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GODDARD SPACE FLIGHT CENTER TEST PHILOSOPHY AND RESULTANT RECORD

by John H. Boeckel, Albert R. Timmins, and Kenneth R. Mercy

Goddard Space Flight Center
Greenbelt, Md. 20771

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16. Abstract

The GSFC test philosophy, emphasizing systems tests of flight hardware, is flexible in order to accommodate different organizational structures, facilities, and capabilities. This report gives data on two classes of programs: in-house and out-of-house at the flight spacecraft systems test level and on the space performance level. Data on learning curves for multi-launch programs show a continuing need for systems tests of flight hardware. Other data show the time required for minimum thermal-vacuum test is the same for both classes—on the order of 13 days. The space record for 73 spacecraft tested in accordance with the GSFC philosophy has been 95% successful, with in-house tested spacecraft maintaining 100%. Most spacecraft have outlasted their intended life by a significant period, and experiments have been more than 80% productive. The space record supports the GSFC test philosophy.

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CONTENTS

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GSFC TEST PHILOSOPHY

Because spacecraft are not only one-shot but are also one-of-a-kind, statistical approaches to testing developed for mass production of consumer goods and weapons are not applicable. Actual flight hardware must be exposed to the expected operating environment to assure a high probability of successful performance in space. In addition, several goals must be achieved by the spacecraft test program:

1. Verify that *designs* (system, subsystem, and component) meet performance requirements.
2. Verify that *particular hardware samples* meet performance requirements.
3. Eliminate defects in material and workmanship.
4. Discover unexpected interactions between subassemblies, particularly when the system is exposed to environmental stress.
5. Verify that ground-support and data processing equipment are compatible with the spacecraft.
6. Train spacecraft operations and data processing personnel.

The various types of tests used to attain these goals are identified and discussed below.

Functional Testing

Systems

GSFC has endorsed the full-systems test approach in which the entire system is tested under conditions which are as realistic as possible. Systems tests generally fall into one of two categories:

Functional tests are intended to establish that each subsystem is doing its designated job

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in conjunction with the other spacecraft subsystems. This testing includes actually calibrating any spacecraft sensors or instrumentation and establishing a spacecraft performance baseline which can be used for comparison throughout the environmental test phase.

Compatibility tests, considered here in their broadest sense, are an extension of the functional tests. Compatibility testing includes electromagnetic compatability (EMC) assessments, radio-frequency interference (RFI) evaluations, and magnetic moment determinations. Early mating of parts may be advisable to determine the mechanical compatibility of the spacecraft with the launch vehicle and the aerodynamic fairing. Finally, the flight spacecraft is tested with the ground-support and data processing equipment, personnel, and procedures that will be used to operate the spacecraft in orbit.

Subsystems

The full-systems test approach does not eliminate the desirability, nor in some cases the necessity, of black-box and subsystem qualification and acceptance testing. Several inherent limitations of systems testing are best overcome at the subsystem or black-box level. This matter will be treated in some detail later.

Environmental Testing

These tests determine the ability of components, subsystems, and the entire spacecraft to withstand environmental rigors that may be experienced before and during launch, and during orbital operation. The tests may be conducted at any or all levels of assembly, but are required at the spacecraft level. The severity and duration of the tests are related to the purpose of the tests as indicated below. At times it is difficult to distinguish between functional testing and environmental testing, particularly when a specific environment, e.g., high vacuum, is required for the performance of a functional test.

Flight Acceptance Testing

All flight hardware is ground-tested in the expected flight environment. The hardware is exposed to simulated loading conditions produced by temperature, pressure (vacuum), and vibration during the launch and the orbital phases of the flight. Functional tests appropriate to the conditions simulated are conducted. Test levels are chosen such that, in theory, there is one chance in twenty of their being exceeded in flight.

Qualification Testing

A prototype model (i.e., the actual flight configuration) is exposed to an environment intended to produce loading conditions and stresses in excess of those expected in flight. The purpose of prototype testing is to insure a margin in the design to provide for uncertainties in areas such as analyses, materials, and workmanship. For qualification, test levels are chosen such that, again in theory, there is one chance in one hundred of their being exceeded in flight.

Proto-Flight Testing

As programs mature cases arise of spacecraft based primarily on previously flown hardware but somewhat different in design and performance. In these cases a prototype spacecraft may not be required. Flight acceptance and qualification testing are combined and performed on the flight spacecraft. The amount of qualification testing required is made consistent with the magnitude of the hardware changes.

While the establishment of test levels is defined above in terms of overall risk, the paucity of applicable data makes this task one which does not yield exact numerical values.

GSFC TEST PRACTICE

In its application of the test philosophy discussed above, GSFC recognizes that there are differences between in-house projects and those conducted entirely by contract. Both follow the same philosophical approach, but the amount of formal testing below the system level is significantly higher for contractor-conducted projects. The major considerations in test planning will be discussed separately for the two cases.

