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TIME REQUIRED FOR AN ADEQUATE THERMAL-VACUUM TEST OF FLIGHT MODEL SPACECRAFT

by A. R. Timmins

Goddard Space Flight Center
Greenbelt, Md.

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ABSTRACT

The test philosophy at the Goddard Space Flight Center emphasizes system testing of flight spacecraft. This report presents data from the thermal-vacuum tests of 11 flight spacecraft.

The data show that total test time is not as important as the time required at four kinds of thermal stress levels. The data base was chosen to include three programs of differing complexity and differing test emphasis, prior to the system test. The individual and collective data indicate a minimum thermal-vacuum system test time of 13 days regardless of the prior test program. The 13 days need to be distributed as follows: 1, 4, 4, and 4 for ambient, transient, cold, and hot thermal-vacuum environments, respectively.

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by

A. R. Timmins*

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INTRODUCTION

One of the cornerstones of test philosophy at the Goddard Space Flight Center is the system tests of the flight spacecraft under environmental stress. Aside from the required tests on the flight spacecraft, there is considerable variation among programs in the amount, severity, and kinds of testing. On the basis of the particular circumstances of his program, the project manager decides if a prototype spacecraft, an engineering model spacecraft, or a thermal model spacecraft will be needed. He also decides the amount of testing to be done at the subsystem level and the piece part level. Among his prerogatives are decisions on the use of many other quality assurance techniques, such as burn-in of electronic parts.

One of the required tests on a flight spacecraft is conducted under simulated space conditions. With respect to this test, an intriguing question is, "How long should the test be conducted in order to eliminate infant mortality failures?" References 1, 2, and 3 discuss the "bathtub" curve (see Figure 1) and the infant mortality region of the curve. While the curve is useful conceptually, it does not answer such questions as: (1) What test time is required to eliminate infant mortality failures? (2) Does each kind of stress produce a distinctive infant mortality result? (3) What is the effect of prior testing at the subsystem level on the system test time requirement?

To assess our practice, a study was made of the past experience at Goddard Space Flight Center. This report reviews the simulated space tests on the IMP, OGO, and Nimbus flight spacecraft. These programs have had different emphases on the amount of testing at the system, subsystem, and piece part level, and the effect of this variation is reviewed. Another aspect included is the performance of the experiments compared with the balance of the

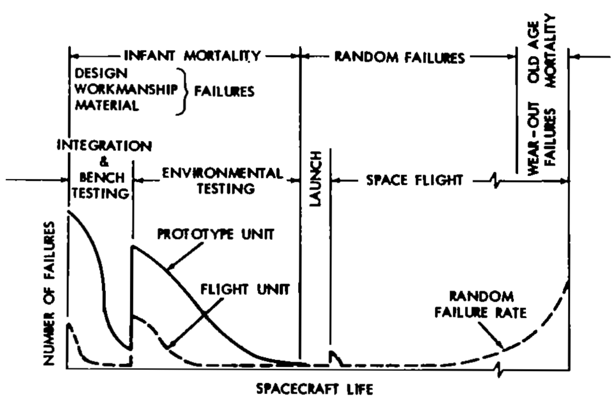


Figure 1—Theoretical failure pattern.

*Test and Evaluation Division.

spacecraft. In general, stringent quality-control activities have not been required of experimenters; therefore, the performance of their hardware in the simulated space test of the flight spacecraft will be examined separately. In addition to discussing these interesting but subordinate points, the review is directed to the principal question: "How long should a flight spacecraft be tested in a simulated space environment?"

LIMITATIONS OF STUDY

The review encompasses the results of the thermal-vacuum tests conducted on selected flight spacecraft. Some of the programs also included solar simulation tests, but those are not included here. A separate study on such tests is in order.

The review does not deal with the effect of a prototype spacecraft on the test results. For the record, the OGO program had a prototype observatory, but it was tested in a thermal-vacuum environment after the first flight observatory test. On the other hand, the prototype Nimbus spacecraft was tested extensively before the flight spacecraft was tested. On the IMP program the role of a prototype spacecraft is even more clouded, as shown by Table 1:

Table 1

Roles of IMP Prototype Spacecraft.

Program	Note
IMP-A	Prototype spacecraft was launched
IMP-B	Prototype data from IMP-A
IMP-C	Prototype data from IMP-A
AIMP-D	Prototype and flight spacecraft
AIMP-E	Prototype and flight spacecraft
IMP-F	Proto-flight spacecraft (one spacecraft)

The effect, if any, of subsystems tests on system test performance will of necessity be judged indirectly. Records are not available of the number or results of such tests for all of the spacecraft under review.

On the other hand, there is the following distinction between the programs:

1. IMP—Subsystem tests were not mandatory, but were performed on a selective basis (Explorer-type spacecraft (100 to 200 pounds) with 9 to 11 experiments).

2. OGO—Subsystem tests required on prototype and flight hardware. Flight hardware subsystems tested for 1 day, prototype hardware subsystems tested for 2 days in thermal-vacuum environment (Observatory-type spacecraft (1200-pound class) with 20 experiments).

3. Nimbus—Most extensive testing of any Goddard program. Subsystems were tested for 12 days. In addition, a sensory ring (about 75 percent of the spacecraft) thermal-vacuum test was conducted for 10 days prior to the test of the complete spacecraft. The spacecraft weighed 800 to 1300 pounds and included 8 to 10 experiments.

