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AN ANALYSIS OF RESULTS OF THERMAL-VACUUM TESTS ON OGO EXPERIMENTS

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ABSTRACT

Simulated space tests conducted at GSFC on experiments for the Orbiting Geophysical Observatory have been reviewed and analyzed. The 374 tests were examined and summarized for the effects of test time, thermal level, sequence, phase, year of test, program, experimenter, and model on the numbers and time distribution of failures. Graphs are presented to show the number of malfunctions with relationship to the duration of the test, together with the influence of prototype and flight models and thermal levels. This report updates and extends the information documented in Reference 1.

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AN ANALYSIS OF RESULTS OF THERMAL-VACUUM TESTS ON OGO EXPERIMENTS

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BACKGROUND

Experiment package testing associated with the OGO (Orbiting Geophysical Observatory) Satellite Program has been underway at GSFC for the past four years. As part of the Past Experience and Performance (PEP) Program, 374 simulated space tests on these experiments have been reviewed and analyzed. An earlier study (Reference 1) considered test data from July 2, 1962 to April 26, 1965. These data were analyzed for the effects of time, thermal level, and model on the number and rate of experiment failures. The data were insufficient to determine the effect of test sequence (whether hot or cold thermal level occurred first) on the number of failures, or to show a statistically significant effect of model or temperature.

Two hundred and seventy simulated space tests with 51 failures were considered in the first analysis (Reference 1). In this analysis, 374 simulated space tests (including the original 270) with 70 failures were studied. All the new data were obtained from tests conducted with a hot-cold sequence, whereas only six tests from the first series followed this sequence. Specific attention has been given to the failed experiments. Each failure is classified according to thermal level, phase, and hours in operation when the failure occurred, in addition to observatory, date, experimenter, model, and sequence of test.

The data used in this analysis cover the thermal-vacuum tests on experiments for OGO-A, OGO-B, OGO-C, and incomplete data on OGO-D. These data were gathered from two sources: the log books maintained by T&E technicians during each test of an experiment, and the 24-hour reports provided by the test engineers. The latter source provided the bulk of the data.

The interpretation of the data from these sources is limited somewhat by the fact that, in many of the reports on the experiments which malfunctioned, the cause of failure was not given. Also, some tests were omitted from the data because they were not conducted for the prescribed time period, e.g., if a flight model was tested satisfactorily for two hours rather than the usual 12, it was not included. Because of lack of data, no attempt was made to link failures to causes (a study which would improve the analysis if the information were available).

The experiment hardware included engineering, prototype, and flight models. The thermal-vacuum test distribution of the experiment models was four conducted on engineering models, 96 on prototype models, and 274 on flight models. Each test was designed to provide information on the performance of an experiment model under vacuum at each of two thermal levels for equal periods of time. The thermal levels were based on maximum and minimum predicted temperatures of the experiments in a non-operating mode in space. Thus, the test temperature levels were obtained with the experiments in a non-operating mode. When the experiment and the thermal-vacuum chamber were at the prescribed temperature, the experiment was turned on. This procedure gives an indication of the temperature which the experiment will reach in space and also gives an indication of any heat dissipation problems. This type of test is commonly referred to as a soak test. The test temperature levels among the three experiment models were as follows.

Prototype	– Body-mounted assemblies	-5° and 45°C
	Appendage	-10 and 50°C
Flight	– Body-mounted assemblies	+5 and 35°C
	Appendage assemblies	0 and 40°C
Engineering	– Same as prototype	

The engineering and prototype experiment models were tested at each of the thermal levels indicated for 24 hours, and the flight experiment models were tested for 12 hours at each thermal level. Thus, the test duration for flight models totaled 24 hours, and the test duration for prototype models totaled 48 hours. (Time to reach each thermal level was not included.) In the majority of cases, the tests were conducted with the cold phase occurring before the hot phase. The time during which an experiment was operated while at either thermal level is called the operating time of the experiment.

TREATMENT OF DATA

The test data were examined and classified by observatory (A, B, C), experiment, model, date, initial thermal level, and success or failure. Of the 374 thermal-vacuum tests recorded, 70 were designated failures. An experiment was considered a malfunction if it failed in either the cold or the hot phase. The malfunction distribution among experiment models was two engineering, 26 prototype, and 42 flight models. Because the test conditions for the engineering models were the same as those for the prototype models, and the number of engineering malfunctions was so small, the failure results of the prototype and engineering models were combined. Henceforth, when the term "prototype models" is used in connection with test performance, the failure results of the two engineering models are included. Thus, the results showed 28 prototype model failures and 42 flight model failures. Since the 374 tests are distributed over 100 tests of prototype models and 274 tests of flight models, the ratio of flight to prototype is nearly 3 to 1.

Of the 70 test failures noted above, 40 occurred during the initial thermal phase, at which time these tests were discontinued. These failures are single-phase test failures. The remaining 30 test failures occurred during the second thermal phase, at which time these tests were discontinued. These failures are two-phase test failures.

The 70 test malfunctions were classified by model, temperature, level, and phase. The distribution was 15 hot failures and 13 cold failures for the prototype model tests, and 21 hot failures and 21 cold failures for the flight model tests. The distribution of the failures into the various phases by model and the number of tests conducted is given in Table A8 of the Appendix.

A time study of the test failure data was also completed. It provided information on the distribution of malfunctions with respect to time, temperature, and model. The study also provided information on malfunctions related to test sequence and on single-phase results compared to two-phase results.

Data also are presented showing number and percentage of failures by observatory (excluding OGO-D, for which data are not complete) and test results itemized by fiscal years 1963 through 1966. A summary of test performance by experimenter and agency is also examined for differences in results.

In addition to classifying the data in many ways to learn what the past performance has been, statistical techniques were used to learn which apparent effects have statistical significance. Various forms of analysis of variance were used to determine the significance of model, temperature level, test sequence, experimenter, observatory number, and year-to-year performance.

DISCUSSION OF DATA

The malfunctions detected in a simulated space test can arise from many causes. Such causes as design limitations, material limitations, production deviations, test errors, and personnel errors are broad categories. More specific data on the causes of malfunctions would be helpful in improving future performance of subsystems and spacecraft systems. Until recently, documentation of such information was not required at GSFC. Even without such specific information on malfunctions, a review of a large program such as OGO should be helpful in assessing what has been done and what should be changed. This study, although restricted to the simulated space tests on the experiments for the OGO program, is based on the most comprehensive subsystem test program ever conducted at GSFC. The data will be discussed under seven major headings.

Malfunctions Versus Time and Temperature

The data from 374 tests are summarized in Figure 1, which shows the time distribution of the 70 malfunctions. There is a strong indication of an expected exponential relationship. This relationship persists even when the malfunctions are segregated into hot and cold categories. The 70 malfunctions are about equally divided between hot and cold tests.

