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A Study of Mariner 10 Flight Experiences and Some Flight Piece Part Failure Rate Computations

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PREFACE

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

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ABSTRACT

Mariner 10, which derived its design pedigree from the JPL Mariner series, was highly successful and contributed significant data toward the understanding of our solar system. The success of the mission with regards to a long-term space environment allows further data to be added to our reservoir of knowledge about the behavior of electronic equipment in space. This report discusses the problems and failures encountered in flight and summarizes the data available through a quantitative accounting of all electronic piece parts on the spacecraft. It also shows computed failure rates for electronic piece parts. It is intended that these computed data be used in the continued updating of the failure rate base used for trade-off studies and predictions for future JPL space missions.

I. INTRODUCTION

Mariner 10 derived its design pedigree from the JPL Mariner series. The success of the mission contributed significant data toward the understanding of our solar system.

On Sunday, March 16, 1975, Mariner 10 had operated in space continuously for more than 16 months. The spacecraft had completed its second 176-day orbit around the Sun. During that same 6-month period, since Mariner 10's second Mercury encounter (September 21, 1974), the planet had rotated three times on its axis and completed two of its own 88-day orbits around the Sun. This planned coincidence had permitted the third and final encounter with the fast-moving planet. In eight more days, Mariner 10 was to have completed its extended mission assignment and exhausted its attitude control gas.

Mariner 10 used the last of its attitude control gas supply at approximately 11:25 GMT on March 24, 1975, and the spacecraft transmitter was turned off for the last time. The historic flight of Mariner 10 was over, 506 days and nearly 1.6 billion kilometers (1 billion miles) of travel from liftoff on November 3, 1973.

This report discusses the problems and failures encountered in flight and summarizes the data available through a quantitative accounting of all electronic piece parts on the spacecraft. It also shows computed failure rates for electronic piece parts. It is intended that these computed data be used in the continuing updating of the failure rate base used for trade-off studies and predictions for future JPL space missions.

II. MARINER VENUS/MERCURY 1973 PROJECT DESCRIPTION

The mission objectives established by NASA were as follows:

Primary: To conduct exploratory investigations of the planet Mercury's environment, atmosphere, surface, and body characteristics during the 1973 Mercury opportunity.

Secondary: To obtain environmental and atmospheric data from Venus during the flyby of Venus, to perform interplanetary experiments while the spacecraft is enroute from Earth to Mercury, and to obtain experience with a dual-planet, gravity-assist mission.

The project started with several restraints that were "firsts" for a JPL-managed program. The most important, of course, was the requirement not to exceed $98 million in costs. There was to be a single launch on an Atlas/Centaur vehicle. The spacecraft would be a Mariner-class vehicle and make maximum use of existing hardware and technology. The spacecraft's TV cameras would take the first pictures of both Venus and Mercury. The mission would be the first multiplanet mission and the first to use a gravity-assist technique. And, for the first time since Surveyor, a spacecraft system contractor was engaged in a JPL-managed space program.

The Mariner 10 scientific instrument complement was selected with the primary objective of conducting an exploratory investigation of Mercury. A brief description of the experiments follows:

(1) A dual fluxgate magnetometer, mounted on a 6-m boom, measured magnetic fields.

(2) A plasma science instrument measured energy and directional spectra of solar wind protons and electrons.

(3) A charged-particle telescope measured high-energy ions and electrons.

(4) Two extreme ultraviolet spectrometers (occultation spectrometer and airglow spectrometer) measured pressure and composition of the Hermian atmosphere.

(5) A body-mounted infrared radiometer measured surface thermal properties.

(6) Television cameras provided high-resolution imaging at long slant range. The cameras had eight position filter wheels to select effective wavelengths of 355 to 578 nm.

III. GENERAL SPACECRAFT DESCRIPTION

The Mariner Venus/Mercury 1973 (MVM'73) spacecraft was designed, built, and tested by the Boeing Aerospace Company, Kent, Washington, under the direction of the Jet Propulsion Laboratory. The spacecraft design was derived from the JPL Mariner series, with some new subsystems and special modifications as required by its sunward trajectory. Table 1 lists the subsystems and responsible organizations for these subsystems. Celestial references for the three-axis stabilized spacecraft were the Sun and the star Canopus. Principal features of the thermal design include the large sunshade located below the octagonal "bus" structure (which housed the spacecraft electronic subassemblies), the rotational capability of the solar panels, and the automatically activated thermal control louvers on the upper five sides of the bus. Rotation of the solar panels about their long axes was to reduce the projected panel area as viewed from the Sun and hence minimize the solar heating of the panels. This technique successfully maintained heat input and electrical output within acceptable limits throughout the total flight range of 1 to 0.46 AU. The spacecraft weighed 502 kg at injection, including 29 kg of hydrazine rocket motor propellant and 2.7 kg of attitude control nitrogen gas. Following the successful launch of the flight MVM'73 spacecraft, the spacecraft was redesignated Mariner 10.

IV. COMPARISON TO PREVIOUS MARINER SPACECRAFT FROM ELECTRONIC PIECE PART VIEWPOINT

Failure rate computations based on data from the Mariner Mars 1969 (MM'69) mission were performed in 1971 by P. O. Chelson (see Ref. 2). Table 2 compares the piece part complexities of the Mariner Mars 1969 spacecraft, the Mariner Mars 1971 (MM'71) spacecraft, and the Mariner Venus/Mercury 1973 spacecraft.

