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Technical Memorandum 33-501

Development and Testing of the Central Computer and Sequencer for the Mariner Mars 1971 Spacecraft

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PREFACE

The work described in this report was performed by the technical divisions of the Jet Propulsion Laboratory, under the cognizance of the Mariner Mars 1971 Project.

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CONTENTS

ABSTRACT

The central computer and sequencer subsystem (CC&S) has been an important part of the Mariner series of interplanetary spacecraft since their inception. As with other spacecraft subsystems, the CC&S has increased in complexity and capability with each spacecraft project. This report describes the design, fabrication, and test associated with the development of the Mariner Mars 1971 CC&S subsystem.

I. INTRODUCTION

The central computer and sequencer (CC&S) subsystem provides the onboard sequencing functions of maneuver control, antenna and telemetry switching, and TV picture-taking sequences desired during the mission. The CC&S subsystem for Mariner Mars 1971 (MM'71) is essentially the same as that developed for the Mariner Mars 1969 (MM'69) project. A functional description of the CC&S subsystem is contained in Ref. 1. The CC&S subsystem development for MM'71 consisted of required design changes to the MM'69 design, and the modification of the MM'69 spare CC&S to be used as the MM'71 proof-test model (and spare), plus the fabrication of two new subsystems for flight.

The fabrication and test of the MM'71 CC&S subsystem and subsystem support equipment was subcontracted to Motorola, Inc., Government Electronics Division, Scottsdale, Ariz.

II. DESIGN CHANGES

A. Computer

A number of design changes to the CC&S were necessitated by the orbital mission and by the use of a larger propulsion engine located on a different spacecraft axis. The required changes were:

(1) Expanded memory from 128 words to 512 words.

(2) CC-1 command format change.

(3) Increased number of output relays.

(4) Added computer capability to start and stop sequencer.

(5) Added digital data interface with attitude control known as "pre-aim."

(6) Added computer "compare" capability.

(7) Modified sync and flag interface buffers.

(8) Changed maneuver sequence from pitch-roll to roll-yaw.

(9) Changed maneuver standby mode from tandem to non-tandem.

(10) Added interface and logic circuitry in the sequencer to accept an accelerometer signal from the attitude-control subsystem.

(11) Added sequencer "compare" function.

(12) Added a power monitor status line.

(13) Added six new DC commands.

Expansion of the CC&S memory was the most significant change to the CC&S. It was necessitated by the fact that the MM'71 mission is more complex than the MM'69 mission, for which the 128-word memory was barely adequate. Preliminary analysis of CC&S memory requirements for the most active phase of the MM'71 mission — orbital operations — indicated that approximately 150 words would be required for Mission A and 225 words for Mission B. These numbers included basic two-orbit timing plus picture-taking sequences and platform slews. As a matter of interest the current orbital planning, three months before orbital operations, requires 400 words. Expansion of the memory required that a new memory subassembly be designed and fabricated. The electrical design of the memory as well as all electrical changes to the CC&S was performed by the CC&S section at JPL. The mechanical design of the memory was performed by the Electronic Packaging and Cabling Section who also supplied the memory subchassis. The impact of the memory expansion on the processing logic, which operates in conjunction with the memory, was minimal because provision for operating with a 512-word memory was built into the original design for MM'69.

The CC-1 format change was required in order to accommodate the 9-bit address required by the 512-word memory as opposed to the original 7 bits. The 2 extra bits were obtained by reducing the CC-1 decode bits from 2 to 1 and by eliminating the CC-1 parity bit. Parity for both a CC-1 and its corresponding CC-2 is handled by the CC-2 parity bit. Figure 1 illustrates the formats of the CC-1 and CC-2 commands.

Thirty-six additional output relays were added, due to the requirement for additional interfaces with other subsystems. Table 1 lists the MM'71 relay interfaces with those on MM'69, for comparison. The largest changes were to the pyrotechnics subsystem for propulsion squib selection, and to the power and data automation subsystems for science instrument sequencing.

The desire to pre-program mission sequences, including maneuvers, was evident early in the design phase. As a result, provisions were added to the computer part of the CC&S to start and stop the sequencer. The computer <u>start</u> capability allows maneuvers utilizing the sequencer to be programmed ahead of time in the computer. The computer <u>stop</u> capability allows the computer to interrupt the sequencer and to insert extra maneuver events into the sequence, e.g., "unwind" turns.

The use of a <u>gimballed</u> engine on the spacecraft to maintain attitude stabilization in pitch and yaw during engine burn necessitated some way to initially align the engine thrust-axis through the spacecraft center of gravity. This pre-alignment, to reduce the autopilot transient at burn-start, was accomplished by a data transfer interface between the CC&S and the attitude-control subsystem. This interface allowed the attitude-control subsystem to accept a 22-bit word from the CC&S and use the information contained therein to align the engine thrust axis.