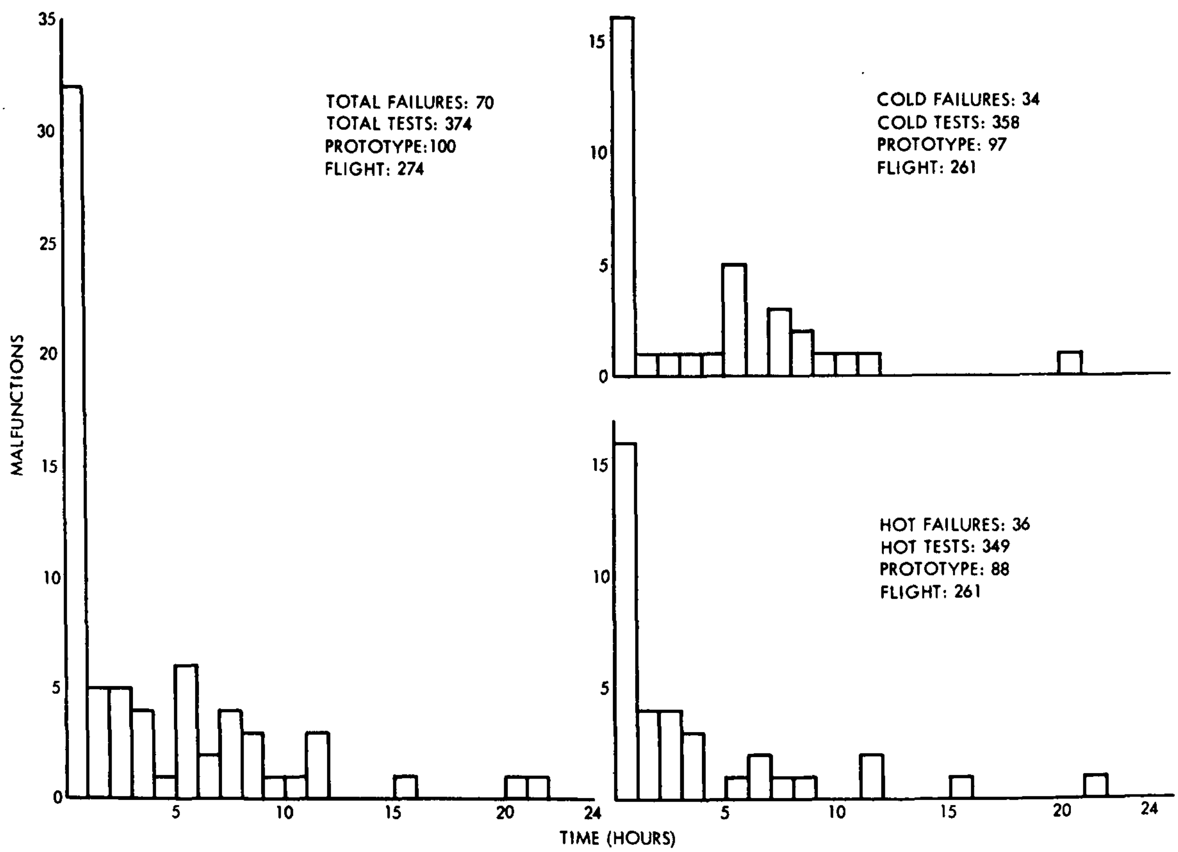

Figure 1–Malfunctions vs. operating time for OGO experiments under simulated space environment.

Malfunctions by Time, Temperature, and Model

When the 70 malfunctions are separated into the categories of time, temperature, and model, the sample size per category becomes quite small. Figure 2 shows the time distribution of malfunctions for each of the four model-temperature categories. The data show that approximately 29 percent of the prototype model tests and 16 percent of the flight model tests had malfunctions. The prototype data also show that approximately three percent of the prototype malfunctions occurred after 12 hours of testing.

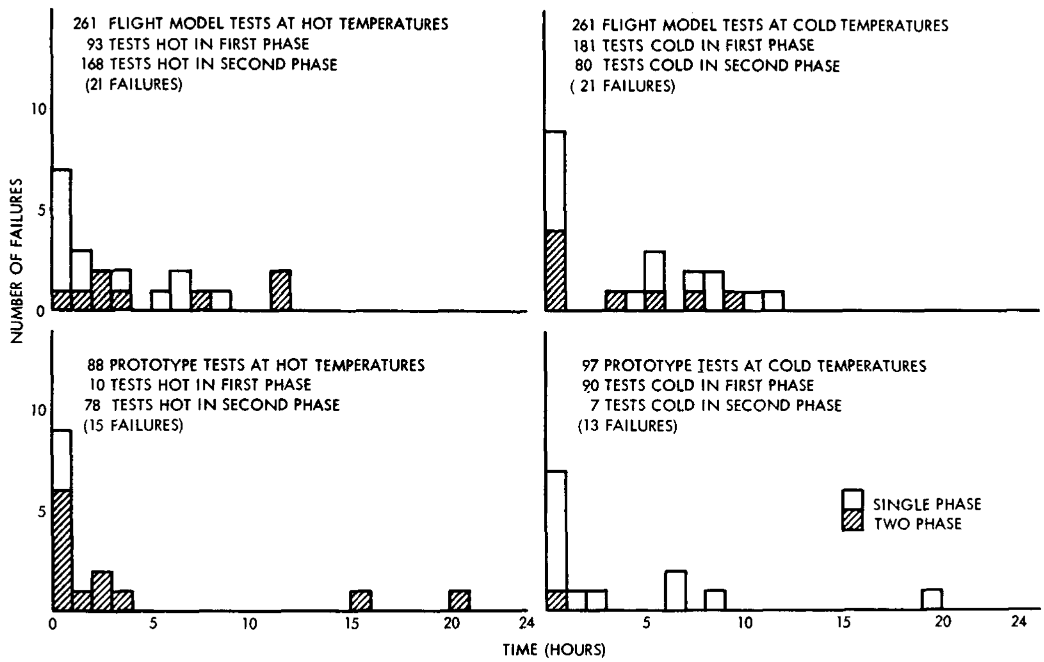

Figure 2–Distribution of malfunctions by time, temperature, model, and phase.

Also shown in Figure 2 is the distribution of single-phase and two-phase malfunctions. Recall that single-phase malfunctions occurred in the first thermal level to which the experiment was exposed. The two-phase malfunctions are those which had already successfully passed the first thermal level. These data are relevant to questions concerning the conduct of the test. Does one test sequence detect more problems than the other? Figure 2 does not give a direct answer, partly because of the disparity in sample size. An analysis of variance is used (refer to the Appendix, Analysis B5) to show that there is a significant interaction between temperature and phase. The data indicate that the hot-cold sequence produces more malfunctions than the reverse sequence.

Single-Phase and Two-Phase Malfunctions

The time distribution of single-phase malfunctions is given in Figure 3. Both the hot and cold graphs show a high initial incidence of malfunctions, and additional malfunctions as test time continues. These data, free from the bias of other thermal conditioning, show the need for spending sufficient time at a thermal level in order to detect some types of malfunctions.

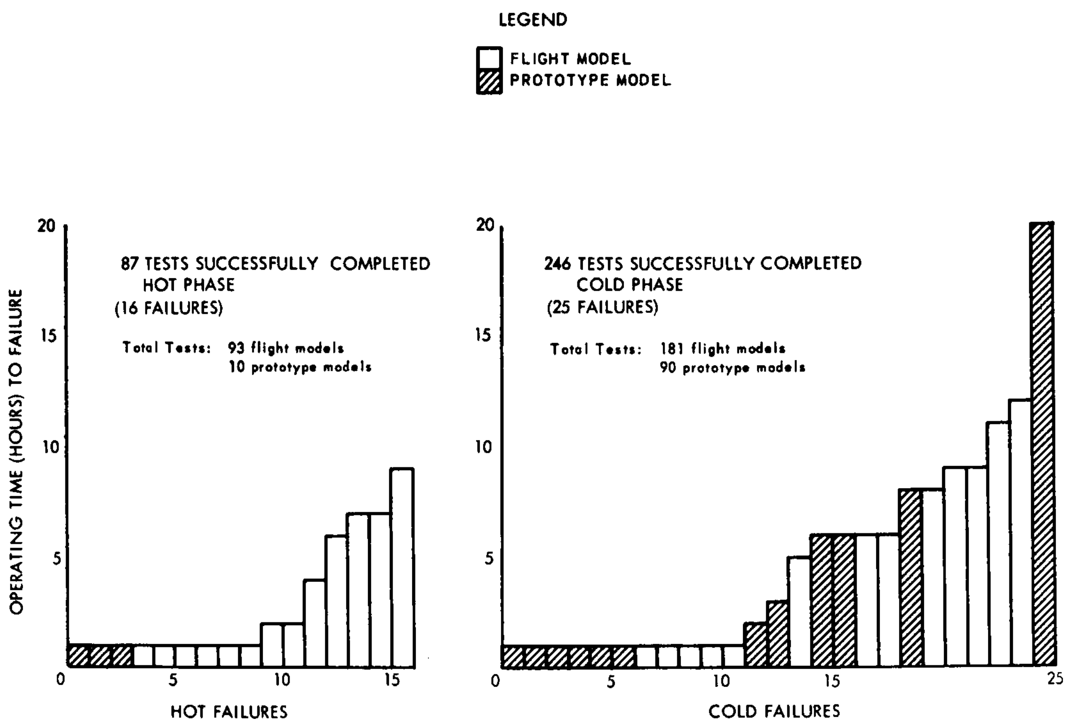

Figure 3–Operating time to failure for single phase tests.

