bipolar calibration (ten points total). Route the signal out of the demodulator through the high-level patch, a 4-cps low-pass filter, and sample at 10 samples/sec for 64 sec at each calibrate step. Five channels for each subsystem shall be tested.

6.0 DATA ANALYSIS

6.1 GENERAL

The accuracy of the ETS-1 data-acquisition system, as defined in Section 4, will be determined for each mode of operation tested. The accuracy value for each mode will include the mean error (bias), an estimate of random variation (noise), and a 99% confidence interval such that 99.9% of the data points will fall within the boundaries of error indicated. Detail analysis is presented in Appendix C.

6.2 PRIMARY OBJECTIVE

The test data shall be analyzed to determine the accuracy of the data-acquisition system for each mode of operation as follows:

6.2.1 System Bias

The system bias value represents the index that describes how the output signal differs, on the average, from a given input signal. The bias values shall be determined by computing the average of the deviations

of the individual observed outputs from the simulated input signal. The system bias, $\bar{X}$, is then defined as

$$\bar{X} = \frac{\sum_{i=1}^t (X_i - N)}{t},$$

where X_i is the i th of t signal output observations for a given mode of an input signal of N .

6.2.2 Signal Noise

Signal noise represents the amount of variation of the output-signal observations about the system bias value ($\bar{X}$) and is a measure of the repeatability or precision that may be expected from a given signal input. Signal noise, S , shall be determined by obtaining a root-mean-square of the deviation about the bias value obtained under paragraph 6.2.1 above. This value may be expressed as follows:

$$S = \sqrt{\frac{\sum_{i=1}^t [(X_i - N) - \bar{X}]^2}{t-1}}$$

The influence of linearity, drift, channel-to-channel variability, and subsystem differences will be evaluated and, if found to be statistically significant, will be made part of the accuracy estimate.

6.2.3 Percent Error

The data shall be converted to percent error, where

$$\text{percent error} = \frac{B_o - F}{I(FS)} \times 100,$$

where B_o is the output for input (F) and $I(FS)$ is the full-scale input.

6.2.4 Confidence Interval

The confidence interval identifies the degree of confidence of the estimated accuracy of the system. That is, an interval will be stated that will include 99.9% of the observed output values of each mode of operation and will ensure 99% confidence that this interval is correct. This interval shall be obtained by taking estimates of the bias ($\bar{X}$) and noise (S) as shown above and selecting a value of K, which is a function of sample size, that will ensure the desired confidence interval. The confidence interval is expressed by the relationship:

$$\text{Confidence interval} = \bar{X} \pm KS.$$

Initial test data will be used to evaluate the required value of K and the sample size for the balance of the testing. The sample size will be adjusted as required to obtain this value. Further details of the analysis of the initial test data and utilization of the analytical data are presented in Appendix C.

6.2.5 Wide-Band Data Analysis

Wide-band-data accuracy analysis for the tests described in Section 5.6.5 is presented in Appendix C.

6.3 SECONDARY OBJECTIVES

The data collected will be used to evaluate the secondary objectives as follows:

6.3.1 Multiplexer Channel Variations

Evaluate more completely the multiplexer channel variation observed in the preliminary tests.

6.3.2 Engineering-Unit Conversion Program

Evaluate the computer programs for converting the raw count data into engineering-unit data. Particular emphasis will be placed on evaluating polynomials for conversion of nonlinear parameters.

6.3.3 Reading Errors

Evaluate the inaccuracies attributable to reading errors in strip-chart and oscillographic recorders.

6.3.4 Magnetic-Tape Errors

Evaluate the errors attributable to the magnetic-tape recorders in the wide-band data system. Of particular interest will be the linearity and phase-shift errors associated with transfer-function data and accelerometer data.

7.0 PERFORMANCE-EVALUATION REPORT (Analysis Report)

A performance-evaluation report shall be issued by NRO after the analysis of test data is completed. This report shall contain the following information as a minimum:

1. Test Objectives

A discussion of the test objectives and a brief description of the tests conducted.

2. Analytical Procedures

A brief description of the analytical procedures used to evaluate the test data.