In-House Projects

GSFC has placed heavy reliance on testing at the system level. There are several consequences of this approach. One hope is, of course, to reduce the total amount of testing and its associated cost. On the other hand, the risk of entering the systems test level with a significant design flaw is increased. Program delay for a fix at this stage is costly, but may or may not be more costly than a complete subsystem test program. The key element in maintaining cost-effectiveness is test planning and some knowledge of hardware quality.

Testing implies discovering whether something performs as intended. Environmental testing requires the kinds of stress to which the device may be expected to be exposed in use. The emphasis here is on investigating the *functional* performance of the hardware when exposed to the stress of the *environment*. It is clear therefore that systems test planning must begin by assuring that all the intended functions of the system are to be checked. With a general outline of functional testing established, one may proceed to a consideration of the manner in which environmental stresses are to be applied. Functional checkout and the application of realistic environmental stress may not be compatible in a systems test. For example, stimulation of a star tracker with a collimator interferes with the tracker's view of cold space. As each of these situations arises, the implications must be carefully considered. In most cases, it is found that a subsystems test can be run which makes up for the deficiency in the systems test.

There are other situations which suggest the desirability of subsystems testing to supplement the systems test. For example:

1. Systems tests seldom run long enough to detect wear-out problems. Wherever a fatigue or wear-out potential exists (chiefly in electromechanical devices), the life characteristics

should be investigated on a component or subassembly basis. Great care must be taken to assure that the sample is truly representative of the flight hardware.

2. After a spacecraft is completely assembled, devices may no longer be realistically operable during systems testing. This occurs in some cases because the spacecraft cannot be operated in all possible orbital modes on the ground.

3. If only systems tests are run, marginal conditions existing at critical subsystem or black-box interfaces may remain undetected. Only testing of the input/output characteristics of the individual black boxes can establish the presence of adequate margins.

In systems testing, the launch environment and the temperature and vacuum aspects of the space environment are emphasized. The effects of space plasma, magnetic fields, and energetic particles must also be considered. In many cases, however, facilities do not exist to permit realistic exposure of the complete system to these stresses. Subsystem tests might seem appropriate, but for these environmental factors one can often avoid an extensive test program by a consideration of the damage mechanisms which could be operative. For example, large classes of semiconductor devices are inherently insensitive to energetic particle fluxes at the levels encountered in space. Testing these under such conditions would be a waste. On the other hand, it is important to know the expected degradation of solar cells for the orbit in question. This problem can be attacked with a limited number of samples at the piece-part level. Careful design review will show that there are many similar situations in which piece-part testing for a particular environmental stress is the appropriate technique.

Test planning is begun with an attempt to make provision for all practical functional tests under environmental stress at the systems level. When either a function, or a resistance to a particular stress cannot be checked at this level, a special subsystem or piece-part test is devised.

Out-of-House Projects

In attempting to apply a systems test philosophy to a project in which the spacecraft is supplied (and probably tested) by a prime contractor, a considerable degree of flexibility is lost because the contractual procedure requires definition of the manner in which successful performance will be judged at a time when it is not possible to establish in detail the probable deficiencies of the systems test program. It is therefore likely that a greater depth of subsystem testing than is used for in-house programs will be specified. Since most prime contractors buy black boxes from vendors, they themselves face the problem of establishing success criteria too early in the program to account for those aspects of performance which will be thoroughly checked out later in the project.

In this pyramid of vendors, it is easily possible to reach extremes in providing assurance. All designs are based on worst-case analysis and mandatory derating; piece-parts are purchased to rigorous specifications; each part is screened and burned-in; each board or module is functionally tested under environmental stress; every black box is qualified. Testing proceeds until the complete system has reached such a point that the only test remaining is the flight itself. This redundant testing approach would provide for a well-ordered and comfortable program, but GSFC makes a conscious effort to limit environmental testing at lower levels of assembly on out-of-house programs (although not so drastically as for in-house programs). There are two basic reasons for such limiting: there is nothing to be gained by retesting the same attribute of a device repeatedly (unless the cost of a fix at a later stage could be extreme); there is a large class of problems which cannot be found by testing below the systems level but which will nevertheless cause delays at that point in the program. The first reason is based on intuitive judgment which must be modified by the situation at hand. The second reason is fully supported by such data as presented by Smith and Waltz (Reference 1).

As part of the Test Philosophy and Resultant Record study a comparison will be made between the results of the two test practice categories (in-house and out-of-house) at the flight spacecraft system test level, and at the space performance level.

SYSTEMS TEST DATA

A study of the results of using the GSFC test philosophy has been made using a sample of 24 spacecraft, fifteen in-house projects, and nine out-of-house projects. The systems test data on flight spacecraft have been analyzed for information and guidance on the following subjects:

1. Comparison of in-house and out-of-house programs. The latter programs usually have more complex and larger spacecraft, more rigid quality control features, and more comprehensive and required testing before the systems tests on the flight spacecraft.

