

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

*Technical Report 32-1544*

*Failure-Rate Computations Based on Mariner Mars  
1969 Spacecraft Data*

*Paul O. Chelson*

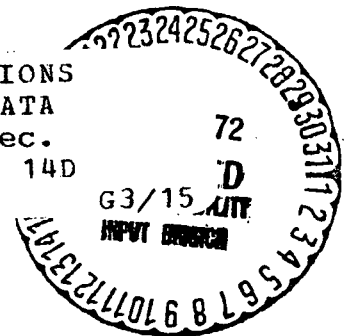
N72-14485 (JPL-TR-32-1544) FAILURE-RATE COMPUTATIONS  
BASED ON MARINER MARS 1969 SPACECRAFT DATA  
P.O. Chelson (Jet Propulsion Lab.) 1 Dec.  
1971 21 p CSCL 14D

Unclas

11798

FAC (NASA CR OR TMX OR AD NUMBER)

(CATEGORY)



JET PROPULSION LABORATORY  
CALIFORNIA INSTITUTE OF TECHNOLOGY  
PASADENA, CALIFORNIA

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## Preface

The work described in this report was performed by the Quality Assurance and Reliability Division of the Jet Propulsion Laboratory.

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## Abstract

This report describes an analysis of in-flight spacecraft part hours and failure data from the *Mariner* Mars 1969 Project. It contains failure rates computed from this data for all electronic and electromagnetic parts on the *Mariners* 6 and 7 spacecraft. Also included are failure rates based on combining flight data from *Mariners* 4, 5, 6, and 7.

# Failure-Rate Computations Based on Mariner Mars 1969 Spacecraft Data

## I. Introduction

The flights of *Mariners 6* and *7* offer significant data concerning the performance and success of electronic and electromagnetic parts in an interplanetary, long term, space environment. This report discusses the part-failure experience for the *Mariner Mars 1969 Project*. The latter section of the report combines data from *Mariners 4, 5, 6, and 7* to get larger samples of data to make the computations statistically more valid. It is intended that the data summarized and the computed failure rates will be used as guidelines for failure rates used on trade-off studies and predictions performed for future Jet Propulsion Laboratory (JPL) space missions.

## II. Brief Description of the Mariner Mars 1969 Project<sup>1</sup>

The *Mariner Mars 1969 Project* launched two spacecraft to Mars. *Mariner 6* and *Mariner 7* were launched on February 24 and March 27, 1969, respectively, and flew to within 3460 km of Mars on July 30 and August 4, 1969.

Each spacecraft weighed 386 kg and was equipped with (1) a movable platform for mounting TV cameras and other scientific instruments, (2) a basic octagon structure containing communication, power, computing and sequencing, data automation, and propulsion equipment, (3) four panels with solar cells to provide electrical power, (4) attitude-control gas jets mounted at the ends of the panels, (5) a directional dish antenna mounted on top of the octagon, and (6) an omnidirectional radio antenna.

The scientific instruments on *Mariner 6* and *Mariner 7* were mounted on the 76-kg movable platform. They were

- (1) An infrared radiometer to measure Mars' surface temperatures.
- (2) A wide-angle TV camera.
- (3) A narrow-angle TV camera with 25.4-cm telescope optics.
- (4) An ultraviolet spectrometer to measure upper atmosphere composition.
- (5) An infrared spectrometer to measure the composition of the lower atmosphere of Mars.

<sup>1</sup>From Office of Public Information, JPL.

In addition, the radio was used for several science experiments: the S-band occultation, the celestial mechanics, and the relativity experiments.

### III. Basis for the Failure-Rate Derivations

Only flight hours and flight failures were considered in the failure-rate computations. Whenever failures are mentioned (prelaunch or postlaunch), these are relevant failures - where a relevant failure (Ref. 1, p. 1) is a random part failure occurring after power turn-on during module, subsystem, and system testing, or flight. Excluded are failures due to human error or induced by operational support equipment. Also excluded are failures due to design errors, mishandling, screening rejections, faulty external workmanship, and early life failures (under 10 h). In other words, a relevant failure is considered a random part failure or noninduced part failure.