3. Statement of Accuracy

A statement of accuracy for each type of channel and a confidence interval for this statement of accuracy. (Also, statements of evaluation shall be included relative to each secondary objective of the test program, if necessary. Test and analysis data shall be appended to the report as required to support the conclusions of the test and analysis program.)

4. Test Adequacy

A discussion of the adequacy of the test and analysis. (This discussion shall include test and analysis limitations, known causes of test-data error, unknown causes of test-data errors and anomalies, methods of improving testing and analysis, and requirements for additional testing.)

5. Recommendations

Recommendations for improving operations, procedures and equipment, and testing and analysis techniques, as appropriate.

8.0 DEFINITIONS

8.1 CONFIDENCE INTERVAL

Degree of assurance that interval will contain the true population parameter. (For the accuracy analysis, the true population parameter is the mean error and includes 99.9% of the observed values).

8.2 MODE

Routing of an input signal through a unique set of classes of components; i.e., transducer, terminal box, signal conditioner, patch board, amplifier, filter, digitizer, recorder.

8.3 CHANNEL

Routing of a signal on a specific set of components in a mode; e.g., component type or model number remains the same, only the serial number of the component changes.

8.4 SUBSYSTEM

A digital data subsystem containing the amplifiers, multiplexers, digitizers, low-pass filter, and format equipment.

8.5 LEVEL

Test level of the input signal represented as 0, 25, 50, 75, and 100%, if applicable.

8.6 NOISE

Noise (precision) is the variation about the observed mean error for a given period and for a particular channel and mode.

8.7 TEST

A sequence of signals from a given input level, test time increment, and channel at a particular mode of operation.

8.8 OBSERVATION

A recorded output for a test.

8.9 BIAS

The deviation of the observed mean from a true input value.

8.10 VARIANCE

Measure of the variation defined as the mean square of the deviations from the observed mean or

$$\sigma^2 = \sum_{i=1}^N \frac{(X_i - \bar{X})^2}{N}.$$

8.11 UNBIASED ESTIMATE OF VARIANCE

Estimate of the population variance, defined as

$$s^2 = \sum_{i=1}^N \frac{(X_i - \bar{X})^2}{N - 1}.$$

8.12 STANDARD DEVIATION

The square root of the variance.

8.13 MEAN

The sum of the observations divided by the number of observations summed (average).

8.14 ACCURACY

Difference in known input and recorded output measured in terms of a 99% confidence interval such that 99.9% of the data points fall within the boundaries indicated.

8.15 DRIFT

Deviation of a signal from a reference point or value because of an elapse of time or an environmental change.

8.16 LINEARITY

The deviation of the average value from the predicted least-squares regression line.

8.17 TRACEABILITY

The calibration of an instrument is said to be traceable when all of the significant accuracy-determining elements in the design, individually and in that particular configuration, are compatible with the accuracy levels at which they are to be verified by comparison with, and tracing through, secondary laboratory standards that are in turn traceable to NBS primary standards.

8.18 PRECISION

Degree of reproducibility among several independent measurements of the same true value under specified conditions.

8.19 SIMULATOR

A device that is capable of generating a voltage or signal to replace the output of a physical transducer or sensor that measures a physical parameter.

APPENDIX A
ETS-1 CALIBRATION SYSTEM

APPENDIX A

1.0 DESCRIPTION

The ETS-1 data-acquisition system utilizes three types of electrical-system calibration: resistive-shunt calibration for strain-gage bridge channels; resistance substitution for RTT channels; and voltage substitution for swept-potentiometer, thermocouple, analog-voltage, and other active or self-generating transducers. Brief descriptions of these systems follow:

1.1 RESISTIVE-SHUNT CALIBRATION

A six-wire, shunt-calibration system is used (see Figure 3 of Appendix B). This system provides two wires exclusive of the bridge excitation and signal leads. These two wires connect a calibration resistor in the signal conditioner across one leg of the strain-gage bridge in the transducer. By thus shunting one leg of the transducer bridge, the bridge is resistively unbalanced, and a voltage is produced at the transducer output. The calibration resistors are selected to produce 0, 25, 50, and 75% of full-scale output signals. In the case of pressure transducers, most transducers are standardized to produce identical outputs at the 25, 50, and 75% calibration steps for one standard set of calibration resistors.

