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ANALYSES OF FLIGHT MODEL SPACECRAFT PERFORMANCE DURING THERMAL-VACUUM TESTS

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Test and Evaluation Division

November 1972

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DURING THERMAL-VACUUM TESTS

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FOREWORD

A natural question which will arise after the results of the present study have been examined is: "What was the space performance of these spacecraft?" An indication of the space performance is given in the following data on the 39 spacecraft included in the present study:

1. There were three mission failures, one of which was related to the vacuum environment.

2. There were no mission failures on twenty of the spacecraft which were in-house (GSFC) tested spacecraft.

3. At the black box level, the number of first day failures (45) was higher than expected. For days 2-30, the number of failures (34) was lower than estimated from an extrapolation of the thermal-vacuum test data developed in this report.

Detailed information on first day space performance is given in NASA Technical Note TN-D-6474[1]. Additional information which covers the first month space performance will be in a forthcoming report.

[1] "A Study of First-Day Space Malfunctions" by A. R. Timmins and R. E. Heuser. NASA TN-D-6474, Sept. 1971.

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ABSTRACT

Malfunction data from the thermal-vacuum tests of 39 flight-model spacecraft have been analyzed. The results are interpreted in terms of the test variables, and in terms of the spacecraft performance. The malfunction data are correlated with the test time as a single variable, and also with the composite variable of time plus temperature. The improvement in spacecraft performance is examined by means of malfunction rates, malfunctions per spacecraft, and the probability of no failure related to test time. The minimum thermal-vacuum test profile required for Goddard Space Flight Center Spacecraft is verified, and the probability of a defect remaining undetected is estimated.

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INTRODUCTION

In 1968 a study of the thermal-vacuum test results from 11 flight model spacecraft was published in NASA Technical Note TN D-4908[1]. A major interest then was the relationship of malfunctions to their times of occurrence in test. From that study conclusions were drawn with respect to the length of time required for an adequate thermal-vacuum test of flight model spacecraft. A serious limitation on the study was the small amount of documented data available. The purpose of the present report is to update and to extend the findings of that study. The test results of 39 spacecraft, compared with the test results of 11 spacecraft used in the earlier study, now provide a better basis for the analysis. The new data were developed for analysis in the same manner as for the 1968 report, in order to facilitate comparison of the two studies. However, the larger data base made additional types of analyses worthwhile, and the present results are a significant extension of the earlier work.

DATA BASE

The available data base comprised 39 flight model spacecraft with some 600 thermal-vacuum test days. Table 1 summarizes the data base and includes comparative data from the 1968 study[1]. The larger data base is highly desirable, but it must also be relevant. The combining of data from observatory type spacecraft with smaller spacecraft, from several diverse programs, and from differing time periods, needs to be justified. This will be done under the section "Analyses of Data". However, as a result of a statistical analysis one observatory program was shown to be significantly different from the balance of the data. This program, the Orbiting Geophysical Observatory, was eliminated from the data base. The data base for this report was therefore 34 spacecraft with 545 total days of thermal-vacuum test time. Table 1 includes only thermal-vacuum test days; some of the spacecraft had solar simulation testing in addition to thermal-vacuum testing, but the results of the solar simulation testing are not included in the data base.

The sources of data used in this report include: (1) the Test and Evaluation (T&E) Division Flight Readiness Review sheets (box scores), (2) T&E test engineers' reports, (3) contractor reports, and (4) GSFC malfunction reports.

1 "Time Required for an Adequate Thermal-Vacuum Test of Flight Model Spacecraft" by A. R. Timmins. NASA TN-4908, Dec. 1968

Table 1

Data Base

Program	Number of Spacecraft	Number of Thermal-Vacuum Test Days	Thermal-Vacuum Test Days Per Spacecraft
Interplanetary monitoring Platform	8	143	17.9
Orbiting Geophysical Observatory	5	63	12.6
Orbiting Solar Observatory	6	93	15.5
Orbiting Astronomical Observatory	2	36	18
Nimbus	3	60	20
Application Technology Satellite	2	15	7.5
Miscellaneous Small Scientific Satellite	13	198	15.2
Total	39	608	15.6
Total Used in this Report (after excluding OGO)	34	545	16
Total (1968 Study)	11	176	16

TREATMENT OF MALFUNCTION AND FAILURE DATA

There are two kinds of malfunction data, failures and problems, which are characteristic of a thermal-vacuum test. The elimination and prevention of failures is of principal interest to attain adequate space performance. However, the elimination of other substandard performance is also of interest and needs to be considered when determining the time required for an adequate thermal-vacuum test. This study will examine both failures and total malfunctions.

The following definitions will distinguish the two kinds of data, and will apply throughout the report:

1. A failure is the loss of operation of any function, part, component, or subsystem whether or not redundancy permitted recovery of operation. Usually requires replacement of the hardware.

2. A problem is any substandard performance or partial loss of function not serious enough to be classed as a failure.

3. A malfunction is any performance outside the specified limits, either a failure or a problem.

The detection of failures in the thermal-vacuum test could be strictly time dependent and the data will be analyzed from this standpoint. However, the data from the 1968 study gave some indication that the detection of failures is related to both time and temperature and identified four different thermal environments. This premise will be further utilized in the present study. The four thermal environments are defined as follows:

1. Ambient -- 25° C ±5° C

2. Transient -- A temperature change from one level to another. When no information concerning the length of a transient was available, the transient was assumed to have lasted 12 hours which is representative of the time required to change a spacecraft temperature level by about 40° C.

3. Cold -- below 20° C

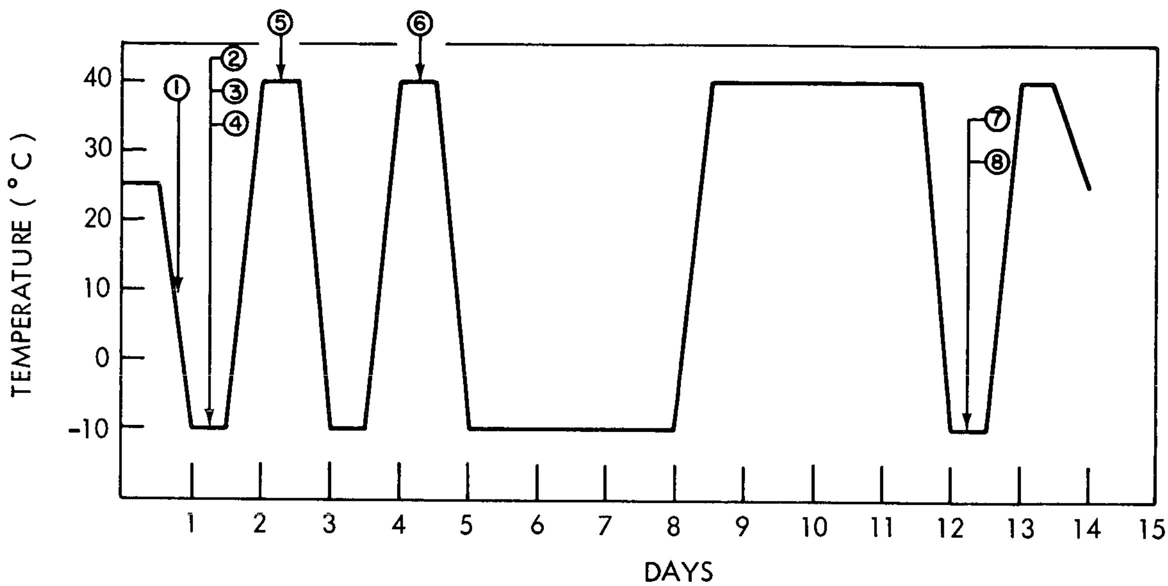
4. Hot -- above 30° C

In each of the four thermal environments the vacuum was 1×10^{-5} torr or better. The only exception was in the ambient test data which did include some malfunctions that occurred at atmospheric pressure during the time the spacecraft was being checked out prior to the start of the test.

A description of each spacecraft malfunction and the time during a test at which the malfunction occurred were obtained for all acceptance tests of the spacecraft used in the study. The malfunctions were classified as either problems or failures.

These malfunctions were then located, with respect to time of occurrence, on thermal-vacuum test temperature profiles drawn for each spacecraft, as illustrated in Figure 1. The malfunctions were then tabulated according to the environment in which they had occurred and the amount of time the spacecraft had been in the environment when the malfunctions occurred.

The number of days of testing in each thermal environment are treated as though they are consecutive, even though they may not be consecutive calendar days. For example, in Figure 1 the sixth day of test is considered the second cold day.



ITEM	FAILURE OR PROBLEM	IDENTIFICATION
1	P	Command receiver had reduced sensitivity at low temperature.
2	P	Optical aspect scan bit readout problem.
3	P	U. of California made counts below limits.
4	P	U. of California automatic disabling circuit problem.
5	P	U. of Iowa high count rates at high temperature.
6	P	U. of Iowa high voltage power supply.
7	F	Experiment accumulator had wrong readout.
8	F	One dimple motor failed to initiate.

Figure 1. Typical Thermal-Vacuum Test Profile

ANALYSES OF DATA

Determination of Appropriate Sample

The 39 spacecraft available for this study could be separated into two general groups by size: (1) large (1,000-3,000 pounds) observatory size spacecraft, (2) smaller (100-800 pounds) Explorer-size spacecraft. Table 1 shows 18 observatories and 21 Explorer class spacecraft. Should these two groups be considered as a single population? Also, should any of the seven programs be excluded because the data were significantly different from the other programs? Examination of the malfunction data showed that neither group, nor the sum of the groups, could be described by a Gaussian distribution. This eliminated the usual techniques for comparing two groups of data, and for testing the applicability of the data. For this reason, a non-parametric test was used to compare the two groups of data, and one particular program. The test, identified as the Wilcoxon-Mann-Whitney test, is described in "Experimental Statistics", Handbook 91, United States Department of Commerce, National Bureau of Standards, p. 16-9.

The basis for comparison, using the above test, was the average failures per day for each spacecraft. Application of the test showed that, at the 5% level of significance, one program was significantly different from either the observatory group or the Explorer group. This program, the Orbiting Geophysical Observatory, was eliminated from the data base. Additional tests showed no significant difference between the observatory group and the Explorer group and these groups were combined. As a result of all these tests, the data base used for this report was one group of 34 spacecraft.

Analyses by Time and Temperature

1. Cumulative malfunctions in thermal-vacuum tests.

Figure 2 displays the failures from the present study versus time in the thermal-vacuum test, and indicates a parabolic rise to a plateau in about 30 days. Figure 2 also displays the same data by time in each of four thermal environments. From these data it appears that the malfunctions are related to time and thermal-stress rather than time alone in the thermal-vacuum tests. This verifies a 1968 finding. The present study will emphasize the time and thermal-stress relationships to the occurrence of malfunctions, but will also examine the relationship of time alone.

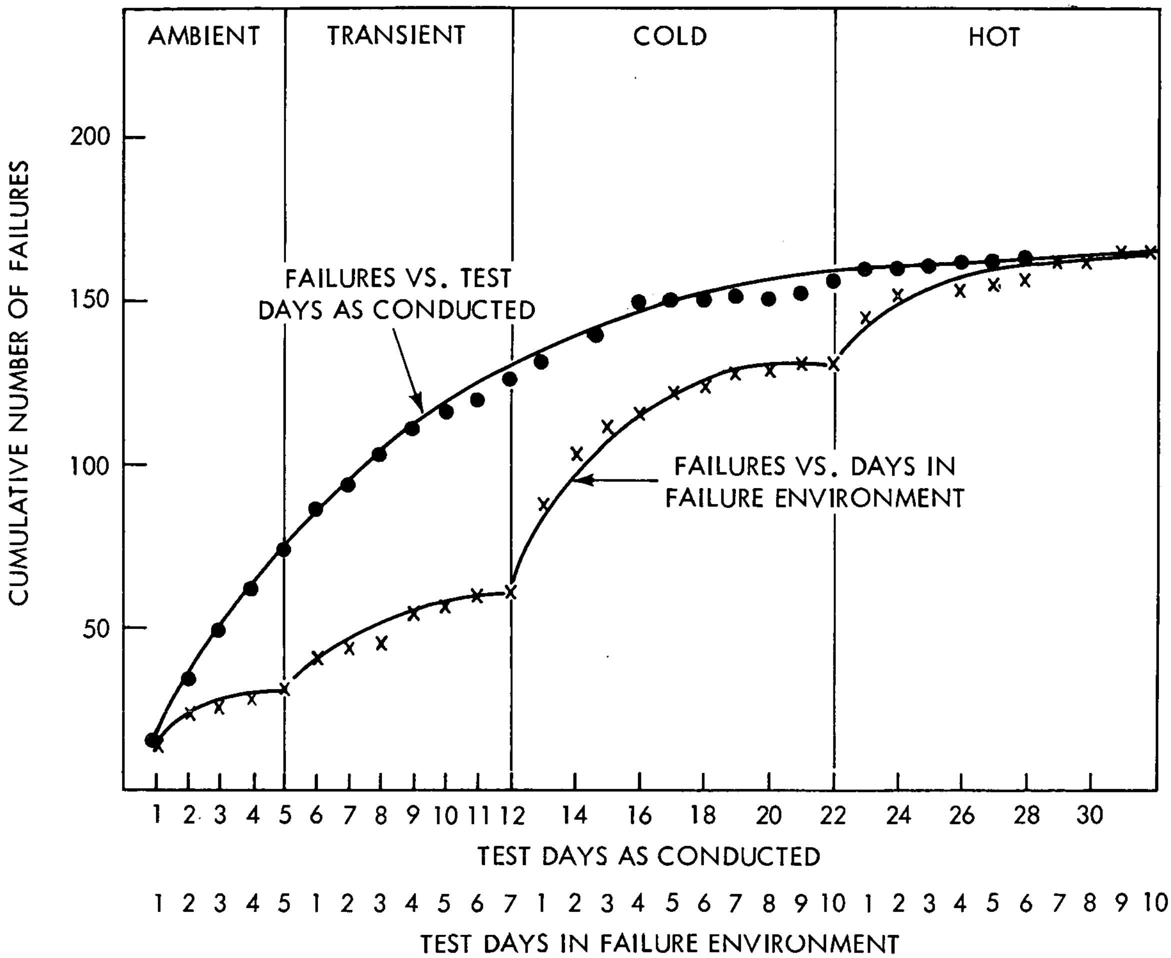


Figure 2. Thermal-Vacuum Failures of Flight Spacecraft vs. Time and Environment

Figure 3, developed from the 1968 study, is presented for ease of comparison with the present study. It shows that whether malfunctions or failures are used, the cumulative number of malfunctions (or failures) reaches a plateau at some point in time. For the ambient environment the plateau is reached after one day, and for the transient, hot, and cold environments the plateau is reached after four days. The time to reach a plateau was then recommended as the minimum necessary for each environment in a thermal-vacuum test. The times were considered minima since the reaching of a plateau may have been due, in part, to the fact that fewer spacecraft were tested at the longer time.

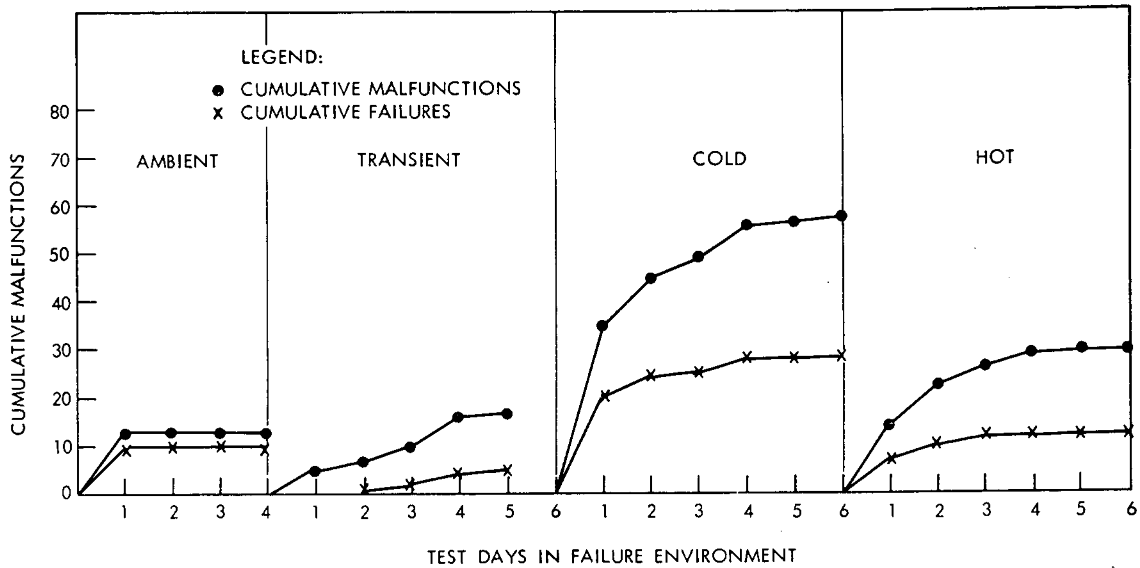


Figure 3. Thermal-Vacuum Malfunctions of Eleven Flight Spacecraft vs. Time and Environment

Figure 4, which has data from 34 spacecraft, can be compared with Figure 3, which was based on data from 11 spacecraft. The shape of the curves are quite similar and both show a ratio of malfunctions to failures of approximately 2 to 1 for each of the four thermal environments. However, a most significant difference is that the time to reach the plateau in Figure 4 is at least double that in Figure 3. The comparison of Figures 3 and 4 infers that our present specification for thermal-vacuum test time should be doubled to eliminate all the failures in a spacecraft. Before making that conclusion two subject areas need to be discussed, that is, limitations on the data and additional analyses of the data.