The time distribution of two-phase malfunctions is given in Figure 4. These data also show the need for dwell time at a thermal level in order to detect some types of malfunctions.

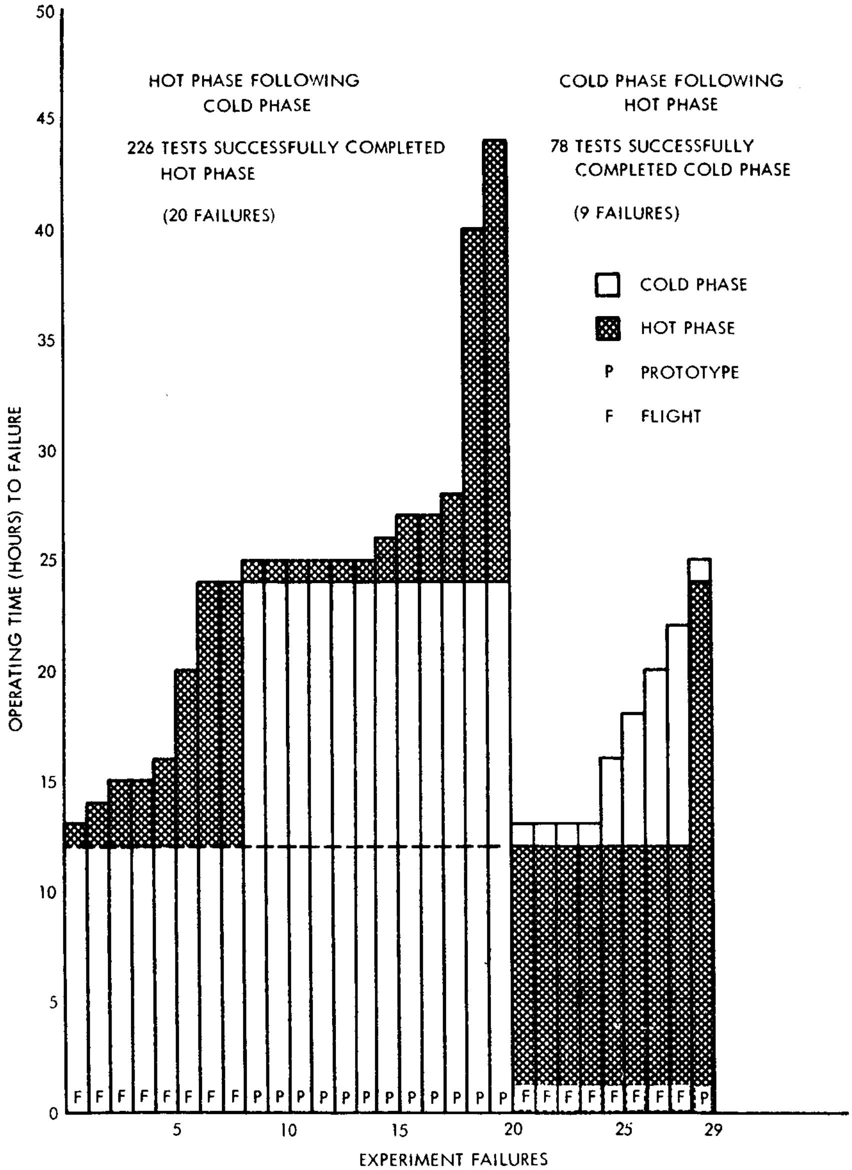

Figure 4–Operating time to failure for two phase tests.

Malfunctions by Individual Experiments

Since tests of many different experimenters were included in the data collected, a study of the individual experiment performances was made. Figure 5 summarizes the results. The number of tests conducted ranges from 26 for Experiment 4902 to 1 for Experiment 5011A, a new design of 5011. Flight model failures range from 5 to none, and prototype failures from 4 to none on the individual experiments. The large number of successful tests for individual experiments is explained by the use of multiple flight models and multiple parts (body, boom, sensor), which were tested separately. It should be noted that the performance depicted in Figure 5 does not include variations in experiment complexity. Table 1 summarizes experiment performance.

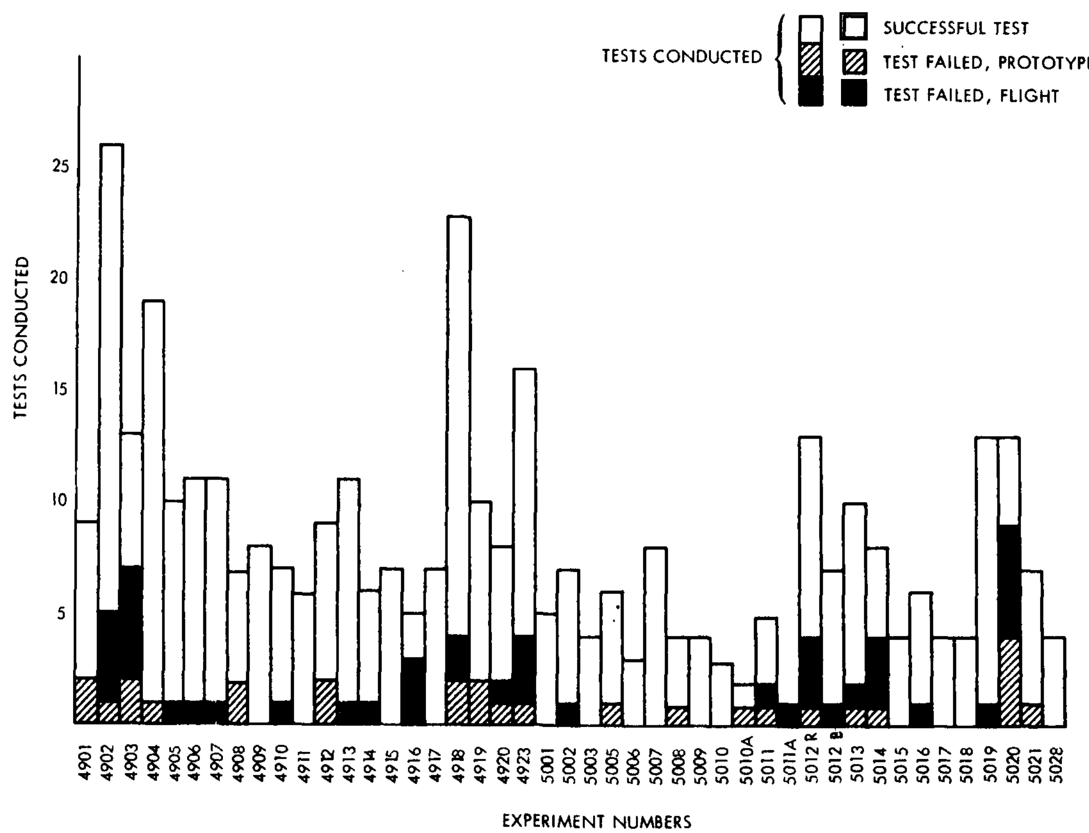

Figure 5–Summary of thermal-vacuum tests by experiment.

TABLE 1
Experiment Performance

Category	Percentage of experiments		
	All tests to June 1966	OGO A and B (4900 series)	OGO C and D (5000 series)
No failures	31	19	42
Failures only on prototype	20	24	17
Failures only on flight models	27	33	21
Failures on prototype and flight models	22	24	21

Experiment and Agency Performance on Flight Models

The experiments are classified as representing government agencies, universities, or other, and their percentage of satisfactory flight model test results are recorded in Figure 6. Of the 45 experiments, 25 were from government agencies, 16 were from universities, and 4 fell into neither of these categories. The average percentage of successes was between 80 and 87 percent for the three groups. Table 2 shows the percentage by agency of flight model tests in various performance ranges.

TABLE 2
Percentage of Successful Tests by Agency

Percentage of successes	Agency		
	Government (percent)	University (percent)	Other (percent)
100	40	69	50
70-99	44	25	25
40-69	8	6	25
0-40	8	0	0

Figure 6–Percentage of success of flight models per experiment.

