NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report 32-1036

Failure Rate Computations Based on Mariner Mars 1964 Spacecraft Data

Frank H. Wright

JET PROPULSION LABORATORY
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Approved by:

F. A. Paul

F. A. Paul, *Manager*
Reliability Programs Section

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Prepared Under Contract No. NAS 7-100
National Aeronautics & Space Administration

Acknowledgment

The author wishes to express his appreciation to Frank F. Baran and Keith L. Emberson for their major contributions to the collection of data used for computing the failure rates shown in this report.

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Abstract

This report describes the analysis of spacecraft parts-hours, and failure data from the *Mariner Mars* 1964 program. It contains failure rates for transistors, resistors, capacitors, diodes, transformers, relays, and coils, using the JPL Problem/Failure Reporting system. Failure data origins, ground rules, and definitions are also given.

Failure Rate Computations Based on Mariner Mars 1964 Spacecraft Data

I. Introduction

The purpose of this report is to publish *Mariner Mars* 1964 failure rate data for reliability predictions and risk/cost allocations of future JPL space programs. To obtain these failure rates, over 1500 Problem/Failure Reports (P/FR's) written on *Mariner C* were analyzed to see if the P/FR data showed relevant failures. Where P/FR data were not clear about the relevancy of the failure, cognizant engineers were contacted to obtain background information. These P/FR's were then jointly re-analyzed with the *Mariner* spacecraft project design personnel to verify their relevancy. Subsystem operating hours were obtained from cognizant engineers. Updated parts lists were also obtained from subsystem engineers. Then, to compute parts-hours, the number of parts were multiplied by the operating hours. To obtain failure rates, parts-hours were divided into the applicable relevant failures. For convenience of presentation, all failure rates will be expressed in %/1000 hr.

II. Basis for Deriving Relevant Failure Rates

A. Definitions

The term *relevant failure* must be understood fully to make the failure rates of this report meaningful, as well as useful. Relevant failure is defined as a JPL-peculiar version of what is usually considered a random failure. Definitions are as listed below:

(1) Parts failure. This occurs when a part fails to perform under prescribed conditions. The failure is due to its inability to perform a satisfactory function within a measurable limit.

(2) Random failure. This type is caused when a change takes place in stress levels that exceed strength levels, revealing latent quality defects, or exposing premature wearout due to undetectable material weaknesses.

(3) Relevant failure. This type is defined as a random failure, occuring after power turn-on during module, subsystem, and system testing. Excluded are failures due to human error, and operational support equipment-induced failures. Also excluded are failures due to design errors, mishandling, screening rejections, faulty workmanship, and early life failures (10 hr).

B. Relevant Failure Example

A good example of a relevant failure was recorded in a P/FR written on October 21, 1964 against the attitude control subsystem. During system test at AFETR, the

Table 3. Typical industry failure rates (as used in a contractor prediction analysis)

Transistor	Resistor	Capacitor	Diode	Transformer	Relay	Coil
0.03	0.023	0.001	0.015	0.2	0.06	0.01

Besides the failure rate table (Table 1), two more tables are shown. Table 2 shows part hours and failures for the various failure rate categories, to allow the purist to compute do-it-yourself failure rates. Table 3 shows typical industry failure rates, as used by an independent contractor for a reliability prediction analysis in December 1963, and is included for comparison. While the statistical basis of Table 3 failure rates is not known, it is thought that they are of point estimate origins. All failure rates are expressed in %/1000 hr.

IV. Inflight Relevant Failure Rates

Getting an accurate count of relevant failures on the *Mariner IV* spacecraft during flight was obviously more difficult than during its ground-based assembly and test, because more conjecture, simulation, and engineering judgment entered into data analysis of inflight problems or failure, with failure data collection also becoming a problem. Fortunately, an extremely thorough job of problem/failure reporting and analysis was done within the *Mariner* project and the supporting divisions during the *Mariner IV* flight.