Of the many electronic piece part types used on the Mariner spacecraft, one type stands alone as having a significant increase in usage between the MM'71 Project and the MVM'73 Project. The microcircuit (integrated circuit)-type part usage per spacecraft increased from 3063 to 4756 or about a 55% increase. To further assess the impact of this growth, an internal examination of integrated circuit (IC) devices was performed. The individual

Table 1. MVM'73 spacecraft subsystem responsibility (Ref. 1)

Subsystem designator	Subsystem	Design and fabrication responsibility
2000	System	Boeing
2001	Structure, STRU	Boeing
2002	Radio frequency, RFS	Boeing
2003	Modulation/demodulation, MDS	Boeing
2004	Power, PWR	Boeing
2005	Central computer and sequencer, CC&S	Boeing
2006	Flight data FDS	JPL
2007	Attitude control A/C	Boeing
2008	Pyrotechnic	JPL
2009	Cabling	Boeing
2010	Propulsion, PROP	Boeing/JPL
2011	Thermal control, T/C	Boeing/JPL
2012	Mechanical devices	Boeing/JPL
2015	Articulation & pointing, APS	Boeing
2016	Data storage, DSS	Boeing
2017	Antennas	Boeing
2032	Plasma science, PSE	MIT
2033	Charged-particle telescope, CPT	University of Chicago
2034	Ultraviolet spectrometer, UVS	Kitt Peak Observatory
2035	Magnetometer, MAG	GSFC
2036	Television science, TV	JPL
2037	X-band transmitter, XTX	JPL
2038	Infrared radiometer, IRR	Santa Barbara Research Center

Table 2. Recent Mariner spacecraft electronic component piece part usage summary [a]

Type part	MM'69 [b]	MM'71 [b]	MVM'73 [b]
Capacitors	3221	3957	5074
Crystals	9	8	18
Diodes	4418	4748	5072
Filters	88	104	116
Fuses	69	131	91
Inductors	351	357	357
Microcircuits	2763	3063	4756
Relays	194	261	245
Resistors	9914	11031	13239
Switches	16	17	6
Thermistors	12	33	39
Transformers	338	342	339
Transistors	3035	3296	3062
Miscellaneous	28	3	7
Totals [b]	24456	27351	32421

[a] Includes science.

[b] Per spacecraft.

circuit elements (i.e., resistor, transistor, etc.) on the IC chip were counted on the higher population, and representative IC part types used on both the MM'71 and MVM'73 spacecraft. The individual circuit elements count on the MM'71 Project averaged 38 parts per IC device. On the MVM'73 Project the count averaged 65 parts per IC device. This increase in circuit element complexity of about 70%, when coupled with the increase of IC part usage, results in an IC growth complexity factor of about 2.6 (MM'71 to MVM'73).

V. MARINER 10 FLIGHT PROBLEMS AND FAILURES

A. REPORTING OF FLIGHT ANOMALIES

The Mission Operations System, operating within the JPL Space Flight Operations Facility, used the Spacecraft Problem/Failure Reporting (PFR) form to report anomalies/failures of spacecraft hardware. The use of the PFR system during flight was a continuation of the problem/failure reporting activity which commenced early in the project, when power was first applied to the flight hardware and continued to launch. There were 41 incidents reported through the PFR system during mission operations. The listing in Table 3 shows all 41 problems/failures. The table identifies the subsystem, date of occurrence, and description of the problem. Of these 41 incidents, 15 were considered significant to the health of the spacecraft. Their occurrence on a time ordinate is shown in Fig. 1.

B. USE OF REDUNDANCY DURING FLIGHT

Both block and functional redundancies were used to maintain and repair the operational status of the spacecraft when failures occurred. Block redundancy (built-in identical backup circuits or hardware) provided fixes for four failures: (1) Power Subsystem, main to standby inverter transfer (PFR 5021); (2) Power Subsystem, different panel currents (PFR 5027); (3) Power Subsystem, 87-W power increase (PFR 5031); and (4) Flight Data Subsystem (FDS), analog to digital converter (A/DC) failure (PFR 5034). Functional redundancy (restoration of function by equivalent functional approach) provided work-arounds for five failures: (1) Television Science Subsystem, optics heater failure (PFR 5001); (2) FDS, power on-reset at gyros on (PFR 5013); (3) roll axis oscillation (PFR 5024); (4) X-band transmitter output

Table 3. Mariner Venus/Mercury 1973 PFRs

PFR No.	Subsystem	Occurrence date	Description of problem/failure from PFR data bank
5001	TVS	11-03-73	TV heaters failed to cycle through positions. Most likely cause is leakage path from heater circuit-raw dc power line to chassis, biasing off FDS MOSFETs that control TV optics heater. Optics heater came on 1-17-74 when direct command DC-64 sent.
5002	MAG	11-03-73	MAG temperature at -54° C (-66° F), 11.1° C (20° F) lower than predicted. Heater function verified by manual command. Not a thermal anomaly; interpretation problem.
5003	PSE	11-03-73	PSE scan package temperature 5.5° C (10° F) below specification limit. PSE temperature was low because PSE not on early in mission and combination of supplemental heater size, test errors, and lower unregulated dc supply voltage. No corrective action.
5004	A/C	11-03-73	Tracker temperature below specification limit of -6.6°C (20°F). Tracker temperature was low because it dissipates less power when star is acquired than in viewing dark field. Temperature only 1.1° C (2° F) below limit and no performance effect.