The university figure (69 percent) for 100 percent successful experiments is noteworthy. The amount of testing of university experiments prior to arrival at GSFC was not determined.

Relationship of Test Time to Malfunctions

One of the vital questions with respect to thermal-vacuum tests of subsystems is "What test duration should be used?". To relate the available data to this question, the data were normalized to eliminate the effect of different sample sizes, and then used in such a way as to develop a continuous function. Figures 7 and 8, utilizing normalized data, show the relationship between malfunctions and test times for the OGO experiments. The presentation also provides a comparison of the effects of temperature and experiment model on the malfunctions versus time relationship.

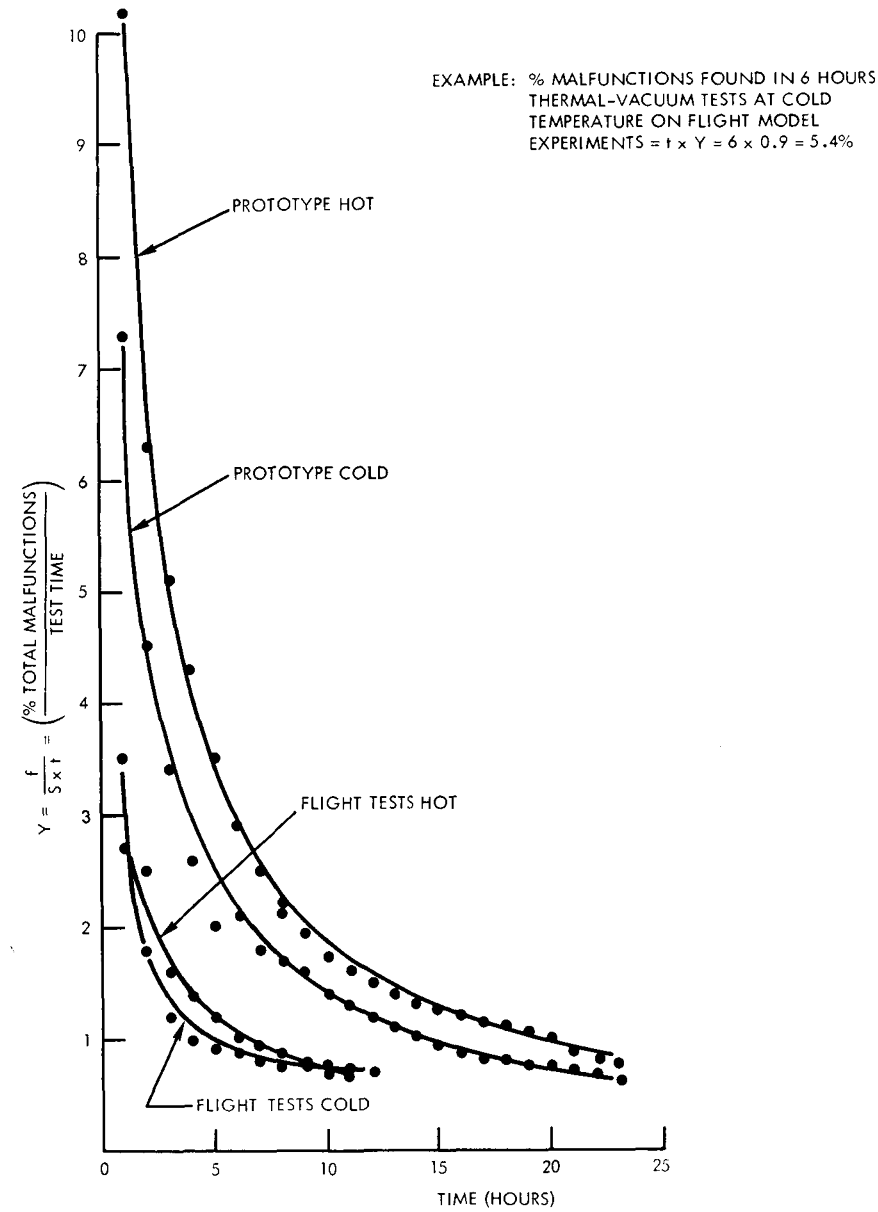

Figure 7–OGO experiment malfunctions with respect to time, temperature, and model.

In Figure 7, the ordinate used is $Y_i = f_i/(S_i)(t_i)$, where f_i is the cumulative number of failures at time t_i, S_i is the number of tests which had not failed at time $t_i - 1$, and t_i is the time the test has been running. The graph shows the following:

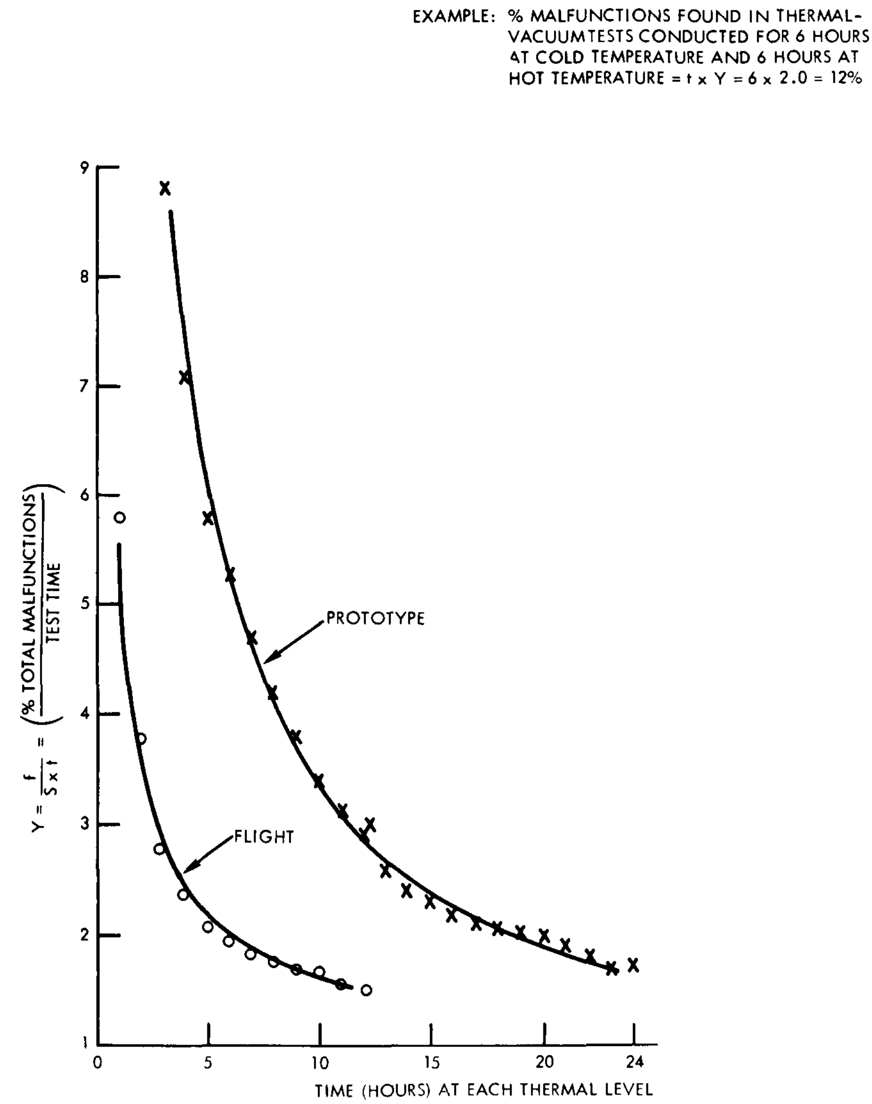

Figure 8—OGO experiment malfunctions with respect to time and model.

1. Prototype models consistently have a greater percentage of breakdown than flight models.

2. Prototype hot tests consistently have more breakdowns than prototype cold tests.

3. The distribution of hot and cold failures for flight models is quite similar.

4. The shape of the prototype hot and cold curves is quite similar.

A most useful relationship would be one which showed the relationship of test time (for both prototype and flight models) to the number of malfunctions. Here, test time is defined as the time at each thermal level. Thus, the effect of changing the present 12-hour (at each thermal level) flight test to an 8- or 16-hour test could be evaluated. Similarly, the effect of changing the prototype test time could be evaluated. The relationship of test time to malfunctions has been developed in Figure 8 for both prototype and flight models, and is premised on the similarity of the hot and cold curves in Figure 7.