Examples of relevant and nonrelevant failures are given in Refs. 1 and 2.

The equipment operating hours used for the failure-rate computations take into account those flight subsystems (or portions thereof) that were nonoperational for portions of the flight.

Only major part classes are considered. Parts with very limited part hours (e.g., batteries) are not considered because the computed failure rates would not have been meaningful.

The JPL Problem/Failure Reporting (PFR) system was used to find relevant part failures both prior to and after launch. When PFR information was sketchy or unclear, appropriate project or subsystem people were contacted to obtain necessary background information.

Prelaunch failures and prelaunch operating hours are not used in the failure-rate computations. The failure rates are based on flight experience only. Prelaunch failure data is presented, however, to give indications of the value of screening and systems testing.

### IV. Screening Program

Screening, qualification, and systems testing all contribute to the removal of early-life- and process-defects-type failures. JPL has a somewhat unique parts program that relies on these tests to reduce the probability of inflight failures. This preconditioning of the parts is illustrated by considering typical screening tests (Table 1) and typical

qualification tests (Table 2). Tables 3 to 5 indicate *Mariner* prelaunch failure experience and Table 6 indicates postlaunch experience. Table 7 indicates screening yields. All this indicates that the prelaunch testing is weeding out many potential flight failures, that is, parts that may have not reached their constant failure-rate period.

## V. Post Launch Mariners 6 and 7 Relevant Failures

### A. Mariner 6

On April 20, 1969, 54 days into the flight, an anomaly occurred involving the attitude control of the spacecraft. The failure was an intermittent that appeared again on May 26, 1969 and on November 11, 1969. The problem appeared to be in the Canopus cone angle update circuitry. This failure was later diagnosed to be most probably a relay failure.

### B. Mariner 7

On November 3, 1969, 221 days into the flight, a failure occurred involving the attitude control. This failure was probably a relay, and in fact probably the same relay that failed on *Mariner 6*. This relay was used in the updating of the Canopus cone angle. It was not catastrophic to the mission, as the Canopus tracker was turned off and the spacecraft placed on roll inertial hold. The spacecraft was still controlled by the gyros as of the last track before attitude control gas depleted.

On July 7, 1969, 102 days into the flight, an anomaly occurred in the central computer and sequencer. The problem was traced to the C1 source driver in the computer event matrix. The most probable cause was deduced to be one of two integrated circuits (IC).

There was also a battery failure, but this is not considered in this study since a battery is not one of the parts for which we have sufficient data to compute a failure rate.

## VI. Mission Time

For *Mariners 6* and *7*, the mission times used for failure-rate computations are from launch to December 1, 1969, at which time the planned mission was terminated. The period after December 1 is the extended mission and is not included in these computations. This gives mission lengths of 6694 h for *Mariner 6* and 5954 h for *Mariner 7*. In addition, the encounter science experiments accumulated

**Table 1. Typical screening tests**

Sequence	Resistors	Capacitors	Diodes	Transistors
Visual inspection	X	X	X	X
First measurement	X	X	X	X
High temperature back bias			X	X
High-low temperature cycle	X		X	
Second measurement	X		X	X
Power burn-in (168 h)	X	X	X	X
Third measurement	X	X	X	X
Final visual	X	X	X	X

**Table 2. Typical qualification tests**

Sequence	Resistors	Capacitors	Diodes	Transistors
Visual inspection	X	X	X	X
High temperature back bias			X	X
High-low temperature cycle	X	X	X	
Temperature coefficient	X			
Vibration and shock	X	X	X	X
Surge voltage		X		
Moisture resistance	X	X		
Dielectric strength	X	X		
Seal test	X	X		
Terminal strength		X		
Power burn-in (2000 h)	X	X	X	X
Final visual	X	X	X	X

**Table 3. Mariner 4 piece part summary<sup>a</sup>**

Type	Quantity	Failures (prelaunch)
Capacitor	5,570	3
Diode	9,922	0
Relay	107	0
Resistor	15,607	2
Transistor	4,323	1
Magnetics	613	5
Integrated circuit (IC)	7	0
Miscellaneous	3,071	
Totals	39,220	11

<sup>a</sup> Ref. 3.