No method is available of satisfactorily normalizing the effect of differing complexity on the test results. This, together with the use of differing numbers of spacecraft per program, precludes using the number of failures as a basis for comparison. The programs are compared by means of a technique that uses failures versus time and environment.

SOURCE OF DATA

The data base comprises about 175 thermal-vacuum test days of flight spacecraft, distributed as shown in Table 2.

The IMP spacecraft included A, B, C, D, E, and F (see Table 1). The OGO spacecraft were A, C, and D (OGO-B had only a solar simulation test). The Nimbus spacecraft were A and C. (Nimbus B followed Nimbus C.)

The data were obtained from the following sources: (1) test and evaluation (T&E) support managers' box scores, (2) reports from T&E project engineers, (3) director's weekly reports, (4) official contractors' reports, and (5) malfunction reports.

Table 2

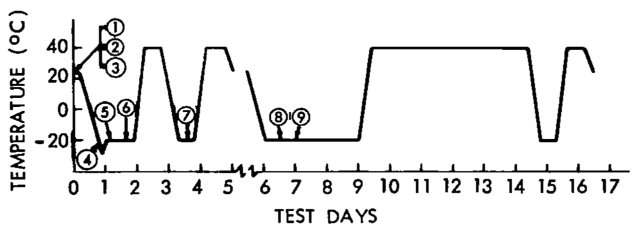
Data Base.

Program	Number of Spacecraft	Test Days	Average Test Days per Spacecraft
IMP	6	94	16
OGO	3	41	14
NIMBUS	2	41	20
TOTAL	11	176	16

FAILURE DATA

For each thermal-vacuum test of the flight spacecraft a thermal profile versus time was made. Each failure was indicated on the thermal profile, as shown by the example in Figure 2. From the individual thermal profiles, summary tables and graphs (Tables 3, 4, and 5, and Figures 3, 4, and 5) were prepared.

Each failure was reviewed to verify its classification. A failure was defined as having occurred when any item could not perform its function. In most cases the item was then removed from the spacecraft for rework or replacement. Available information on each failure was reviewed, in order to associate the failure with the thermal environment causing the failure.



Item Number	Failure or Malfunction	Identification
1	F	MIT Experiment
2	F	Ion & electron experiment
3	F	Optical aspect computer
4	M	Ion & electron experiment
5	M	GSFC magnetometer experiment
6	F	Attitude control system
7	F	Performance parameter card
8	M	Optical aspect moon time
9	M	Iowa experiment

Figure 2—Typical thermal-vacuum test profile.

The failures were then segregated into the following thermal categories:

1. Ambient (25 °C ±5 °C)
2. Transient
3. Cold (below 20 °C)
4. Hot (above 30 °C)

Table 3

Distribution of Thermal-Vacuum Failures from 11 Flight Spacecraft[1] by Environment and Test Days.

Environment	Test Days[2]										Failures	
	1	2	3	4	5	6	7	8	9	10	Total	Average/Spacecraft
Ambient	9	0	0	0	0						9	0.8
Transient	0	1	1	5	1	0	0				8	0.7
Cold	20	9	1	3	0	0	0	0			33	3.0
Hot	7	3	2	0	0	0	0	0			12	1.1
Total											62	5.6

[1]6 IMP, 3 OGO, and 2 Nimbus spacecraft.
[2]Test days are not consecutive.

Table 4

Distribution of Thermal-Vacuum Failures from 11 Flight Spacecraft[3] by Environment Test Program and Test Days.

Environment	Spacecraft[3]	Test Days[5]										Failures	
		1	2	3	4	5	6	7	8	9	10	Total	Average/Spacecraft
Ambient	IMP	5	0									5	1.0
	OGO	2	0									2	1.0
	Nimbus	2	0	0	0	0						2	1.0
Transition	IMP	0	0	0	3	0						3	0.5
	OGO	0	0	0								0	---
	Nimbus	0	1	1	2	1	0	0				5	2.5
Cold	IMP	6	3	1	0	0	0					10	1.7
	OGO	12[4]	6	0	2	0	0	0	0			20	6.7
	Nimbus	2	0	0	1	0						3	1.5
Hot	IMP	2	1	1	0	0	0					4	0.7
	OGO	2	1	1	0	0	0	0	0			4	1.3
	Nimbus	3	1	0	0	0	0	0	0			4	2.0
Total												62	5.6

[3]6 IMP, 3 OGO, and 2 Nimbus spacecraft.
[4]Five associated with poor connections and/or connectors.
[5]Test days are not consecutive.

A failure in any of these environments was assumed to be the result of that environment alone, even if one of the other environments preceded it. For instance, if a 4-day test was conducted consisting of 1 day at each of the above listed environments, and a failure occurred on day 3 (cold), it would be classed as a 1-day cold failure. If the test lasted 8 days, the same sequence as before but with the sequence repeated, and a failure occurred on the seventh day, it would be classed as a 2-day cold failure.

The amount of bias introduced by this treatment is not known. However, the results show clearly that several infant mortality periods must be covered in a simulated space test.

An additional simplification was used for the transient failures. These failures were detected at a time when the temperature of the spacecraft was being changed from one level to another. Each transient was assumed to last 12 hours, regardless of the temperature difference between levels and regardless of the direction of the temperature change. This simplification, two transients per day, permitted the presentation of these data in the same manner as the other three thermal environments.