1.2 RESISTANCE SUBSTITUTION

For RTTs either a triple-bridge or a constant-current potentiometric-type signal conditioner is used (see Figure 1 of Appendix B). In either case, calibration is accomplished by substituting precision resistors for the transducer in the signal conditioner, thus simulating the transducer resistance at 0, 25, 50, 75, and 100% of the full-scale temperature range. The transducer cannot be left in the circuit for calibration as it is in the case of the strain gages because its resistance varies with the ambient temperature.

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1.3 VOLTAGE SUBSTITUTION

For transducers such as thermocouples that generate signal voltages without external excitation, voltage-substitution calibration is used (see Figure 2 of Appendix B). These "active" channels are calibrated by substituting voltages from a precision voltage divider in the signal conditioner for the transducer. This divider provides calibration voltages of 0, 25, 50, 75, and 100% of the full-scale channel setup range. Voltage substitution is also used for swept-potentiometer transducers that are not active or self-generating. However, in this case, the transducer and the calibration voltage divider in the signal conditioner are in parallel across the excitation power supply in both the calibration and operational modes. This eliminates the possibility of calibration error caused by different excitation-power-supply loading during calibration and operation.

APPENDIX B

SIMULATORS

APPENDIX B

The schematics included herein are the proposed designs of simulators for use during the ETS-1 data-acquisition-accuracy test program. The simulated input levels for the two types of thermocouples used in the diagnostic channels shall be provided by high-quality thermocouple transducers. These transducers shall be stabilized at the ice point. The calibration of all simulators and transducers shall be traceable to the National Bureau of Standards. The speed and flow simulators shall utilize a calibrated sinewave generator or pulse source (preferably a function generator). The analog and wide-band mode shall use a function generator and dc power supply.

Schematics included are:

Figure 1 - RTT Simulator

Figure 2 - Swept-Potentiometer Transducer Simulator

Figure 3 - Four-Arm Strain-Gage Simulator

Resistors are all $\pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$, 1/2 W with four terminals

R-1 = 1736.60 Ω

S-1 Daven 142-DB-6

R-2 = 1380.00 Ω

J-1 Micro- 058-0006 235774

R-3 = 814.94 Ω

Dott

R-4 = 328.25 Ω

R-5 = 33.212 Ω

R-6 = 5.584 Ω

Figure 1 - RTT Simulator

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* 1%, 5 PPM/C° ~ All others 0.05%, 5 PPM/C°

Calibration of Simulator;

$$\frac{V_{F - B, C}}{V_{A, E - B, C}} \text{ vs } 0\%, 25\% \text{ --- } 100\% \text{ Switch Position}$$

Figure 2 - Swept-Potentiometer Transducer Simulator

Bridge trim resistors (R-9 & R-10)

Bridge trim resistor (BT) value to be determined for each individual CCT to trim in each bridge. Make from No. 28 Manganium Wire.

Resistor Values:

R-1 = $27,910\Omega \pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$

R-2 = $37,280\Omega \pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$

R-3 = $56,000\Omega \pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$

R-4 = $112,200\Omega \pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$

R-5 thru R-8 = $350\Omega \pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$

R-9 = $10,000\Omega \pm 0.01\%$, 5PPM/ $^{\circ}\text{C}$

R-10 = 20 Ω Potentiometer,

Daystrom 200-66, 20 Ω

Daystrom Incorporated, Potentiometer Division

Archbald, Pennsylvania

Switch S-1, L&N

Figure 3 - Four-Arm Strain-Gage Simulator

APPENDIX C

DATA ANALYSIS

APPENDIX C

1.0 NARROW-BAND DATA ANALYSIS

In this report accuracy is the difference between the known input and the recorded output stated in terms of a 99% confidence interval such that 99.9% of the data points will fall within the boundaries indicated. The intent in the statistical design and subsequent data analysis is to obtain maximum useful information and to achieve the accuracy objectives with a minimum expense and within the schedule requirements of the test program. The data analysis must also produce results that are valid and applicable to overall analysis of the ETS-1 test program. Under these considerations, the test plan was developed to enable error isolation of other factors such as drift, linearity, subsystem variability, and channel-to-channel variability and to obtain data that would be available for further studies if required. The data results from the Test-Cell-A tests and from other NRO tests have been considered in this program.