By using the results of this P/FR system as a basis of failure-occurrence analysis, it appeared that two definite part failures occurred during the flight (there are still several P/FR's without sufficient information to make a failure/no-failure decision). The two definite primary failures were a film resistor in the plasma probe and the Geiger-Mueller tube in the ion chamber. However, these two "definite" failures break down into *no* relevant failures under the ground rules described in Section II. Under these ground rules, analysis definitely indicated that the resistor failure in the plasma probe must be classified a design failure, and not a relevant failure. The Geiger-Mueller tube failure is a borderline case between a relevant failure or a wear-out failure, but it makes little difference because this analysis does not compute failure rates for tubes. Therefore, for the seven part groups under consideration on the postlaunch *Mariner IV*, there are no known inflight relevant failures.

This analysis does not use any of the brief inflight data from *Mariner III* because the terminal nature of this mission precluded the collection of significant data.

For computing the flight time (from launch date to October 1, 1965) for *Mariner IV*, a figure of 7392 hr was used. However, while some subsystems worked for all this time (e.g., portions of the radio, CC&S, etc.), others had only brief activation (such as the television, tape recorder, etc.) and appropriate operating times for these subsystems were used. Compensations were also made for that part of the flight electronics that were not activated.

Table 4. Prelaunch *Mariner IV* failure rates

Type	Transistor	Resistor	Capacitor	Diode	Transformer	Relay	Coil
Class 1							
Point estimate	0.0259	0.0151	0.055	0.0118[a]	0.1905	0.9781[a]	8.8476
Best estimate	0.0519	0.0227	0.0733	0.0118	0.381	0.9781	11.0595
One sided 90% confidence limit	0.101	0.04	0.121	0.027	0.741	2.28	17.9
Class 3							
Point estimate	0.0259	0.0151	0.0183	0.0118[a]	0.1905[a]	0.9781[a]	2.2119[a]
Best estimate	0.0519	0.0227	0.0366	0.0118	0.1905	0.9781	2.2119
One sided 90% confidence limit	0.101	0.04	0.071	0.027	0.44	2.28	5.18

[a] One failure assumed.

The rates shown in the following tables are based on computations made in this analysis. Table 4 shows the failure rate history of *Mariner IV* before its launch on November 28, 1964. Table 5 shows the failure rate history of *Mariner IV* after its launch to October 1, 1965. Because this is flight configuration hardware, only the Class 3 failure category applies. Table 6 gives the failure rate history of *Mariner IV* from first assembly and test to October 1, 1965. It combines the failures and parts hours of Table 4 and Table 5. Table 7 gives failure rates computed from a combination of prelaunch *Mariner* 1964 Program failure data and the flight data from *Mariner IV* that is current to October 1, 1965.

All failure rates are expressed in %/1000 hr. Table 8 shows the various parts hours and failure combinations used as a basis for the contents of this section, and allows those with stamina to compute variations on the failure rates given. Figures 1 and 2 give *Mariner IV* failure frequency in graph form. Figure 1 is a histogram plotting failures versus time, while Fig. 2 is a freehand curve of the monthly peaks of Fig. 1 which, when logically extended, is impressively similar to the well-known reliability "bathtub" curve. The dotted lines at the end of the curve represent an extrapolation of the expected *Mariner IV* performance, with the time to wear-out unknown.

Table 5. Class 3 postlaunch *Mariner IV* failure rates

Type	Transistor	Resistor	Capacitor	Diode	Transformer	Relay	Coil
Point estimate[a]	0.0043	0.0012	0.003	0.002	0.0388	0.1603	0.4035
Best estimate[a]	0.0043	0.0012	0.003	0.002	0.0388	0.1603	0.4035
One sided 90% confidence limit	0.01	0.0029	0.0071	0.0047	0.091	0.37	0.94

[a] Point estimate and best estimate failure rates are identical, because one failure is assumed for all point estimates.