During the MM'69 flight operations, in-flight CC&S updates were checked by reading out the entire content of the CC&S memory. This was time consuming and required interruption of the engineering telemetry. In order to provide a quicker check of the CC&S memory after coded command (CC) updates without interrupting the engineering telemetry a memory-word "compare" function was added to the CC&S. This "compare" function allows two memory words to be compared with each other and an event signal to be sent to telemetry if the two words are the same. The memory check using this compare function is accomplished by adding 511 of the 512 words together. This memory sum (511 words) is then compared with the 512th word (called checksum) which contains the 511-word sum as calculated by, and loaded into the CC&S memory, from the ground.

The sync and flag buffer modifications listed above were incorporated to reduce their sensitivity to noise. Noise sensitivity, particularly with the sync buffers, was a problem on MM'69.

The previously discussed modifications were associated with the computer part of the CC&S. The modifications made to the sequencer and the power-monitoring circuitry are discussed in Subsection B.

B. Sequencer

Because the propulsion engine on-board the MM'71 spacecraft is located on a different axis from that of MM'69, the maneuver turn sequence was changed from pitch-roll to roll-yaw. This was just a wire change within the CC&S.

On MM'69 all nominal maneuvers were planned as tandem maneuvers which dictated that the standby mode be tandem standby. On MM'71 the most important maneuver (orbit insertion) will not be a tandem maneuver. Therefore, the standby state was changed to non-tandem to maximize the probability of being able to perform this maneuver in the event of certain failures.

Because the characteristics of the new and larger propulsion engine on board the spacecraft were not known to sufficient accuracy to time the maneuver motor-burn duration, an accelerometer was added to the attitude-control subsystem for use in controlling the burn duration. The output signal from the accelerometer is routed to the CC&S where additional circuitry was added to allow the accelerometer signal to be processed to generate the CC&S motor-stop event. The accelerometer output during motor burn consists of a train of pulses with each pulse corresponding to approximately a 0.03 m/s velocity increase. During motor burn, these pulses are counted in the CC&S until the required total velocity change has occurred, whereupon the CC&S issues the motor stop event. The orbit insertion maneuver was known to be a 1600-m/s velocity change which would total approximately 53,000 accelerometer pulses. Because the register used within the CC&S to count these pulses overflows at 2047, a divide-by-32 function was added to reduce the number of pulses counted to less than 2047 for the long orbit-insertion maneuver. The divide-by-32 function was mechanized within the CC&S such that it is normally in effect (in deference to the orbit insertion maneuver). Direct command DC-29 was added to switch out the divide-by-32 function when performing short motor-burn maneuvers.

Because the orbit insertion maneuver is a one-time-only function, assurance that correct maneuver information has been loaded into the sequencer prior to the maneuver is very important. Because of this, a sequencer compare function was added to compare, bit-by-bit, any previously stored data with data currently being loaded into the sequencer. Therefore, if the same data word is sent to the sequencer twice, a compare-event signal will be sent to telemetry for each of the eleven data bits, plus one for turn polarity, as the second load word is clocked into the sequencer.

A status line was added between the power-monitor relay in the CC&S and the CC&S support equipment to monitor the state of that relay during test. The power-monitor relay resets whenever power drops below 80% of nominal. Other than the CC&S not operating when the relay is reset, there previously was no direct way to observe the state of that relay.

Six new DC command functions were added to the CC&S as follows:

DC-29. Selects the 1-to-1 accelerometer count mode in the sequencer. The sequencer is normally in the 1-to-32 mode for the orbit insertion maneuver.

DC-51. Disables the tolerance detector. This command replaces the CC-5 command on MM'69.

DC-52. Sets flag 7 in the computer.

DC-84. Sets flag 6 in the computer.

DC-85. Enables the tolerance detector. This command is the compliment of DC-51 above and was associated with DC-33 on MM'69.

DC-86. Sets flag 8 in the computer.

Also, all gold-aluminum integrated circuits (ICs) were replaced with aluminum-aluminum ICs in order to avoid the inherent problems encountered with the gold-aluminum devices on MM'69.

The above changes were incorporated electrically into the design by JPL, including a breadboard verification. After breadboard verification the modifications were given to the contractor for incorporation into the production drawings. Concurrently, associated subsystem support equipment modifications were determined by JPL, and those likewise were given to the contractor for incorporation into the subsystem support equipment drawings. Bench checkout equipment (BCE) for the CC&S has typically been the responsibility of the Spacecraft Computers Section. Therefore, required modifications to the BCE were accomplished at JPL and the modified BCE supplied to the contractor as government-furnished equipment.