In Figure 8, the ordinate Y_i is $f_i/S_i\ t_i$, where S_i is now the total number of tests (considering both phases as one test) which had not failed at time $t_i -1$. The curve can be used to obtain conservative estimates of the number of malfunctions which can be expected with different test times. For example, for a test time of 6 hours for flight experiments, 12 percent failures (or 12 failures per 100 tests) would be estimated (test time multiplied by ordinate value, or 6 times 2.0). Similarly, malfunction estimates for 8-, 10-, and 12-hour tests for flight model experiments would be 14, 16, and 18 percent. Caution is recommended for any extrapolation of these curves. For instance, extrapolating the flight model curve to 24 hours would indicate 28 percent malfunctions, whereas the bar graph data (Figure 2) could be used to predict 18 or 19 percent.

Attention is called to the use of f/s rather than $f/f+s$. The f/s was used because the tests which had failures were not continued for the full test time. This results in overstating the percentage of failures. For instance, Figure 8 would indicate 38 percent failures for 24-hour prototype tests, whereas Figure 2 data would indicate about 30 percent.

ANALYSIS OF DATA

The raw and developed data in Figures 1 through 8 indicate the effect of model, temperature, phase, time, experimenters, observatories, and years on the number of malfunctions detected in simulated space tests. In several cases, the effect is somewhat uncertain, especially when clouded by unequal sample sizes. Additional confidence in the interpretation of the data would be gained if there were some means of showing that the effects could or could not be ascribed to chance.

Statistical techniques were applied to the data to determine if the observed differences between models, phases, years, observatories, experimenters, and temperature levels were significant, or if these differences could possibly be expected even if the above factors contributed equally to test failures.

The model for the analysis of variance method used in most of the analyses is described in Part A of the Appendix. This method is used to adjust variation in sample sizes by weighting the observed failures.

Analysis of Model and Temperature Effects

In the analysis of models versus temperature effects (see Appendix, Analysis B1), the interaction between model and temperature effects was significant; therefore, two additional analyses were conducted – one of prototype versus flight model, and the other of hot versus cold failures (see Appendix, Analysis B2). The conclusion was that, while the difference between percentage of successes for prototype and flight models was significant, the difference between hot and cold temperature failures was not. This is not a surprising conclusion from the observed data.

Prototype and flight model tests differ essentially in two respects – duration of test, and temperature levels. An attempt to eliminate any differences arising from duration of test was made in Table A7, which does not include prototype failures occurring after 12 hours in either phase. However, the analysis still shows a significant model effect and no significant temperature effect (see Appendix, Analysis B3).

Analysis of Temperature, Phase, and Model Effects

An analysis of temperature, model, and phase effects was made, but no significant differences were observed at the 5 percent level (see Appendix, Analysis B4). However, some sample sizes included in this analysis were as small as 7 tests, and the failures in the categories were not weighted in the manner used earlier, but were recorded as percentages. At the 10 percent level, model, temperature, phase, and temperature-phase interaction are significant.

The significant temperature effect, which appeared only when phase was considered, led to the analysis of temperature versus phase effects, disregarding model (see Appendix, Analysis B5). The data for this analysis, found in Table A-14, shows almost twice as many hot failures in single-phase as in two-phase, and about the same percentage of cold failures in both phases. The analysis, using weights, shows a significant temperature-phase interaction. Examination of the data with reference to the analysis shows that a test sequence of hot-then-cold produces the greatest percentage of failures.

Analysis of Year Effects

An increased percentage of successful tests from year to year might be expected. From examining the data (see Appendix, Analysis B6), no significant year-to-year effects were observed. One explanation for lack of improvement in performance might be new experiments which have been designed and tested. However, the data show that the number of prototype tests in 1965 was reduced to 16, compared to 39 for 1964.

Analysis of Observatory Effects

An analysis of failures by observatories A, B, and C shows no significant difference in the experiment malfunctions when classified by observatories (see Appendix, Analysis B7).

Analysis of Experimenter Effects

Differences in performance among experimenters are examined in the Appendix, Analysis B8. Successful tests by experimenters range from 31 percent to 100 percent. The data indicate a significant difference between experimenters.

CONCLUSIONS

1. There is a statistically significant difference between percentage of prototype failures and percentage of flight model failures.

2. The distribution of prototype model failures by test time is consistently higher than the distribution of flight model failures.

3. The use of equal test times at the high and low thermal levels is justified.

4. The hot-cold temperature sequence of testing produces a greater percentage of failures than the cold-hot sequence.

5. The distribution of failures with respect to time has exponential characteristics. The data are not sufficient to define an exponential relationship.

6. There are at least two failure modes evident – initial failures at the beginning of each phase and failures which require time at the thermal level to produce the failure.

7. There has been no improvement in percentage of satisfactory tests from 1963 to 1966.

8. There is not a significant difference among observatory test results.

9. There is a significant difference among the performances of individual experimenters.

10. An improvement in evaluation of results could be made if failure analysis information were available. This would permit segregation of environmentally induced failures from failures caused by other factors.

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2. Rao, C. R., "Advanced Statistical Methods in Biometric Research," J. Wiley and Sons, pp. 94-103, 1962.

Appendix

ANALYSIS OF DATA

ANALYSIS OF VARIANCE

A. Methods

Three variations of the analysis of variance were used. These can be identified as:

1. Two-factor analysis, each factor at two or more levels, with unequal numbers of observations for each category.

2. One-factor analysis with the factor at many levels.

3. Three-factor analysis with each factor at two levels.

Methods No. 2 and 3 are conventional and will not be outlined here. Method No. 1 is used in order to remove the bias associated with unequal sample sizes. This method is described fully in Reference 2 and is outlined below for ready reference.

a. Description of problem: Two factors, A and B, are to be compared at two levels (for example, Factor A might be models at prototype and flight levels; factor B might be temperature at levels 1 and 2), where the numbers of observations in each category are not equal.

b. Data:

Table A1

	Factor B		
	Level 1	Level 2	Level
Factor A Level 1	X_{11} (n_{11})	X_{12} (n_{12})	$X_{1.}$ $(n_{1.})$
Level 2	X_{21} (n_{21})	X_{22} (n_{22})	$X_{2.}$ $(n_{2.})$
Total	$X_{.1}$ $(n_{.1})$	$X_{.2}$ $(n_{.2})$	$X_{..}$ $(n_{..})$

x_{ij} is the number of failures in the category of the i^{th} level of Factor A and the j^{th} level of Factor B.

n_{ij} is the number of tests in the category of the i^{th} level of A and the j^{th} level of B.

$X_{.1}$ = Sum of all failures at level 1 of Factor B $(X_{11} + X_{21})$.

$(n_{.1}) = n_{11} + n_{21}$

n = Total number of observations

$X_{..}$ = Total number of failures

c. Computations:

(1) Percentage failures for each category:

Table A2

	Factor B		
Factor A	$\frac{X_{11}}{n_{11}} = \bar{X}_{11}$	$\frac{X_{12}}{n_{12}} = \bar{X}_{12}$	$\frac{X_{1.}}{n_{1.}} = \bar{X}_{1.}$
	$\frac{X_{21}}{n_{21}} = \bar{X}_{21}$	$\frac{X_{22}}{n_{22}} = \bar{X}_{22}$	$\frac{X_{2.}}{n_{2.}} = \bar{X}_{2.}$
	$\frac{X_{.1}}{n_{.1}} = \bar{X}_{.1}$	$\frac{X_{.2}}{n_{.2}} = \bar{X}_{.2}$	$\frac{X_{..}}{n} = \bar{X}_{..}$

(2) Weights:

$$w_1 = \frac{n_{11} \times n_{21}}{n_{.1}} ; \quad w_2 = \frac{n_{12} \times n_{22}}{n_{.2}} .$$

(3) Difference between A levels:

$$d_1 = \bar{X}_{11} - \bar{X}_{21} ; \quad d_2 = \bar{X}_{12} - \bar{X} - \bar{X}_{22} .$$