Table 6. Total *Mariner IV* failure rates

Type	Transistor	Resistor	Capacitor	Diode	Transformer	Relay	Coil
Class 1							
Point estimate	0.0036	0.0021	0.0078	0.0017[a]	0.0322	0.1377[a]	1.3651
Best estimate	0.0073	0.0031	0.0104	0.0017	0.0644	0.1377	1.7064
One sided 90% confidence limit	0.0143	0.0056	0.0175	0.004	0.124	0.315	2.72
Class 3							
Point estimate	0.0036	0.0021	0.0026	0.0017[a]	0.0322[a]	0.1377[a]	0.3412[a]
Best estimate	0.0073	0.0031	0.0052	0.0017	0.0322	0.1377	0.3412
One sided 90% confidence limit	0.0143	0.0056	0.0102	0.004	0.074	0.315	0.78

[a] One failure assumed.

Table 7. Class 3 total *Mariner 1964* program failure rates

Type	Transistor	Resistor	Capacitor	Diode	Transformer	Relay	Coil
Point estimate	0.0112	0.0009	0.0032	0.002	0.0098[a]	0.0421	0.111[a]
Best estimate	0.0123	0.0012	0.004	0.0025	0.0098	0.0843	0.111
One sided 90% confidence limit	0.0172	0.0022	0.0066	0.0041	0.022	0.165	0.258

[a] One failure assumed.

Table 8. Parts,hour-and failure-summary

Type	Transistor	Resistor	Capacitor	Diode	Transformer	Relay	Coil
Prelaunch *Mariner IV* part hours	3,847,480	13,203,842	5,451,111	8,411,010	524,839	102,231	45,210
Postlaunch *Mariner IV* part hours[a]	23,198,442	80,935,046	32,964,356	49,646,268	2,576,558	623,688	247,798
Total *Mariner IV* part hours[a]	27,045,922	94,138,888	38,415,467	58,057,278	3,101,397	725,919	293,008
Total *Mariner* 1964 part hours[a]	88,741,399	309,316,230	124,139,330	193,807,690	10,165,600	2,372,226	899,430
Class 1 prelaunch *Mariner IV* failures	1	2	3	0	1	0	4
Class 3 prelaunch *Mariner IV* failures	1	2	1	0	0	0	0
Class 3 postlaunch *Mariner IV* failures	0	0	0	0	0	0	0
Class 1 total program *Mariner IV* failures	1	2	3	0	1	0	4
Class 3 total program *Mariner IV* failures	1	2	1	0	0	0	0
Class 3 total *Mariner* 1964 program failures	10	3	4	4	0	1	0