**Table 4. Mariner 5 piece part summary<sup>a</sup>**

Part	Quantity	Failures (prelaunch)
Capacitor	4,594	2
Diode	5,047	0
Relay	85	1
Resistor	10,781	0
Transistor	3,027	1
Magnetics	871	1
IC	594	1
Miscellaneous	269	0
Totals	25,268	6

<sup>a</sup> Ref. 3.

**Table 5. Mariner Mars 1969 piece part summary<sup>a</sup>**

Type	Quantity (per spacecraft)	Failures (prelaunch) <sup>a</sup>
Capacitor	3,222	1
Diode	4,418	4
Relay	194	8
Resistor	9,916	1
Transistor	3,035	9
Magnetics	693	4
IC	2,763	104
Miscellaneous	218	4
Totals	24,459	135

<sup>a</sup> Represents three flight spacecraft and spares; Ref. 3.

**Table 6. In-flight failures**

Spacecraft	Failures <sup>a</sup>
<i>Mariner 4</i>	None
<i>Mariner 5</i>	None
<i>Mariner 6</i>	1 relay
<i>Mariner 7</i>	1 IC, 1 relay

<sup>a</sup> Considering the part classes studied in this report.

Table 7. Mariner screening results<sup>a</sup>

Project	Resistors		Capacitors		Diodes		Transistors	
	Quantity	Rejected, %	Quantity	Rejected, %	Quantity	Rejected, %	Quantity	Rejected, %
Mariner Mars 1964	101,446	14	65,493	27	36,205	9	28,100	37
Mariner Venus 1967	23,343	19	9,112	26	12,170	42	6,418	57
Mariner Mars 1969	56,716	6	16,925	17	25,757	27	17,881	30

<sup>a</sup>Screening results for JPL furnished parts only. The quantity of parts screened by the subsystem contractors is not represented in these data; Ref. 3.

59 h between July 29, 01:27:40 and July 31, 12:32:50 on *Mariner 6*, and 80 h between August 1, 22:24:01 and August 5, 06:29:02 on *Mariner 7*.

The updates of *Mariner 4* and *Mariner 5* data were based on the following times: *Mariner 4* accumulated 26,832 flight hours between launch (November 28, 1964) and December 20, 1967, while *Mariner 5* accumulated 4824 flight hours between launch (June 14, 1967) and January 1, 1968.

## VII. Failure-Rate Computations

In all failure-rate computations, raw data (i.e. failures and part hours) will be included. This will allow readers to combine *Mariner* data with their own or other data of similar background to get larger data samples. If this is done, care must be exercised to combine only data from like missions, i.e. missions with similar environments and whose projects had similar screening programs.<sup>2</sup>

Computed failure rates for the combined *Mariner 6* and *Mariner 7* missions are presented in Table 8. Failure rates are shown only for general part types, because the data is too limited to compute useful failure rates for part classes. Even so, many of the failure rates for some part types are not meaningful because of too few part hours. They should be considered only as upper bounds on the "true" failure rate.

Table 9 presents the results of combining data for the *Mariners 4* through *7* missions. These failure rates are based on a very large amount of part hours and are statistically the most valuable we can present. The raw data for these failure rates is presented in the Appendix.

<sup>2</sup>Screening programs are "similar" only at a gross level; not even all *Mariner* Mars 1969 subsystems were screened by programs identical in details.

All failure rates have been computed two ways. The point estimate failure rate is found by dividing the number of failures by the accumulated part hours, assuming one failure in the case where none occurred. The 90% upper confidence level is found using the Chi-Squared distribution. The meaning of the 90% upper confidence limit can be seen as follows. Let  $\lambda_u$  be the computed upper 90% confidence limit for the failure rate for a particular part type. Then there is a 90% probability that the "true" failure rate for this part type is less than  $\lambda_u$  and only a 10% chance that the "true" failure rate could be greater than  $\lambda_u$ .