2. Distribution of malfunctions by test conditions and by spacecraft subsystems.

3. Learning curves on multi-spacecraft programs.

4. Time required for an adequate thermal-vacuum test of flight-model spacecraft.

The following definitions are used for the systems test data presented:

1. A *malfunction* is any performance outside the specified limits, either a failure or problems.

2. A problem is any substandard performance or partial loss of any function.

3. A failure is the complete loss of operation of any function or subsystem.

Comparison of In-House and Out-of-House Programs

Figure 1 shows the performance of flight spacecraft in systems tests. The malfunctions per spacecraft were 17 and 41 for the in-house and out-of-house programs respectively. In both programs about 40% of the malfunctions were serious enough to be classed as failures. No significance should be attached to the relative numbers in the two classes of programs because there has been no normalizing to account for differing complexity between the spacecraft in the two classes. (Neither weight nor the number of piece-parts is considered suitable for normalizing. For instance, the ratio of average weights for out-of-house to in-house spacecraft is 7:1. Thus, if a comparison were to be based on problems per pound of spacecraft, the relative standing implied in Figure 1 would be reversed.)

The data does show conclusively that the systems tests were needed for both classes of program, and that despite rigid quality assurance requirements and required testing for all subsystems, complex spacecraft exhibited a surprisingly high incidence of malfunctions in the systems tests.

The experiments which are flown are often state-of-the-art hardware, and invariably are minimized in weight and size. As such, they might be expected to be more vulnerable to environmental stresses than other parts of a spacecraft. Figure 2 shows that approximately 50% of the malfunctions and failures have been in experiments in both classes of programs. In other words, systems tests would have been needed even if there had been no experiment hardware.

Distribution of Malfunctions

In a separate study of the learning curves associated with multi-launch programs, all the malfunctions in 22 spacecraft were classified by test conditions and also by spacecraft subsystems.

By Test Condition

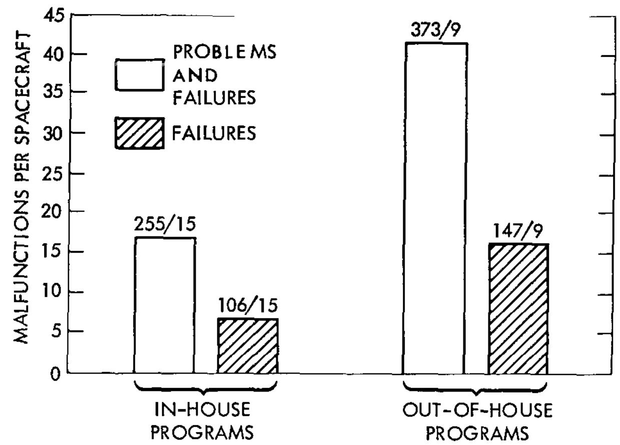

Figure 1—Performance of flight spacecraft in systems tests.

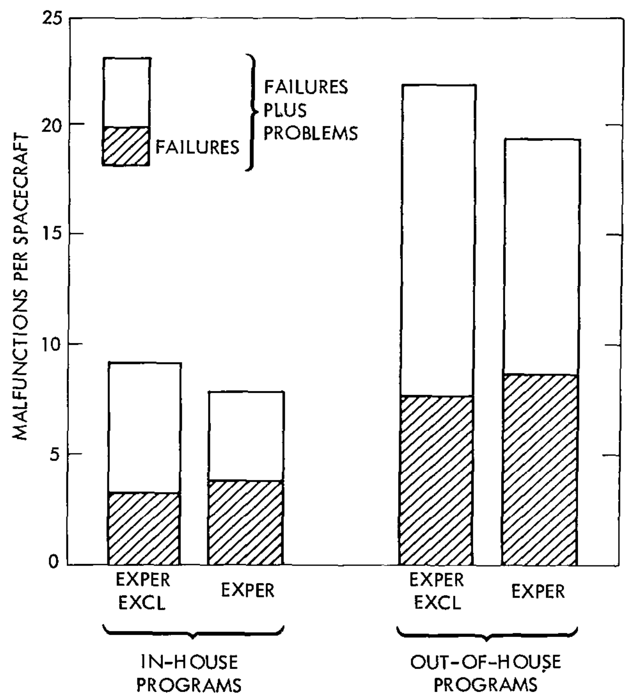

Figure 2—Performance of flight spacecraft in systems tests.

All the malfunctions were categorized into one of the following test conditions: Functional—the malfunctions occurred during operation of the system after it had entered the test phase of the program; no environmental stress was applied. Structural—includes all mechanical types of tests such as vibration, acceleration, and deployment. Space simulation—includes all thermal and thermal-vacuum tests.