In addition to the above listed changes there were a number of minor cleanup modifications to correct deficiencies found during the MM'69 project.

The contractors design effort started in February of 1969. It consisted mainly of incorporating the necessary modifications to the CC&S into the production drawings.

III. FABRICATION

The fabrication phase of the MM'71 CC&S project consisted of modifying the MM'69 spare subsystem to be used as the MM'71 PTM/spare, and fabricating two new CC&S subsystems for flight. The rework of the MM'69 spare consisted of replacing all IC modules plus reworking those cordwood modules affected by the required design changes. As a result of this, all modules were removed from the motherboards, and new boards with connectors fabricated. Those cordwood modules that were to be reused unmodified were cleaned, tested, and placed in bonded stores until needed for the rebuild. The total fabrication effort involved 143 modules (both IC and cordwood) per subsystem, mounted on a total of 11 motherboards, plus the memory subassembly.

Electrical component parts procurement was the responsibility of JPL. Procured and screened parts were delivered to the subcontractor for use during the fabrication effort.

IV. TESTS

There were four levels of CC&S testing: module, board, subsystem, and spacecraft.

Module testing included a pre-pot and a post-pot test. These tests were room-temperature functional tests only. After the necessary modules were mounted on a motherboard, board level tests were performed which consisted of voltage (±20%) and temperature (TA[1] limits) margin tests. After all boards completed test, subsystem tests were conducted which again included voltage and temperature margin tests. Finally the subsystem was delivered to the Spacecraft Assembly Facility (SAF) and spacecraft level tests began.

Problems that showed up during module tests typically were the workmanship-type problems of missed welds, components mounted wrong, etc. Board and subsystem level tests uncovered circuit deficiencies because these tests included margin and environmental testing.

PFR control of problems was initiated with initial power application at the module level. The types and quantities of CC&S PFRs are summarized in Table 2.

[1]TA = type - approval.

V. SIGNIFICANT PROBLEMS UNCOVERED DURING TESTS

There were five significant problems that showed up at various levels of testing. These were:

(1) Relays

(2) Memory vacuum problem

(3) Solder joints

(4) Short motor burn

(5) Computer short-count

Problems with the TO-5-can relays used as CC&S output interface devices showed up early in the test cycle and persisted through the various CC&S test phases prior to launch. The problems with the relays were two-fold: drive-coil overdrive and pressure on the TO-5 can. Early relay failures were associated with overdriving the drive coils of the relays during margin tests. These relays inherently fail to operate if the drive voltage into the coils is too high. The overdrive condition typically is above the voltage levels encountered during margin tests. However, one lot of relays was more sensitive to overdrive than is normal. When a number of these relays failed during test, it was decided to replace all the relays from that lot. However, continued failure of output relays occurred after the suspect lot of relays was replaced. Because of the proximity of the failing relays to circuit-board/heat sink mounting screws, an investigation was conducted to ascertain the susceptibility of these relays to mechanical pressure.

The investigation revealed that mechanical pressure applied between the mounting leads and the top of the TO-5 relay can could cause non-operation. It was further determined that the source of this pressure was the heat sink that was mounted on top of the relay-can to dissipate heat generated within each relay when the CC&S relay hold function was enabled. When originally assembled, there was a small built-in gap between each relay can and the heat sink which was filled with a beryllium oxide compound for heat transfer. Apparently, however, efforts to maintain this gap during relay replacement for the overdrive problem failed, with resultant pressure being applied to the relay can. Due to schedule consideration the best solution to this problem was the removal of the heat sink. Investigation revealed that the maximum temperature that the relays would be subjected to during launch, with "relay hold" applied and no heat sink, would be of short duration and below the screening temperature level for the relays.

The memory vacuum problem became evident the first time the memory was subjected to vacuum as part of the required TA test. This vacuum sensitivity, which resulted in catastrophic failure of the magnetic-core memory plane, was traced to trapped air underneath the polyurethane-coated memory plane. Under vacuum this trapped air expanded underneath the plane such that the very fine magnet wire that is strung through the magnetic cores was stretched and broken. The solution to the problem was, of course, the elimination of the trapped air. This was accomplished by more careful application of a two-sided adhesive tape used to hold the magnetic-core plane to the mounting board, and better application of the polyurethane coating material.

Cracked solder joints were associated with two board-mounted transformers on the CC&S power supply board. Analysis of the problem was inconclusive, but the best explanation appears to be that the mounting of heavy components by straight pins soldered to plated through-holes is conducive to cracked solder joints. The combination of a heavy part plus the differences in thermal expansion coefficients of the transformer lead material, solder, board, and coating materials appears to contribute to the problem particularly when subjected to environmental test (temperature, vibration). At the time this problem showed up, the project schedule did not allow for the ultimate solution of changing to flexible-wire transformer leads. The corrective action for this problem was to inspect the solder joints and rework as necessary after environmental testing was completed. Future projects utilizing these transformers will be cautioned to utilize flexible leads.