The statistical-analysis procedure utilizes analysis of variance methods designed specifically to evaluate the objectives of the ETS-1 data-acquisition-system accuracy. To prevent testing at redundant levels or the requirement for an excessive number of channels or observations to be evaluated at each mode, preliminary testing has been conducted. The results of the preliminary test data enabled an optimum number of channels, input levels, drift time increments, and repeated observations per test to yield meaningful data to achieve the desired goals from the remaining tests.

1.1 DATA ANALYSIS FOR PRIMARY OBJECTIVE

The accuracy for each observation is defined as the difference between the known input and the recorded output. The accuracy of each mode shall be analyzed in terms of a 99% confidence interval that will include 99.9% of the data points. This interval will be obtained by computing the system bias and the system standard deviation (noise), where system bias, $\bar{X}$, is defined as

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$$\bar{X} = \frac{\sum_{i=1}^t (X_i - N)}{t},$$

where

X_i = recorded output,

N = known input,

t = number of observations;

system standard deviation (noise), S , is defined as

$$S = \sqrt{\frac{\sum_{i=1}^t [(X_i - N) - \bar{X}]^2}{t-1}};$$

and the 99% confidence interval for 99.9% of the data points is defined as

$$99\% \text{ confidence interval} = \bar{X} \pm KS,$$

where K is a function of the number of observations. K is 3.520 for $N = 640$ observations. Accuracy can be represented schematically as follows:

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The above equations are defined with the assumption that each recorded output is a random sample from a normal population and that factors comprising the accuracy estimate are independent. If these assumptions do not prove valid, statistical modifications in the above definitions will be made to ensure valid and meaningful estimates of accuracy.

1.2 TEST ANALYSES

The data collected and analyzed from the final tests described in Section 5 will permit the following factors to be evaluated for their contribution to the ETS-1 data-acquisition-system accuracy.

- a. System bias
- b. Channel-to-channel variability
- c. Subsystem-to-subsystem variability
- d. Linearity
- e. Drift
- f. Noise

1.2.1 Bias

Bias will be computed for each of the modes by using the following equation:

$$\bar{X} = \sum_{i=1}^t \frac{(X_i - N)}{t},$$

where

- X_i = recorded output,
- N = known input,
- t = number of observations.

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1.2.2 Channel-to-Channel and Subsystem Variability

Each test defined in Section 5 will be run on two subsystems using 20 channels per mode, 10 channels for each subsystem; and each channel will yield 640 observations. Each test will be subjected to the following analyses.

1.2.3 Analysis of Variance Method

If the inaccuracy estimate for a given mode is excessive, the variation of each of the test variables contributing to the inaccuracy must be studied. The differences observed for each variable are compared with the estimate of noise. If the observed differences are insignificant, the variability can be combined or pooled into the error or noise estimate. If significant differences are observed, these differences must be considered as contributing to the inaccuracy of a mode. Similarly, if the noise estimates are different, statistical methods will be used to arrive at a meaningful and realistic estimate of noise.

To illustrate the method of analysis, consider the two subsystems and ten channels for each subsystem at a given input level and drift time interval. Define S_n^2 as the error mean square or noise estimate caused by the ten channels for one subsystem, and define S_{cc}^2 as the channel-to-channel mean square for each subsystem, where

$$S_n^2 = \frac{1}{990} \sum_{m=1}^{100} \sum_{i=1}^{10} (X_{im} - \bar{X}_i)^2;$$

$$S_{cc}^2 = \frac{100}{9} \sum_{i=1}^{10} (\bar{X}_i - \bar{X}_j)^2;$$

$$\bar{X}_j = \frac{1}{1000} \sum_{m=1}^{100} \sum_{i=1}^{10} X_{im}; \text{ and}$$

$$\bar{X}_i = \frac{1}{100} \sum_{m=1}^{100} X_m;$$

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where

m = observations,

i = channel,

j = subsystem.