Table 1 shows the distribution of 759 malfunctions found during the systems tests of 22 spacecraft. The high incidence of functional type malfunctions is indicative of schedule pressure, dependence on the test phase to clean up some operational details, and the limitations of the subsystem test program in eliminating problems. The small percentage of structural type malfunctions is a tribute to the design, fabrication control, and testing for this part of a spacecraft program. The space simulation test phase uncovers a surprising number of malfunctions considering the rather benign stresses involved. The data in Table 1 indicate that this environment is especially effective with experiments. If only experiment malfunctions are considered, over 50% are detected during the space simulation tests.

Table 1

Malfunctions Observed During Systems Tests of 22 Flight Spacecraft.
(Distribution by test condition)

Test Conditions	Excluding Experiments		Including Experiments	
	Number of Malfunctions	%	Number of Malfunctions	%
Functional	210	56	347	46
Structural	50	13	95	12
Space simulation	115	31	317	42
TOTAL	375	100	759	100

By Spacecraft Subsystems

Table 2 shows the same data as Table 1 but the malfunctions are distributed by spacecraft subsystem. One distribution shows that 51% of the total problems are attributable to experiments. While this figure does show the need for improvement in performance to eliminate problems at the flight system level, it must be pointed out that most spacecraft have carried 6 to 10 experiments, and some spacecraft have carried 20. When experiments are excluded, the other distribution in Table 2 shows that 41% of the problems were attributable to the command and data handling hardware.

Learning Curves

In a program with five spacecraft launches, the fifth spacecraft could reasonably be expected to have fewer problems at the systems test level than the first spacecraft. Five multilaunch programs were reviewed with the results shown in Figure 3. These programs, involving 22 spacecraft, were also the source of the data in Tables 1 and 2. Program 2 was an in-house program, and shows a desirable learning curve for the first three spacecraft. The fourth spacecraft, identified as a protoflight spacecraft, was sufficiently different in design that it ordinarily would have had a prototype.

Table 2

Malfunctions Observed During Systems Tests of 22 Flight Spacecraft.
(Distribution by spacecraft subsystem)

Spacecraft Subsystem	Excluding Experiments		Including Experiments	
	Number of Malfunctions	%	Number of Malfunctions	%
Experiments	-	0	384	51
Structure	56	15	56	7
Thermal	18	5	18	2
Power	72	19	72	10
Stabilization and control	76	20	76	10
Command and data handling	153	41	153	20
TOTAL	375	100	759	100

Instead, it was a guinea pig, the flight unit being tested to prototype levels—hence the name protoflight spacecraft. While this could explain the. increased number of malfunctions for the fourth spacecraft, no satisfactory explanation exists for the poor performance of the fifth spacecraft.

Programs 1, 3, 4 and 5, shown in Figure 3, were out-of-house programs. Except for program four, no learning curve is in evidence, regardless of exclusion of experiments.

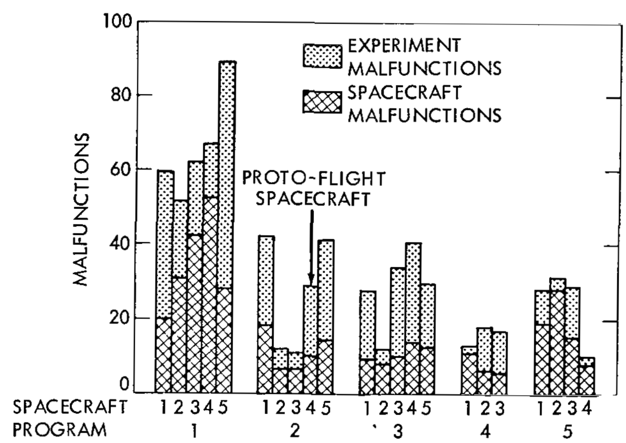

Figure 3—Malfunction learning curves on flight spacecraft.

Simulated Space Test Time

The literature is replete with discussions of the theoretical failure pattern bathtub curve (Figure 4) and the need to get past the infant mortality region of the curve to minimize space malfunctions. Supposedly, with sufficient testing in the environmental test phase, the random failure rate region of the "bathtub curve" will be reached and space performance maximized. The problem is: What test period is necessary in order to eliminate the infant mortality malfunctions?

A special study was made of the performance of 11 flight spacecraft in thermal-vacuum tests. (Six of the spacecraft were of the in-house type and five were of the out-of-house type.) If time under vacuum were the only controlling variable (Figure 5), the data show the number of failures decreasing with time and indicate a minimum test period of 16 days to reach a plateau. However,

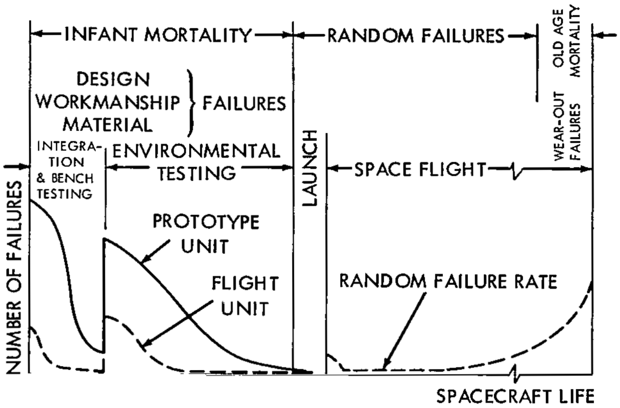

Figure 4—Theoretical failure pattern.