The short motor-burn problem appeared during spacecraft tests on the PTM in the space simulator. The problem was early turn-off of accelerometer controlled motor burn intervals. After much investigation, the problem was traced to noise on the accelerometer interface between the attitude-control and CC&S subsystems. The solution for this problem was the addition of a resistance-capacitance filter added to the accelerometer interface. The filter was physically added to the case-harness, because time did not permit incorporation of the filter within the CC&S subsystem.

The computer short-count problem showed up four times during spacecraft testing on two of the three spacecraft. The problem was the issuance of a CC&S event 1 to 5 s early. Investigation revealed that noise on one of two signal lines was the most logical explanation. There was some concern about this problem because one of the suspect signal lines was an intersubsystem interface signal, and the possibility of this being a spacecraft problem presented itself. The other suspect signal line was a CC&S-support equipment interface line which would not be a concern in flight. A special computer event routine was loaded into the CC&S that was able to determine which signal line was being affected by noise. This special routine was run continuously on each spacecraft whenever the CC&S was not needed for other sequences. This problem only reappeared once after the special program was loaded into the CC&S. This single instance indicated that the problem was associated with the CC&S-support equipment interface signal. Because this was not a flight interface, and because of schedule considerations, no corrective action was taken for this problem.

VI. SOFTWARE

Software efforts for this project have concentrated on specifying increased capabilities for the Command Generation (COMGEN) program, and preparing required CC&S programmed sequences for use during the mission.

The increased capabilities for COMGEN were necessitated by the more complex mission associated with an orbiter. Also, orbital operations implies continued complex daily sequencing over an extended period of time. This type of operation requires daily updates that consist of many ground commands to change the CC&S orbital sequence. To aid in the generation of these commands, new COMGEN requirements were specified to accept inputs from other programs and to generate the necessary commands automatically.

In generating the required over-all mission sequence, subsequences were developed and cataloged as sequence "blocks." These blocks are defined in the MM'71 Space Flight Operations Plan 610-29, Vol. IV, Section 3, "Spacecraft Block Dictionary." The CC&S software effort involved here was to program these blocks for use in the CC&S, and, where required, develop linking routines that would allow use of several of these blocks together in generating day-to-day CC&S controlled spacecraft sequences.

REFERENCE

1. Mariner Mars 1969 Final Project Report, Vol. I. Development, Design, and Test, Technical Report 32-1460. Jet Propulsion Laboratory, Pasadena, Nov. 1, 1970.

Table 1. CC&S relay output

	MM'69	MM'71
Attitude control	8	12
Power	6	12
Pyrotechnics	5	14
TV	1	1
Scan	7	7
Data automation subsystem	2	7
Radio-frequency subsystem	4	5
Frequency and timing subsystem	4	5
DSS	5	9
CC&S	1	4
Support equipment	1	1
Spares	4	7
TOTAL	48	84

Table 2. CC&S PFR summary

	PTM	Flight 1	Flight 2	Spares	Scrap	Total	Module	Board	Subsystem	Spacecraft
Design	15	5	3			23	1	11	2	9
Workmanship	4	10	12	3	5	34	17	14	3	
Part failure	7	5	4	1		17	2	6	9	
Manufacturing	7	7	3			17	8	6		3
Operator error	4	1				5		2	1	2
Support equipment failure	6	1	3			10		7	3	
Damage					1	1	1			
Test	1	3	1			5	1	1	2	1
Miscellaneous	6	8	5		1	20	2	7	9	2
Unknown	7	3	1		1	12	1		4	7
Total	57	43	32	4	8	144	33	54	33	24
Module	2	6	13	4	8	33				
Board	27	18	9			54				
Subsystem	16	11	6			33				
Spacecraft	12	8	4			24				

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
CC 1	1	1	0	0	1	1	1	1	0	1	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I
CC 2	1	1	0	0	1	1	1	1	0	1	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	P

(hatched) BITS USED FOR FLIGHT COMMAND SUBSYSTEM CODING ONLY

A = CC & S MEMORY ADDRESS BITS

I = INFORMATION BITS TO BE LOADED INTO MEMORY

P = PARITY (ADJUSTED FOR ODD NUMBER OF ONES IN IN BITS 9 THROUGH 26 OF BOTH CC 1 AND CC 2)

Fig. 1. CC-1 and CC-2 formats

NASA — JPL — Coml., L.A., Calif.