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REPORT NO. RN-S-0389
TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE
ETS-1 DATA SYSTEM PRELIMINARY
ACCURACY TEST, DATA ANALYSIS
APRIL 1967

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AEROJET-GENERAL CORPORATION
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ABSTRACT

This report contains an analysis of preliminary test data obtained to determine the accuracy of the ETS-1 digital data system. The tests, which met the requirements of RN-S-0308, ETS-1 Data Acquisition System Accuracy Test Specification, were designed to aid in defining the overall test plan for the comprehensive determination of ETS-1 digital data system uncertainty.

Engineering unit tapes of the data were not available during the period the analyses were conducted. Thus, it was necessary to analyze the data "by hand," using digital printouts. To reduce the computation time, a selected number of data channels were completely analyzed and spot checks made of other channels. The data appeared very consistent. It is believed that a firm basis has been established for revisions to the final test plan.

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I. SUMMARY

The preliminary channels checked indicate that ETS-1 has an excellent narrow-band digital data acquisition system. The principal findings were:

A. The uncertainty of a random channel from a single signal path in the 100 s/s high-level system was $\pm 0.20\%$ of full-scale. Statistically, it can be stated that 99.9% of the data will fall within this range with a 99% confidence. Included in this uncertainty are channel-to-channel variations, subsystem differences, noise, linearity, and drift.

B. The channel-to-channel variability was found to be 0.023% for subsystems 1 and 2. In 18 of the 20 channels, the error was found to be distributed normally. In the two remaining channels, a bimodal distribution was found, deviating 0.14% and 0.07% from a normal distribution. The bimodal distribution was caused by a bias in one of the multiplexer channels used to sample data in each channel.

C. The random variation for a single channel (defined as noise, and measured by the average standard deviation) was $\pm 0.026\%$. Excluding the two channels with bimodal distribution, the noise was $\pm 0.020\%$.

D. The multiplexer channel variation was found to be a major contributor to noise. The variation within a typical channel was as high as $\pm 0.025\%$, and in the bimodal channel a variation of 0.14% was observed.

E. The bias error (defined as the average deviation from the known input) was -0.008% for subsystem 1 and -0.093% for subsystem 2.

F. No drift over a 12-hour period was detected in the two channels that were analyzed.

G. Linearity analysis performed for a single channel at a single test condition shows a $\pm 0.01\%$ variation from a straight line. Using the 0% and 75% full-scale calibration points for system calibration, a -0.01% bias was observed.

H. No significant crosstalk effects were detected.

I. As expected aliasing exists to some extent in the ten samples-per-second low-level system. Frequencies greater than 5 cps in this system can result in an incorrect DC output or an erroneous frequency indication. Parameters utilizing these channels are long time-constant, low response type of measurements. This problem is not significant in 100, 50, or 10 s/s high-level systems which have satisfactory filters. No further testing for aliasing effects is planned.

J. The frequency response curve for the Ampex analog tape is flat to 10K cps with a rolloff characteristic of 3 db down at 12K cps. The oscillograph is flat to 1000 cps with a rolloff characteristic of 3 db down at 3000 cps.

Preliminary test data indicated that the original test program could be reduced by more than 60% without the loss of any significant information. The modified test plan will include two additional tests not described in the original test plan.

II. METHOD OF ANALYSIS

The preliminary tests were conducted both before engineering unit conversions were available on magnetic tape at NTO and data reduction routines were prepared at AGC. Consequently, the data were sent to AGC as digital printouts. It was, therefore, necessary to manually evaluate the data. Since each operational mode contained 320,000 points (640 points per channel, ten channels per subsystem, two subsystems, five input step levels, and five time intervals for drift), a graphical statistical analysis was employed to evaluate each factor. This analysis utilizes a counting technique to create a frequency distribution and plots the cumulative frequency distribution on probability paper.* The data that were analyzed by this method are listed in Table 1. The data that were used for the analysis were the computed values

$$\text{percent error} = \frac{\text{output} - \text{input}}{\text{input (FS)}} \times 100,$$

where:

- Input = known simulation input,
- Input (FS) = full scale input = $\frac{4}{3} \times 75\%$ channel calibration value (100% calibration step not utilized)
- Output = $\frac{\text{full scale}}{\text{system constant}} M (X - X_0)$,
- System Constant = digital system range (10,000 counts),
- M = calibration factor (ideal counts/observed counts),
- X_0 = calibration zero offset in counts, and
- X = data points in counts.

*Probability paper shows a normal distribution as a straight line; therefore, from the graphs each factor and its variational patterns can be determined and used to achieve the analysis objectives of the preliminary tests. An explanation of the use and interpretation of probability paper analysis is included in Section V.