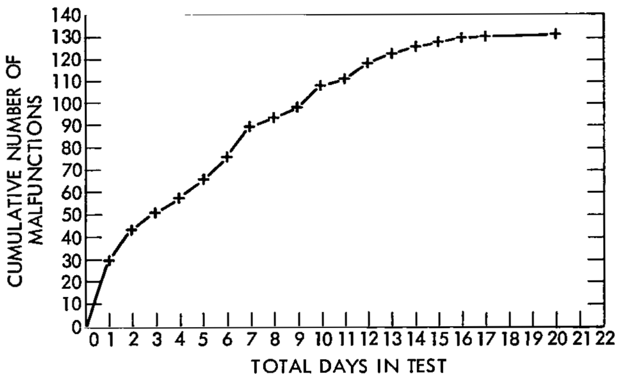

Figure 5—Thermal-vacuum malfunctions of eleven flight spacecraft vs time.

the influence of thermal stress has not been included. When the same data were examined separately with regard to thermal stresses and time, (Figure 6) the total time was about the same, but the curve had a significantly different shape. Note should be made that the thermal-vacuum test cycles for the eleven spacecraft were not uniform, nor were the days at each thermal environment consecutive. In other words, the data from each spacecraft test have been segregated and arranged into the form shown in Figure 6. This arrangement postulates the cause of failure as time with a thermal stress. These data indicate a different infant mortality curve may be associated with each different kind of stress.

The performance of the in-house and out-of-house programs is given in Figure 7. The data show that the time required for either class in each thermal environment is approximately equal. The minimum period required for an adequate thermal-vacuum test of flight model spacecraft is approximately 13 days. The distribution of time for the ambient, transient, hot, and cold environments is 1 day, 4 days, 4 days, and 4 days respectively. Reference 2 emphasizes that the times given are *minimum* and gives the number of spacecraft for each data point. Reference 2 also gives a recommended test profile for maximizing test efficiency versus time.

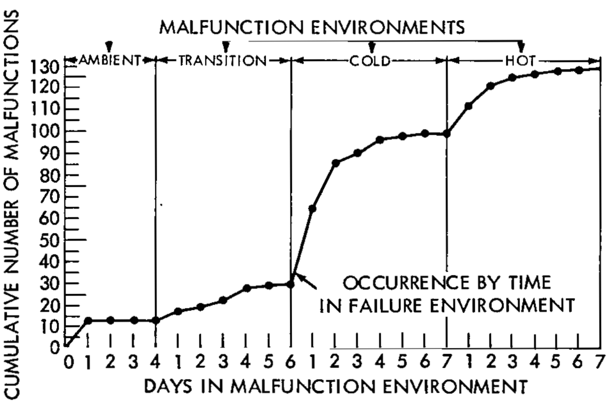

Figure 6—Thermal-vacuum malfunctions of eleven flight spacecraft vs time and environment.

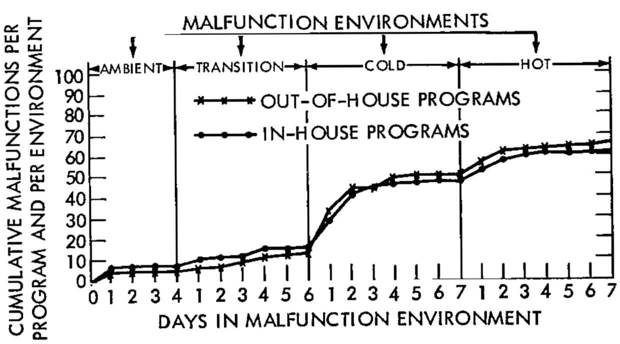

Figure 7—Comparison of programs in thermal-vacuum tests of flight spacecraft.

SPACE PERFORMANCE

Spacecraft Life in Orbit

The GSFC test philosophy can be evaluated by analyzing the flight experience records. Of the 24 spacecraft discussed previously, 23 have produced useful data in orbit. One spacecraft failed to return information. Thus, based on useful data received, a success record of 96% was achieved for this sample. Table 3 is a comparison of the life of each spacecraft after launch with the

Table 3

Spacecraft Life vs Intended Life as of January 1969.