[a] To October 1, 1965

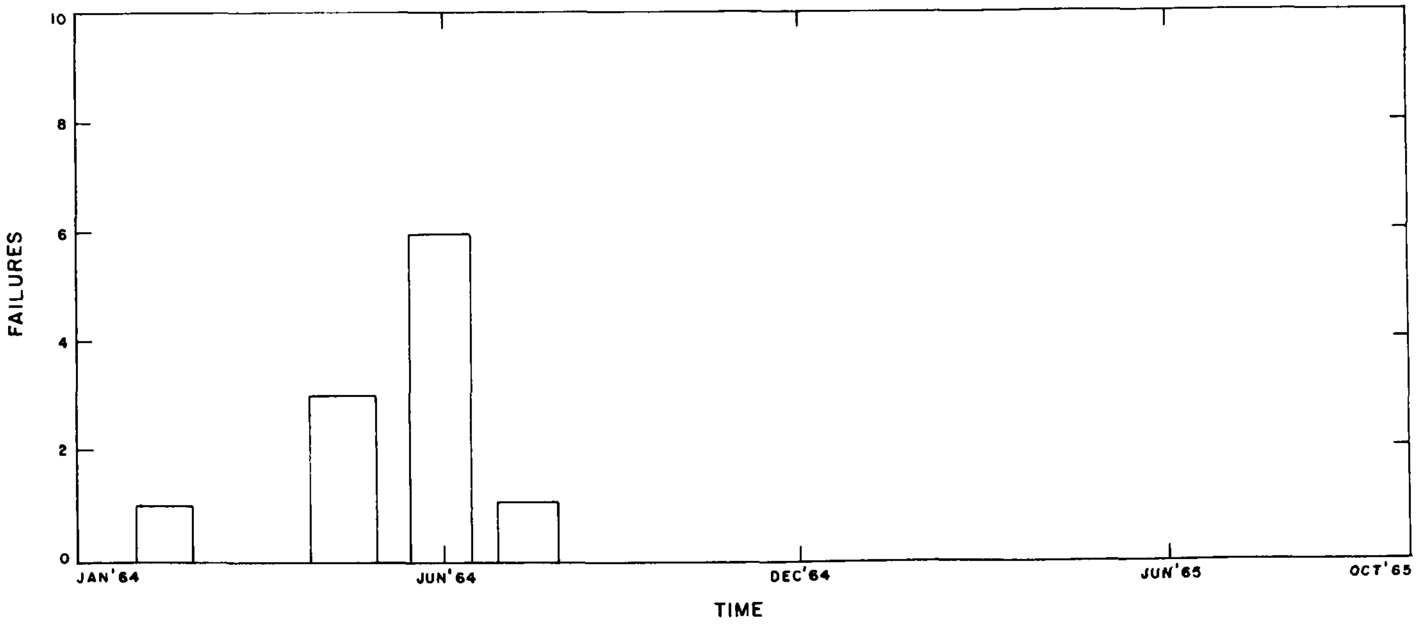

Fig. 1. Bar graph of total program *Mariner IV* failure experience

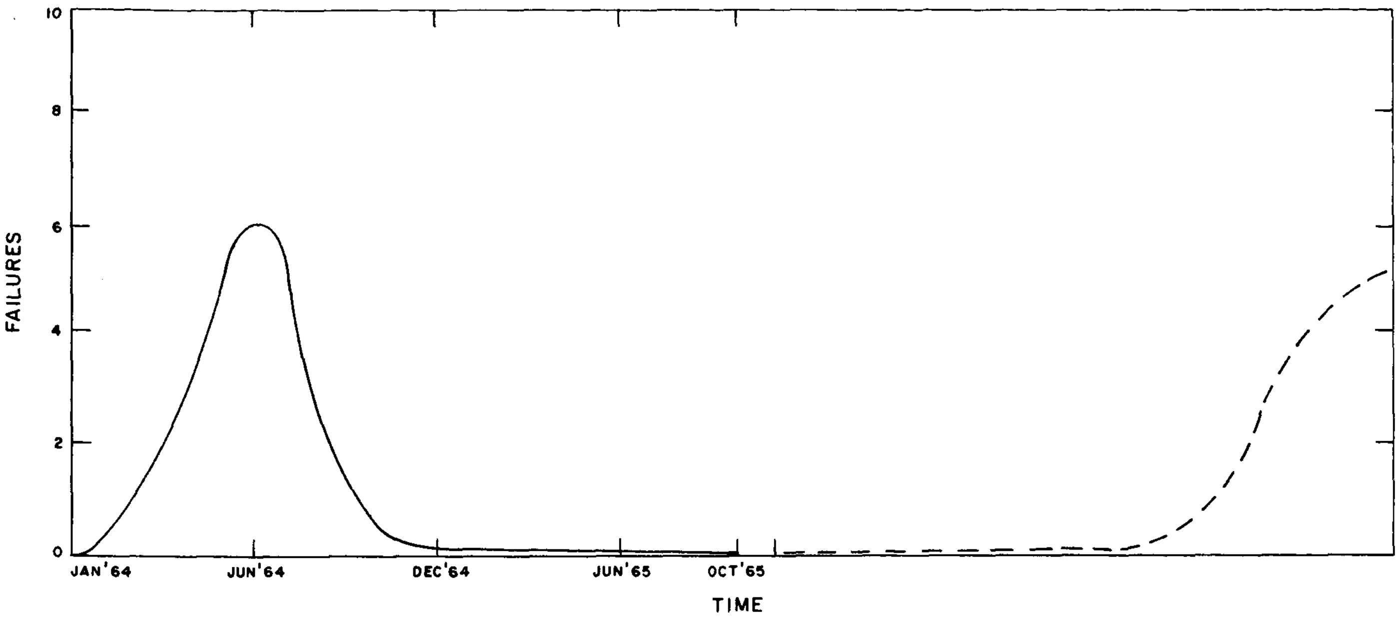

Fig. 2. Curve representation of *Mariner IV* total program experience

V. Conclusions

This report represents a first attempt at parts failure statistics and recommendation for a *Mariner Mars* spacecraft reliability analysis. The various failure rate configurations given should have real value if wisely used in reliability models and studies of future JPL space programs. These failure rates illustrate JPL assembly, test, and flight experience; they also give an approximate quantitative representation of the worth of the parts screening program and the effectiveness of JPL circuit derating techniques.

Another interesting result of the flight analysis is the comparison of the relevant part failures on the *Mariner IV* spacecraft (no known relevant failures) to the ground-based experience of this spacecraft (11 relevant failures); which adds significant data to the growing evidence that once a spacecraft passes the launch environment, the probability of mission success being degraded by random failures is greatly lowered, perhaps by several orders of magnitude. This contrasts the belief (held until recently) that the random failure frequency in space was about equal to that in a well-controlled laboratory environment on Earth.

Significantly, Figs. 1 and 2 show that the dominant failure experience period centered on June of 1964 and lasted approximately four months. This time period coincided with the major period of spacecraft testing at JPL before shipment of the flight spacecraft to Cape Kennedy. Relevant failure frequency became significant when this testing began, and stopped when the flight spacecraft were shipped to the Cape. This would tend to indicate that the greatest incidence of hardware failure (not only relevant failures, but failures caused by design, workmanship, and human error), will occur during final subsystem testing and full systems test, which is ordinarily the time period when schedule and manpower constraints are the most critical.

It was not possible to make this analysis as thorough as originally intended. Therefore, in concluding this report, it seems appropriate to mention specific areas not accomplished in this analysis that should be considered in future JPL analyses of this type.