TABLE 1

DATA ANALYZED FOR PRELIMINARY ETS-1 DATA ACCURACY TESTS

Mode 16

Subsystem 1 - 10 channels at 0% and 10 channels at 75% full-scale,
640 points per channel

4 levels (0%, 25%, 50%, 75%) for a single channel,
640 points per level

5 time intervals (0, 2, 4, 8, 12 hours) for a single channel,
640 points per interval

Subsystem 2 - 10 channels at 75% full-scale, 640 points per channel

5 time intervals (0, 2, 4, 8, 12 hours) for a single channel,
640 points per interval

Frequency Response Analysis

Ampex Tape Recorder - 12 frequencies for each of five channels at
640 points per frequency

Oscilloscope - 12 frequencies for each of five channels at
640 points per frequency

AC Crosstalk

8 frequencies for a single channel each compared to calibration levels,
640 points per frequency

DC Crosstalk

High Level 100 s/s and 10 s/s

4 channels at 75% full-scale, each channel compared to calibration,
640 points per channel

III. DISCUSSION

Report RN-S-0308 describes the types of tests and factors to be considered to provide a complete estimate of the accuracy of the diagnostic portion of the ETS-1 data acquisition system. Twenty-six operational modes were chosen to be evaluated to adequately describe the end-to-end accuracy of the system. To permit the ETS-1 accuracy objectives to be achieved with a minimum number of tests and at low cost, a preliminary test program was included as part of the overall study. Based on the results of the preliminary studies, the overall objectives were to be reviewed and a final test plan prepared.

This report presents the results of the preliminary test plan and includes the intended revisions to the final test plan. The following is a brief summary of the preliminary tests conducted.

1. End-to-end accuracy: twenty channels (ten in each subsystem) were input with a strain gage simulator and checked at 0, 25, 50 and 75% of full scale in the digital output.
2. Drift: The accuracy tests, (Item 1 above), were repeated after 2, 4, 8, and 12 hours of system operation to check for drift.
3. Frequency response: five channels were checked with a sinusoidal input from 10 cps to 100 KC. The data were recorded on tape and monitored with an oscilloscope. The data were not digitized for this test.
4. Aliasing: five channels were checked with a sinusoidal input from 0.5 to 500 cps. The data were digitized for this test.
5. AC crosstalk: sinusoidal signals from 7 to 2000 cps were input into one channel. The other channels on the same multiplexer were terminated into 350 ohms at the test stand and checked for crosstalk coupling in the digital output.

6. DC crosstalk: one channel in the low-level and one channel in the high-level system were input with the millivolt output from a strain gage simulator. The remainder of the channels from the multiplexer used in each system were terminated into 350 ohms at the test stand and checked for stray signal indications in the digital output.

A. TOTAL VARIATION OF STRAIN GAGE MODE

The standard deviation of the strain gage mode (see Table 1, Mode 16) can be defined by the relationship

$$\sigma_T = \sqrt{\sigma_c^2 + \sigma_S^2 + \sigma_N^2 + \sigma_L^2},$$

where:

σ_T = total standard deviation,

σ_c = channel-to-channel standard deviation = 0.023%,

σ_S = subsystem standard deviation = 0.043%,

σ_N = standard deviation of noise = 0.026%, and

σ_L = standard deviation due to non-linearity = 0.010%

For Mode 16,

$$\begin{aligned}\sigma_T &= \sqrt{(0.023\%)^2 + (0.043\%)^2 + (0.026\%)^2 + (0.010\%)^2} \\ &= 0.056\%\end{aligned}$$

The criteria established in RN-S-0308 are to determine an interval which will contain 99.9% of the data points with a confidence of 99%. The interval is defined as

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

where $K = 3.520$ for $N = 640$. The confidence interval is $0 \pm 3.520 \times 0.056\%$
 $= \pm 0.20\%$.

B. CHANNEL-TO-CHANNEL VARIABILITY

Ten channels were selected from subsystem 1 and ten channels from subsystem 2 of mode 16 to determine the variation between channels. The schematic for mode 16 is shown in Figure 1. The 20-channel variation patterns are plotted in Figures 2 and 3. To interpret the data of Figures 2 and 3, consider each channel as a separate normal curve with a mean and standard deviation. The mean is defined as the percent error at the 50% probability value. The standard deviation is defined as the difference in percent error corresponding to the 84% and 50% probability point. To determine the channel-to-channel variability, the 50% point or average of each channel is plotted in Figure 4. Subsystem 1 shows a standard deviation of 0.024%, and subsystem 2 a standard deviation of 0.020%. The assumption of normality is justified from the straight line relationship as seen in Figure 4. In subsystem 1 (see Figure 2) channel S312.16 shows a bimodal distribution as represented by a displaced straight line. The displacement is 0.14% from the original curve. The displacement is associated with differences observed from multiplexer variation in the channel, although no reason for the relatively large variation can be ascertained at this time. A similar displacement of 0.07% was observed on channel S603.16 for subsystem 2 (see Figure 3). If the bimodal values are included in the analysis, the standard deviations of the averages would not differ appreciably.