One limitation is the method of presenting the data in Figures 3 and 4. This method will not show a plateau until all failures in all spacecraft have been removed. If this criterion were used the total test time would not only be unduly expensive, but would impose on the useful life of some spacecraft components. As in many decisions, the time required for an adequate thermal-vacuum test must take into account risk and cost. This report will not discuss the costs of testing related to program costs. It will develop the data showing the relationship of the time and temperature of the thermal-vacuum test to the detection of failures and thus to the probability of launching with a failure.

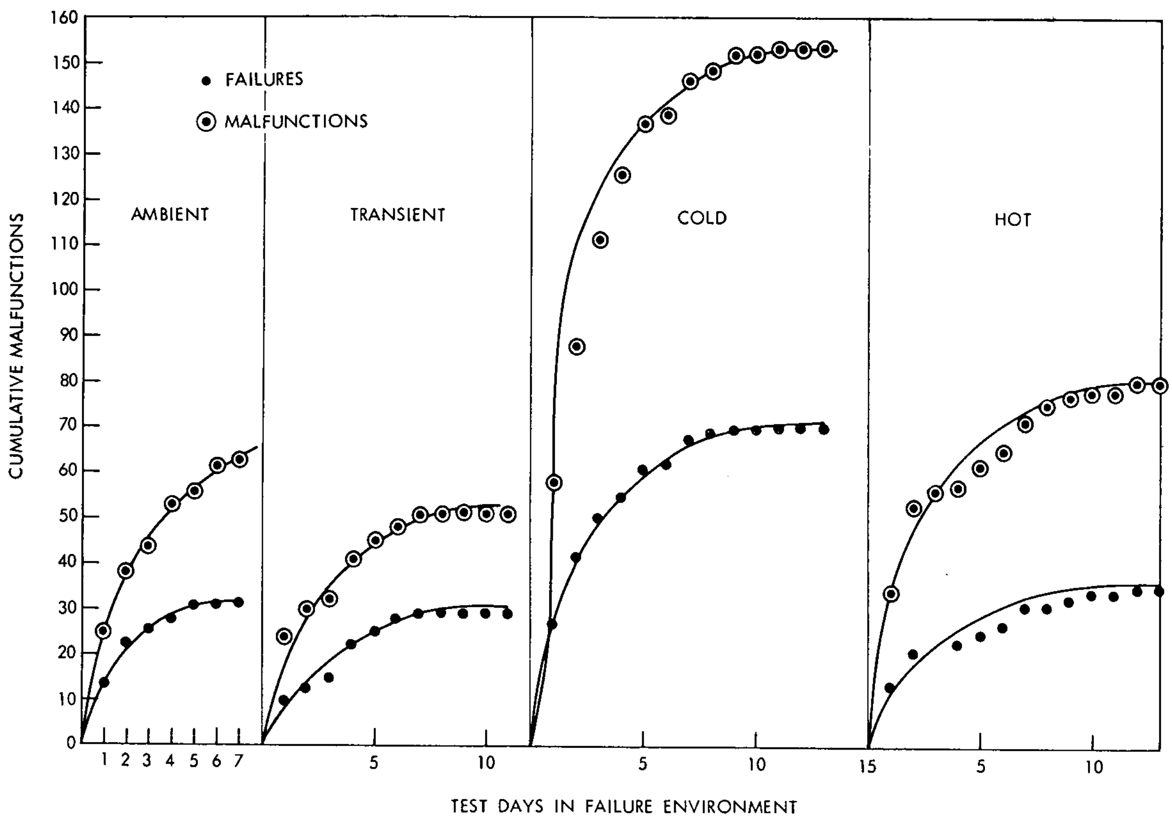


Figure 4. Cumulative Thermal-Vacuum Malfunctions of 34 Flight Spacecraft vs. Time and Environment

The four thermal classifications of the data also have some limitations, as listed below:

Ambient. Some of the first day malfunctions in this environment came from pre-test checkouts, when the spacecraft were not under vacuum.

Transient. The data in this environment are not considered completely accurate since the spacecraft were not always monitored during transitions. For example, one program showed no failures during the transition time from one temperature level to another, even though the total failures were the highest of any program.

Hot and Cold. Some of the malfunctions detected in these environments may have occurred in the transient environment, as discussed above.

2. Malfunctions per Spacecraft Versus Time and Temperature in Thermal-Vacuum Tests

To circumvent the problem of decreasing sample size with time in test, the number of malfunctions (and failures) occurring on each day of test were normalized to a per spacecraft basis. These data are presented in Figure 5. A generally decreasing number of malfunctions per spacecraft with time is evident in each of the four thermal environments. However, there are exceptions to the general trend, and the data do not indicate a definite test time requirement for a specified (or failure free) performance. Note is made that even on a per spacecraft basis the variability after 6 or 7 days may be associated with the small sample size.

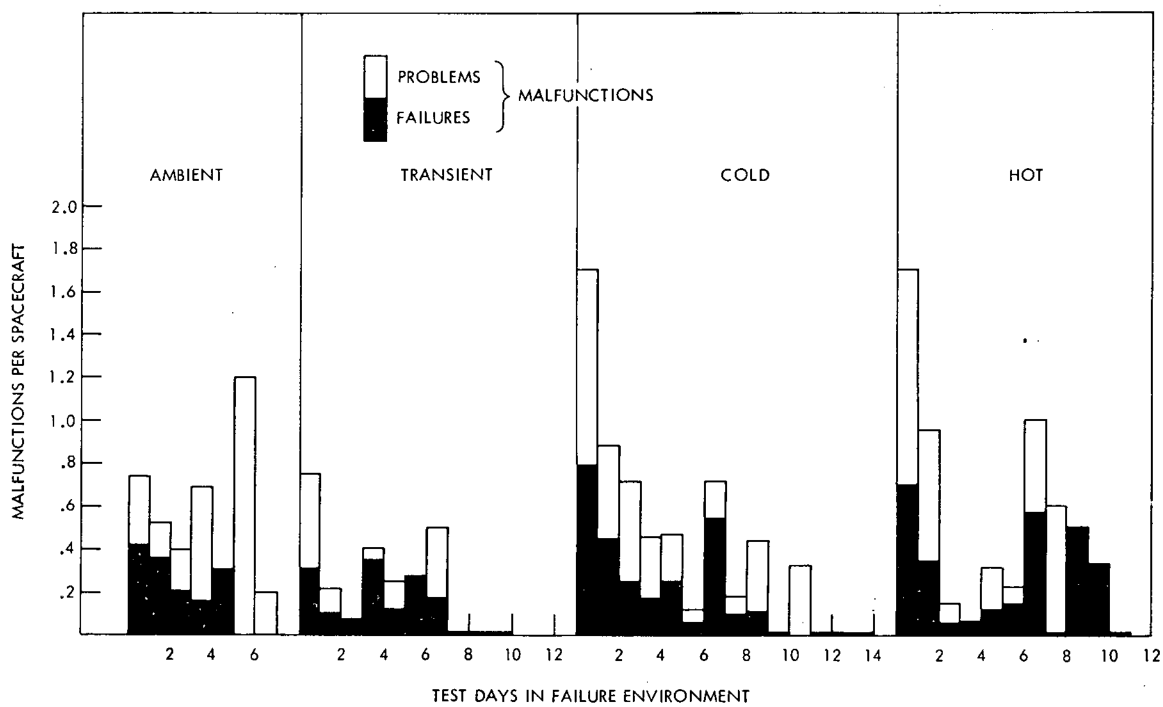


Figure 5. Thermal-Vacuum Malfunctions per Spacecraft of Flight Spacecraft by Day and Environment

3. Malfunction Rates

In Figure 6, the data from Figure 5 are plotted cumulatively by day. Drawing the best straight line through the points for day 2 through day 6 yields some interesting results. The slopes of the lines for the ambient, transient, and cold environments are nearly equal. The slope in the hot environment, as drawn, is

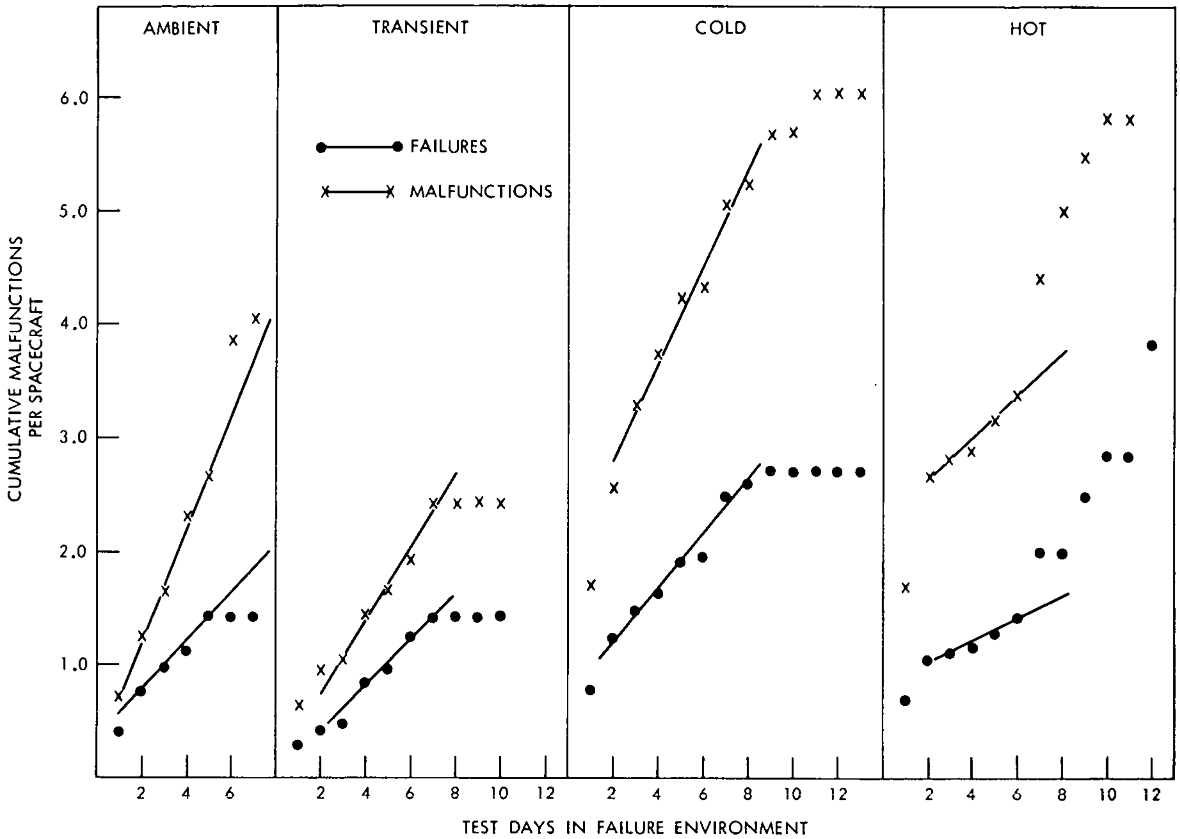


Figure 6. Malfunction and Failure Rates of Flight Spacecraft in Thermal-Vacuum Tests

significantly less. The failure rate (per spacecraft per day) is 0.2 or less, and the malfunction rate 0.5 or less from day 2 to day 7 and possibly longer (if allowance is made for the decrease in sample size at the longer test times). Thus a failure rate of 0.2 failures per spacecraft per day would be a conservative estimate for any of the four thermal environments after day 2. This can also be stated as: (a) After day 2, one out of five spacecraft will have a failure on day 3, or (b) After day 2, a spacecraft may be tested in one thermal environment five additional days before detecting another failure. Similar statements can be made for malfunctions except the rate is about double.

Figure 4 gives the impression that the number of malfunctions per day decreases continuously and reaches a plateau after eight days in each thermal environment. As was mentioned in the discussion of Figure 4, this is somewhat of a false impression, since the number of spacecraft in test is also decreasing. Figure 5 shows that the malfunctions per spacecraft after two days is not decreasing continuously. Considering malfunctions per spacecraft rather than cumulative malfunctions does alleviate the problem of changing sample size, but does not remove all the inconsistencies encountered in the latter stages of each of the four test environments. When the data are plotted as in Figure 6 a constant malfunction (and failure) rate from day two through day six best describes the malfunction rate in each of the four thermal environments.

4. Effect of Retest Data

Figures 5 and 6 both include all the thermal-vacuum retest data on all the spacecraft. The retest data could be contributing to the variability noted after 3 or 4 days in each of the four thermal environments. To examine this factor, the data were segregated and only the data from the first thermal-vacuum test on each spacecraft were used to construct Figures 7 and 8. Figure 7 appears to have the same trend as Figure 5, and the same inconsistencies when the sample size becomes less than seven or eight. The data from Figure 7 were used to construct Figure 8. Although somewhat less consistent than the data (Figure 6) which included retest, the failure rates are surprisingly almost identical, and the malfunction rates nearly so between the four thermal environments. Table 2 summarizes the malfunction rates with and without retest data for each of the four thermal environments.

Table 2

Malfunction Rates Days 3-6 of Flight Spacecraft in Thermal-Vacuum Tests

Thermal-Vacuum Environment	Malfunctions/Day		Failures/Day	
	Excluding Retests	Including Retests	Excluding Retests	Including Retests
Ambient	0.5	0.5	0.2	0.2
Transient	0.5	0.3	0.4	0.2
Cold	0.4	0.4	0.2	0.2
Hot	0.1	0.2	0.1	0.1

From these data the best estimate for failures is 0.2 failures per spacecraft per day after day 2 in each of the four thermal environments. The corresponding value for estimating malfunctions is 0.4. These numbers should be valuable for estimating reliability and conducting studies of cost effectiveness. On the basis of similarity of the data with and without retest, all subsequent analyses will include all retest data.

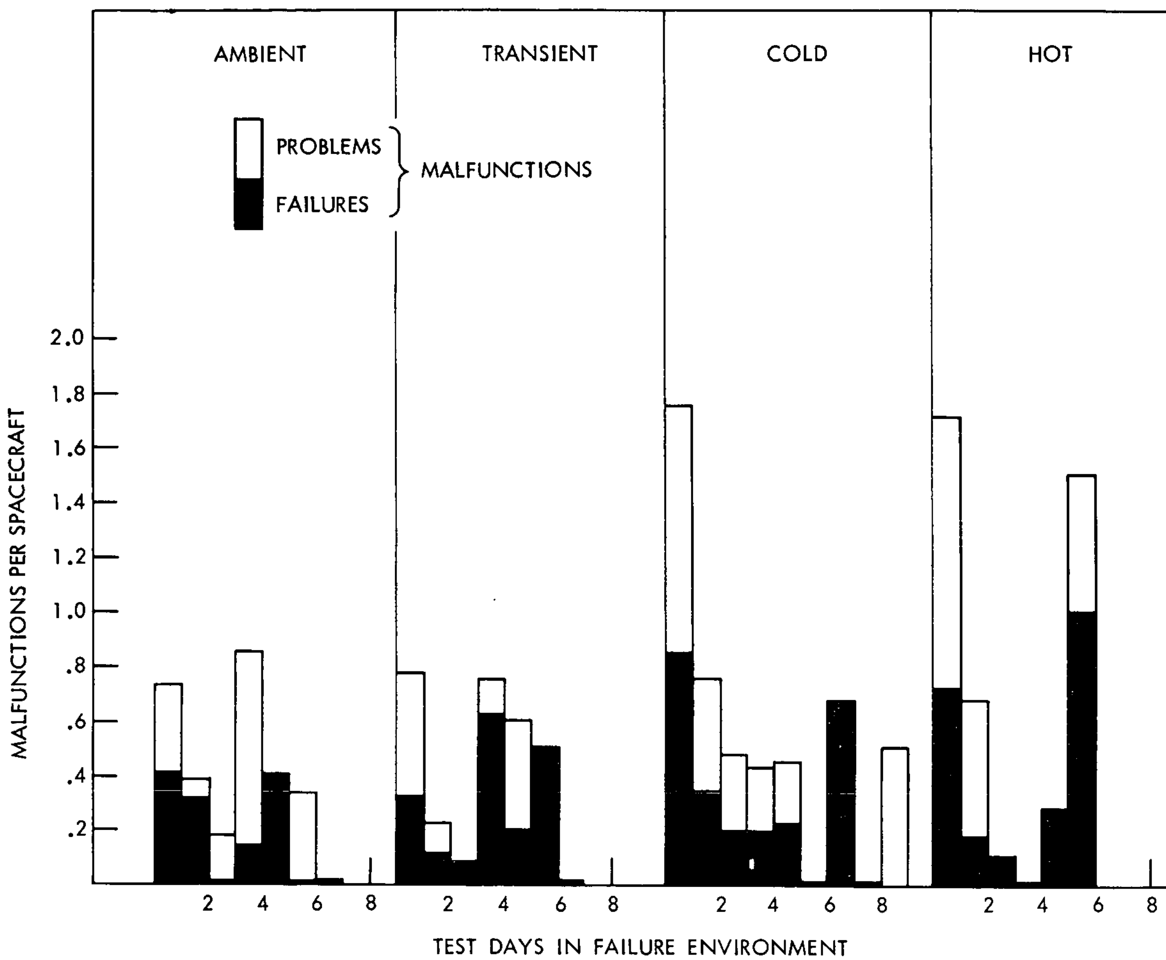


Figure 7. Malfunctions in Thermal-Vacuum System Tests of Flight Spacecraft by Day and Environment (Retests Excluded)

5. Probability of a Malfunction in Four Thermal-Vacuum Environments

The foregoing data include all malfunctions and failures on each spacecraft. This treatment of the data would be deceptive if, for instance, all the malfunctions occurred in one spacecraft. To examine the effect of multiple malfunctions on one spacecraft the data were arranged by the percent of spacecraft in test each day that had malfunctions on that day. Figure 9 shows these data which include retest data. After two days in each of the four thermal-vacuum environments, the data indicate that 10 to 20% of the spacecraft had failures on succeeding days in each of the environments. Total malfunctions are not as consistent, but an estimate of 20 to 40% is appropriate.