(4) Sum of squares:

(a) Interaction:

$$w_1 d_1^2 + w_2 d_2^2 - \frac{(w_1 d_1 + w_2 d_2)^2}{w_1 + w_2} .$$

(b) Between B ignoring A:

$$(X_{.1}) (\bar{X}_{.1}) + (X_{.2}) (\bar{X}_{.2}) - (X_{..}) (\bar{X}_{..}).$$

(c) Between A ignoring B:

$$(X_{1.}) (\bar{X}_{1.}) + (X_{2.}) (\bar{X}_{2.}) - (X_{..}) (\bar{X}_{..}) .$$

(d) Between cells:

$$(X_{11}) (\bar{X}_{11}) + (X_{12}) (\bar{X}_{12}) + (X_{21}) (\bar{X}_{21})$$

$$+ (X_{22}) (\bar{X}_{22}) - (X_{..}) (\bar{X}_{..}) .$$

(e) Between A classes:

$$(d) - (b) - (a)$$

(f) Between B classes:

$$(d) - (c) - (a)$$

(g) Total:

$$\frac{X_{11}^2}{n_{11}} + \frac{X_{12}^2}{n_{12}} + \frac{X_{21}^2}{n_{21}} + \frac{X_{22}^2}{n_{22}} - \frac{X_{..}^2}{(n)(2)(2)}$$

(h) Within cells:

$$(g) - (d).$$

NOTE: This method may be extended to cover p cases of Factor B. This was utilized in the analysis of observatory and year results.

d. Table derived from computations:

Table A3

Source of variation	Sums of squares	Degrees of freedom	Mean square	F
A	(e)	1	(e)/1 = (j)	$\frac{(j)}{x}$
B	(f)	p-1	(f)/p-1 = (k)	$\frac{(k)}{x}$
Interaction AxB	(a)	p-1	(a)/p-1 = (ℓ)	$\frac{(\ell)}{(m)}$
Within cells	(h)	n-2p	(h)/n-2p = (m)	
Total	(g)	n-1		

The larger of (ℓ) and (m), indicated by an "X" in the table, is used as the denominator for the F ratio.

The calculated F value for (y, z) degrees of freedom is compared to the 5 percent critical point for the F distribution unless otherwise indicated.

If the interaction term was significant, a one-way analysis of variance analyzing different levels of the same factor was used.

B. Analyses

1. Analysis of variance (Method 1) for four model-temperature categories.

a. Model versus temperature data:

Table A4

Model	Temperature		Total
	Hot	Cold	
Prototype	15* / (88)*	13 / (97)	28 / (185)
Flight	21 / (261)	21 / (261)	42 / (522)
Total	36 / (349)	34 / (358)	70 / (707)

*Numerator = failures.
Denominator ≑ total tests or phases.

b. Computations:

(1)

Table A5

Model	Temperature		Total
	Hot	Cold	
Prototype	0.170	0.135	0.152
Flight	0.082	0.082	0.082
Total	0.104	0.097	0.100
d_i	0.089	0.053	
w_i	65.55	69.81	135.36
$w_i\ d_i$	5.82	3.73	9.55
$w_i\ d_i^2$	0.52	0.20	0.715

(2) Sums of squares:

(a) Interaction:

$$(0.715) - \frac{(9.55)^2}{135.36} = 0.042.$$

(b) Between temperature, ignoring model:

$$36\ (0.104) + 34\ (0.097) - 70\ (0.1) = 0.011.$$

(c) Between models, ignoring temperature:

$$28\ (0.152) + 42\ (0.082) - 70\ (0.1) = 0.673.$$

(d) Between cells:

$$15\ (0.170) + 21\ (0.082) + 13\ (0.135) + 21\ (0.082)$$

$$- 70\ (0.1) = 0.727.$$

(e) Between models:

$$0.727 - 0.042 - 0.011 = 0.674.$$

(f) Between temperatures:

$$0.727 - 0.673 - 0.042 = 0.012.$$

(g) Total:

$$(0.170)\ (15) + (0.135)\ (13) + (0.082)\ (21) + (0.082)\ (21)$$

$$- \frac{70\ (0.1)}{4} = 5.99.$$

(h) Within cells:

$$5.99 - 0.727 = 5.27.$$

c. Summary of Analysis B1:

Table A6

Source of variation	Sums of squares	d.f.	Mean squares	F	5% point
Model	0.673	1	0.673	15.94	161
Thermal level	0.012	1	0.012	0.277	161
Interaction	0.042	1	0.042	5.56	3.84
Within cells	5.27	703	0.008		

d. Conclusions: There is no reason to conclude there is a difference between model levels or thermal levels. However, since the interaction term is significant, a one-way analysis should be performed.

2. Analysis of variance (Method 2) for model and temperature categories.

a. Between model levels:

(1) Between models sum of squares:

$$\frac{28^2}{185} + \frac{42^2}{522} - \frac{70^2}{707} = 0.669.$$

(2) Total sum of squares:

$$70 - \frac{70^2}{707} = 62.97.$$

(3) Residual:

$$62.97 - 0.669 = 62.30.$$

(4) Residual mean squares:

$$\frac{62.30}{705} = 0.0896.$$

(5) $F_{(1,705)} = \frac{0.669}{0.0896} = 7.46;\ F_{(1,\infty)} = 3.84$ (95 percent level).

Conclusion: There is a significant difference between flight model percentage of failures and prototype percentage of failures.

b. Between temperature levels:

(1) Total sum of squares: 62.97.

(2) Between temperature sum of squares:

$$\frac{36^2}{349} + \frac{34^2}{358} - \frac{70^2}{707} = 0.010.$$

(3) Residual:

62.96.

(4) $F_{(1,705)} = \frac{0.01}{62.96/705} = 0.112;\ F_{(1,\infty)} = 3.84$ (95 percent level).

Conclusion: There is no reason to conclude there is a difference between hot and cold thermal effects.

3. Analysis of variance (Method 2) for model and temperature categories, excluding prototype failures occurring after 12 hours. This was an attempt to eliminate any bias induced because of different test times for prototype and flight model tests.

a. Data for analysis:

Table A7

Model	Temperature		Total
	Hot	Cold	
Prototype	13* / (88)*	12 / (97)	25 / (185)
Flight	21 / (261)	21 / (261)	42 / (522)
Total	34 / (349)	33 / (358)	67 / (707)

*Numerator = failures.
Denominator = tests conducted.

b. Calculations:

(1) Total sum of squares:

$$67 - \frac{67^2}{707} = 60.54.$$

(2) Sum of squares between models:

$$\frac{25^2}{185} + \frac{42^2}{522} - \frac{67^2}{707} = 0.426.$$

(3) Residual: 60.114.

(4) 4. $F_{(1,705)}$ $\frac{0.42594}{60.114/705} = 4.91$; $F_{(1,\infty)} = 3.84$ (95 percent level).

(5) Sum of squares between temperatures:

$$\frac{34^2}{349} + \frac{33^2}{358} - \frac{67^2}{707} = 0.00502.$$

(6) Residual sum of squares: 60.53

(7) 7. Residual mean squares: 0.08735.

(8) 8. F = 0.05746.

Conclusion: After eliminating prototype failures occurring after 12 hours, there is reason to indicate a significant difference between prototype and flight models.

4. Analysis of variance (Method 3) for eight model-temperature-phase categories.

a. Temperature, model, and phase data:

Table A8

Model	Temperature			
	Hot		Cold	
	First phase	Second phase	First phase	Second phase
Prototype	$\frac{3^*}{(10)}$	$\frac{12}{(78)}$	$\frac{12}{(90)}$	$\frac{1}{(7)}$
Flight	$\frac{13}{(93)}$	$\frac{8}{(168)}$	$\frac{13}{(179)}$	$\frac{8}{(80)}$

*Numerator = failures.
Denominator = tests conducted.