The usefulness of failure data is influenced by two conflicting requirements. An insufficient amount limits confidence in summarized results, and the need for recency (especially so with fast-moving space technology) tends to limit the amount of spacecraft data. To maintain the usefulness of the data from the present study, detailed tables have been included in Appendix A in a form that can be used to add to the amount of data or to substitute recent for outmoded data.

MALFUNCTION DATA

A malfunction is defined as any performance outside the specified limits. Thus, the malfunction data include all failures and, in addition, include substandard performance. Examples of malfunctions which were not failures are: (1) voltages outside specification at one (or both) temperature extremes; (2) equipment nonoperable at low temperatures though satisfactory on return to normal temperature; (3) temporary shift in modulation, synchronization, frequency, etc.

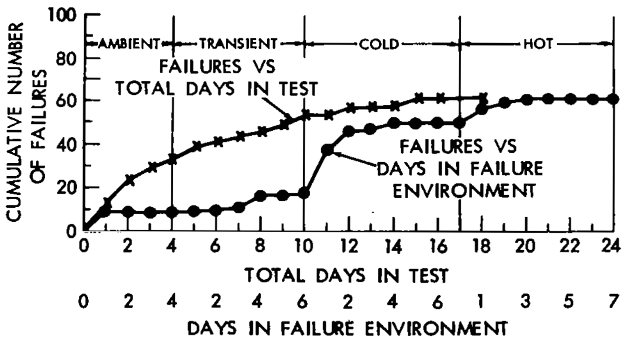


Figure 3—Thermal-vacuum failures of flight spacecraft versus time and environment.

The malfunction data were reviewed in the same manner as the failure data, and similarly put on thermal profile plots. From the individual thermal profiles, summarized graphs (Figures 6 and 7) were developed. The same assumptions and treatment of data were made with respect to time of occurrence of a malfunction and environment of a malfunction as with the failure data. Some detailed malfunction data are included in Appendix A in a form that can be used to increase the sample size or to substitute recent for outmoded data.

DISCUSSION OF FAILURE DATA

Failures Versus Environments

The most significant feature of Figure 3 is related to the infant mortality region of the "bathtub" curve. The top curve, FAILURES VS. TOTAL DAYS IN TEST, is in time sequence and would be valid if the cause of failure was only time in vacuum. This curve is not related to the four thermal environments shown. It was constructed by summarizing all failures by the day on which they occurred, and plotting them cumulatively. The second curve, FAILURES VS. DAYS IN FAILURE ENVIRONMENT, was constructed by segregating the data into four thermal environments, and plotting failures in each environment in time sequence. The order of the four thermal environments for the bottom curve is arbitrary. The data show that total days under a simulated space environment give a curve distinctly different from one constructed according to four thermal environments used in the tests. The important feature is that each of the four thermal environments appears to have a time-dependent plateau. This apparently indicates an infant mortality region for each of the four thermal environments. Extending this interpretation leads one to ask if there are other types of thermal stress that may exist in space but are not covered in the simulated space test reported on here. For instance, the thermal-vacuum test data reported herein included no instances where energy was radiated to one side of the spacecraft while the other side radiated to the simulated cold of space. Such stresses can be simulated (solar simulation test) but are not part of the present study.

Comments on each of the four phases of the thermal-vacuum tests as shown in Figure 3 follow below.

1. Ambient failures—Most of these failures were detected either in pretest checkouts or in the early part of the test before thermal conditioning was started. There is no need indicated for additional testing in this environment. However, a requirement for a full day of operation in this environment is an efficient way to eliminate non-thermal-related failures.
2. Transient failures—The data base for these failures is considered somewhat weak. This part of a test is not normally monitored as completely as those parts when thermal equilibrium exists. In some cases a complete spacecraft checkout is deferred until the new thermal level is reached. Despite these test and reporting limitations, the data show that transient temperature failures occurred after 2, 3, and 4 days of this type of conditioning.
3. Cold failures—The data show that this environment contributed about 55 percent of the total failures. Some of the first-day cold failures may have been caused by transient failures that were not detected until a complete checkout after thermal stabilization. Also, some of these first-day cold failures would possibly have occurred if the hot phase had occurred first. Nevertheless, these uncertainties are not sufficient to change the strong effect of this environment. Even if all the first-day cold failures were discounted, the total number of cold failures would still be greater than for any of the other environments. Figure 3 shows that a minimum of 4 days is needed to reach the plateau in this environment. These results agree with two previous studies, References 4 and 5, which pointed out the need for adequate cold temperature testing.

4. Hot failures—These failures average about one per flight spacecraft. None of the failures occurred after 3 days at this thermal level, but the number of spacecraft under test should be noted (Table 5). Whereas all 11 spacecraft were tested for 2 days, only seven of the spacecraft were tested for more than 3 days. In other words, the curve should be regarded as a minimum with respect to the time necessary to reach the plateau.

Table 5

Number of Spacecraft per Test Day.