## VIII. Conclusions

A failure-rate analysis such as this, based on a very limited number of flight spacecraft, is limited statistically because of the small sample size involved. This is especially true of the *Mariner 1969* data when considered alone. When data from *Mariners 4* through *7* is combined, the sample is much larger; however, differences such as parts program actions, part-type design, and processing variations result in a more heterogeneous set of data. Obviously, some of the part types have much fewer part hours than others. Failure rates based on the small samples do not pretend to have any validity [e.g., traveling wave tubes (TWTs) and gyros], but they are presented so that the raw data might be used by others to combine with their own data.

Caution must be exercised in applying failure rates to part types with special differences from the sample parts. For example, the majority of the IC failures in Table 5 were due to "purple-plague"-type corrosions in the gold-aluminum bonds; a feature that is not universal to all IC device designs.

The data presented illustrates the effectiveness of the JPL parts screening program and its subsystem and system

tests. As was shown by the screening yields, screening did its share in eliminating defective parts from the program. Tables 3 through 5 indicate that system testing also found many part failures. Between screening and systems testing, most early-life- and process-defect part failures were removed. This undoubtably contributed to the in-flight success of the *Mariner* spacecraft.

*Mariners 4* through *7* dramatically proved to be highly reliable inflight spacecraft. These long-term interplanetary voyages provide a large data bank of deep-space-environment part experience. It is hoped that both the failure rates computed herein, and the raw part-hour data will help to provide the planners and designers of future deep-space missions with realistic part failure rates.

Table 8. Combined flight failure-rate data for Mariners 6 and 7

Generic type and class	Quantity	Part flight hours	Failures	Failure rate, 10 <sup>-6</sup> failures/h	
				Point estimate <sup>a</sup>	90% upper confidence limit
Electrical					
Capacitors					
Ceramic	1,922	7,488,871	0	—	—
Glass	1,084	4,078,218	0	—	—
Metalized	118	283,399	0	—	—
Mica	52	328,848	0	—	—
Mylar	118	433,507	0	—	—
Paper	8	25,574	0	—	—
Tantalum					
Foil	362	1,513,730	0	—	—
Solid	2,362	8,119,883	0	—	—
Wet	132	622,115	0	—	—
Special	462	2,233,693	0	—	—
<b>Total capacitors</b>	<b>6,620</b>	<b>25,127,838</b>	<b>0</b>	<b>0.0397</b>	<b>0.0916</b>
Silicon-controlled rectifiers (SCRs)	16	88,675	0	—	—
Silicon-controlled switches (SCSs)	32	52,260	0	—	—
<b>Total SCRs and SCSs</b>	<b>48</b>	<b>140,935</b>	<b>0</b>	<b>7.0954</b>	<b>16.3373</b>
Cores	2	12,648	0	79.0638	182.0445
Crystals	20	88,953	0	11.2418	25.8844
Diodes					
General purpose	842	4,474,196	0	—	—
Power	4	25,296	0	—	—
Quad	122	471,312	0	—	—
Reference, general purpose	894	4,340,211	0	—	—
Reference, precision	172	537,332	0	—	—
Signal and computer	3,948	15,973,181	0	—	—
Switching	2,016	8,883,903	0	—	—
Varactor	8	50,592	0	—	—
Special	76	380,552	0	—	—
<b>Total diodes</b>	<b>8,082</b>	<b>35,136,575</b>	<b>0</b>	<b>0.0284</b>	<b>0.0655</b>
Fuses	138	785,149	0	1.2736	2.9325
Inductors					
Low frequency (AF)	68	242,397	0	—	—
RF	566	2,953,934	0	—	—
<b>Total inductors</b>	<b>634</b>	<b>3,196,331</b>	<b>0</b>	<b>0.3128</b>	<b>0.7203</b>
IC					
Linear	120	246,011	0	—	—
Logic	5,326	15,152,310	1	—	—
<b>Total IC</b>	<b>5,446</b>	<b>15,398,321</b>	<b>1</b>	<b>0.0649</b>	<b>0.2525</b>

Table 8. (contd)