C. NOISE

The estimate of noise, or the variation within a given channel, is determined from the slope of each curve in Figures 2 and 3. The percent error differential from 50% to 84% probability (0.020%) represents an estimate of the standard deviation. It can be seen that the slopes of all the channels are the same, indicating homogeneity of variation. Since one of ten channels in each subsystem contains a bimodal distribution, it is necessary to include this source of variation until the cause is found and eliminated. Bimodal channels

Figure 1 - Schematic, Mode 16 and AC Crosstalk Test

$$\text{PERCENT ERROR} = \frac{\text{OUTPUT} - \text{INPUT}}{\text{INPUT (F.S.)}} \times 100$$

Figure 2 - Channel-to-Channel Variability Analysis, Subsystem 1, 75% Full-Scale Step

Figure 3 - Channel-to-Channel Variability Analysis, Subsystem 2, 75% Full-Scale Step

Figure 4 - Subsystem and Channel-to-Channel Variation

S312.16 and S603.16 (as shown in Figures 2 and 3) are assumed to constitute a single distribution which can be represented by a straight line through the two segments of the curve. The slopes or standard deviations for channels S312.16 and S603.16 are 0.070% and 0.030%, respectively. To obtain an overall estimate of noise, these values are combined with the remaining channels by the following relation:

$$\begin{aligned}\sigma_N^2 &= \frac{\sigma^2 (S312.16) + \sigma^2 (S603.16) + 18 \sigma_n^2}{20} \\ &= \frac{(.070\%)^2 + (.030\%)^2 + 18 (.020\%)^2}{20}, \\ \sigma_N &= 0.026\%,\end{aligned}$$

where σ_N is the standard deviation for noise and σ_n represents the individual channel standard deviations.

Detailed analysis of noise shows that a systematic component of multiplexer channel variation exists for both subsystems.

D. SUBSYSTEM DIFFERENCE

The average of each of the ten channels for each subsystem is shown in Figure 4. The difference between the two average lines of each subsystem represents the subsystem difference, 0.085%. This is equivalent to a standard deviation of 0.043% for each subsystem.

E. BIAS

Bias of a particular channel is defined as the deviation of the average output when compared to the true input. Bias in terms of Figures 2 and 3 would be the deviation from 0% error at a probability of 50%. Subsystem 1 has a bias of -0.008% and subsystem 2 has a bias of -0.093%. In addition, the channel-to-channel variability adds to the channel bias total by ± 0.026%.

F. LINEARITY EVALUATION

Channel S315.16 was evaluated at 10%, 25%, 50%, 75%, and 0% full-scale, at a sampling rate of 100 s/s. This rate resulted in 640 points for each level. In addition, the average of ten channels at 75% and 0% were also compared. The distribution of each level is shown in Figure 5. The average value for each level is plotted in Figure 6. This plot shows a curve line varying $\pm 0.01\%$ about 0% error which is equivalent to the true 45° calibration straight line. If the 0% and 75% are used for evaluating linearity, a -0.01% bias will result when compared to use of a least square fit. The 25% and 50% points were based on one channel consisting of 640 points. No difference was found comparing 0% and 75% points for one channel (640 points) and the average of the ten channels (6400 points).

G. DRIFT

One channel from subsystem 1 and one channel from subsystem 2 were utilized to measure drift, as shown in Figures 7 and 8. The averages are plotted in Figure 9. Since each of the five times represents 640 points, the drift lines in Figure 9 represent 3200 points. As seen in Figure 9, no trend can be detected for each channel or differences between the two channels.

H. WITHIN CHANNEL VARIATION

Variation between the ten multiplexer channel connections for a particular data channel was investigated. There are distinct differences, as indicated in Figures 10, 11, 12, and 13. For channel S315.16 an average range of 0.04% , and for channel S609.16 an 0.07% range were observed. These magnitudes correspond to the noise estimates of each channel. For channel S312.16, a single multiplex channel had an extreme variation giving the bimodal distribution noted previously (see Figure 12). Channel S603.16 (see Figure 13) had two distinct groups of multiplexer variations to give the bimodal distribution.