Table 3 (contd)

PFR No.	Subsystem	Occurrence date	Description of problem/failure from PFR data bank
5005	A/C	11-03-73	Tracker failed to acquire Vega in brightness gate 2. Vega acquisition missed due to desensitization of tracker by exposure to Earth. Recovery completed within 24 h and is operating satisfactorily.
5006	T/C	11-04-73	Camera temperatures exceeded lower specification limit of -15°C (5°F), due to TV heaters not functioning, reference PFR 5001. TV heaters came on 1-12-74 and camera temperatures returned to normal.
5007	PSE	11-05-73	Scanning electrostatic analyzer (SEA) ion and electron counts too low. Possible failure modes were: (1) SEA aperture door failed to open, (2) SEA analyzer plates damaged during launch, and (3) component or solder failure in SEA electronics. Cause unknown.
5008	SYSTEMS	11-03-73	Incorrect scan clock and cone commands reversed scan platform operations program (SPOP). All CC-6 coded commands to be run through SPOP and command generation.

Table 3 (contd)

PFR No.	Subsystem	Occurrence date	Description of problem/failure from PFR data bank
5009	PSE	11-12-73	Scanning electron spectrometer (SES) channel A has 1881 counts added to all data. Problem had cleared when channel A checked on 12-20-73. SES is sensitive to 2.4-kHz rise time and may have cleared due to slight change in rise time.
5010	A/C	11-13-73	Bright particle caused loss of Canopus lock. Particle tracked in plus direction and lost. Roll search to Canopus inhibited by setting of roll search inhibit logic in the A/C electronics. Corrective action is to send DC-21 to allow roll search.
5011	A/C	11-20-73	A/C N_2 gas usage higher than expected. 9.07 g/day (20 mlb/day) initial estimate was based on insufficient data. Cruise usage was actually about 4.54 g/day (10 mlb/day) per prelaunch predicts.
5012	TVS	11-16-73	Camera A cathode current low at turn-on. Degradation probably due to leaving TVS power on due to TV heaters not coming on (PFR 5001). Diagnostic tests run and vidicon beams off in Earth-Venus cruise. TVS power off in Mercury cruise.

Table 3 (contd)

PFR No.	Subsystem	Occurrence date	Description of problem/failure from PFR data bank
5013	SYSTEMS	11-21-73	FDS power-on-reset (POR) when gyros turned on by command 7M1, pre-roll control maneuver. Another POR on day 341. Probable causes are random combination of normal 2.4-kHz bus dip at gyro turn-on and converted common mode noise in FDS. Precautions and contingencies now used.
5014	APS	11-26-73	No platform telemetry response to 2 of 8 CC-6 commands. Reference PFR 5019 for corrective action.
5015	XTX	12-07-73	XTX output power drop from 96 to 90 data numbers (DN). Several 6 DN changes in XTX output level seen since launch, during S/C maneuver with XTX case temperature of 10°--15.5° C (50°--60° F). XTX output is now 1.5 dB above requirement. 6 DN = 0.3 dB. Satisfactory above 15.5° C (60° F).
5016	MAG	11-07-73	MAG flipper failed to complete stroke. Flipper continued incomplete strokes until 2-21-74 when cable warming to -26.1° C (-15° F) allowed complete stroke. Work-around procedure used to ensure adequate power for flips.

Table 3 (contd)

PFR No.	Subsystem	Occurrence date	Description of problem/failure from PFR data bank
5017	A/C	12-07-73	Tracker failed to acquire Canopus six times. Low temperature, prolonged darkness exposure in roll control maneuver and gate calibration accuracy caused marginal acquisition conditions. Use gate G-2 for future acquisitions after prolonged dark condition.
5018	APS	12-15-73	Abnormal backlash in cone slews at 160 deg. Reference PFR 5019 for corrective action.
5019	SYSTEMS	12-18-73	Scan cone slew sluggish from 150 to 179 deg. Cone limits established.
5020	SXA	12-25-73	High-gain antenna (HGA) drive changed from 84 to 8[illegible] DN. Low-gain antenna (LGA) drive changed from 0 to 9 DN. Fault in hybrid cavity or in S-band radiating cavities. 11 state changes occurred before final cure on 3-4-74. Check design and fabrication cleanliness on future projects.
5021	SYSTEMS	01-09-74	Power Subsystem went from main to standby chain. Probably due to shorted Dickson 1N3892 diode in the main booster/regulator. Modify in-flight sequences to minimize Power Subsystem stresses.