Generic type and class	Quantity	Part flight hours	Failures	Failure rate, 10 <sup>-6</sup> failures/h	
				Point estimate <sup>a</sup>	90% upper confidence limit
Electrical					
Photosensitive devices	44	240,729	0	4.1540	9.5646
Rectifiers					
Fast recovery	624	3,045,528	0	—	—
General purpose	46	165,814	0	—	—
Power	34	215,016	0	—	—
<b>Total rectifiers</b>	<b>704</b>	<b>3,426,358</b>	<b>0</b>	<b>0.2918</b>	<b>0.6719</b>
Resistors					
Carbon composition	7,018	27,782,389	0	—	—
Carbon film	2,168	12,547,095	0	—	—
Metal film	6,228	16,256,731	0	—	—
Temperature sensitive	4	278	0	—	—
Wire wound	1,180	5,585,970	0	—	—
Special	1,964	3,063,604	0	—	—
<b>Total resistors</b>	<b>18,562</b>	<b>65,236,067</b>	<b>0</b>	<b>0.0153</b>	<b>0.0352</b>
Thermistors	16	1,112	0	899.2805	2070.5935
Transformers					
Audio	220	1,378,771	0	—	—
Power	80	336,470	0	—	—
Pulse	192	326,069	0	—	—
<b>Total transformers</b>	<b>492</b>	<b>2,041,310</b>	<b>0</b>	<b>0.4898</b>	<b>1.1279</b>
Transistors					
Chopper	114	420,720	0	—	—
Dual	304	809,195	0	—	—
Junction	614	2,444,401	0	—	—
Isolated gate	68	4,726	0	—	—
High frequency	8	556	0	—	—
Medium power	3,750	15,971,929	0	—	—
Power	238	804,608	0	—	—
Small signal	744	2,415,909	0	—	—
Switching	96	557,068	0	—	—
Unijunction	64	292,155	0	—	—
Special	48	3,336	0	—	—
<b>Total transistors</b>	<b>6,048</b>	<b>23,724,603</b>	<b>0</b>	<b>0.0421</b>	<b>0.0970</b>
Electromechanical					
Motors	2	139	0	7194.2446	16564.7482
Potentiometers					
Composition	16	1,112	0	—	—
Wire-wound	60	154,278	0	—	—
<b>Total potentiometers</b>	<b>76</b>	<b>155,390</b>	<b>0</b>	<b>6.4354</b>	<b>14.8175</b>

Table 8. (contd)

Generic type and class	Quantity	Part flight hours	Failures	Failure rate, 10 <sup>-6</sup> failures/h	
				Point estimate <sup>a</sup>	90% upper confidence limit
Electromechanical					
Relays					
Latching	268	1,631,251	2	—	—
Nonlatching	120	671,317	0	—	—
<b>Total relays</b>	<b>388</b>	<b>2,302,568</b>	<b>2</b>	<b>0.8684</b>	<b>2.3115</b>
Mechanical					
Gyros	6	1,500	0	666.6666	1535.0000
TWTs	2	12,648	0	79.0638	182.0445

<sup>a</sup>Note that for the case of no failures, the point estimate is computed assuming one failure. This corresponds to an upper 52% confidence limit.

Table 9. Combined Mariner 4 through 7 postlaunch failure rates

Characteristics	Part type							
	Integrated Microcircuit	Transistor	Capacitor	Diode	Resistor	Inductor	Transformer	Relay
Part hours <sup>a</sup>	18,263,777	122,847,849	165,865,881	242,176,068	410,174,364	5,326,067	12,813,505	4,952,799
Failures	1	0	0	0	0	0	0	2
Failure rate, 10 <sup>-6</sup> failures/h								
Point estimate	0.0547	0.0063	0.0060	0.0041	0.0024	0.1877	0.0780	0.4038
90% upper confidence limit	0.2129	0.0187	0.0138	0.0095	0.0056	0.4323	0.1796	1.0746

<sup>a</sup> See appendix for detailed part-hour breakdown.

## References

1. Wright, Frank H., "Failure Rate Computations Based on *Mariner* Mars 1964 Spacecraft Data", Technical Report 32-1036. Jet Propulsion Laboratory, Pasadena, Calif., Jan. 15, 1967.
2. Wright, Frank H., "Failure Rate Analysis of *Mariner* Venus 1967 Spacecraft Data", Technical Report 32-1266. Jet Propulsion Laboratory, Pasadena, Calif., June 1, 1969.
3. Gavin, T., and Lockyear, W., "Electronic Parts for Long Duration Missions", *Astronautics & Aeronautics*, Sept. 1970.