A number of comparisons will be made. The ratio of S_{cc}^2 to S_n^2 will be evaluated by using the F distribution to determine whether or not there is channel-to-channel variation within each of the subsystems. Similar analyses will be made to determine whether S_n^2 and S_{cc}^2 for each of the subsystems can be combined or pooled. If channel-to-channel variability is significant, this variation must be included in the overall accuracy estimate for the mode. The two subsystems will be tested for significance by using the pooled estimate as the basis for comparison.

1.2.4 Linearity

Linearity, as used in this study, will be a comparison of the system bias at different input levels. Thus, if the system bias is the same at each input level, the system is considered linear as compared with the variation about the system bias. The analytical procedure requires determination of a least-square regression equation of the data points and a comparison of any lack of linearity with the noise or random fluctuation of the data by the use of analysis of variance techniques. In addition, each average value will be compared with the regression value. The primary concern of this analysis is to evaluate linearity in terms of its contribution to inaccuracy. Therefore, the error must be compared with the known input value rather than being an analysis of recorded output values alone, because a linearly increasing system bias can also contribute to system inaccuracy.

1.2.5 Drift

Drift will be evaluated by obtaining the system average values at each time increment and comparing them with the system averages at zero time for each level of known input. Thus, drift will be defined as

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$$\% \text{ drift error} = \frac{\bar{X}_t - \bar{X}_o}{\bar{X}_o} \times 100,$$

where

$\bar{X}_t$ = system average at t hours,

$\bar{X}_o$ = system average at zero hours.

1.2.6 Noise

Noise is defined as an evaluation of the random fluctuation in signal output about the average of the output (bias) as defined in Section 1.2. The noise estimates from each test will be combined or pooled when proven to be statistically insignificant. If the noise estimates are statistically different, an averaging technique will be developed for combining the noise estimate.

2.0 WIDE-BAND DATA ANALYSIS

The purpose of the wide-band-data accuracy analysis is to determine a measure of accuracy for wide-band channels of the ETS-1 data-acquisition system. Accuracy for wide-band analysis is defined as the ability of the ETS-1 data-acquisition system to reproduce a given input signal as a function of frequency and time. In order to measure wide-band-data accuracy, each factor that may affect the reproducibility of a signal must be identified and measured. The factors that will be used to evaluate the wide-band accuracy portion of this study will be amplitude attenuation, phase shift, noise, drift, crosstalk, channel-to-channel and patch-routing differences, and ac and dc linearity as a function of frequency and level.

2.1 DATA ANALYSIS

The wide-band data will be analyzed by test personnel at Aerojet's Sacramento Plant. The test will be performed to enable data to be collected

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for analysis in four parts, as described in Paragraph 5.6.5. These parts are dc and ac input for non-zero-suppressed channels and ac, square-wave, and phase-shift input for zero-suppressed channels. Phase lag is a test to detect phase change by visual means. In addition, speed-and-flow and common-mode tests will be performed.

2.1.1 DC Input

Five voltage levels, 0, 25, 50, 75, and 100% are recorded on the magnetic tape for each of 20 channels. The data will be processed at NRO by using a sampling rate of 100 samples/sec for each 10-sec test interval. This process will yield 1000 data points per test. The following analysis will be performed:

2.1.1.1 DC Amplitude Attenuation

Average and standard deviation, as well as a least-squares regression equation for the five dc levels for each channel, will be computed for each test point. A test point consists of 1000 data points obtained for a given test level. The output averages for each of the five input levels will be compared with the simulator input to determine dc attenuation and will be represented as percent of full-scale error.

$$\% \text{ error} = \frac{\bar{E}_o - E_i}{E_i (FS)} \times 100, \quad (1)$$

where

$\bar{E}_o$ = observed average output in volts,

E_i = simulator input in volts,

$E_i (FS)$ = full-scale simulator input.