Figure 5 - Probability Versus Percent Error, Linearity Evaluation, Channel S315.16

Figure 6 - Signal Level Versus Percent Error, Linearity Evaluation, Channel S315.16

Figure 7 - Drift Evaluation, Subsystem 1, Channel S315.16

Figure 8 - Drift Evaluation, Subsystem 2, Channel S609.16

Figure 9 - Drift Evaluation Averages

Figure 10 - Variation Within Channel S315.16

Figure 11 - Variation Within Channel S609.16

Figure 12 - Variation Within Channel S312.16, Bimodal Distribution

Figure 13 - Variation Within Channel S603.16, Bimodal Distribution

I. SECONDARY CHARACTERISTICS

The remaining secondary characteristics were investigated to provide supporting data to the overall analysis of the ETS-1 data acquisition system. These remaining secondary characteristics include frequency response, AC and DC crosstalk, and aliasing.

J. FREQUENCY RESPONSE

A sine-wave signal generator was used as the input to Mode 16, and a 100 MV peak amplitude signal was produced for frequencies of 10, 100, 500, 1K, 2K, 5K, 10K, 15K, 50K, and 100K cycles per second to each of five oscillograph and Ampex analog tape channels. Data for the oscillograph and magnetic tape analysis were obtained from NTO. Figure 14 shows the frequency response for the oscillograph trace to be flat to 1000 cps, with a rolloff characteristic of 3 db down at 3000 cps. Figures 15 and 16 show the frequency response of the Ampex magnetic tape recorder to be flat to 10K cps, with a rolloff characteristic of 3 db down at 12K cps. Since the analog tape data were obtained from an oscillograph playback with an 8:1 time base expansion, a correction is applied to the Ampex analog tape, as shown in Figure 16.

The frequency response of the digital data system is limited by the sampling rate and the filters in the system. Details of this are discussed under aliasing.

K. AC CROSSTALK

A sine-wave generator and an oscilloscope were patched to Mode 16, as shown in Figure 1, and used in the frequency test. The sine signal was placed on channel D1-14 at 10, 15, 20, 60, 100, 500, 1000 and 2000 cps. The data for 18 unused channels, which were reported in counts, were evaluated. No significant influence due to AC crosstalk was found. To illustrate the

Figure 14 - Oscillograph Frequency Response

Figure 15 - Ampex Analog Tape Frequency Response

Figure 16 - Corrected Ampex Analog Tape Frequency Response

variation magnitude, the variation of each of the eight frequencies for a single channel is presented in Figure 17. To obtain a comparable reference, each frequency was compared to the calibration value, as shown in Figure 17, and the means and standard deviations for each frequency were determined and are listed in Table 2. It can be seen from the table that no significant difference exists in the mean or standard deviations for the different frequency inputs when compared to calibration (no stimulated signal). However, the variation of noise is larger on the average (0.05% versus 0.02%) from that observed in the end-to-end accuracy test. The order of magnitude was still acceptably low and no effort was made to investigate the causes for the slight increase.

L. DC CROSSTALK

A 75% full-scale calibration step was input to channel D1-14 (see Figure 18) and four unused channels were evaluated for influence due to the DC signal for both 10 s/s and 100 s/s. The DC crosstalk test data were in counts based on 10,000 counts for full-scale. Therefore, as in AC crosstalk, the data were normalized using the 0% step as a reference. The means and standard deviation for the unused channels are listed in Table 2 and plotted in Figures 19 and 20.

The results show that for the 75% impressed signal, the unused channels are approximately 0.052% lower on the average than the 0% signal and both signals have a standard deviation of approximately 0.05%. However, this shift is also true for the signal channel and therefore cannot be charged to crosstalk. The magnitude is relatively small and no additional tests are planned to investigate these minor changes.

Figure 17 - AC Crosstalk Evaluation, 100 S/S, High Level, Channel D1-02

Figure 18 - DC Crosstalk Test Schematic

TABLE 2
ETS-1 AC AND DC CROSSTALK EVALUATIONS

AC CROSSTALK

Frequency, cps Channel No. D1-02	Mean, % Corrected to 0 Level		Standard Deviation %
	<u>Actual</u>	<u>Corrected</u>	
0	-0.125	0	0.050
10	-0.118	+0.007	0.053
15	-0.110	+0.015	0.053
20	-0.116	+0.009	0.049
60	-0.121	+0.004	0.051
100	-0.126	-0.001	0.058
500	-0.130	-0.005	0.055
1000	-0.135	-0.010	0.050
2000	-0.125	0	0.055