In the three factor case, percentage of failures for each category was used to help eliminate bias. Three two-way analyses were conducted and combined.

b. Computations:

(1)

Table A9

Model	Temperature			
	Hot		Cold	
	First phase	Second phase	First phase	Second phase
Prototype	.300	.158	.136	.125
Flight	.141	.048	.073	.101

Total sum of Squares:

$$(0.300)^2 + (0.141)^2 + (0.158)^2 + (0.048)^2 + (0.136)^2 + (0.073)^2$$
$$+ (0.125)^2 + (0.101)^2 - \frac{1.082^2}{8} = 0.04043.$$

(2) Model vs. temperature:

Table A10

Model	Temperature		Total
	Hot	Cold	
Prototype	0.458	0.261	0.719
Flight	0.189	0.174	0.363
Total	0.647	0.435	1.082

(a) Total sum of squares:

$$1/2\ [(0.458)^2 + (0.261)^2 + (0.189)^2 + (0.174)^2] - \frac{(1.082)^2}{8} = 0.02559.$$

(b) Model:

$$1/4\ [0.719^2 + 0.363^2] - \frac{1.082^2}{8} = 0.0158.$$

(c) Temperature:

$$1/4\ [0.647^2 + 0.435^2] - \frac{1.082^2}{2} = 0.0056.$$

(d) Model X temperature interaction:

$$0.02559 - 0.0158 - 0.0056 = 0.00419.$$

(3) Model vs phase:

Table A11

Model	Phase		Total
	First	Second	
Prototype	0.436	0.283	0.719
Flight	0.214	0.149	0.363
Total	0.650	0.432	1.082

(a) Total sum of squares:

$$1/2\ [0.436^2 + 0.283^2 + 0.214^2 + 0.149^2] - \frac{1.082^2}{8} = 0.02274.$$

(b) Model: 0.0158

(c) Phase:

$$1/4\ [(0.650)^2 + (0.432)^2] - \frac{1.082^2}{8} = 0.00594.$$

(d) Model X phase interaction:

$$0.02274 - 0.0158 - 0.00594 = 0.001.$$

(4) Temperature vs phase:

Table A12

Phase	Temperature		Total
	Hot	Cold	
First	0.441	0.209	0.650
Second	0.206	0.226	0.432
Total	0.647	0.435	1.082

(a) Total sum of squares:

$$1/2\ [0.441^2 + 0.205^2 + 0.209^2 + 0.226^2] - \frac{1.082^2}{8} = 0.0193.$$

(b) Temperature: 0.0056.

(c) Phase: 0.00594.

(d) Temperature × phase interaction:

$$0.0193 - 0.0056 - 0.00594 = 0.00776.$$

Table A13
Summary of the Three Two-Way Analyses

Source of variation	Sum of squares	d.f.	Mean square	F	5% point	10% point
Model	0.0158	1	0.0158	112.8	161	39.8
Temperature	0.0056	1	0.0056	40	161	39.8
Phase	0.00594	1	0.00594	42	161	39.8
M × T	0.00419	1	0.00419	29	161	39.8
M × T	0.001	1	0.001	7	161	39.8
T × P	0.00776	1	0.00776	55	161	39.8
Residual	0.00014	1	0.00014			
Total	0.04043	7				

Conclusions: When phase and temperature are considered along with model, the different effects are not significant at the 5 percent level, but model, temperature, phase, and temperature-phase interaction are significant at the 10 percent point.

5. Analysis of variance (Method 1) of four phase-temperature categories.

a. Phase vs. Temperature Data:

Table A14

Temperature	Phase		Total
	First	Second	
Hot	16 / (103)	20 / (246)	36 / (349)
Cold	25 / (271)	9 / (87)	34 / (358)
Total	41 / (374)	29 / (333)	70 / (707)

b. Calculations:

(1)

Table A15

Model	Phase		Total
	First	Second	
Hot	0.155	0.081	0.103
Cold	0.092	0.103	0.095
Total	0.110	0.087	0.099
d_i	0.063	-0.022	0.041
w_i	74.6	64.3	64.3
$d_i w_i$	4.7	-1.41	3.29
$d_i^2 w_i$	0.30	0.03	0.33

(2) Sum of squares:

(a) Interaction:

$$0.33 - \frac{(3.29)^2}{64.3} = 0.16.$$

(b) Temperature ignoring phase:

$$(0.103)\ (36) + (0.095)\ (34) - (0.099)\ (70) = 0.008.$$

(c) Phase ignoring temperature:

$$(0.11)\ (41) + (0.087)\ (29) - (0.099)\ (70) = 0.103.$$

(d) Between cells:

$$(0.155)\ (16) + (0.081)\ (20) + (0.092)\ (25) + 9\ (0.103) - (0.099)\ (70) = 0.397.$$

(e) Temperature:

$$0.397 - 0.103 - 0.16 = 0.134.$$

(f) Phase:

$$0.397 - 0.008 - 0.16 = 0.229.$$

(g) Total:

$$(0.155)\ (16) + (0.081)\ (20) + (0.092)\ (25) + 9\ (0.103) - \frac{(70)^2}{(707)\ (4)} = 5.59.$$

(h) Within Cells: 5.19.

c. Summary of Analysis B5;

Table A16

Source of variation	Sums of squares	d.f.	Mean squares	F	5% point
Phase	0.229	1	0.229	1.43	161
Temperature	0.134	1	0.134	0.84	161
Interaction	0.16	1	0.16	22.85	3.84
Within Cells	5.19	703	0.007		
Total	5.713	706			

<u>Conclusions:</u> There is no reason to believe that either temperature or phase differences contribute significantly to test results. However, the interaction term is significant.

6. Analysis of variance (Method 1) for eight model-year categories.

a. Model versus year data:

Table A17

Model	Fiscal Year			
	63	64	65	66
Prototype	13 / (38)	9 / (39)	4 / (16)	2 / (7)
Flight	2 / (14)	15 / (97)	17 / (123)	8 / (40)

b. Computations:

(1)

Table A18

	63	64	65	66	Total
Prototype	0.351	0.237	0.250	0.286	0.286
Flight	0.143	0.158	0.141	0.200	0.156
Total	0.294	0.180	0.154	0.213	0.191
d_i	0.208	0.079	0.109	0.086	0.482
w_i	10.157	27.143	14.12	5.96	57.375
$d_i\, w_i$	2.118	2.128	1.55	0.511	6.307
$d_i^2\, w_i$	0.442	0.167	0.170	0.044	0.822

(2) Sum of squares:

(a) Interaction:

$$0.822 - \frac{(6.307)^2}{57.375} = 0.12901.$$

(b) Between dates ignoring model:

$$15\ (0.294) + 24\ (0.180) + 21\ (0.154) + 10\ (0.213) - 70\ (0.191) = 5.082.$$

(c) Total between cells:

$$13\ (0.351) + 9\ (0.237) + 4\ (0.25) + 2\ (0.286) + 2\ (0.143) +$$

$$15\ (0.158) + 17\ (0.141) + 8\ (0.20) - 70\ (0.191) = 5.895.$$

(d) Between models:

$$5.895 - 5.082 - 0.129 = 0.684.$$

(e) Between dates ignoring temperature:

$$28\ (0.286) + 42\ (0.156) - 70\ (0.191) = 5.525.$$

(f) Between dates:

$$5.895 - 5.525 - 0.1290 = 0.240.$$

(g) Total:

$$13\ (0.351) + 9\ (0.237) + 4\ (0.25) + 2\ (0.286) + 2\ (0.143) +$$

$$15\ (0.158) + 17\ (0.141) + 8\ (0.20) - \frac{70^2}{374\ (8)} = 13.26.$$

(h) Within cells:

$$13.26 - 5.89 = 7.37.$$

c. Summary of Analysis B6:

Table A19

Source of variation	Sum of squares	d.f.	Mean square	F	5% point
Model	0.64	1	0.684	15.9	10.13
Year	0.240	3	0.0802	0.037	9.28
Interaction	0.129	3	0.043	2.15	2.60
Within cells	7.37	366	0.0204		

Conclusions: The interaction and the effect of date on percentage of failures are not significant. There is a significant difference between prototype and flight models.