Table 3 (contd)

PFR No.	Subsystem	Occurrence date	Description of problem/failure from PFR data bank
5022	SYSTEMS	01-05-74	HGA dish stopped before reaching stop position. Curled HGA cabling wrapped around the HGA boom. HGA dish position limits set to avoid problem and incremental commands used near limits.
5023	DSS	01-10-74	DSS stuck in parking window when commanded low-rate playback. Relative humidity in DSS may be 57% to 80%, causing excess catalyst A in magnetic heads to come out, reacting with oxide coating and causing sticking. Park on window and exit with high torque.
5024	A/C	01-30-74	High-rate roll gyro oscillations and high gas use. Roll gyro had steady 3.62-Hz oscillation. Extensive tests and analysis indicate most likely cause is exciting seventh S/C structural mode. Use solar sailing to minimize gas use.
5025	DSS	02-09-74	DSS tape stuck at left end of tape. Not in parking window. Reference PFR 5023 for analysis and corrective active.

Table 3 (contd)

PFR No.	Subsystem	Occurrence date	Description of problem/failure from PFR data bank
5026	STRU	03-12-74	Solar panel tilted to 50 deg. Temperature over 115°C (239°F). Specification limit of 115°C (239°F) applies to cell surface. Temperature transducer on opposite side. Peak cell temperature was 133.3°C (272°F) and average was 126.1°C (259°F). Flight acceptance temperature is 120°C (248°F).
5027	POWER	03-19-74	On panel tilt to 76 deg, current differential between panels increased. Probably a partial failure in section 1 of -X panel. Cause unknown.
5028	UVS	03-20-74	Airglow (AG) high-voltage power turned off in playback. Similar problem occurred in subsystem tests on both UVS AG units (Reference prelaunch PFRs 5802 and 5805), but no occurrence in system tests. Commands will be sent during Mercury encounter to reset UVS AG if off at the time of UVS AG state change. No significant change in DSS drive volts or power telemetry.
5029	PROP	03-21-74	Engine catalyst bed resistance decrease after post-trajectory correction maneuver (TCM). Drop after TCM 1 was 16% and after TCM 2 was 12%. 1% = 0.09% in delta velocity. Catalyst bed

Table 3 (contd)

PFR No.	Subsystem	Occurrence date	Description of problem/failure from PFR data bank
			resistance stabilized after TCM 3. Flight impulse errors less than 1/4 of specification.
5030	T/C	03-26-74	HGA boom temperature exceeded specification limit of 90°C (194°F). Cause is unknown. No corrective action.
5031	SYSTEMS	03-30-74	Spacecraft drawing 87 watts added power; TV heaters off. Prime suspected cause is booster regulator in the power conditioning equipment. Other symptoms include: DSS drive toggles on/off, no response to DC-43 and 47, X-band spikes, +4 V TV power dropped 4 DN, S/C bus temperature up and RFS frequency change.
5032	XTX	03-30-74	XTX output dropped from 81 to 3 DN. Possibly due to loss of voltage regulation in chopper transformer circuit. Carrier can be recovered by turning XTX power off and then back on.
5033	MDS	03-31-74	No response to DC-43 (switch traveling-wave tube to low power). Switches probably have component failure or circuit degradation. No more DC-42's or 43's will be sent.

Table 3 (contd)

PFR No.	Subsystem	Occurrence date	Description of problem/failure from PFR data bank
5034	FDS	04-16-74	Analog engineering data from FDS analog/digital converter 2 went to 127 DN. Appears to be due to isolated part failure in FDS.
5035	POWER	04-29-74	+X solar panel current increase when tilted away from Sun. Data analysis reveals all responses normal.
5036	PSE	07-30-74	PSE SES electron multiplier count rate decreasing. Normal wearout. No corrective action except turn off until Mercury encounter II. Predictable event.
5037	DSS	08-19-74	DSS appears jammed approximately 21.3 m (70 ft) from right end of tape. Probably caused by head-to-tape weld causing the tape to loop and jam. Turned off subsystem.
5038	A/C	09-04-74	Canopus tracker lost Canopus lock due to bright particle tracking. Remain in cruise mode to minimize oscillations.
5039	A/C	09-05-74	Canopus tracker lost lock, storm of bright particles. Same analysis and closure action as PFR 5038.
5040	A/C	10-05-74	Lost Canopus acquisition due to bright particles. Maintain roll drift mode until Mercury encounter III.
5041	A/C	11-27-74	Yaw position exceeds limit, switch amplifier did not fire. Exact cause not determined.