DC CROSSTALK

Channel No.	0% Full-Scale		75% Full-Scale		Corrected Mean to 0%
	Mean, %	Std.Dev., %	Mean, %	Std.Dev., %	
High level, 100 s/s (640 points)					
Signal D1-14	-0.050	0.035	-0.085	0.025	-0.035
D1-02	-0.120	0.039	-0.187	0.045	-0.067
D1-05	-0.003	0.041	-0.058	0.050	-0.055
D1-15	-0.048	0.050	-0.103	0.048	-0.055
D1-18	-0.058	0.048	-0.090	0.052	-0.042
Average	-0.057	0.045	-0.109	0.049	-0.052
Low Level, 10 s/s (64 points)					
Signal A1-17	+0.085	0.015	+0.138	0.015	+0.053
A1-06	-0.105	0.017	-0.089	0.027	+0.016
A1-09	-0.148	0.013	-0.140	0.014	+0.008
A1-18	-0.019	0.012	+0.025	0.017	+0.044
A1-21	-0.090	0.015	-0.088	0.020	+0.002
Average	-0.090	0.014	-0.073	-0.020	+0.017

Figure 19 - DC Crosstalk Evaluation, 100 S/S, High Level

Figure 20 - DC Crosstalk Evaluation, 10 S/S, Low Level

M. DATA ALIASING

Frequencies that occur during a test that are greater than one-half of the digital data system multiplexer sampling rate (called the Nyquist frequency) will show frequencies in the test data that are lower than the actual test frequencies and can cause errors in the average output. This condition is called aliasing or a foldover effect. An example of the errors which can be introduced by aliasing are shown on Figure 21. Part A of this figure illustrates a condition in which a lower frequency is observed in the digital output but the amplitude is maintained. Part B illustrates the condition where an extraneous high-frequency component, (e.g., noise) is influencing the true test signal. The resultant output is a low-frequency signal which is magnified in amplitude. A third aliasing effect is illustrated on Part C of Figure 21. In the case shown, an oscillating signal is shown which is being sampled at the same or an exact multiple frequency as the oscillation. In this case, a steady DC signal would be indicated which is greater than the average of the true signal. The magnitude of the error in this case will be a function of the starting position of the wave front and is not predictable.

The solution to the aliasing problem is either: (1) use a filter which will filter-out high frequencies and eliminate the aliasing influence, or (2) increase the data sampling rate to minimize the influence of data sampling. Filters of 40 cps, 20 cps, and 4 cps are used on high-level signals for the 100 s/s, 50 s/s, and 10 s/s sampling rates in the ETS-1 data system. These filters effectively reduce any significant aliasing effects. However, 320 of the 960 channels in the ETS-1 digital data system are 10 s/s low-level channels which do not have a filter to reduce any aliasing effect that may exist. Normally, the parameters assigned to these channels are long time-constant, low response type of measurements and aliasing does not become a significant factor.

PART A
 ALIASING EFFECT
 WITH NO EXTERNAL
 SIGNAL

PART B
 ALIASING EFFECT
 WITH AN EXTERNAL
 SIGNAL

PART C
 DC ALIASING EFFECT
 (TEST FREQUENCY =
 EXACT MULTIPLE OF
 SAMPLING RATE)

Figure 21 - Aliasing Effects

Figure 22 - Aliasing Test Setup

IV. INTENDED 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 magnitude of the errors observed were sufficiently small (0.01% - 0.15% full scale) to justify a complete revision of the accuracy test plan defined in RN-S-0308. Several of the tests now appear to be redundant.

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

Specification revisions based upon analysis of the preliminary test data are presented below. This section includes the basic test plan to implement these recommendations.

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

2. Evaluate drift for several thermocouple channels. The thermocouple reference junction can be assessed with regard to stability.

3. Twenty channels are adequate to evaluate digital data system accuracy through the various paths. It is recommended that ten channels be routed to each subsystem to verify the difference 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 with a $\pm 0.01\%$ accuracy.

4. Evaluate the influence of the bimodal distribution observed during the preliminary tests by re-running a strain gage mode with at least 25 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 in the event that more data is needed prior to corrective action being 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 speed and flow mode which includes a frequency to DC conversion. This mode was not included in the RN-S-0308 test plan.

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 at the start of each test. The first-hand observation of the test helps in the subsequent analysis.

A. OBJECTIVES

1. Primary Objective

The primary objective, which has not changed, is to determine the data acquisition system accuracy for each normally used signal path.