2.1.1.2 Linearity

A least-squares fit of the output data will be made, and two measures will be obtained to assess linearity. First, the slope (b)

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and the intercept (a) will be determined, and the line will be statistically tested for linearity by means of the traditional analysis of variance methods. The second measure of linearity is the deviation of the average of each output level from the regression line as a percent of full-scale, or

$$\% \text{ linear deviation} = \frac{\bar{E}_O - E_R}{E_i (\text{FS})} \times 100, \quad (2)$$

where E_R is the predicted regression value for $\bar{E}_O$.

2.1.1.3 Noise

Noise is defined as the root-mean-square value of the deviations from the regression line, or

$$\sigma_n = \sqrt{\frac{N}{\sum_{i=1}^N} \frac{(E_O - E_R)^2}{N - 1}}. \quad (3)$$

The influence of digital noise will be determined by digitizing a constant signal on the analog tape in the same manner as for an output level and determining its standard deviation. If the variation is significant, a corrected noise estimate will be made by using the following relationship:

$$\sigma_{nc} = \sqrt{\sigma_n^2 - \sigma_D^2}, \quad (4)$$

where

nc = corrected noise standard-deviation estimate,

n = original noise standard deviation,

D = standard deviation of digitizing system.

2.1.1.4 DC Crosstalk - Wide-Band Channels

Means and standard deviations will be determined for each of the ten channels in which no signal was imposed. The zero-volt

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level for each channel will be used as reference to determine whether any cross-talk can be detected. The relation in Equation 1 will be used in measuring dc crosstalk.

2.1.1.5 Drift

The 20 channels will be tested every hour for 10 sec. At each of these time intervals, a mean and standard deviation will be computed to determine whether or not drift is an important variable. A calibration will also be made at this time each hour to ensure that the gain drift of the wide-band amplifier is measured.

2.1.1.6 Channel-to-Channel Difference

The means will be compared to detect any significant differences by using the analysis of variance methods as defined in the narrow-band portion of the accuracy study.

2.1.1.7 Patch Routing Differences

The mean and standard deviation of low-level patches 1 and 2 will be compared and related to the narrow-band results. The patch routing is defined in Section 5 under the test description.

2.1.2 AC Input

The four ac voltages will be recorded on analog magnetic tape for 20 channels. The test will be performed for three frequencies, 10, 500, and 2000 cps for non-zero-suppressed channels at peak levels of 3, 6, 15, and 30 mv. The output amplitude averages will be computed at each level and frequency. For zero-suppressed channels, frequencies of 1, 5, 10, and 50 cps will be used. Peak ac levels of 3, 6, 15, and 30 mv will be superimposed on 75 mv dc.

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2.1.2.1 AC Amplitude Attenuation

The average amplitude output will be compared with the input for each of the four input levels for each frequency. The amplitude difference for each level and frequency will be determined by using the relationship in Equation 1. In addition, the attenuation will be determined in decibels, where

$$\text{db} = 20 \log E_o/E_i. \quad (5)$$

This analysis will be conducted for non-zero- and zero-suppressed channels.

2.1.2.2 AC Amplitude Linearity

The average output amplitude for each level will be used to evaluate linearity as defined in Section 2.1.1.2.

2.1.2.3 AC Crosstalk

By a procedure similar to that described in Section 2.1.1.4, crosstalk will be evaluated for the ten unstimulated channels per patch system for both zero- and non-zero-suppressed channels. The relation in Equation 1 will be used to evaluate ac crosstalk at all frequencies.

2.1.2.4 Common Mode Rejection

Four input voltages will be evaluated for influence of common mode effects. The data will be observed on an oscilloscope (or oscillograph), and evidence of ripples will be investigated. If ripples or indications of signals are observed, the magnitudes and frequencies will be recorded.

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2.1.3 Step Input - Zero-Suppressed Channels

A 1-cps square-wave input at four different levels will be inserted, and the response will be recorded. This test will permit the evaluation of transfer functions and a comparison of amplitude gain attenuation by the sine and step input methods. The data will be digitized, and AGC Job 2909 will be used on the IBM 360-40 computer to perform the analysis. This program is the same one that will evaluate XE wide-band-data transfer functions. Zero-suppression of these channels will be achieved by the AGC-designed zero-suppressed channel rack.