Spacecraft			Days		Ratio: Useful to Intended Life
Explorer No.	Name	Launch Date	Intended Life	Useful Life	
Tested In-House					
XV	S-3b	10-27-62	60	95	1.59
XVII	S-6	4-2-63	90	100	1.11
XII	S-3	8-15-61	365	112	.31
XXXVIII	RAE-A	7-4-68	365	180*	-
XXI	IMP-B	10-4-64	365	182	.50
ARIEL II	S-52	3-27-64	365	194	.53
XVIII	IMP-A	11-26-63	365	300	.82
XXXII	AE-B	5-25-66	180	301	1.67
XIV	S-3a	10-2-62	365	310	.85
ARIEL I	S-51	4-26-62	365	320	.88
XXXV	IMP-E	7-19-67	365	469*	-
XXXIV	IMP-F	5-24-67	365	585*	-
XXVIII	IMP-C	5-29-65	365	702*	-
XXVI	EPE-D	12-21-64	365	886	2.43
XXXIII	AIMP-D	7-1-66	180	913*	-
Tested Out-of-House					
	OAO-1	4-8-66	365	0	0
	NIMBUS-1	8-28-64	180	26	.14
	OGO-5	3-4-68	365	302*	-
	ATS-3	11-5-67	1095	421*	-
	OGO-4	7-28-67	365	541*	-
	OGO-2	10-14-65	365	719	1.97
	ATS-1	12-6-66	1095	755*	-
	NIMBUS-2	5-12-66	180	976	5.42
	OGO-1	9-4-64	365	1578*	-

*Spacecraft continues to operate as of January 1969.

intended life. The table is given for information only, and is not meant to infer that the satisfactory completion of a test program is related to life performance. For this discussion a spacecraft success is based on the scientific data obtained, and not on attaining the intended life. Mission success criteria are developed by the Project and Project Scientist, and approved by NASA Headquarters prior to launch. Success or failure of spacecraft, vehicle, and mission is judged by NASA Headquarters. As an example, the Explorer XXI spacecraft was a success, based on the scientific data obtained, but the mission and launch vehicle were classed as failures because the apogee achieved was about 50,000 miles rather than 140,000 miles. The successful spacecraft, Table 3, have life ranges from 26 to 1500 days with the latter still operating as of January 1969. The intended lifetime depends on the program requirements. The majority of the spacecraft have exceeded their life requirements with many maintaining operational performance for an additional year or more. The long lifetimes of OGO spacecraft have been discussed in Reference 4 which also indicates that failure rates due to catastrophic failure of high population piece parts are much lower than predicted. It appears that the parts selection and control in addition to various tests conducted at parts and subsystem level, have contributed to the long lives of these spacecraft.

Selection of data from Table 3 can yield useful information on spacecraft life in orbit. Considering only in-house spacecraft with an intended life of one year, the ratio of useful life to intended life is revealing. For launches before Explorer XXVI (Dec. 1964) the ratio is 0.65. After (and including) that spacecraft the average ratio is 1.50. In addition, four of the five post-1965 spacecraft are still operating, so that a ratio of 2.00 is anticipated. Considering only out-of-house spacecraft with an intended life of one year, the ratio is 1.70 for post-1965 launches. Three of these five spacecraft are still operating; one of the five failed completely the first day. Omitting this failure, an appropriate estimate of useful life for out-of-house spacecraft launched after 1965 is 3 years. (The two spacecraft with intended life of 3 years do not have sufficient space time for any attempt to be made to estimate useful life.)

Test Philosophy vs Orbital Results

The bathtub curve, depicting frequency of failure vs time (Reference 3) (Figure 4), has been a guide for establishment of the GSFC test philosophy. The curve suggests that if a spacecraft is completely assembled and checked out, it experiences many failures early in life (usually referred to as infant mortality). GSFC's system environmental tests are designed to locate and correct the failures which could occur during this period so that flight operation can be conducted under the random failure part of the curve. A comparison of the failures per spacecraft during the test phase to the failures during the first 30 days of flight for spacecraft tested both in-house and out-of-house is shown in Figure 8. The sharp decline in failures after launch indicate that infant mortality failures have been greatly reduced, but not eliminated, by the systems test.

A further analysis showing the flight experiences vs time is presented in Figure 9. The ordinate represents the failures per spacecraft per 90 days, and the abscissa is 90-day time periods after launch. The failures have been classed as major and minor: major if a severe degradation of spacecraft performance is noted; minor if an experiment is degraded, or if a spacecraft subsystem is lost but backed up by redundancy. The two curves—one for major failures, the other for major plus minor—show a sharp drop in failure rate after the first 90 days. First day failures account for a large portion of the early failures. The data show the infant mortality phase still existed after 90 days, and the random failure rate was not reached until after approximately six months in orbit. This statement ignores the period from 360 to 450 days, for which no explanation has been found.

The plot also indicates that wear-out will not necessarily be related to any specific time period after launch. Although wear-out of some spacecraft subsystems is known to occur, the failure mode does not appear to increase at any particular point in the life cycle. Thus a wear-out period for spacecraft hardware has not been shown in the data accumulated to date.