Figure 23 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 end-to-end system error where system error is calculated by using the equation

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

where:

E- OUT = observed output,

E- IN = known simulator input, and

E-IN (FS) = full-scale simulator input.

2. Secondary Objectives

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

Figure 23 - Proposed Data Acquisition System Accuracy Test Schematic

e. Document linearity and subsystem differences for each of the signal paths.

B. REVISED TEST PROGRAM

Figure 23 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 original test program is summarized in Table 3. The accuracy test objectives will evaluate the error that can result in the different possible signal paths through the digital data system and will not consider transducer errors.

TABLE 3
ORIGINAL ETS-1 ACCURACY TEST PROGRAM DEFINED IN RN-S-0308

Signal Path (Mode No.)	Channel Type	Characteristics of Signal Path		
		Digitizing Rate	Recording System	Amp.
1	C/A Thermocouple	50 S/S HL	Strip Chart	NB
2	C/A Thermocouple	10 S/S LL		
3	C/A Thermocouple	50 S/S HL		NB
4	C/C Thermocouple	50 S/S HL	Strip Chart	NB
5	C/C Thermocouple	10 S/S LL		
6	C/C Thermocouple	50 S/S HL		NB
7	W/WRE Thermocouple	50 S/S HL	Strip Chart	NB
8	W/WRE Thermocouple	10 S/S LL		
9	W/WRE Thermocouple	50 S/S HL		NB
10	WRE/WRE Thermocouple	50 S/S HL	Strip Chart	NB
11	WRE/WRE Thermocouple	10 S/S HL		
12	WRE/WRE Thermocouple	50 S/S HL		NB
13	4 Arm Strain Gage 350 ohm	10 S/S LL		
14	4 Arm Strain Gage 350 ohm	10 S/S HL		NB
15	4 Arm Strain Gage 350 ohm	50 S/S HL	Strip Chart Magnetic Tape	WB
16	4 Arm Strain Gage 350 ohm	100 S/S HL	Magnetic Tape	WB
17	4 Arm Strain Gage 350 ohm	50 S/S HL	Oscillograph	NB
18	4 Arm Strain Gage 120 ohm	50 S/S HL	Oscillograph	WB
19	4 Arm Strain Gage 60 ohm	50 S/S HL		WB
20	2 Arm Strain Gage 120 ohm	50 S/S HL		WB
21	2 Arm Strain Gage 120 ohm	10 S/S HL	Strip Chart	WB
22	RTT	10 S/S HL		NB
23	RTT	10 S/S LL		
24	Swept Potentiometer	50 S/S HL		
25	Analog Voltage	50 S/S HL		WB
26	Analog Voltage	50 S/S HL	Strip Chart	WB

The reasons for modifying the original test program will be explained for each test mode.

1. Mode 1a and 1b - Strain Gage

a. General

Two strain gage signal paths replace the nine modes defined in RN-S-0308. (Modes 13-21, Table 3). The original test program included multiple checks of some parameters and included various interaction effects. Since the variation of the end-to-end error is expected to be on the order of 0.1% or 0.2% of full scale, it is felt there is no justification for these multiple studies.

The following summarize the change in the objectives:

Objectives Deleted

Reason for Elimination

Investigate 10 s/s
low level system

This will be covered in test 4. There is no reason for redundant testing.

Investigate 350,
120 and 60 ohm
strain gage, and
4 arm and 2 arm
strain gages

The resistance of the strain gages is very low relative to the data system and no differences in impedance effects are expected. The difference in accuracy of the various strain gages is not a part of the data system accuracy.

Interactions with
various recording
instruments i.e.,
strip charts, tape
recorder, etc.

The preliminary test results indicated excellent accuracy with the alternate recording instruments and there is no need to conduct tests with them alternately in use. Test 1b will include them.

Objectives Added

Comprehensive
testing of all
multiplexer channel
variations

A periodic bias error was observed in the preliminary tests and this must be more completely investigated.

b. Test 1a and 1b

Using a strain gage simulator (Figure 24), route the signal to the strain gage signal conditioner, 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 and to the 10 s/s multiplexer. Run the test 64 seconds 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 magnetic tape recorders. Route the signal to a 40 cps low pass filter and 100 s/s digitizing sampling rate. Patch 25 channels to each subsystem so 50 channels of data will be available to study the variability expected in some of the multiplier channels. Provisions must be made to permit re-running this test without changing the setup to study the cause of the difference. Run the 50 channels at 0%, 25%, 50%, and 75% full scale for 6.4 seconds. Record the ten channels on the three recording systems for the same 6.4 seconds at 75% full scale. The purpose of recording this data is to evaluate readability.