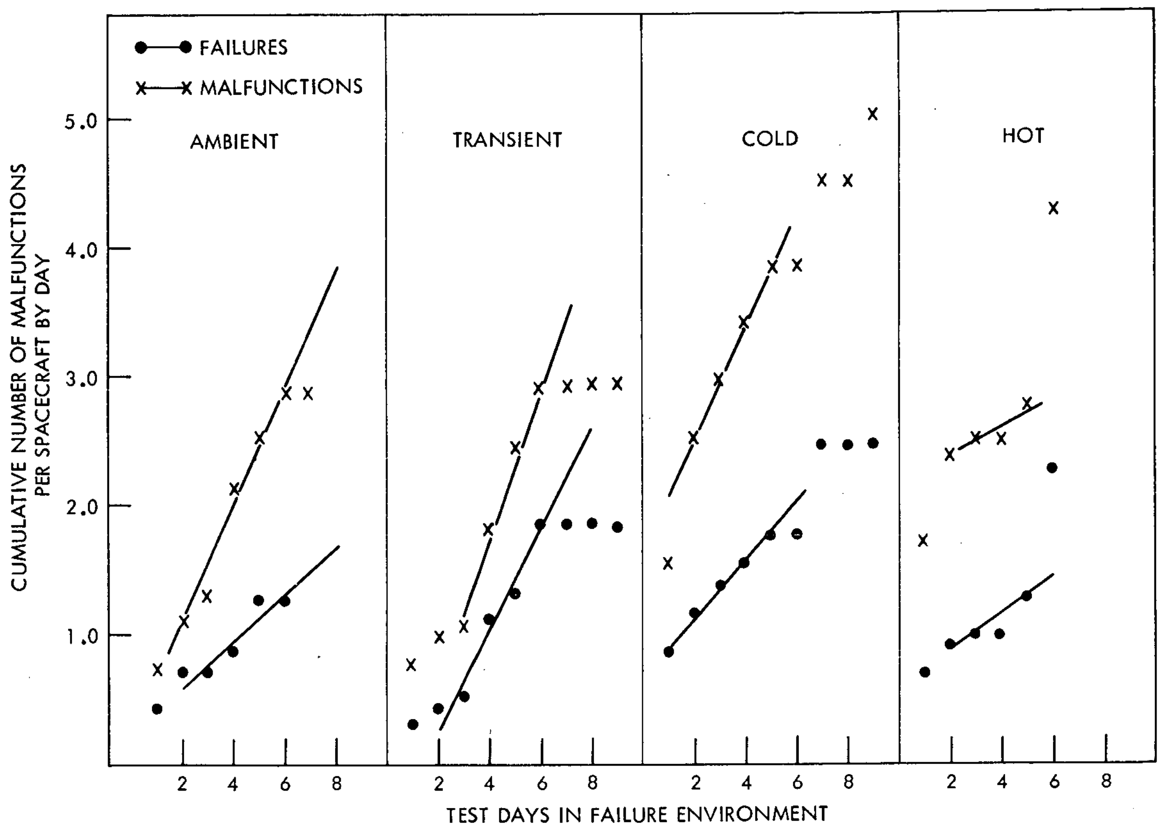


Figure 8. Malfunction Rates of Flight Spacecraft in First Thermal-Vacuum Test (Retests Excluded)

6. Comparison of Experiment and Total Spacecraft Failures

Most of the experiments flown on the spacecraft included in this study were state-of-the-art hardware. Restrictions on weight, volume, and power are additional difficulties. For these reasons one might anticipate that experiments would be more prone to malfunctions than the balance of the spacecraft. This comparison, is made in Figure 10 for each of the four thermal environments. Grossly, experiments comprise about 50% of the total failures encountered in each of the four thermal environments. Figure 10 also permits comparison of cumulative experiment failures to cumulative total failures for each day in test.

Table 3 utilizes the data from Figure 10 to show the percentage of total failures due to experiments for each day in each of four thermal-vacuum environments.

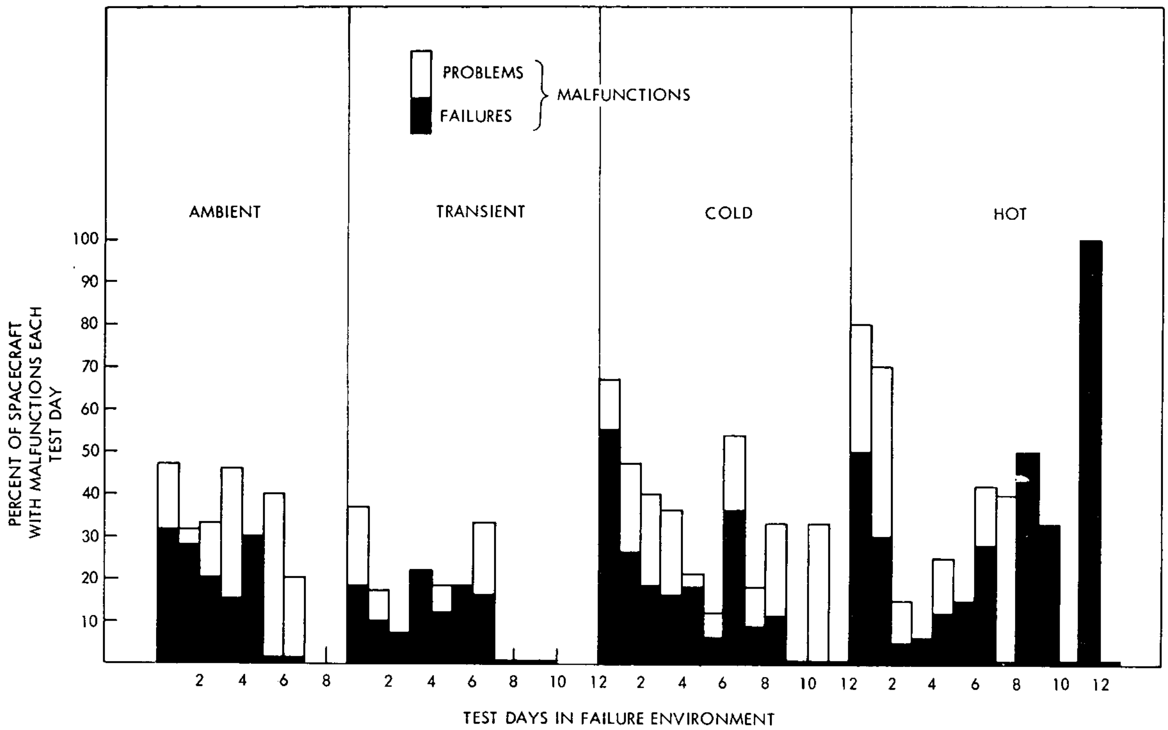


Figure 9. Probability of Flight Spacecraft Malfunction During Thermal-Vacuum Tests

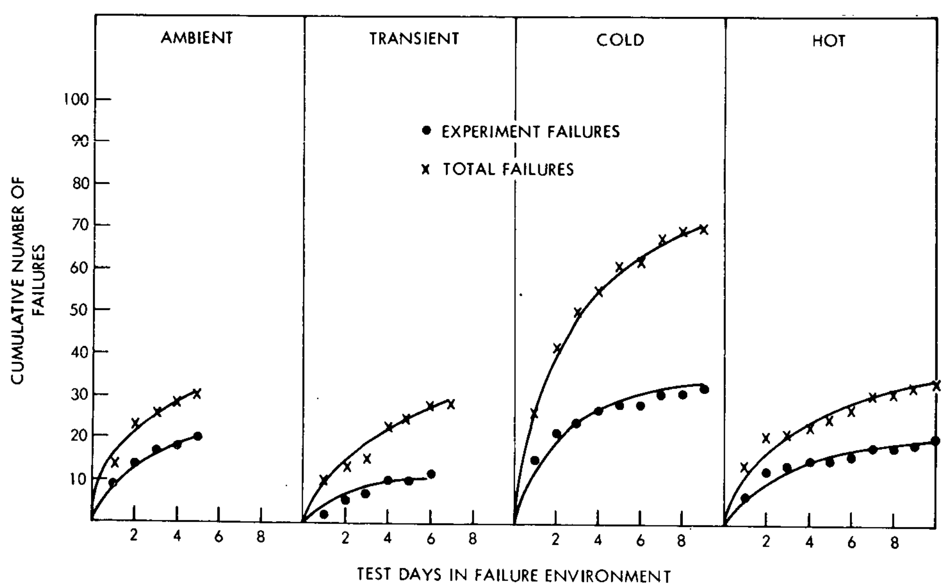


Figure 10. Comparison of Experiment Failures with Total Failures in Thermal-Vacuum System Tests of Flight Spacecraft

Table 3

Percent of Total Failures Due to Experiments in Thermal-Vacuum Tests of Flight Model Spacecraft

Thermal Environment	Test Day					
	1	2	3	4	5	6
Ambient	64*	61*	65*	64*	64*	--
Transient	20	38	47	43	40	43
Cold	55	50	48	49	46	45
Hot	50	62	64	65	60	59
All Thermal-Vacuum	51	54	55	54	49	51

$$*\text{Percentage} = \frac{\text{cumulative experiment failures}}{\text{cumulative total failures}} \times 100$$

7. Effect of Decreasing Sample Size

All the spacecraft were not tested for the same length of time, nor to the same time-temperature profile. This results in a decreasing sample size with total test time, and also with each of the four thermal environments. Should the data be truncated at some time because the sample size was too small to yield meaningful results? The data were not Gaussian distributed so the usual techniques for determining sample sizes and confidence levels were not applicable. Further, the functional form of the distribution was not known, so no technique was found for truncating the data by sample size with some confidence level, probability, or other statistical measure. However, a method was used which compared each day relative to the other days, and the comparison was influenced by the number of spacecraft in test on each day. The method was to compute the standard error of the mean for each day, and to compare the error on successive days. The standard error of the mean is equal to the sample standard deviation divided by the square root of the number of spacecraft. This procedure can be used regardless of the distribution, and shows, relatively, the effect of the sample size. Figure 11 displays the failure means and standard error of the means for flight spacecraft by day and thermal environment. If the data are truncated when the standard error of the mean is 100% greater than on the first day, the truncation would occur as shown in Table 4.

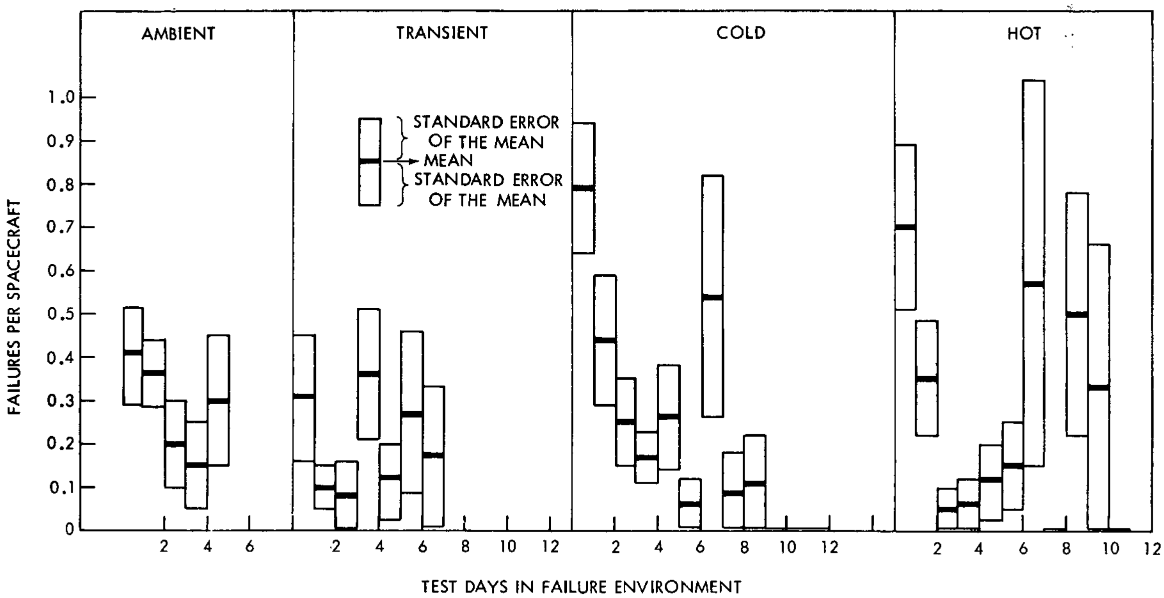


Figure 11. Failure Means and Standard Error of the Means for Flight Spacecraft by Day and Environment

Table 4

Truncation of Thermal-Vacuum Test Data Using 100% Variation in the Standard Error of the Mean as the Discriminator

Thermal-Vacuum Environment	Truncate After (Days)	Minimum Sample Size at Truncation (No. of Spacecraft)
Ambient	5	10
Transient	7	6
Cold	6	16
Hot	6	13

Although the probability measure (that the value of the mean is bounded by the standard error) is unknown, the measure is the same for each day. Using the truncation values given in Table 4 makes the data of Figures 5 and 6 much more consistent.

8. Failure Mean and Range per Spacecraft

Another look at the variability of the data versus time and sample size is given in Figure 12. The total range of failures together with the means are given for each day and each thermal environment. The actual data range emphasizes that in the real world the failures are in units of one, and that the standard error of the mean does not indicate the extreme values.

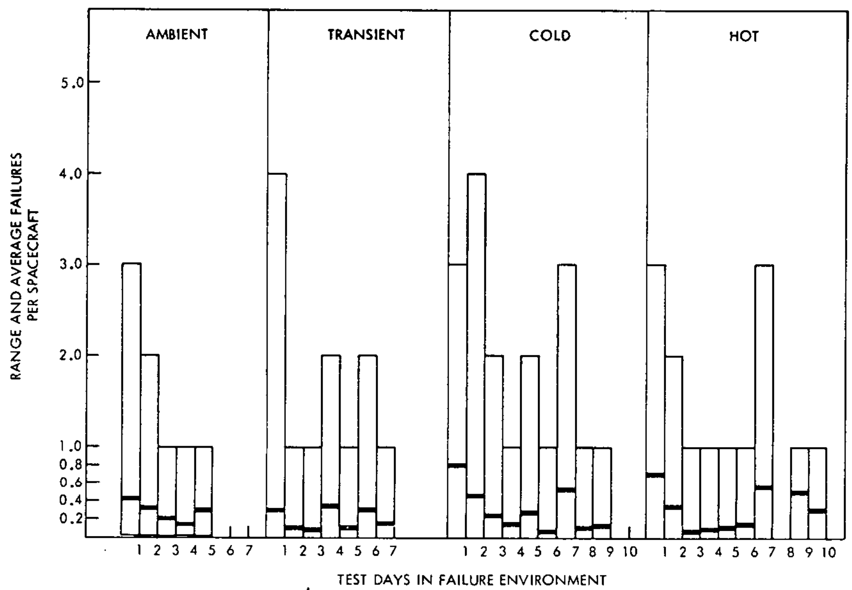


Figure 12. Range of Thermal-Vacuum Failures per Flight Spacecraft by Day and Environment

Analyses by Time in Test

The analyses to this point have emphasized the performance of the flight model spacecraft in four different thermal-vacuum environments, which comprise one thermal-vacuum test. The rationale for these analyses was that there is a different infant mortality region for each of the four thermal environments. This rationale is still considered valid. However, the thermal-vacuum tests, as conducted, do not have each thermal-environment in time sequence (as explained on page 5). Further, about 70 percent of the spacecraft tests are interrupted for repair and fixes, and retests have varying times. These factors make it desirable to analyze the thermal-vacuum tests in the time sequence in which they were conducted.