Environment	Spacecraft[7]	Test Days[6]										Total Test Days
		1	2	3	4	5	6	7	8	9	10	
Ambient	IMP	6	0									6
	OGO	3	1	0								4
	Nimbus	2	2	1	1	1	0					7
Transition	IMP	6	6	6	6	3	1	0				28
	OGO	3	3	2	0							8
	Nimbus	2	2	2	2	2	1	1				12
Cold	IMP	6	6	6	5	5	1	0				29
	OGO	3	3	3	2	2	1	1	1	0		16
	Nimbus	2	2	2	2	1	0					9
Hot	IMP	6	6	6	4	4	3	2	0			31
	OGO	3	3	2	1	1	1	1	1	0		13
	Nimbus	2	2	2	2	2	1	1	1	0		13
TOTAL												176

[6] For example: Both Nimbus spacecraft were tested under transient thermal conditioning for 5 days (not consecutive). One of the two was tested for 7 days.
[7] 6 IMP, 3 OGO, and 2 Nimbus spacecraft.

Failures Per Program

The three programs under study are quite different with respect to weight, complexity, number of piece parts and subsystems, and funding. Attempts to normalize these factors were unsatisfactory and demonstrated that meaningful comparisons could not be made on the basis of the number of failures. However, it was desired to know the effect of the amount of subsystem testing before the test of the complete spacecraft. (Table 6 shows the differences between the three programs with respect to test requirements.) One premise which was not based on the total number of failures but should be useful in comparing the programs is as follows: If the three programs had differing effectiveness in eliminating infant mortality failures prior to the thermal-vacuum test of the flight spacecraft, then the time taken to reach a plateau in the four thermal phases of the system test should be different. Figure 4 illustrates this kind of comparison; the following comments are applicable:

Table 6

Piece Parts and Subsystems Test Requirements.

Environment	Required Subsystem Tests		Required Burn-In of Piece Parts		Required Preferred Parts	
	Experiments	Other	Experiments	Other	Experiments	Other
IMP-A	No	No	No	No	No	No
-B	↓	↓	↓	↓	↓	↓
-C						
-D						
-E						
-F	Yes	Yes				
OGO-A	Yes	Yes	No	No	No	Yes
-C	Yes	Yes	No	No	No	Yes[9]
-D	Yes	Yes	No	Yes	Yes	Yes[9]
Nimbus-A	Yes	Yes	No[8]	No[8]	No	No
-C	Yes	Yes	No[8]	No[8]	No	No

[8]Required 1000-hour bake or 300-hour burn-in.
[9]Contractor list.

1. IMP program—Figure 4 summarizes data for all six IMP spacecraft. A plateau was reached in 3 days or less for the ambient, cold, and hot phases. The only transient failures occurred between six and eight transients (two transients per day). As discussed before, there may be a few failures in the other phases which should be in the transient phase. The summarized data in Figure 4 indicate that adequate test times have been used for the thermal-vacuum tests of the flight spacecraft. Several cautions need mention in the use of these composite data. (1) All spacecraft were not tested for the same length of time; Table 3 shows the number of spacecraft per test day per phase. (2) Figure 4 summarizes only the failures. A summary of total malfunctions (failures plus undesired limitations) is presented in Figure 7. (3) The summarized data do not take into account learning curve improvement. IMP B had two failures and IMP C no failures while IMP D had seven failures. This trend agrees with the IMP learning curve where the B and C spacecraft were very similar to the A spacecraft, but IMP D underwent major design, mission, and hardware changes.

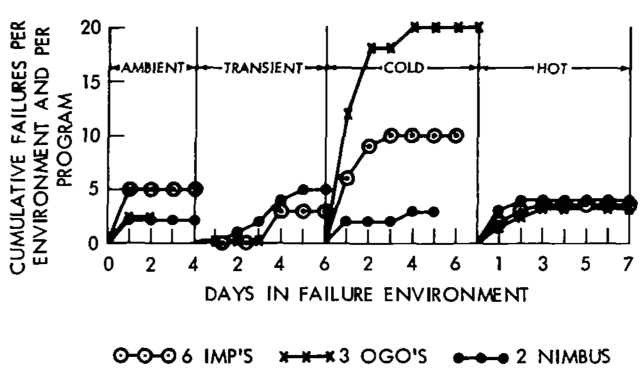


Figure 4—Thermal-vacuum failures of flight spacecraft by environment, program, and time.

2. OGO program—The summarized data for OGO-A, -C, and -D are shown in Figure 4. Plateaus for the ambient, cold, and hot phases were reached in 1, 4, and 3 days, respectively. The results for the transient phase show no

failures at all. How many may have occurred in this phase but were reported in a different phase is not known. The integrated System Test for this observatory takes about 8 hours to complete, so considerable leeway exists in the time when a failure is first detected.

3. Nimbus program—Figure 4 shows the summarized data for Nimbus A and C. Plateaus for the ambient, cold, and hot phases were reached in 1, 4, and 2 days, respectively. The data for the transient phase show failures occurring up to and including 10 transients (equivalent to 5 days of this type of conditioning). The reason that this environment appears more significant for this program is attributed to more exposure to testing of this kind (Table 5) and excellent documentation. While transients have always been a part of the thermal-vacuum test, these data suggest that additional emphasis may be fruitful. The data do not demonstrate a superiority of one program over the others when the "time to plateau" criterion is used. If a program utilizing a philosophy of maximum testing prior to integration had shown a superiority in the "time to plateau" criterion, then a benefit could be inferred. However, the opposite interpretation—subsystem testing does not affect system test results—is not warranted. What the results would have been if no subsystems tests had been made on all the programs is not known. The conclusion that can be made is that a simulated space test on the flight spacecraft was needed for all three programs.