2. Mode 2 Resistance Temperature Transducer (RTT)

a. General

One RTT test will replace the two scheduled tests in RN-S-0308. This single test can achieve all desired objectives. RTT's are

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 24 - Four-Arm Strain Gage Simulator

utilized, in general, for three basic temperature ranges: (1) narrow range cryogenic (35°R to 60°R); (2) wide range cryogenic (35°R to 610°R); and (3) noncryogenic measurements (360°R to 560°R). Two principal types of signal conditioners are utilized for these ranges. These are the constant current signal conditioners for cryogenic measurement and triple bridge signal conditioning for "hot" or noncryogenic measurement. 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 conditioner.
4. Evaluation of linearity for wide range cryogenic measurement.

b. Test 2

Route the RTT signal from the RTT simulator (see Figure 25) to the signal conditioner. Two simulators will be used. One simulator will route the signal to the triple bridge signal conditioner while the second simulator will route the signal to the constant current signal conditioner. The triple bridge circuit will include a range of temperature from -100° to +150°F (mode card RTT0) and data will be taken with resistance setting of 1380.0 ohms (32°F) and 1736.6 ohms (150°F). The constant current will be evaluated for narrow and wide range cryogenic temperatures. Therefore, two mode cards will be required; the narrow range cryogenic will include the range -425°F to -400°F (mode card CC01) and will be tested at resistance settings of 5.584 ohms (0%) and 33.212 ohms (100%). The wide range cryogenic will include the temperature range of -425°F to 150°F (mode card CC03) and will include readings at all six resistance readings shown in Figure 25. Only one channel can be tested with the RTT simulators at a time. Each of the three ranges will be tested for 64 seconds for ten channels in subsystem 1. The conditioned signal for all three ranges will be routed to the low level patch

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 25 - RTT Simulator

board, to a narrow band amplifier, through a 4 cps low pass filter and sampled at 10 samples per second, high level.

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 26.

b. Test 3

Route the signal from the simulator to the signal conditioner, to the high level patch, through a wide band amplifier, and 4 cps low pass filter and sampled at 10 s/s high level. Test at 0%, 25%, 50%, 75% and, if possible, at 100% full scale for 64 seconds for 20 channels, ten channels routed to subsystem 1 and ten channels routed to subsystem 2.

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 RN-S-0308. A review of the preliminary data and all the possible thermocouple signal paths indicate that factors such as adding a strip chart recorder, changing the sampling rate, and studying different thermocouple types are not the type of information required for the digital data system accuracy. Approximately 85% of the total thermocouples are C/A and C/C types and both are routed through precision thermocouple reference junctions. Tungsten-Tungsten Rhenium (W/WRe) thermocouples do not utilize a reference junction. The signal conditioning mode cards for all thermocouple

* 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 26 - Swept Potentiometer Simulator

channels are basically the same and exhibit very similar electrical characteristics eliminating any need for evaluating 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 utilized for inputting signals at 0°C ice bath and 100°C boiling water. A digital voltmeter reading will be made 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 s/s 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 seconds at each of the two test temperatures.

(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 per second, high level. Test 5 will be repeated at 2, 4, 8, and 12 hours to evaluate reference junction drift (ice bath temperature only).

5. Mode 6 Analog

a. General

The analog mode in RN-S-0308 in its present form will not yield data that would be meaningful to the accuracy program. Since data will be collected on magnetic tape and the tape used for further data processing, it is believed that a special test to evaluate linearity and accuracy on the tape would be more appropriate. It is intended that the tape accuracy figure would also apply to the wide band data on magnetic tapes.

b. Test 6, Analog

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 subsystem for a minimum of 10 seconds per input.

(1) Insert DC voltage levels at ± 10 MV, ± 50 MV, ± 100 MV, ± 200 MV, ± 500 MV and ± 1.0 VDC (1.0 volt DC is 100% of full scale).

(2) Repeat B-1 utilizing a 500 cps AC signal. All voltages will be AC RMS (1.0 volt RMS is 100% of full scale).

(3) Short circuit the simulator output and record the wide band channel noise.

6. Mode 7, Speed and Flow

a. General

The speed and flow signal path was omitted from RN-S-0308 and is being included since it is an important signal path and includes

components not included in the other paths. The signal is conditioned and is fed into a frequency - DC converter producing two signals; an analog signal and a pulsed signal. The pulse and analog signals will be utilized in this test.

b. Test 7

Route the signal from the simulator to the frequency/DC converter. The pulse signal is patched to the high level patch and routed directly to the 10 samples per second digitizer. The analog signal is patched to the magnetic tape recorder. Three channels to each subsystem will be tested for 6.4 seconds.