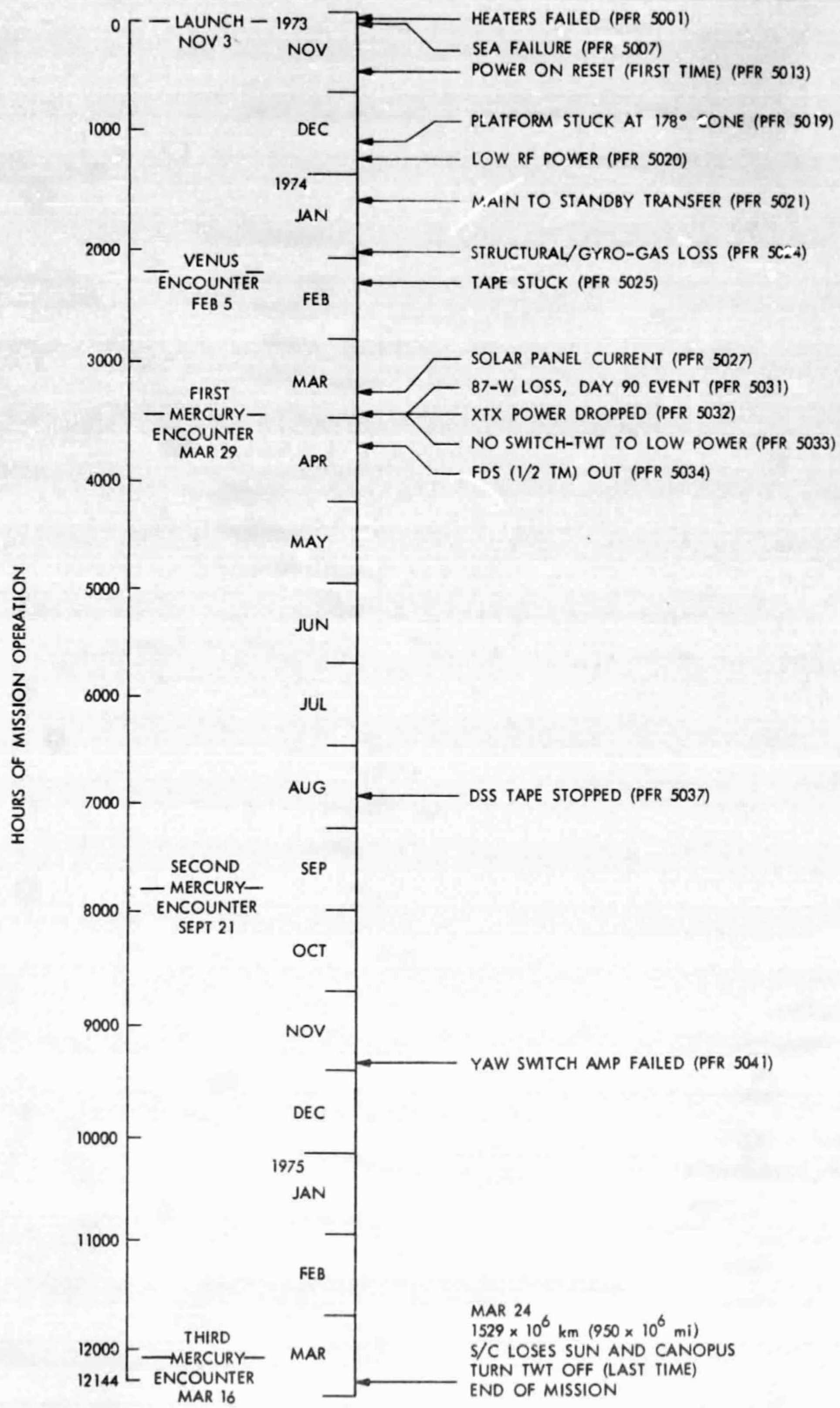

Fig. 1. Mariner 10 significant spacecraft events

power drop (PFR 5032); and (5) no Modulation/Demodulation Subsystem (MDS) response to DC-43 command (PFR 5033).

At least one of the failures involving block redundancy (main to standby inverter switch, PFR 5021) and one of the failures where functional redundancy was applied (roll axis oscillation, PFR 5024) would have been catastrophic to the mission without redundancy. One failure involving block redundancy (the A/DC in the FDS, PFR 5034) occurred after the extended mission had commenced but prior to the second encounter. Without redundancy, it would probably have caused loss of the extended mission. There was one failure where an unplanned extra power load (PFR 5031) was supported by the solar array, preventing mission failure. The solar array is considered to be block redundant for this discussion.

Redundancy was effectively used to help keep the spacecraft operating normally.

C. ANOMALOUS OCCURRENCES

A review of the 15 most significant problems and failures shows them all to be anomalous occurrences, that is, occurrences which were not predicted and not anticipated or secondary occurrences resulting from another event or failure.

The remaining problems or failures were a mix among anomalous occurrences (AO), secondary occurrences (SO), and non-anomalous occurrences (NAO). The latter category is defined as a condition which was understood, operating as designed, but not expected. These occurrences are due to an imperfect understanding of the design, and hence, an erroneous prediction or interpretation of the performance. The three conditions are summarized by PFR number.

AO			SO	NAO
5001*	5016	5028	5003	5002
5004	5017	5029	5006	5010
5005	5018	5030	5012	5011
5007*	5020*	5031*	5019*	5038
5008	5021*	5034*	5025*	5039
5009	5022	5035	5026	5040
5013*	5023	5036	5032*	
5014	5024*	5041*	5033*	
5015	5027*		5037*	

*15 most significant problems or failures.

VI. PARTS PROGRAM BACKGROUND

A. ELECTRONIC PARTS ENGINEERING

It is felt that a key element to the successful mission was an integrated overall parts control program. Some elements of the program are identified here to convey the extensiveness, completeness, and depth of controls utilized on the project:

(1) Parts Control Documentation

(2) Parts Selection and Standardization

(3) Parts Qualification

(4) Specification Writing and Review

(5) Application Review and Stress Analysis

(6) Parts Control List

(7) Parts Rating and Classification

(8) Screening, Monitoring, and Data Analysis

The result of the efforts applied by JPL and Boeing engineering was a parts control program that supported the design engineers in the design/build/test cycle of the hardware. Table 4 shows the quantity of parts per spacecraft by subsystem and by generic part type. Table 5 shows the number of parts by part types rated acceptable (Q & A), conditionally acceptable (T), unknown quality (Y), or unacceptable (X). See Table 6 for definitions of the above ratings. In addition, for added background information, Table 7 identifies the electronic piece part yields from screening tests under Boeing responsibility.