## Appendix

### Detailed Breakdown of Flight Part Hours for the Mariners 4 through 7 Missions

When dealing with part classes that have very few part hours, one must be very careful if one makes failure-rate computations for these classes. Even if such computations are prefaced many times over with cautionary remarks such as "poor upper bound because of limited data", someone, somewhere, will latch on to the number, ignore the cautions, and misuse it.

For this reason, failure rates have been computed only for general part types and not for detailed part classes. However, since some readers may have further data that

they may wish to combine with the *Mariner* data, and others may just wish to know the breakdown, a detailed breakdown of flight part hours is listed in Table A-1. This list was arrived at using the projects' parts listings with variations between projects in their grouping of part types and classes. For example, *Mariner Mars 1969* considers wet, solid, and foil tantalum capacitors. I regret that *Mariner 4* data is available only for general part types.

Table 6 lists the flight failure experience for the *Mariners*.

Table A-1. Mariner flight part-hour summary

Part type	Flight part hours			Total
	Mariner 4	Mariner 5	Mariners 6 and 7	
Electrical				
Capacitors				
Ceramic	(footnote a)	7,611,504	7,488,871	15,100,375
Feed-thru		362,840	—	362,840
Glass		5,520,004	4,078,218	9,598,222
Metallized		34,548	283,399	317,947
Mica		152,684	328,848	481,532
Mylar		415,968	433,507	849,475
Paper		77,184	25,574	102,758
Plastic film		154,368	—	154,368
Polycarbonate		4,824	—	4,824
Porcelain		434,160	—	434,160
Tantalum				
Foil		—	1,513,730	1,513,730
Solid		—	8,119,883	8,119,883
Wet		—	622,115	622,115
Total tantalum		5,950,100	10,255,728	16,205,828
Teflon		53,064	—	53,064
Special		—	2,233,693	2,233,693
Variable		472,752	—	472,752
<b>Total capacitors</b>	<b>119,494,043</b>	<b>21,244,000</b>	<b>25,127,838</b>	<b>165,865,881</b>
Cells, cadmium sulfide		183,312	—	183,312
Connectors, miniature		2,454,644	—	2,454,644
SCRs		—	88,675	88,675
SCSs		—	52,260	52,260
<b>Total SCRs and SCSs</b>		<b>283,468</b>	<b>140,935</b>	<b>424,403</b>
Cores, toroidal		1,616,040	12,648	1,628,688
Crystals				
Filter		4,824	—	4,824
Frequency control		62,712	—	62,712
<b>Total crystals</b>		<b>67,536</b>	<b>88,953</b>	<b>156,489</b>
Delays, line-precision		4,824	—	4,824
Diodes				
General purpose		—	4,474,196	4,474,196
Matched pair		28,944	—	28,944
Power		—	25,296	25,296
Quad		—	471,312	471,312
Reference				
General purpose		1,424,704	4,340,211	5,764,915
Precision		88,164	537,332	625,496
Signal and computer		16,942,036	15,973,181	32,915,217

TABLE A-1. (contd)