V. INTERPRETATION AND USE OF PROBABILITY PAPER

To evaluate large quantities of data manually, it is desirable to perform the computation in a systematic manner that will yield results that are simple, concise, and statistically valid. The method that is used is to plot the data on probability paper which displays a normal distribution as a straight line. By this means it is possible to determine the median value, standard deviation, variation between items, and, in addition, to make other desired comparisons. If the normal assumption does not hold, the error in this assumption is readily apparent and the modification and interpretation of results can easily be made. A feature favoring the use of probability paper is the ease of communication using statistical characteristics. There is no need to use mathematical definitions since all statistical parameters are determined graphically. This appendix will describe the procedure and method of analysis to obtain typical statistical characteristics.

A. PROCEDURE

The procedure for use of probability paper will be applied to a single set of 640 points shown in Table 4 for a particular channel for a 75% step signal. The procedure is as follows:

1. Establish Intervals for Analysis

Determine the highest and lowest value of percent error and establish 10 - 20 intervals within the range. Since the high and low values were -0.01% to -0.14%, thirteen intervals of 0.01% were used as shown in column 1 of Table 4.

2. Determine a Frequency Distribution

Count the number of values from the 640 observations for each of the 13 intervals as shown in column 2 of Table 4.

TABLE 4
DISTRIBUTION OF DIGITAL DATA SYSTEM ERROR
FOR A SINGLE CHANNEL

ETS-1

Percent Error $\frac{\text{out-in}}{\text{in(fs)}} \times 100$	Actual Data			Normal Distribution		
	Frequency, No. of Items	Cumulative Frequency	% Cum. Frequency	Frequency, No. of Items	Cumulative Frequency	% Cum. Frequency
(1)	(2)	(3)	(4)	(5)	(6)	(7)
-0.14				2	2	0.312
-0.13	4	4	0.624	8	10	1.56
-0.12	11	15	2.34	19	29	4.52
-0.11	30	45	7.02	39	68	10.61
-0.10	102	147	22.93	67	135	21.06
-0.09	102	249	38.84	97	232	36.19
-0.08	95	344	53.67	113	345	53.82
-0.07	57	401	62.56	109	454	70.83
-0.06	127	528	82.37	85	539	84.09
-0.05	29	557	86.90	54	593	92.51
-0.04	33	590	92.04	29	622	97.04
-0.03	41	631	98.44	13	635	99.06
-0.02	7	638	99.53	4	639	99.69
-0.01	2	640	99.84	1	640	99.84

3. Determine Cumulative Frequency

Add each frequency for each successive interval as shown in column 3 of Table 4. To illustrate, for -0.09%, 249 represents all the frequencies that have an error equal to or less than 0.09%.

4. Compute Percent Cumulative Frequencies

Column 3 of Table 4 is divided by $N + 1$ or 641. 641 is used instead of 640 to assure use of last interval. 100% does not exist in a true normal distribution.

Plot column 1 as the ordinate and column 4 of Table 4 as the abscissa on probability paper as shown in Figure 27. A straight line through the 13 points is adequate for this analysis. Columns 5, 6 and 7 of Table 4 compare the fitted straight line or normal curve with the observed data. As shown in Figure 27, the 50% probability point for a normal distribution is the arithmetic mean and for this set of data is -0.077%. The standard deviation is the difference between the 84% and 50% probability points (or the 50% and 16% probability points). The standard deviation is 0.021%. If a number of curves are plotted, the variation between the curves can be determined by observing the variation at the 50% point, assuming the standard deviations (slopes) are the same: i.e., the values at the 50% point can be plotted on an additional sheet of probability paper and the variation of the averages determined in a manner similar to the analysis of the data in Figure 27.

B. INTERPRETATION OF USE OF PROBABILITY PAPER

To understand the use of probability paper, the data in Table 4 columns 1 and 2 are plotted in Figure 28 as a histogram. A normal curve represented as a solid line is fitted to these data. The curves in Figure 28 are accumulated as represented by columns 1 and 4 in Figure 29. In Figure 30

the axes are reversed to present the curve in a form similar to that used with probability paper. By adjusting the percent or probability scale, a straight line for Figure 30 can be constructed. This is the basis for use of probability paper, as shown in Figure 27.

Figure 27 - Digital Data System Error Distribution For a Single Channel Using Probability Paper

Figure 28 - Error Distribution of Digital Data System For a Single Channel

Figure 29 - Cumulative Error Distribution of Digital Data System For a Single Channel

Figure 30 - Cumulative Error Distribution of Digital Data System For a Single Channel