1. Percent of Spacecraft with Malfunctions Versus Time

Figure 13 shows the percent of the spacecraft which had malfunctions, plotted against the day of the test. Thirty-five percent of the spacecraft had failures on the first day of the test. After 11-13 days the percent of spacecraft with failures was approximately 15%. The data beyond this time period are not consistent but the trend indicates a level of about 5% at 18-20 days. The data for malfunctions are similar except the percentage values are about 45 for the first day, and 20-30 after 11-13 days of test. The results in Figure 13 include all the retest data.

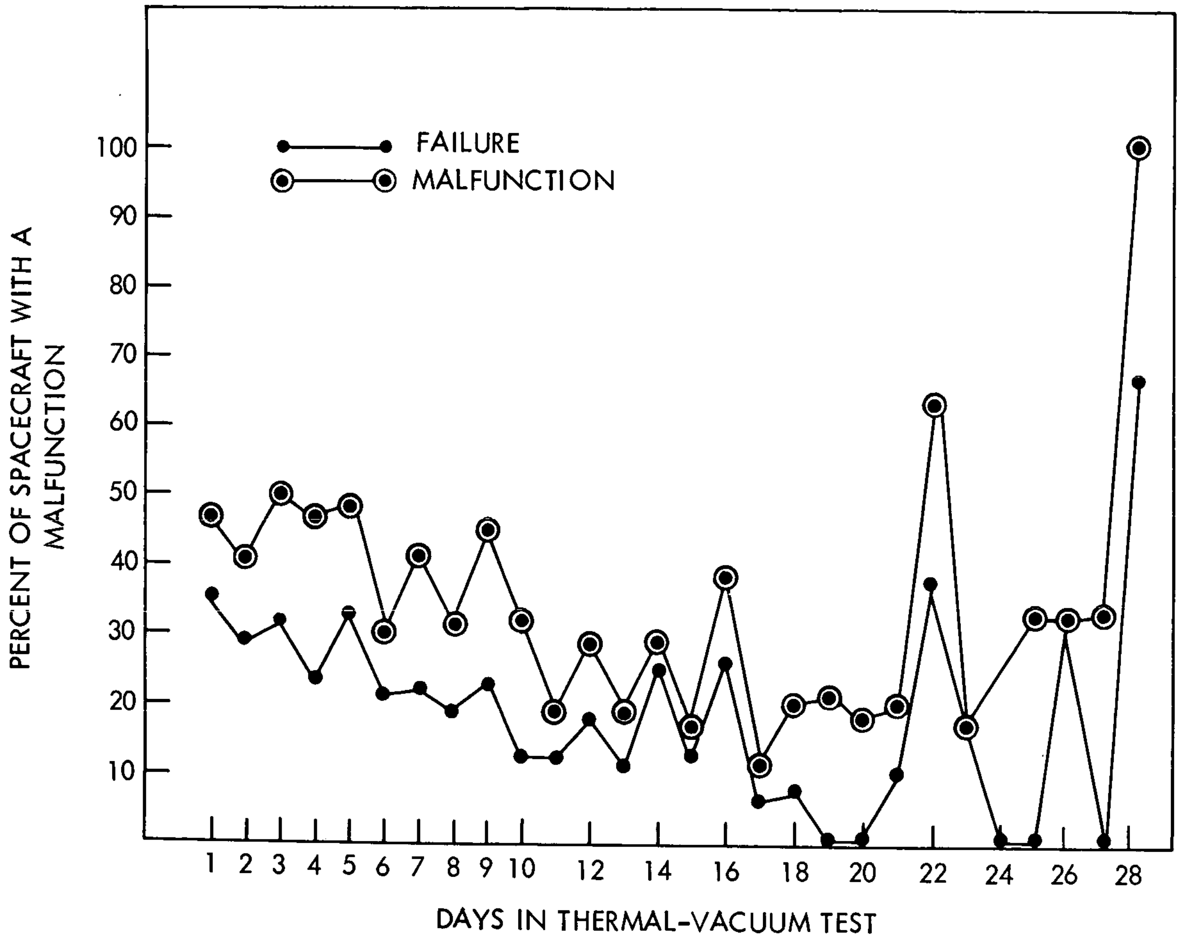


Figure 13. Probability of Malfunctions in Thermal-Vacuum Tests as Conducted

2. Malfunctions per Spacecraft Versus Time

The flight model spacecraft performance in the thermal-vacuum tests as conducted is given in Figures 14 and 15. Figure 14 gives the malfunctions per spacecraft (together with the standard error of the mean) versus the days in test. After 13 days in test the malfunctions per spacecraft had a mean of approximately 0.25 with a range of the mean $\pm .15$. The standard error of the mean shows that data beyond 21 days should be ignored.

Figure 15 gives the failures per spacecraft (together with the standard error of the mean) versus days in the thermal-vacuum test. The trend of the data indicates a mean value of about 0.15 ± 0.1 failures per spacecraft after 13 days in test, and a mean value of approximately $.05 \pm .05$ after 20 days. The standard error of the mean indicates the data in the 12-16 day time period is somewhat variable, and also indicates the data beyond day 21 should be ignored.

3. Probability of No Failures During the Thermal-Vacuum Test

The emphasis, properly, has been on the malfunctions or lack of performance. However, a look at the performance level attained is also of interest. Figure 16a shows the percent of spacecraft with no failures for each day in the thermal-vacuum test. Noteworthy is the 10-15 day test period which shows that 85% of the spacecraft in this test time have no failures on any specific day. (The thermal-vacuum test time required in the GSFC General Specification S-320-G-1 is about 14 days.) Figure 16b shows the percent of spacecraft with no failures for all subsequent test days after any given test day. Again looking at the 10-15 day test time period, the percentage of no failure spacecraft increases from 30% to 55%. These data also show that the percentage increases to 75% after 18 days. The figures after day 13 are associated with very small sample sizes, and are influenced by a few spacecraft. By excluding four spacecraft which had failures after 22-25 days of testing, the dotted curve in Figure 16b shows excellent results after 15 days of testing.

CONCLUSIONS

1. The occurrence of malfunctions in a thermal-vacuum test is related to the variables of time and temperature-stress, not time alone.

2. At least four kinds of thermal-stress need to be considered in developing a specification for a thermal-vacuum test.

3. The greatest number of defects occur in the first two days of each of the four thermal-environments. Subsequently, the detection rates (malfunctions per spacecraft) are reasonably constant for the extent of the data.

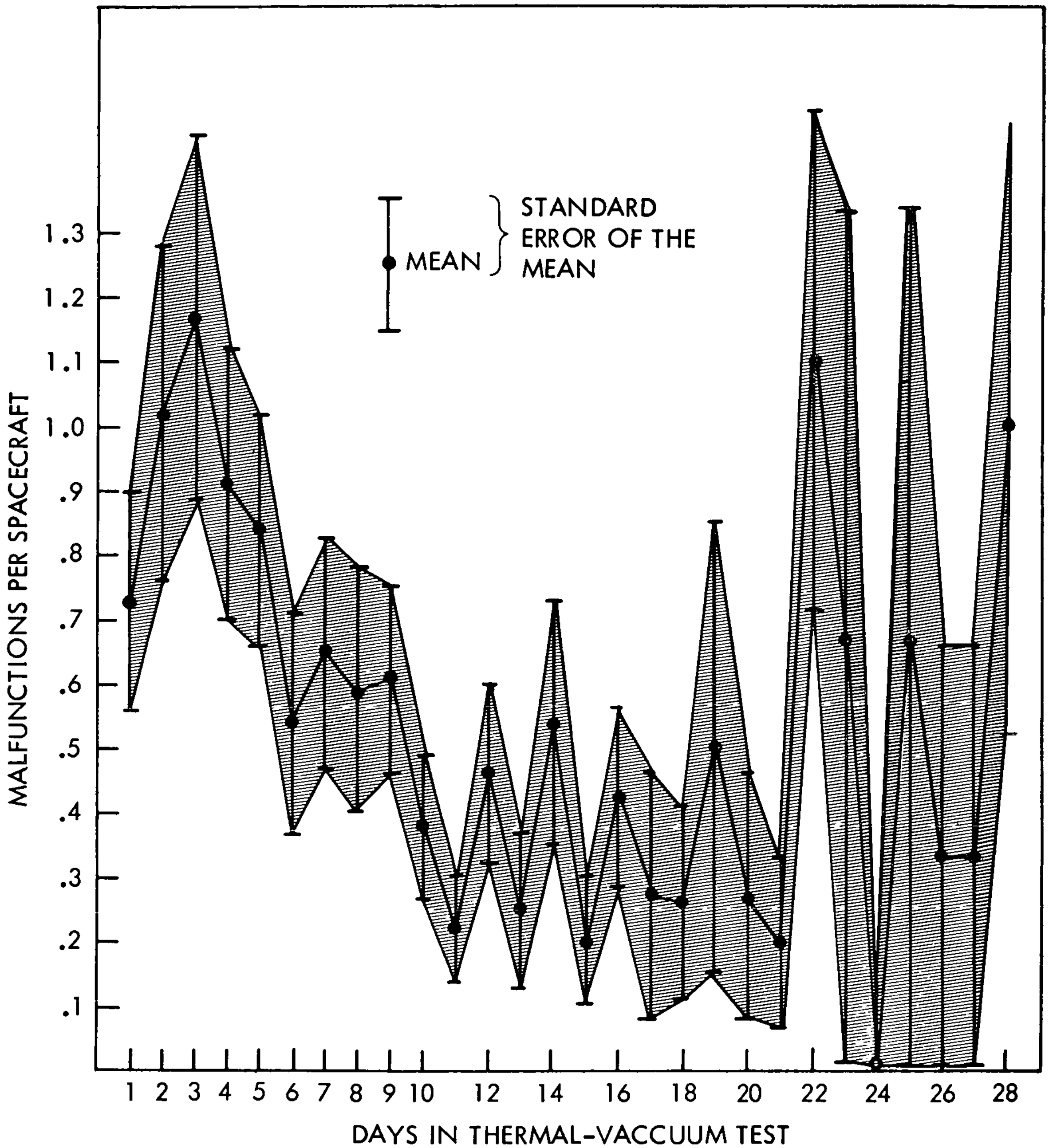


Figure 14. Malfunctions per Spacecraft by Day in Thermal-Vacuum Tests as Conducted

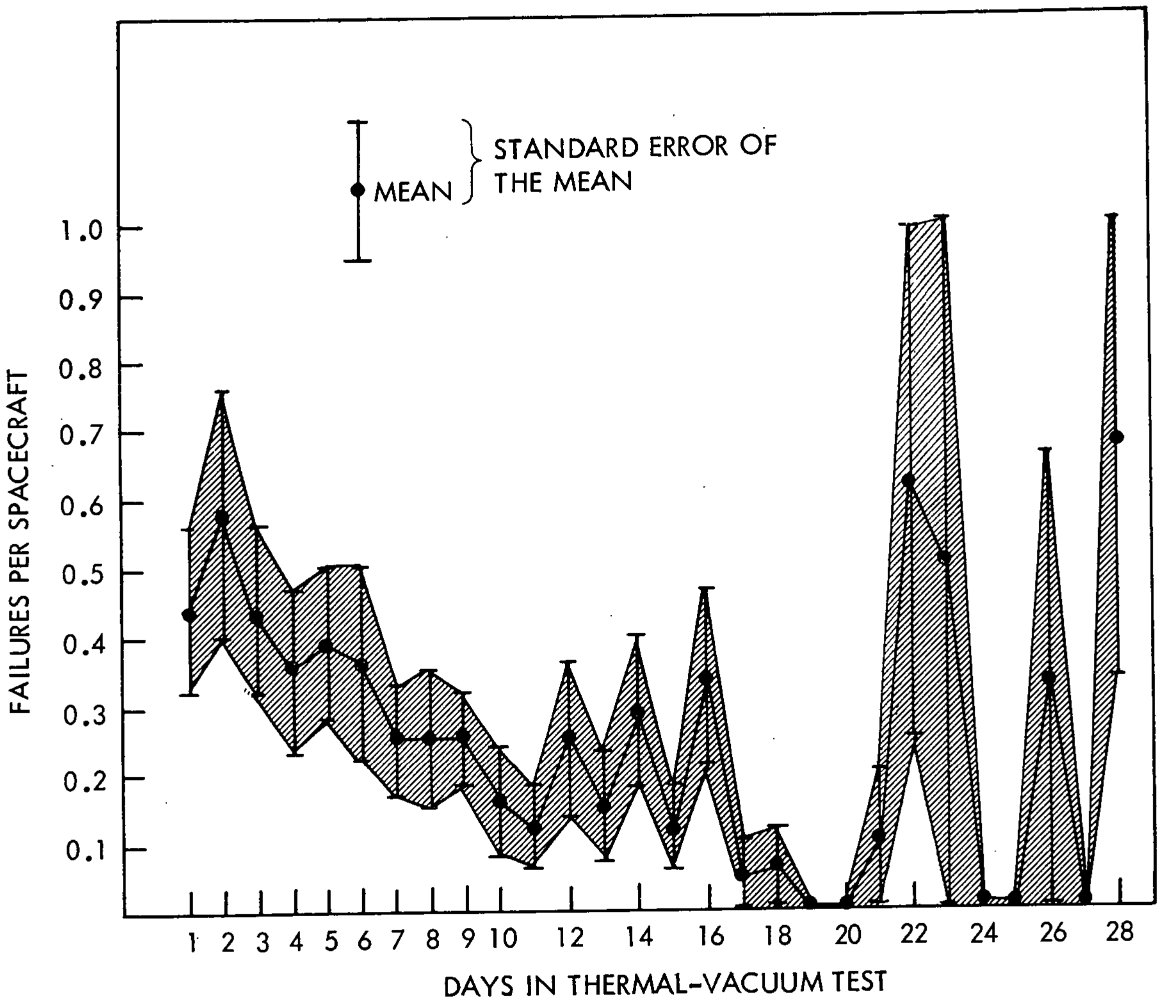


Figure 15. Failures per Spacecraft by Day in Thermal-Vacuum Test as Conducted

4. The data on detection of defects are similar in number and time distribution whether or not retest data are included.

5. Experiment failures comprise approximately 50% of the total defects detected, both initially and throughout the test.

6. For tests as conducted at GSFC about 85% of the spacecraft will have no failures (on a given day) in the test time period of 10-15 days.

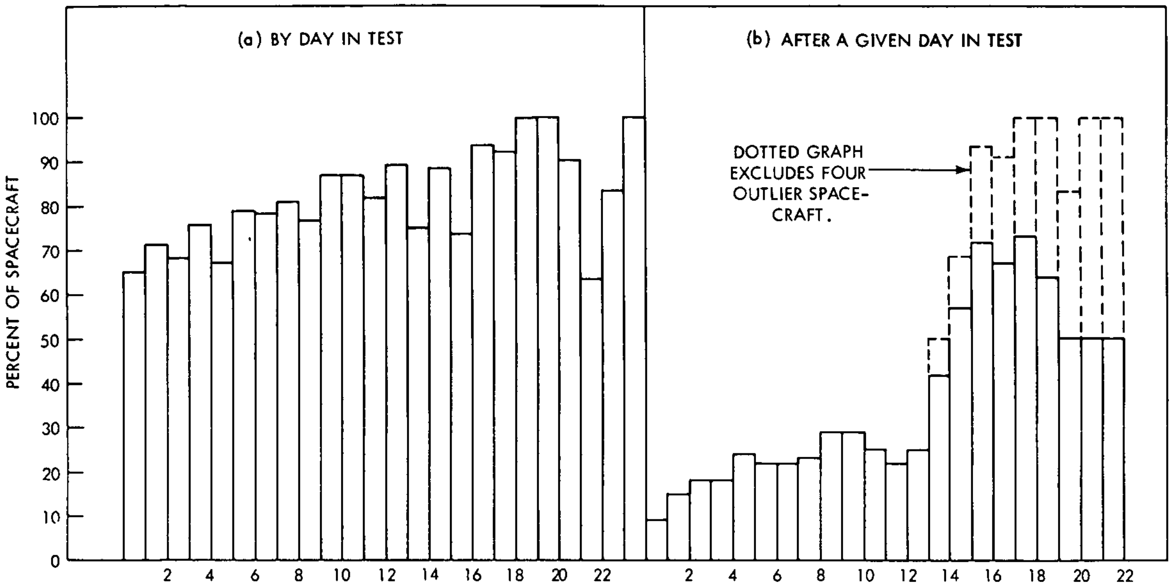


Figure 16. Probability of Spacecraft with No Failures

7. The time required for a thermal-vacuum test is related to the risk acceptable for not detecting a failure.

8. Sufficient data are not extant for assessing the acceptable risk vs. time relationship with any statistical confidence levels.