B. INTEGRATED CIRCUITS

The integrated circuit (IC) acquisition process was similar to that used in the Mariner Mars 1971 Project. For the Boeing IC buy, JPL furnished quality inspectors at the manufacturing source to perform pre-encapsulation visual inspection. In addition, these inspectors performed source inspection for the JPL IC buy. JPL bought ICs for the CC&S, RFS, and TV Subsystems and supported the PSE Principal Investigator in source inspection of his IC procurement.

Table 4. Quantity of parts in MVM'73 spacecraft[a]

		RFS						A/C							APS		DSS										
Part type	STRU	RFS	TWTA	MDS	PWR	CC&S	FDS	Chassis	CT	Elect.	Gyro	PYRO	PROP	Mech dev.	APE	Scan act.	DSS elect.	DSS tape & chassis	PSE	CPT	UVS	MAG	TVS	XTX	IRR	Press XDCR	Totals
Capacitors		660	64	677	274	129	471		105	101	48	64			70		523		199	548	207	143	560	106	75	50	5074
Crystals		9		2	2		2										1			2							18
Diodes		316	100	602	591	1242	161		94	182	96	57			116		254	4	210	242	69	36	504	44	77	75	5072
Filters		72	22																					22			116
Fuses		6		2	47		18		4						10							4					91
Inductors		170	16	4	11	76	15				5	2			8		5		2		8	12		20	3		357
Microcircuits		6		333	17	366	2547		31						191		232		113	92	59	563	158	3	45		4756
Relays		7	2	7	30	161	4		3	12	7						8		4								245
Resistors	9	787	134	2622	678	1141	818	11	280	295	121	172	6	2	425	18	1394	2	484	975	300	752	1433	82	173	125	13239
Switches					1									5													6
Thermistors		3	2		4		1													9		6		8	1	5	39
Transformers		57	16	117	53	15	11		4	8	5	2			2		6		17		2	4	7	6	2	5	339
Transistors		122	48	618	103	368	98		37	74	36	35			81		292	4	97	253	92	291	320	18	33	40	3062
Miscellaneous		3																1						3			7
Total	9	2218	404	4984	1811	3498	4146	11	558	672	318	332	6	7	903	18	2715	11	1126	2121	737	1311	2982	312	411	300	32421

[a]See Reference 3

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Table 5. MVM'73 part type matrix

Part type	Q	A	Y	X	T	Totals
Capacitors	30	33	33	2	1	99
Crystals		6				6
Diodes	64	93	18		2	177
Filters		3	7			10
Fuses	3					3
Inductors	2	18	38	1		59
Microcircuits	58	40	34		1	133
Relays	6	2		1	1	10
Resistors	54	20	21	1	4	100
Switches	1	1				2
Thermistors	4	2	1	1		8
Transformers	6	38	72	1		117
Transistors	40	59	38	16		153
Miscellaneous[a]		1	2			3
Totals	268	316	264	23	9	880

[a]Attenuators, isolators, and motors.

Other flight science experimenters performed their own procurement and control of parts. JPL and Boeing integrated circuit procurement specifications included requirements for step-by-step product flow, process controls, traceability and accountability, environmental tests, electrical tests, operating burn-ins, and appropriate documentation. Primary attention was given to material selection and in-process visual inspections, which were

Table 6. Part reliability classifications

Classification	Definition
Q	On the current issue of the JPL Preferred Parts List (or of same part family as a part on the JPL PPL) or formally qualified by subcontractor, and subcontractor's qualification test results reviewed and found acceptable.
A	Only limited qualification/evaluation performed; adequate for MVM'73 use; may or may not be further qualified.
T	Part (or part family) is on test or scheduled for testing during current fiscal year.
Y	Not recommended for spacecraft use based upon lack of adequate reliability data, or there is an indication from available history that the part has certain characteristics which make it less than desirable.
X	Found to be inferior and definitely not recommended for spacecraft use. Use of the part presents serious risk. (Project decision to use was based on individual part application, as well as cost and time constraints of qualification and substitution actions.)

performed 100% at several inspection points by both the manufacturer's quality assurance inspectors and by the JPL resident source inspectors.

C. PARTS FAILURE ANALYSIS

There were 213 part problems identified through the PFR system on the MVM'73 Project prior to launch. Ninety of these parts were diagnosed by JPL. A few parts, which by obvious mishandling or electrical overstress during testing, were not diagnosed. The remainder of the parts problems was diagnosed by Boeing or their subcontractors.

Of the 213 prelaunch parts investigated, 95 were ICs, 33 were transistors, and 9 were diodes. All parts that failed for unknown or questionable reasons, or where the Cognizant Engineer or other personnel were concerned in any way, were diagnosed for cause, and a failure analysis report was written by JPL or Boeing.