Experiments Versus Other Subsystems

Figure 5 presents summarized failure data on 11 flight spacecraft on this subject. The data show no significant difference in the number or occurrence of failures between the experiments and other subsystems. The observation is valid for each of the four environmental phases shown. The data show a slightly different result when examined by program. Table 7 shows a detailed comparison by spacecraft and by program. The percentages of failures ascribed to experiments were 64, 54, and 14 percent, respectively, for the IMP, OGO, and Nimbus programs. It has been said that experiments cause most of the problems encountered during the test phase of a program. The data show this to be true on individual spacecraft, but not in general.

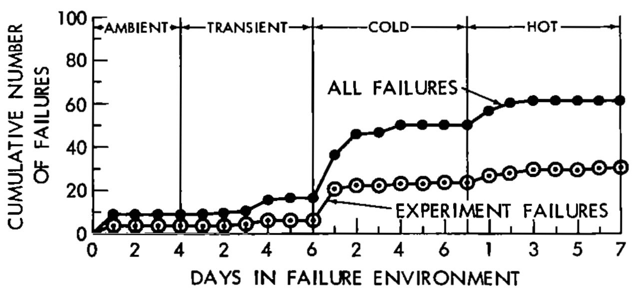


Figure 5—Comparison of experiment failures with total failures in thermal-vacuum tests of flight spacecraft.

DISCUSSION OF MALFUNCTION DATA

The data discussed thus far have dealt only with failures, that is, difficulties serious enough to preclude satisfactory operation in space. Generally, the items were repaired or replaced before flight. In addition to the failures, there were other instances of unsatisfactory performance: intermittent operation, equipment outside tolerance, inoperable though undamaged at temperature extremes, temporarily out of synchronization, etc. If our objective is to detect and correct these malfunctions in addition to the failures, testing may take longer than it does for failures alone. Such data have been accumulated and summarized in the same manner as the failure data. The

Table 7

Comparison of Experiments with Other Subsystem Failures and Malfunctions.

Spacecraft	Failures		Malfunctions[10]		Totals	
	Experiments	Other Subsystems	Experiments	Other Subsystems	Failures	Malfunctions
IMP-A	3	1	11	2	4	13
IMP-B	2	0	6	2	2	8
IMP-C	0	0	2	4	0	6
IMP-D	3	4	9	6	7	15
IMP-E	2	3	5	4	5	9
IMP-F	4	0	8	4	4	12
Subtotal	14	8	41	22	22	63
OGO-A	3	4	5	6	7	11
OGO-C	9	6	11	10	15	21
OGO-D	2	2	5	9	4	14
Subtotal	14	12	21	25	26	46
Nimbus I	0	6	1	9	6	10
Nimbus II	2	6	8	3	8	11
Subtotal	2	12	9	12	14	21
Grand Total	30	32	71	59	62	130
Grand Total in %	48	52	55	45	48	100

[10]*Failures plus other anomalies (out-of-specification, out-of-tolerance, intermittents, etc.).*

data to be discussed are identified as malfunction data. The data include all the failure data discussed previously, but also include all the other discrepancies that affect the spacecraft performance. The summarized data are displayed graphically in Figures 6 and 7. In general, the same trends are evident for the malfunction data as have already been discussed for the failure data. Specific comments on the malfunction data follow:

Malfunctions Versus Environments

For the four thermal environments (ambient, transient, cold, and hot), the minimum time to reach a plateau is 1, 4, 4, and 4 days, respectively. Figure 6 shows the four environments in descending order of severity to be cold, hot, transient, and ambient.

The transient data again indicate (Figures 6 and 7) that additional time in this environment may be fruitful.

Exceptions to the general trend were the OGO performance in the transient environment, and Nimbus in the hot environment. The Nimbus plateau was reached in 2 days whereas the other

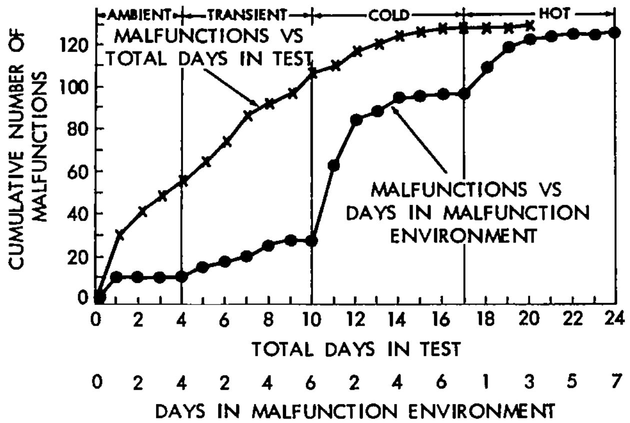


Figure 6—Thermal-vacuum malfunctions of flight spacecraft versus time and environment.

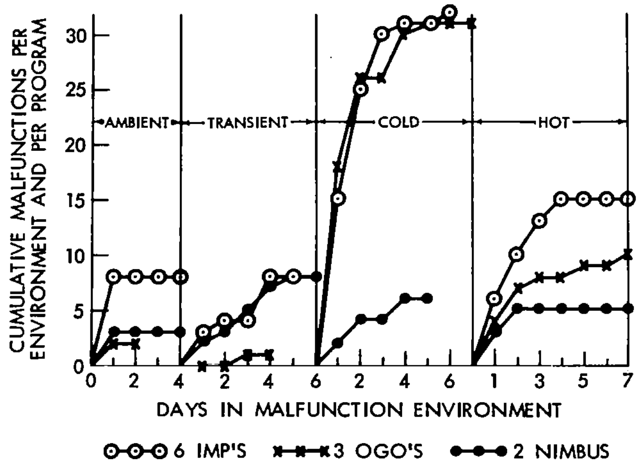


Figure 7—Thermal-vacuum malfunctions of flight spacecraft by environment, time, and program.

programs took from 4 to 6 days. Only one malfunction was reported for OGO in the transient phase, whereas the other programs reported transient malfunctions up to 5 days.