9. No change is recommended at this time in the thermal-vacuum test profile specified in GSFC General Specification S-320-G-1.

10. The specification for the thermal-vacuum test of spacecraft can be safely based on the failure data in contradistinction to total malfunctions.

APPENDIX A

ANALYSES OF DATA EXCLUDING RETESTS

One consideration in the treatment of data for this report was the influence of retest data. A retest is a test made after fixing malfunctions detected in a previous test. That is, if retest data were excluded would the time distribution of malfunctions be significantly affected? The data were examined both ways (with and without retest data), and indicated the retest data (a major part of the data) could be included. Therefore the analyses in the report include both the initial thermal-vacuum tests and the retests. This Appendix has been included to preserve the data and analyses made where retest data were excluded. The data will be useful in the future when the data base can be enlarged, and additional analyses conducted.

Figure A-1 shows the probability of a malfunction in flight spacecraft during each of the four thermal phases of a thermal-vacuum test. Comparison can be made with Figure 9 in the text which includes the first thermal-vacuum test and all retests.

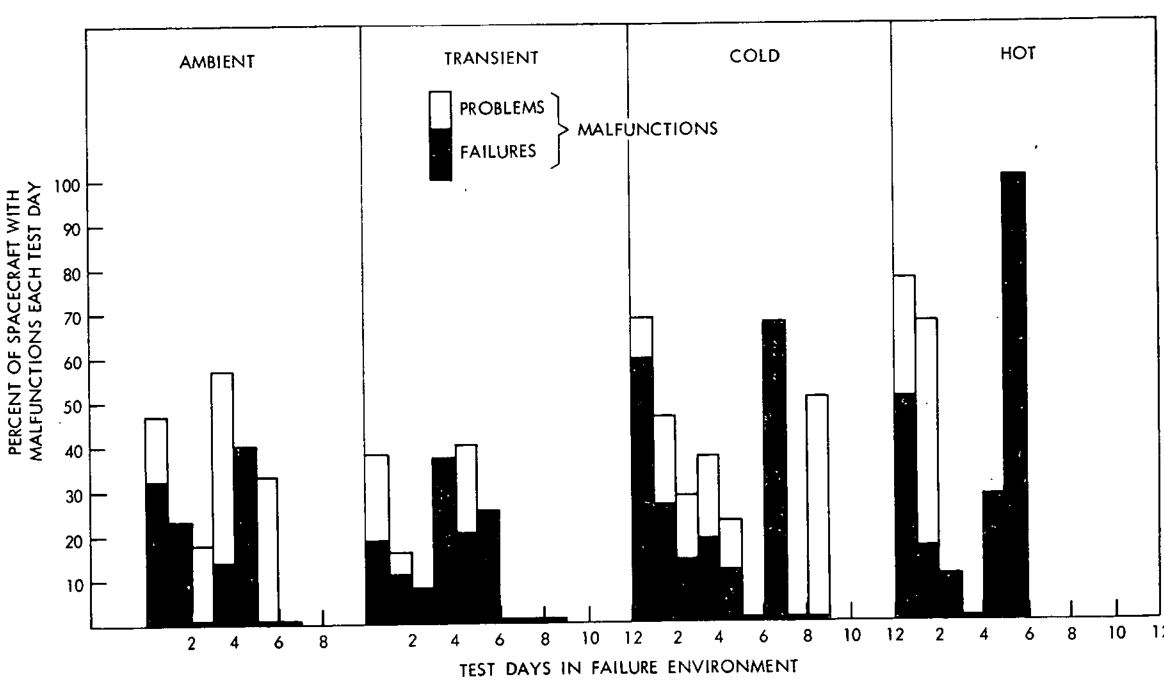


Figure A-1. Probability of a Malfunction in Flight Spacecraft by Time and Thermal-Vacuum Environment (with Retest Data Excluded)

Figure A-2 shows the probability of a malfunction in flight spacecraft versus time in a thermal-vacuum test. Comparison can be made with Figure 13 in the text.

Figure A-3 shows the failures per spacecraft versus time in a thermal-vacuum test. Comparable data which include retest data are in Figure 15 in the text.

Figure A-4 shows the failure means (and standard error of the means) for flight spacecraft by day and environment in the initial thermal-vacuum test. Comparable data which include retest data are in Figure 11 in the text.

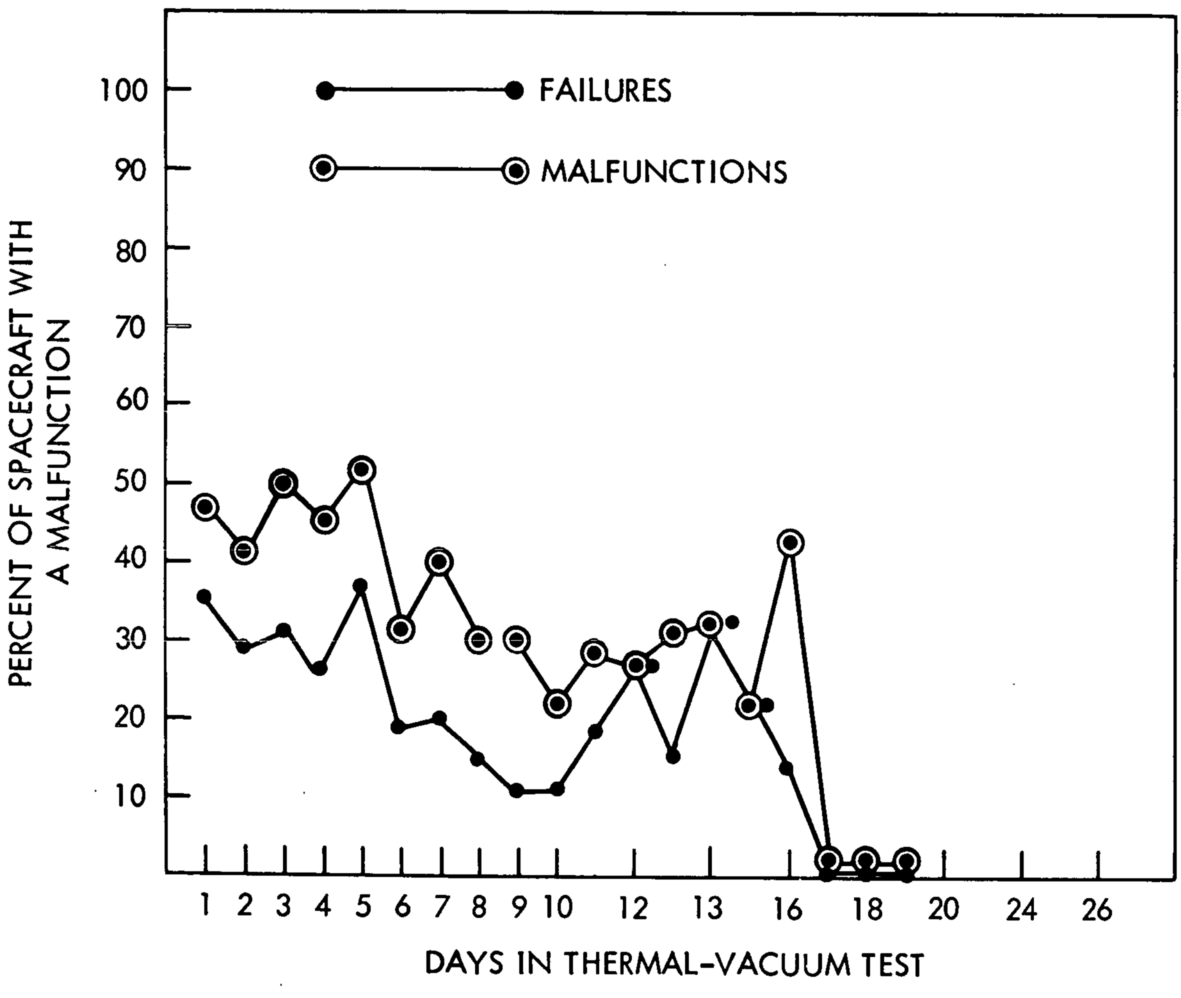


Figure A-2. Probability of a Malfunction in Flight Spacecraft in Thermal-Vacuum Tests as Conducted (with Retest Data Excluded)

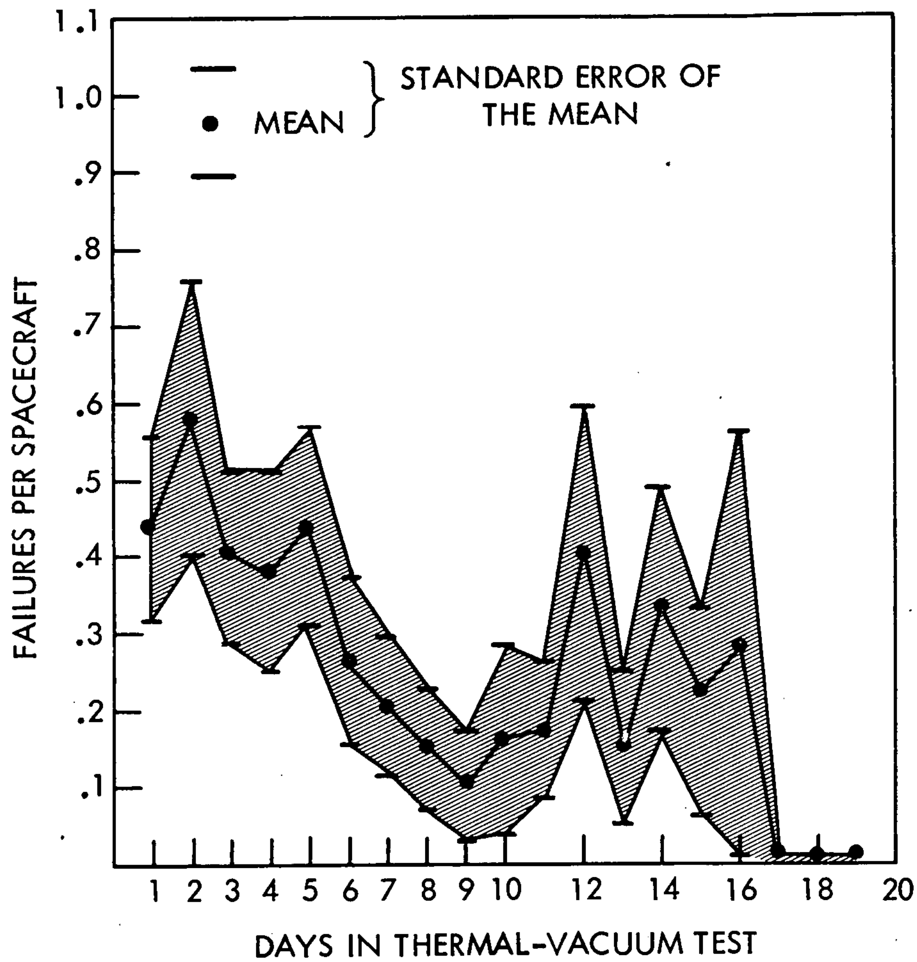


Figure A-3. Failures per Spacecraft by Day in Thermal-Vacuum Test as Conducted (with Retest Data Excluded)

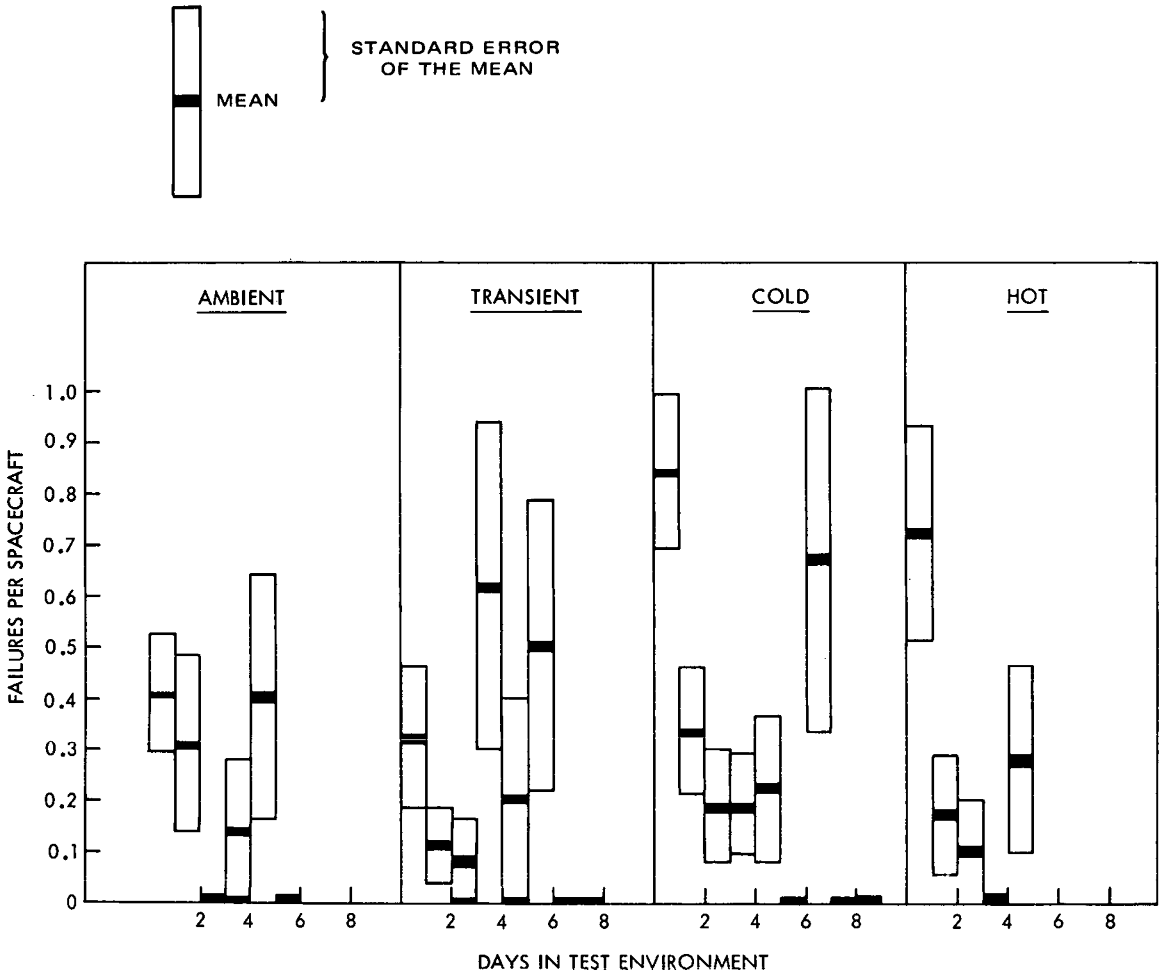


Figure A-4. Failure Means and Standard Error of the Means for Flight Spacecraft by Day and Environment (with Retest Data Excluded)

APPENDIX B

DATA USEFUL TO FUTURE ANALYSES

In studies of the kind made for this report a common difficulty is the lack of sufficient data to characterize trends and distributions. The data base for this report was threefold greater than a similar study in 1968, and has enabled additional analyses and interpretations to be made. Future studies will need to be made and will have the advantage of additional data. The data from the present study is documented in this Appendix in a form that will enable future data to be easily added for further analyses.