Table 7. Electronic part yields from screening (Boeing data)

Part	Total parts purchased	Number rejected	Yield, %
Capacitors	2714	857	68
Diodes	4673	1430	69
Fuses	495	188	62
Microcircuits	1305	215	84
Relays	277	116	58
Resistors	16460	1878	89
Transformers	8	0	100
Transistors	1697	395	77

Before launch, all part problems were identified, analyzed, and resolved. Those part problems of greatest concern were discussed and reviewed at the consent-to-launch meeting, along with associated risks so that NASA and JPL management could judge the adequacy of the fix and/or risk.

VII. SPACECRAFT OPERATING CONFIGURATION AND FAILURE RATE COMPUTATIONS

A. SPACECRAFT REDUNDANCY

To determine the number of piece parts that was operating during the mission, the redundancy of the spacecraft system design was reviewed. Figure 2 is extracted from the Spacecraft System Requirements Document 615-12, Rev. A (Ref. 4) and shows those subsystem elements with redundancy.

4.4 RELIABILITY REQUIREMENTS

4.4.1 Redundancy Requirements

Redundancy shall be applied in the following areas:

a) Two S-band RF power amplifiers shall be provided, each with its own power supply. Only one shall be operated at a time.
b) Two S-band RF exciters shall be provided, each with its own power supply. Only one shall be operated at a time.
c) Two power booster-regulator and main inverter chains shall be provided. In the event of a failure of one of the power booster-regulator and main inverter chains, it shall automatically be removed from the line and the second power chain shall be activated.
d) Dual pyrotechnic circuits shall be armed in parallel and shall perform all electroexplosive functions in parallel.
e) The CC&S shall provide redundant capability for executing the maneuver sequence.
f) The modulation/demodulation subsystem shall provide identical redundant telemetry modulation units. Only one shall be operated at a time.
g) The articulation and pointing subsystem shall provide redundant capability for addressing its output actuators.
h) The flight data subsystem shall include redundant oscillators, power converters, and memories.
i) Dual attitude control gas assemblies shall be provided, including storage tanks, regulators, valves and jets. In the event of failure of one assembly including loss of gas through leakage, adequate torque capability and gas capacity shall exist in the remaining assembly to control the S/C for the duration of the mission where gas usage during the mission is based on expected rather than worst-case conditions.

Fig. 2. Redundancy requirements (extracted from Ref. 4)

B. SPACECRAFT OPERATING CONFIGURATION AND ELECTRONIC PARTS COUNT

Redundant parts which were not powered were identified and accordingly deleted from the RFS, MDS, Power, and FDS Subsystem parts count. Table 8 is revised from Table 4 and lists all parts used in the failure rate calculations of this report. Table 8 represents parts used in active circuits when power was applied to that subsystem.

The non-imaging science instruments were the responsibility of the Principal Investigators. These instruments are the plasma science, charged particle telescope, ultraviolet spectrometer, magnetometer and infrared radiometer. Because these instruments used parts that were procured and screened by each experimenter, there was not the same accountability of parts in the procurement and processing cycle as there was for the engineering subsystems. Also, the X-band transmitter was treated as an experiment and did not have the same parts screening requirements. The above instruments will not be used for failure rate determination in this paper. The TVS did have identical attention paid to parts procurement, handling, and screening like all other engineering subsystem parts and is included in the parts failure rate determinations.

C. SPACECRAFT OPERATING TIME DURING THE MISSION

The mission commenced on November 3, 1973, and ended on March 24, 1975, for a total of 506 days or 12, 144 hours of operations. All engineering subsystems were powered during the mission except the Data Storage Subsystem (DSS). The DSS electronics were turned off after the DSS tape jammed (PFR 5037). This was after 6936 hours of operation. The DSS transport had about 1000 hours of running time. The TV Subsystem was turned on several times for a total of 3077 hours during the mission.

D. ELECTRONIC PIECE PART FAILURE RATES

Because of the very limited number of failures during flight, all parts in the calculations are kept grouped as a generic family, i.e., resistors, capacitors, ICs, etc.

Data is too limited to compute useful failure rates for sub-generic classes of parts. The reader is cautioned that even the generic failure rates

Table 8. Quantity of operating parts in MVM'73 spacecraft (used in calculations)

Part Type	STRU	RFS		MDS	PWR	CC&S	FDS	A/C				PYRO	PROP	Mech dev	APS		DSS[a]		TVS[b]	Press XDCR	Totals
		RFS	TWTA					Chassis	CT	Elect	Gyro				APE	Scan act	DSS elect	DSS tape & chassis			
Capacitors		551	32	573	243	129	456		105	101	48	64			70		523		560	50	3505
Crystals		9		1	2		2										1				15
Diodes		264	50	550	565	1242	141		94	182	96	57			116		254	4	504	75	4194
Filters		60	11																		71
Fuses		6		1	47		18		4						10						86
Inductors		142	8	4	9	76	8				5	2			8		5				267
Microcircuits		6		255	10	366	2547		31						191		232		158		3796
Relays		7	1	4	30	129[c]	4		3	12	7						8				205
Resistors	9	552	67	2388	610	1141	768	11	280	295	121	172	6	2	425	18	1394	2	1433	125	9919
Switches					1									5							6
Thermistors		3	1		4		1													5	14
Transformers		48	8	115	45	15	11		4	8	5	2			2		6		7	5	281
Transistors		102	24	542	85	368	73		37	74	36	35			81		292	4	320	40	2113
Miscellaneous		3																1			4
Total	9	1853	202	4433	1651	3466	4029	11	558	672	318	332	6	7	903	18	2715	11	2982	300	24476

[a] DSS electronics was on 6936 h
DSS tape was on ≈1000 h.