Malfunctions Versus Programs

The programs show a remarkable similarity in the time to reach a plateau in each environment. The data (Figure 7) indicate, that the Nimbus program has the best demonstration (longest time at the plateau) of eliminating the infant mortality malfunctions in the hot environment. The three programs have almost equivalent performance in the cold environment, and the time at a plateau is not nearly as convincing as the plateau time in the hot environment. The data suggest a minimum of 3 days without malfunction for each thermal environment as a reasonable demonstration that infant mortality malfunctions have been eliminated. The OGO and IMP programs show equivalent performance (except for the transient phase) despite a significant difference in the subsystem test requirements (Table 6). Probably the most important point with respect to malfunctions versus programs is that systems tests of flight spacecraft are necessary regardless of the amount of testing that has been done previously.

Experiments Versus Other Subsystems

Figure 8 and Table 7 show that on a summary basis experiments have not been very different from other subsystems with respect to occurrence of malfunctions. The IMP experience is somewhat different from the total experience in that about 64 percent of the IMP malfunctions were ascribed to experiments. However, examination of the six IMP spacecraft data shows that experiment performance

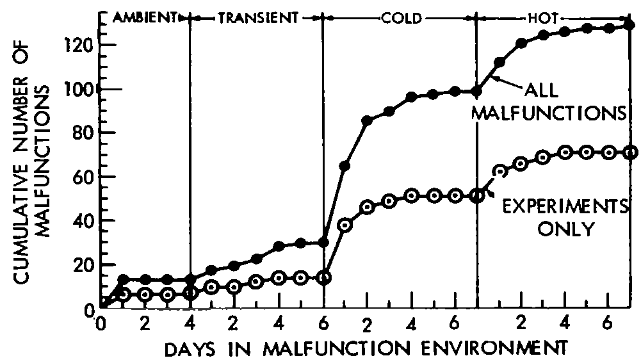


Figure 8—Comparison of experiment malfunctions with total malfunctions in thermal-vacuum tests of flight spacecraft.

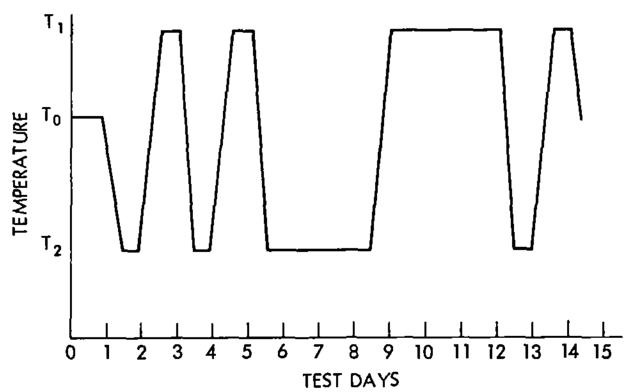
was as good as other subsystems in three of the spacecraft. The Nimbus data are also different from the total experience in that only 30 percent of their malfunctions were ascribed to experiment-type hardware (cameras, radiometers, etc.).

The data do not support the opinion that experiments always cause more malfunctions than other subsystems. However, with respect to a specific program, experiments did account for the majority of the malfunctions. A project manager may anticipate trouble with an experiment for various reasons, such as: complexity, state-of-the-art hardware, or past performance. Despite his best efforts the real world of schedules, hardware, and people prevent the elimination of all malfunctions before the systems test on the flight spacecraft.

RECOMMENDED THERMAL-VACUUM PROFILE

Figure 9 gives the minimum requirements for an adequate thermal-vacuum test of a flight spacecraft—based on experience gained from the present study. An additional minimum requirement should be that at least 24 hours of trouble-free operation be demonstrated at the end of each of the four thermal-vacuum environments.

The recommended profile can be varied to meet specific program needs. For instance, the test can be started with a hot cycle when this is advantageous. The hot cycle at the end of the profile is recommended to minimize contamination of the spacecraft. (With this procedure the thermal-vacuum chamber wall is a cold sink when the hot spacecraft is returned to ambient temperature.)



T_0 ROOM TEMPERATURE.
T_1 MAXIMUM PREDICTED SPACE TEMPERATURE.
T_2 MINIMUM PREDICTED SPACE TEMPERATURE.

Figure 9—Recommended thermal-vacuum profile for flight spacecraft.

CONCLUSIONS

The data for this study was from the thermal-vacuum tests of flight spacecraft, and the conclusions are applicable to the data base.

A thermal-vacuum test of flight spacecraft is necessary regardless of the previous piece part and subsystem test requirements.

Infant mortality curves are related to both time and kind of stress.

At least three kinds of thermal stress need to be applied for sufficient time to eliminate infant mortality failures.

The minimum time recommended for the ambient, transient, cold, and hot environments is 1, 4, 4, and 4 days, respectively.