Table B-1

Performance Data of Flight Model Spacecraft in Thermal-Vacuum Tests by Day and Thermal Environment

	Day	Failures/ S/C	Failures/ S/C First T-V Only	Fraction of S/C Having a Failure	Fraction of S/C Having a Failure During First T-V	Fraction of S/C Having Failures After Day X	Day X
AMBIENT	1	.41	.41	.32	.32	.52	0
	2	.36	.31	.28	.23	.40	1
	3	.20	0	.20	0	.46	2
	4	.15	.14	.15	.14	.38	3
	5	.30	.40	.30	.40	.30	4
	6	0	0	0	0	0	5
	7	0	0	0	0	0	6
TRANSIENT	1	.31	.32	.18	.19	.40	0
	2	.10	.11	.10	.11	.35	1
	3	.08	.08	.07	.08	.34	2
	4	.36	.62	.22	.37	.31	3
	5	.12	.20	.12	.20	.31	4
	6	.27	.50	.18	.25	.27	5
	7	.17	0	.16	0	.33	6
	8	0	0	0	0	0	7
	9	0	0	0	0	0	8
	10	0		0		0	9
	11	0		0		0	10

Table B-1 (Continued)

	Day	Failures/ S/C	Failures/ S/C First T-V Only	Fraction of S/C Having a Failure	Fraction of S/C Having a Failure During First T-V	Fraction of S/C Having Failures After Day X	Day X
C	1	.79	.84	.55	.59	.73	0
O	2	.44	.34	.26	.26	.50	1
L	3	.25	.19	.18	.14	.40	2
D	4	.17	.19	.16	.18	.36	3
	5	.26	.22	.17	.11	.30	4
	6	.06	0	.06	0	.37	5
	7	.54	.67	.36	.67	.45	6
	8	.09	0	.09	0	.18	7
	9	.11	0	.11	0	.11	8
	10	0		0		0	9
	11	0		0		0	10
	12	0		0		0	11
	13	0		0		0	12
	14	0		0		0	13
H	1	.70	.72	.50	.50	.60	0
O	2	.35	.17	.30	.16	.50	1
T	3	.05	.10	.05	.10	.42	2
	4	.06	0	.06	0	.43	3
	5	.12	.28	.12	.28	.37	4
	6	.15	1.00	.15	1.00	.30	5
	7	.57		.28		.28	6
	8	0		0		.40	7
	9	.50		.50		.50	8
	10	.33		.33		.33	9
	11	0		0		1.00	10
	12	1.00		1.00		1.00	11
	13	0		0		0	12

Table B-2

Performance Data of Flight Model Spacecraft in Thermal-Vacuum Tests as Conducted

Day	Failures per S/C	Failures per S/C First T-V Only	Fraction of S/C Having a Failure	Fraction of S/C Having a Failure First T-V Only	Fraction of S/C Having Failures After Day X	Day X
1	.44	.44	.35	.35	.94	0
2	.58	.58	.29	.29	.91	1
3	.44	.40	.32	.31	.85	2
4	.35	.38	.24	.26	.79	3
5	.39	.44	.33	.37	.78	4
6	.36	.26	.21	.19	.72	5
7	.25	.20	.22	.20	.75	6
8	.25	.15	.19	.15	.75	7
9	.25	.10	.23	.11	.74	8
10	.16	.16	.13	.11	.64	9
11	.12	.17	.13	.18	.64	10
12	.25	.40	.18	.27	.71	11
13	.15	.15	.11	.15	.70	12
14	.29	.33	.25	.33	.70	13
15	.12	.22	.13	.22	.54	14
16	.34	.28	.26	.14	.47	15
17	.05	0	.06	0	.33	16
18	.06	0	.07	0	.40	17
19	0	0	0	0	.33	18
20	0		0		.45	19
21	.10		.10		.50	20
22	.62		.38		.50	21
23	.50		.17		.50	22
24	0		0		.75	23
25	0		0		1.00	24
26	.33		.33		1.00	25

Table B-3

Number of Spacecraft in Each Thermal Environment of the Thermal-Vacuum Tests of Flight Model Spacecraft

Day	Thermal-Vacuum Environment	Figs. 2, 4, 5, 6, 9, 10, 11, 12, 16b	Fig. 3	Figs. 7, 8, 16a, A-1, A-4, w/o retest
1	Ambient	34	11	34
	Transient	32	11	31
	Cold	34	11	32
	Hot	20	11	18
2	A	25	3	13
	T	28	11	18
	C	34	11	26
	H	20	11	12
3	A	15	1	11
	T	26	10	12
	C	32	11	21
	H	19	10	10
4	A	13	1	7
	T	22	8	8
	C	30	9	15
	H	16	7	9
5	A	10	1	5
	T	16	4	5
	C	23	7	9
	H	16	7	7
6	A	5	0	3
	T	11	1	4
	C	16	2	6
	H	13	4	2
7	A	5		1
	T	6		1
	C	11		3
	H	7		0

Table B-3 (Continued)

Day	Thermal-Vacuum Environment	Figs. 2, 4, 5, 6, 9 10, 11, 12, 16b	Fig. 3	Figs. 7, 8, 16a, A-1, A-4, w/o retest
8	A	0		0
	T	2		1
	C	11		2
	H	5		0
9	A	0		0
	T	2		1
	C	9		2
	H	4		0
10	A	0		
	T	2		
	C	6		
	H	3		
11	A	0		
	T	2		
	C	3		
	H	1		
12	A	0		
	T	0		
	C	2		
	H	1		

Table B-4

Number of Spacecraft by Day in Thermal-Vacuum Tests of Flight Model Spacecraft

	All tests	Excluding retests
Day	Figs. 13, 14, 15, 17	Figs. A-2, A-3
1	34	34
2	34	34
3	34	32
4	34	31
5	33	27
6	33	26
7	32	20
8	32	20
9	31	19
10	31	18
11	31	17
12	28	15
13	27	13
14	24	9
15	24	9
16	23	7
17	18	2
18	15	1
19	15	1
20	11	
21	10	
22	8	
23	6	
24	4	
25	3	
26	3	
27	3	
28	3	

APPENDIX C

RESULTS WITH THE OGO PROGRAM INCLUDED IN THE DATA BASE

The body of this report gave the basis for excluding the OGO (Orbiting Geophysical Observatory) program from the data base. Prior to excluding the data of the OGO program several analyses were made, and those data have been included in this Appendix. Further, in order to preserve the data from the OGO program by itself several tables have been included in this Appendix. Thus future analyses may be made which compare the results of a complex observatory type spacecraft to the test and space performance of the OGO program. An interesting note is that the OGO data does not appear to alter drastically the time-temperature-failure relationships.

A comparison of the Figures in this Appendix with corresponding figures in the body of the report will support the following observations:

(1) Inclusion of the OGO data changes significantly the values of the malfunction rates (Figures C-4, C-6).

(2) Higher first day failures in the hot and cold environments in the first thermal-vacuum test (C-8).

(3) Inclusion of the OGO data raises the percent of spacecraft with a malfunction (Figs. C-9, C-10, C-11).

(4) For other comparisons neither the trend nor the interpretation of data is significantly different by the inclusion of the OGO data.

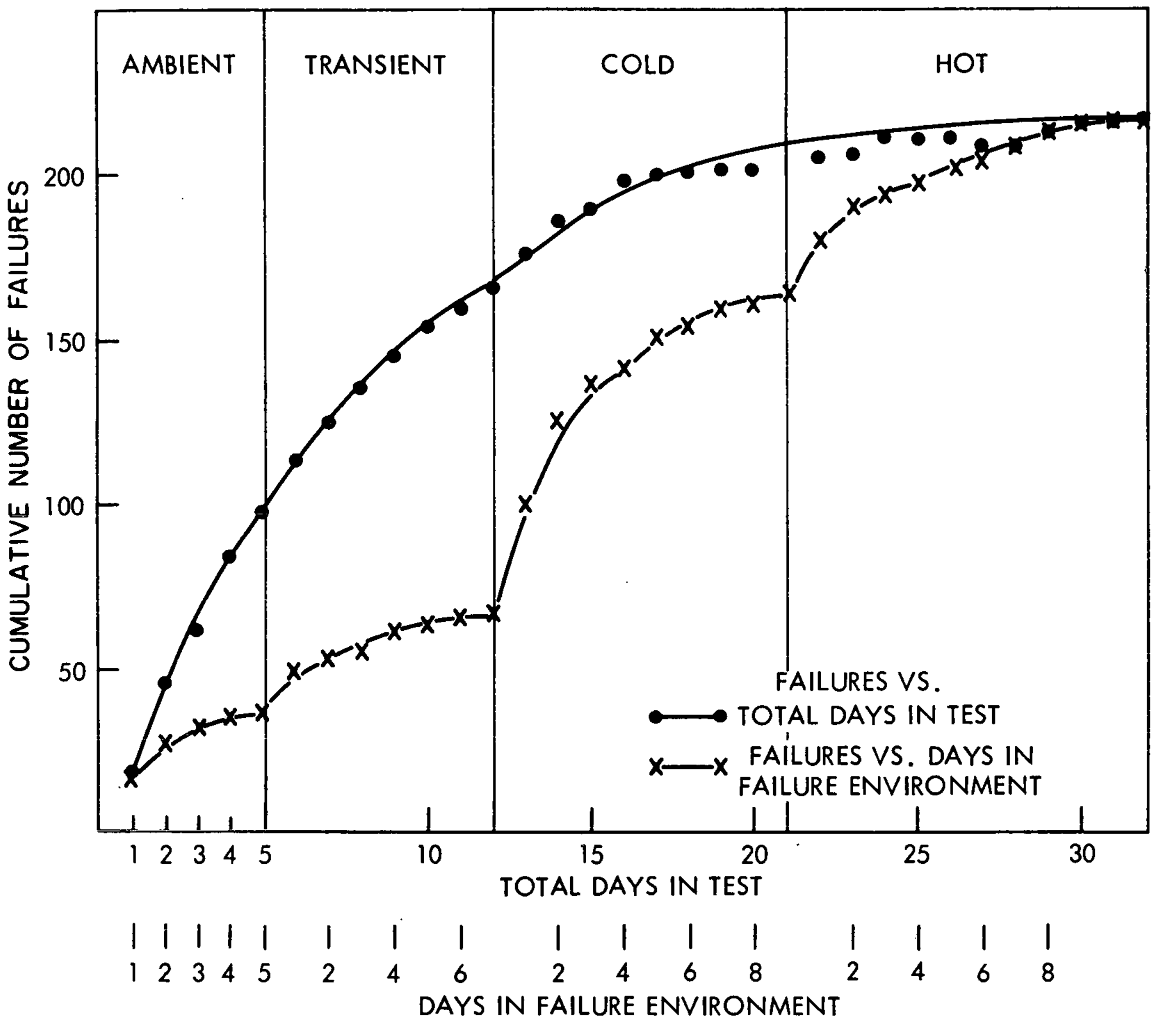


Figure C-1. Thermal-Vacuum Failures of 39 Flight Spacecraft versus Time and Environment

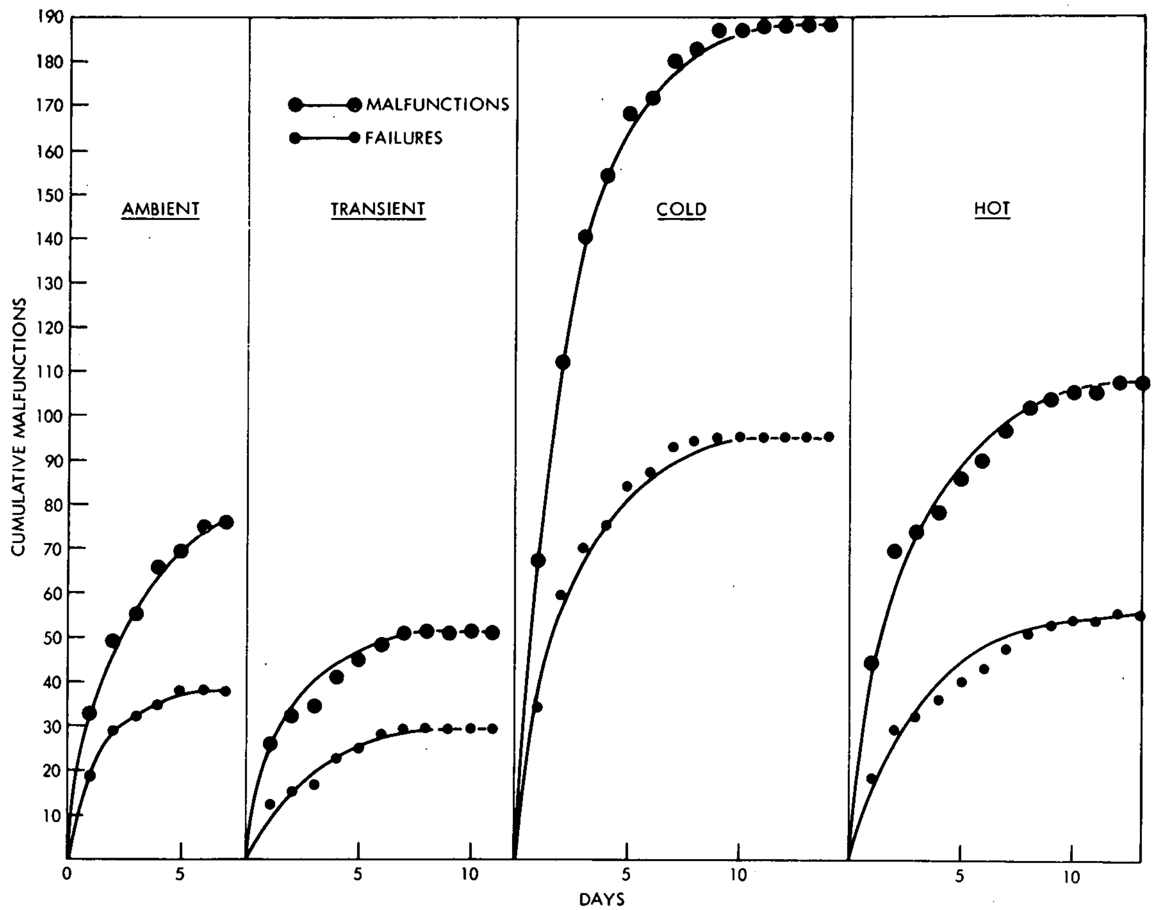


Figure C-2. Thermal-Vacuum Malfunctions of 39 Flight Spacecraft versus Time and Environment

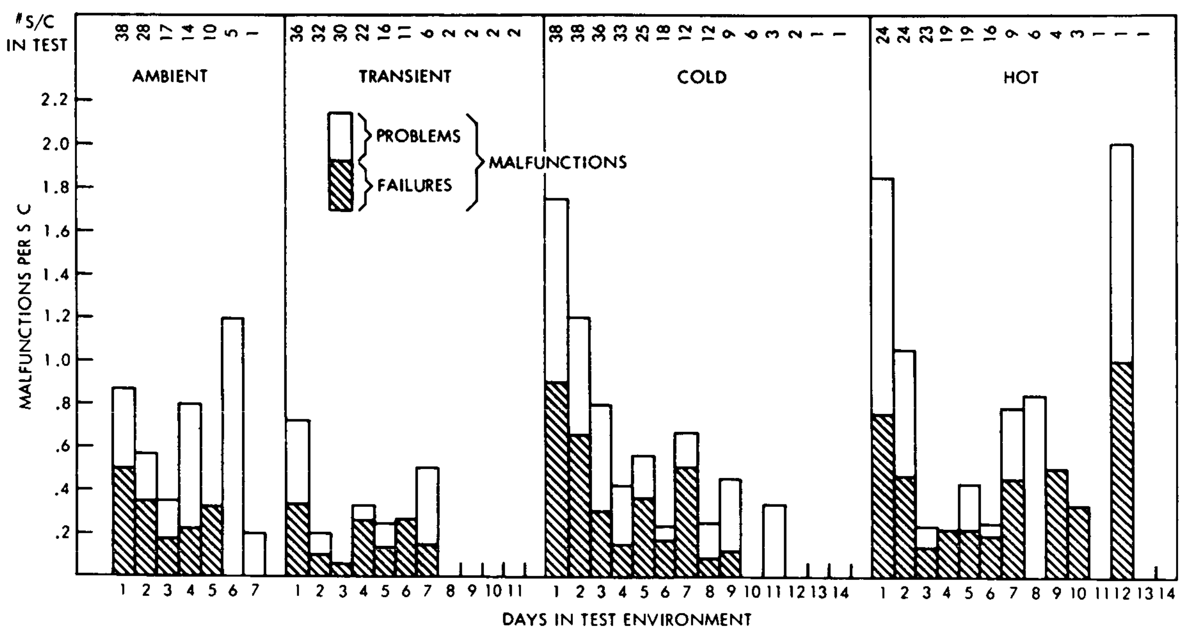


Figure C-3. Normalized Thermal-Vacuum Malfunctions of Flight Spacecraft by Day and Environment