2.1.3.1 Transfer-Function Evaluation

Phase and gain will be determined for each of the 20 zero-suppressed channels for each of the four levels. The gain and phase listings will be presented. In addition, analog and digital time recording for the input and output will be obtained from the AGC processing system for each input level. These recordings will be used to visually evaluate the data-system step response. The gain and phase for each level will also be plotted on log scales by using the Job 2909 computer-program routine.

2.1.3.2 Accuracy of Gain and Phase Plots

A 99% confidence interval for gain and phase will be established from the 20 channel gain and phase values recorded for each level of input. The variation thus obtained will serve as an index for the accuracy of transfer functions for XE tests. A comparison shall also be made with the sine-input frequency response to determine whether any differences exist.

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2.1.3.3 Noise Evaluation

Transfer-function analyses consisting of gain and phase listings for the ten unstimulated channels will be performed if the AGC program for random inputs is checked out. If not, power-spectral-density plots of the output will be made to detect any significant levels and resonant frequencies for noise. The output can contain crosstalk, system noise, and possible digitizing noise.

2.1.3.4 Correlation of Input Levels

A correlation analysis will be performed to determine whether input level has any influence on the response of the data system in terms of amplitude and gains. The -3db level for amplitude ratio and the 90° phase lag will be compared with each input level.

2.1.4 Phase Lag

A second method of obtaining phase lag, in addition to the step input, will be to determine the elapsed time from a signal input from an oscillator and the input to the magnetic tape as determined by an oscilloscope. Lissajous figures will be observed, and phase lag will be determined. The data will be obtained for each level for a single channel. These data will be compared with the phase lag obtained from step input.

2.1.5 Speed and Flow

Six signal frequencies, 0, 4, 8, 12, 16, and 20 kc, are fed as input into the frequency-dc converter to yield a pulse and an analog signal. The pulse signal is routed to a digital system counter and to an analog tape. The analog signal is digitized at the 10-sample/sec high-level data system. These three sets of data, pulse digitized data, pulse analog tape data, and

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analog digitized data, are collected for six channels, three channels for each subsystem; and the test is performed at 100- and 1000-mv levels. The entire test is repeated stepping to each of six frequencies, 0, 100, 200, 300, 400, and 500 cps. The entire system will be calibrated at 200 and 20,000 cps.

2.1.5.1 Evaluation of Digital System Counter

The digital system counter will be evaluated for each channel and normalized by the time interval.

$$\text{Average no. of cycles/sec (f)} = \frac{\text{total no. of cycles}}{\text{time interval}}. \quad (7)$$

The 10-sample/sec high-level digital data system will yield a dc level value (D). A measure of accuracy will be obtained from the relation

$$\% \text{ error} = \frac{D_1 - D_c}{D_c (\text{FS})} \times 100, \quad (8)$$

where D_1 is the observed dc level, D_c is the calibrated dc level, and $D_c (\text{FS})$ is the full-scale calibrated dc level.

2.1.5.2 Analog-Tape Evaluation

The analog tape obtained with the pulse signal will be fed as input to the frequency-dc converter at the AGC test area to yield an analog signal. This signal will be fed to an analog-to-digital converter to yield a dc signal (D_2), and a second percent error will be determined by using the relation in Equation 8.

2.1.5.3 Channel-to-Channel and Subsystem Evaluation

The differences in the percent errors for the three channels and two systems will be evaluated by the analysis of variance methods described in Paragraph 1.2.3.

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2.1.5.4 Transient Evaluation

The time to reach 90% of the steady-state level will be determined for each step-frequency input. These times will be correlated with frequency response. The steady-state responses for the six step frequencies will be evaluated according to Paragraphs 2.1.5.1 through 2.1.5.3.

2.1.6 LVDT and VR

Five signals at four levels will be tested to evaluate the linear velocity displacement transducer and variable-reluctance signal paths. The analysis will evaluate the difference between input and output signals according to the relation in Equation 1.

3.0 DATA ANALYSIS AND PROCESSING EVALUATION

As part of the wide-band-data accuracy test, the accuracy of the AGC wide-band data-processing system and of the analysis system will be determined, since the inputs on the tape are well defined and documented. The tapes will also be made available to WANL to evaluate their wide-band data-processing and -analysis system.