The minimum time (in each thermal environment) required to eliminate infant mortality failures in flight spacecraft is not related to the amount of piece part and subsystem tests required.

On an overall basis the performance of experiments has been as good as other spacecraft subsystems.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland, July 1968
124-12-03-01-51

REFERENCES

1. Boeckel, J. H., "The Purposes of Environmental Testing for Scientific Satellites," NASA Technical Note D-1900, July 1963.

2. New, J. C., "Experiences in Simulating the Space Environment for Scientific Satellites," NASA Technical Memorandum X-55120, 1965.

3. New, J. C., "Achieving Satellite Reliability Through Environmental Tests," NASA Technical Note D-1853, July 1963.

4. Timmins, A. R., and Rosette, K. L., "Experience in Thermal-Vacuum Testing Earth Satellites at Goddard Space Flight Center," NASA Technical Note D-1748, August 1963.

5. Timmins, A. R., "The Effectiveness of System Tests in Attaining Reliable Earth Satellite Performances," NASA Technical Note D-3713, November 1966.

Appendix A

Detailed Tables on Failures and Malfunctions

Table A-1

Thermal-Vacuum System Test Failures on Flight Spacecraft.

Program		Days										Totals	
		1	2	3	4	5	6	7	8	9	10	Spacecraft	Program
IMP-A	A	0←										0	
	T	0	0	0	0←							0	
	C	1	0	0	0	0←						1	
	H	1	1	1	0	0	0←					3	
IMP-B	A	0←										0	
	T	0	0	0	$2T^7$←							2	
	C	0	0	0	0 ←							0	
	H	0	0	0←								0	
IMP-C	A	0←										0	
	T	0	0	0	0	0←						0	
	C	0	0	0←								0	
	H	0	0	0←								0	
IMP-D	A	0←										0	
	T	0	0	0	T^8	0←						1	
	C	3	2	1	0	0	0←					6	
	H	0	0	0	0	0←						0	
IMP-E	A	3←										3	
	T	0	0	0	0←							0	
	C	1	1	0	0	0←						2	
	H	0	0	0	0	0	0 ←					0	
IMP-F	A	2 ←										2	5
	T	0	0	0	0	0←						0	3
	C	1	0	0	0	0←						1	10
	H	1	0	0	0	0←						1	4
OGO-A	A	2	0←									2	
	T	0	0←									0	
	C	2	2	0 ←								4	
	H	0	1 ←									1	
OGO-C	A	0 ←										0	
	T	0	0	0 ←								0	
	C	9*	3	0	2	0 ←						14	
	H	0	0	1 ←								1	
OGO-D	A	0←										0	2
	T	0	0	0←								0	0
	C	1	1	0	0	0	0	0	0 ←			2	20
	H	2	0	0	0	0	0	0	0 ←			2	4
Nimbus I	A	2	0 ←									2	
	T	0	T^4		$2T^8$ ←							3	
	C	1	0	0	0 ←							1	
	H	0	0	0	0	0	0	0	0 ←			0	
Nimbus II	A	0	0	0	0	0 ←						0	2
	T	0	0	$1T^6$	0	$1T^{10}$	0	0 ←				2	5
	C	1	0	0	1	0 ←						2	3
	H	3	1	0	0	0 ←						4	4

C = cold, H = hot, T = transient, A = ambient; → = duration of phase; $2T^7$ = two failures on seventh transient.
*Five of these were related to a connection problem.

Table A-2

Thermal-Vacuum Test Malfunctions on Flight Spacecraft.

Spacecraft		Days 1	2	3	4	5	6	7	8	9	10	Totals Spacecraft	Program	Grand
IMP-A	*A	1 ←										1		
	*T	T^2	0	0	0 ←							1		
	*C	2	1	0	0	0 ←						3		
	*H	2	2	2	2	0	0 ←					8		
IMP-B	A	0 ←										0		
	T	T^1	0	0	$3T^7$ ←							4		
	C	1	0	1	1	0 ←						3		
	H	1	0	0 ←								1		
IMP-C	A	0 ←										0		
	T	0	0	0	0	0 ←						0		
	C	2	3	0 ←								5		
	H	0	1	0 ←								1		
IMP-D	A	0 ←										0		
	T	T^1	0	0	T^8	0 ←						2		
	C	5	4	2	0	0	1 ←					12		
	H	1	0	0	0	0 ←						1		
IMP-E	A	3 ←										3		
	T	T^1	0	0	0 ←							1		
	C	2	3	0	0	0 ←						5		
	H	0	0	0	0	0	0 ←					0		
IMP-F	A	4 ←										4	8	
	T	0	0	0	0	0 ←						0	8	
	C	3	0	1	0	0 ←						4	32	
	H	2	1	1	0	0 ←						4	15	
OGO-A	A	2	0 ←									2		
	T	0	0 ←									0		
	C	4	3	0 ←								7		
	H	1	1 ←									2		
OGO-C	A	0 ←										0		
	T	0	0	0 ←								0		
	C	9	4	0	4	1 ←						18		
	H	0	2	1 ←								3		
OGO-D	A	0 ←										0	2	
	T	0	0	T^5 ←								1	1	
	C	5	1	0	0	0	0	0	0 ←			6	31	
	H	4	0	0	0	1	0	1	1 ←			7	12	
Nimbus I	A	3	0 ←									3		
	T	$2T^2$	T^4	0	$2T^8$ ←							5		
	C	1	1	0	0 ←							1		
	H	0	1	0	0	0	0	0	0 ←			1		
Nimbus II	A	0	0	0	0	0 ←						0	3	13
	T	0	0	$2T^6$	0	T^{10}	0	0 ←				3	8	17
	C	1	1	0	2	0 ←						4	5	68
	H	3	1	0	0	0 ←						4	5	32