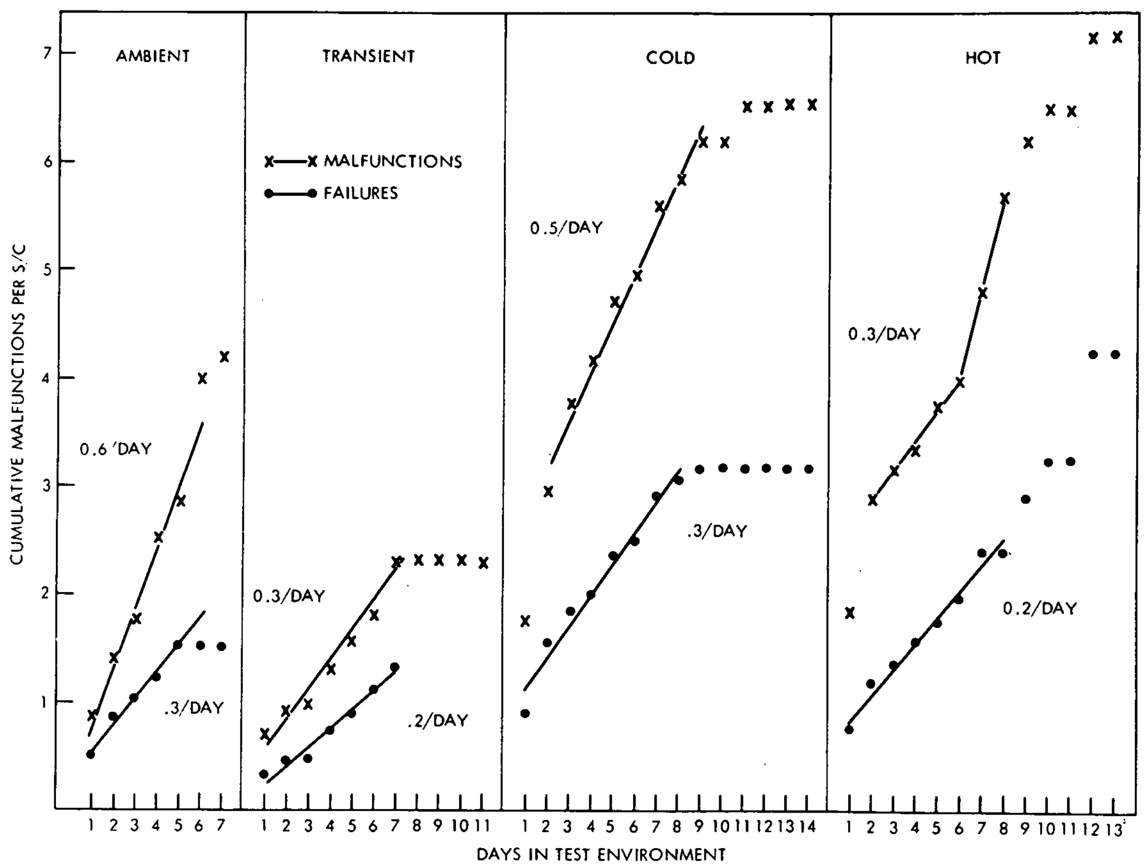


Figure C-4. Malfunction Rates of Flight Spacecraft in Thermal-Vacuum Tests

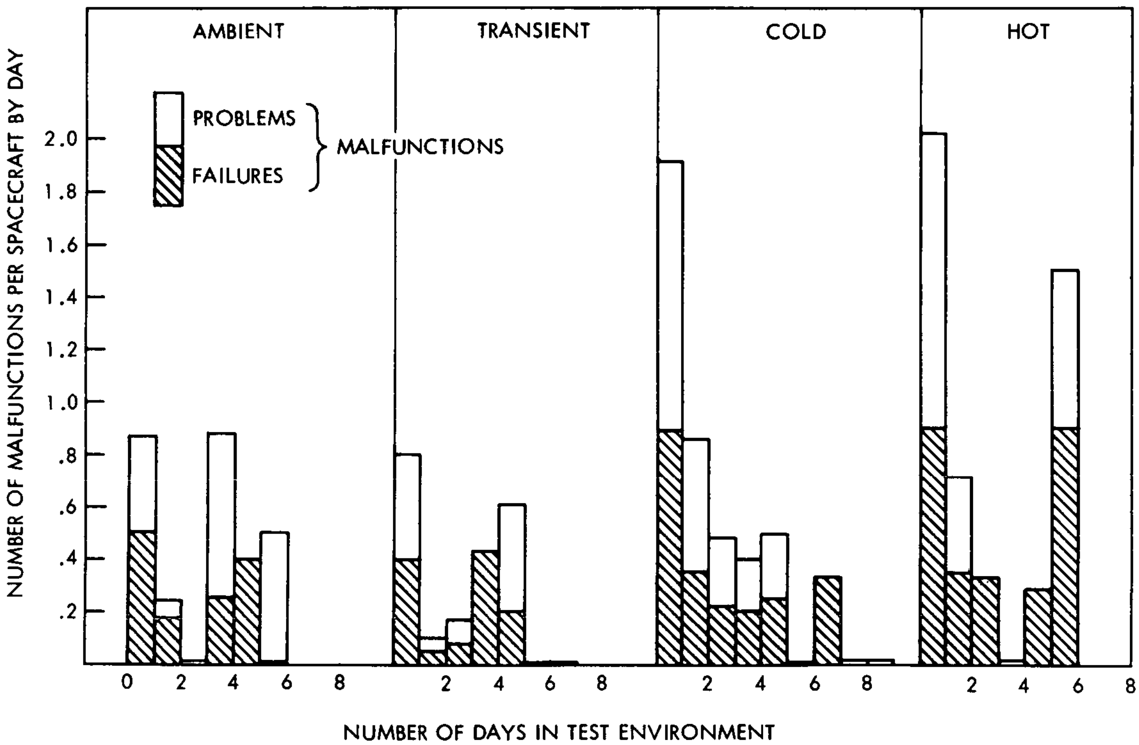


Figure C-5. Malfunctions in Thermal-Vacuum Tests of Flight Spacecraft Excluding Retests

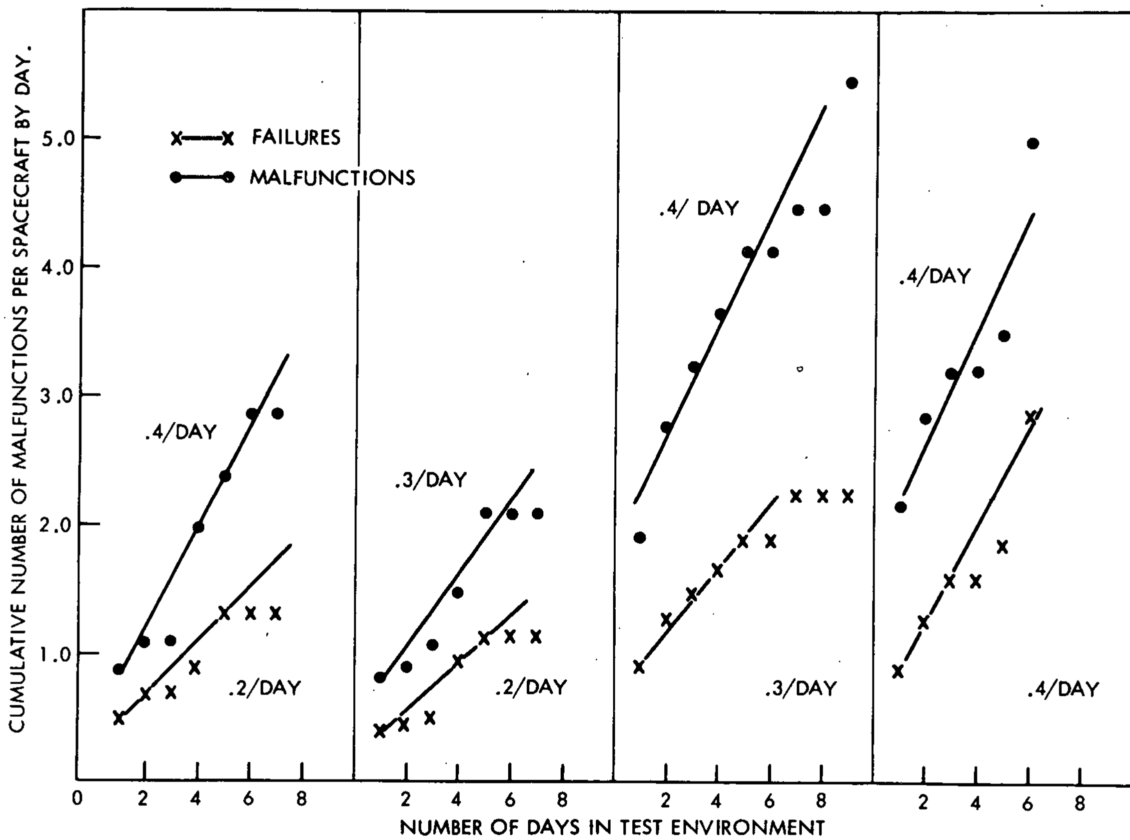


Figure C-6. Malfunction Rates of Flight Spacecraft in First Thermal-Vacuum Tests (Retests Excluded)

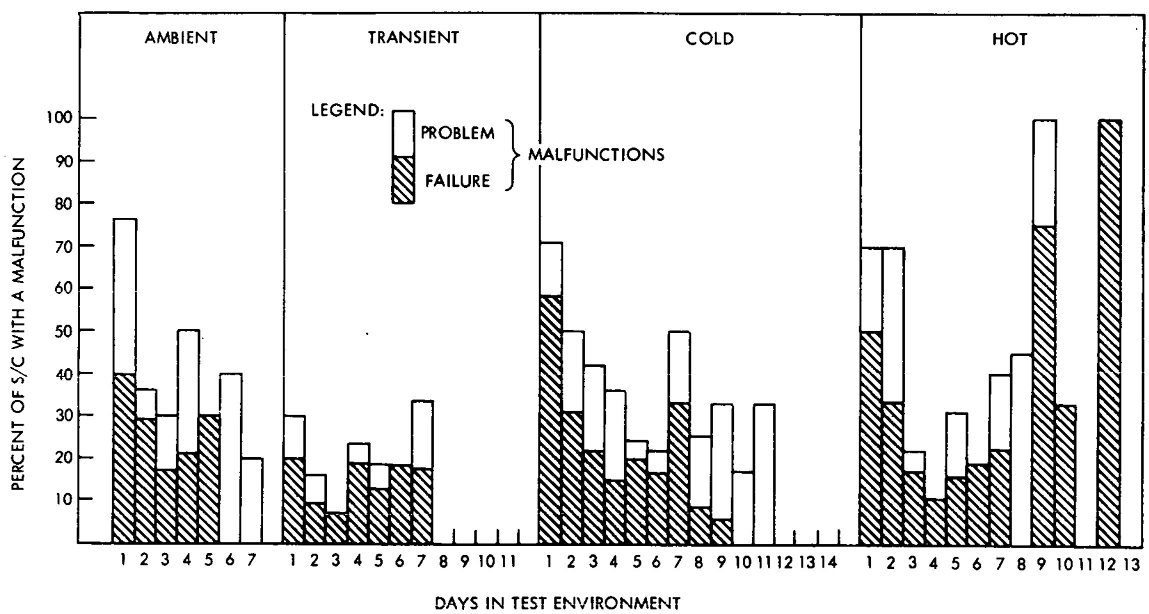


Figure C-7. Probability (versus Time and Environment) of a Malfunction in Flight Spacecraft During Thermal-Vacuum Tests

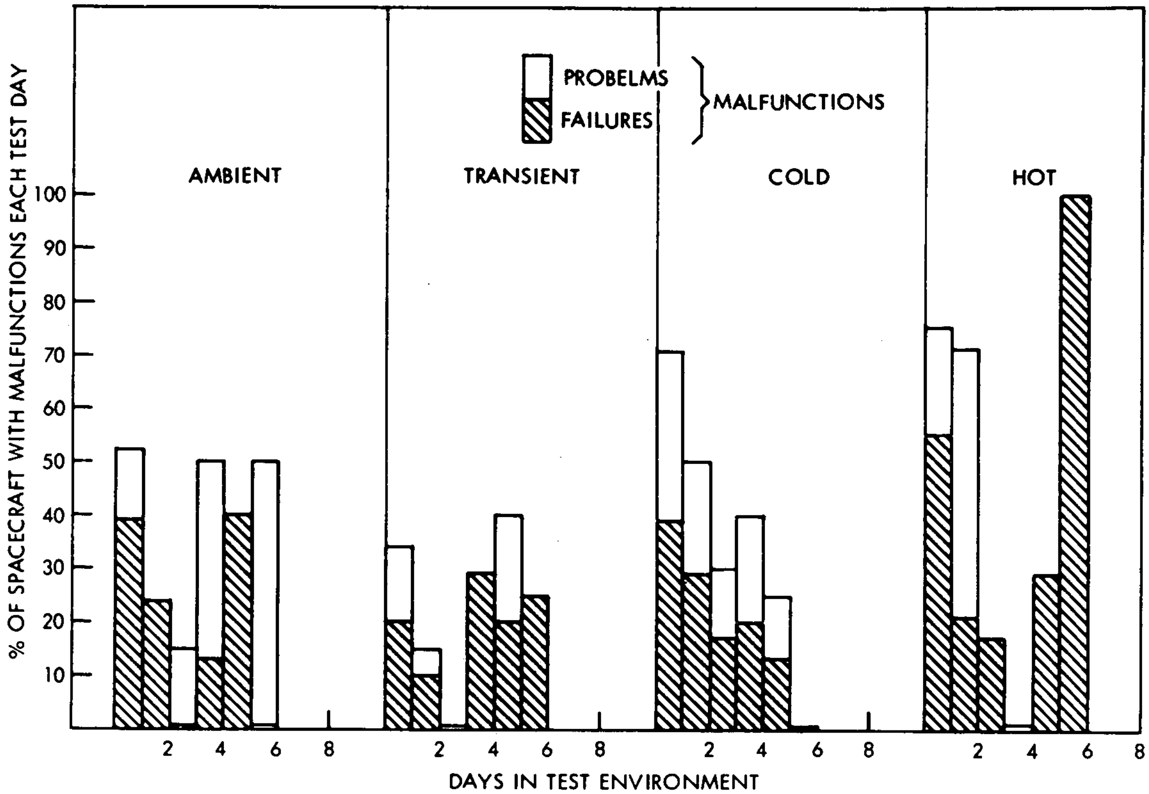


Figure C-8. Probability (versus Time and Environment) of a Malfunction in Flight Spacecraft During a First Thermal-Vacuum Test (Retests Excluded)

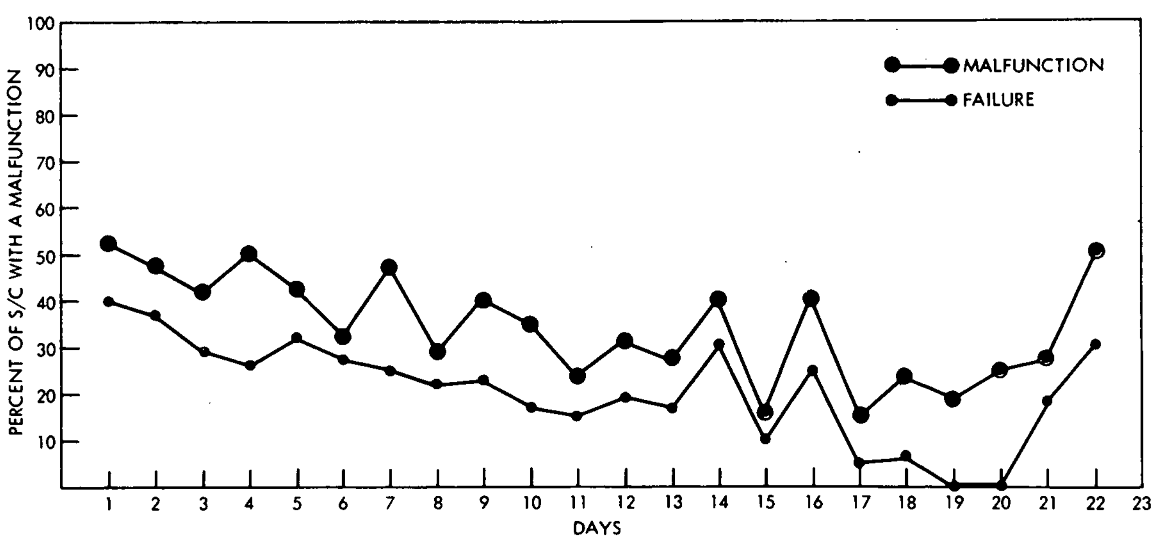


Figure C-9. Probability (versus Time) of a Malfunction in Thermal-Vacuum Tests as Conducted