Future studies should probe deeper into failure rate analysis of the parts group. As mentioned in Section 2, because of priority constraints it was not possible in this study to break a broad part group down into its subsets; e.g., no analysis was made of the failure frequency of power diodes, computer diodes, zener diodes—but just *all* diodes. This type of generality extended to all seven part categories. This created a good margin for bias, because the application, complexity, and manufacturer of various part types often is a good indication of their failure rate. For example, reliability analysis on other programs has shown zener diodes to fail with greater regularity than computer diodes, yet this analysis grouped these members of the diode family together and it was unfortunately not possible to make such fine distinctions.

The relay and coil failure rate given should also be considered with statistical doubt. First, due to the difficulty in accumulating accurate data, relay failure rates were based on straight operating time failures. Relay actuations were not considered, which is unfortunate, because the number of actuations of cycles before failure is the best measure of relay reliability. Secondly, statistically small relay and coil part hour totals were accumulated due to a low number of these devices on the spacecraft, which gave a poor statistical failure rates base for predictions (especially true with the experience of coils during the *Mariner IV* analysis).

Other valuable future spacecraft analyses would calculate and compare relevant failure frequencies for parts, subsystems, and systems during bench testing, subsystem and system type approval (TA) testing, for flight acceptance (FA) testing, and during flight. Another interesting analysis would explore the part history of the relevant part failures on future programs; i.e., how many were screened, not screened, hi rel, etc.

Therefore, the reliability analyses made or recommended in this report would be considerably enhanced if made during future JPL space programs, and not just on the spacecraft system, but on all special mission elements brought into existence with it.

As *Mariner IV* continues its deep space orbit around the Sun, additional parts-hr data has become available which will not be shown in this publication. The flight experience will be reflected in an updated version of this report to be published in early 1968.