7. Analysis of variance of malfunctions found in thermal-vacuum tests of the experiments.

a. Model versus observatory data:

Table A20

Model	Observatory			Total
	A	B	C	
Prototype	14* / (55)	2 / (5)	11 / (38)	27 / (98)
Flight	17 / (116)	7 / (53)	13 / (87)	37 / (256)
Total	31 / (171)	9 / (58)	24 / (125)	64 / (354)

*Numerator = tests failed.
Denominator = tests conducted.

b. Computations:

(1)

Table A21

Model	Observatory			Total
	A	B	C	
Prototype	0.255	0.400	0.289	0.275
Flight	0.147	0.132	0.149	0.144
Total	0.181	0.155	0.192	0.181
d_i	0.108	0.268	0.140	0.131
w_i	37	4.56	26.45	68
$d_i w_i$	4.0	1.22	3.7	8.92
$d_i^2 w_i$	0.431	0.328	0.52	1.28

(2) Sums of squares:

(a) Interaction:

$$(1.28)^2 - \frac{(8.92)^2}{68} = 0.1099.$$

(b) Between observatories ignoring models:

$$31\ (0.181) + 9\ (0.155) + 24\ (0.192) - 64\ (0.181) = 0.03.$$

(c) Between models ignoring observatories:

$$27\ (0.275) + 37\ (0.144) - 64\ (0.181) = 1.16.$$

(d) Between cells:

$$14\ (0.255) + 2\ (0.4) + 11\ (0.289) + 17\ (0.147) + 7\ (0.132)$$

$$+ 13\ (0.149) - 64\ (0.181) = 1.32.$$

(e) Between models:

$$1.32 - 0.1099 - 0.03 = 1.18.$$

(f) Between observatories:

$$1.32 - 0.1099 - 1.16 = 0.05.$$

(g) Total:

$$12.90 - 1.446 = 11.45.$$

(h) Within cells:

$$11.45 - 0.1099 = 11.34.$$

c. Summary of Analysis B7:

Table A22

Source of variation	Sum of squares	d.f.	Mean square	F	5% point
Model	1.18	1	1.18	21.49	18.51
Observatory	0.05	2	0.025	0.456	19.00
Interaction	0.110	2	0.055	1.69	3.0
Within cells	11.34	348	0.032		
Total	11.45	353			

Conclusions: There is a significant difference between prototype and flight models.

There is no significant interaction.

There is no reason to believe that there is a difference in the experiment malfunctions when classified by observatories.

8. Analysis of variance (Method 2) among 45 experimenters.

a. Data:

Data for this analysis are in Table A23.

(1) Notation:

O_i: observed number of failures for the i^{th} experimenter.

m_i: total number of tests by the i^{th} experimenter
$i = 1, 2, \ldots, 45$

(2) Observed number of failures: $\Sigma O_i = 70$

(3) Total number of tests: $\Sigma m_i = 374$

$$\Sigma \frac{O_i^2}{m_i} = 24.53.$$

b. Calculations:

(1) Total sums of squares:

$$70 - \frac{(70)^2}{374} = 58.57$$

(2) Among experimenters:

$$24.53 - \frac{(70)^2}{374} = 11.43$$

(3) Residual:

$$58.57 - 11.43 = 47.14$$

(4) $$F_{(44,\ 329)} = \frac{\frac{11.43}{44}}{\frac{47.14}{329}} = 1.81.$$

(5) 5 percent point is 1.39.

Conclusion: There is a significant difference in percentage of failures among experimenters.

Table A23
Summary of Tests by Experimenter and Model

Experiment number	Raw data							Percent successful		Data for analysis of variance		
	Experimenter			Flight tests		Proto. tests		Flight	Proto-type	Tests (m_i)	Failed (O_i)	$\frac{O_i^2}{m_i}$
	Name	Agency	Code	Total	Unsat.	Total	Unsat.					
4901	Anderson	Calif.	U	5	0	4	2	100	50	9	2	0.444
4902	Wolfe (Bader)	Ames R.C.	G	21	4	5	1	81	80	26	5	0.96
4903	Bridge	MIT	U	9	5	4	2	44	50	13	7	3.769
4904	Cline	GSFC	G	14	0	5	1	100	80	19	1	0.053
4905	Konradi (Davis)	GSFC	G	8	1	2	0	88	100	10	1	0.1
4906	MacDonald, Evans, Davis	GSFC	G	9	1	2	0	89	100	11	1	0.091
4907	Simpson	Chicago	U	9	1	2	0	89	100	11	1	0.091
4908	Van Allen	S. U. Iowa	U	3	0	4	2	100	50	7	2	0.571
4909	Winkler	Minn.	U	6	0	2	0	100	0	8	0	0
4910	Smith	JPL	O	6	1	1	0	83	100	7	1	0.14
4911	Heppner	GSFC	G	5	0	1	0	100	100	6	0	0
4912	Sagalyn	AF CRL	G	6	0	3	2	100	34	9	2	0.444
4913	Whipple	GSFC	G	9	1	2	0	89	100	11	1	0.091
4914	Hargreaves	NBS	G	4	1	2	0	75	100	6	1	0.167
4915	Taylor	GSFC	G	5	0	2	0	100	100	7	0	0
4916	Alexander	GSFC	G	5	3	0	0	40	100	5	3	1.8
4917	Helliwell	Stanford	U	6	0	1	0	100	100	7	0	0
4918	Haddock	Michigan	U	14	2	9	2	86	78	23	4	0.695
4919	Mange	NRL	G	6	0	4	2	100	50	10	2	0.4
4920	Wolff	GSFC	G	7	1	1	1	86	0	8	2	0.5
4923	Kronmiller	GSFC	G	12	3	4	1	75	75	16	4	1.0
5001	Haddock	Michigan	U	3	0	2	0	100	100	5	0	0
5002	Helliwell	Stanford	U	5	1	2	0	80	100	7	1	0.143
5003	Morgan	Dartmouth	U	4	0	0	0	100	100	4	0	0
5005	Smith	JPL	O	4	0	2	1	100	50	6	1	0.167
5006	Heppner	GSFC	G	2	0	1	0	100	100	3	0	0

Table A23
Summary of Tests by Experimenter and Model (Continued)

Experiment number	Raw Data							Percent successful		Data for analysis of variance		
	Experimenter			Flight tests		Proto. tests		Flight	Prototype	Tests (m_i)	Failed (O_i)	$\frac{O_i^2}{m_i}$
	Name	Agency	Code	Total	Unsat.	Total	Unsat.					
5007	Anderson	JPL	O	7	0	1	0	100	100	8	0	0
5008	Simpson	Chicago	U	3	0	1	1	100	0	4	1	0.25
5009	Webber	Minn.	U	3	0	1	0	100	100	4	0	0
5010	Van Allen	S. U. Iowa	U	2	0	1	0	100	100	3	0	0
5010A	Van Allen and Krimigis	S. U. Iowa	U	0	0	2	1	100	50	2	1	0.5
5011	Hoffman	GSFC	G	3	1	2	1	66	55	5	2	0.8
5011A	Hoffman	GSFC	G	1	1	0	0	0	100	1	1	1.0
5012	Reed (Body Unit)	GSFC	G	10	3	3	1	70	67	13	4	1.2
5012	Blamont – OPEP Unit	U. Paris	U	4	1	3	0	75	100	7	1	0.14
5013	Mange	NRL	G	8	1	2	1	88	50	10	2	0.4
5014	Barth	JPL	O	6	3	2	1	50	50	8	4	2.0
5015	Leite	Michigan	U	4	0	0	0	100	100	4	0	0
5016	Taylor	GSFC	G	5	1	1	-	80	100	6	1	0.17
5017	Newton	GSFC	G	2	0	2	0	100	100	4	0	0
5018	Nilsson	GSFC	G	4	0	0	0	100	100	4	0	0
	(Alexander)	GSFC	G									
5019	Bourdeau	GSFC	G	7	1	6	0	86	100	13	1	0.077
5020	Hinteregger	AFCRL	G	8	5	5	4	37	20	13	9	6.23
5021	Kreplin	NRL	G	6	0	1	1	100	0	7	1	0.143
5028	Block	GSFC	G	4	0	0	0	100	100	4	0	0
Total	45			274	42	100	28	85	72	374	70	24.53

Code: U – University
G – Government
O – Other
( ) – Name in parentheses qas formerly associated with the experiment.