[b] TV was on 3077 h.

[c] Does not include 32 relays in CC&S which were quad redundant.

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for some part types are not meaningful because of too few part hours. Where there were no failures, a point estimate is computed assuming one failure. This corresponds to about an upper 52% confidence limit. All operating piece parts and part hours are included in the computations. All failure rates have been computed two ways. The point estimate failure rate is found by assuming one failure has occurred, and dividing that failure by the accumulated part hours to obtain failures/hour. 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 λ_u be the computed upper 90% confidence limit for the failure rate for a particular part type. Then there is a 90% probability that λ_u is greater than the "true" failure rate for this part type and only a 10% chance that λ_u is less than the "true" failure rate.

Table 9 shows computed failure rates for Mariner 10. The data is displayed in such a manner that the reader may use this data in combination with data from missions with similar heritage and develop a larger data sample.

At the first Mercury encounter, an 87-watt power increase occurred (PFR 5031). A short in Bay 1 was the most likely mechanism. No specific piece part failure fits the failure model. It is not likely that an IC failure would cause 87 watts of power dissipation. A diode is as likely to have caused the failure as any other part, and to allow for this possibility a computation was made. See footnote c in Table 9.

The high-gain antenna drive dropped approximately 3 dB, 52 days after launch (PFR 5020). The problem was verified as an S-band feed problem. The fault was either inside the hybrid cavity or in the S-band radiating cavity. The problem was intermittent in nature and 11 RFS state changes occurred over a 69-day period, and then the problem cured itself. This was not an electronic piece part failure.

Subsystem failures that were attributed to piece part failures during the mission were: (1) Power Subsystem, main to standby inverter transfer (PFR 5021), a diode; (2) Flight Data Subsystem A/DC failure (PFR 5034), an IC; and (3) altitude control yaw switch amplifier failure to fire (PFR 5041), a diode.

Table 9. Flight failure[a] rate data for Mariner 10

Generic part type	Operating part hours (10^6)	Failure rate, 10^{-6} failures/hour: Point estimate	Failure rate, 10^{-6} failures/hour: 90% upper confidence limit
Capacitors	34.76	0.029	0.067
Crystals	0.18	5.6	13.0
Diodes	45.02	0.044	(0.008,0.141)[b,c]
Filters	0.86	1.16	2.68
Fuses	1.04	0.96	2.21
Inductors	3.21	0.31	0.720
Integrated circuits	43.45	0.023	(0.001,0.109)[b]
Relays	2.45	0.408	0.941
Resistors	100.19	0.010	0.023
Switches	0.07	14.0	33.0
Thermisters	0.17	5.9	13.5
Transformers	3.31	0.30	0.701
Transistors	21.24	0.047	0.109

[a] Note that for the case of no failures, the point estimate is computed assuming one failure. This corresponds to about an upper 52% confidence limit. Computed in the point estimate failure rate data are two diode failures and one IC failure.

[b] These are 90% confidence intervals, when actual failures occurred.

[c] The point estimate assuming possibility of three diode failures is 0.067 and the 90% confidence intervals are (0.018, 0.172).

E. DORMANCY CONSIDERATIONS FOR ELECTRONIC PIECE PARTS

The UVS and IRR experiments, as well as the TV Subsystem, were turned off (dormant) for major periods of time during the mission. In addition, one redundant RFS (exciter) and one redundant telemetry portion of the MDS were turned off at any given time during the mission. There were no part failures experienced in those equipments during the time they were turned on or off. The accumulative non-operating part hours are summarized in Table 10. Only dormant hours followed by power turn-on conditions are displayed in this table. These data are presented to give a quantitative expression of dormancy considerations relative to electronic piece parts.

REFERENCES

1. Mariner Venus/Mercury 1973 Spacecraft Program, Final Report, D208-37000-1, Boeing Aerospace Company, Seattle, Wash., July 1974.

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3. Bentler, K., Dougherty, D., and Golden, C. T., Parts Usage List, Electronic/Electromechanical – MVM73 Spacecraft, D208-30243-1, Contract No. 953000, The Boeing Company, Seattle, Wash., July 10, 1973.

4. Mariner Venus/Mercury 1973 Spacecraft System Requirements Document, Report 615-12, Rev. A, Exhibit No. III to Contract No. 953000, Feb. 14, 1972 (JPL internal document).

Table 10. Dormancy[a] part hours of hardware on Mariner 10

Subsystem or experiment	Total piece parts	In-flight hours of non-operation	Non-operating part hours (10^6)
UVS	737	9196	6.8
IRR	411	11491	4.7
RFS (exciter) and one TWTA	567	12144	6.9
TVS	2982	9067	27.0
MDS (1/2 TMU)	551	12144	6.7
		Total part hours	52.1

[a]All equipments were turned on during or after encounter III with no problems/failures.

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