Part type	Flight part hours			Total
	Mariner 4	Mariner 5	Mariners 6 and 7	
Electrical				
Special		—	380,552	380,552
Switching		—	8,883,903	8,883,903
Varactor		28,944	50,592	79,536
Varicap		77,184	—	77,184
Zener		399,908	—	399,908
<b>Total diodes</b>		<b>18,989,884</b>	<b>35,136,575</b>	<b>54,126,459</b>
Rectifiers				
Fast recovery		227,512	3,045,528	3,273,040
General purpose		3,457,888	165,814	3,623,702
High voltage		772,172	—	772,172
Power		—	215,016	215,016
<b>Total rectifiers</b>		<b>4,457,572</b>	<b>3,426,358</b>	<b>7,883,930</b>
<b>Total diodes and rectifiers</b>	<b>180,165,679</b>	<b>23,447,456</b>	<b>38,562,933</b>	<b>242,176,068</b>
Filters, RFI		82,008	—	82,008
Fuses, isolation		81,580	785,149	866,729
Gyracs		14,472	1,500	15,972
Inductors				
RF		458,280	2,953,934	3,412,214
Saturated reactor		7,900	—	7,900
Low frequency		773,756	242,397	1,016,153
<b>Total inductors</b>	<b>889,800</b>	<b>1,239,936</b>	<b>3,196,331</b>	<b>5,326,067</b>
Lamps		—	139	139
Magamps, precision		4,824	—	4,824
IC				
Linear		—	246,011	246,011
Buffer		241,200	—	241,200
Clock drive		9,648	—	9,648
Expander		135,072	—	135,072
Flip-flop		820,080	—	820,080
Gate		1,534,032	—	1,534,032
<b>IC, total logic</b>		<b>2,865,456</b>	<b>15,152,310</b>	<b>18,017,766</b>
<b>Total IC</b>		<b>2,865,456</b>	<b>15,398,321</b>	<b>18,263,777</b>
Photosensitive devices		—	240,729	240,729
Relays	2,257,251	392,980	2,302,568	4,952,799

TABLE A-1. (contd)

Part type	Flight part hours			Total
	Mariner 4	Mariner 5	Mariners 6 and 7	
Electrical				
Resistors				
Carbon composition		10,592,352	27,782,389	38,374,741
Carbon film		18,234,720	12,547,095	30,781,815
Glass		11,111,612	—	11,111,612
Metal film		7,946,644	16,256,731	24,203,375
Temperature sensitive		28,944	278	29,222
Wire-wound		1,731,100	5,585,970	7,317,070
Special		—	3,063,604	3,063,604
<b>Total resistors</b>	<b>295,292,925</b>	<b>49,645,372</b>	<b>65,236,067</b>	<b>410,174,364</b>
Switches, motorized		4,824	—	4,824
Thermistors, precision		14,472	1,112	15,584
Transducers				
Pressure		53,064	—	53,064
Temperature		241,200	—	241,200
<b>Total transducer</b>		<b>294,264</b>	<b>—</b>	<b>294,264</b>
Transformers				
Audio		316,088	1,378,771	1,694,859
Power		156,280	336,470	492,750
Pulse		974,448	326,069	1,300,517
Surge limiter		5,100	—	5,100
<b>Total transformers</b>	<b>9,320,279</b>	<b>1,451,916</b>	<b>2,041,310</b>	<b>12,813,505</b>
Transistors				
Chopper		1,412,284	420,720	1,833,004
Dual		370,300	809,195	1,179,495
Junction FET		—	2,444,401	2,444,401
Isolated gate FET		—	4,726	4,726
Field effect (junction and IS gate)		96,480	2,449,127	2,545,607
General purpose		8,790,048	—	8,790,048
High frequency		—	556	556
Medium power		—	15,971,929	15,971,929
Power		279,844	804,608	1,084,452
Small signal		2,954,772	2,415,909	5,370,681
Switching		—	557,068	557,068
Special		—	3,336	3,336
Unijunction		37,848	292,155	330,003
<b>Total transistors</b>	<b>85,181,670</b>	<b>13,941,576</b>	<b>23,724,603</b>	<b>122,847,849</b>
Tubes				
Geiger-Mueller		14,472	—	14,472
RF power		260	—	260
Regulator		14,472	—	14,472
Traveling wave		3,820	12,648	16,468
<b>Total tubes</b>		<b>33,024</b>	<b>12,648</b>	<b>45,672</b>

TABLE A-1. (contd)

Part type	Flight part hours			Total
	<i>Mariner</i> 4	<i>Mariner</i> 5	<i>Mariners</i> 6 and 7	
Electromechanical				
Motors	—	—	139	139
Potentiometers				
Composition		—	1,112	1,112
Wire-wound		—	154,278	154,278
<b>Total potentiometers</b>		119,176	155,390	274,566

<sup>a</sup>No part-class breakdown available for *Mariner 4*.