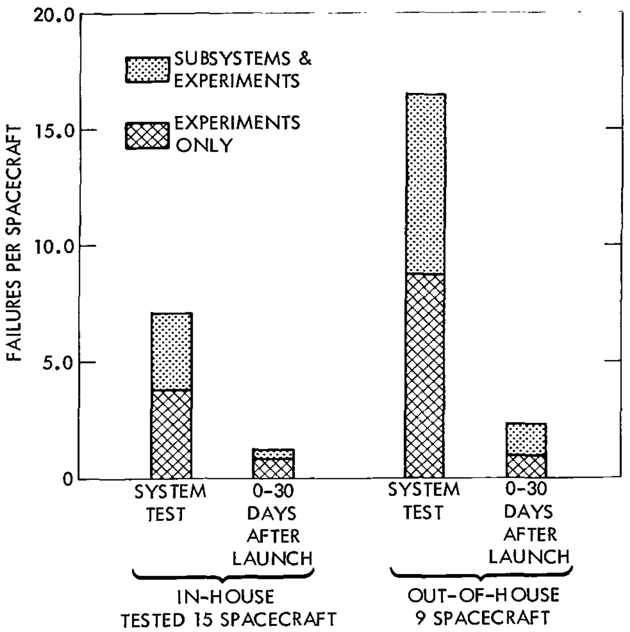

Figure 8—Spacecraft failures test vs flight.

Another analysis of the space data was made to see if the intended life had any influence on the failure times. Intended life is synonomous with mission life requirements, and is preferred to design life which is usually longer than intended life by a factor depending on the designer.

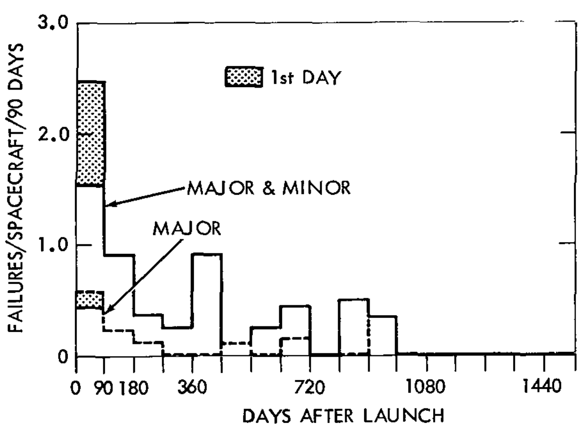

Figure 9—Major and minor spacecraft failures vs time in flight.

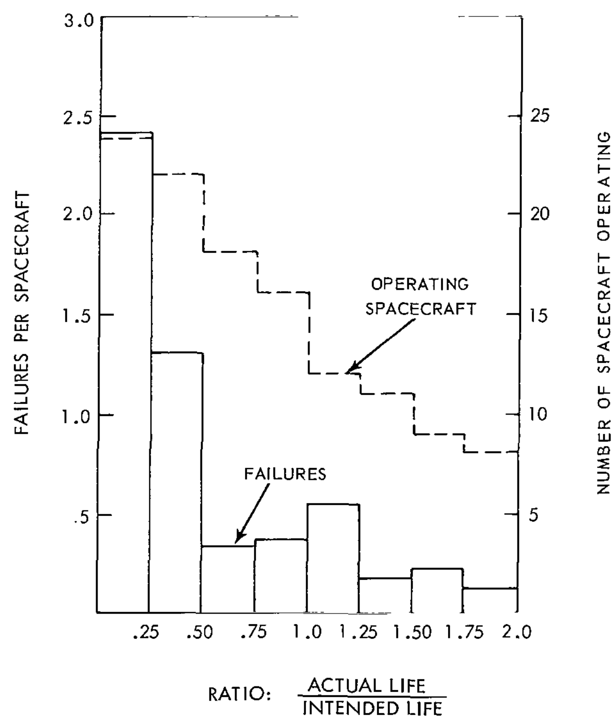

Figure 10—Space failures related to intended life.

The same data base as Figure 9 is used, but the flight time is given as a ratio of the actual flight time to the intended flight time. Both major and minor failures are included. The days to each failure is divided by the intended life, and the ratio plotted as shown in Figure 9A. Only four of the total 24 spacecraft were operating beyond a ratio (actual life to intended life) of two. The apparent increase in failures at a ratio of 1.0 to 1.25 is influenced by four failures on one spacecraft, and is not considered representative. The graph will also be influenced somewhat as data from the ten spacecraft which are still operating (Table 3) become available. With the reservations, as noted, the interpretation is the same as with Figure 9. That is, a definite wear-out period for spacecraft hardware has not been found in data accumulated to date.

Analysis of the Initial Post Launch Failures

The flight failure data have been summarized in Table 4. A total of 109 major and minor failures for 24 spacecraft indicate the following:

First Day

Forty-six percent of the spacecraft experienced first day failures.