C = Cold T = Transient → = Duration of phase H = Hot A = Ambient $2T^7$ = Two malfunctions on seventh transient

Table A-3

Summary of Thermal-Vacuum Malfunctions of Flight Spacecraft.*[11]

A. Distribution of Malfunctions by Environment and Test Days.

Environment	Test Days										Total	Average/ Spacecraft
	1	2	3	4	5	6	7	8	9	10		
Ambient	13	0	0	0	0						13	1.2
Transient	5	2	3	6	1	0	0				17	1.5
Cold	35	20	4	7	1	1	0	0			68	6.2
Hot	14	9	4	2	1	0	1	1			32	2.9
											130	11.8

B. Distribution of Malfunctions by Environment, Test Days, and Program.

Environment	Spacecraft	Test Days										Total	Average/ Spacecraft
		1	2	3	4	5	6	7	8	9	10		
Ambient	IMP	8	0									8	1.3
	OGO	2	0									2	0.7
	Nimbus	3	0	0	0	0						3	1.5
Transient	IMP	3	1	0	4	0						8	1.3
	OGO	0	0	1								1	0.3
	Nimbus	2	1	2	2	1	0	0				8	4.0
Cold	IMP	15	11	4	1	0	1					32	5.3
	OGO	18	8	0	4	1	0	0	0			31	10.3
	Nimbus	2	1	0	2	0						5	2.5
Hot	IMP	6	4	3	2	0	0					15	2.5
	OGO	5	3	1	0	1	0	1	1			12	4.0
	Nimbus	3	2	0	0	0	0	0	0			5	2.5
												130	11.8

C. Distribution of Malfunctions by Program.

Program	Total	Average/ Spacecraft
IMP	63	10.5
OGO	46	15.3
Nimbus	21	10.5
Total	130	11.8

[11] 6 IMP, 3 OGO, and 2 Nimbus spacecraft.

Table A-4

Summary of Experiment Malfunctions in Thermal-Vacuum Tests of Flight Spacecraft.[11]

A. Distribution of Malfunctions by Environment and Test Days.

Environment	Test Days										Totals	Average Per Spacecraft
	1	2	3	4	5	6	7	8	9	10		
Ambient	7	0	0	0	0						7	0.6
Transient	3	0	2	2	0	0	0				7	0.6
Cold	24	8	3	2	0	0	0	0			37	3.4
Hot	12	3	3	2	0	0	0	0			20	1.8
Totals											71	6.5

B. Distribution of Malfunctions by Environment, Test Days, and Program.

Environment	Program*	Test Days										Totals	Average Per Spacecraft
		1	2	3	4	5	6	7	8	9	10		
Ambient	IMP	5	0									5	1.0
	OGO	1	0									1	0.3
	Nimbus	1	0	0	0	0						1	0.5
Transient	IMP	3	0	0	2	0						5	0.8
	OGO	0	0	0								0	0.0
	Nimbus	0	0	2	0	0	0	0				2	1.0
Cold	IMP	12	4	2	0	0	0					18	3.0
	OGO	11	3	1	1	0	0	0	0			16	5.3
	Nimbus	1	1	0	1	0						3	1.5
Hot	IMP	6	3	2	2	0	0					13	1.2
	OGO	4	0	1	0	0	0	0	0			5	1.7
	Nimbus	2	0	0	0	0	0	0	0			2	1.0
Totals												71	6.5

[11] 6 IMP, 3 OGO, and 2 Nimbus spacecraft.

Table A-5

Summary of Experiment Failures in Thermal-Vacuum Tests of Flight Spacecraft.[12]

A. Distribution of Experiment Failures by Environment and Test Days.

Environment	Test Days										Totals	Average Per Spacecraft
	1	2	3	4	5	6	7	8	9	10		
Ambient	4	0	0	0	0						4	0.4
Transient	0	0	1	2	0	0	0				3	0.3
Cold	14	2	0	1	0	0	0	0			17	1.5
Hot	3	1	2	0	0	0	0	0			6	0.5
Totals											30	2.7

B. Distribution of Experiment Failures by Environment, Test Days and Program.

Environment	Program*	Test Days										Totals	Average Per Spacecraft
		1	2	3	4	5	6	7	8	9	10		
Ambient	IMP	4	0									4	0.7
	OGO	0	0									0	0.0
	Nimbus	0	0	0	0	0						0	0.0
Transient	IMP	0	0	0	2	0						2	0.3
	OGO	0	0	0								0	0.0
	Nimbus	0	0	1	0	0	0	0				1	0.5
Cold	IMP	4	0	0	0	0	0					4	0.7
	OGO	10*	2	0	0	0	0	0	0			12	4.0
	Nimbus	0	0	0	1	0						1	0.5
Hot	IMP	2	1	1	0	0	0					4	0.7
	OGO	1	0	1	0	0	0	0	0			2	0.7
	Nimbus	0	0	0	0	0	0	0	0			0	0.0
Totals												30	2.7

*Five from one failure.

[12] 6 IMP, 3 OGO, and 2 Nimbus spacecraft.

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