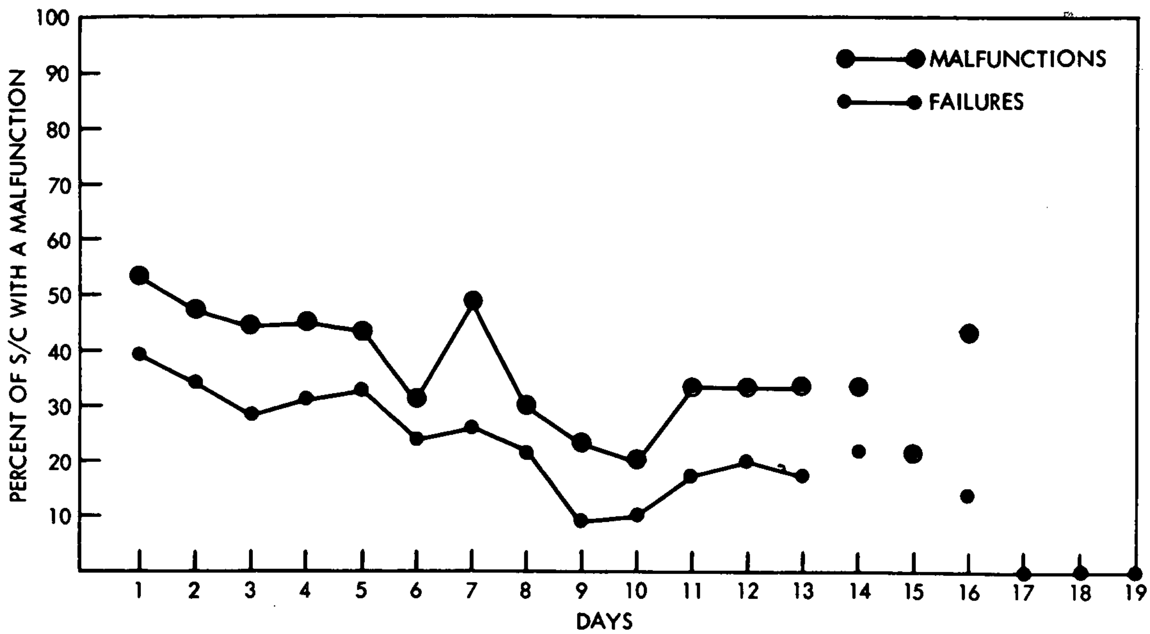


Figure C-10. Probability (versus Time) of a Malfunction in Thermal-Vacuum Tests as Conducted (Retests Excluded)

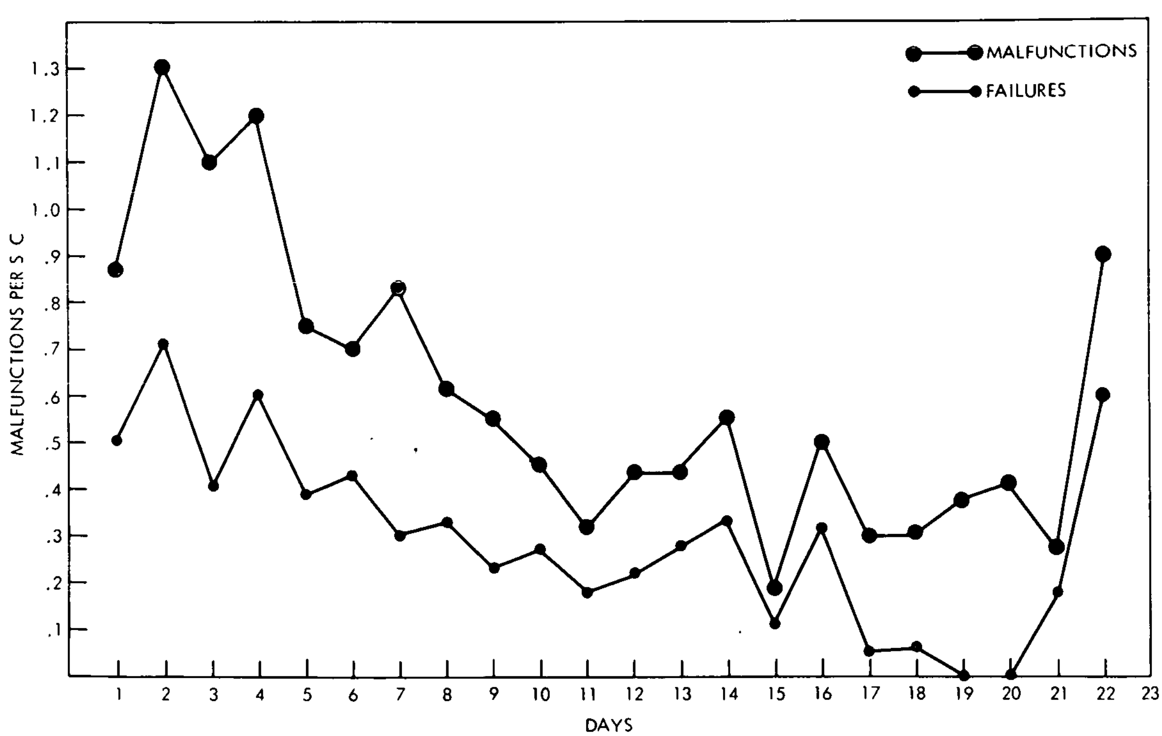


Figure C-11. Malfunctions per Spacecraft by Day in Thermal-Vacuum Tests as Conducted

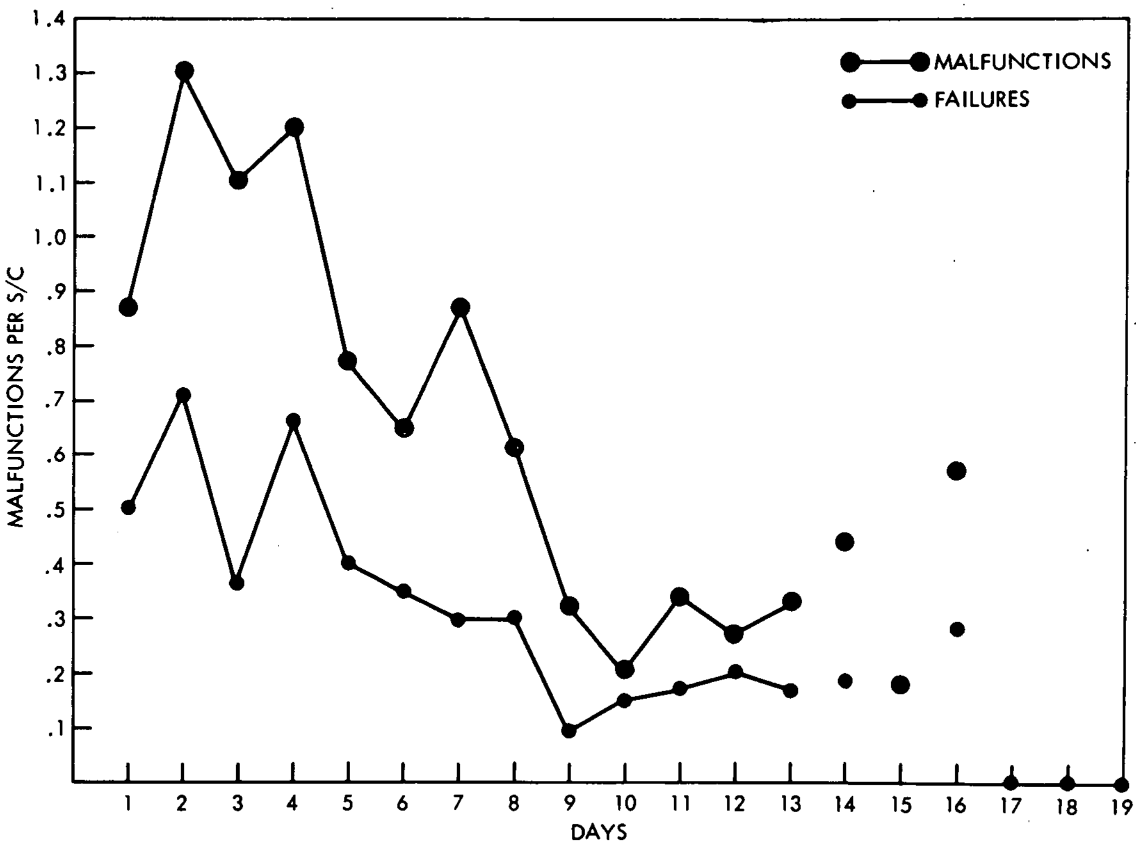


Figure C-12. Malfunctions per Spacecraft by Day in Thermal-Vacuum Tests (Excluding Retests)

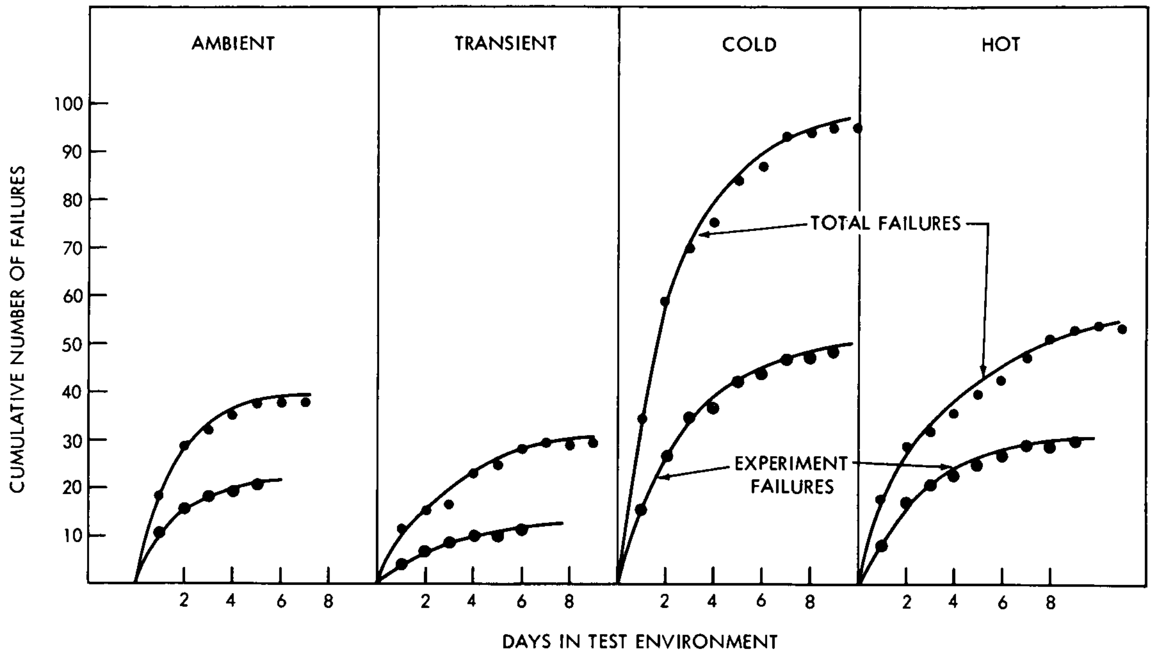


Figure C-13. Comparison of Experiment Failures with Total Failures in Thermal-Vacuum Tests of Flight Spacecraft

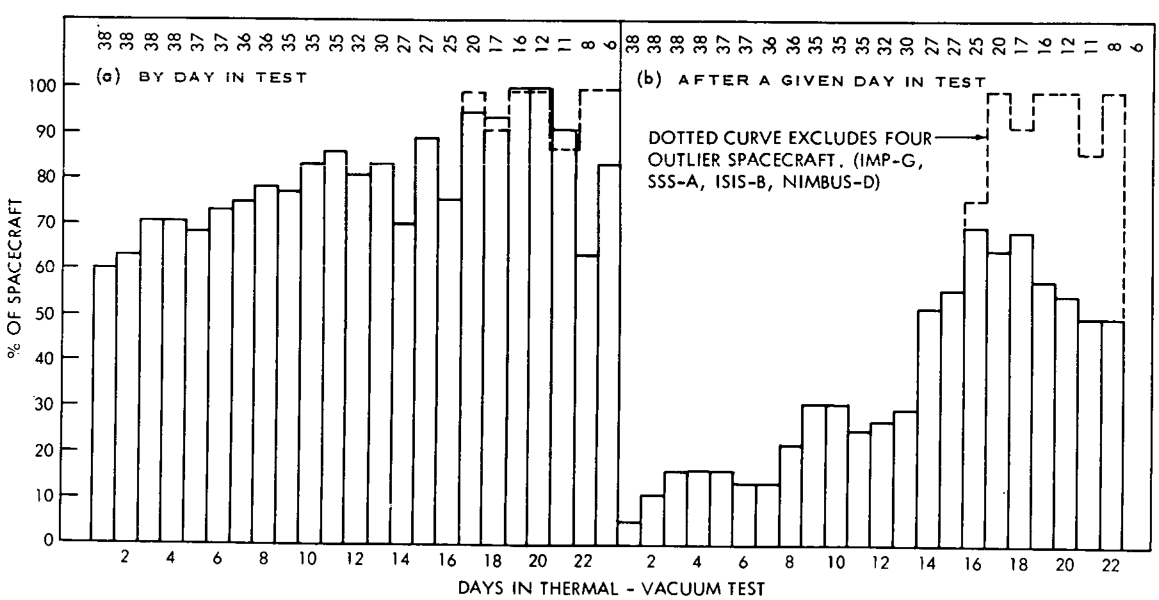


Figure C-14. Probability (versus Time) of a Spacecraft with No Failures

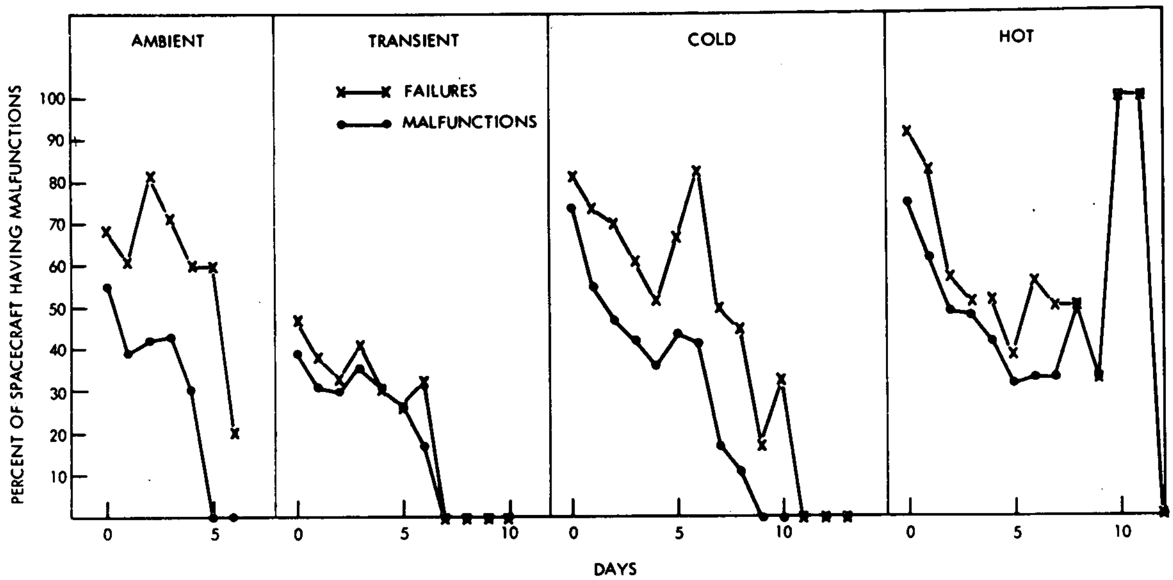


Figure C-15. Probability (versus Time and Environment) of a Malfunction after Each Day in Each Environment

Table C-1

Comparison of Malfunction Rates With and Without the OGO (Orbiting Geophysical Observatory) Data

Thermal-Vacuum Test Environment	Malfunction Rates*		Failure Rates*	
	With OGO data	Without OGO data	With OGO data	Without OGO data
Ambient	0.6	0.5	0.3	0.2
Transient	0.3	0.3	0.2	0.2
Cold	0.5	0.4	0.3	0.3
Hot	0.3	0.2	0.2	0.1

* The rates are per day, after day 2 to day 7.

Table C-2

Occurrence of OGO Malfunctions in Thermal-Vacuum Tests

Test Day	Test Environment							
	Ambient		Transient		Cold		Hot	
	Malfunctions	Failures	Malfunctions	Failures	Malfunctions	Failures	Malfunctions	Failures
1	8(5)*	4(5)	4(5)	2(5)	13(5)	7(5)	11(5)	4(5)
2	3(3)	1(5)	0(5)	0(5)	14(5)	10(5)	6(5)	4(5)
3	1(2)	0(3)	0(5)	0(5)	7(5)	3(5)	2(5)	2(5)
4	2(1)	1(1)	0(1)	0(1)	2(4)	0(4)	3(3)	3(3)
5	-	-	-	-	4(3)	3(3)	3(3)	2(3)
6	-	-	-	-	2(2)	2(2)	1(3)	1(3)
7	-	-	-	-	0(1)	0(1)	0(1)	0(1)
8	-	-	-	-	1(1)	0(1)	2(1)	0(1)

* Figures in parentheses are the number of spacecraft under test.