Twenty percent of all failures noted during the life of the spacecraft before January 1969 occurred in the first day.

Fourteen percent are related to experiments and 6% are related to spacecraft subsystems.

First 30 Days

Sixty-three percent of the spacecraft had failures.

Thirty-five percent of all failures occurred in the initial 30-day flight period.

Table 4

Summary of Spacecraft Failure Data.

	Spacecraft Tested		
	In-House	Out-of-House	Total
Number of spacecraft	15	9	24
Major + minor flight failures	57	52	109
1st day:			
Experiment	10	5	15 (14%)
Subsystem	2	5	7 (6%)
			22 (20%)
1-30 day:			
Experiment	13	11	24 (22%)
Subsystem	5	9	14 (13%)
			38 (35%)
Number of spacecraft having failures in first 30 days (Major + minor)	9 (of 15)	6 (of 9)	15 (63%)
Number of spacecraft having failures on 1st day (Major & minor)	8 (of 15)	3 (of 9)	11 (46%)

Success Record

The operational performance for 73 spacecraft tested in accordance with the GSFC test philosophy has been appraised relative to the production of useful data and the mission objective. Figure 10 shows a plot of the percentage success for spacecraft vs the launch year. Success is here defined as achieving mission objectives; and, also, is defined as returning useful data from the operating spacecraft even if the injection prevented achieving mission objectives. The record has been superb for the initial ten years of this new technology. In fact, GSFC has been able to maintain 100% success for all spacecraft tested at the center.

Experiments are the major operational requirement of all scientific and applications spacecraft. The success of the GSFC program is measured by the useful data obtained. Figure 11 shows a summary of experiment record to December 1966. The 62% success represents fully satisfactory operation of the experiment, and an additional 28% of the experiments provided some useful data. In some cases useful data have been obtained when the vehicle did not meet orbital requirements, and even when the mission was declared a failure as in OGO-1. The experimenter also obtained useful data in some cases with degraded or partially operating equipment. Thus, on an overall basis, about 90% of the experiments have produced useful data over the seven year period.

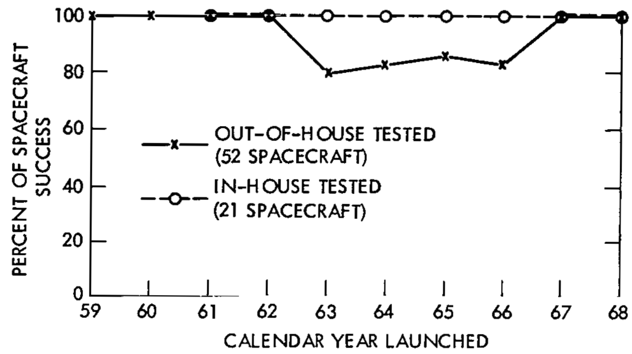

Figure 11—Spacecraft flight success record 1959 - 1968.

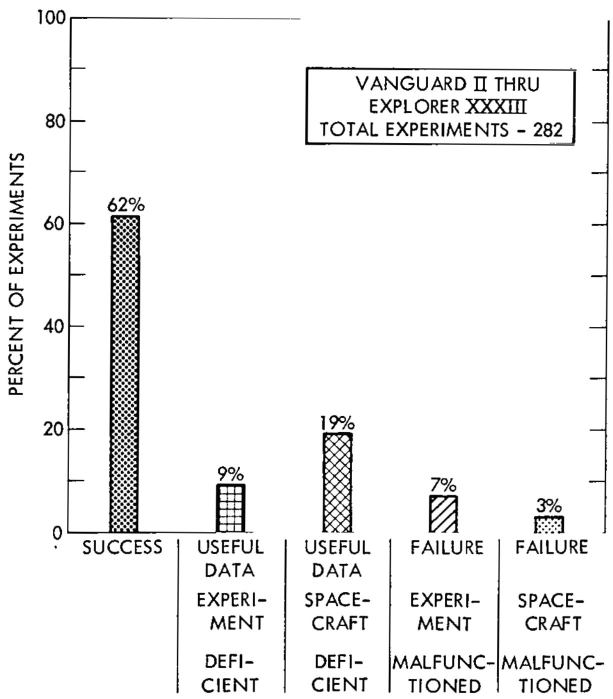

Figure 12—Experiment record 1959 - 1966.

CONCLUSIONS

1. The need for systems level testing has been demonstrated for both in-house and out-of-house spacecraft.

2. Multi-launch programs do not eliminate the need for environmental testing of later flight systems.

3. Spacecraft life has been increasing since 1961, and a useful life in excess of one year can be achieved with present GSFC practice on both in-house and out-of-house programs.

4. The overall space performance has been satisfactory for both in-house and out-of-house spacecraft.

5. The test philosophy at Goddard Space Flight Center is applicable to both in-house and out-of-house programs.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland, September 18, 1969
326-124-12-03-01

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